CGIAR Challenge Program on
WATER & FOOD

AGRO-ECOLOGICAL ZONES OF KARKHEH RIVER BASIN

A reconnaissance assessment of climatic and edaphic patterns and their similarity to areas inside and outside the Basin

E. De Pauw, A. Mirghasemi, A. Ghaffari, B. Nseir

Improving On-farm Agricultural Water Productivity in the Karkheh River Basin Project (CPWF PN 8)

3

Strengthening Livelihood Resilience in Upper Catchments of Dry Areas by INRM (CPWF PN 24)

ICARDA
International Center for Agricultural Research in the Dry Areas

AEERO
Agricultural Extension, Education and Research Organization

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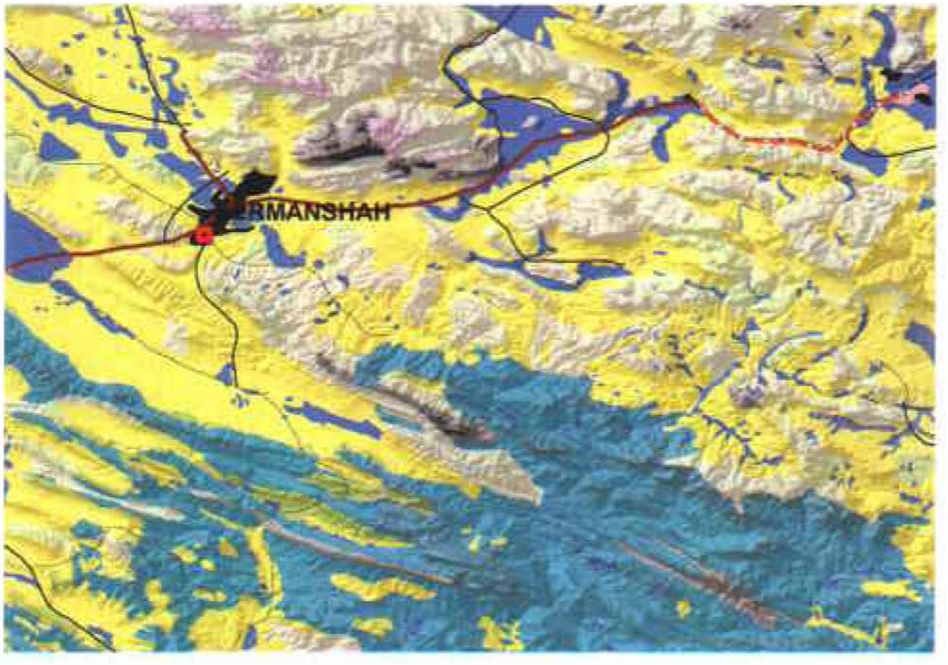

E. De Pauw, A. Mirghasemi, A. Ghaffari, B. Nseir

Challenge Program Projects;
IMPROVING LIVELIHOOD RESILIENCE BY INTEGRATED NATURAL RESOURCE MANAGEMENT IN UPPER CATCHMENTS OF DRY AREAS (PN24)
and
IMPROVING ON-FARM AGRICULTURAL WATER PRODUCTIVITY IN THE KARKHEH RIVER BASIN (PN8)

ICARDA International Center for Agricultural Research in the Dry Areas

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Abstract

The two Challenge Program projects working in the Karkheh River Basin (KRB), "Improving livelihood resilience by integrated natural resource management in upper catchments of dry areas" and "Improving on-farm agricultural water productivity in the Karkheh River Basin", have research objectives that require the agro-ecological characterization of the KRB, and the identification of the recommendation domains for the research conducted at benchmark sites within the basin. To achieve these objectives within a limited period of time and with limited resources, new GIS-based methodologies, applicable world-wide, were developed or fine-tuned.

This study has several major components: an assessment and mapping of the agricultural environments in the entire Karkheh River Basin (KRB); the setting of the selected benchmark sites for the two Challenge Program projects in relation to these environments; and the mapping of the possible out-scaling domains (from a biophysical perspective) at the level of the Karkheh River Basin, Iran and the CWANA region.

The agricultural environments of the KRB were mapped using the concept of agro-ecological zones (AEZ), integrated spatial units arising from the integration of climatic, topographic, land use/land cover and soil conditions. The AEZ were derived by the following six-step procedure:

o Generating raster surfaces of basic climatic variables through spatial interpolation from station data;

o Generating a spatial framework of agroclimatic zones (ACZ);

o Simplifying the relevant biophysical themes (agroclimatic zones, land use/land cover and landform/soils);

o Integrating the simplified frameworks for agroclimatic zones, land use/land cover and landforms/soils (soilscapes) by overlaying in GIS;

- Removal of redundancies, inconsistencies, and spurious mapping units;
- Characterization of the spatial units in terms of relevant themes.

Using this methodology, the entire Karkheh River Basin (50,764 km2) was classified into 46 unique AEZ, of which only five occupy nearly 60% of the basin.

On the basis of major differences in climatic conditions, land use patterns and terrain-soil characteristics, three major agricultural regions, the Northern, Middle and Southern Agricultural regions, are distinguished and described. In addition, an overview is provided of the biophysical conditions that prevail in the four benchmark sites selected in the basin. The AEZ present in the benchmark sites occupy 90% of the KRB. Hence on this criterion, the benchmark sites are highly representative, even though some of the AEZ may occupy only a small area in the benchmark sites. On the other hand, with the exception of a few small areas in Merek, the oak forest belt, which is characteristic of the Middle Karkheh Agricultural Region, is not present in the benchmark sites. Neither are the badlands, which occupy substantial areas in the Middle and Southern Karkheh Agricultural Regions, and the sand dunes of the Southern Karkheh Agricultural Region.

In the last section of the report, a methodology is developed to assess whether the technological, institutional and policy options for the farmers and communities developed in the benchmark sites, have possibilities of application in areas outside these sites. The methodology is based on assessing the similarity in conditions between each of the benchmark sites and different target areas for out-scaling (the KRB, Iran and CWANA). The approach taken is confined to the biophysical domain only and involves several stages of assessment. In a first stage climatic similarity in biophysical conditions is assessed using temperature and precipitation as indicators and similarity indices for quantification. In further stages, the climatic similarity index is combined with a landform similarity index and a land use/cover similarity index. Soils, a potentially important indicator, were not considered in the light
soil information, but can be brought into the similarity assessment at a later stage, once better data become available.

Irrespective of the out-scaling domain and the way similarity is defined, the areas similar to Azadegan and Sorkhe, the two irrigated

benchmark sites, are small, as they contain homogeneous environments and irrigated areas are always a minority land cover. On the other hand, a much higher degree of similarity is found in the three out-scaling domains with the upper catchment benchmark sites, Honam and Merek, due to the fact that in both sites the presence of different topographic conditions and land uses allow covering a larger out-scaling domain.

1. INTRODUCTION

The Karkheh River Basin (KRB), covers an area of about 50,000 km^2 in the west of Iran, near the border with Iraq (Fig.1). Although climatically mostly semi-arid or arid, the basin has a tremendous diversity in soil and water resources, topography and land use systems. This diversity within a context of scarcity of both water and land resources, of poverty and of growing population (Heydari et al., 2007) makes good land use planning essential.

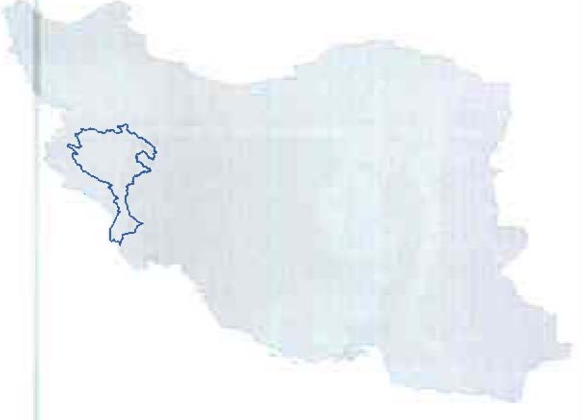


Figure 1. Location of the Karkheh River Basin in Iran

Agricultural planning covers many charges and can be undertaken at different levels. It ranges from the physical location of research stations, the introduction of particular crops, cultivars and technologies to suit the conditions in different areas, the allocation of water resources to agriculture, fertilizer recommendations, policies and regulations for rural land use, inputs and technology subsidies, etc. The more planners are aware of the SWOTs (strengths, weaknesses, opportunities and threats) of geographically well defined areas, the more effective and targeted their planning can be.

Two Challenge Program projects are operating in the KRB: one ("Improving livelihood resilience by integrated natural resource management in upper catchments of dry areas") dealing with issues of poverty, livelihood strategies and land degradation in the rainfed areas of the upper catchments; and the other ("Improving on-farm agricultural water productivity in the Karkheh River Basin"), aiming to improve livehoods through improved water productivity in the irrigated areas of the lower catchment. Both projects have research objectives that require the agro-ecological characterization of the KRB, and the identification of the recommendation domains for the research conducted at benchmark sites within the basin. To achieve these objectives within a limited period of time and with limited resources, new GIS-based methodologies, applicable world-wide, were developed or fine-tuned.

In this study the use of the spatial concept of 'agro-ecological zone' is advocated as a support tool for agricultural planning. The term 'agro-ecological zones' has no single meaning in the literature. For example, the Food and Agriculture Organization of the United Nations (FAO), followed later by the International Institute for Applied Systems Analysis (IIASA), has a 25-year legacy of studies based on a concept of 'agro-ecological zones' as spatial entities that delineate areas with different production potential (or 'suitability') for specific crops (e.g., FAO, 1978; Fischer et al., 2000). Put differently, FAO and IIASA methods produce crop *suitability* maps.

In this study, the term *agro-ecological* zones is used in a broader sense of *integrated* and more or less homogeneous spatial units in which the particular combinations of available water resources, climate, terrain, and soil conditions create unique environments, associated with distinct farming systems and land-use and settlement patterns. In other words, our approach produces *synthesis maps* of agricultural environments.

An agro-ecological zones (AEZ) map, in our own meaning, is an essential tool for agricultural planning. By integrating the key components of the agricultural environments, it offers a birds'-eye view of internal diversity, agricultural potential and constraints that decision-makers find easier to understand than a stack of single-theme maps.

Whereas in the past, the manual integration of spatial data from different disciplines was impractical. GIS technology makes integration through an automated process now perfectly feasible. Collaborative research between ICARDA and different national agricultural research systems, particularly in Iran, Morocco, Syria and Turkey, has confirmed the feasibility of rapidly defining agro-ecological zones by the combination of climatic, land use/land cover, terrain, soil and other data using GIS procedures. Hence, in addition to the increase in knowledge on the Karkheh River Basin itself, the methodology used in this study has much value for the rapid identification of resource issues in other parts of the world as well.

The report is structured around two key themes. Chapter 2, which follows this introductory chapter, is about the characterization of the entire Karkheh River Basin using the AEZ approach. It explains the methodology used for obtaining the agro-ecological zones of KRB through GIS procedures. It contains a section that summarizes the results and provides an overview of the agro-ecological zones. The chapter also includes a discussion on the value of the AEZ information for agricultural planning and attempts to link the KRB case study to others in order to point out challenges in generating useful planning information. Chapter 3 is entirely dedicated to the benchmark sites, starting with a brief characterization, and explanation of the methodology of similarity mapping used to define the biophysical extrapolation domains within three different target areas, the KRB, Iran, and the CWANA region. It contains a section that summarizes the results of the similarity assessment and discusses the future study requirements for the benchmark sites as well as the potential of similarity analysis for identifying representative benchmark sites for integrated natural resource management research. Chapter 4 draws overall conclusions on the use of the AEZ and benchmark site approach towards out-scaling site-specific research. The annexes provide additional information in the form of tables, maps and photographs.

2. AGRO-ECOLOGICAL ZONES

2.1. METHODOLOGY

2.1.1. Overview

The AEZ map for the KRB was made by overlaying of single raster themes related to climate, terrain, soils and land use. Three layers were considered adequate in order to generate the AEZ map:

- agroclimatic zones
- land use/land cover
- soils (+ landforms)

The themes used for overlaying are simplifications of more complex thematic classifications. Simplification was necessary in order to avoid (i) a replication of the single-theme maps, and (ii) unnecessary complexity for the purpose of the AEZ map.

2.1.2. Steps

The agro-ecological zones were generated by the following 6-step procedure:

a) Generating raster surfaces of basic climatic variables through spatial interpolation from station data;
b) Generating a spatial framework of agroclimatic zones (ACZ) by combining the basic climatic surfaces into more integrated variables that provide a better, although simplified, synthesis of climate conditions;
c) Simplifying the relevant biophysical themes (agroclimatic zones, land use/land cover and landform/soils);
d) Integrating the simplified frameworks for agroclimatic zones, land use/land cover and landforms/soils (soilscapes) by overlaying in GIS;
e) Removal of redundancies, inconsistencies, and spurious mapping units; and
f) Characterization of the spatial units in terms of relevant themes.

a. Generating raster surfaces of basic climatic variables

A database of point climatic data covering monthly averages of precipitation totals, minimum and maximum temperature for the main stations in Iran, covering the period 1973-1998, was made available from the Organization of Meteorology, based in Tehran.

Reference (potential) evapotranspiration (PET) estimates according to the method of Penman-Monteith (Allen et al., 1998) were generated by a two-step disaggregated regression with temperature. This consisted of calculating first the PET according to the temperature-based Hargreaves method, as described by Choisnel et al.(1992), followed by conversion into Penman-Monteith PET (PET-PM) estimates using known PET-PM values for different climatic zones in accordance with the Köppen classification (Köppen and Geiger, 1928). More details on the calculation procedure for PET are provided in Annex 9.

The 'thin-plate smoothing spline' method of Hutchinson (1995), as implemented in the ANUSPLIN software (Hutchinson, 2000), was used to convert this point database into 'climate surfaces'. The Hutchinson method is a smoothing interpolation technique, using elevation obtained from a digital elevation model as a co-variable, in which the degree of smoothness of the fitted function is determined automatically from the data by minimizing a measure of the predictive error of the fitted surface, as given by the generalized cross-validation (GCV).

b. Generating Agroclimatic Zones

The ACZ of KRB were obtained by clipping from the Agroclimatic Zones Map of Iran (Ghaffari et al., 2004). They are based on the UNESCO classification system (1979), which is based on three major criteria:

- Moisture regime
- Winter type
- Summer type

The classes are shown in Tables 1-3.

In this classification system the moisture regime is determined by the ratio of annual rainfall over annual reference evapotranspiration (also referred to as aridity index), calculated according to the Penman-Monteith method. It is therefore particular to this system that in the definition of the moisture regime not only the water supply (precipitation) is considered, but also the water demand (evapotranspiration). Different classes may thus result from different values of the two terms (Table 1)

The UNESCO system is basically open-ended and any particular climate can be simplified by the three attributes, moisture regime, winter type and summer type. For example, the climate *SA-C-VW* is characterized by a semi-arid moisture regime, a cool winter type and very warm summer type.

De Pauw et al. (2004) provide more details on the methods used in Step 1 and Step 2. Figure 2 outlines the combination of basic and derived climatic surfaces used to generate the Agroclimatic Zones theme.

In accordance with this methodology the following maps were prepared, which are shown in Annex 1:

- Mean annual precipitation (Fig. 28)
- Mean annual reference evapotranspiration (Fig. 29)
- Aridity index (Fig. 30)
- Mean temperature during warmest month (Fig. 31)
- Mean temperature during coldest month (Fig. 32)
- Agroclimatic Zones (Fig. 33)

In addition to these, a number of other climatic maps, also in Annex 1, were prepared to provide further insights into the agricultural climates of the KRB:

- Mean annual growing degree days (Fig. 34)
- Moisture-limited growing period (Fig. 35)
- Temperature-limited growing period (Fig. 36)

Table 1. Classes for the moisture regime

Moisture regime	**Hyper-arid (HA)**	**Arid (A)**	**Semi-arid (SA)**	**Sub-humid (SH)**	**Humid (H)**	**Per-humid (PH)**
Aridity index	<0.03	0.03-0.2	0.2-0.5	0.5-0.75	0.75-1	>1

The *winter type* is determined by the mean temperature[1] of the coldest month (Table 2).

Table 2. Classes for the winter type

Winter type	**Warm (W)**	**Mild (M)**	**Cool (C)**	**Cold (K)**
Mean temp. coldest month	> 20°C	> 10°C	> 0°C	≤ 0°C

The *summer type* is determined by the mean temperature[1] of the warmest month (Table 3).

Table 3. Classes for the summer type

Summer type	**Very warm (VW)**	**Warm (W)**	**Mild (M)**	**Cool (C)**
Mean temp. warmest month	> 30°C	> 20°C	> 10°C	≤ 10°C

[1]Sum of the monthly average of daily minimum and maximum temperature divided by two

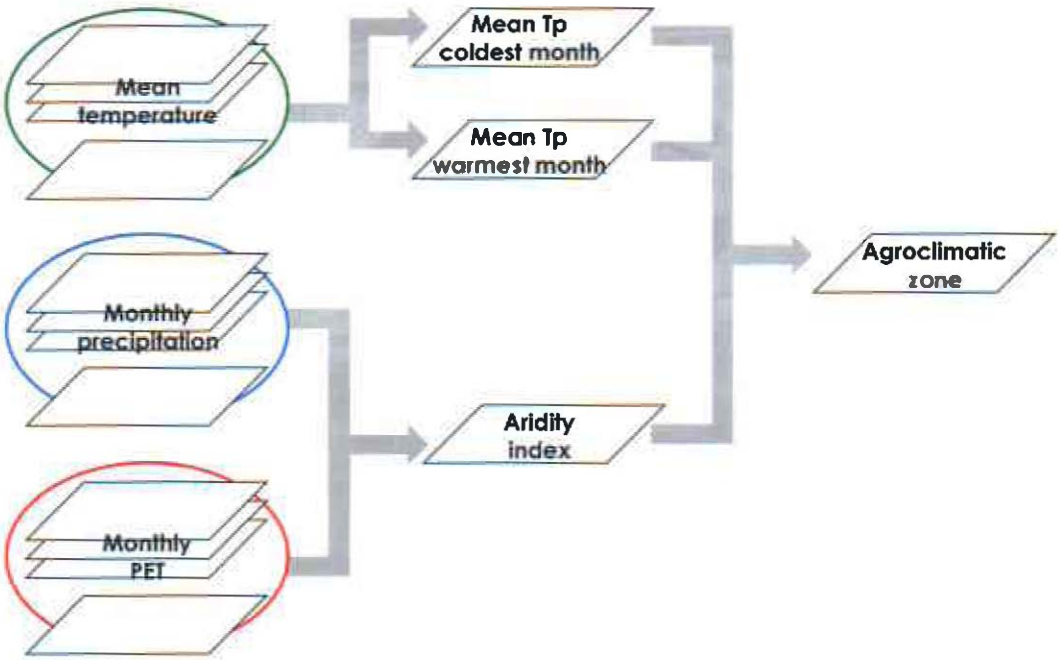


Figure 2. Developing the Agroclimatic Zones framework

- Growing period limited by both temperature and moisture (Fig. 37)
- Onset of the moisture-and temperature limited growing period January-June (Fig. 38)
- Onset of the moisture-and temperature limited growing period July-December (Fig. 39)
- End of the moisture-and temperature limited growing period (Fig. 40)

The methods used for generating these maps are described by De Pauw (2002).

c. Simplification of thematic component layers

Agroclimatic zones
The ACZs were regrouped by making no distinction between 'warm' (W) and 'very warm' (VW) summers for the arid (A) and semi-arid (SA) moisture regimes, and by regrouping ACZs that occupy very small areas in KRB. This synthesis reduced the original 8 'old' ACZ classes in KRB to 4 'new' classes (Table 4).

Table 4. Old and new agroclimatic zones

Old ACZ	Old ACZ ID	New ACZ	New ACZ ID
A-M-VW; A-M-W	16,19	Arid (A), mild (M) winter , warm to very warm summer (W-VW)	1
SA-C-VW; SA-C-W	32, 33	Semi-arid (SA), cool (C) winter; warm to very warm summer (W-VW)	2
SA-K-W	37	Semi-arid (SA) , cold (K) winter; warm (W) summer	3
SA-K-M; SH-K-W; SH-K-M	38, 50, 51	Miscellaneous (inclusions)	4

The simplified map of Agroclimatic Zones is shown in Annex 1, Figure 43.

Land use/land cover
The Land Use/Land Cover Map of KRB is based on the country vector map produced by FWRO (1998) by visual interpretation of hardcopy Landsat images and field checking. The map was prepared by clipping from the latter map to the KRB boundary and conversion to raster using a cell size of 0.000833 decimal degrees, equal to the resolution of the high-resolution SRTM (Shuttle Radar Topographic Mission) digital elevation model. For the KRB area it contains 12 classes, as listed in the first column of Table 5. This map is shown in Annex 1, Figure 41.

Table 5. Old and new land use classes

Old Class	Old Class ID	New Class	New Class ID
Irrigated farming	4	Irrigated cultivation	1
Dry farming	2	Rainfed cultivation	2
Scattered dry farming	5		
Bare lands	8	Bare lands	3
Forest	3	Forest	4
Range	1	Range	5
Wetlands	10	Wetlands	6
Rock outcrops	6		n.a.
Saline areas	9		n.a.
Sand dunes	11		n.a.
Urban areas	7		n.a.
Lake/reservoir	12		n.a.

For the purpose of differentiating AEZs, the 12 classes were reduced to six. These six classes are, with the exception of the 'rainfed cultivation' class (in which 2 LULC classes were merged), the same as their counterparts in the original map. Four of the original LULC classes (saline areas, sand dunes, urban areas, lakes/reservoirs) were taken out of the simplified Land Use/Land Cover theme and regrouped as 'General Themes' in the AEZ map. The class 'Rock outcrops' was added to the corresponding class 'Rock outcrops and very shallow soils' in the Soil Management Domains Map (see further). The areas with classes that were taken out of the new LULC classification were reclassified as 'n.a.' (not applicable).

The simplified map of Land Use/Land Cover is shown in Annex 1, Figure 44.

Soils
The original 1:1,000,000 digitized Soil Map of Iran (1996 edition) was clipped to the KRB outline. The Soil Map of Iran is a soil association map, in which the soil components are classified according to Soil Taxonomy . The association contains listings of dominant, associated and included soils, but no percentages. Each mapping unit is also classified as a SOTER landform (FAO, 1995). The original map of soilscapes is shown in Annex 1, Figure 42. The numeric labels of the map refer to the soil association codes, which are further specified in Annex 2.

Landsat satellite imagery and comparison with the SRTM DEM confirmed that boundary delineation of the soil mapping units matched landforms well in most places. Therefore, the map was accepted as a framework for identifying *major soil types within a broad physiographic framework,*

[2]http://srtm.csi.cgiar.org/SRTM_FAQ.asp

thus eliminating the need for defining a separate landform framework based on a digital elevation model for the KRB.

The soil classes of the Soil Map of Iran were then regrouped in accordance with their major properties with respect to 'usability' into 'soil management domains'(SMD). The regrouping of the soilscapes into SMDs was based on the dominant soil taxonomic unit (Table 6).

use category 'wetlands'. The areas with classes that were taken out of the new SMD classification were reclassified as 'n.a.' (not applicable).

The Simplified Soil Map obtained by this procedure is shown in Annex 1, Figure 45.

Landforms
Although for the purpose of developing the AEZ map for the KRB, there was no need to create a separate landform map, the latter

Table 6. Old and new soil classes

Old classes: dominant soils	AEZ code	Soil Management Domain (SMD)	SMD Code
Marsh	Marsh		n.a.
Calcic Ustochrepts, Calcixerollic Xerochrepts, Typic Calciustolls	Well_Drained_Agri_Soil	Well drained, calcareous soils of plains, suitable for agriculture	1
Aridic Ustifluvents, Typic Torrifluvents, Typic Ustifluvents, Fluventic Xerochrepts	Alluvial_Soils	Alluvial soils	2
Typic Endoaquepts, Aquic Calcixerolls, Typic Fluvaquents, Typic Halaquepts	Poor_Drained_soils	Soils with deficient drainage	3
Typic Haplogypsids	Gypsiferous_Soil	Gypsiferous soils	4
Aridic Ustorthents	Poorly_Developed	Poorly developed soils of arid regions	5
Rock outcrop	Rock outcrop	Rock outcrops or very shallow soils	6
Dune land, all Psamments	Dune land; Sandy soils	Sand sheets and dunes	n.a.
Typic Haplosalids	Saline_Soil	Saline soils	n.a.
Badland	Badlands	Strongly eroded badlands	n.a.
Urban	Urban	Urbanized areas	n.a.

(Source soil information: Soil and Water Research Institute, 1996)

The classes 'Dune land', 'sandy soils', 'saline soils', 'badlands' and 'urban' were taken out from the new soil map and added to the corresponding General Theme layers in the AEZ map. The class 'Marsh' was taken out of the new soil map and added to the land could be useful in its own right for a better understanding of the structure of different landscapes within the Basin, particularly when looking at individual sub-zones, watersheds and benchmark sites (see chapter 3). For this reason, a map of

Landforms has been prepared on the basis of the SRTM DEM, using the criteria 'elevation', 'slope' and 'aspect'.

Four elevation zones were recognized (< 800 m, 800-1300 m, 1300-1800 m, and >1800 m). Four slope classes were differentiated (0-5%, 5-12%, 12-30%, >30%), and three aspect classes (undifferentiated, northern aspect and southern aspect) using the relevant surface functions in ArcGIS. The aspect was 'North' if the compass bearing was in the range 0-67.5 and 292.5-360, and 'South' if the compass bearing was in the range 112.5 and 247.5. Any other compass bearing or the class 'Flat' fell in the category Undifferentiated aspect'.

The map of Landforms is shown in Annex 1, Figure 46.

d. Integration of thematic layers

Once the component layers have been established, AEZs are generated through simple overlaying in a GIS procedure that retains all characteristics and attributes of the component themes. Given the range of combinations that are possible by the overlaying process, it is necessary to represent AEZs through a unique ID. A simple coding system was developed by concatenating numerical codes for each theme that is used for identifying the AEZs. In our assumption that agricultural environments can be reasonably represented by the themes climate, land use/land cover, landforms and soils, a generalized coding system would have the format 'CULS', in which:

C: Climate Code
U: Land Use/Cover Code
L: Landform Code
S: Soil Code

For KRB, the Landform and Soil Codes can be combined into a single code S (soil management domain), leading to 3-digit codes with CUS format. By overlaying the 3 themes the AEZ codes are generated using the appropriate multipliers and summation method.

Thus, for example, the AEZ code 221 is the result of the combination of:

- Climate code: 2 (multiplier 100)
- Land use/cover code: 2 (multiplier 10)
- Soil management domain code: 1 (multiplier 1)

The full description of the code is then: Semi-arid, cool winter; warm to very warm summer; *well drained, calcareous soils of plains, suitable for agriculture.*

e. 'Cleaning-up' procedures

These involve the introduction of special rules to remove redundancy or inconsistencies as well as GIS-based automatic procedures to remove 'spurious' mapping units, created by the overlaying process.

The creation of new units in GIS through overlaying propagates and exacerbates errors that were already present in the component datasets. Simplification of these datasets (Step 3) was one way to reduce the errors resulting from overlaying. Another source of errors is the combination of information layers with different levels of spatial precision, which is the main reason for the spurious mapping units.

To harmonize the soil and land use/land cover maps, which sometimes provided conflicting or inconsistent information, special decision rules were introduced on the basis of priority to the most accurate information.

- If the Land Use/Cover code =1 (irrigated) the SMD codes were not considered[3]. In such cases, the AEZ codes therefore always have the format C10.
- If the Land Use/Cover code =2 (rainfed) the SMD codes were not considered[4]. In such cases, the AEZ codes therefore always have the format C20.

Using overlay processing on the raster dataset causes sometimes small dispersed clusters (ranging from a few pixels to several hundred) of one class to appear inside another class. To solve this problem an

Table 7. Percentages of frost day classes within specific AEZs

AEZ	0-1 days	1-30 days	30-60 days	60-90 days	90-120 days	120-150 days	150-180 days	>180 days
160	0	100	0	0	0	0	0	0
251	0	6	11	53	31	0	0	0
351	0	0	0	0	76	23	0	0
206	0	14	36	40	11	0	0	0
120	0	100	0	0	0	0	0	0
306	0	0	0	0	56	43	2	0
456	0	0	0	0	0	37	60	3
151	0	100	0	0	0	0	0	0
155	1	99	0	0	0	0	0	0
156	0	100	0	0	0	0	0	0

automated cleanup procedure was applied using GIS functions, available in standard GIS software, to absorb the 'orphaned' pixels into their nearest neighbors. The cleaning steps using GIS software-specific functions are outlined in Annex 4.

f. Characterization of the AEZs

Up to now, the spatial units established through the overlaying of climatic, land use/land cover, terrain and soil themes are characterized only in terms of the classes of their component themes. However, probably the most important step is to characterize the AEZs more deeply in terms of other themes relevant to planning. This could be biophysical themes, such as frost occurrence, growing periods, soil management groups, but also socioeconomic themes, such as farming systems.

The characterization is in the form of overlays of additional themes, which are brought in relationship to specific AEZs through a composition table. An example is given in Table 7 for the theme 'Number of frost days'.

The composition table shows the proportion each class of the overlaying theme occupies in each AEZ. It can be interpreted as a 'probability', based on a frequency count, that a particular class will be encountered in a given AEZ.

2.2. RESULTS

2.2.1. Overview

A total of 46 AEZs and 5 General Themes were identified using the methodology described in Section 2. Of these, nine cover 80% of the KRB (Table 8).

Another seven occupy more than 1% of the KRB each, whereas 35 units cover only a very small (<1%) part of the basin. As procedures were already included in the methodology to remove spurious units, the large number of classes points instead to the great diversity in agricultural environments in the basin.

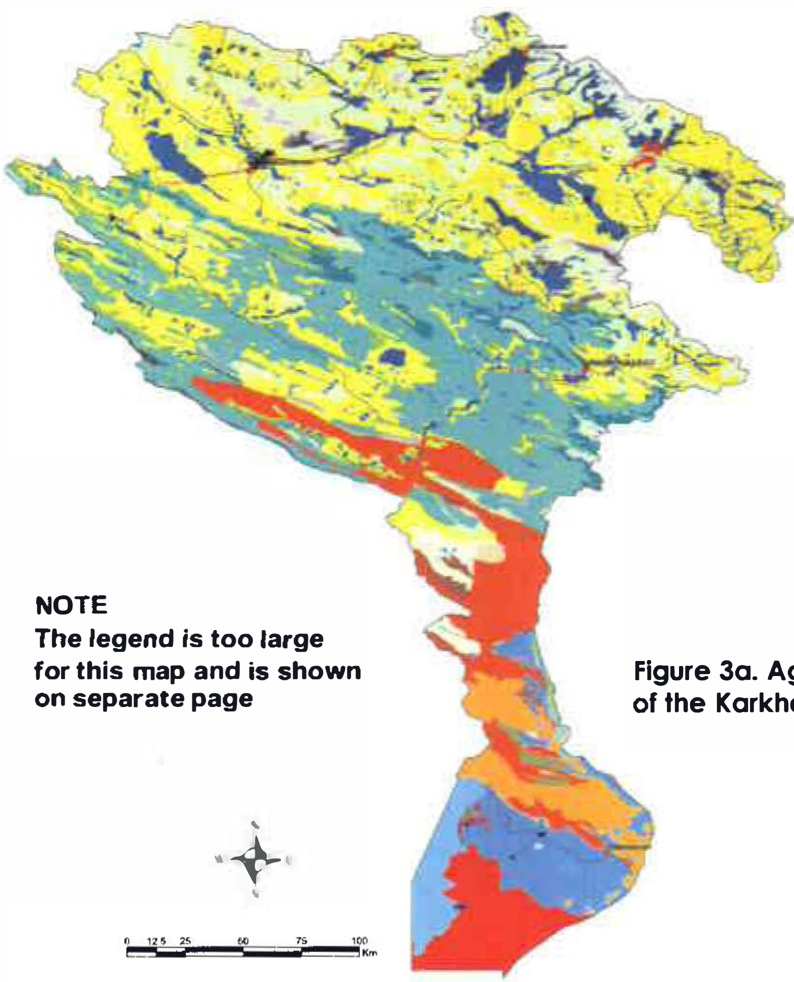
About 60% of the KRB has a semi-arid climate, with the majority having a fairly warm climate (cool to mild winters with warm to very warm summers), although 20% of the basin, with cold winters, is much cooler. Irrigation is prominent in less than 10% of KRB. Noteworthy is also the considerable area (9%) occupied by 'badlands'.

The spatial distribution of the AEZs and General Themes is shown in the AEZ map of Figure 3. In addition, database attribute tables were prepared that summarize for each AEZ the relative importance of classified ranges of precipitation, growing-degree days, frost days, and length-of-growing period (Annex 7).

*It is assumed that if irrigated agriculture is present, landform and soils are non-limiting and therefore do not need to be considered.
*It is assumed that if rainfed agriculture is present, soils are non-limiting and therefore do not need to be considered.

Table 8. Predominant AEZs in KRB

AEZ code	% of KRB	Climate	Land use	Soilscape
220	18.26	Semi-arid, cool winter; warm to very warm summer	Rainfed cultivation	n.a.
246	17.04	Semi-arid, cool winter; warm to very warm summer	Forest	Rock outcrops or very shallow soils
320	10.26	Semi-arid, cold winter; warm summer	Rainfed cultivation	n.a.
356	9.20	Semi-arid, cold winter; warm summer	Range	Rock outcrops or very shallow soils
Badlands	9.12	Undifferentiated	Undifferentiated	Undifferentiated
210	4.86	Semi-arid, cool winter; warm to very warm summer	Irrigated cultivation	n.a.
110	4.42	Arid, mild winter, warm to very warm summer	Irrigated cultivation	n.a.
Saline areas	3.35	Undifferentiated	Undifferentiated	Undifferentiated
Sand dunes	3.15	Undifferentiated	Undifferentiated	Undifferentiated



NOTE
The legend is too large for this map and is shown on separate page

Figure 3a. Agro-ecological Zones of the Karkheh River Basin: Map

LEGEND

106: Arid, mild winter, warm to very warm summer; Rock outcrops or very shallow soils

110: Arid, mild winter, warm to very warm summer; Irrigated cultivation.

120: Arid, mild winter, warm to very warm summer; Rainfed cultivation

131: Arid, mild winter, warm to very warm summer; Bare lands; Well drained, calcareous soils of plains, suitable for agriculture

132: Arid, mild winter, warm to very warm summer; Bare lands Alluvial soils

133: Arid, mild winter, warm to very warm summer; Bare lands Soils with deficient drainage

135: Arid, mild winter, warm to very warm summer; Bare lands Poorly developed soils of arid regions

141: Arid, mild winter, warm to very warm summer; Forest Well drained, calcareous soils of plains, suitable for agriculture

142: Arid, mild winter, warm to very warm summer; Forest; Alluvial soils

145: Arid, mild winter, warm to very warm summer; Forest; Poorly developed soils of arid regions

146: Arid, mild winter, warm to very warm summer; Forest; Rock outcrops or very shallow soils

151: Arid, mild winter, warm to very warm summer; Range Well drained, calcareous soils of plains, suitable for agriculture

152: Arid, mild winter, warm to very warm summer; Range; Alluvial soils

153: Arid, mild winter, warm to very warm summer; Range; Soils with deficient drainage

154: Arid, mild winter, warm to very warm summer; Range; Gypsiferous soils

155: Arid, mild winter, warm to very warm summer; Range; Poorly developed soils of arid regions

156: Arid, mild winter, warm to very warm summer; Range; Rock outcrops or very shallow soils

160: Arid, mild winter, warm to very warm summer; Wetlands.

162: Arid, mild winter, warm to very warm summer; Wetlands; Alluvial soils.

206: Semi-arid, cool winter; warm to very warm summer; Rock outcrops or very shallow soils

210: Semi-arid, cool winter; warm to very warm summer; Irrigated cultivation

220: Semi-arid, cool winter; warm to very warm summer; Rainfed cultivation.

231: Semi-arid, cool winter; warm to very warm summer; Bare lands; Well drained, calcareous soils of plains, suitable for agriculture

241: Semi-arid, cool winter; warm to very warm summer; Forest; Well drained, calcareous soils of plains, suitable for agriculture

246: Semi-arid, cool winter; warm to very warm summer; Forest; Rock outcrops or very shallow soils

251: Semi-arid, cool winter; warm to very warm summer; Range Well drained, calcareous soils of plains, suitable for agriculture

253: Semi-arid, cool winter; warm to very warm summer; Range; Soils with deficient drainage.

256: Semi-arid, cool winter; warm to very warm summer; Range; Rock outcrops or very shallow soils.

306: Semi-arid, cold winter; warm summer; Rock outcrops or very shallow soils

310: Semi-arid, cold winter; warm summer; Irrigated cultivation.

320: Semi-arid, cold winter; warm summer; Rainfed cultivation.

331: Semi-arid, cold winter; warm summer; Bare lands; Well drained, calcareous soils of plains, suitable for agriculture

336: Semi-arid, cold winter; warm summer; Bare lands; Rock outcrops or very shallow soils.

341: Semi-arid, cold winter; warm summer; Forest; Well drained, calcareous soils of plains, suitable for agriculture

346: Semi-arid, cold winter; warm summer; Forest; Rock outcrops or very shallow soils

351: Semi-arid, cold winter; warm summer; Range; Well drained, calcareous soils of plains, suitable for agriculture

352: Semi-arid cold winter; warm summer; Range; Alluvial soils.

353: Semi-arid, cold winter; warm summer; Range; Soils with deficient drainage.

356: Semi-arid, cold winter; warm summer; Range; Rock outcrops or very shallow soils

406: Miscellaneous (inclusions); Rock outcrops or very shallow soils

410: Miscellaneous (inclusions); Irrigated cultivation.

420: Miscellaneous (inclusions); Rainfed cultivation

441: Miscellaneous (inclusions); Forest; Well drained, calcareous soils of plains, suitable for agriculture

446: Miscellaneous (inclusions); Forest; Rock outcrops or very shallow soils.

451: Miscellaneous (inclusions); Range Well drained, calcareous soils of plains, suitable for agriculture

456: Miscellaneous (inclusions); Range; Rock outcrops or very shallow soils

General Themes

Urban areas

Saline areas

Sand dunes

Water bodies

Badlands

Figure 3b. Agro-ecological Zones of the Karkheh River Basin: Legend

2.2.2. Agricultural regions

The AEZs offer a useful framework for the synthesis of information related to the biophysical component of agricultural environments. For agricultural development planning, this is only one aspect that affects the comparative strengths, vulnerabilities, opportunities and threats in different agricultural areas. Others are the characteristics of prevailing agricultural production and livelihood systems, which encompass a wide range of attributes, related to population, integration within markets, resource access, culture, agricultural practices, input-output relationships, public investment, tenure systems, etc.

In agricultural development, it is most useful to have spatial frameworks for rural areas that encompass both biophysical and socioeconomic features. In many developed countries the concept of 'agricultural region' is firmly entrenched and, while the term is not standardized, it is well understood as a holistic spatial entity with its own biophysical and socioeconomic 'personality'.

For example, in France the 'petite région agricole' (PRA) is a kind of planning zone, homogeneous in biophysical environments and types of production systems and farm enterprises. The PRAs are used for formulating agricultural development plans and projects, and even as a basis for aggregation and analysis of farm enterprise statistics. They are an example of the successful spatial integration of the more stable attributes of biophysical environments with the more dynamic socioeconomic variables of rural spaces. They are established to the point that PRA-maps exist for the main administrative subdivisions in France (regions and departments) and PRA-specific diagnostic studies and project development are even on the curriculum of some graduate programs .

[1]E.g., http://graduateschool.paristech.org/cours.php?id=26422

Although there is a very large database available about socioeconomic conditions in Iran, the latter has at the moment been insufficiently synthesized to come up with a zoning system that can meet the information standards and depth of the French system of planning zones. Nevertheless, it is certainly possible to provide a rudimentary and provisional zoning system for the Karkheh River Basin, on the basis of major differences in climatic conditions, land use patterns and terrain-soil characteristics (Figure 4). These 'agricultural regions' are in fact so markedly different in their biophysical personality that they must also have a socioeconomic coherence and impact on the rural livelihoods and hence merit a separate description.

The following sections contain short narratives for each agricultural region.

Photographs illustrating landscapes and other distinguishing features of the agricultural regions are to be found in Annex 2. In order to ensure that the names used for the agricultural regions do not lead to confusion with the basin subdivisions used by the Challenge Program for 'Upper' and 'Lower' Karkheh Basin, we employ the following equivalence:

- Northern Agricultural Region (Sub-zone A): part of the Upper Karkheh Basin
- Central Agricultural Region (Sub-zone B): part of the Upper Karkheh Basin
- Southern Agricultural Region (Sub-zone C): Lower Karkheh Basin

2.2.2.1. Northern Agricultural Region (Sub-zone A)

This region, covering about 20,720 km^2, is characterized by an alternation of parallel plains and high mountains with a general NW-SE alignment (Fig. 5). The Geological Map of Iran at 1:2,500,000 scale (National Iranian Oil Company, 1957) indicates that the region inherits its topographic structure from the outcropping, tilting and folding of hard limestones and marbles, mostly of Jurassic and lower Cretaceous age.

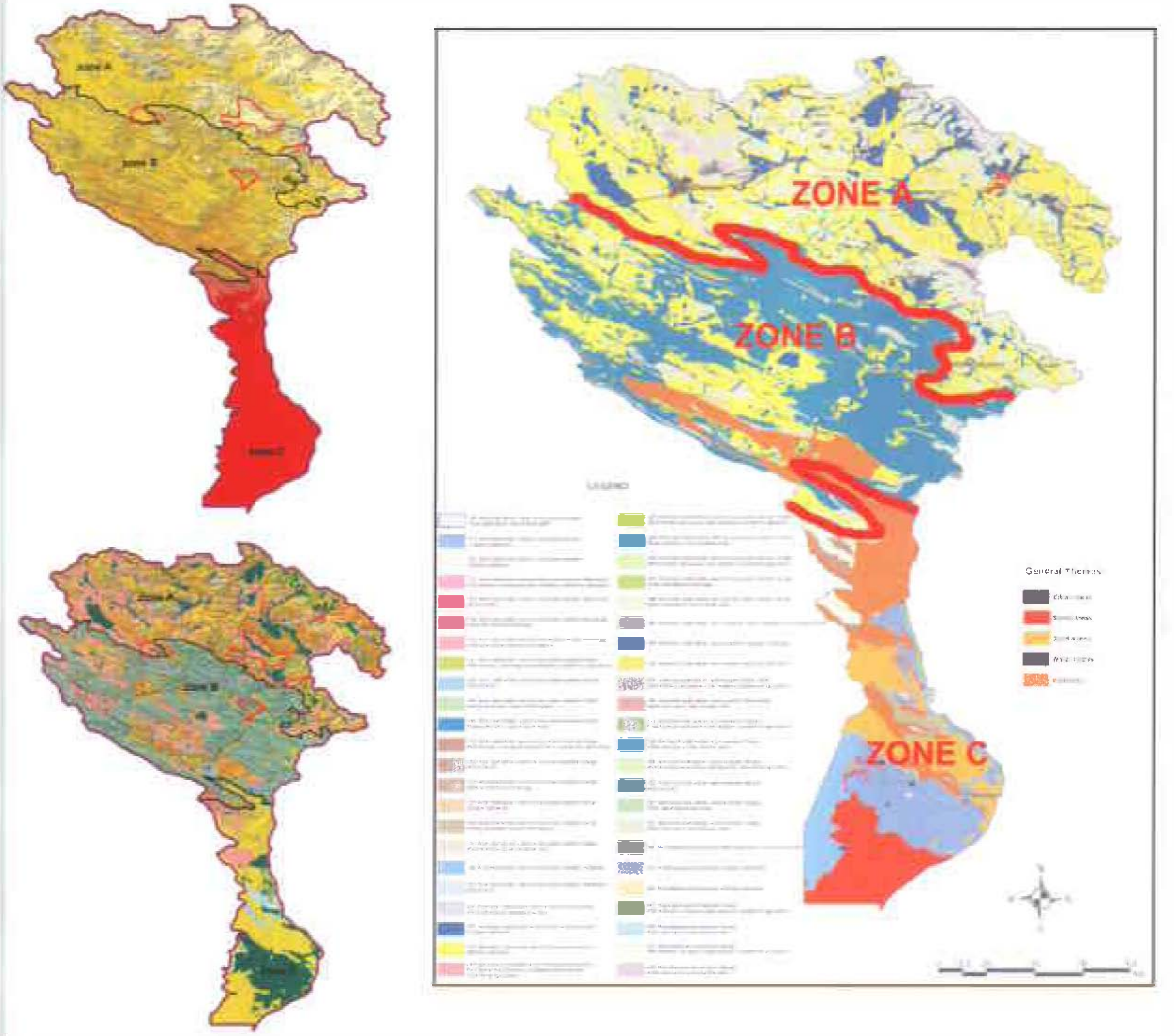


Figure 4. Regrouping of KRB AEZ into major sub-zones A, B,C (right) using major differences in agroclimatic characteristics (top left) and land use/land cover (bottom left).

This agricultural region is generally situated at high elevation, with about 37% of the plains between 1300 and 1800 m, and another 14% above 1800 m. Agricultural land use is very important in this region, with 49% of the area under rainfed crops, and 16% under irrigated crops. Rangelands are important (32%), whereas forest areas are insignificant (<1%).

While semi-arid, precipitation, although varying considerably from year to year, is quite good, with annual totals exceeding 400 mm in nearly 75% of the region (Fig. 28). The high percentage of irrigated land use, in a region that has relatively good rainfall, points to adequate availability of water resources. On the other hand, considering that about half of the region (47%) is unsuitable for growing crops due to topographic limitations (slopes >12%), there must be a shortage of land for agriculture. This may explain the practice of growing crops on steep slopes, a practice of which the Honam benchmark site (see chapter 3) shows good examples (Fig.73 and Fig.74).

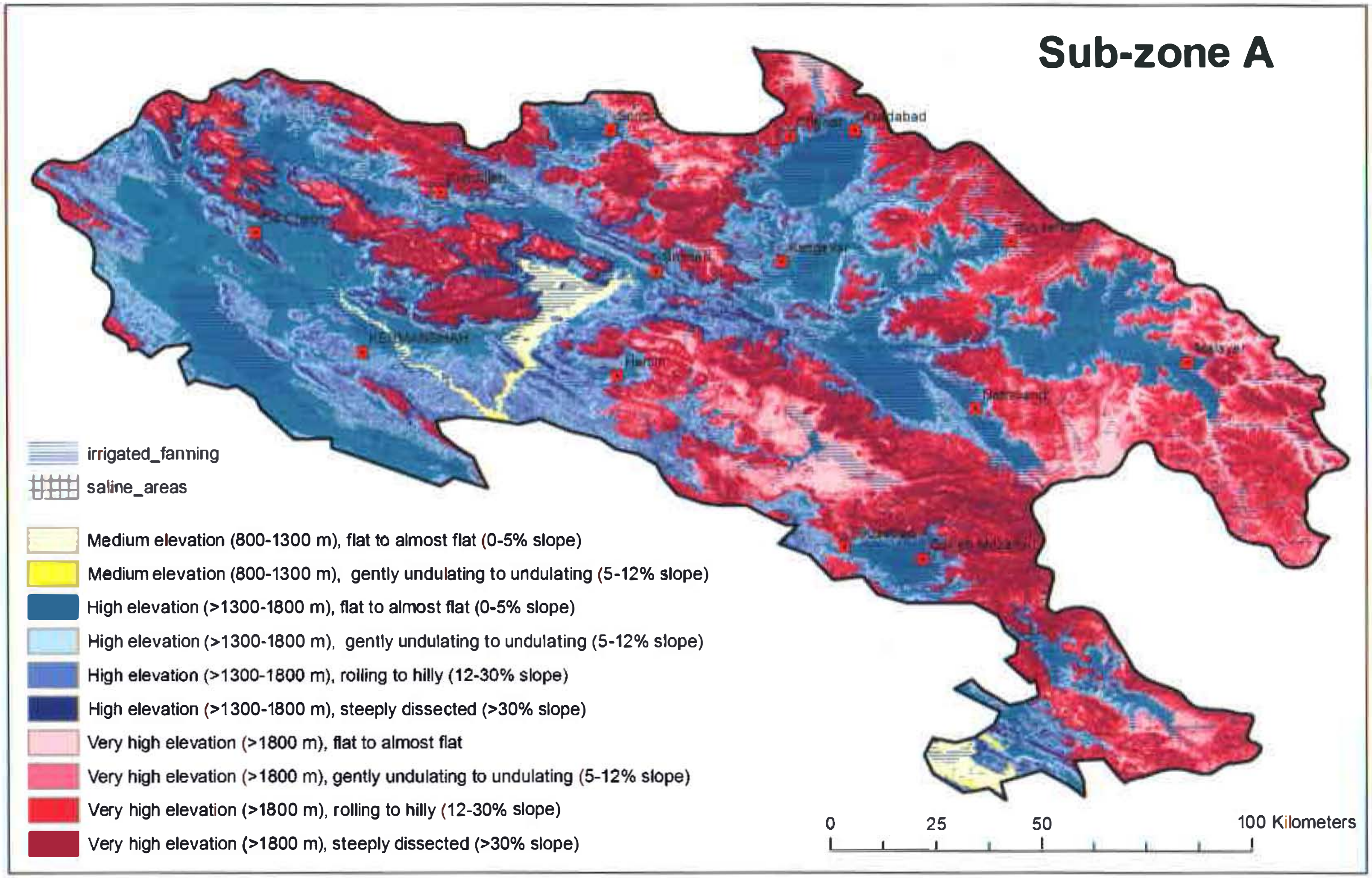


Figure 5. Overview map of Northern Agricultural Region (Sub-zone A)

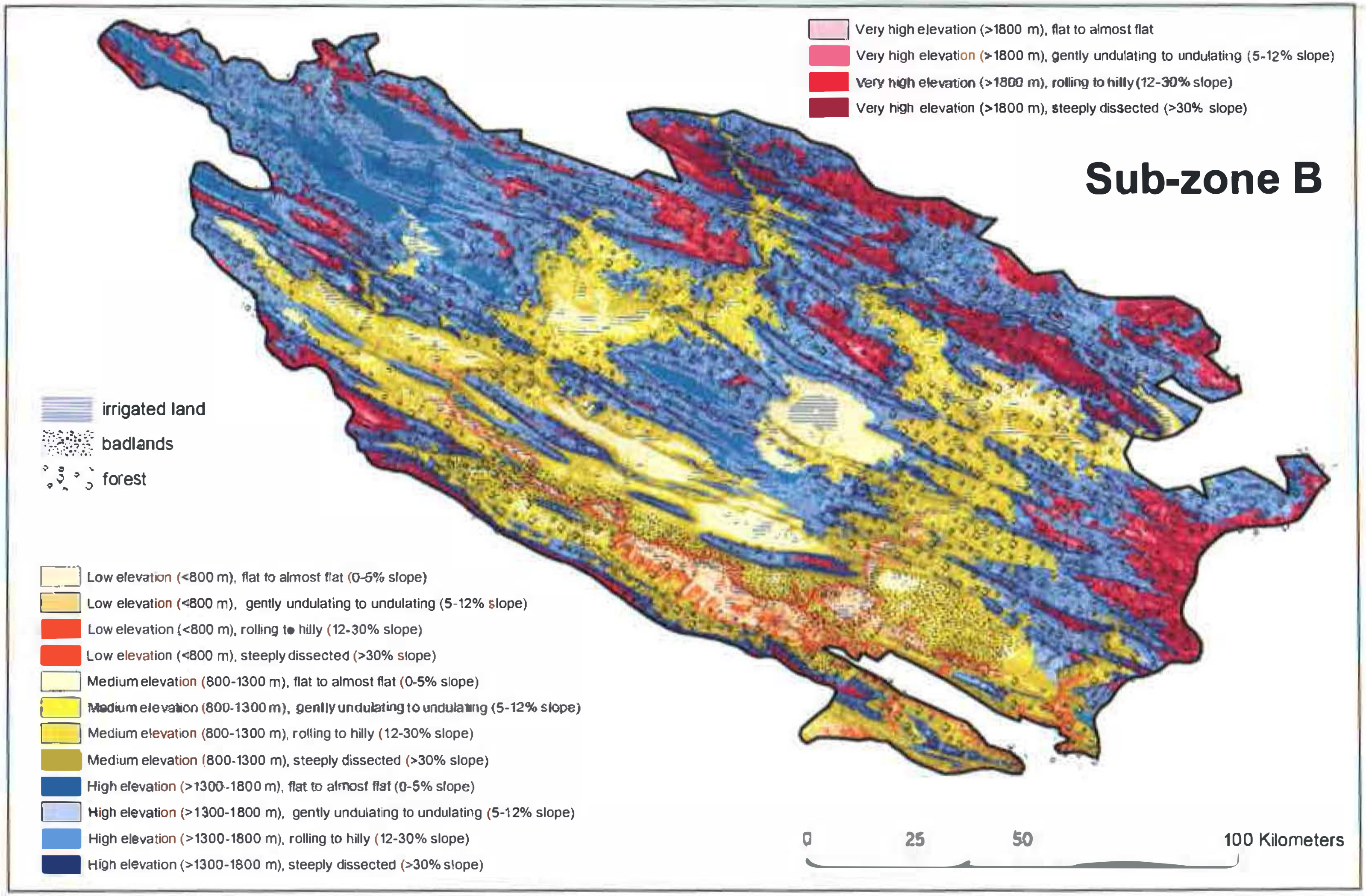


Figure 6. Overview map of Central Agricultural Region (Sub-zone B)

In addition to a shortage of suitable land, the major limitation to agriculture appears to be cold. Using 'growing degree days' (GDD) as an indicator of the thermal energy available for crops, 70% of the region that is not limited by steep slopes (<12%), has 3,000-5,000 GDD per year, which is certainly low in comparison to the Southern Agricultural Region, which has nearly twice as much. Unsurprising in this region of high elevation, the available water resources can thus not be put to optimal use for agriculture, as cold affects the duration of the growing season and the prevalence of frost. The moisture- and temperature-limited growing period is less than 120 days in 73% of the region that is not limited by steep slopes.

The end of the autumn growing season is December in the plains and November in the mountains, whereas the onset of the spring growing season is February in the lower plains, March in the mountains and the higher plains, and April in the higher mountains.

2.2.2.2. Central Agricultural Region (Sub-zone B)

The Central Agricultural Region, which covers about 20,000 km^2 in the KRB, shows the same NW-SE landscape structure as the Northern Region, but the elevation differences between plains, hills and mountains are less pronounced (Fig. 6). Also, here the geological inheritance is very obvious, with alternating stratified lithological materials, ranging from hard limestones to softer and often unconsolidated and easily erodible calcareous sediments. As a result, about 7% of the region is considered 'badlands' characterized by severe current erosion and high erodibility (Fig. 56). The Geological Map of Iran (Fig.47) indicates that the strata are of increasingly younger age towards the south, from Upper Cretaceous in the north, towards Eocene, Oligo-Miocene and Lower Miocene in the south of the region. Generally this agricultural region is at lower elevation than the Northern Region.

Although roughly a similar proportion of this region (48%) is between 1300 and 1800 m, a much higher part of this region is located between 800 and 1300 m (33%), and a small proportion (5%) is even lower than 800 m.

Also, the land use pattern is very different from the Northern Agricultural Region. There is less rainfed agriculture (27%), a lot less irrigated agriculture (3%), but in contrast more than 58% of this region is covered by oak forest. The proportion of pure rangelands is small (7.5%), but the open forest areas have a dual function, providing additional grazing land. Owing to topographical limitations (slopes >12%), 63% of the land in this agricultural region is unsuitable for agriculture.

In view of the lower elevation the temperature regime is less restricted by cold conditions as in the Northern Region. In 68% of this region the temperature 'stock' exceeds 5,000 GDD per year, with even 35% of the region in the range 6,000-7,000 GDD, and less than 22% with less than 5,000 GDD. The moisture regime is certainly not less favourable than in the north, with >90% of this sub-zone receiving more than 400 mm annual precipitation, and the aridity index (Fig. 30) is comparable. In fact, the growing period during which neither temperature nor moisture is limiting to plant production, is longer, with nearly 80% of this region having a growing period of 120-210 days. Hence the potential for rainfed agriculture is better than in the northern region, but the potential for irrigated agriculture is limited by a lack of surface water resources and dam sites.

2.2.2.3. Southern Agricultural Region (Sub-zone C)

The Southern Agricultural Region covers about 9,740 km^2. In this sub-zone, the land-

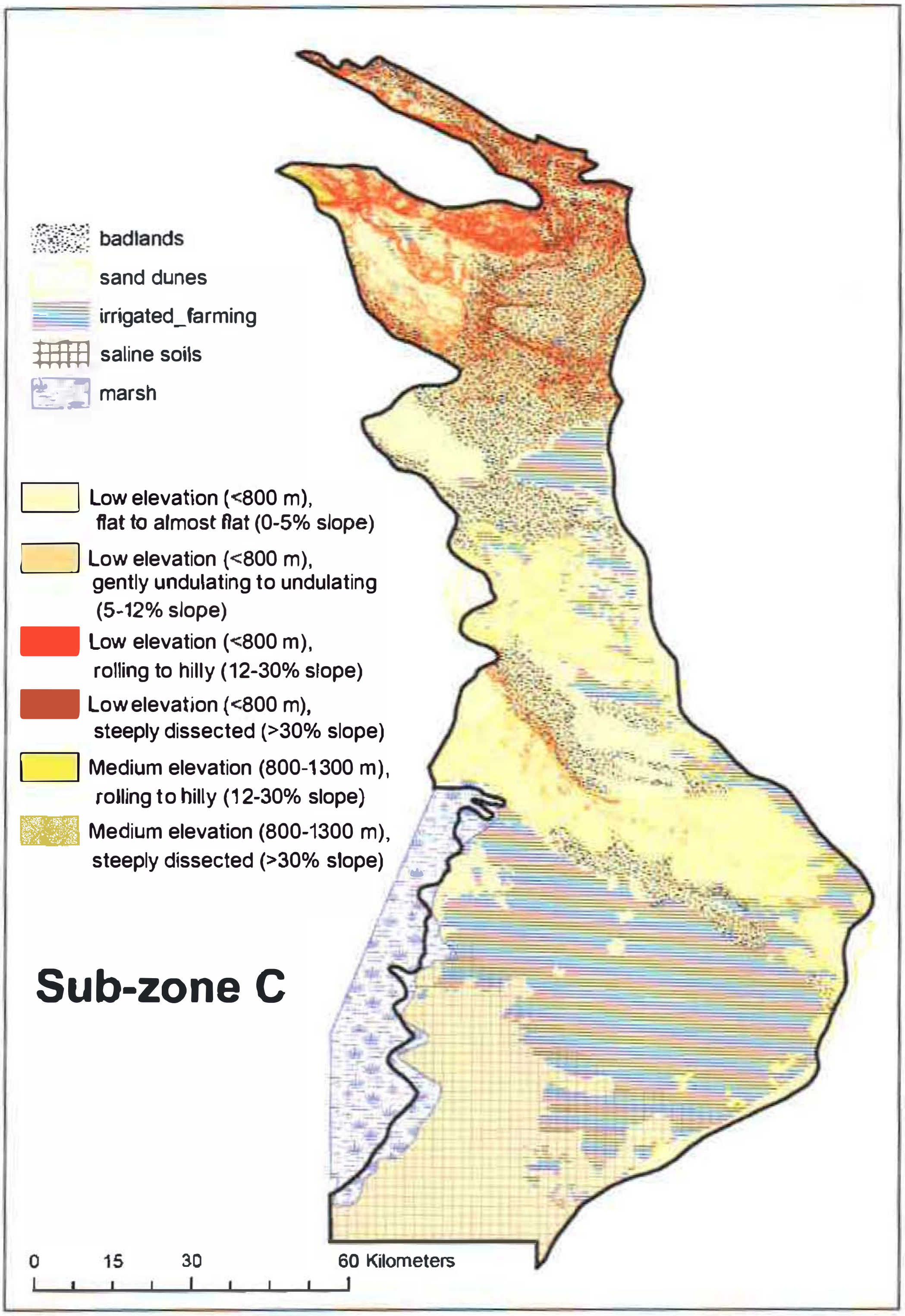


Figure 7. Overview map of Southern Agricultural Region (Sub-zone C)

scape is predominantly a gently sloping plain, with a few interspersed hill ranges, particularly in the north (Fig. 7). The plain is filled with Quaternary sediments, mostly of alluvial origin, that get finer and more clayey southward.

Irrigated agriculture covers a large part (30%) of this region. Most of it is concentrated in a southern zone, around Ahwaz. The Azadegan plain and benchmark site (section 3.1) are very representative for this plain, characterized by heavy clayey soils with much salinity. In the north, around Dezful, is a second large plain with irrigated agriculture and soils that are less affected by salinity than in the southern alluvial plain.The Sorkhe extension area is just inside the area of the KRB and offers a benchmark site that is representative of these conditions.

The remainder of this agricultural region is much less attractive from an agricultural perspective. Low-quality rangelands cover about 52% of the region. Severely eroded and gullied sediments and rocks occupy about 23% of the region, whereas another 17% is covered with sand dunes. As mentioned earlier, salinity is a major problem in the south, and from the soil map it is estimated that about 18% of the region is affected by soil salinity.

In the Southern Agricultural Region, precipitation is considerably less than in the Northern and Central agricultural regions. A strong gradient of declining precipitation, from 300-350 mm in the north to 140-200 mm in the south, ensures that rainfed agriculture is limited to 8% of the region, all of it in the north, whereas further south only irrigated agriculture is possible. On the other hand, temperature is no longer a limiting factor for crop and biomass production. Nearly the entire agricultural region (94%) has 8,000-9,000 GDD, which is comparable to tropical regions, and nearly twice as high as in the Northern Agricultural region.

This implies a huge potential in the irrigated areas for growing two and even three crops per year, subject to the successful management of available irrigation water and soil salinity.

2.3. DISCUSSION

There is nothing new about the AEZ concept. Agro-ecological zones have been used or are intended to be used in different regions or countries for a variety of agricultural purposes. These may include identification of agricultural production zones (e.g., Horn of Africa, Sri Lanka, Kenya), fertilizer use recommendations (e.g., Tanzania), positioning of research stations (e.g., Iran), targeting of new technologies and crop cultivars (e.g., Central Africa, Bangladesh), regional comparative advantage and crop subsidy planning (e.g., Turkey).

Virtually all systems for defining AEZs in different countries are 'ad-hoc' and 'standalone', based on different classification methods. This situation is testimony to a perceived need to respond to particular agricultural planning objectives with an approach that is both 'holistic' and classifies land into distinct, non-overlapping management zones.

2.3.1. Methodological issues

The basic premises in our approach are the following:

- For various kinds of agricultural planning it is important to keep the number of spatial units manageable (in the tens, not the hundreds).
- For the definition of these spatially homogeneous agricultural environments it is necessary and sufficient to combine themes related to climate, land use/land cover, terrain and soils.
- These homogeneous environments can be further characterized using theme-specific attribute tables that relate the AEZs to themes relevant to particular planning objectives

- GIS technology makes this feasible at a wide range of scales.

The advantage of our approach to planners is that, by making use of the database capabilities of a GIS system, the same spatial framework (AEZs) can be retained, irrespective of the particular theme. The limited number of spatial entities makes it a far less cumbersome operation to check on a particular piece of information. While the thematic information is summarized in a composition table, it is not lost since the more detailed spatial information for each theme is retained in the spatial database of thematic maps, which can still be consulted if and when needed.

Secondly, new layers of spatial information can be added, if relevant for particular planning purposes, and in a flexible manner. For example, the AEZ framework could be used for mapping different kinds of land degradation. A possible, but not exclusive, format for a land degradation attribute table is the one presented in Table 9.

Table 9. A theoretical example of an attribute table related to land degradation for some of the AEZ of the KRB

	Severity of land degradation							
AEZ	**WAT**	**WIN**	**SAL**	**LOG**	**GWT**	**FOR**	**RAN**	**SOI**
220	2	1	1	1	3	1	1	3
246	2	1	1	1	1	3	2	2
320	3	2	1	1	3	1	1	3
356	3	3	1	1	1	1	4	2
Badlands	4	3	2	2	1	1	3	3

Notes:
WAT: water erosion; WIN: wind erosion; SAL: salinization; LOG: waterlogging; GWT: lowering of the groundwater table; FOR: forest degradation; RAN: rangeland degradation; SOI: soil fertility decline; Ratings: 1: none-slight; 2: moderate; 3: severe; 4: very severe

Table 10. Problems in KRB and (partial) use of AEZ approach

Problem/Need	**AEZ solutions**
Understanding resource constraints and potentials	Rapid identification of areas with different resource issues
Identifying suitable benchmark sites for integrated research	Identification of biophysically representative environments
Improving clarity, integration and synthesis of information on biophysical environments	Single synthesis map linked to attribute database; limited number of mapping units
Targeting appropriate crop varieties for different environmental stresses	Mapping of spatial domains of various stresses (low or high temperatures, frost, salinity, erosion, short growing season, irrigation water availability, aridity, drought)
Assessing resource degradation in upper catchment	Identification of current and potential hotspots of resource degradation using AEZ framework
Identifying technological options for land and water management	Reference to 'Lessons learnt' from similar agro-ecological zones inside or outside Iran
Fertilizer/nutrient use recommendations for improving water and land productivity	Delineation of areas with high, moderate or low potential/risks for irrigated or rainfed agriculture; delineation of areas with potential for supplemental irrigation

The method for defining AEZs outlined in the previous section can be used at different scales, ranging from the global to the sub-national, subject to the use of appropriate and well-matching datasets, and adapted to the particular planning needs. Although it may be considered desirable to define AEZs once and for all, this may not be practical given the differences in quality of essential datasets. AEZs defined at a global or regional scale will make use of global or regional datasets, national or sub-national AEZs will have to use (more accurate) national or sub-national datasets.

On the other hand, irrespective of scale, the principles for applying this method remain the same. In addition to our KRB case study at sub-national level, we have applied the same approach for the mapping and characterization of Syria, using national datasets, and of ICARDA's mandate region (North Africa, West and Central Asia) using regional datasets.

2.3.2. Potential uses for the AEZ framework

The main use of the AEZ framework is as a tool for rapid identification of different biophysical environments and characterization of resources and constraints to assist agricultural research planning and policy development. Table 10 shows its applicability to address different problems in the KRB.

3. BENCHMARK SITES

Benchmark sites are an essential component of integrated natural resource management (INRM) approach to agricultural research. In the ICARDA vision of INRM implementation they are relatively small areas, used to develop, test, adapt, and evaluate improved genetic and natural resources management practices and technologies under real-life conditions and not in research stations (Oweis et al., 2006). In order to allow a meaningful extrapolation of the research conducted in these benchmark sites, they have to be representative of the larger target areas of the research, meaning that they should resemble the broader agro-ecological zone(s) of interest in terms of the major agricultural, environmental, and human elements.

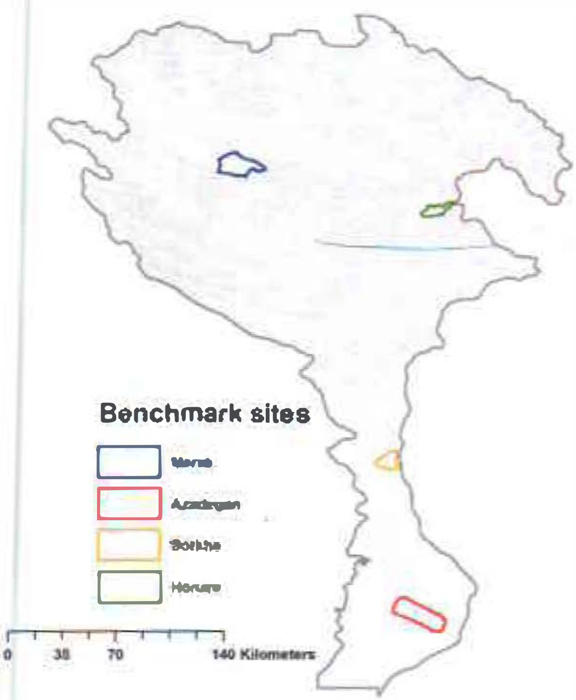


Figure 8. Location of the benchmark sites

Four benchmark sites have been established in the KRB, two for the Upper Basin and two for the Lower Basin. The location of these sites is shown in Figure 8. The sites of the Upper-KRB, Honam and Merek, were delineated as hydrological catchments. Those of the Lower-KRB, were established as 'project areas', representative of larger areas in the Lower-KRB that were simply too flat to allow a delineation through the hydrological catchment concept.

In the following sections an overview is provided of the biophysical conditions at these benchmark sites. Furthermore, the climatic and edaphic similarity is assessed in other areas in the KRB, Iran and finally the CWANA region.

This is then followed by a discussion on the ability of this kind of similarity analysis to select the most suitable benchmark sites from a number of candidate sites. Views of the benchmark sites are provided in Annex 3.

3.1. AGRO-ECOLOGICAL ZONES OF THE BENCHMARK SITES

The biophysical characterization of the benchmark sites provided in this section is entirely derived by extraction from the KRB-level maps of Agro-ecological Zones (Fig. 3), landforms (Fig. 46), land use/land cover (Fig. 41) and soils (Fig. 42). It needs to be stated explicitly and upfront that these thematic maps only show indicative climatic and edaphic conditions within the benchmark sites. They are used in the absence of more detailed maps, but cannot be considered a substitute for a proper agroeological characterization at local level. Particularly, in the case of the soil map, the level of detail is inappropriate for a benchmark site.

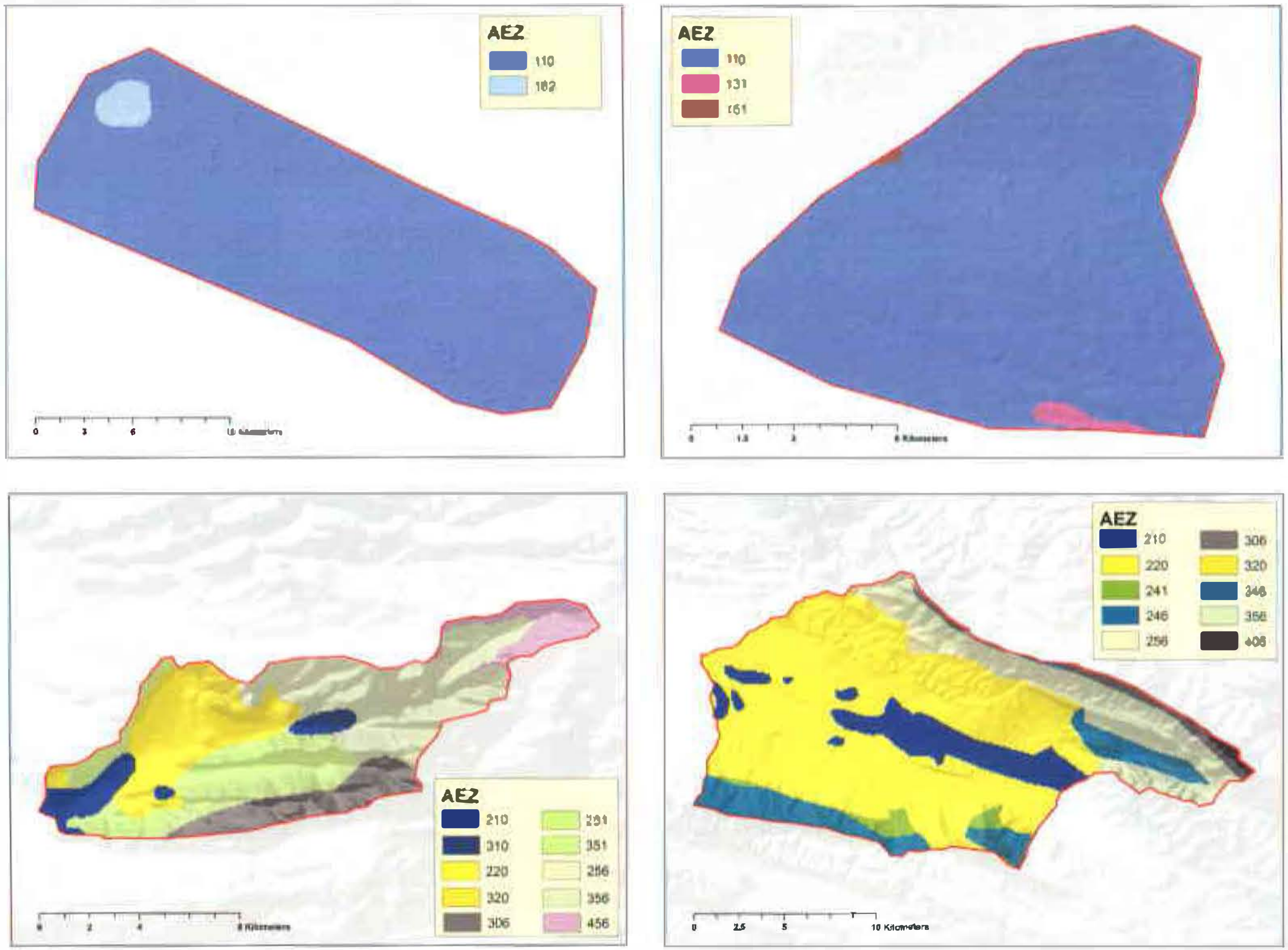


Figure 9. Agro-ecological zones of the benchmark sites, anti-clockwise from upper left: Azadegan, Honam, Merek, Sorkhe

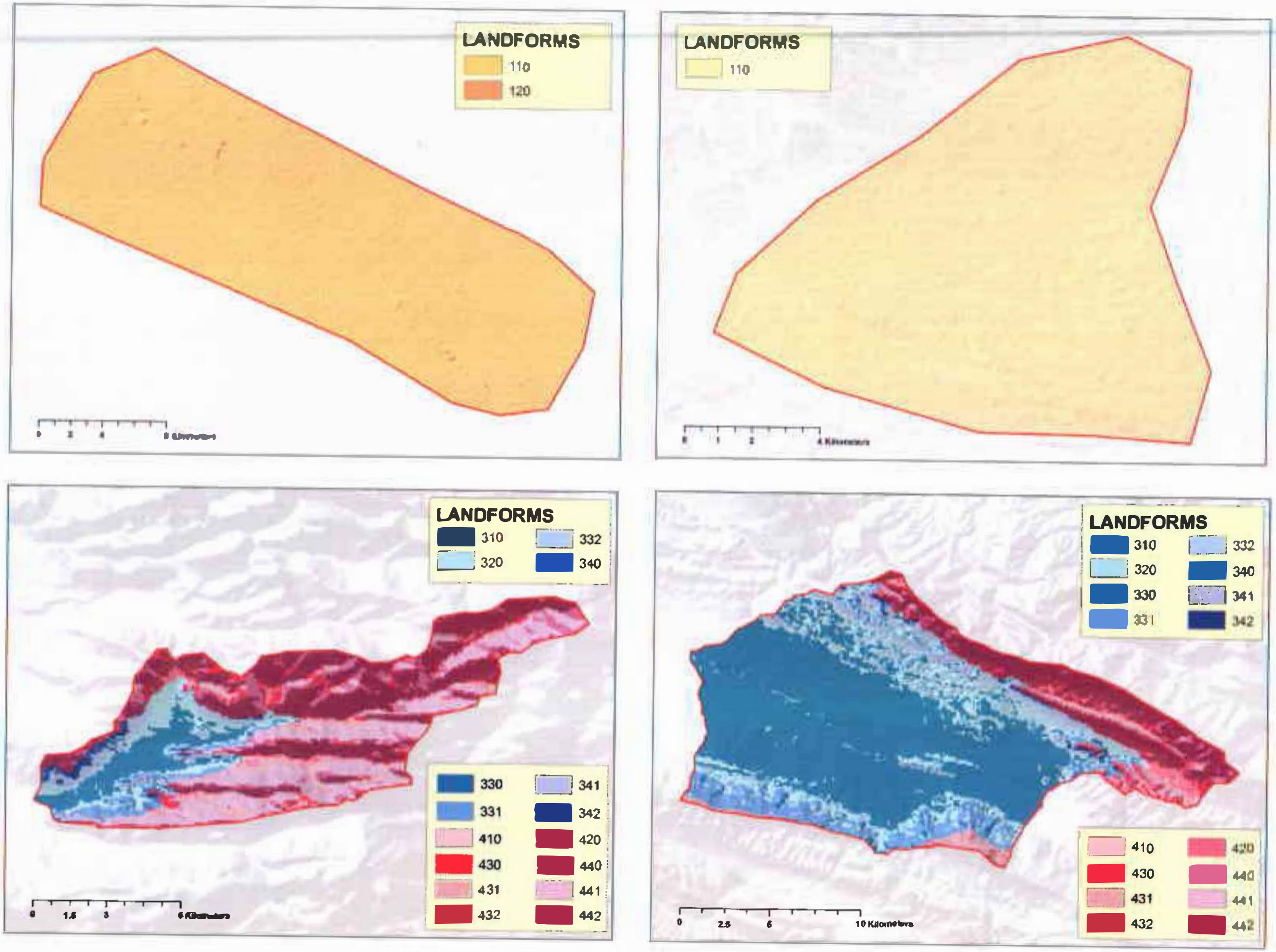


Figure 10. Landforms of the benchmark sites, anti-clockwise from upper left: Azadegan, Honam, Merek, Sorkhe

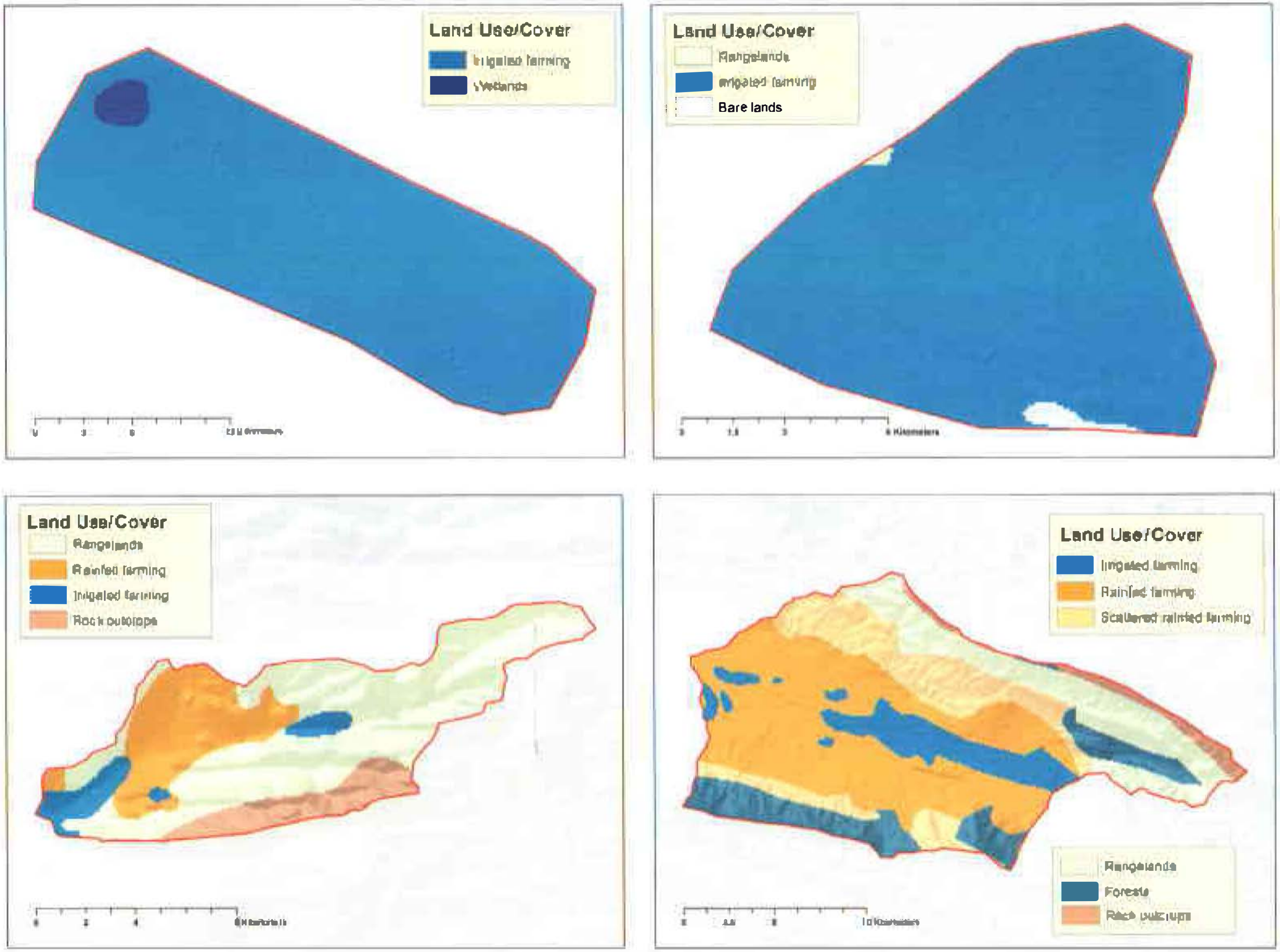


Figure 11. Land use/land cover in the benchmark sites, anti-clockwise from upper left: Azadegan, Honam, Merek, Sorkhe

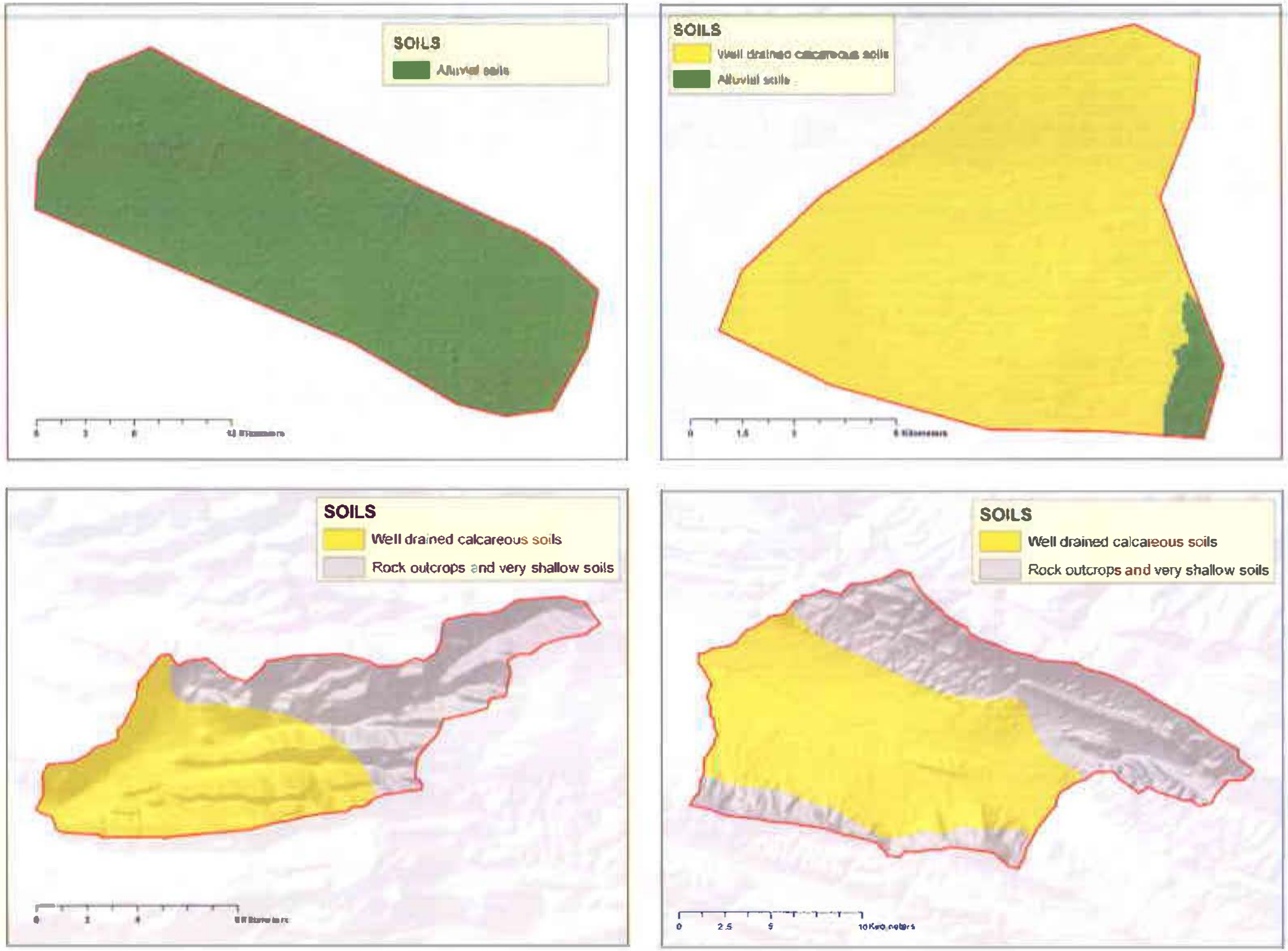


Figure 12. Soils of the benchmark sites, anti-clockwise from upper left: Azadegan, Honam, Merek, Sorkhe

In Figure 10 are the extracted maps of landforms, whereas Figure 11 shows the land use/land cover and Figure 12 the soils. The codes for the landforms are explained in Annex 8.

Azadegan and Sorkhe are mostly in the same AEZ, since they are both located in irrigated plains and have the same arid climate with mild winters and warm to very warm summers. Although the soils are very different in salinity levels (section 2.2.4), this is not reflected in the AEZ since the soil map (Fig.12), although noting a distinction between alluvial soils in Azadegan and calcareous agricultural soils in Sorkhe, does not allow inclusion of this important management property.

Honam and Merek share a number of AEZ (210, 256, 306, 320 and 356), yet the differences between these two benchmark sites are more pronounced than between Azadegan and Sorkhe. Honam is essentially an elongated and fairly narrow valley with steep hillslopes, in which the latter predominate over the valley. In the case of Merek, it is the opposite with a broad valley and rather narrow piedmont and mountain slopes. In terms of land use/land cover, both sites are diversified, each containing irrigated and rainfed crops, rangelands and bare rock outcrops. Merek, on the other hand, is the only benchmark site where there are some open forest areas (Fig. 11 and Fig.70). Again, on the basis of soils (Fig. 12) no distinction can be made between these two benchmark sites in view of the inappropriate scale of the soil map.

Precipitation and temperature data for the benchmark sites, obtained by extraction from the relevant climate surfaces, are summarized in Table 11 and Figure 13.

Table 11. Summary of precipitation and temperature data for the benchmark sites

Benchmark site	Factor	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Azadegan	Precip., mean	42.7	25.9	30.0	11.6	3.0	0.0	0.0	0.0	0.0	4.0	22.8	43.3
	Precip., st.dev.	1.1	0.8	1.0	0.8	0.1	0.0	0.0	0.0	0.0	0.0	0.6	1.7
	Temp., mean	12.2	14.3	17.5	22.2	27.8	31.4	32.9	32.4	29.4	24.2	18.2	14.0
	Temp., st.dev.	0.3	0.2	0.1	0.2	0.3	0.4	0.4	0.3	0.3	0.2	0.1	0.2
Honam	Precip., mean	58.6	61.1	91.0	59.2	32.2	2.0	1.2	0.6	0.3	24.9	51.2	66.1
	Precip., st.dev.	2.2	3.1	3.4	4.1	3.4	0.7	0.3	0.2	0.2	1.0	2.7	2.9
	Temp., mean	-1.5	0.2	4.1	9.4	13.9	19.2	22.9	22.5	18.5	12.8	6.6	1.8
	Temp., st.dev.	2.3	2.4	2.2	1.8	1.8	1.6	1.6	1.6	1.5	1.6	1.7	2.1
Merek	Precip., mean	69.8	69.5	98.7	55.6	30.1	1.0	0.4	0.1	0.3	25.4	62.0	76.3
	Precip., st.dev.	1.2	2.4	1.9	2.7	2.0	0.1	0.2	0.1	0.1	0.6	1.4	0.5
	Temp., mean	0.7	2.3	6.2	11.6	16.2	21.5	25.4	24.9	20.6	14.9	8.7	4.0
	Temp., st.dev.	1.1	1.1	1.1	1.0	1.0	0.9	0.9	0.9	0.8	0.8	0.9	1.0
Sorkhe	Precip., mean	76.1	54.2	53.9	25.9	6.0	0.0	0.0	0.0	0.0	8.6	32.5	68.8
	Precip., st.dev.	1.7	0.8	2.1	0.4	0.1	0.0	0.0	0.0	0.0	0.2	0.7	2.1
	Temp., mean	10.8	13.1	16.5	22.2	29.0	33.6	35.4	35.0	31.8	25.4	18.6	13.4
	Temp., st.dev.	0.1	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.0	0.0	0.0

Notes:

Precip_mean: mean monthly precipitation (mm)
Precip_ st.dev: standard deviation (mm)
Temp_mean: mean monthly temperature (mm)
Temp._ st.dev: standard deviation (mm)

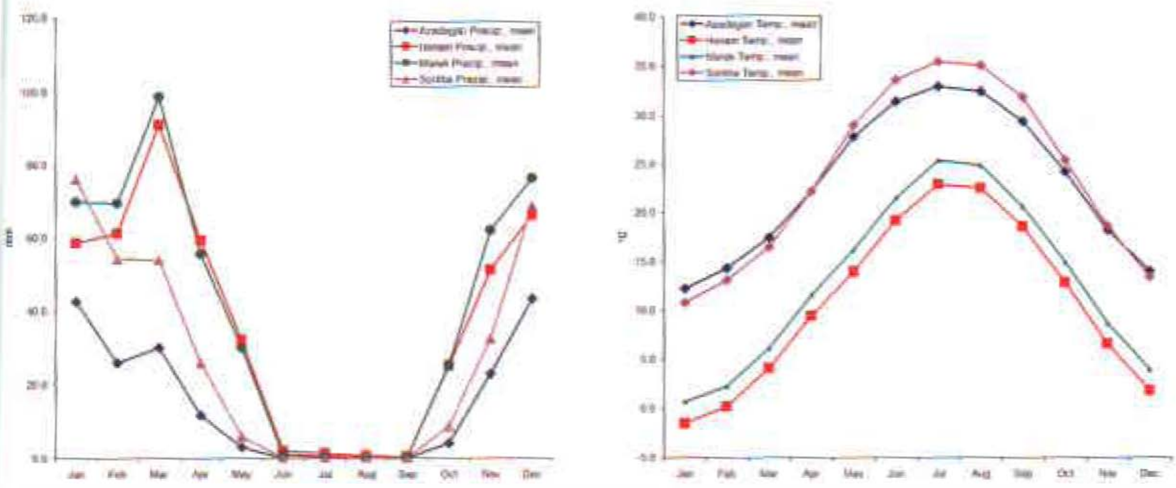


Figure13. Mean monthly precipitation (left) and temperature (right) at the benchmark sites

Climatically, there is again some similarity between Azadegan and Sorkhe on the one hand, and Honam and Merek on the other. Pair-wise the temperature patterns are indeed close matches, although there are more differences in the precipitation patterns. The winter-spring precipitation pattern is nearly identical between Honam and Merek, but the autumn patterns deviate slightly. For Azadegan and Sorkhe the precipitation patterns deviate substantially, with more rainfall for Sorkhe.

The AEZ present in the benchmark sites occupy 90% of the KRB, hence on this criterion the benchmark sites are highly representative, even though some of the AEZ may occupy only a small area in the benchmark sites. On the other hand, with the exception of a few small areas in Merek, the oak forest belt, which is so characteristic of the Middle Karkheh Agricultural Region (section 2.2.3), is not present in the benchmark sites. Neither are the badlands, which occupy substantial areas in the Middle and Southern Karkheh Agricultural Regions, and the sand dunes of the Southern Karkheh Agricultural Region. Although less interesting from a crop production perspective, all three areas are important targets for soil conservation, land reclamation and forest improvement.

3.2. EXTRAPOLATION DOMAINS

3.2.1. General approach

The technological, institutional and policy options for resource-stressed farmers and communities developed in the benchmark sites, have application possibilities in the dry areas far beyond these sites. A first approach to an ex-ante analysis of where else these technological options have potential relevance is by looking at similarity in agro-ecologies and socioeconomic conditions.

To assess similarity in biophysical conditions, we can include in the analysis the key themes of the agro-ecological zones approach: climate, landforms, land use/land cover and soils. To assess similarity in socioeconomic conditions, the best way is through a map of farming systems. However, such map does not exist for either Iran or KRB, hence no attempt has been made at this stage to assess similarity in socioeconomic conditions.

The approach taken is, therefore, only confined to the biophysical domain and involves several stages of assessment. In the first stage, climatic similarity in biophysical conditions is assessed using temperature and precipitation as indicators and similarity indices for quantification.

In further stages the climatic similarity index is combined with a landform similarity index and a land use/cover similarity index. These procedures are explained in the next section.

3.2.2. Methodology

3.2.2.1. Climatic similarity

In climatic similarity analysis, the value of a climatic parameter or index at one location (the 'match' location) is compared with other ('target') locations in order to quantify the degree of similarity in climatic conditions. In this particular case, the climatic pattern of each one of the four KRB benchmark sites has been used as representative of the match location. The target areas are KRB, Iran and the CWANA region.

The model used to assess similarity is a very simple distance function:

$$S = I_{1(\Delta_t)} * I_{2(\Delta_p)}$$

The functions I_1 and I_2 are *similarity indices* for respectively air temperature and precipitation. They model the drop in similarity under increasing dissimilarity for air temperature Δ_t and precipitation Δ_p, respectively, as

$$I_1 = e^{\left(-\frac{\Delta_t}{\sigma_t}\right)} \text{ and } I_2 = e^{\left(-\frac{\Delta_p}{10\times\sigma_p}\right)},$$

with σ_t [°C^{-1}]and σ_p [mm^{-}]user-defined calibration constants (Fig. 14).

In this study the calibration factor for air temperature σ_t is set to 7.0, which corresponds to a drop in similarity by 20% under Δ_t = 2°C and of about 50% under Δ_t = 5°C. The calibration factor for precipitation σ_p is set to 3.0, which corresponds to a drop in similarity of 50% under Δ_p = 20 mm and of about 80% under Δ_p = 50 mm.

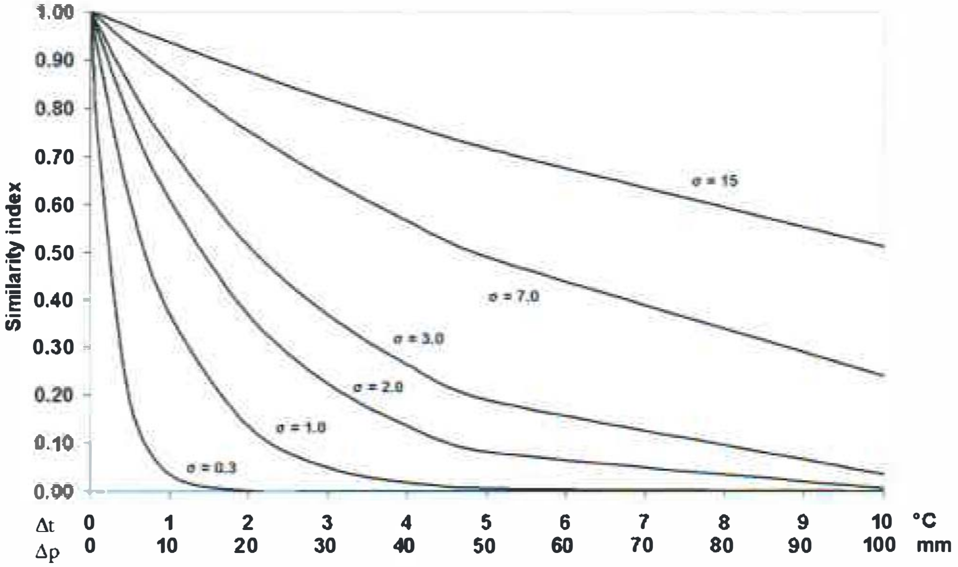


Figure 14. Use of calibration factors to adjust sensitivity to a climatic parameter

Data input was in the form of climatic grids (12 mean monthly precipitation and average temperature surfaces). To assess similarity within KRB, the grid cells had SRTM-DEM (90 m) resolution. whereas for the wider-area assessments (Iran and CWANA) different grids were used with GTOPO30-DEM resolution (30 arc-second; 1 km).

The dissimilarity in temperature Δ_t was computed as follows (De Pauw, 2002):

$$\Delta_t = \sqrt{\frac{\sum_{i=1}^{12}(t_{i+s} - T_i)^2}{12}},$$

where i is month number, t is mean monthly air temperature in the target point, T is mean monthly air temperature in the matching point (°C), s is a phase shift in month numbering.

The phase minimizes the deviation in temperature between match and target location and is obtained by shifting the temperature array until the covariance:

$$Cov(\overline{Tm},\overline{T}) = \sum_{i=1}^{12}(Tm_i - \overline{Tm}) \cdot (T_i - \overline{T})$$

reaches a maximum. This way the seasonal pattern in different geographic locations can be synchronized. In a climatically homogeneous region the phase is 0. The maximum possible phase is 11.

The same phase (s) was then applied to calculate the dissimilarity in precipitation pattern (Δ_p):

$$\Delta_p = \sqrt{\frac{\sum_{i=1}^{12}(p_{i+s} - P_i)^2}{12}},$$

where p is monthly precipitation in each target point, P monthly precipitation in the match point.

The above formulas apply for a similarity assessment based on a point to point comparison. However, within a benchmark site a range of precipitation and temperature conditions may exist. To ensure that the internal climatic variations do not exaggerate the dissimilarity that may arise by taking only one point inside the benchmark site. the precipitation and temperature conditions in two points are considered, that represent a minimum and maximum. These points can be seen as end points of transects across the major temperature and/or precipitation gradients that represent 80-90% of the climatic conditions inside the benchmark site. For temperature or precipitation between these two values, 100% similarity is assumed. In Figure 15, the two end points of the transect cover about 90% of the temperature and precipitation conditions inside the Merek site.

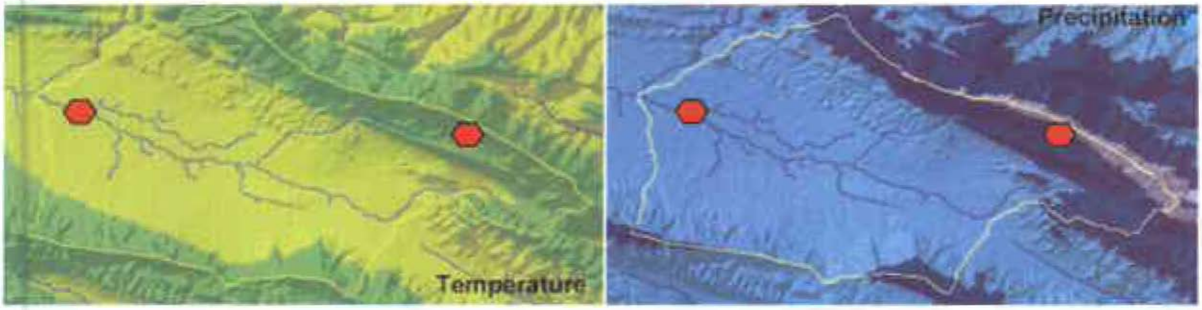


Figure 15. Assessing area similarity using two points along a gradient of temperature (left) and precipitation (right)

3.2.2.2. Similarity in landforms and land use/land cover

Whereas climatic similarity is assessed through a continuous variable, the climatic similarity index, similarity in landforms and land use/land cover is assessed as a crisp feature, which can have only two states, either similar or non-similar. This simplification is necessary in view of the fact that landforms or land use are usually characterized through a classification, rather than a continuous variable. To make the similarity assessment work using classifications, it is important that the classifications used are adapted to the level of out-scaling envisaged and to the detail of the available datasets, and are used in a way to avoid exclusion of transitional classes.

To assess similarity of landforms, a simplified 3-class system is used, based on the concept of 'relief intensity' and applied to the GTOPO30 DEM[6] dataset. 'Relief intensity' is derived from the maximum elevation difference between two neighbouring pixels and classified as follows:

- Plains: relief intensity 0-50 m
- Hills: relief intensity 50-300 m
- Mountains: relief intensity >300 m

In contrast to the climatic factors used in the similarity mapping, which are continuous variables, landforms are classified variables and similarity is thus expressed by two states only, 'similar' if the landform has the same class as in the benchmark site, and 'non-similar' if it has a different class. The landform similarity index is 1 if similar, and 0 if non-similar.

Any pixel outside the benchmark sites was considered 'similar in landforms' to Azadegan or Sorkhe, if it was classified as 'Plains'. It was considered similar to Honam if it was classified as either 'Hills' or 'Mountains'. As Merek contains all landform categories (plains, hills and mountains) similarity in landforms was irrelevant to the similarity assessment.

To assess similarity of land use/land cover the 19-class Land Use/Land Cover digital dataset, developed by the FRWO (1998), was simplified to a 10-class system, of which only the following are relevant for the similarity assessment

- Irrigated farming
- Rainfed farming
- Rangelands
- Forests

As in the case of landforms, similarity is expressed by two states, 'similar' if the land use/land cover has the same class as in the benchmark site, and 'non-similar' if it has a different class, and the land use/land cover similarity index is 1 if similar, and 0 if non-similar.

Any pixel outside the benchmark sites was considered 'similar in land use/land cover' to Azadegan or Sorkhe, if it was classified as 'Irrigated farming'. It was considered similar to Honam if it was classified as either 'Irrigated farming' or 'Rangelands'. It was considered similar to Merek if it was classified as either 'Rainfed farming', 'Forests' or 'Rangelands'.

3.2.2.3. Similarity in all evaluated factors

The total similarity was calculated as the product for all evaluated factors at three levels of out-scaling: (i) the KRB, (ii) Iran and (iii) the CWANA plus northern Mediterranean region.

At the level of KRB the landform was not taken into consideration for the similarity assessment. Since both climatic and land use/land cover data were used at high resolution (SRTM), there was no point in using a third variable at a 10 times lower resolution, as is necessary to differentiate macro-level landforms.
Hence at the level of KRB the total similarity was calculated as:

$$S_{total} = S_{climate} * S_{LULC}$$

with $S_{climate}$ the climatic similarity index as calculated in section 3.2.2.1, and S_{LULC} the land use/land cover similarity index.

[6] Documentation: http://edc.usgs.gov/products/elevation/gtopo30/README.html

Table 12. Degree of similarity of selected target areas with the benchmark sites (in %)

Similarity of target area	with benchmark site	No similarity	Very little similarity	Some similarity	Moderate similarity	High similarity	Very high similarity
CWANA	Azade	97.00	0.62	1.72	0.44	0.18	0.05
(22,383,412	Honam	79.78	8.92	5.58	4.11	1.30	0.31
km²)	Merek	20.94	48.94	23.28	6.01	0.67	0.15
	Sorkhe	97.02	0.95	1.77	0.22	0.03	0.01
Iran (1,624,760	Azade	96.03	0.57	1.70	0.87	0.37	0.46
km²)	Honam	61.97	3.89	13.98	12.12	5.45	2.59
	Merek	20.94	48.94	23.28	6.01	0.67	0.15
	Sorkhe	96.03	0.69	2.21	0.53	0.29	0.25
KRB							
(50,000 km²)	Azade	86.13	3.44	4.60	0.31	0.36	5.15
	Honam	73.81	3.08	6.88	0.74	4.03	11.45
	Merek	17.65	4.17	9.05	10.37	25.99	32.77
	Sorkhe	86.13	1.03	6.81	3.62	1.82	0.60

Notes:

Terminology used for degree of similarity is as follows:
No similarity: total similarity index is zero; *Very little similarity*: total similarity index is 0 to 0.1;
Some similarity: total similarity index is 0.1 to 0.3; *Moderate similarity*: total similarity index is 0.3 to 0.5; *High similarity*: total similarity index is 0.5 to 0.7; *Very high similarity*: total similarity index is >0.7

At the level of Iran and the CWANA plus Northern Mediterranean Region all three factors were considered and the total similarity calculated as:

$$S_{total} = S_{climate} * S_{LF} * S_{LULC}$$

with SLF the landform similarity index.

3.2.3. Results

The results are summarized in Table 12 and shown in the following three sets of maps (Figures 16-27), grouped by out-scaling domain.

If we adopt a conservative interpretation of 'similarity' by considering only the classes 'high similarity' and 'very high similarity' to represent similar areas, we can draw several conclusions. In general, it can be noted that, irrespective of the out-scaling domain and the way similarity is defined, the areas similar to Azadegan and Sorkhe are small, 51,300 km² and 9,500 km² respectively. To some extent this is understandable, since these benchmark sites have a single land use type, irrigated farming, and irrigation is across CWANA, at least in area, a minority land use. If we include 'moderate similarity' in the definition of 'similar', the areas similar in CWANA to Azade increase to nearly 150,000 km² and to nearly 60,000 km² for Sorkhe. However, one has to be careful doing so since in irrigated areas the key factors that affect similarity are climatic conditions, which determine crop water and irrigation requirements, and soil types. The latter are not even included in this evaluation of similarity.

At the level of the KRB, Merek is a well chosen benchmark site, with nearly 60% of the basin being either 'highly similar' or 'very highly similar'. Also, Honam is a representative site, covering 15% of the KRB. At the level of Iran and CWANA, the Honam site is more representative, representing 8% of the

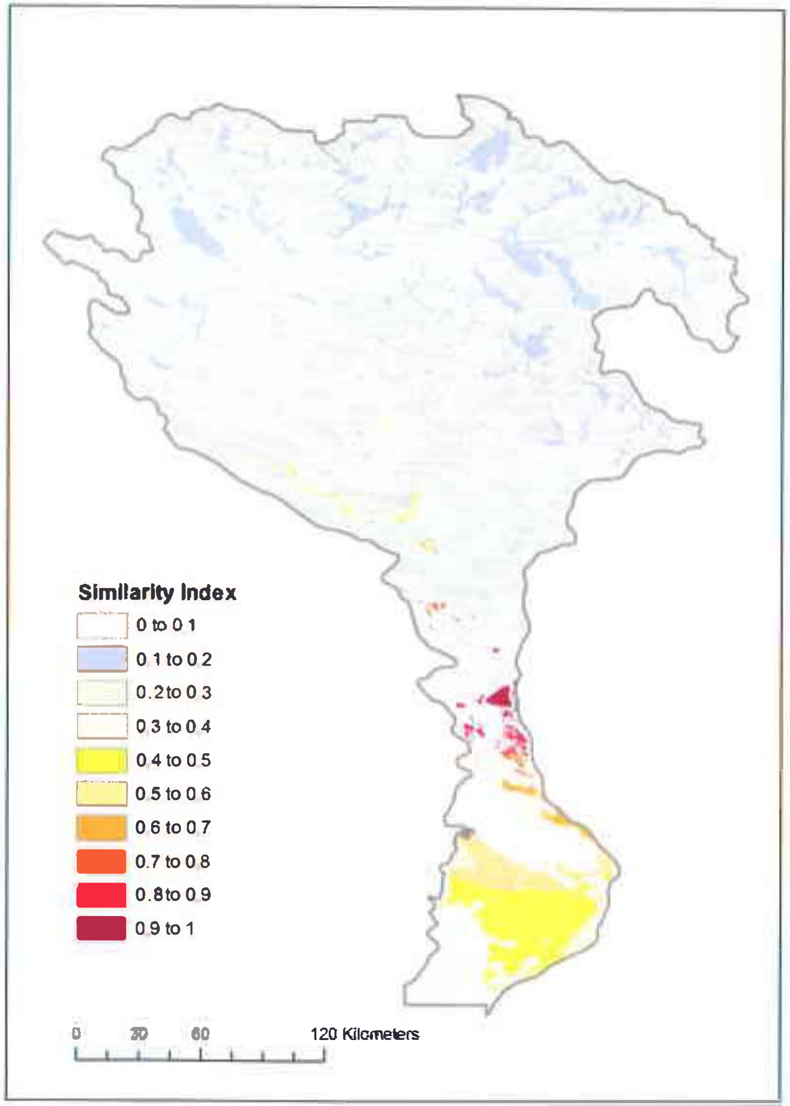


Figure 16. Similarity of KRB in climate and land use/land cover to the Sorkhe benchmark site

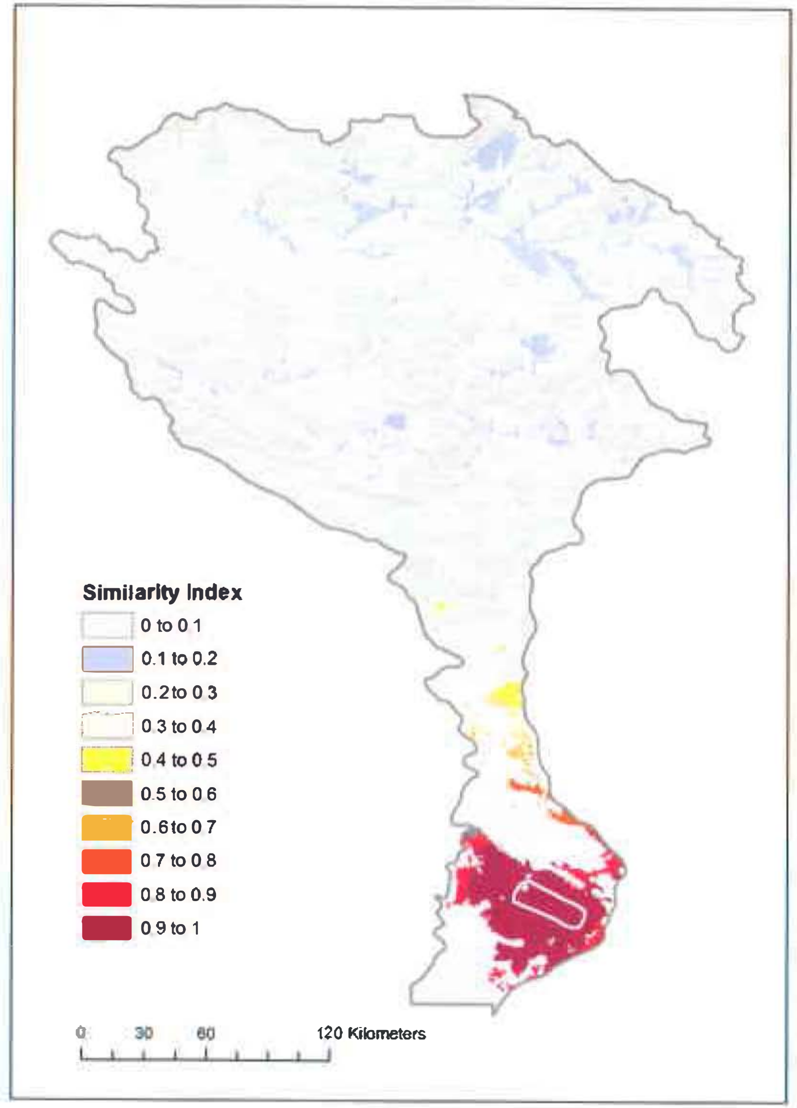


Figure 17. Similarity of KRB in climate and land use/land cover to the Azadegan benchmark site

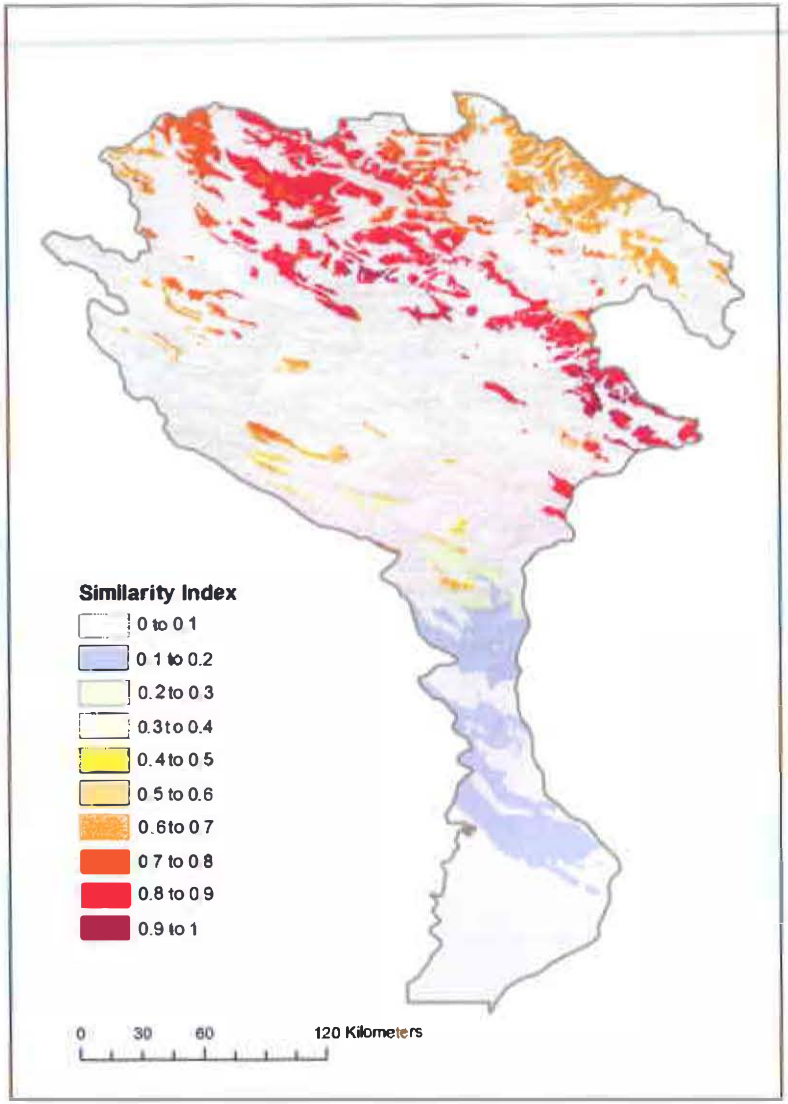


Figure 18. Similarity of KRB in climate and land use/land cover to the Honam benchmark site

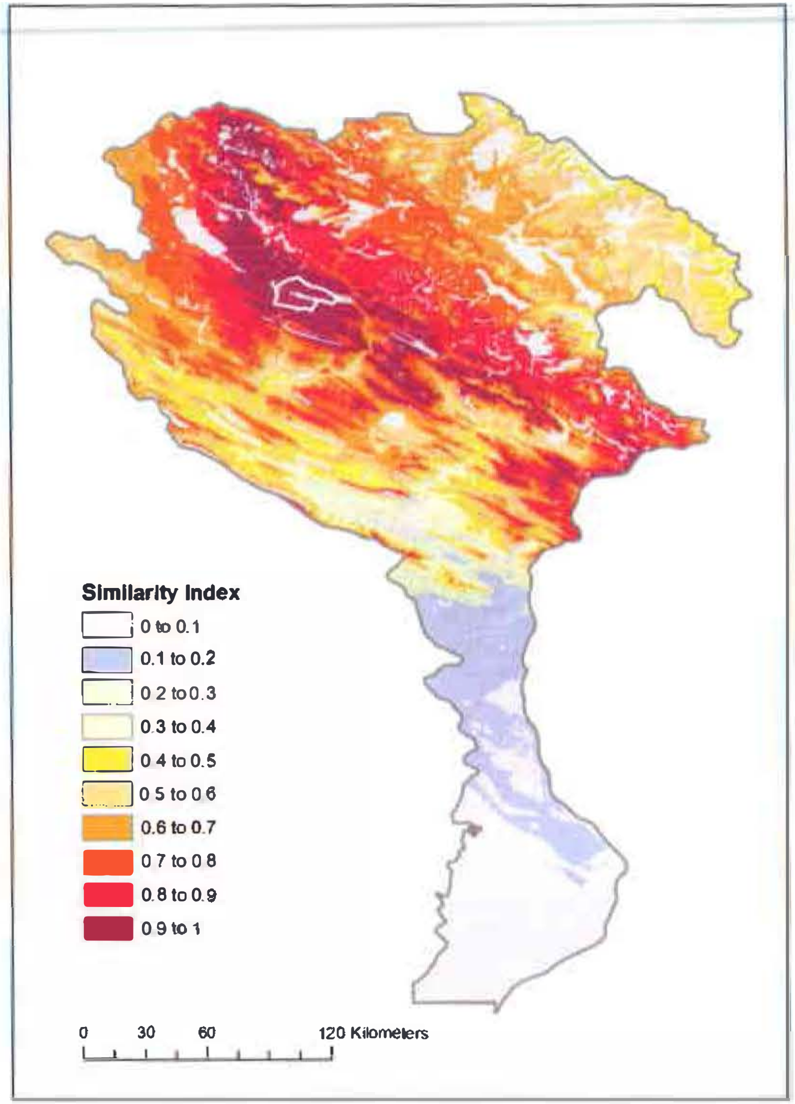


Figure 19. Similarity of KRB in climate and land use/land cover to the Merek benchmark site

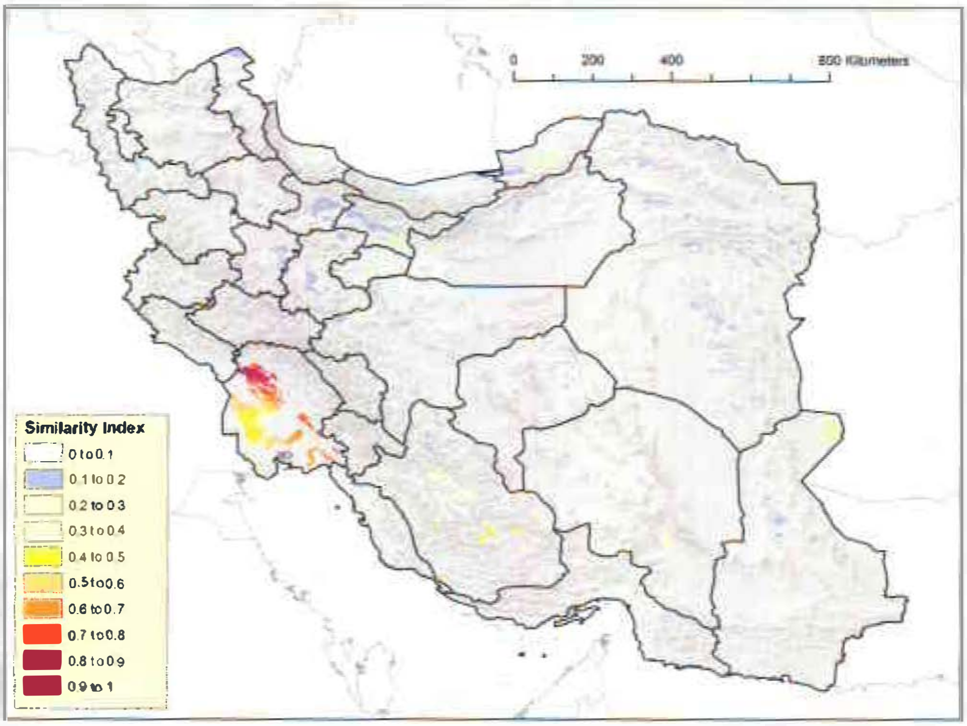


Figure 20. Similarity of Iran in climate, land use/land cover and landforms to the Sorkhe benchmark site

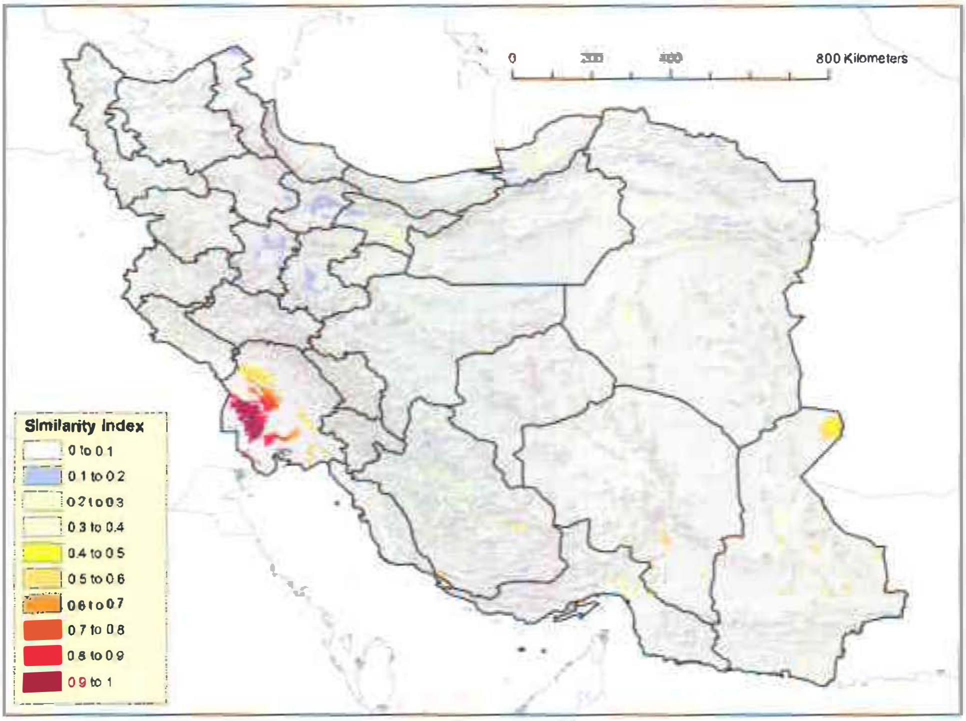


Figure 21. Similarity of Iran in climate, land use/land cover and landforms to the Azadegan benchmark site

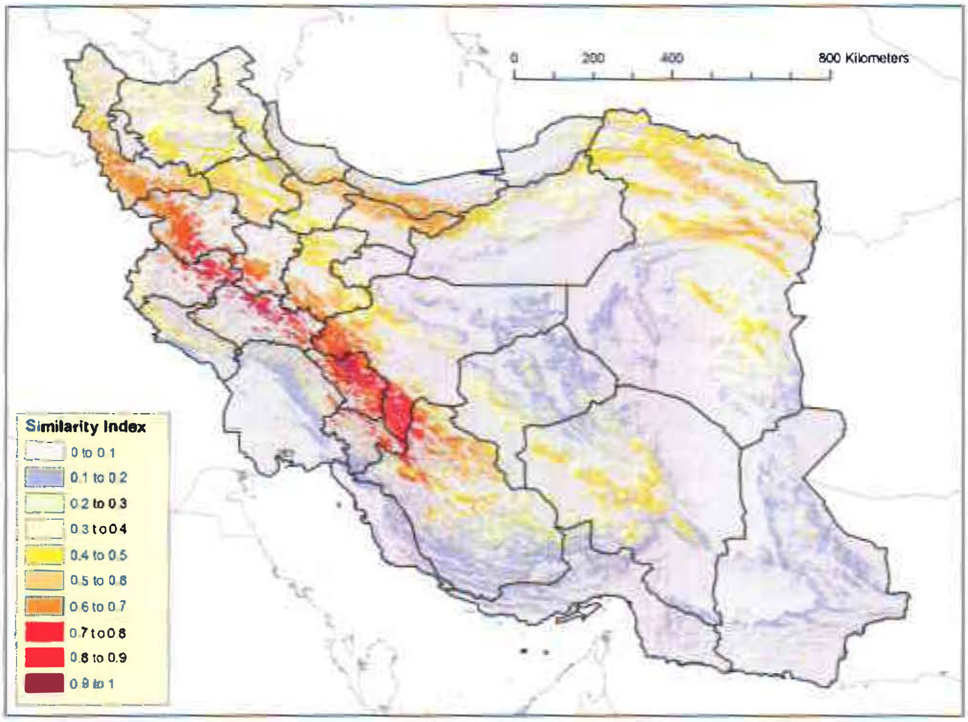


Figure 22. Similarity of Iran in climate, land use/land cover and landforms to the Honam benchmark site

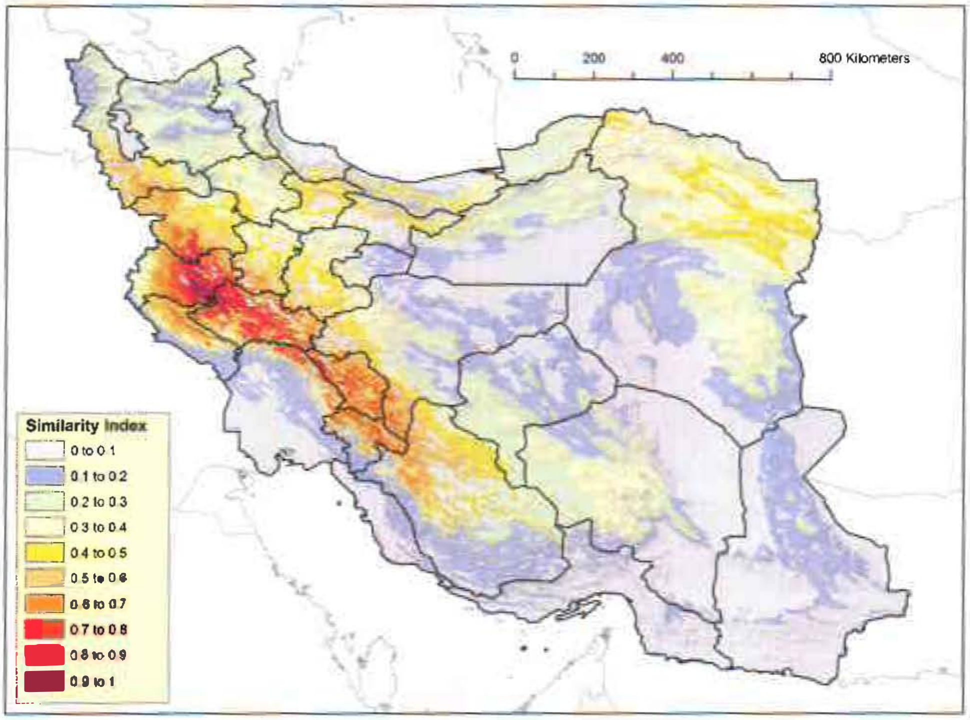


Figure 23. Similarity of Iran in climate, land use/land cover and landforms to the Merek benchmark site

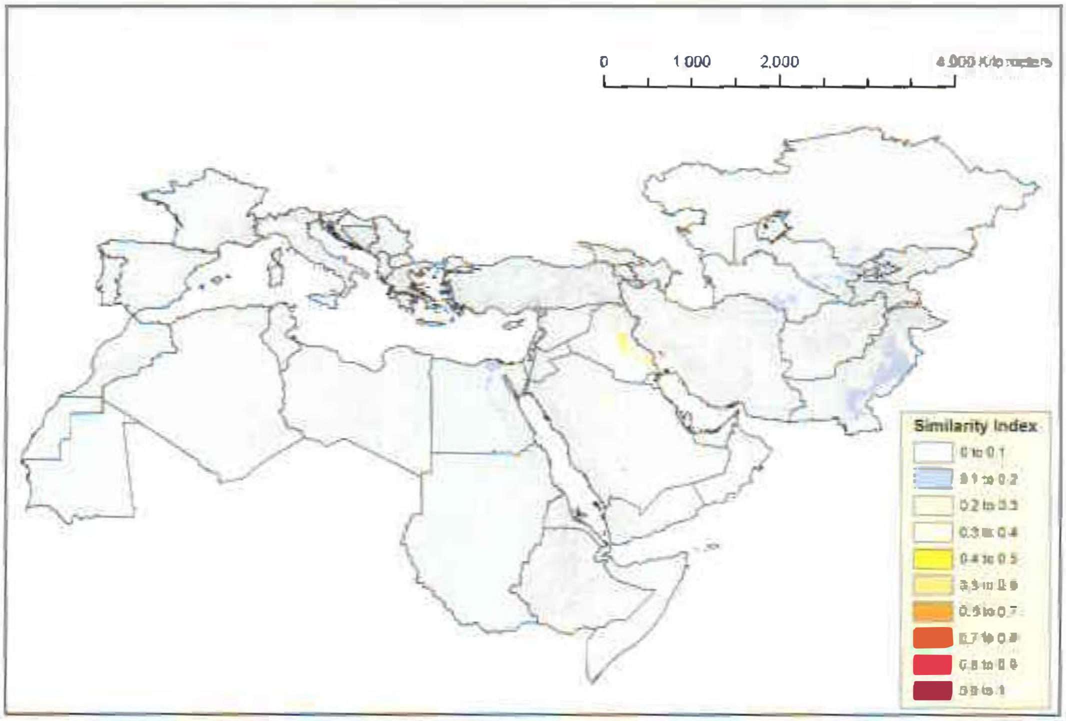


Figure 24. Similarity of CWANA and Northern Mediterranean in climate, land use/land cover and landforms to the Sorkhe benchmark site

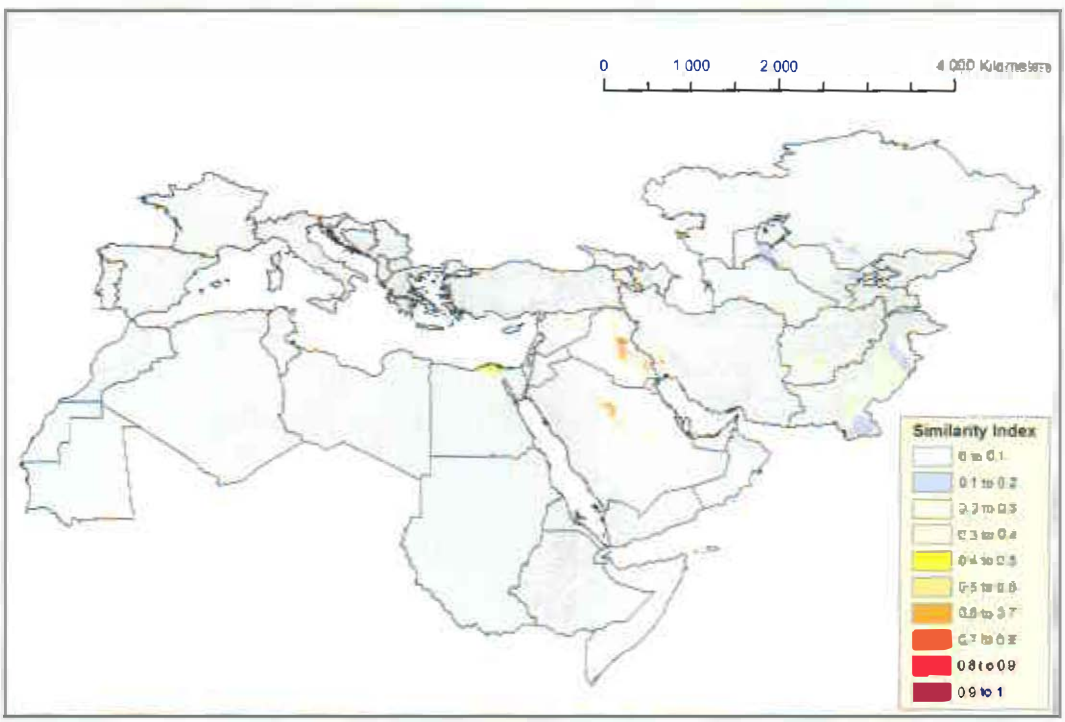


Figure 25. Similarity of CWANA and Northern Mediterranean in climate, land use/land cover and landforms to the Azadegan benchmark site

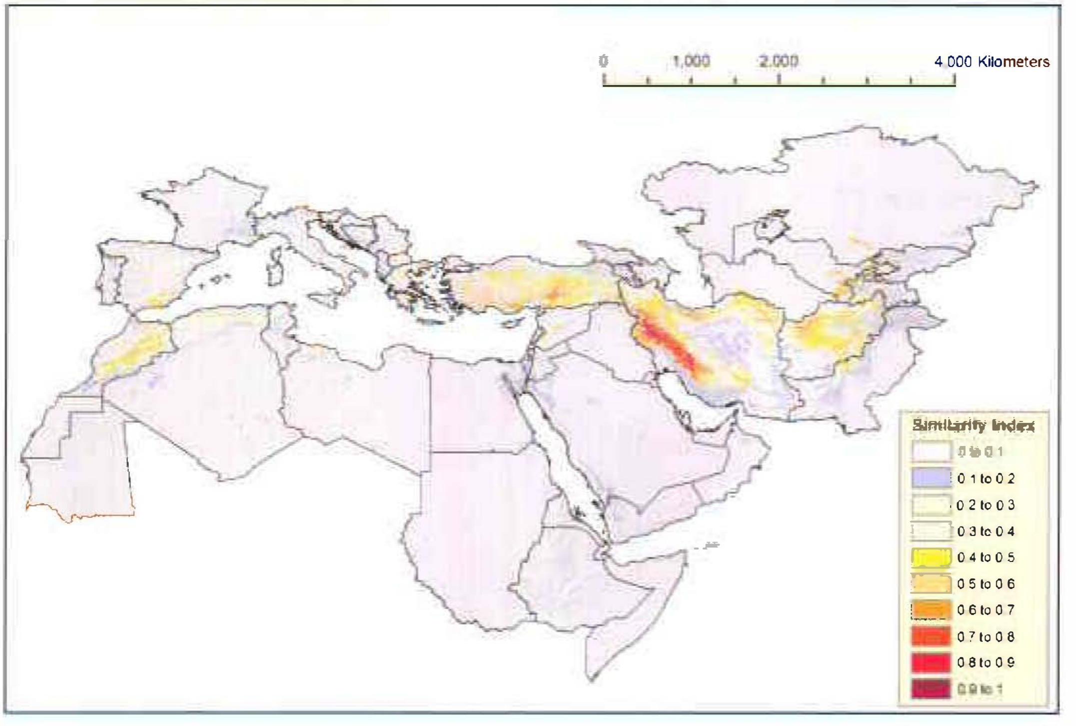


Figure 26. Similarity of CWANA and Northern Mediterranean in climate, land use/land cover and landforms to the Honam benchmark site

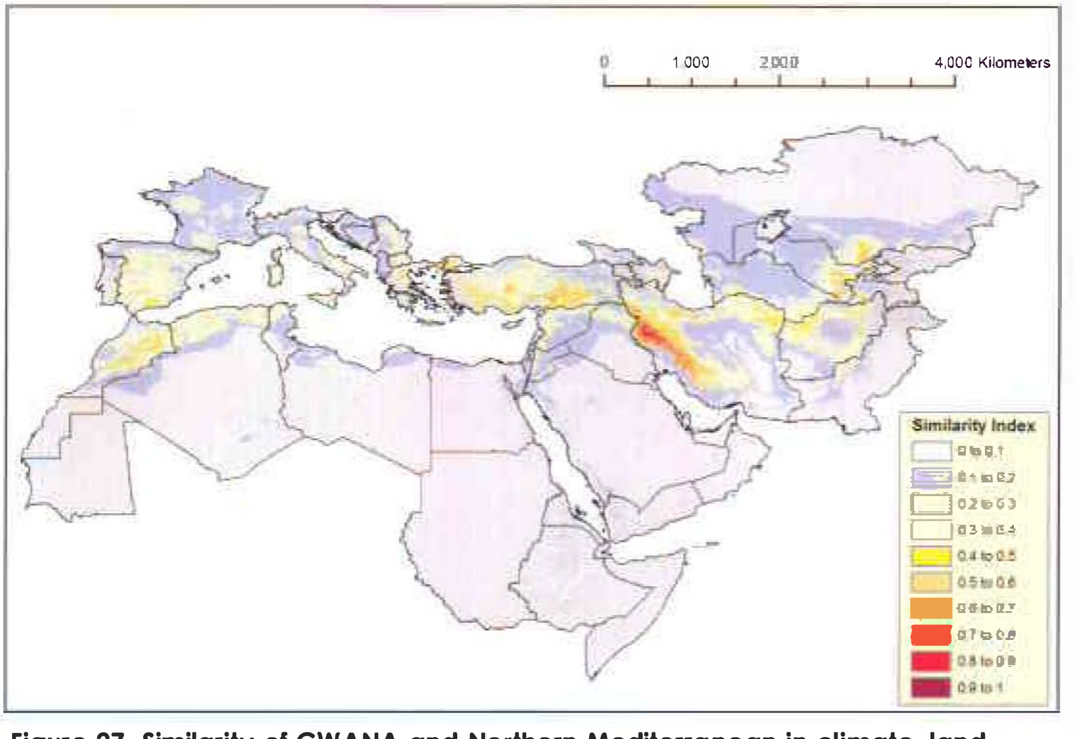


Figure 27. Similarity of CWANA and Northern Mediterranean in climate, land use/land cover and landforms to the Merek benchmark site

country (130,638 km^2) and 1.6% of CWANA (361,569 km^2). This high degree of similarity is due to the fact that in both sites the presence of different topographic conditions and land uses allows to cover a larger outscaling domain.

Generally speaking, the percentage of land that can be considered 'similar' increases as one comes nearer to the benchmark sites. This is explained as a typical case of spatial auto-correlation, as expressed by Tobler's 'first law of geography', quoted by O'Sullivan and Unwin (2003), that 'everything is related to everything else, but near things are more related than distant things'.

3.3. DISCUSSION

3.3.1. Data needs for the benchmark sites
Similarity analysis, as presented in earlier sections, offers excellent potential for outscaling site-specific research, on condition that (i) the benchmark sites are properly characterized, and (ii) there is sufficient information available about the agricultural environments of the target areas to allow a meaningful comparison.

In the case of the KRB, these conditions are not fully met. The benchmark sites cannot be considered as properly characterized since no biophysical information has been collected that gives sufficient confidence that the internal variability in the climate, terrain, land use/land cover, soils and water resources of these sites is well represented. Figures 9-12, which zoom into the benchmark sites, are based on datasets at a level of detail appropriate for the basins but not for benchmark sites. Especially knowledge about the soils is totally inadequate, which is why no attempt has been made to include soils into the similarity assessment. The latter is, therefore, only confined to similarity in climatic, landforms and land use patterns (see also section 3.2.2.).

All benchmark sites require resource studies at a level of detail that is adequate for making management plans. They require an automatic weather station, a digital elevation model at a minimum resolution of 50 m, an up-to-date classification of land-use/land cover based on supervised classification of Landsat or finer-resolution multiband satellite imagery, and a soil survey at the level of a soil series. For the rangelands eco-geographical and botanical surveys are needed to assess the status of the plant biodiversity and degradation of the natural vegetation.

3.3.2. Similarity analysis for identifying representative benchmark sites for integrated natural resource management research
In section 3.2. we discussed the implementation of similarity analysis when the benchmark sites are already established. However, this method can also be used to select the best from a number of candidate benchmark sites, 'best' meaning in this context the one that is most representative of the evaluated criteria.

First, each candidate watershed or benchmark site needs to be ranked against a set of criteria, which will vary according to the purpose of the study and may include both biophysical and socioeconomic factors. Examples are minimum population size, presence of major land use types, poverty, market access etc. Of the biophysical criteria, climate will invariably be one of the most important. After the criteria are selected, the benchmark sites can be selected through score maximization against the major criteria.

The process is illustrated in Table 13, in which 6 candidate benchmark sites are compared in their ability to represent the agricultural regions, or sub-zones, of the KRB. For each benchmark site climatic similarity maps were prepared at the level of the KRB and statistics of the similarity indices (minimum, maximum, mean and

Table 13. Similarity of the sub-zones of KRB with different candidate benchmark sites

		Subzone A				Subzone B				Subzone C			
Similarity in	**with**	**Minimum**	**Maximum**	**Average**	**S.D.**	**Minimum**	**Maximum**	**Average**	**S.D.**	**Minimum**	**Maximum**	**Average**	**S.D.**
Precipitation	Chegeni	0.5716	0.9981	0.7985	0.1119	0.5593	0.9988	0.9059	0.0874	0.3058	0.9264	0.4690	0.1311
Precipitation	Honam	0.5980	0.9970	0.8029	0.0954	0.5172	0.9987	0.8874	0.0928	0.3190	0.9411	0.4848	0.1328
Precipitation	Merek	0.5222	0.9959	0.7530	0.1218	0.5192	0.9955	0.8196	0.0831	0.2763	0.7954	0.4214	0.1157
Precipitation	Mirbak	0.4878	0.9991	0.8241	0.1053	0.4122	0.9428	0.6909	0.0869	0.3429	0.6867	0.4755	0.0903
Precipitation	Sorkhe	0.3355	0.6329	0.5548	0.0569	0.2943	0.8053	0.5361	0.0772	0.4687	0.9999	0.6985	0.1516
Precipitation	Azadegan	0.2034	0.5515	0.4060	0.0786	0.1761	0.4681	0.3272	0.0475	0.3575	0.9999	0.7894	0.1862
Temperature	Chegeni	0.4009	1.0000	0.9804	0.0639	0.4822	1.0000	0.9629	0.0877	0.3949	0.9953	0.4440	0.0358
Temperature	Honam	0.5921	1.0000	0.9670	0.0412	0.2708	1.0000	0.7361	0.1916	0.2253	0.5963	0.2512	0.0194
Temperature	Merek	0.3209	1.0000	0.9257	0.1091	0.2846	1.0000	0.7826	0.1905	0.2342	0.6442	0.2634	0.0211
Temperature	Mirbak	0.4908	1.0000	0.9114	0.1068	0.2165	1.0000	0.6340	0.1929	0.1784	0.4914	0.2007	0.0161
Temperature	Sorkhe	0.0566	0.3834	0.1916	0.0448	0.0873	0.86	0.3275	0.1178	0.3815	0.9999	0.8679	0.0723
Temperature	Azadegan	0.0645	0.4326	0.2183	0.0510	0.0994	0.8118	0.3671	0.1245	0.4256	0.9999	0.9059	0.0690
Prec&Temp	Chegeni	0.2948	0.9981	0.7834	0.1248	0.3432	0.9988	0.8744	0.1281	0.1208	0.9221	0.2110	0.0750
Prec&Temp	Honam	0.4243	0.9970	0.7745	0.0915	0.1979	0.9966	0.6492	0.1696	0.0719	0.5612	0.1235	0.0426
Prec&Temp	Merek	0.2227	0.9959	0.6986	0.1476	0.1808	0.9955	0.6462	0.1849	0.0647	0.5124	0.1123	0.0390
Prec&Temp	Mirbak	0.3233	0.9982	0.7545	0.1447	0.1335	0.9428	0.4411	0.1620	0.0612	0.3347	0.0961	0.0243
Prec&Temp	Sorkhe	0.0229	0.2036	0.1063	0.0260	0.0377	0.6905	0.1823	0.0923	0.2298	0.9999	0.6133	0.1737
Prec&Temp	Azadegan	0.0180	0.1376	0.0875	0.0216	0.0256	0.3692	0.1234	0.0568	0.1522	0.9999	0.7273	0.2122

Note:
S.D.: standard deviation

standard deviation) calculated for each sub-zone using stan 'ard GIS functions.

By comparing the mean similarity index for the evaluated factors (in this example precipitation, temperature, and both combined) the candidate benchmark site with the highest mean score can be considered the one that best represents the target area (in this example each sub-zone).

in this example, it turns out that Chegeni would have been a better choice for representing the climatic features of both sub-zone A and sub-zone B than Honam, which was selected instead. Whereas both equally well represent sub-zone A, Che_eni is better for representing both sub-zones A and B, which constitute the entire upper catchment.

For sub-zone C, Azadegan is, from a climatic perspective, the most representative benchmark site. However, as mentioned in section 2.2.4, the selection of two benchmark sites in sub-zone C was based on differences in soil characteristics.

4. CONCLUSIONS

In order to reduce the great complexity of agricultural environments, this report provides a generalized approach for defining agro-ecological zones using GIS procedures. It is based on the combination of terrain (DEM), climatic, land use/land cover, soil and other data. The GIS procedures can be applied to a wide range of scales, subject to data availability at the required level of detail for the integration to be meaningful. The datasets are combined in an overlaying procedure of different biophysical frameworks, each one characterized separately through its own specific attributes.

This approach is useful to define areas that can be considered relatively homogeneous in their biophysical characteristics and can thus serve as a first basis for area-specific agricultural (research) planning. Characterization of the identified AEZ in terms of themes relevant for specific planning purposes is an essential step.

For agricultural planning the idea of synthesis maps is useful as they provide to non-specialists greater clarity than thematic layers, but they need to include also socioeconomic information, which is more difficult to spatialize. A farming systems framework appears the most useful and easy to combine with an AEZ framework. Experience gained in Syria in combining farming systems data (Wattenbach, 2005) with an agricultural regions map indicates that this approach has much potential to provide an adequate spatial basis for agricultural planning and project development, but that it requires at the same time a substantial investment in the generation, integration and updating of local and scientific knowledge on rural environments.

It is too early to confirm that the 'benchmark site' approach used in KRB, as a key element of the INRM paradigm to agricultural research, is achieving its goal of speeding up the process of technology options targeting through identification of the recommendation domains. Our study demonstrates that it is certainly possible to quantify through relatively simple GIS operations to what extent the four benchmark sites, established in KRB, are representative of successively larger target areas. However, the current inadequate status of characterization of these sites does not allow a great deal of confidence in the ex-*ante* mapping of the recommendation domains. The most gaping shortcoming is in soil information.

In terms of the agro-ecological conditions that exist within the benchmark sites, they are highly representative. On the other hand, important potential target areas for soil conservation, land reclamation and forest improvement are not represented by benchmark sites. These target areas include the oak forest belt of the Middle Karkheh Agricultural Region, the badlands, which occupy substantial areas in the Middle and Southern Karkheh Agricultural Regions, and the sand dunes of the Southern Karkheh Agricultural Region.

At a more general level, the case study of the KRB indicates that the staged approach to similarity mapping, adopted in this study, consisting of incorporating sequentially more factors in the similarity assessment, is a workable principle. It can be generalized to other areas, on condition that the information available at both the level of the benchmark site and the target areas can be effectively compared.

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Annexes

ANNEX 1. MAPS

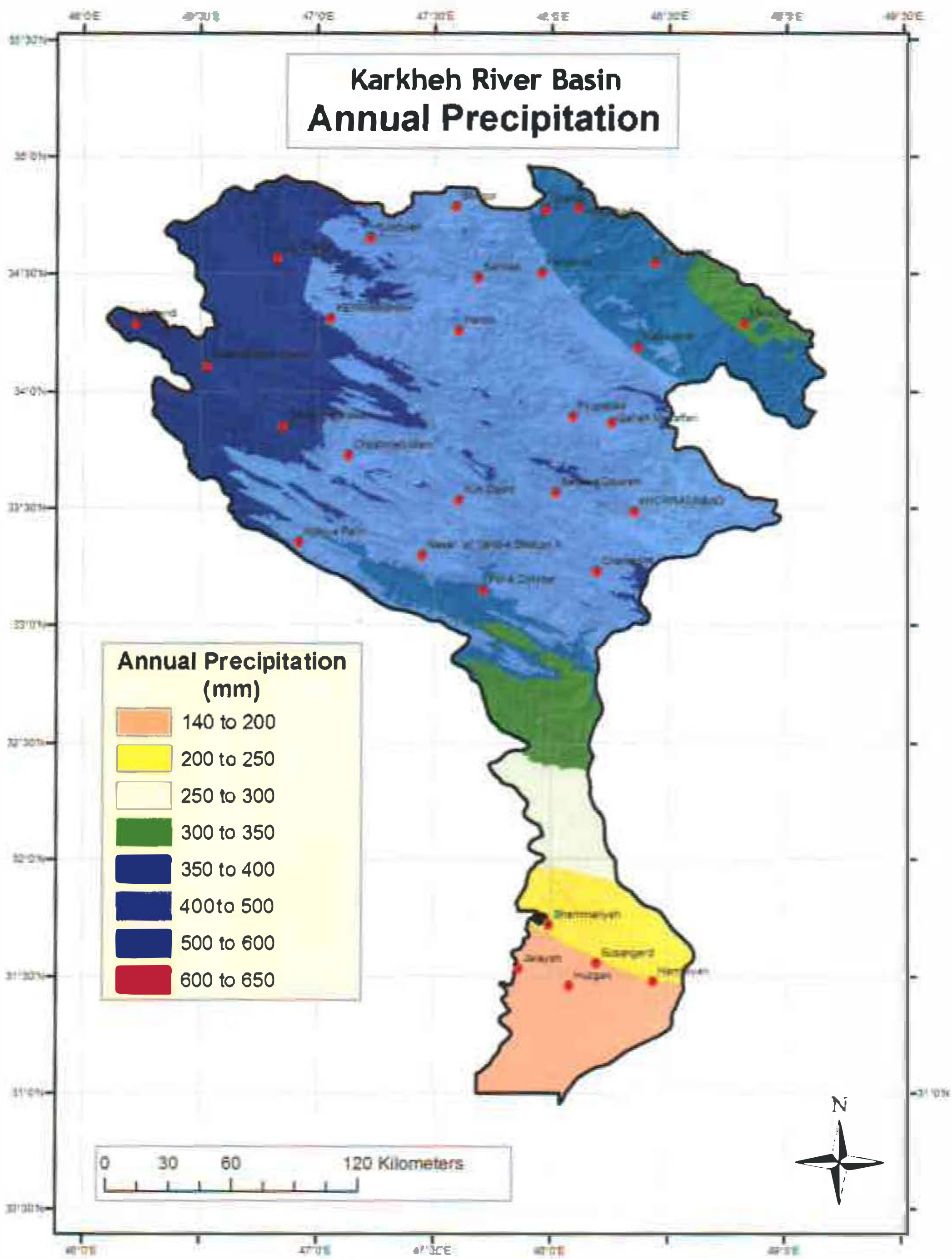


Figure 28. Mean annual precipitation (mm)

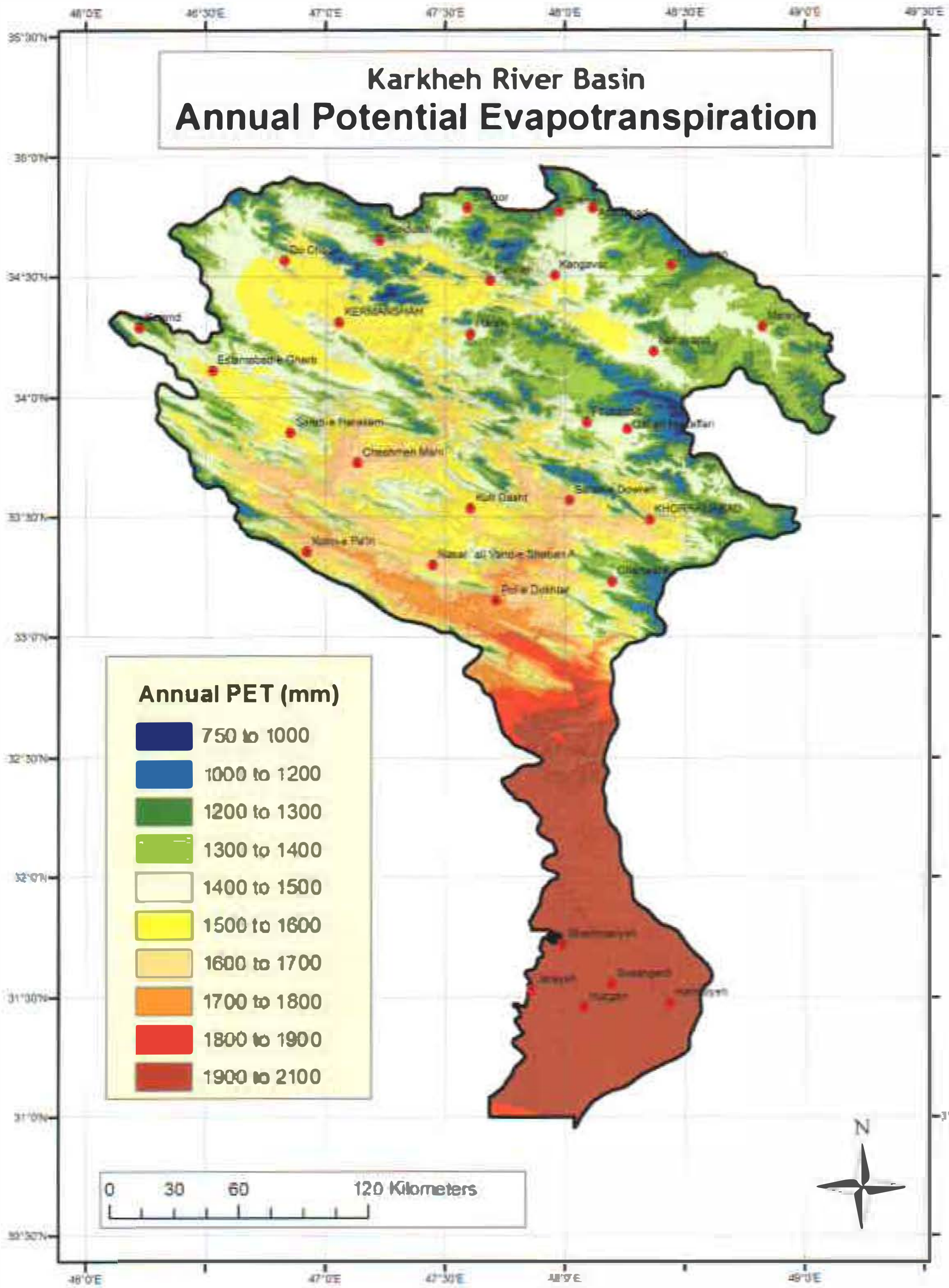


Figure 29. Mean annual reference evapotranspiration (mm)

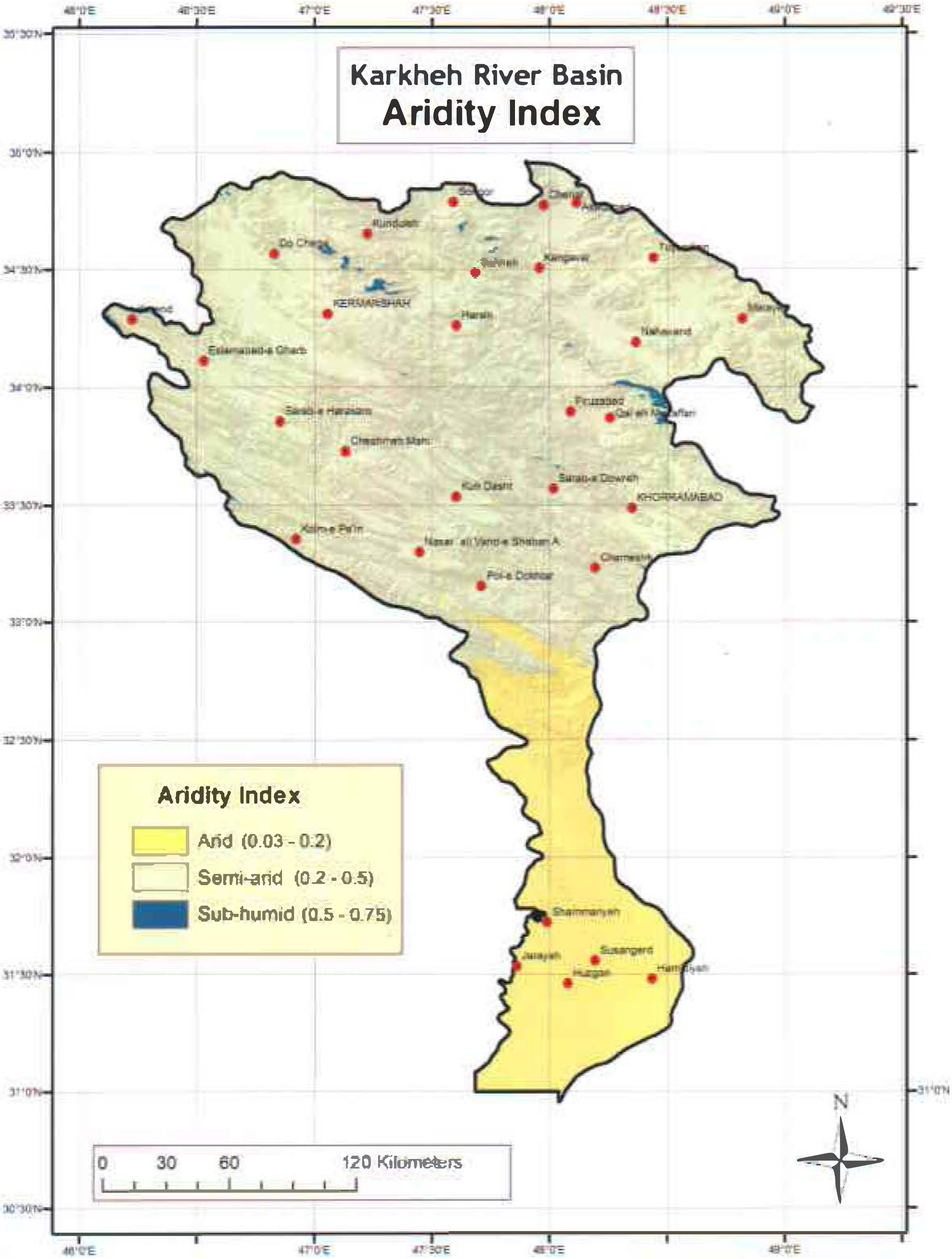


Figure 30. Aridity Index (ratio annual precipitation/PET)

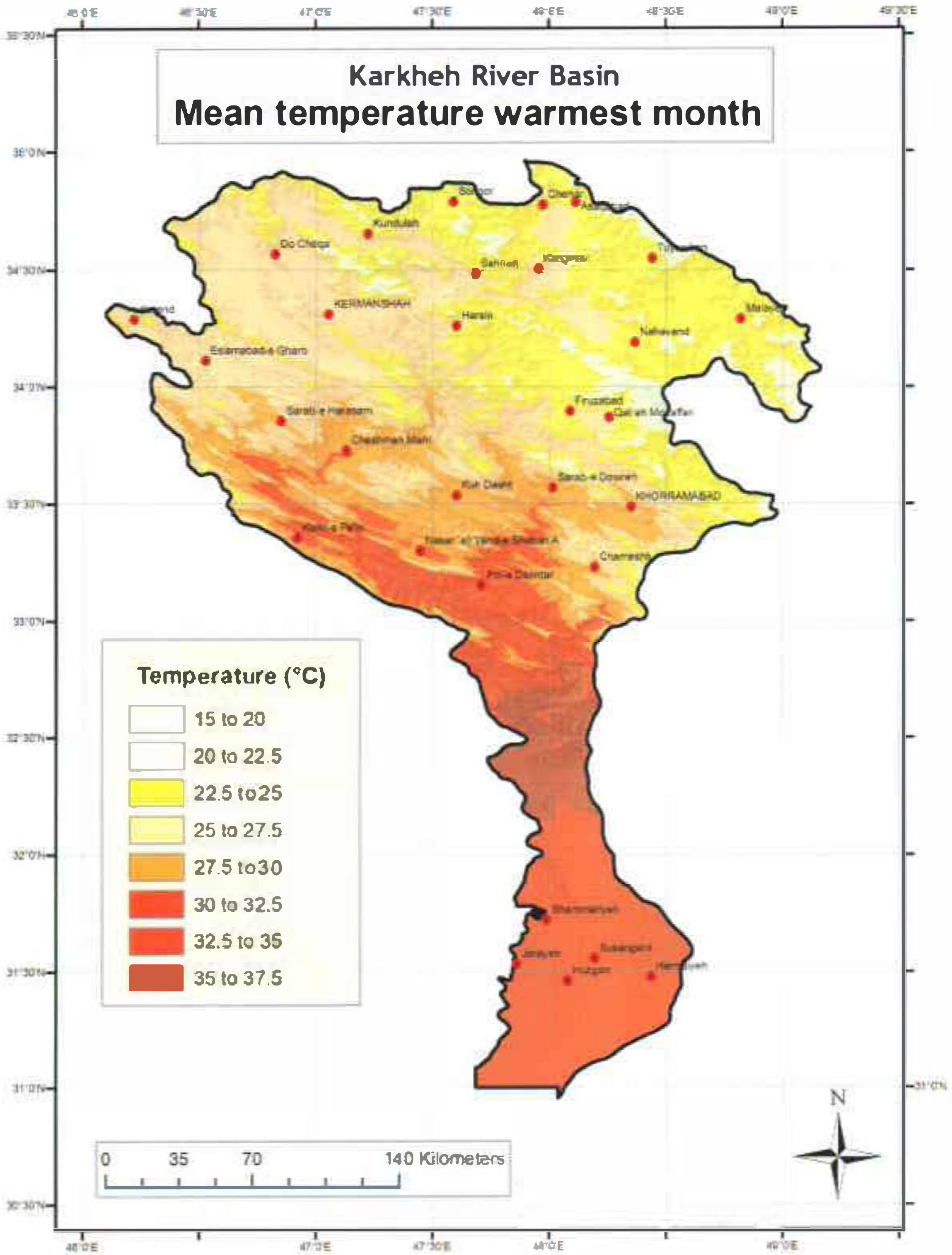


Figure 31. Mean temperature during warmest month (°C)

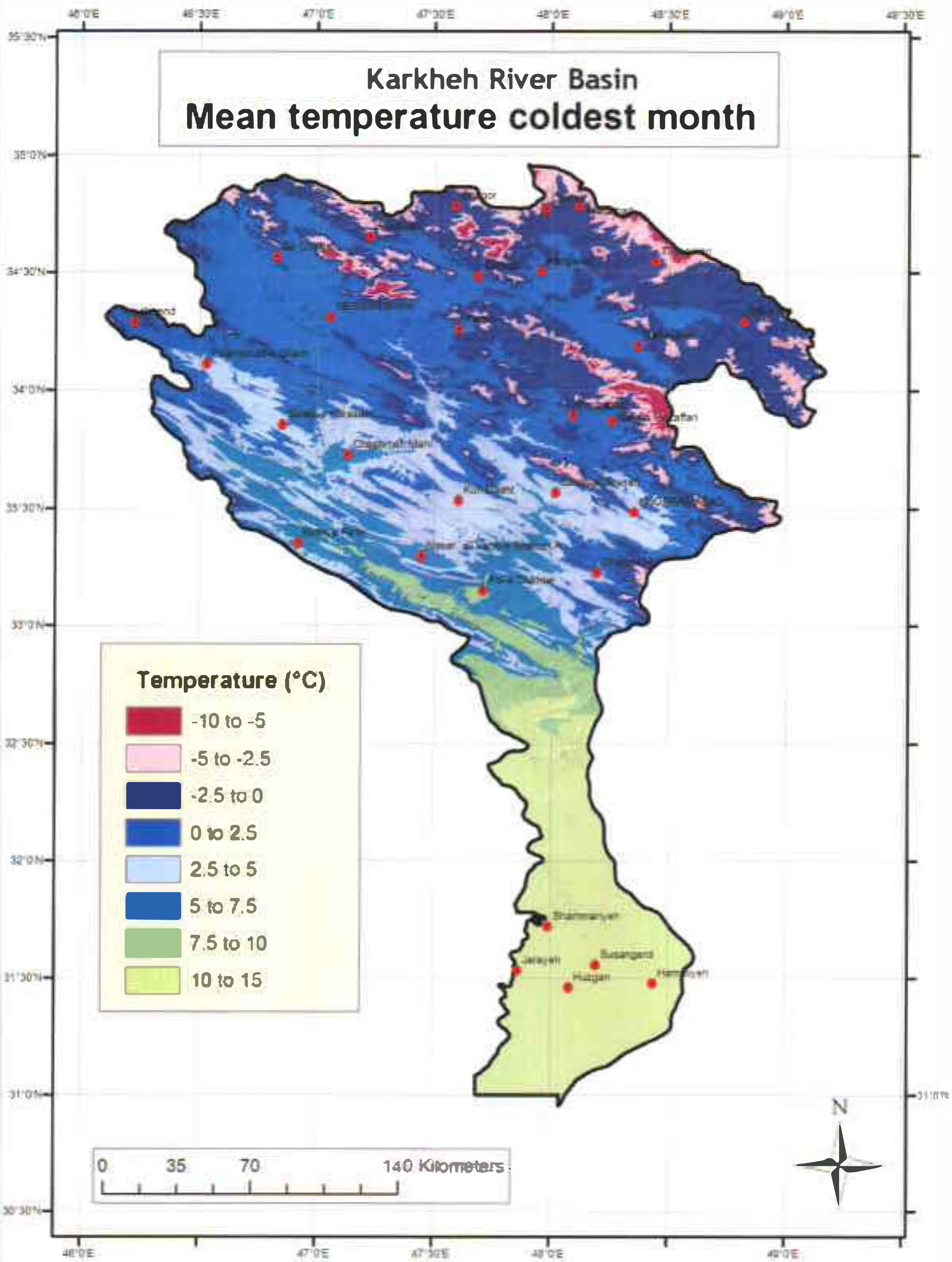


Figure 32. Mean temperature during the coldest month (°C)

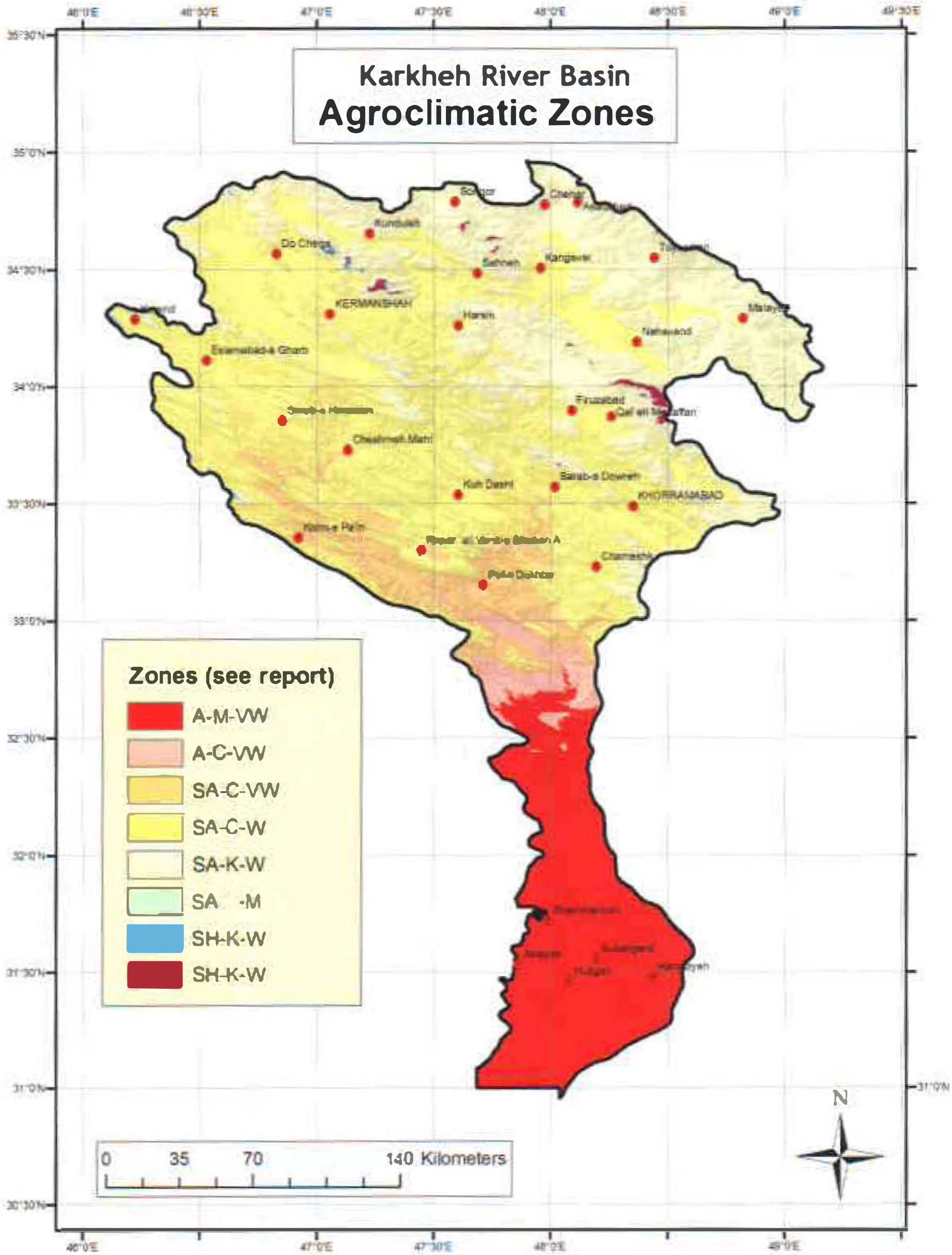


Figure.33. Agroclimatic Zones

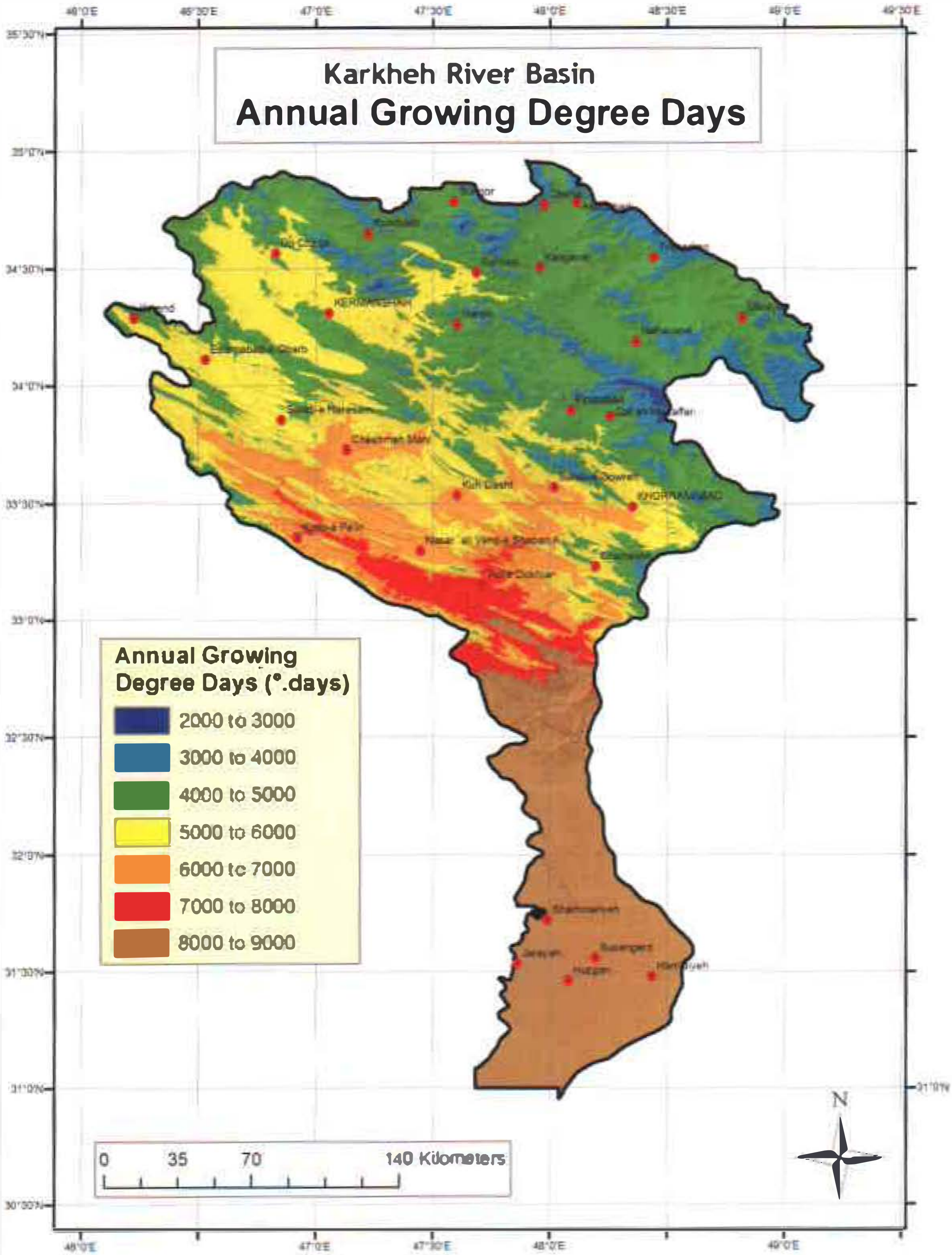


Figure 34. Annual Growing Degree Days

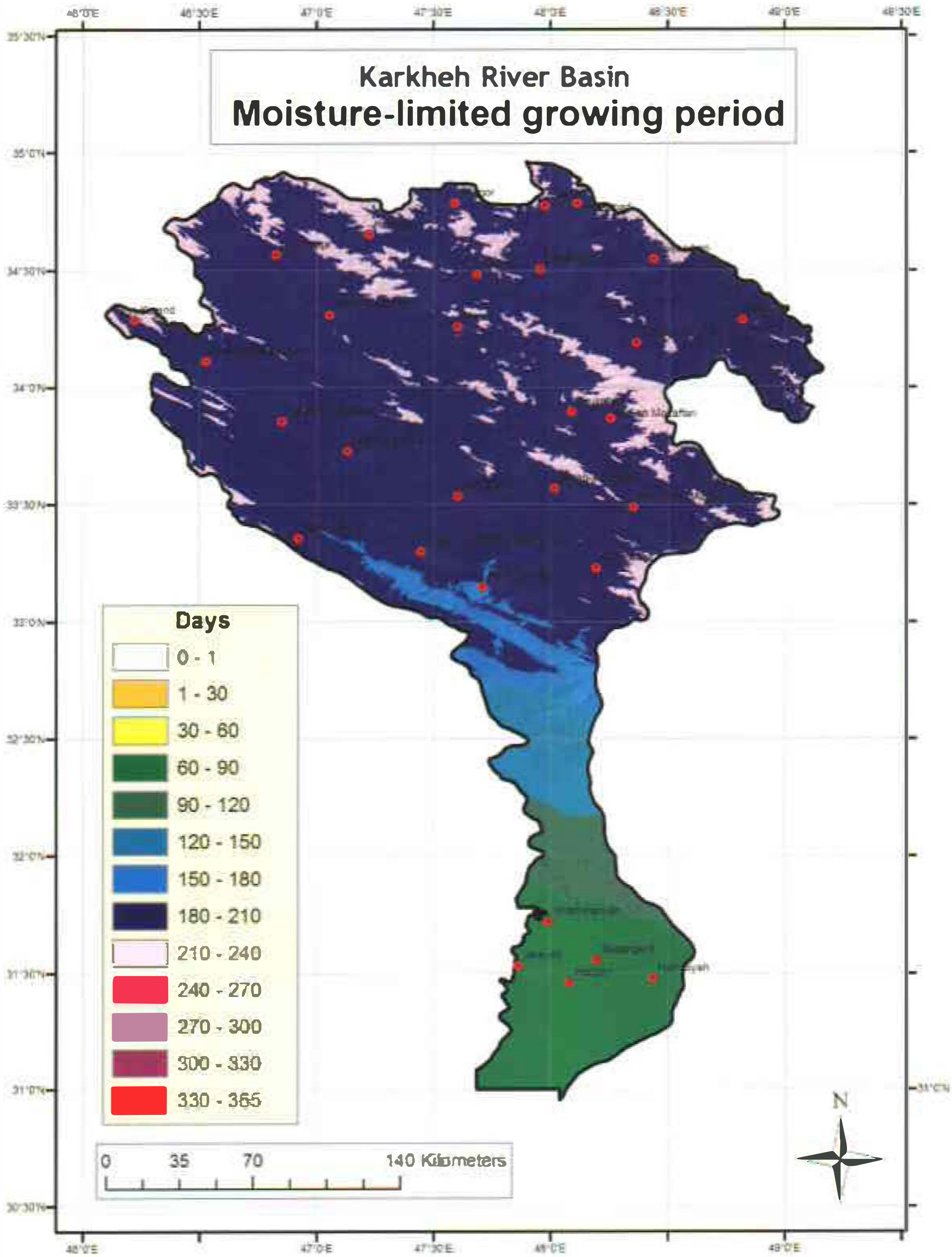


Figure 35. Growing period limited by moisture

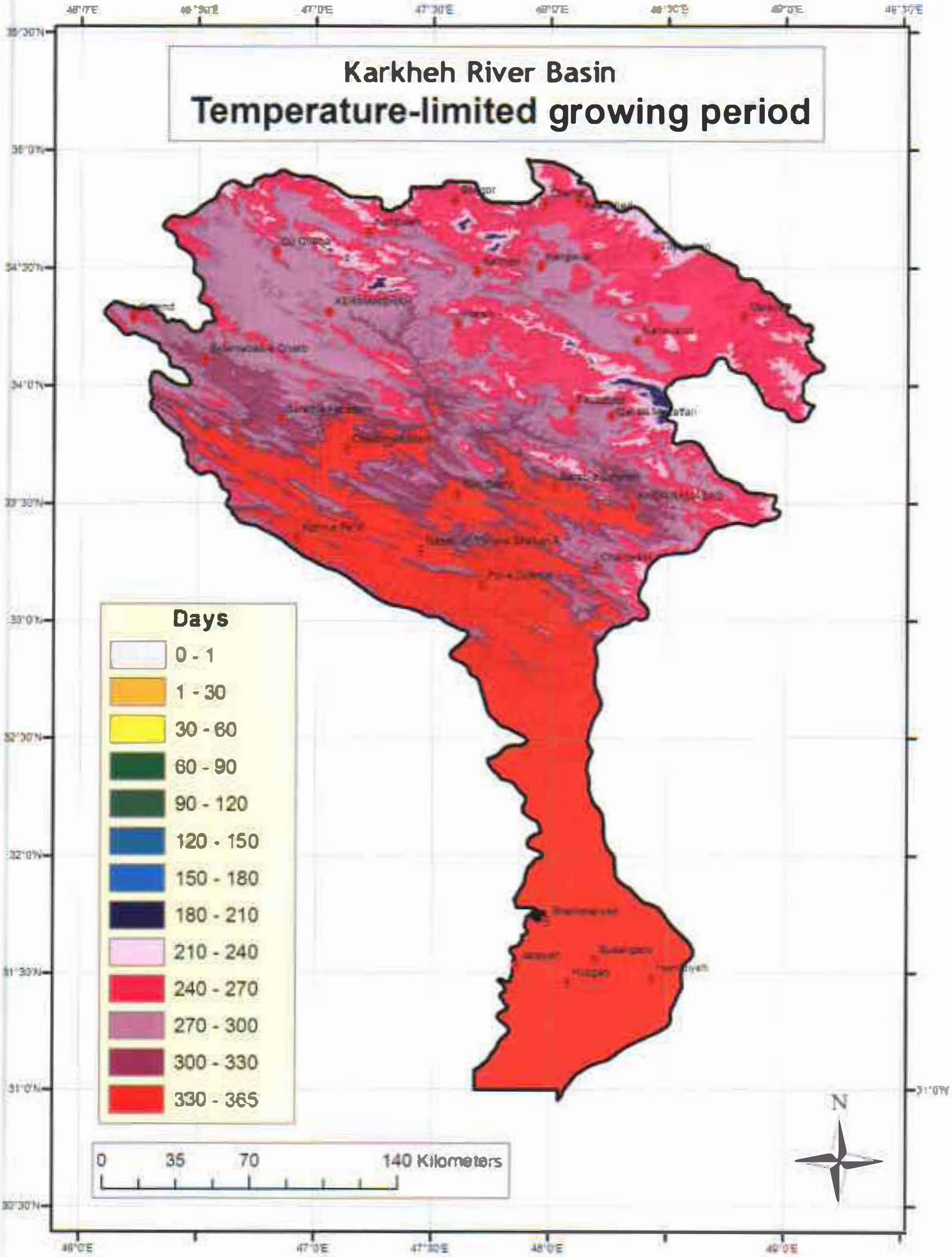


Figure 36. Growing period limited by temperature

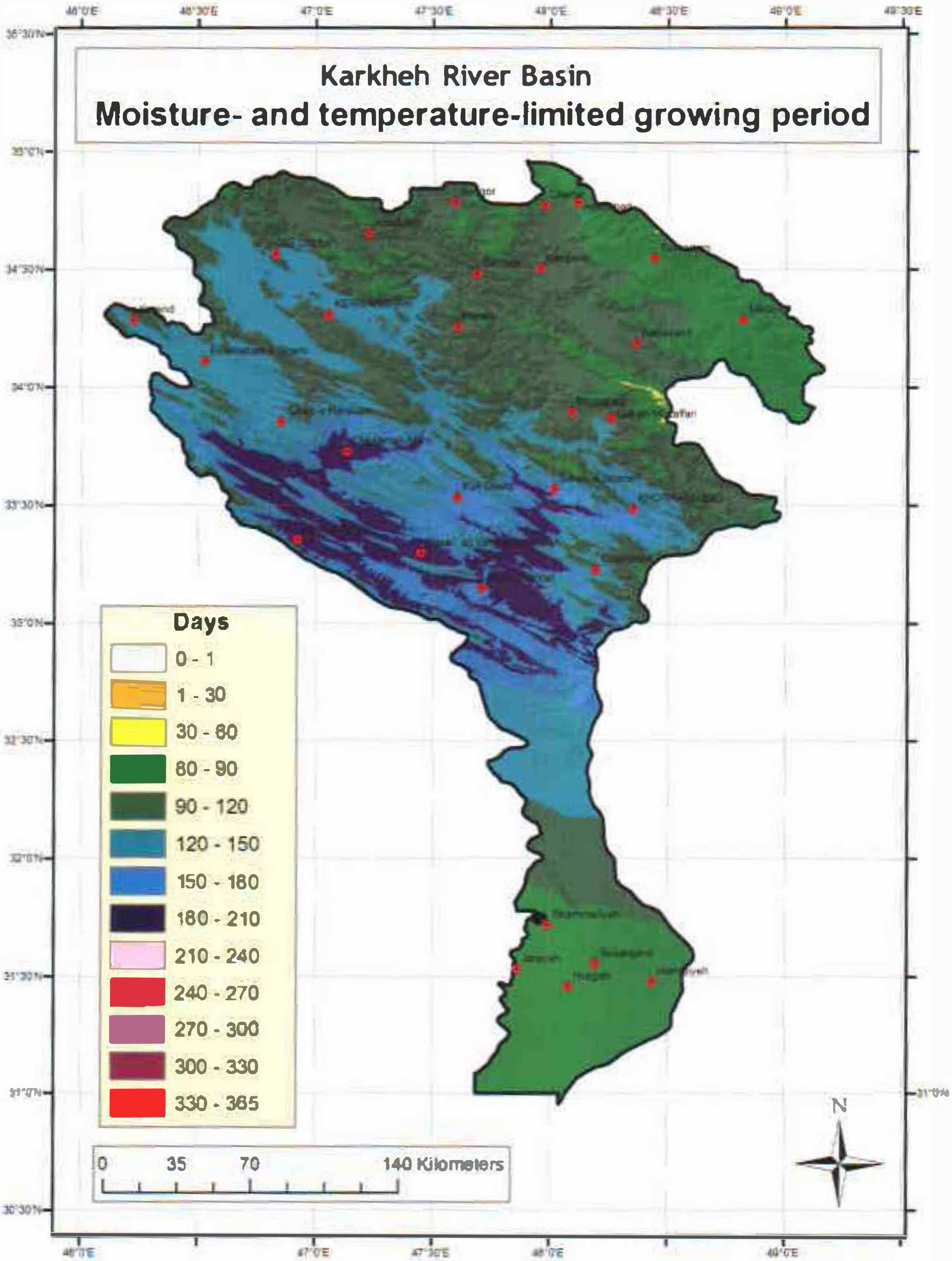


Figure 37. Growing period limited by both moisture and temperature

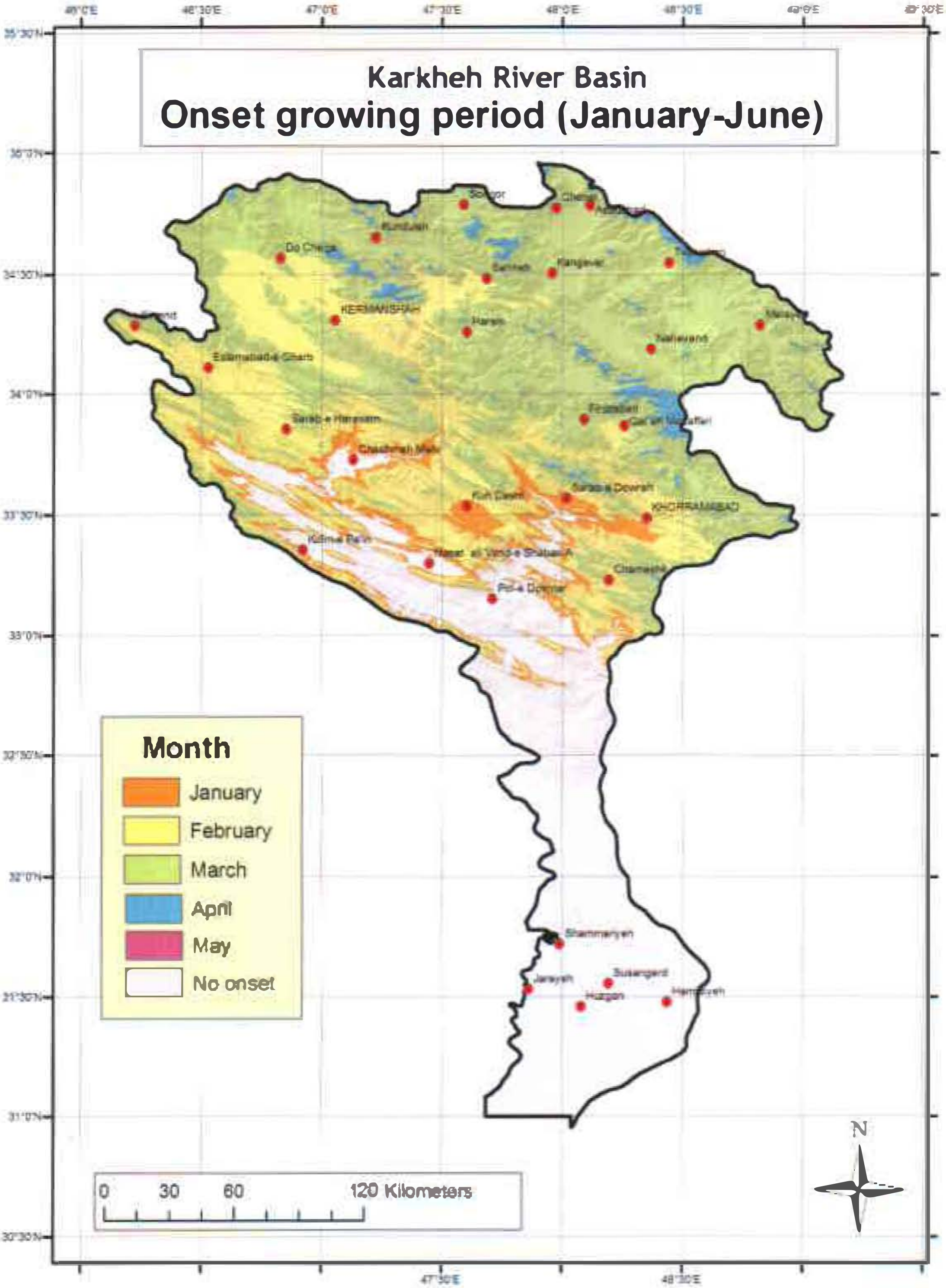


Figure 38. Onset month of the temperature-and moisture-limited growing period (period: January-June)

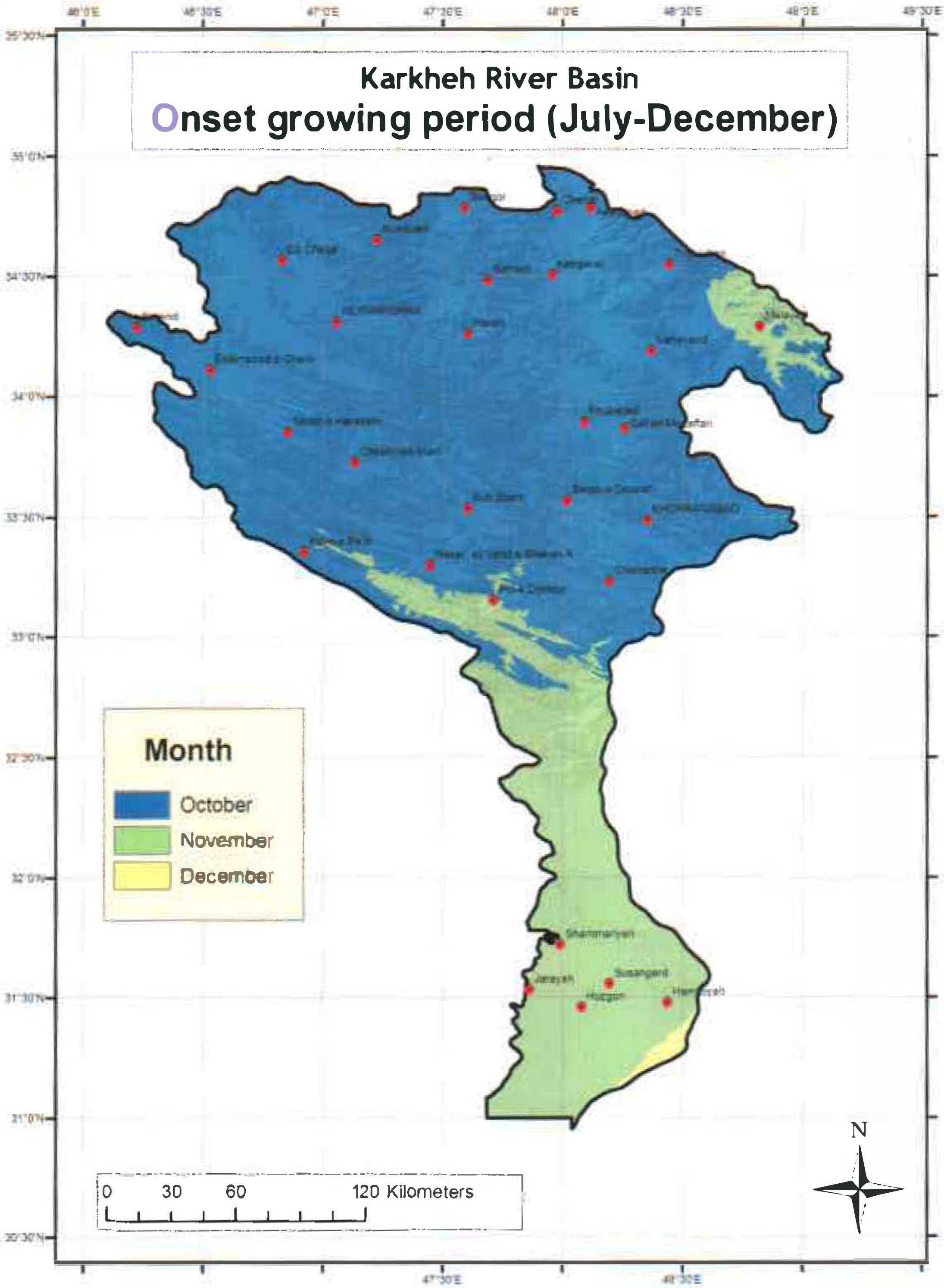


Figure 39. Onset month of the temperature-and moisture-limited growing period (period: July-December)

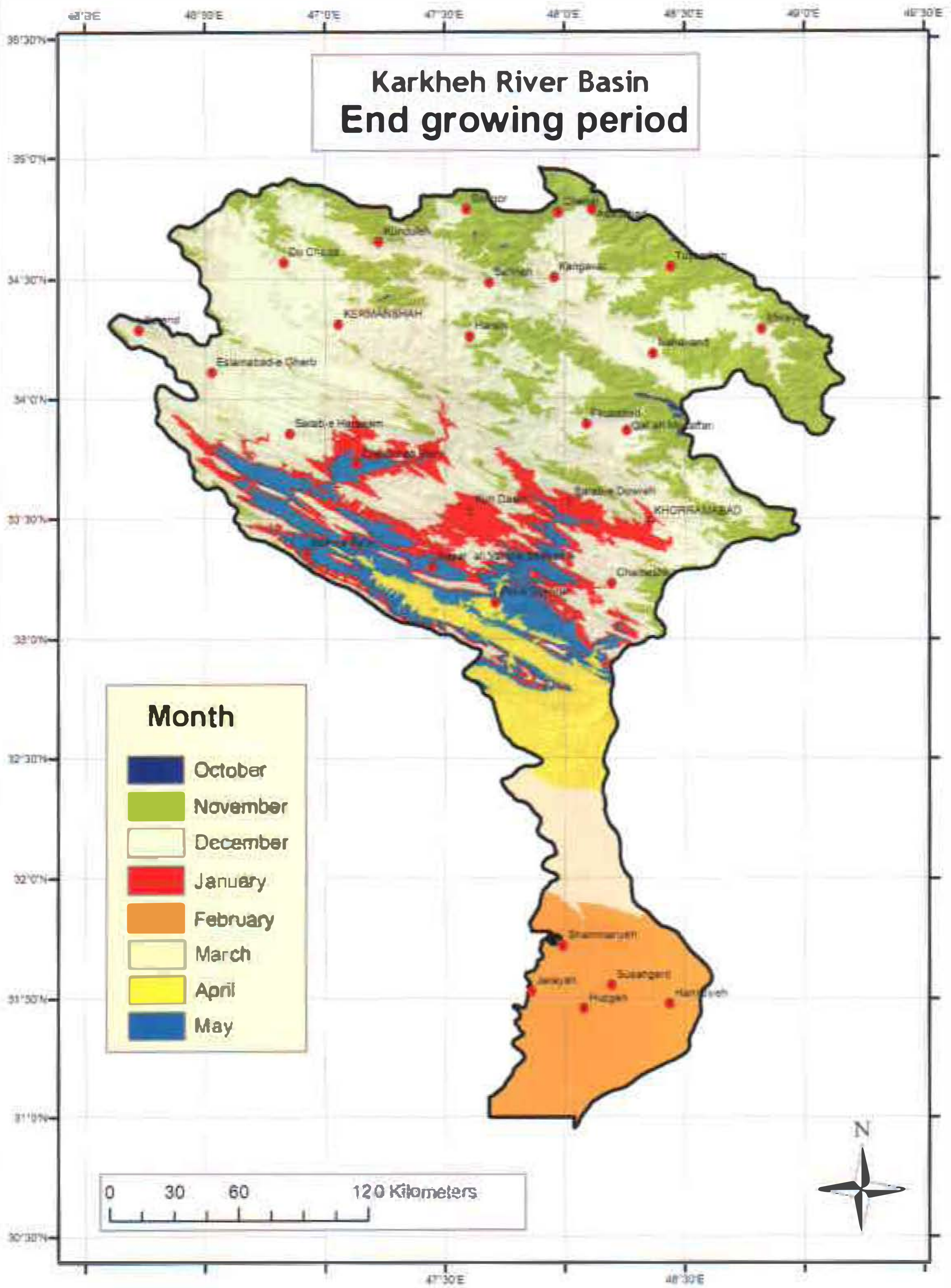


Figure 40. End month of the temperature-and moisture-limited growing period

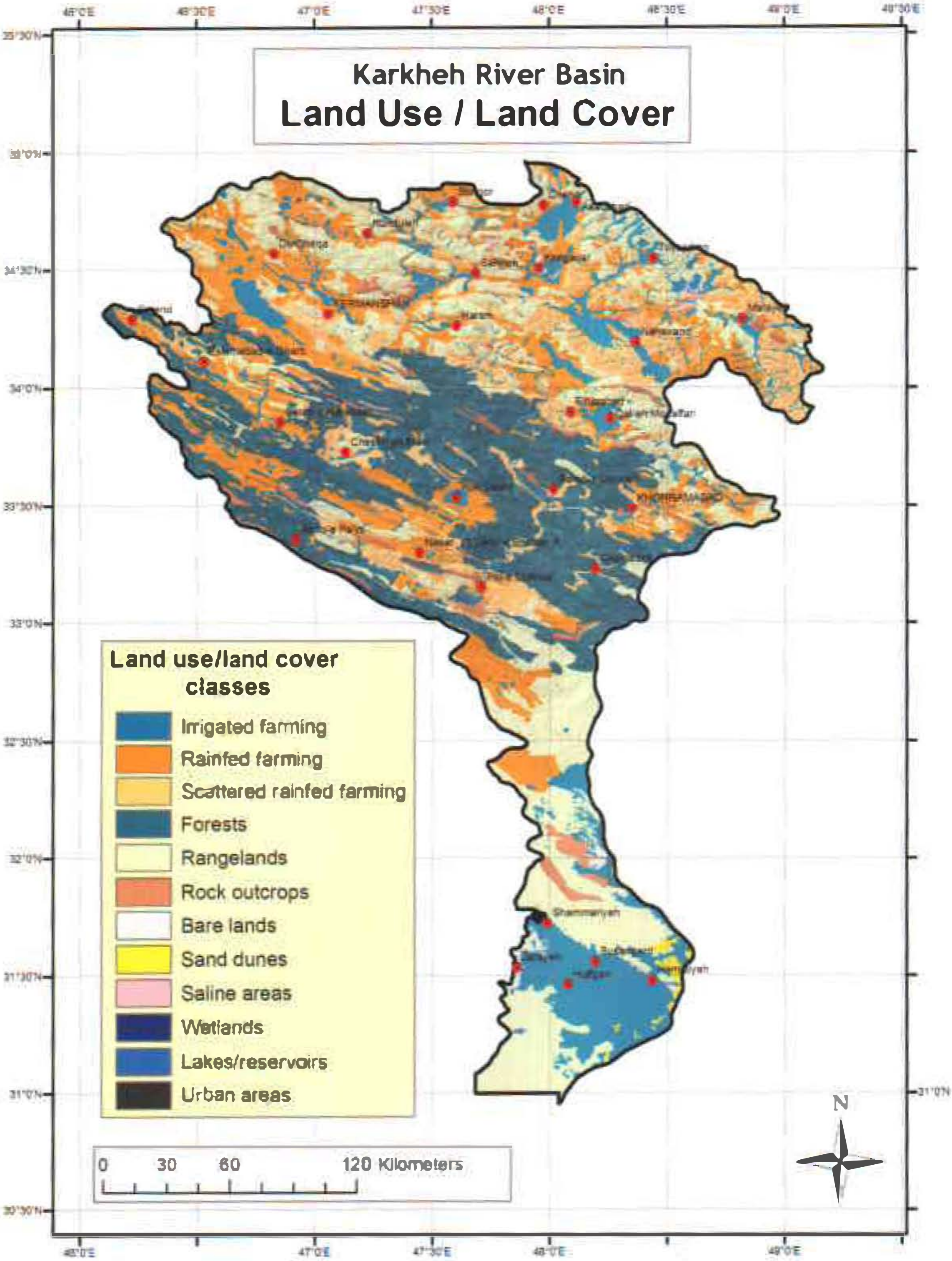


Figure 41. Land use/land cover

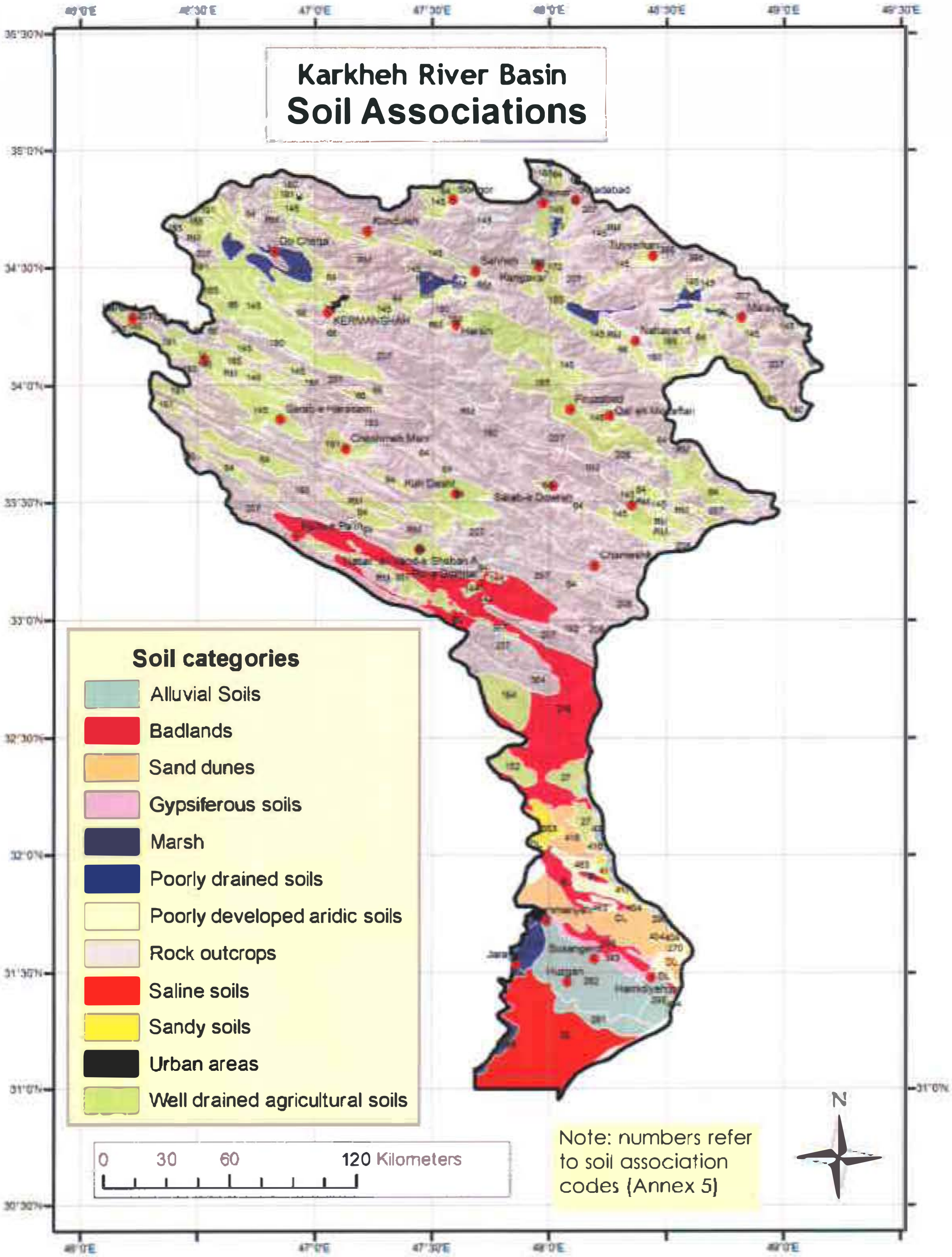


Figure 42. Soils of the Karkheh River Basin

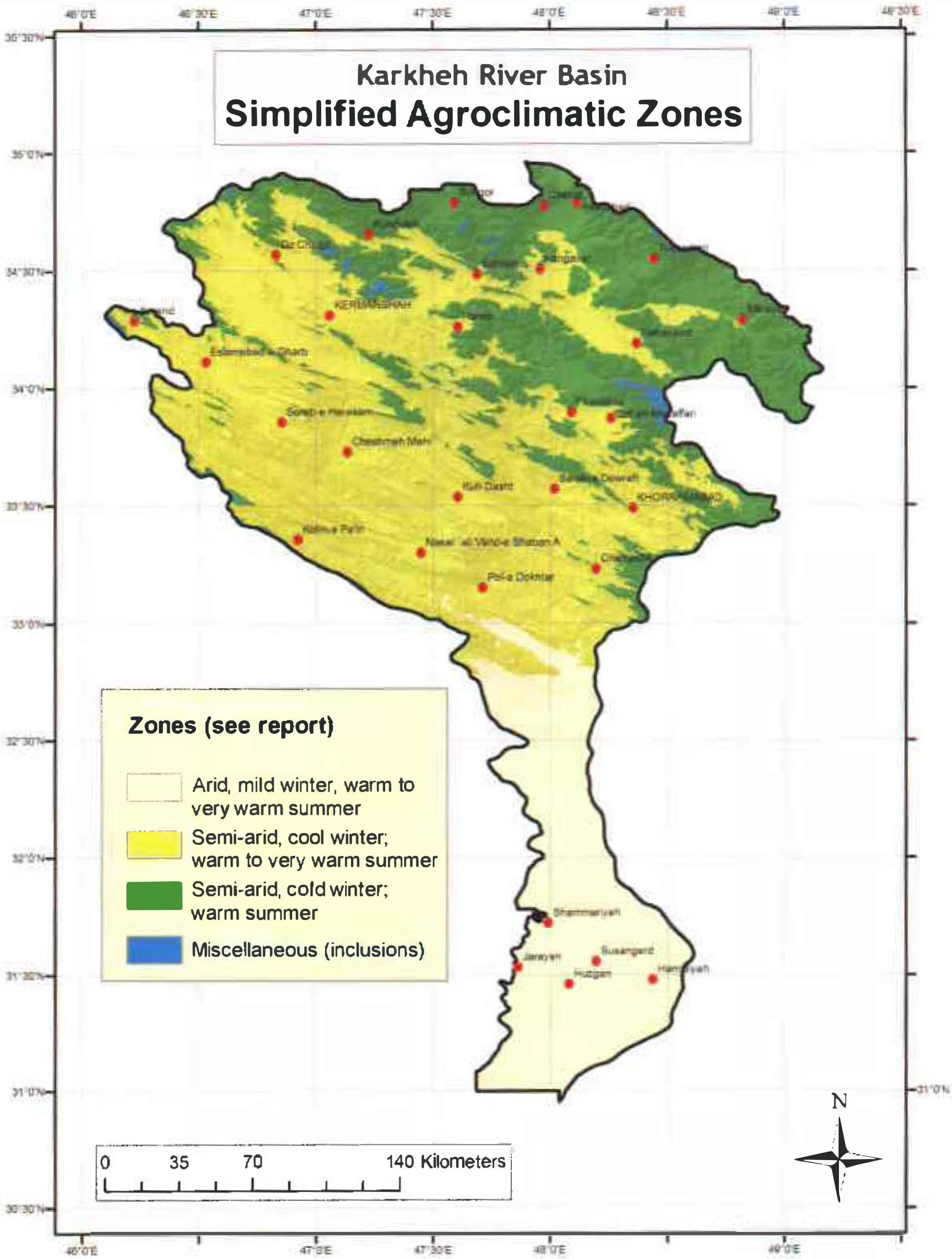


Figure 43. Simplified Agroclimatic Zones

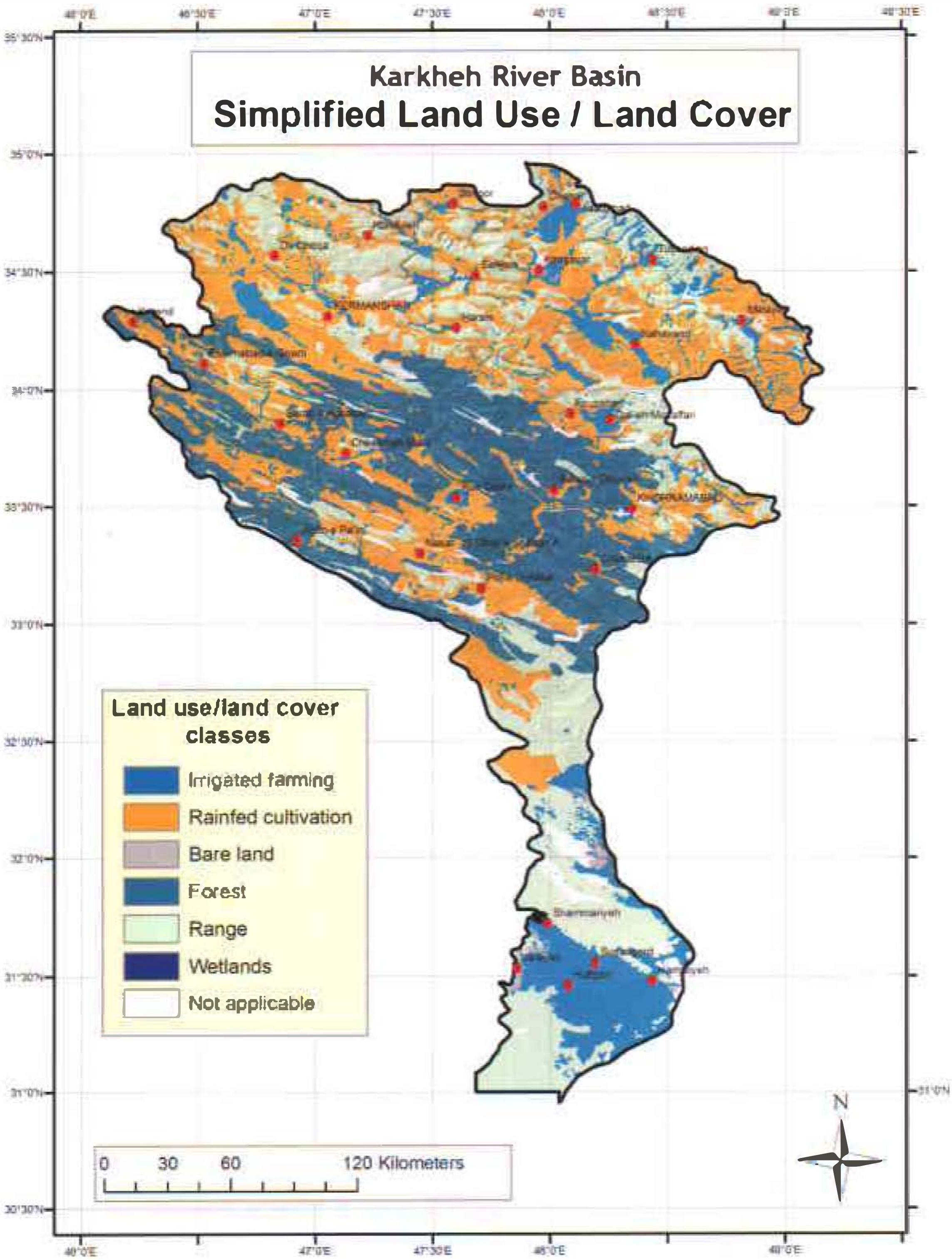


Figure 44. Simplified map of land use/land cover

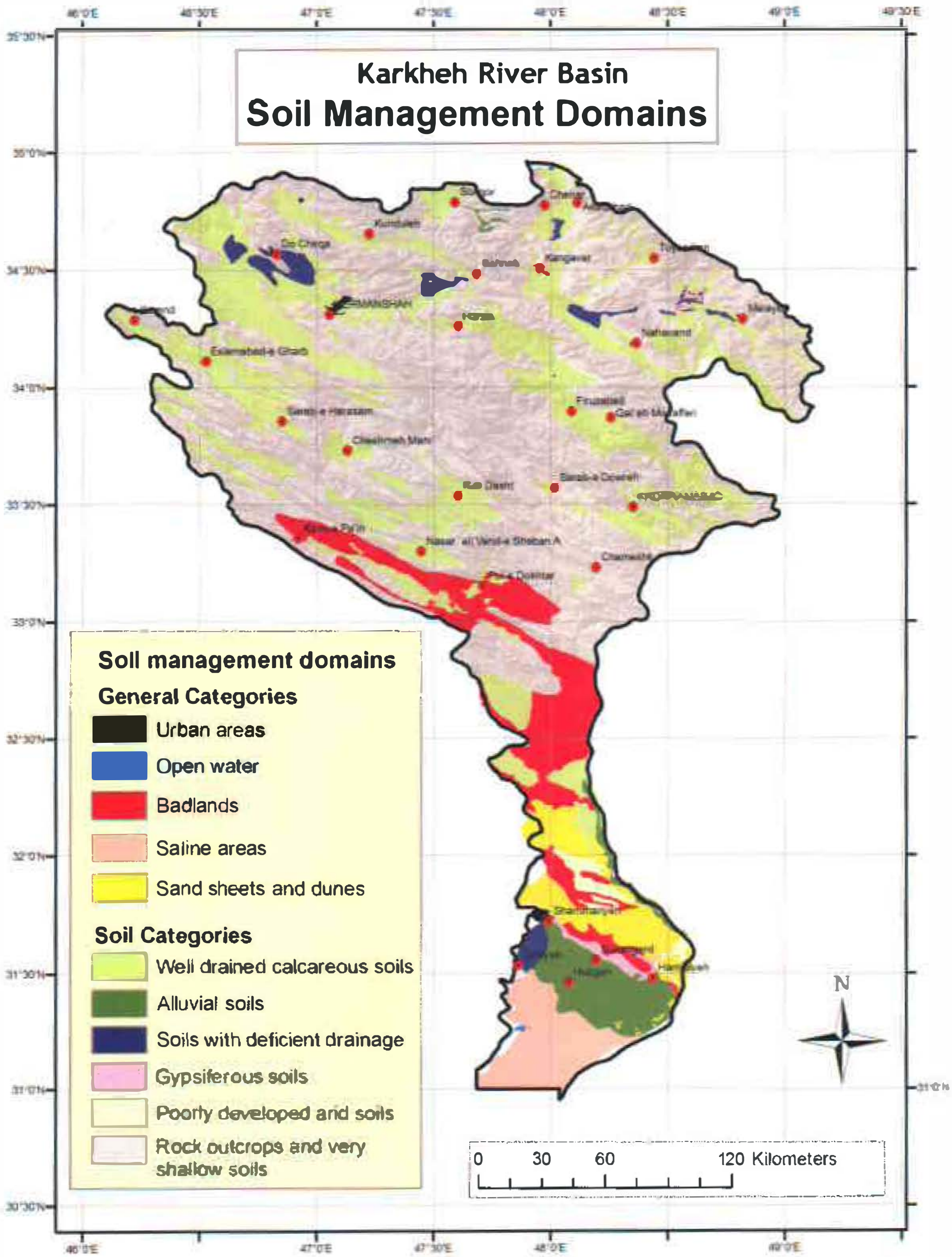


Figure 45. Soil Management Domains

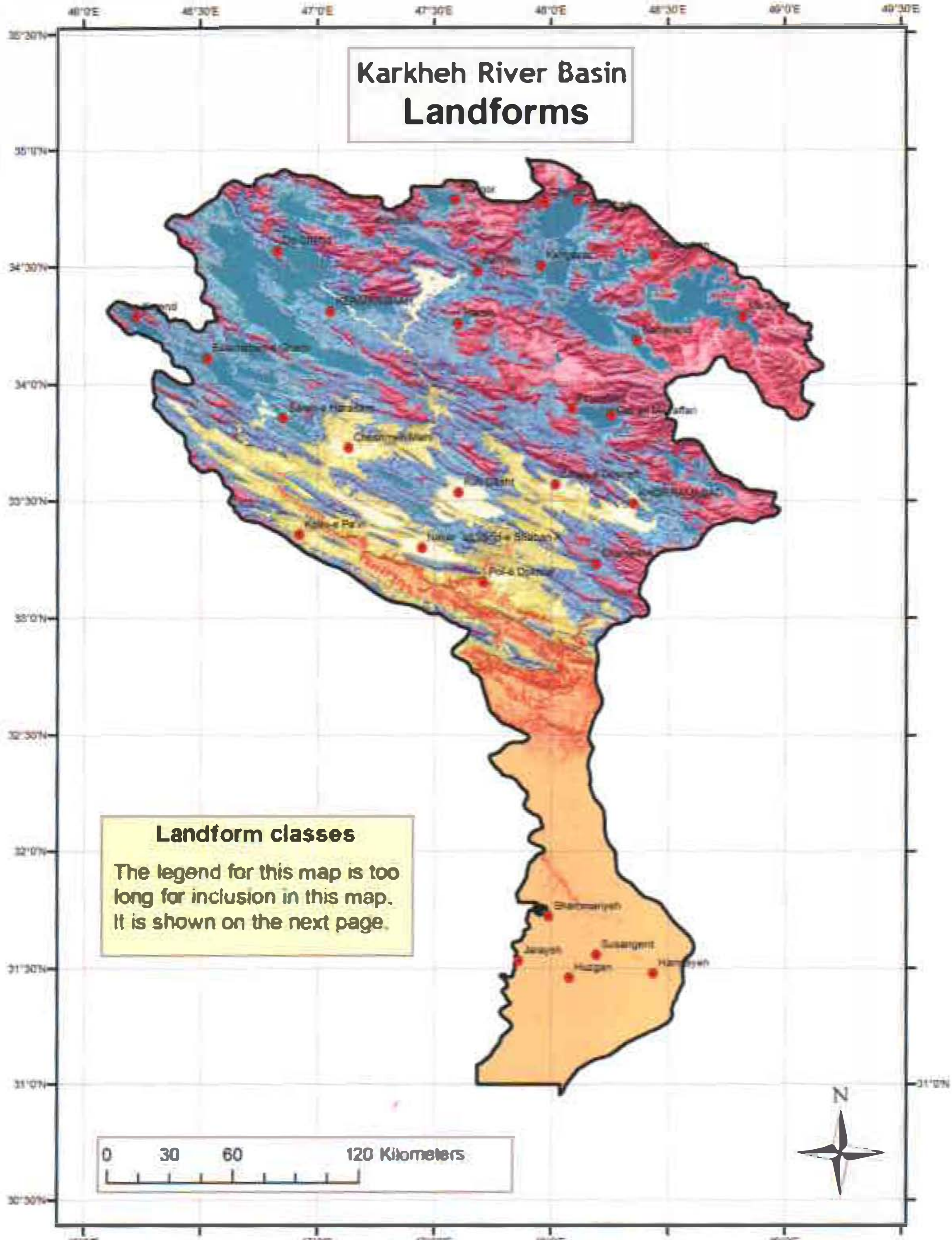


Figure 46a. Landforms

Karkheh River Basin
Landforms: Legend

- Low elevation (<800 m), flat to almost flat (0-5% slope)
- Low elevation (<800 m), gently undulating to undulating (5-12% slope)
- Low elevation (<800 m), rolling to hilly (12-30% slope), undifferentiated aspect
- Low elevation (<800 m), rolling to hilly (12-30% slope), northern aspect
- Low elevation (<800 m), rolling to hilly (12-30% slope), southern aspect
- Low elevation (<800 m), steeply dissected (>30% slope), undifferentiated aspect
- Low elevation (<800 m), steeply dissected (>30% slope), northern aspect
- Low elevation (<800 m), steeply dissected (>30% slope), southern aspect
- Medium elevation (800-1300 m), flat to almost flat (0-5% slope)
- Medium elevation (800-1300 m), gently undulating to undulating (5-12% slope)
- Medium elevation (800-1300 m), rolling to hilly (12-30% slope), undifferentiated aspect
- Medium elevation (800-1300 m), rolling to hilly (12-30% slope), northern aspect
- Medium elevation (800-1300 m), rolling to hilly (12-30% slope), southern aspect
- Medium elevation (800-1300 m), steeply dissected (>30% slope), undifferentiated aspect
- Medium elevation (800-1300 m), steeply dissected (>30% slope), northern aspect
- Medium elevation (800-1300 m), steeply dissected (>30% slope), southern aspect
- High elevation (>1300-1800 m), flat to almost flat (0-5% slope)
- High elevation (>1300-1800 m), gently undulating to undulating (5-12% slope)
- High elevation (>1300-1800 m), rolling to hilly (12-30% slope), undifferentiated aspect
- High elevation (>1300-1800 m), rolling to hilly (12-30% slope), northern aspect331
- High elevation (>1300-1800 m), rolling to hilly (12-30% slope), southern aspect
- High elevation (>1300-1800 m), steeply dissected (>30% slope), undifferentiated aspect
- High elevation (>1300-1800 m), steeply dissected (>30% slope), northern aspect
- High elevation (>1300-1800 m), steeply dissected (>30% slope), southern aspect
- Very high elevation (>1800 m), flat to almost flat
- Very high elevation (>1800 m), gently undulating to undulating (5-12% slope)
- Very high elevation (>1800 m), rolling to hilly (12-30% slope), undifferentiated aspect
- Very high elevation (>1800 m), rolling to hilly (12-30% slope), northern aspect
- Very high elevation (>1800 m), rolling to hilly (12-30% slope), southern aspect
- Very high elevation (>1800 m), steeply dissected (>30% slope), undifferentiated aspect
- Very high elevation (>1800 m), steeply dissected (>30% slope), southern aspect
- Very high elevation (>1800 m), steeply dissected (>30% slope), southern aspect

Figure 46b. Legend of the Landforms Map

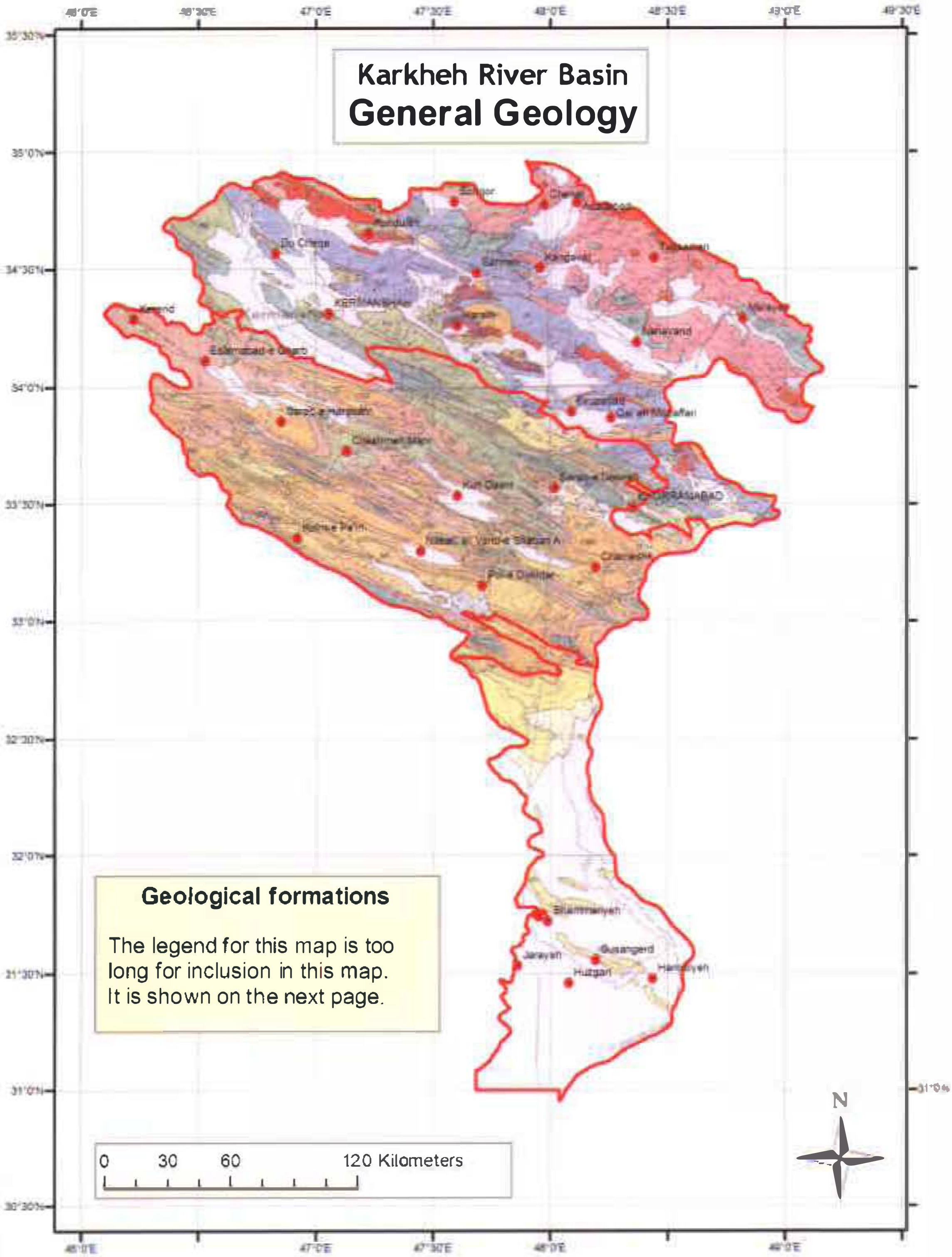


Fig 47a. Generalized geological map

Generalized Geological Map - Legend

Figure 47b. Generalized geological map: legend

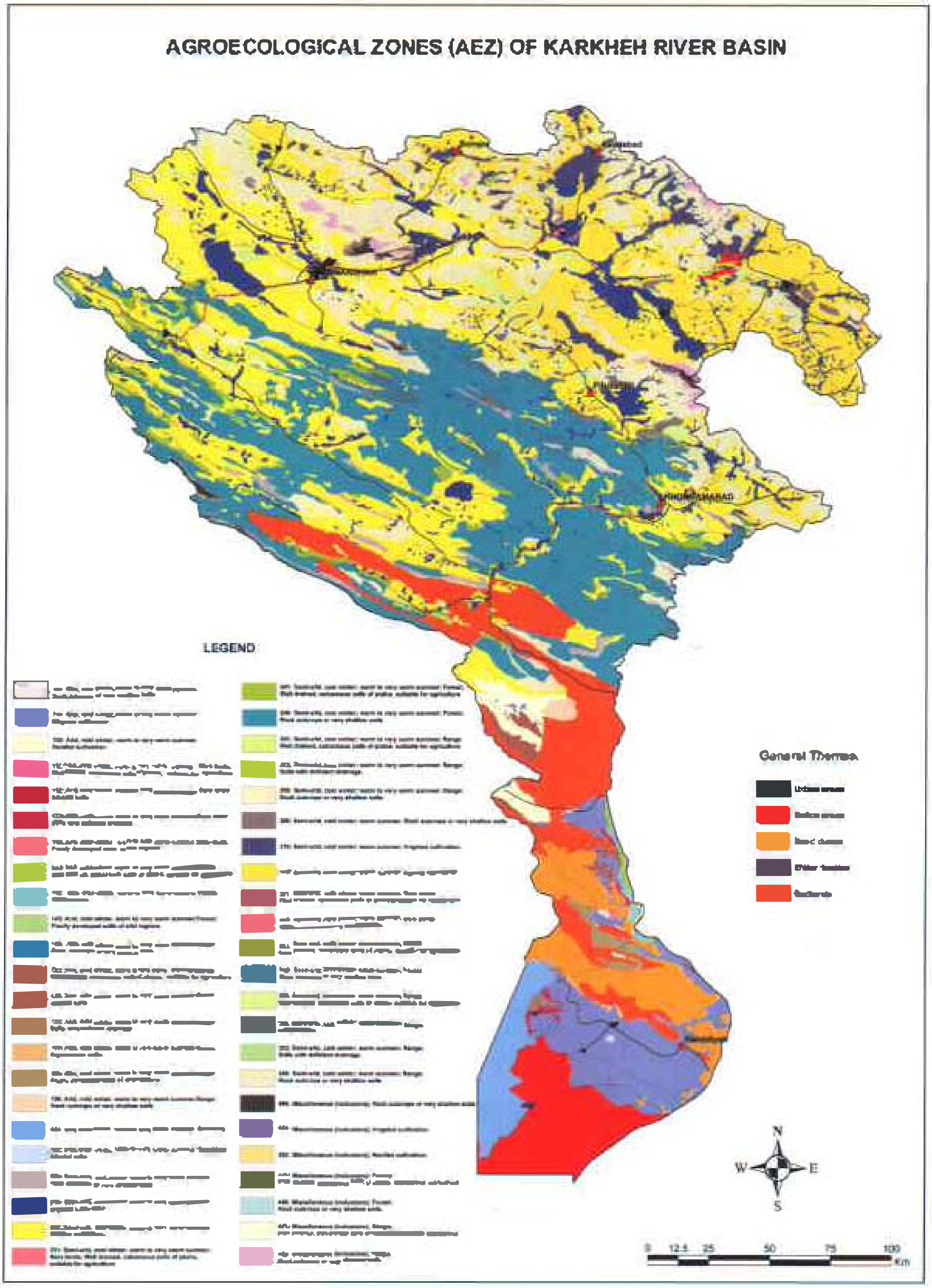


Figure 48. Agro-ecological Zones

Figure 49. Northern Agricultural Region. Rainfed agriculture in plains and on lower hill slopes is the dominant land use.

Figure 50. Northern Agricultural Region. Irrigated agriculture occupies the lowest parts of valleys.

Figure 51. Northern Agricultural Region. Rangelands are the normal land use on steep or stony hillslopes and cover about 36% of this region. Their condition varies considerably at local level, from good to severely overgrazed.

Figure 52. Northern Agricultural Region. Encroachment of rainfed agriculture onto steeper slopes, at the expense of traditional rangeland areas.

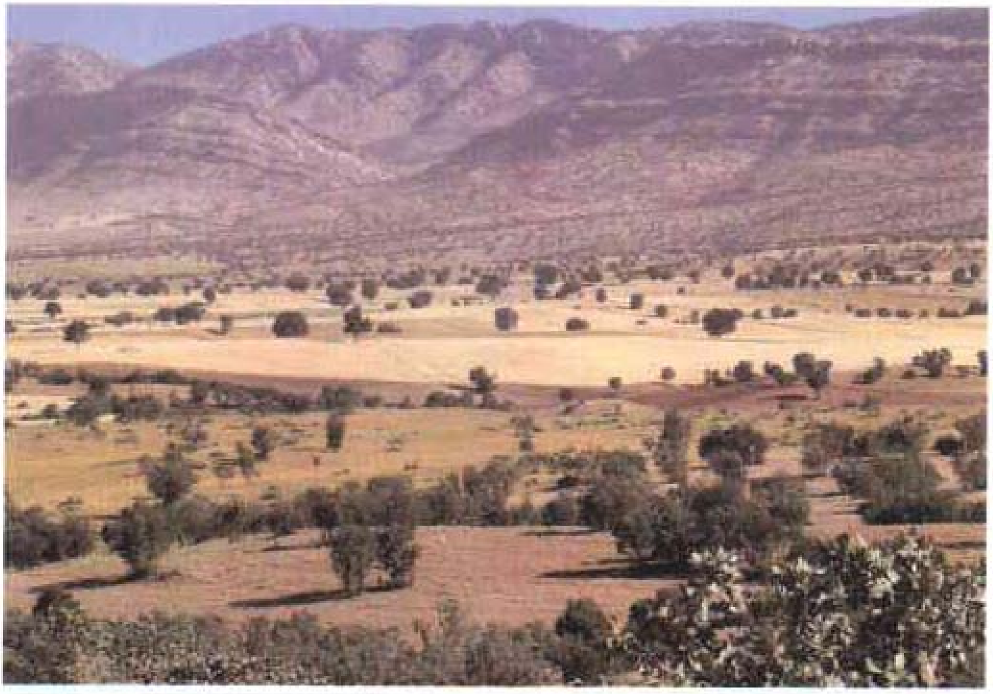


Figure 53. Central Agricultural Region, typical cuesta landscape with mostly rainfed agriculture on lower slopes, a parkland type of open oak forest on pediment slopes and rangelands on the rocky steep upper slopes.

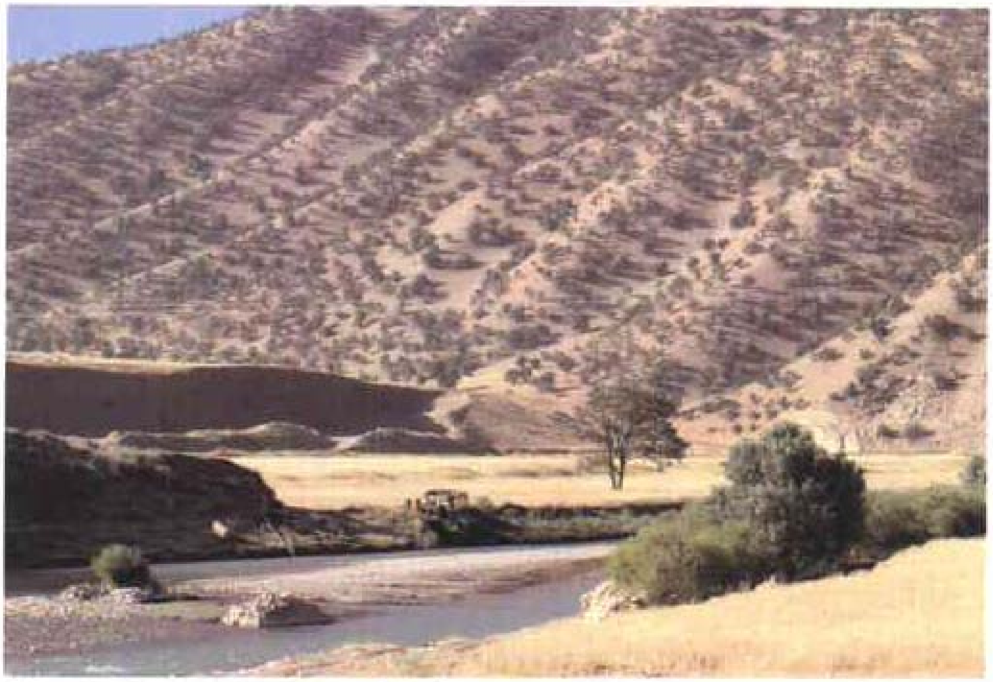


Figure 54. Central Agricultural Region, open 'forest' cover on erodible slopes near the Kashkan river.

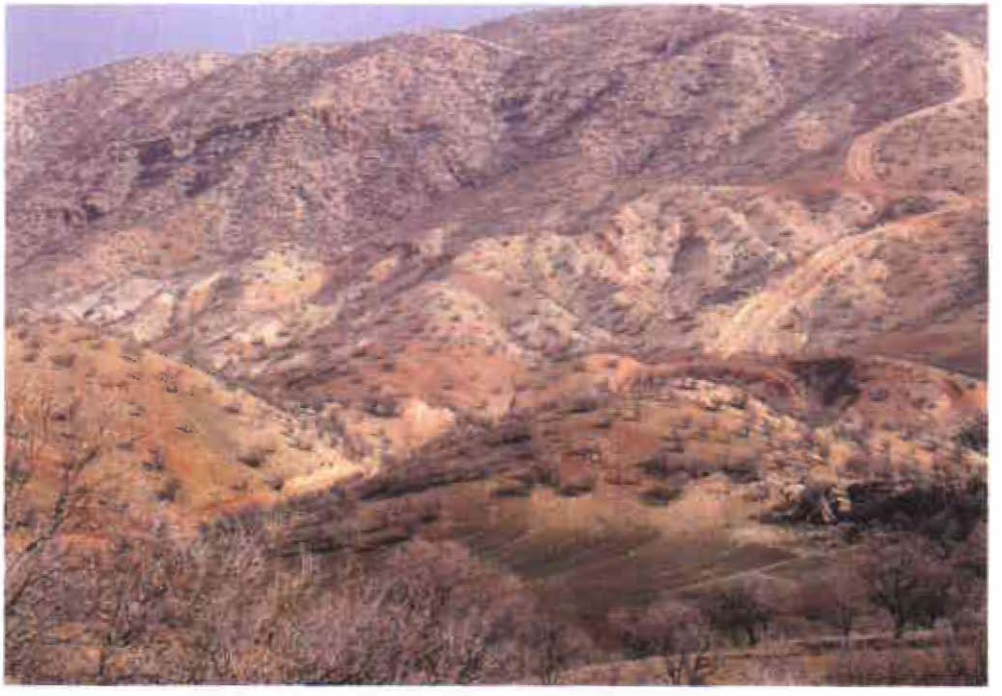


Figure 55. Central Agricultural Region, erodible sediments of the Kashkan formation.

Figure 56. Central Agricultural Region, typical 'badlands'. As indicated in Figure 55, these badlands are linked to specific 'soft' geological parent materials which start to outcrop in this agricultural region and continue in the Southern Agricultural Region.

Figure 57. Central Agricultural Region, consolidated clayey sediments, marls, that due to easy physical disintegration in a semi-arid environment are almost 'doomed' to severe erosion.

Figure 58. Southern Agricultural Region, floodplain of the Karkheh river with typical Tamarix woodland and uneven terrain due to changing sedimentation patterns

Figure 59. Southern Agricultural Region, unleveled land earmarked for irrigation development.

Figure 60. Southern Agricultural Region, land leveling for irrigation development in progress.

Figure 61. Dasht-e-Abbas irrigated area. Whereas in the north of the Southern Agricultural Region, soil salinity is not (yet) a major problem, the main limitations are low crop water productivity, partly due to inadequate leveling, and focus on few staple crops.

Figure 62. The southern part of the Southern Agricultural Region is badly affected by soil salinity, as the white crusts in the background of this photo demonstrate. Note the common practice of plastic mulches to extend the growing season for vegetables.

Figure 63. The prevalence of clayey soils developed on fine alluvium makes drainage and leaching of salts difficult.

Figure 64. Sand dunes cover about 17% of the Southern Agricultural Region. Exposed geological materials provide the source of the sands, which once removed by water erosion from the geological deposit can be easily blown away and deposited elsewhere during the dry season.

Figure 65. Southern Agricultural Region, protected area with sand dunes stabilized by spraying with tar (see freshly treated slopes in the background)

Figure 66. Sand treated with tar breaks up into smaller fragments and develops some kind of aggregation that allows plants and shrubs to settle.

ANNEX 3. VIEWS OF THE BENCHMARK SITES

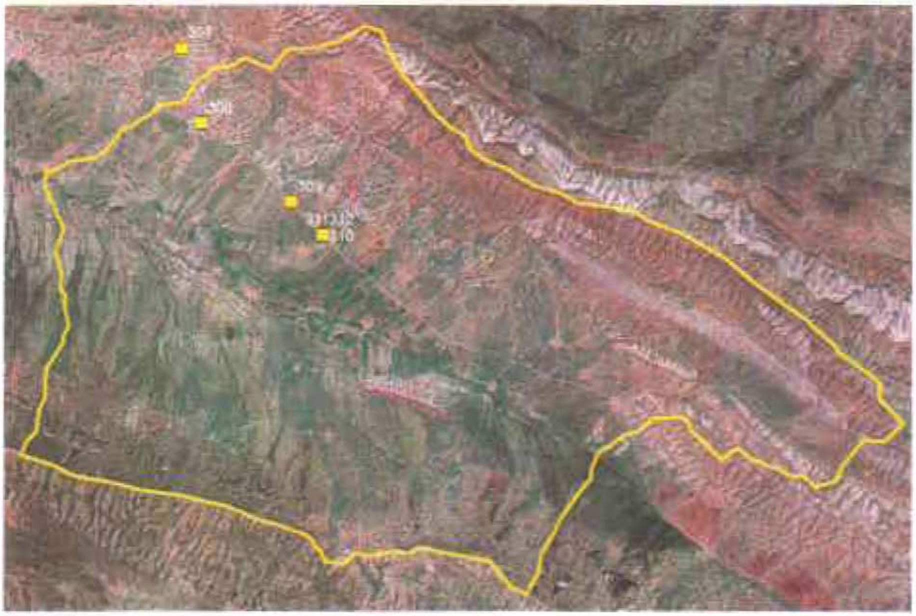


Figure 67. Satellite image of the Merek benchmark site, typical of the mixed farming system in the warmer parts of the Upper Karkheh River Basin, with mostly rainfed crops, limited irrigated land and rangelands and degraded oak forest on the hillslopes.

Figure 68. Agricultural landscape of the Merek benchmark site, with denuded hills and footslopes in the foreground, mostly rainfed crops and some groundwater-irrigated crops in the plain. (June '04)

Figure 69. Cross-section through Merek landscape structure, with degraded rangelands and forests in the foreground, plains with mostly rainfed crops in the middle, and rangelands on the foothills and steep mountains in the back (March '05)

Figure 70. Merek benchmark site, view across the long and short slopes of the cuesta, with degraded open oak forest and rangelands (June '04)

Figure 71. Satellite image of the Honam benchmark site, representative of the mixed farming system, with rainfed and irrigated cropping and rangelands, typical of the colder areas in the Upper Karkheh River Basin.

Figure 72. Landscape overview of the Honam benchmark site, with rangelands on the hillslopes and mountains, and irrigated and rainfed field and tree crops in the narrow valley (March 2005)

Figure 73. Upper reaches of the Honam watershed: cultivation of wheat and barley on steep slopes. Note the absence of erosion. (June 2004)

Figure 74. Honam benchmark site: cultivation on steep slopes with donkeys (March 2005)

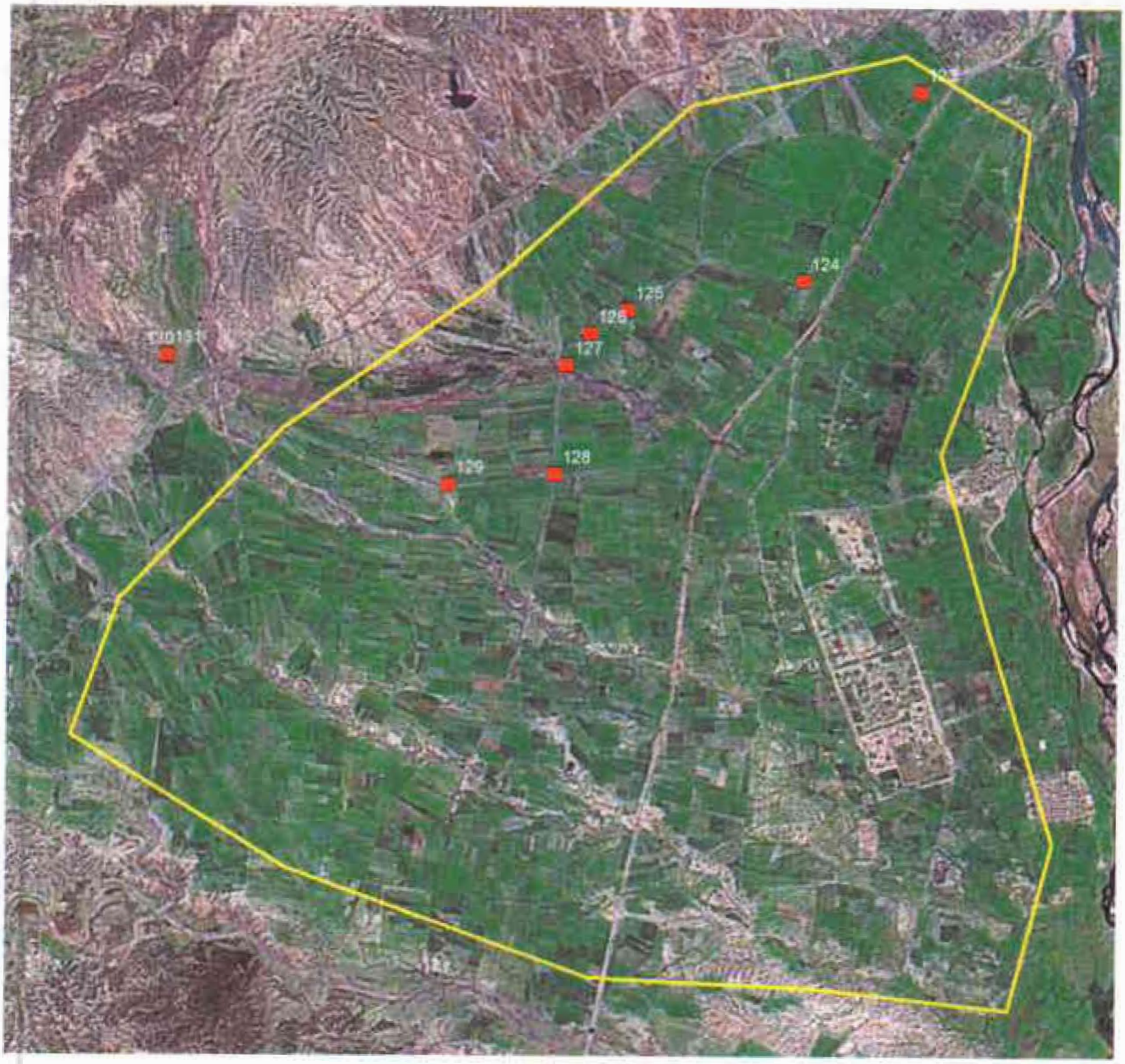


Figure 75. Satellite image of the Sorkhe irrigated area, representative for the fully irrigated cropping systems typical of the northern plains of the Lower Karkheh River Basin around Dezful.

Figure 76. Sorkhe, irrigated wheat area, near GPS point 126. Note the uneven crop stands (March 2005)

Figure 77. Sorkhe, irrigated wheat area, near GPS point 126. Low crop water productivity due to poor leveling (March 2005)

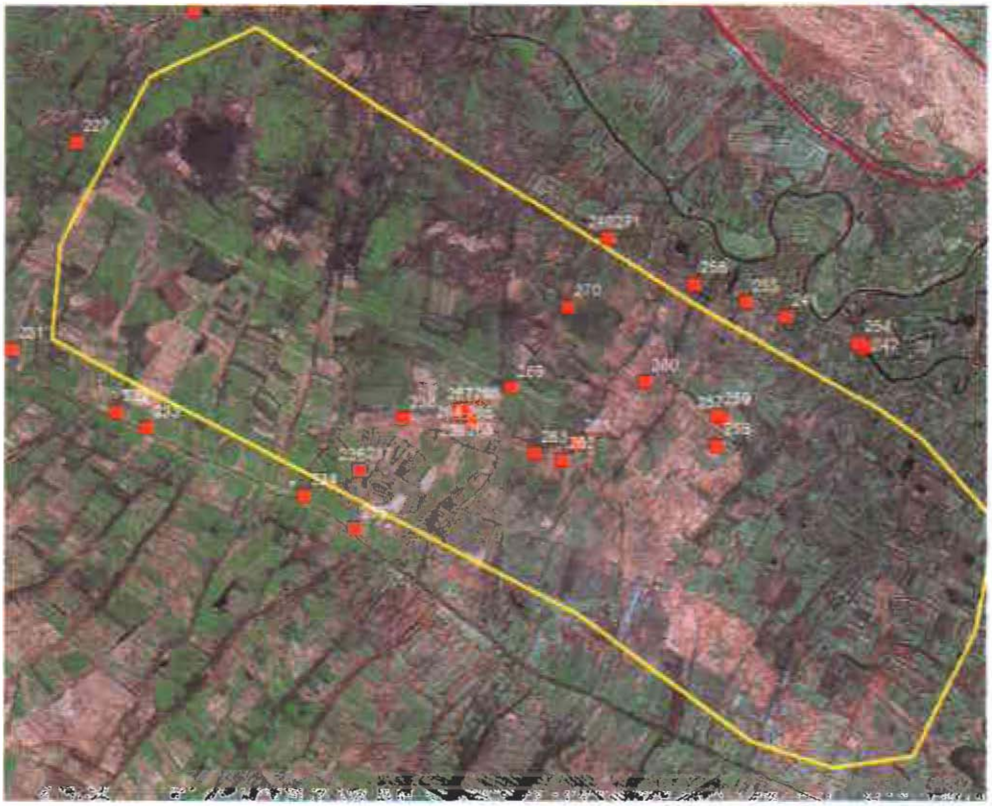


Figure 78. Satellite image of the Azadegan irrigated area, representative for large areas of salt-affected irrigated soils with currently low productivity in the southern plains of the Lower Karkheh River Basin. Note the generally low greenness due to low crop productivity and areas taken out of production (brown spots).

Figure 79. Azadegan irrigated area, near GPS point 239. Note the substantial variations in wheat biomass (March 2005)

Figure 80. Azadegan irrigated area, near GPS point 239. These open spots in the wheat crop are due to pronounced salinity and are visible on satellite imagery (March 2005)

Figure 81. Azadegan irrigated area, near GPS point 239. Salt crusts developing on the soil surface. Soils are heavy clays and more difficult to drain (March 2005)

ANNEX 4. CLEANING UP PROCEDURES USING GIS FUNCTIONS

In order to remove small dispersed clusters (ranging from a few pixels to several hundred) of one class that appear inside another class, a cleanup procedure was applied to absorb the 'orphaned' pixels into their nearest neighbors. The following procedure, which can be literally implemented in ArcGIS or ArcView (through Avenue functions) was followed:

1. Isolate the class containing fragmented pixels using a logical expression (e.g. AEZ=220). This creates a layer with binary values (0 or 1).
2. Apply 'SetNull' function (e.g. SetNull(Temp=0,Temp)), which creates a grid with Value=1 and the zeros become 'No Data'.
3. Apply 'RegionGroup' function on the new grid. This function creates clusters where the pixels are connected to each other and gives each region a unique ID.
4. Select the regions that consist of less than or equal to 10 pixels. This threshold was chosen through visual interpretation of the AEZ map, which helped to identify the smallest clusters with natural shape. (e.g. [Temp01].Count <= 10, which again creates a grid with 0 and 1 values)
5. Mask out the chosen pixels, using the 'SetNull' function to replace the values 1 by NoData.
6. Apply the 'Nibble' function to replace the areas in the AEZ layer corresponding to the mask with the values of nearest neighbors.

Figure 82 shows the steps for removing noisy pixels.

Figure 82. Steps for removal of noisy pixels

ANNEX 5. Listing and composition of individual soil mapping units

Soilscape ID	Dominant soil	Label (mostly Soil Taxonomy)	Associated soil	Included soil	AEZ Code
393	DGH,T	Typic Haplogypsids	EOT,T	XRO	Gypsiferous_Soil
35	DSH,T	Typic Haplosalids	DMH,I	EOT,T	Saline_Soil
270	EOU,D	Aridic Ustorthents	AUH,D	IOU,DK	Poorly_Developed
271	EOU,D	Aridic Ustorthents	DSQ,G	DSQ,T	Poorly_Developed
463	EOU,D	Aridic Ustorthents	IOU,D	IOU,DK	Poorly_Developed
319	EQV,T	Typic Fluvaquents	DMH,F		Poor_Drained_soils
353	ESU,D	Sandy soils	EVU,D	XDL	Sandy soils
404	ESU,D	Sandy soils			Sandy soils
411	ESU,D	Sandy soils		DRH,U	Sandy soils
281	EVT,T	Typic Torrifluvents	DSQ,G	EVT,Q	Alluvial_Soils
282	EVT,T	Typic Torrifluvents			Alluvial_Soils
295	EVU,D	Aridic Ustifluvents			Alluvial_Soils
296	EVU,T	Typic Ustifluvents	EOU,T		Alluvial_Soils
43	EVU,T	Typic Ustifluvents			Alluvial_Soils
144	IOU,K	Calcic Ustochrepts	EOU,L	XRO	Well_Drained_Agri_Soil
184	IOU,K	Calcic Ustochrepts	IOU,F		Well_Drained_Agri_Soil
27	IOU,K	Calcic Ustochrepts	IOU,F	EOU,T	Well_Drained_Agri_Soil
145	IOX,C	Calcixerollic Xerochrepts	IOX,F	EVX,T	Well_Drained_Agri_Soil
146	IOX,C	Calcixerollic Xerochrepts	IOX,T	IQH,T	Well_Drained_Agri_Soil
172	IOX,C	Calcixerollic Xerochrepts	IOX,T	EOX,T	Well_Drained_Agri_Soil
185	IOX,C	Calcixerollic Xerochrepts	VXK,T		Well_Drained_Agri_Soil
191	IOX,C	Calcixerollic Xerochrepts	VXK,T		Well_Drained_Agri_Soil
64	IOX,C	Calcixerollic Xerochrepts	XRO	EOX,L	Well_Drained_Agri_Soil
148	IOX,F	Fluventic Xerochrepts	EVX,T		Alluvial_Soils
173	IQE,T	Typic Endoaquepts	IOX,C	VXK,A	Poor_Drained_soils
96	IQH,T	Typic Halaquepts	IQE,T		Poor_Drained_soils
152	MUK,T	Typic Calciustolls	IOU,K	EOU,T	Well_Drained_Agri_Soil
357	MUK,T	Typic Calciustolls	IOU,K	EOU,T	Well_Drained_Agri_Soil
138	MXK,Q	Aquic Calcixerolls	IQE,T	MXK,T	Poor_Drained_soils
248	XBL	Badlands	EOU,L	XRO	Bad land
399	XBL	Badlands	XRO	IOU,K	Bad land
BL	XBL	Badlands			Bad land
416	XDL	Dune land	ESU,T		Dune land
DL	XDL	Dune land			Dune land
466	XMA	Marsh			Marsh
180	XRM	Rock outcrop	DKH,LX	EOT,LX	Rock outcrop
192	XRM	Rock outcrop	EOX,L	EOX,T	Rock outcrop
207	XRM	Rock outcrop	IOU,L	EOU,L	Rock outcrop
364	XRM	Rock outcrop	IOX,C	EOX,L	Rock outcrop
386	XRM	Rock outcrop	XBL	IOU,L	Rock outcrop
RM	XRM	Rock outcrop			Rock outcrop
U	XUR	Urban			Urban

Annex 6. Listing and composition of individual Agro-ecological Zones

AEZ code	Pixel count	%	Climate	Land use	Soilscape
106	3,316	0.05	Arid, mild winter, warm to very warm summer	n.a.	Rock outcrops or very shallow soils
110	324,447	4.42	Arid, mild winter, warm to very warm summer	Irrigated cultivation	n.a.
120	70,511	0.96	Arid, mild winter, warm to very warm summer	Rainfed cultivation	n.a.
131	2,395	0.03	Arid, mild winter, warm to very warm summer	Bare lands	Well drained, calcareous soils of plains
132	3,564	0.05	Arid, mild winter, warm to very warm summer	Bare lands	Alluvial soils
133	6,451	0.09	Arid, mild winter, warm to very warm summer	Bare lands	Soils with deficient drainage
135	1,456	0.02	Arid, mild winter, warm to very warm summer	Bare lands	Poorly developed soils of arid regions
141	7,583	0.10	Arid, mild winter, warm to very warm summer	Forest	Well drained, calcareous soils of plains
142	9,492	0.13	Arid, mild winter, warm to very warm summer	Forest	Alluvial soils
145	966	0.01	Arid, mild winter, warm to very warm summer	Forest	Poorly developed soils of arid regions
146	4,224	0.06	Arid, mild winter, warm to very warm summer	Forest	Rock outcrops or very shallow soils
151	39,711	0.54	Arid, mild winter, warm to very warm summer	Range	Well drained, calcareous soils of plains
152	3,164	0.04	Arid, mild winter, warm to very warm summer	Range	Alluvial soils
153	6,010	0.08	Arid, mild winter, warm to very warm summer	Range	Soils with deficient drainage
154	4,597	0.06	Arid, mild winter, warm to very warm summer	Range	Gypsiferous soils
155	28,955	0.39	Arid, mild winter, warm to very warm summer	Range	Poorly developed soils of arid regions
156	19,808	0.27	Arid, mild winter, warm to very warm summer	Range	Rock outcrops or very shallow soils
160	120,086	1.64	Arid, mild winter, warm to very warm summer	Wetlands	n.a.
162	947	0.01	Arid, mild winter, warm to very warm summer	Wetlands	Alluvial soils
206	71,088	0.97	Semi-arid, cool winter; warm to very warm summer	n.a.	Rock outcrops or very shallow soils
210	356,647	4.86	Semi-arid, cool winter; warm to very warm summer	Irrigated cultivation	n.a.
220	1,340,995	18.26	Semi-arid, cool winter; warm to very warm summer	Rainfed cultivation	n.a.
231	1,792	0.02	Semi-arid, cool winter; warm to very warm summer	Bare lands	Well drained, calcareous soils of plains
241	133,216	1.81	Semi-arid, cool winter; warm to very warm summer	Forest	Well drained, calcareous soils of plains
246	1,251,383	17.04	Semi-arid, cool winter; warm to very warm summer	Forest	Rock outcrops or very shallow soils
251	89,408	1.22	Semi-arid, cool winter; warm to very warm summer	Range	Well drained, calcareous soils of plains
253	2,246	0.03	Semi-arid, cool winter; warm to very warm summer	Range	Soils with deficient drainage
256	227,085	3.09	Semi-arid, cool winter; warm to very warm summer	Range	Rock outcrops or very shallow soils
306	58,781	0.80	Semi-arid, cold winter; warm summer	n.a.	Rock outcrops or very shallow soils
310	203,599	2.77	Semi-arid, cold winter; warm summer	Irrigated cultivation	n.a.
320	753,205	10.26	Semi-arid, cold winter; warm summer	Rainfed cultivation	n.a.
331	244	0.00	Semi-arid, cold winter; warm summer	Bare lands	Well drained, calcareous soils of plains

336	1,498	0.02	Semi-arid, cold winter; warm summer	Bare lands	Rock outcrops or very shallow soils
341	7,079	0.10	Semi-arid, cold winter; warm summer	Forest	Well drained, calcareous soils of plains
346	187,349	2,55	Semi-arid, cold winter; warm summer	Forest	Rock outcrops or very shallow soils
351	82,947	1.13	Semi-arid, cold winter; warm summer	Range	Well drained, calcareous soils of plains
352	1,058	0.01	Semi-arid, cold winter; warm summer	Range	Alluvial soils
353	1,292	0.02	Semi-arid, cold winter; warm summer	Range	Soils with deficient drainage
356	675,796	9.20	Semi-arid, cold winter; warm summer	Range	Rock outcrops or very shallow soils
406	15,750	0.21	Miscellaneous (inclusions)	n.a.	Rock outcrops or very shallow soils
410	668	0.01	Miscellaneous (inclusions)	Irrigated cultivation	n.a.
420	4,086	0.06	Miscellaneous (inclusions)	Rainfed cultivation	n.a.
441	35	0.00	Miscellaneous (inclusions)	Forest	Well drained, calcareous soils of plains
446	12,344	0.17	Miscellaneous (inclusions)	Forest	Rock outcrops or very shallow soils
451	106	0.00	Miscellaneous (inclusions)	Range	Well drained, calcareous soils of plains
456	46,312	0,63	Miscellaneous (inclusions)	Range	Rock outcrops or very shallow soils
Saline areas	245,718	3.35			
Sand dunes	230,957	3.15			
Urban	14,974	0.20			
Water bodies	1,438	0.02			
Badlands	669,557	9.12			
Total	7,343,020				

ANNEX 7. Climatic characterization of agro-ecological zones

Table 14. Percentage occurrence of precipitation classes in each AEZ

AEZ	Pixel Count	0-50	50-100	100-150	150-200	200-250	250-300	300-350	350-400	400-450	450-500	500-550	550-600
106	3297	0	0	0	0	31	65	4	0	0	0	0	0
110	324452	0	0	0	70	16	11	2	0	0	0	0	0
120	70547	0	0	0	0	0	31	69	0	0	0	0	0
131	2405	0	0	0	0	0	100	0	0	0	0	0	0
132	3571	0	0	0	20	0	80	0	0	0	0	0	0
133	6447	0	0	0	100	0	0	0	0	0	0	0	0
135	1445	0	0	0	4	0	96	0	0	0	0	0	0
141	7581	0	0	0	0	0	66	34	0	0	0	0	0
142	9510	0	0	0	0	14	86	0	0	0	0	0	0
145	966	0	0	0	0	0	100	0	0	0	0	0	0
146	4206	0	0	0	0	0	0	100	0	0	0	0	0
151	39747	0	0	0	0	0	35	65	0	0	0	0	0
152	3141	0	0	0	18	22	60	0	0	0	0	0	0
153	6011	0	0	0	77	23	0	0	0	0	0	0	0
154	4597	0	0	0	0	100	0	0	0	0	0	0	0
155	28949	0	0	0	1	77	23	0	0	0	0	0	0
156	19816	0	0	0	0	0	0	100	0	0	0	0	0
160	120088	0	0	0	91	9	0	0	0	0	0	0	0
162	947	0	0	0	100	0	0	0	0	0	0	0	0
206	71164	0	0	0	0	0	0	1	12	47	31	10	0
210	356832	0	0	0	0	0	0	1	26	41	12	20	0
220	1341571	0	0	0	0	0	0	2	8	38	24	28	0
231	1785	0	0	0	0	0	0	0	99	1	0	0	0
241	133178	0	0	0	0	0	0	4	7	33	17	38	1
246	1251642	0	0	0	0	0	0	0	6	45	34	14	0
251	89233	0	0	0	0	0	0	5	4	40	13	38	0
253	2236	0	0	0	0	0	0	8	23	36	1	32	0
256	226742	0	0	0	0	0	0	2	10	33	36	20	0
306	58895	0	0	0	0	0	0	4	20	14	38	25	0
310	203255	0	0	0	0	0	0	20	49	25	6	0	0
320	752924	0	0	0	0	0	0	13	36	36	10	4	0
331	249	0	0	0	0	0	0	32	35	31	3	0	0
336	1489	0	0	0	0	0	0	31	63	4	2	0	0
341	7027	0	0	0	0	0	0	0	0	33	26	39	1
346	187064	0	0	0	0	0	0	0	0	6	66	27	2
351	82915	0	0	0	0	0	0	9	19	44	19	9	0
352	1056	0	0	0	0	0	0	0	0	100	0	0	0
353	1304	0	0	0	0	0	0	71	29	0	0	0	0
356	676421	0	0	0	0	0	0	4	24	26	31	15	0
406	15739	0	0	0	0	0	0	0	0	0	20	79	0
410	654	0	0	0	0	0	0	0	1	21	30	49	0
420	4034	0	0	0	0	0	0	0	0	0	53	22	25
441	35	0	0	0	0	0	0	0	0	0	0	0	100
446	12323	0	0	0	0	0	0	0	0	0	0	65	34
451	98	0	0	0	0	0	0	0	0	83	17	0	0
456	46104	0	0	0	0	0	0	0	1	15	24	59	0

Note:
This table shows for each AEZ the percentage of each specified precipitation class (0-50 mm, 50-100 mm etc.)

Table 15. Percentage occurrence of growing period classes (as limited by moisture) in each AEZ

AEZ	Pixel Count	0-1	1-30	30-60	60-90	90-120	120-150	150-180	180-210	210-240	240-270	270-300	300-330	330-365
106	3297	0	0	0	36	60	0	4	0	0	0	0	0	0
110	324452	0	0	0	87	8	5	0	0	0	0	0	0	0
120	70547	0	0	0	0	4	71	25	0	0	0	0	0	0
131	2405	0	0	0	0	100	0	0	0	0	0	0	0	0
132	3571	0	0	0	20	80	0	0	0	0	0	0	0	0
133	6447	0	0	0	100	0	0	0	0	0	0	0	0	0
135	1445	0	0	0	4	96	0	0	0	0	0	0	0	0
141	7581	0	0	0	0	59	14	27	0	0	0	0	0	0
142	9510	0	0	0	23	77	0	0	0	0	0	0	0	0
145	966	0	0	0	0	100	0	0	0	0	0	0	0	0
146	4206	0	0	0	0	0	0	100	0	0	0	0	0	0
151	39747	0	0	0	0	27	64	9	0	0	0	0	0	0
152	3141	0	0	0	43	57	0	0	0	0	0	0	0	0
153	6011	0	0	0	100	0	0	0	0	0	0	0	0	0
154	4597	0	0	0	100	0	0	0	0	0	0	0	0	0
155	28949	0	0	0	75	25	0	0	0	0	0	0	0	0
156	19816	0	0	0	0	0	41	59	0	0	0	0	0	0
160	120088	0	0	1	99	0	0	0	0	0	0	0	0	0
162	947	0	0	0	100	0	0	0	0	0	0	0	0	0
206	71164	0	0	0	0	0	0	7	90	3	0	0	0	0
210	356832	0	0	0	0	0	0	3	97	0	0	0	0	0
220	1341571	0	0	0	0	0	0	4	94	2	0	0	0	0
231	1785	0	0	0	0	0	0	0	100	0	0	0	0	0
241	133178	0	0	0	0	0	0	8	89	3	0	0	0	0
246	1251642	0	0	0	0	0	0	4	93	2	0	0	0	0
251	89233	0	0	0	0	0	0	5	92	3	0	0	0	0
253	2236	0	0	0	0	0	0	0	100	0	0	0	0	0
256	226742	0	0	0	0	0	0	7	92	1	0	0	0	0
306	58895	0	0	0	0	0	0	0	33	67	0	0	0	0
310	203255	0	0	0	0	0	0	0	90	10	0	0	0	0
320	752924	0	0	0	0	0	0	0	76	24	0	0	0	0
331	249	0	0	0	0	0	0	0	99	1	0	0	0	0
336	1489	0	0	0	0	0	0	0	90	10	0	0	0	0
341	7027	0	0	0	0	0	0	0	52	48	0	0	0	0
346	187064	0	0	0	0	0	0	0	47	53	0	0	0	0
351	82915	0	0	0	0	0	0	0	64	36	0	0	0	0
352	1056	0	0	0	0	0	0	0	57	43	0	0	0	0
353	1304	0	0	0	0	0	0	0	98	2	0	0	0	0
356	676421	0	0	0	0	0	0	0	39	61	0	0	0	0
406	15739	0	0	0	0	0	0	0	0	99	1	0	0	0
410	654	0	0	0	0	0	0	0	0	100	0	0	0	0
420	4034	0	0	0	0	0	0	0	0	100	0	0	0	0
441	35	0	0	0	0	0	0	0	0	100	0	0	0	0
446	12323	0	0	0	0	0	0	0	0	100	0	0	0	0
451	98	0	0	0	0	0	0	0	0	100	0	0	0	0
456	46104	0	0	0	0	0	0	0	0	99	1	0	0	0

Note:
This table shows for each AEZ the percentage of each specified growing period class (growing period 0-1 day, 1-30 days, 30-60 days, etc.)

Table 16. Percentage occurrence of growing period classes (as limited by temperature) in each AEZ

AEZ	Pixel Count	0-1	1-30	30-60	60-90	90-120	120-150	150-180	180-210	210-240	240-270	270-300	300-330	330-365
106	3297	0	0	0	0	0	0	0	0	0	0	0	0	100
110	324452	0	0	0	0	0	0	0	0	0	0	0	0	100
120	70547	0	0	0	0	0	0	0	0	0	0	0	0	100
131	2405	0	0	0	0	0	0	0	0	0	0	0	0	100
132	3571	0	0	0	0	0	0	0	0	0	0	0	0	100
133	6447	0	0	0	0	0	0	0	0	0	0	0	0	100
135	1445	0	0	0	0	0	0	0	0	0	0	0	0	100
141	7581	0	0	0	0	0	0	0	0	0	0	0	0	100
142	9510	0	0	0	0	0	0	0	0	0	0	0	0	100
145	966	0	0	0	0	0	0	0	0	0	0	0	0	100
146	4206	0	0	0	0	0	0	0	0	0	0	0	0	100
151	39747	0	0	0	0	0	0	0	0	0	0	0	0	100
152	3141	0	0	0	0	0	0	0	0	0	0	0	0	100
153	6011	0	0	0	0	0	0	0	0	0	0	0	0	100
154	4597	0	0	0	0	0	0	0	0	0	0	0	0	100
155	28949	0	0	0	0	0	0	0	0	0	0	0	0	100
156	19816	0	0	0	0	0	0	0	0	0	0	0	0	100
160	120088	0	0	0	0	0	0	0	0	0	0	0	0	100
162	947	0	0	0	0	0	0	0	0	0	0	0	0	100
206	71164	0	0	0	0	0	0	0	0	0	10	42	18	31
210	356832	0	0	0	0	0	0	0	0	0	12	68	5	15
220	1341571	0	0	0	0	0	0	0	0	0	12	55	11	22
231	1785	0	0	0	0	0	0	0	0	0	1	99	0	0
241	133178	0	0	0	0	0	0	0	0	0	4	46	20	29
246	1251642	0	0	0	0	0	0	0	0	0	9	48	21	23
251	89233	0	0	0	0	0	0	0	0	0	21	62	5	12
253	2236	0	0	0	0	0	0	0	0	0	13	87	0	0
256	226742	0	0	0	0	0	0	0	0	0	21	54	8	17
306	58895	0	0	0	0	0	0	0	0	39	61	0	0	0
310	203255	0	0	0	0	0	0	0	0	7	93	0	0	0
320	752924	0	0	0	0	0	0	0	0	15	85	0	0	0
331	249	0	0	0	0	0	0	0	0	0	100	0	0	0
336	1489	0	0	0	0	0	0	0	0	43	57	0	0	0
341	7027	0	0	0	0	0	0	0	0	4	96	0	0	0
346	187064	0	0	0	0	0	0	0	0	10	90	0	0	0
351	82915	0	0	0	0	0	0	0	0	17	83	0	0	0
352	1056	0	0	0	0	0	0	0	0	1	99	0	0	0
353	1304	0	0	0	0	0	0	0	0	2	98	0	0	0
356	676421	0	0	0	0	0	0	0	0	36	64	0	0	0
406	15739	0	0	0	0	0	0	1	48	41	11	0	0	0
410	654	0	0	0	0	0	0	0	97	2	0	0	0	0
420	4034	0	0	0	0	0	0	0	56	23	21	0	0	0
441	35	0	0	0	0	0	0	0	0	0	100	0	0	0
446	12323	0	0	0	0	0	0	0	0	70	30	0	0	0
451	98	0	0	0	0	0	0	0	83	17	0	0	0	0
456	46104	0	0	0	0	0	0	2	51	48	0	0	0	0

Note:
This table shows for each AEZ the percentage of each specified growing period class (growing period 0-1 day, 1-30 days, 30-60 days, etc.)

Table 17. Percentage occurrence of growing period classes (as limited by moisture and temperature) in each AEZ

AEZ	Pixel Count	0-1	1-30	30-60	60-90	90-120	120-150	150-180	180-210	210-240	240-270	270-300	300-330	330-365
106	3297	0	0	0	36	60	0	4	0	0	0	0	0	0
110	324452	0	0	0	87	8	5	0	0	0	0	0	0	0
120	70547	0	0	0	0	4	71	25	0	0	0	0	0	0
131	2405	0	0	0	0	100	0	0	0	0	0	0	0	0
132	3571	0	0	0	20	80	0	0	0	0	0	0	0	0
133	6447	0	0	0	100	0	0	0	0	0	0	0	0	0
135	1445	0	0	0	4	96	0	0	0	0	0	0	0	0
141	7581	0	0	0	0	59	14	27	0	0	0	0	0	0
142	9510	0	0	0	23	77	0	0	0	0	0	0	0	0
145	966	0	0	0	0	100	0	0	0	0	0	0	0	0
146	4206	0	0	0	0	0	0	100	0	0	0	0	0	0
151	39747	0	0	0	0	27	64	9	0	0	0	0	0	0
152	3141	0	0	0	43	57	0	0	0	0	0	0	0	0
153	6011	0	0	0	100	0	0	0	0	0	0	0	0	0
154	4597	0	0	0	100	0	0	0	0	0	0	0	0	0
155	28949	0	0	0	75	25	0	0	0	0	0	0	0	0
156	19816	0	0	0	0	0	41	59	0	0	0	0	0	0
160	120088	0	0	1	99	0	0	0	0	0	0	0	0	0
162	947	0	0	0	100	0	0	0	0	0	0	0	0	0
206	71164	0	0	0	0	32	35	22	11	0	0	0	0	0
210	356832	0	0	0	1	51	32	8	7	0	0	0	0	0
220	1341571	0	0	0	1	39	37	12	11	0	0	0	0	0
231	1785	0	0	0	0	100	0	0	0	0	0	0	0	0
241	133178	0	0	0	0	18	50	20	13	0	0	0	0	0
246	1251642	0	0	0	0	34	41	16	9	0	0	0	0	0
251	89233	0	0	0	2	55	30	8	5	0	0	0	0	0
253	2236	0	0	0	8	69	23	0	0	0	0	0	0	0
256	226742	0	0	0	0	61	21	14	4	0	0	0	0	0
306	58895	0	0	0	50	50	0	0	0	0	0	0	0	0
310	203255	0	0	0	53	47	0	0	0	0	0	0	0	0
320	752924	0	0	0	50	50	0	0	0	0	0	0	0	0
331	249	0	0	0	67	33	0	0	0	0	0	0	0	0
336	1489	0	0	0	97	3	0	0	0	0	0	0	0	0
341	7027	0	0	0	10	90	0	0	0	0	0	0	0	0
346	187064	0	0	0	11	89	0	0	0	0	0	0	0	0
351	82915	0	0	0	41	59	0	0	0	0	0	0	0	0
352	1056	0	0	0	2	98	0	0	0	0	0	0	0	0
353	1304	0	0	0	98	2	0	0	0	0	0	0	0	0
356	676421	0	0	0	55	45	0	0	0	0	0	0	0	0
406	15739	0	0	8	69	24	0	0	0	0	0	0	0	0
410	654	0	0	30	70	0	0	0	0	0	0	0	0	0
420	4034	0	0	9	66	25	0	0	0	0	0	0	0	0
441	35	0	0	0	0	100	0	0	0	0	0	0	0	0
446	12323	0	0	0	57	43	0	0	0	0	0	0	0	0
451	98	0	0	0	100	0	0	0	0	0	0	0	0	0
456	46104	0	0	14	86	0	0	0	0	0	0	0	0	0

Note:

This table shows for each AEZ the percentage of each specified growing period class (growing period 0-1 day, 1-30 days, 30-60 days, etc.)

Table 18. Percentage occurrence of frost day classes in each AEZ

AEZ	Pixel Count	0-1	1-30	30-60	60-90	90-120	120-150	150-180	180-210	210-240	240-270	270-300	300-330	330-365
106	3297	0	100	0	0	0	0	0	0	0	0	0	0	0
110	324452	11	89	0	0	0	0	0	0	0	0	0	0	0
120	70547	0	100	0	0	0	0	0	0	0	0	0	0	0
131	2405	0	100	0	0	0	0	0	0	0	0	0	0	0
132	3571	4	96	0	0	0	0	0	0	0	0	0	0	0
133	6447	0	100	0	0	0	0	0	0	0	0	0	0	0
135	1445	4	96	0	0	0	0	0	0	0	0	0	0	0
141	7581	0	100	0	0	0	0	0	0	0	0	0	0	0
142	9510	0	100	0	0	0	0	0	0	0	0	0	0	0
145	966	0	100	0	0	0	0	0	0	0	0	0	0	0
146	4206	0	100	0	0	0	0	0	0	0	0	0	0	0
151	39747	0	100	0	0	0	0	0	0	0	0	0	0	0
152	3141	0	100	0	0	0	0	0	0	0	0	0	0	0
153	6011	0	100	0	0	0	0	0	0	0	0	0	0	0
154	4597	0	100	0	0	0	0	0	0	0	0	0	0	0
155	28949	1	99	0	0	0	0	0	0	0	0	0	0	0
156	19816	0	100	0	0	0	0	0	0	0	0	0	0	0
160	120088	0	100	0	0	0	0	0	0	0	0	0	0	0
162	947	0	100	0	0	0	0	0	0	0	0	0	0	0
206	71164	0	14	36	40	11	0	0	0	0	0	0	0	0
210	356832	0	8	11	57	25	0	0	0	0	0	0	0	0
220	1341571	0	11	21	49	19	0	0	0	0	0	0	0	0
231	1785	0	0	0	99	1	0	0	0	0	0	0	0	0
241	133178	0	17	32	46	5	0	0	0	0	0	0	0	0
246	1251642	0	10	35	47	9	0	0	0	0	0	0	0	0
251	89233	0	6	11	53	31	0	0	0	0	0	0	0	0
253	2236	0	0	0	67	33	0	0	0	0	0	0	0	0
256	226742	0	10	15	41	34	0	0	0	0	0	0	0	0
306	58895	0	0	0	0	56	43	2	0	0	0	0	0	0
310	203255	0	0	0	0	84	16	0	0	0	0	0	0	0
320	752924	0	0	0	0	75	25	0	0	0	0	0	0	0
331	249	0	0	0	0	68	32	0	0	0	0	0	0	0
336	1489	0	0	0	0	29	71	0	0	0	0	0	0	0
341	7027	0	0	0	0	96	4	0	0	0	0	0	0	0
346	187064	0	0	0	0	91	8	0	0	0	0	0	0	0
351	82915	0	0	0	0	76	23	0	0	0	0	0	0	0
352	1056	0	0	0	0	90	10	0	0	0	0	0	0	0
353	1304	0	0	0	0	95	5	0	0	0	0	0	0	0
356	676421	0	0	0	0	55	44	1	0	0	0	0	0	0
406	15739	0	0	0	0	23	23	53	1	0	0	0	0	0
410	654	0	0	0	0	0	0	96	4	0	0	0	0	0
420	4034	0	0	0	0	21	8	72	0	0	0	0	0	0
441	35	0	0	0	0	100	0	0	0	0	0	a0	0	0
446	12323	0	0	0	0	39	61	1	0	0	0	0	0	0
451	98	0	0	0	0	0	7	93	0	0	0	0	0	0
456	46104	0	0	0	0	0	37	60	3	0	0	0	0	0

Note:
This table shows for each AEZ the percentage of each specified frost day class (0-1 frost days, 1-30 frost days, 30-60 frost days, etc.)

ANNEX 8. Landform classes

Table 19. Landform categories based on elevation, slope and aspect

Landform Code	Landform category
110	Low elevation (<800 m), flat to almost flat (0-5% slope)
120	Low elevation (<800 m), gently undulating to undulating (5-12% slope)
130	Low elevation (<800 m), rolling to hilly (12-30% slope), undifferentiated aspect
131	Low elevation (<800 m), rolling to hilly (12-30% slope), northern aspect
132	Low elevation (<800 m), rolling to hilly (12-30% slope), southern aspect
140	Low elevation (<800 m), steeply dissected (>30% slope), undifferentiated aspect
141	Low elevation (<800 m), steeply dissected (>30% slope), northern aspect
142	Low elevation (<800 m), steeply dissected (>30% slope), southern aspect
210	Medium elevation (800-1300 m), flat to almost flat (0-5% slope)
220	Medium elevation (800-1300 m), gently undulating to undulating (5-12% slope)
230	Medium elevation (800-1300 m), rolling to hilly (12-30% slope), undifferentiated aspect
231	Medium elevation (800-1300 m), rolling to hilly (12-30% slope), northern aspect
232	Medium elevation (800-1300 m), rolling to hilly (12-30% slope), southern aspect
240	Medium elevation (800-1300 m), steeply dissected (>30% slope), undifferentiated aspect
241	Medium elevation (800-1300 m), steeply dissected (>30% slope), northern aspect
242	Medium elevation (800-1300 m), steeply dissected (>30% slope), southern aspect
310	High elevation (>1300-1800 m), flat to almost flat (0-5% slope)
320	High elevation (>1300-1800 m), gently undulating to undulating (5-12% slope)
330	High elevation (>1300-1800 m), rolling to hilly (12-30% slope), undifferentiated aspect
331	High elevation (>1300-1800 m), rolling to hilly (12-30% slope), northern aspect
332	High elevation (>1300-1800 m), rolling to hilly (12-30% slope), southern aspect
340	High elevation (>1300-1800 m), steeply dissected (>30% slope), undifferentiated aspect
341	High elevation (>1300-1800 m), steeply dissected (>30% slope), northern aspect
342	High elevation (>1300-1800 m), steeply dissected (>30% slope), southern aspect
410	Very high elevation (>1800 m), flat to almost flat
420	Very high elevation (>1800 m), gently undulating to undulating (5-12% slope)
430	Very high elevation (>1800 m), rolling to hilly (12-30% slope), undifferentiated aspect
431	Very high elevation (>1800 m), rolling to hilly (12-30% slope), northern aspect
432	Very high elevation (>1800 m), rolling to hilly (12-30% slope), southern aspect
440	Very high elevation (>1800 m), steeply dissected (>30% slope), undifferentiated aspect
441	Very high elevation (>1800 m), steeply dissected (>30% slope), southern aspect
442	Very high elevation (>1800 m), steeply dissected (>30% slope), southern aspect

ANNEX 9. Calculation procedure for reference (Potential) evapotranspiration

The Penman-Monteith method is the current standard for the calculation of PET according to the formula:

$$PET = W.\,R_n \;+\; (1-W) * f(U) * (es - ea)$$

with W: temperature-related weight factor;
Rn: net radiation in equivalent evaporation (in mm/day)
f(U): wind-related function
(es-ea): difference between saturation vapour pressure at mean air temperature and the mean actual vapour pressure of the air;

The full calculation procedure for the Penman-Monteith formula can be found in Allan et al (1998). PET data calculated according to the Penman-Monteith method (PET_{PM}) were not available for most stations in Iran because not all climatic variables were available. For this reason it was necessary to *estimate* PET from data that are commonly available. Given the database, the most feasible option at the level of Iran was to establish correlations between PET and temperature. This should work quite well, because in dryland region temperature is the main contributing factor to evapotranspiration. In fact, by establishing a direct relationship between PET and the mean temperature, as in the following example involving many stations from around the world (Fig. 83), a high degree of correlation can be established:

$$PET_{PM} = 5.227e^{0.0685Temp} \quad (r^2 = 0.76)$$

However, from initial tests it was established that the highest correlations were consistently obtained from a two-step procedure:

- estimate PET from temperature according to the Hargreaves method (PET_{HG});
- estimate $PET_{Penman\text{-}Monteith}$ from $PET_{Hargreaves}$ through regression (Fig. 84).

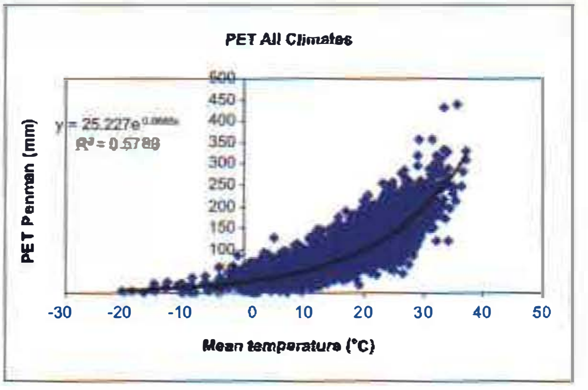


Figure 83. Correlation between PET Penman-Monteith and temperature (all climates combined)

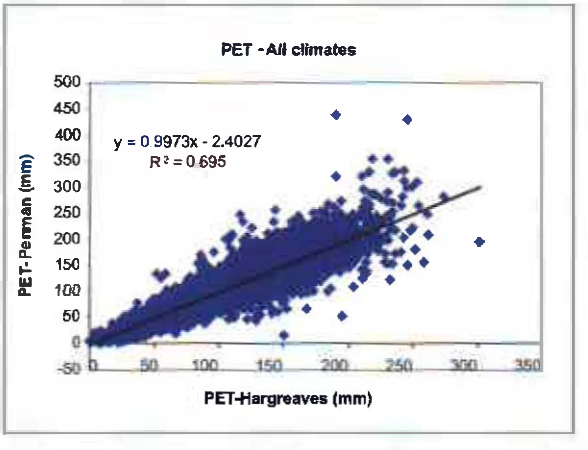


Figure 84. Correlation between PET Penman-Monteith and PET Hargreaves (all climates combined)

In addition, it was found that if stations are disaggregated according to climatic zones, the two-step approach generally leads to better correlations, and therefore, better estimates of PET_{PM}. This is probably due to the following reasons:

- The intermediate calculation of PET_{HG} allows to incorporate the effect of day length, the degree of continentality, and indirectly, radiation on PET.
- The disaggregation according to climatic zones allows to recognize some more subtle linkages, e.g., between temperature and time at which rainfall occurs (winter or summer), or temperature and relative humidity (which will be different between temperate and arid/semi-arid climates).

The Köppen system of climate classification was found to be particularly suitable for disaggregating the correlations between PET_{PM} and PET_{HG} because it is a system with global applicability and requires only temperature and precipitation data.

Method for disaggregated regressions

From the FAOCLIM 2.0 global climate database monthly PET, calculated by the Penman-Monteith method (FAO, 2002), for 4253 stations from countries with dryland areas were extracted. For each of these stations the Köppen agroclimatic zone was calculated in accordance with the criteria in Debaveye (1985). At the same time the PET was calculated according to the Hargreaves method. This method is based on the combination of temperature data and calculated extraterrestrial radiation and has the following formula (Choisnel, 1992):

$$PET = .0023 * Ra * (T_{mean} + 17.8) * (T_{max} - T_{min})$$

with: Ra: extraterrestrial radiation ($mm.day^{-1}$)

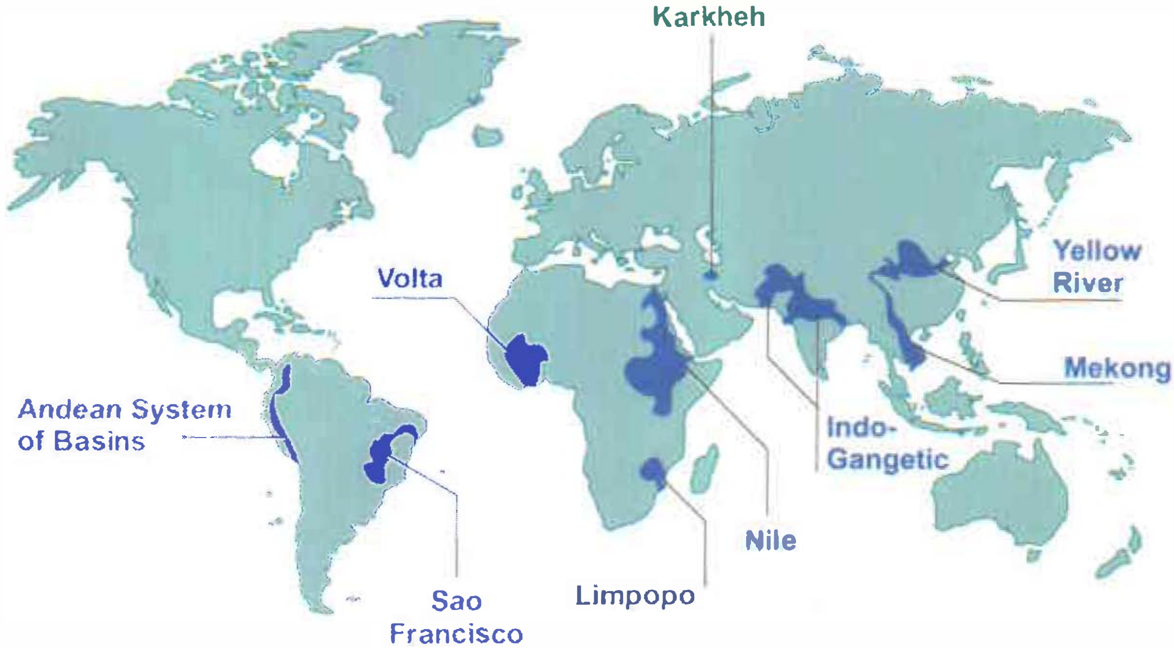
Correlations were then established between PET-Penman/Monteith (PET_{PM}) and PET-Hargreaves (PET_{HG}) for each major Köppen climatic zone. For dryland and temperate climates with summer drought, good approximations of PET_{PM} are achieved (Table 17).

Table 20. Statistical relationships for dryland climates between PET-Penman/Monteith and PET-Hargreaves differentiated by Köppen climatic zones

Climatic zone		Equations	R^2
BSs	semi-arid (steppe) climate with summer drought	$PET_{PM} = 1.0653\ PET_{HG} - 4.0674$	.793
BWs	arid (desert) climate with summer drought	$PET_{PM} = 1.1823\ PET_{HG} - 7.5911$	.818
Csa	warm temperate rainy climate with summer drought and hot summers	$PET_{PM} = 1.0704\ PET_{HG} - 9.504$	.876
Csb	warm temperate rainy climate with summer drought and warm summers	$PET_{PM} = 0.9165\ PET_{HG} - 7.2432$	.860
Cfa	warm temperate rainy climate without dry season and hot summers	$PET_{PM} = 0.9429\ PET_{HG} - 5.719$	.805
Cfb	warm temperate rainy climate without dry season and warm summers	$PET_{PM} = 0.8469\ PET_{HG} + 1.3915$	.775
Cfc	warm temperate rainy climate without dry season and cool summers	$PET_{PM} = 0.7257\ PET_{HG} + 5.6185$	.802
Ds	Subarctic climate with warm summer	$PET_{PM} = 0.9773\ PET_{HG} - 6.3775$	.931
Dw	subarctic climate with cold, dry winter	$PET_{PM} = 0.8307\ PET_{HG} + 4.6389$	.855

CGIAR Challenge Program on
WATER & FOOD

Benchmark river basins



The CP Water & Food is a research, extension and capacity building program aims at increasing the productivity of water used for agriculture. The CP Water & Food is managed by an 18-member consortium, composed of five CGIAR/Future Harvest Centres, six National Agricultural Research and Extension Systems (NARES) institutions, four Advanced Research Institutes (ARIs) and three international NGOs. The project is implemented at nine river basins (shown above) across the developing world. The Karkheh River Basin (KRB) in western Iran is one of the selected basins. The programs' interlocking goals are to allow more food to be produced with the same amount of water that is used in agriculture today, as populations expand over the coming twenty years. And, do this in a way that decreases malnourishment and rural poverty, improves peoples' health and maintains environmental sustainability.

Improving On-farm Agricultural Water Productivity in the Karkheh River Basin Project (CPWF PN 8)
Strengthening Livelihood Resilience in Upper Catchments of Dry Areas by Integrated NRM (CPWF PN 24)

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