Agroecological Characterization Studies in the Aras and the Daryacheh-Uromieh basins, NW Iran

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2007

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ABSTRACT

Land suitability studies are essential in the rainfed drylands of Iran in the light of the great diversity in agroecological conditions, which can be suitable for some crops, but marginal or unsuitable for others. This study aims to introduce in Iran GIS-based methods, developed at the International Center for Agricultural Research in the Dry Areas (ICARDA), for agroecological characterization and land evaluation. For this purpose a relatively small pilot area was selected, consisting of 4 sub-basins located in the Aras and the Daryacheh-Uromieh basins of Eastern Azerbajan Province, North West Iran, covering about 32,000 km^2. This area has been selected for (i) its convenient location in the near neighbourhood of the DARI Headquarters in Maraghe, facilitating field work, ground truthing and institutional support, and (ii) its tremendous ecological diversity, making it representative for large areas in Iran, and allowing widespread application of the methods detailed in this report.

The study has two major components, an agroecological characterization of the pilot area, followed by a classification of suitability for eight crops (barley, wheat, lentil, chickpea, olive, potato, sugarbeet, and safflower). All results are provided in the form of maps (a total of 108) with table and text summaries. The methods used are fully described in the main text, with annexes where more detailed explanations are necessary, to allow their replication in other parts of the country.

The characterization part of this report includes descriptions of the characteristics and mapping of the patterns of precipitation, temperature, frost, potential evapotranspiration, aridity, climatic productivity indicators, growing periods, land use/land cover, landforms, soils and agroecological zones. A special section is dedicated to the use of a method of climatic similarity analyses to detect the degree of similarity between a selected location and each part of the study area. This kind of mapping is particularly useful to identify in which areas technologies developed at research stations are most likely to succeed as a result of ecological similarity with these stations.

In the land evaluation part of the report the results of the suitability assessment for the selected crops are mainly presented in the form of maps that indicate suitability of the individual factors, moisture and temperature regime, climate, topography and the suitability from the integration of all factors in the form of percentages of the suitability classes ‘highly suitable’, ‘moderately suitable’, ‘marginally suitable’ and ‘non-suitable’.

Few datasets were used in this study, yet they are the basis for the large range of maps that have been generated. The basic data, from which all other datasets are derived, are climatic data (precipitation and temperature), a land use/land cover map, a digital elevation model and a soil map. It can therefore be concluded that with a relatively limited and widely available dataset a good knowledge can be obtained of the agroecology and crop suitabilities in different parts of Iran. One severe limitation, which has restricted the optimal use of the land suitability methods, is the lack of sufficiently detailed soil information. New approaches, making optimal use of already existing primary and secondary information, are necessary to improve the results by making them more soil-specific.

1. INTRODUCTION

The dryland areas of Iran, for which the *Drylands Agricultural Research Institute (DARI)* has a mandate, are characterized by considerable weather variability, as well as major abiotic stresses, in particular drought and cold. They are also very diverse in landscapes and soil patterns. The combination of these interacting factors leads to different agroecological conditions, which can be suitable for some crops, but marginal or unsuitable for others. The intensification of crop production in these areas needs to take into consideration the agroecological diversity, and adapt cropping and land use patterns to the opportunities and constraints of each agroecological niche.

Land suitability studies make it possible to match particular land uses to well-defined parts of landscapes. The principle of the approach is to find optimal combinations between land characteristics and requirements of different land uses. Land suitability studies aim to answer questions, such as “how suitable is this area for a specific crop?”. Since they already have built in the principle of sustainable use, such studies are important tools for land use planning. They may, on the one hand, promote complementary land use, and on the other hand, help to avoid inappropriate land use, leading to degradation of land and water resources, poverty and social instability.

This report provides an account of the agroecological characterization and land suitability studies that have been undertaken in the Aras and the Daryacheh-Uromieh basins of Eastern Azerbajan Province, North West Iran. This area has been selected for several reasons:

- It is conveniently located in the near neighbourhood of the DARI Headquarters in Maraghe, facilitating field work, ground truthing and institutional support
- It is a useful ‘pilot area’ in the sense that the tremendous ecological diversity it entails makes it representative for large areas in Iran and allows widespread application of the methods detailed in this report.

The structure of the report is simple. After this introduction, there is a short chapter with a general description of the study area. Chapter 3 explains the methods used in this study. In order not to overburden this chapter, more methodological details are provided in Annexes 2-5. Chapter 4 presents an overview of the results, with the maps in Annex 1. Chapter 5 outlines further studies that could be undertaken as a follow-up to this first (biophysical) assessment of the agricultural environments of the study area.

As the wide range of maps produced testifies, perhaps the main value of this report is in its ‘pilot’ function of documenting a set of GIS-based methods that can be used in other parts of Iran to generate within a fairly short period of time a useful agroecological characterization and crop suitability maps on the basis of a limited dataset on climate, land use, topography and soils.

The study is the outcome of a fruitful collaboration between DARI and the GIS Unit at ICARDA. The institutional framework for this collaboration is the ongoing Iran-ICARDA collaborative program.

2. THE STUDY AREA

The study area is located in Eastern Azerbajan Province in the northwest corner of Iran, between 37º 23' and 39º 44' northern latitude and 45º 65' to 48 º 37' eastern longitudes. The study area has been delimited on the basis of hydrological basins and sub-basins. It includes 2 sub-basins of the Aras Basin and 2 sub-basins of Daryache-Uromieh Basin (Fig.1) . The sub-basins in Aras are 214 (area: 13,877 km^2) and 215 (area: 4,024 km^2). In the Daryache-Uromieh Basin the pilot area includes sub-basins 223 (area: 12,265 km^2) and 225 (area: 1,899 km^2). The total area covered by the pilot area is 32,055 km^2.

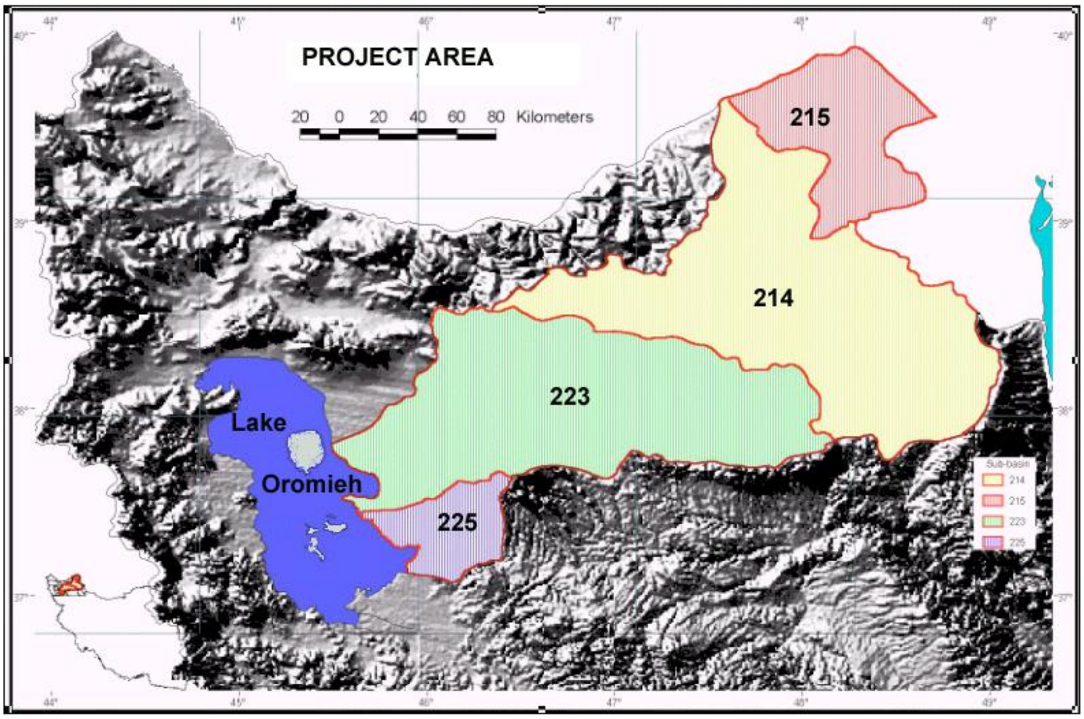

Figure 1. Location of the study area and four sub-basins in NW Iran

The study area borders Azerbajan and Armenia in the north and Lake Oromieh in the west, and is in the east in the vicinity of the Caspian Sea. Tabriz, Ardebil, Maragheh, Parsabad, Sarab, Azar Shahr, Bostan Abad, Bonab, Germi and Bileh Savar are the urban areas.

Within the pilot area the elevation varies tremendously, from a minimum of 30 meter in Bileh Savar to 4811 meter at the top of Sabalan mountain. Hence it is not surprising that the area contains a very diverse range of climatic conditions, soil types, landforms and land use/land cover patterns. This makes the study area very representative of the diversity of physical environments that can be expected in the rainfed areas of Iran and is one of the reasons why it has been selected as a ‘pilot area’.

Figure 2 shows the structure of the landscape as an alternation of plains, hills and mountains. The plains are the main areas where agriculture is practiced, a significant part of it irrigated. Vast rangeland areas do occur in the hills and mountain ranges that alternate with the plain landscapes. Particularly two very high volcanic domes, Sahand in the west and Sabalan in the east, form the backbone of the landscapes in the pilot area.

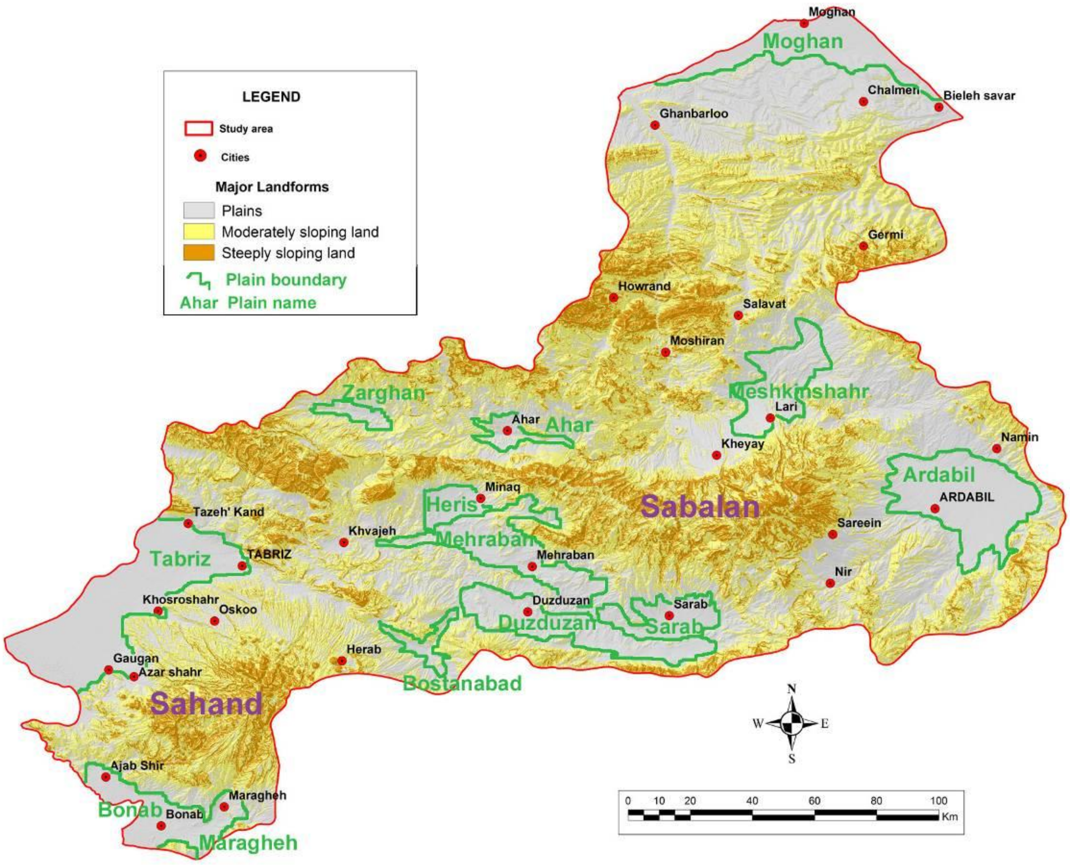

Figure 2. Landscape structure of the pilot area (in green the major agricultural plains).

Crop production and animal husbandry are both very important in the study area. Cereals, food legumes, potato, sugar beet, oilseed crops, cotton, forage crops, vegetables, fruits, particular apple and grapes, are cultivated in this area. As for sugar beet it is the only area to produce seeds for cold areas of the country. Huge and good quality pastures allow farmers to integrate crop production with animal husbandry. One of the biggest and important agri-industrial units located in the north part with highly developed agriculture.

3. METHODOLOGIES

3.1. Data used

Few datasets were used in this study, yet they are the basis for the large range of maps generated by this study. The basic data, from which all other datasets are derived, are climatic data (precipitation and temperature), a land use/land cover map, a digital elevation model and a soil map.

A database was established of point climatic data covering monthly averages of precipitation and temperature for the main stations in Iran, covering the period 1973-1998 (Appendix 1, Tables 2-3). These quality-controlled data were obtained from the Organization of Meteorology, based in Tehran. From Iran 126 stations were accepted with a precipitation record length of at least 20 years, and 590 stations with a temperature record length of at least 5 years. The database also included some precipitation and temperature data from neighboring countries, obtained from the FAOCLIM2 database (FAO, 2001), leading to a total database of 244 precipitation stations and 627 temperature stations. From this database, covering all of Iran, the climatic conditions in the study area were derived.

Land use/land cover information was obtained from the Iran Land Use/Land Cover vector map, prepared by the Agricultural Planning and Economic Research Institute (APERI) in Tehran, clipped to the study area. Boundary adjustment of this map was made by visual interpretation of Landsat-7 satellite imagery in digital form, obtained from the Iranian Remote Sensing Center. These virtually cloud-free images of 1998 were converted into a radiometrically corrected mosaic, and represent late spring/ early summer conditions at the end of a good growing season.

A representation of the topography in the study area was obtained by the use of digital elevation models (DEM). In the very beginning of the project, topographical maps at scale 1:250,000, with 50 m contour interval in the plains and 100 m interval elsewhere, were compiled for the study area and the contours were digitized. From this a digital elevation model (DEM) was developed for the study area using the TIN function in the 3-D Analyst extension of ArcView. However, when the SRTM[1] DEM was released, with 3 arc-seconds (90 m) horizontal and 30 m vertical resolution, the topographic information extracted from this global dataset, was used instead.

Soil information for the study area was extracted from the Soil Map of Iran at scale 1:1,000,000. This map was available in digital form with map units in the form of soil associations, using the Soil Taxonomy classification system, and with associated attribute tables. It is based on the interpretation of a 10x10 km grid of soil profiles, which have been described and sampled for chemical and physical analysis.

3.2. Spatialization and transformation of climatic data

3.2.1. Basic climate surfaces

The ‘thin-plate smoothing spline’ method of Hutchinson (1995), as implemented in the ANUSPLIN software (Hutchinson, 2000), was used to convert the station-based climatic database into ‘climate surfaces’. These are raster-based files that are geographically referenced, contain continuous climatic values, and can be imported into a GIS system. The Hutchinson method is a smoothing interpolation technique in which the degree of smoothness of the fitted function is determined automatically from the data by minimizing a

[1] Shuttle Rader Topographic Mission: http://www.dgadv.com/srtm30/

measure of the predictive error of the fitted surface, as given by the generalized cross-validation (GCV).

Three independent spline variables were used, *latitude*, *longitude* and *altitude*. The latter was input to the model in the form of a DEM ASCII grid file. The DEM used to generate the climate surfaces was the SRTM DEM with 3 arc-second (approximately 90 m) resolution. Parameter estimation was undertaken over a regular grid with the same dimensions and resolution as the user-provided DEM. In order to automate the process of climate surface generation, which is rather cumbersome, an auxiliary software product CLIMAP was used (Pertziger and De Pauw, 2002). This Excel-based software provides a user-friendly interface for running ANUSPLIN and for generating derived surfaces using CLIMAP-provided models.

Using above procedure, surfaces of mean monthly precipitation, minimum, maximum and mean temperature were generated with 3 arc-second resolution.

3.2.2. Derived climate surfaces

By applying various transformations on the basic climate surfaces, involving different formulas or iterative calculation procedures, new GIS layers were generated for a more focused agroclimatic characterization of the study area. Depending on the specific climatic theme, the operations used to generate new layers were either elementary raster calculations on the existing basic climatic layers, or calculations involving a pre-programmed model. The list of derived climate surfaces generated for the more in-depth agroclimatic characterization of the study area is given below:

- Ratio of Autumn (September-November) to Annual Precipitation
- Ratio of Winter (December to February) to Annual Precipitation
- Ratio of Spring (March to May) to Annual Precipitation
- Ratio of Summer (June to August) to Annual Precipitation
- Mean temperature of the coldest month
- Mean temperature of the warmest month
- Minimum temperature of the coldest month
- Maximum temperature of the warmest month
- Annual growing degree days (above 0°C)
- Annual chilling degree days (below 0°C)
- Annual number of frost days
- Average onset month of frost
- Average end month of frost
- Annual potential evapotranspiration
- Aridity index
- Agroclimatic zones
- Length of the moisture-limited growing period
- Length of the temperature-limited growing period
- Length of the moisture- and temperature-limited growing period under rainfed conditions
- Length of the moisture- and temperature-limited growing period under rainfed and irrigated conditions
- Onset of the moisture-limited growing period
- Onset of the temperature-limited growing period
- Onset of the moisture- and temperature-limited growing period (January-June)
- Onset of the moisture- and temperature-limited growing period (July-December)
- End of the moisture-limited growing period

- End of the temperature-limited growing period
- End of the moisture- and temperature-limited growing period (January-July)
- End of the moisture- and temperature-limited growing period (August-December)
- Climatic biomass productivity index for crop group I (C3 plants) under rainfed conditions
- Climatic biomass productivity index for crop group I (C3 plants) under rainfed and irrigated conditions
- Climatic biomass productivity index for crop group II (C3 plants , warm environment) under rainfed conditions
- Climatic biomass productivity index for crop group II (C3 plants , warm environment) under rainfed and irrigated conditions
- Climatic biomass productivity index for crop group III (C4 plants) under rainfed conditions
- Climatic biomass productivity index for crop group III (C4 plants) under rainfed and irrigated conditions
- Climatic biomass productivity index for crop group IV (C4 plants, cool environment) under rainfed conditions
- Climatic biomass productivity index for crop group IV (C4 plants, cool environment) under rainfed and irrigated conditions

The details for the specific transformations undertaken on the basic climate surfaces in order to obtain each of the above climatic themes are explained in Annex 2. The vast majority of these transformation methods have been published elsewhere, notably in De Pauw (2002), De Pauw et al. (2004a), and De Pauw et al. (2004b), and were implemented with ICARDA's CLIMAP software.

3.3. Climatic similarity mapping

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 three locations, representing different climatic conditions, have been used for comparison with climatic conditions in different parts of the study area. The match locations were Ardabil, Maraghe and Moghan.

Similarity was expressed in a *relative* way, meaning that the degree of similarity refers to the relative diversity within the study area. This approach only looks at the range of climatic conditions observed within this area, not outside, by ranking the distances between the different target locations and the match location. This approach effectively results in a form of contrast enhancement of similarity, since the 0-1 scale is maintained, and is useful when one is only interested in the range of variation within the study area, and does not want to compare with external environments.
For the calculation details of relative similarity mapping is referred to Annex 2.8.

3.4. Agroecological zoning

The Agroecological Zones map for the study area was made by overlaying the single raster themes related to climate, terrain, soils and land use. 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.
In detail the agroecological zones were generated by the following 5-step procedure:

- Generating raster surfaces of basic climatic variables through spatial interpolation from station data;
- Generating a layer of agroclimatic zones (ACZ);
- Simplifying the relevant biophysical themes (agroclimatic zones, land use/land cover and landform/soils);
- 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;

The first two steps have been described in sections 3.2.1, 3.2.2 and Annex 2.5. For more details on the thematic simplification and 'cleaning up' procedures is referred to Annex 4.

3.5. Land suitability mapping

Land suitability was mapped in accordance with the FAO Framework for Land Evaluation (FAO, 1976) using the following 5-step method:

- Step 1: Definition of homogeneous land units
- Step 2: Definition of relevant land utilization types (LUT)
- Step 3: establishing the ecological requirements of the defined land utilization types
- Step 4: identifying land limitations
- Step 5: Land suitability classification

3.5.1. Definition of homogeneous land units

In this study the evaluation was undertaken at the level of individual grid cells, hence a 'homogeneous' land unit was defined by the particular climatic, topographic, and soil characteristics used to match the properties of land to the crop requirements

3.5.2. Definition of relevant land utilization types

The evaluation refers to land utilization types which are single crops, common in the study area: barley, wheat, lentil, chickpea, olive, potato, sugarbeet, safflower.
The evaluation does not consider interactions between these crops, as they might occur through common dryland practices, such as fallowing, rotations, etc. If certain crops are normally grown under irrigated conditions, the evaluation extends only to the areas where irrigation water is effectively available.

3.5.3. Establishing the edaphic requirements of the defined land utilization types

From the literature information was collected about the ecological requirements of the crops selected as LUTs. The main sources were Sys et al. (1993), ECOCROP (FAO, 2007), Edwards et al. (1983), Ghaffari (2000) and several Internet sites.

The crop requirements were expressed by means of a set of critical threshold values, which determine the limits between the land suitability classes. None or slight limitations define the S1 level (very suitable), moderate limitations the S2 level (moderately suitable), and severe limitations the S3 level (marginally suitable to unsuitable). Very severe limitations result in a non-suitable (N) class.

The values for these class-defining thresholds were based on expert knowledge and their determination has been the most difficult part of this study. As the sources usually did not agree too well and rarely revealed their own sources, it was necessary to come to a 'best-bet' estimate for the thresholds. Annex 5 provides tables with these 'best-bet' ecological requirements for the selected crops.

3.5.4. Identifying land limitations and rating their severity

Once crop requirements are agreed upon, it is possible to match them with the actual values of the rated characteristics for each grid cell. The easiest way to do this matching is by converting the values of the rated characteristics into *limitation ratings*, using the threshold values of step 3 and Annex 5. For the climate surfaces and the slope layers this was done through a raster operation in GIS using Quickbasic programs that generate the limitation ratings as an intermediate step towards the final land suitability classes.

For the soils, the resolution of the map and the available information implied in the Soil Taxonomic units did not allow a detailed assessment of the management properties of relevance to the crops being assessed. Only soil depth, stoniness, texture, and salinity could be inferred from the soil classification units with sufficient confidence and converted into four limitation rating layers. Important soil characteristics, e.g. those related to their fertility status, were not rated because soil fertility in dry areas usually is a management issue, not a physical constraint, can not be rated consistently from the soil taxonomic label, and can rarely be spatially represented.

Since the available soil map for the study area is a soil association map, it is not possible to produce a single layer of soil suitability, unless the assessment is done only for the most important soil. However, there are cases that the most common soil occupies less than 50% of the association, and this approach would not provide information for numerous other soils, which in aggregate or in agricultural potential, could be quite important. For this reason it is preferred to generate four soil-related layers, each representing the proportion of a grid cell occupied by each suitability class.

The following seven layers with limitation ratings were produced as intermediate results:

- Suitability of the thermal regime
- Suitability of the moisture regime
- Suitability of the topography
- Proportion of the land with either soil suitability class S1, S2, S3 or N.
  For olive, an additional limitation ratings layer, 'suitability of the cold period' was added.

3.5.5. Land suitability classification

This final step involves the combination of the limitation rating layers of climate with those of topography and soils. The integration is done by the method of the Most Limiting Factor (MLF). This means that, for example, a severe limitation in the moisture regime cannot be compensated by e.g. an excellent soil. The final rating will be determined by the factor that is most limiting, in this case precipitation. Compensation of deficient precipitation is only possible in the case of irrigation. This case is considered in the modeling by incorporating a layer of the irrigated areas.

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The land suitability classification model can then be represented by the following equation:

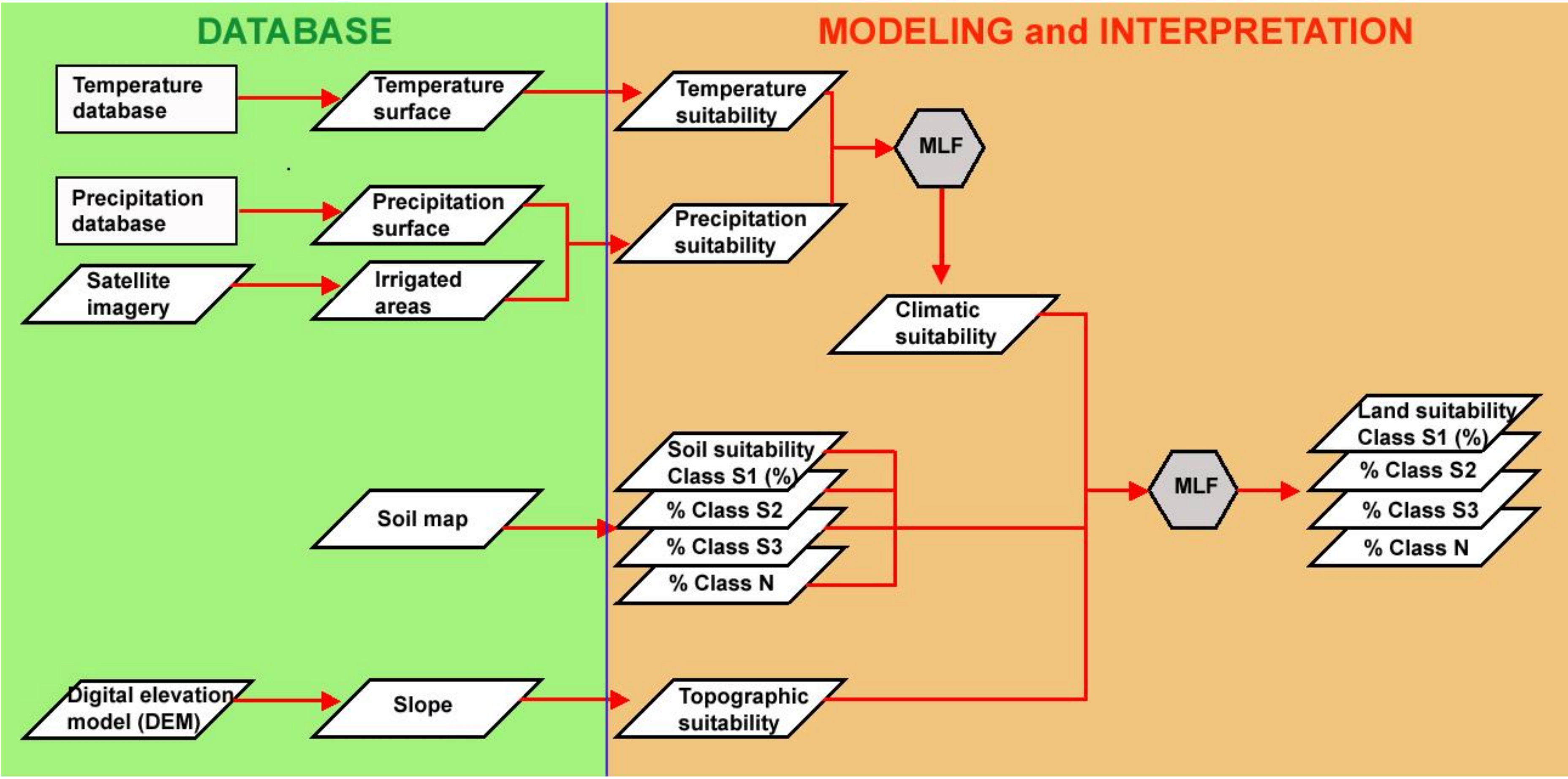

Figure 3. Flowchart of the land suitability classification model

Note: MLF: most limiting factor method

$$Suit_i = Max\ (Suit_{Temp}, Suit_{Prec}, Suit_{Soil,i}, Suit_{Topo})$$

and for olive :

$$Suit_i = Max\ (Suit_{Temp}, Suit_{cold}, Suit_{Prec}, Suit_{Soil,i}, Suit_{Topo})$$

in which $Suit_i$ = combined suitability by integration of climatic, soil and topographic factors, Max= highest limitation rating, $Suit_{Temp}$ = suitability of the thermal regime, $Suit_{cold}$ = suitability of the cold period, $Suit_{Prec}$= suitability of the moisture regime, $Suit_{Soil,i}$ = proportion of each grid cell with soil suitability class S_i, $Suit_{Topo}$ = suitability of the topography.

Figure 3 illustrates the empirical decision model implemented through land limitation ratings.

3.5.6. Special procedures

In order to improve the precision of the suitability assessment, it was found useful to modify the general methodology by the following steps:

- Use of growing degree days instead of temperature data, for some crops
- Use of the land use map to improve the soil map accuracy
- Use of the aspect to adjust the temperature grid

For some crops (e.g. wheat, barley, maize, other cereals) the temperature requirements are often expressed more precisely in terms of growing degree days (above a threshold temperature relevant to the crop), rather than in average temperature for the year, the growing season or specific months. The specific growing degree thresholds used to define different suitability classes for the crops of interest (all except olive) are provided in Annex 5.

Aspect (exposure to slopes with different directions) is a factor that affects temperature in sloping land. South-facing slopes are usually warmer and drier than north-facing slopes. The difference in temperature can be as much as 2-3°C. If working with growing degree days (e.g. above 0°C), the effect will only be noticeable above a minimum threshold temperature (e.g. -0.5°). In view of the importance of aspect on the thermal regime of sloping lands, it was decided to make an adjustment of the pixel temperature values, derived from the temperature surfaces, in accordance with decision rules in Annex 5.1.

A review of the soil map indicated that in many areas they were significant discrepancies with the land use/land cover map, leading to major inconsistencies in the suitability ratings. For example, if on the one hand the soil map indicates for a specific area, shallow or stony soils, and the satellite imagery shows, on the other hand, that the same area is under irrigated crops, this is a major inconsistency. For this reason it was decided to adjust the percentages of the soil suitability classes 'non-suitable' and 'marginally suitable' for the irrigated and rainfed areas in accordance with the decision rules of Table 27 in Annex 5.2.

4. RESULTS

4.1. Precipitation

4.1.1. Annual precipitation

Across the study area, annual precipitation is generally low, with 400 mm or less in more than 75% of the area, and less than 500 mm in 98% of the area. Only on highest mountain peaks more, during most of the year in the form of snow

Map 1 shows the spatial distribution of the mean annual precipitation. The distribution follows essentially an orographic pattern, with the lowest precipitation in the basins, and precipitation increasing towards the mountain tops, which act as water traps. The lowest precipitation (200-300 mm) is in the plains of Moghan, Tabriz, Bonab, Meshkinshahr, Mehraban and Sarab. Higher precipitation (300-400 mm) occurs in the other plains.

4.1.2. Distribution throughout the year

Maps 2-5 show the percentage of the mean annual precipitation in the autumn (September-November), the winter (December to February), the spring (March to May) and the summer months (June to August).

Autumn precipitation (Map 2) is common in most of the pilot area: in 82% of the area it contributes 20-30% of the annual precipitation, and in another 13% it contributes 30-40%. This area with the highest contribution of autumn precipitation to the annual total is located in the eastern part of the pilot area, bordering the Caspian see basin.

In about 90% of the pilot area winter precipitation contributes 20-30% to the annual total (Map 3)

The study area is mainly a spring precipitation area (Map 4): in 60% of the area the spring contributes 40-50% to the annual precipitation total. In the east this is slightly less with a 30-40% contribution in the remaining 40% of the pilot area.

The pilot area also shows a clear Mediterranean influence with little summer precipitation (Map 5). Nevertheless its transition to the more continental climates of Central Asia and Russia, with spring-summer precipitation patterns, is expressed by a not inconsiderable contribution of 10-20% in >80% of the pilot area.

4.2. Temperature

As a result of the major elevation differences in the pilot area, there is a very large variation in temperature.

The mean temperature of the coldest month (Map 6), with minima of -18 to -15 °C on the highest mountain tops to 3-6 °C in the Moghan plain, shows that within the pilot area the climate in winter can be very diverse, from extremely cold to relatively mild winters.

The mean temperature of the warmest month (Map 7) follows a similar but opposite pattern along the elevation contours, with minima of 9-15 °C on the Sahand and Sabalan higher elevations up to 24-27 °C in the Tabriz and Moghan plains.

Maximum and minimum temperatures obviously show more extremes and a higher range, with a range of -18 to -15 °C for the minimum temperature of the coldest month on Sahand and Sabalan (Map 8), and a range of 30-33 °C for the maximum temperature of the warmest month in the Moghan and Bonab plains (Map 9).

4.2.1. Annual growing degree days

Temperature patterns can also be represented as the distribution of available atmospheric energy, which can be used, for example, to evaporate water or make plants grow faster. This

representation of temperature as a source of energy for plant growth and biomass productioncan be done through the concept of *growing degree days* (GDD, also accumulated heat units), which sum the daily temperatures above a threshold (e.g., 0 °C) for a specified period (e.g., one year). Map 10 of annual growing degree days shows, unsurprisingly, the same pattern as the maps of mean temperature, only the units (°C days) are different.
The plains of Moghan, Meshkinshahr and Tabriz have the highest levels of thermal energy, in the range 4000-5500 GDD, which covers about 32% of the pilot area. Twenty percent of the pilot area has less than 3000 GDD, which may limit the thermal growing season.

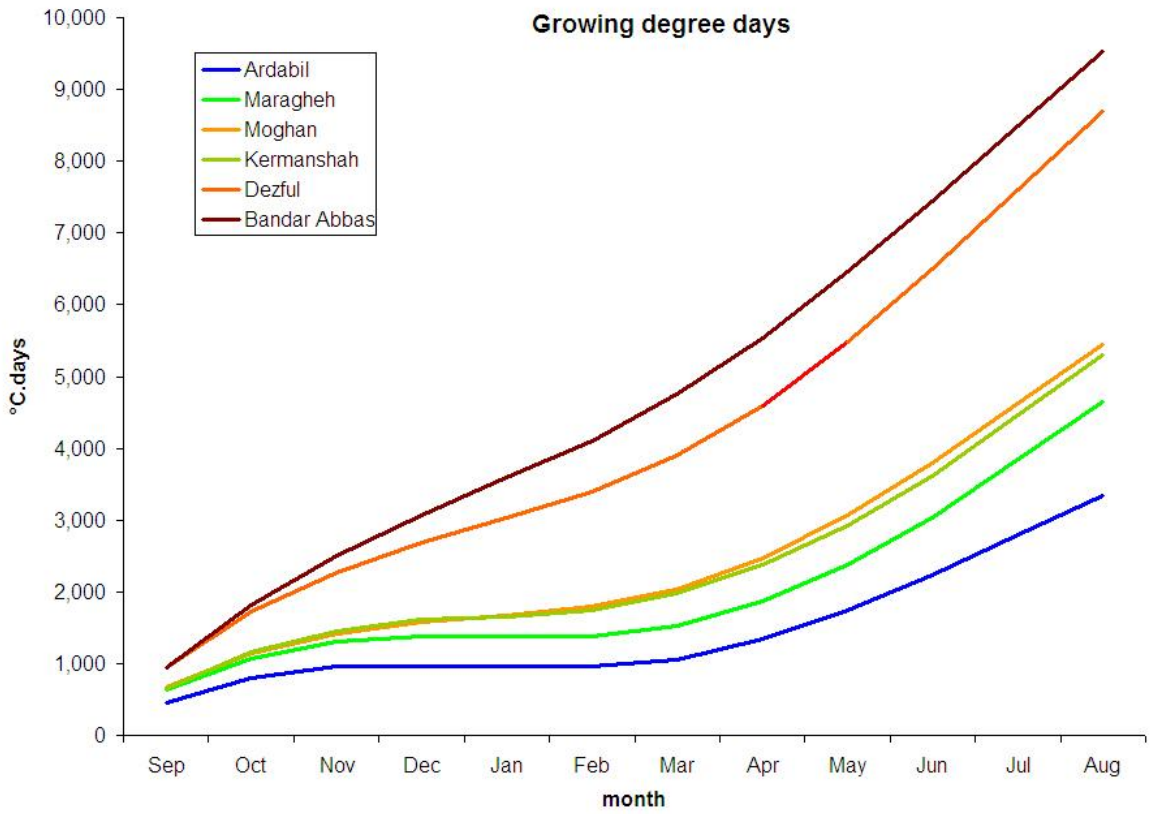

Figure 4. Comparison of the accumulated monthly growing degree days for stations inside and outside the pilot area

In comparison to other parts of Iran, particularly those located in the middle and south of the country, the GDD levels within the pilot area are relatively low. This is demonstrated by Figure 4, which compares GDD for Ardabil, Maragheh and Moghan against Kermanshah, Dezful and Bandar Abbas. The warmest part of the pilot area, the Moghan plain, is comparable to the coolest of the three other stations (Kermanshah), whereas the warmest of these three (Bandar-Abbas) has more than 2.5 times the GDD of the average for the pilot area (3647 GDD).

4.2.2. Annual chilling degree days

Some crops require a cold period for optimal growth and yield formation. The intensity of the required cold period can be expressed through the concept of 'chilling requirement' and quantified by the *chilling degree days* (CDD, also *accumulated cold units*), a summation on annual basis of the daily temperatures below the same threshold as GDD, in this case 0°C, and the same units (°C days). Map 11 shows that in about 60% of the pilot area at least 100 CDD can be expected.

4.3. Frost

From the temperature data it can already be inferred that frost must be a dominant characteristic in much of the pilot area. The three maps and summary statistics related to frost provide evidence that this is indeed the case.

The map of frost duration (Map 12) shows that the entire pilot area is subject to frost, with a minimum of 30-60 days in the Moghan plain, up to 210-240 days on the high levels of the Sabalan mountain, where the peak is never frost-free. A full 75% of the pilot area can expect between 90 and 180 frost days per year.

Elevation is the main determining factor for both onset and end of frost. With the exception of the Sabalan peak, which is never frost-free, the earliest onset (August) and the latest end month of frost (July) are on the top of the Sahand and the Caspian Sea mountains, and the higher elevations of the Sabalan. At lower elevations, the frost starts later and ends earlier, with the latest frost onsets in November in the Moghan, Tabriz, Bonab, Maragheh and Meshkinshahr plains (Map 13), and the earliest frost ends in April in the Moghan, Tabriz and Bonab plains (Map 14).

In more than half of the pilot area frost starts in October, whereas November is the second most important month for the onset of frost. In more than 90% of the pilot area frost starts in either October or November. In more than half of the pilot area frost ends in May, and in about 95% of the area frost ends between April and June.

4.4. Potential evapotranspiration

As mentioned earlier, the potential evapotranspiration (PET) offers a measure of the consumptive water use of the atmosphere, as related to a reference crop. As PET is primarily determined by temperature, it is not surprising that, similar with the GDD (Map 10), the levels of PET are generally low in the pilot area.

The average annual PET for the pilot area is about 1000 mm, whereas for 90% of the pilot area the annual PET is in the range 800-1200 mm (Map 15). The highest values (1100-1300 mm) are in the Moghan, Tabriz, Bonab and the lowest parts of the Meshkinshahr plains, whereas low values (600 to 900 mm) prevail on the mountain slopes of Sahand and Sabalan.

4.5. Aridity index

The vast majority (87%) of the pilot area is semi-arid (Map 16). There is a small pocket of aridity in the valley that runs in north-south direction through Moshiran. Towards the higher elevations the climate becomes sub-humid or even humid (12% of the pilot area).

4.6. Agroclimatic zones

The map of agroclimatic zones (Map 17) confirms the essential features of the pilot area: semi-arid and relatively cold conditions.

Nearly 70% of the pilot area has a semi-arid climate with cold winter, either with warm summer (SA-K-W climate, 38%) or with mild summer (SA-K-M, 31%). A significant part of the pilot area is still semi-arid, but with mild winter (SA-C-M, 18%), whereas about 11% is more humid but with cold winters and mild summers (SH-K-M).

4.7. Growing period characteristics

The growing period is a climatic concept, which gives an indication of the time during the year in which neither moisture nor temperature are limiting crops. Hence, there are two aspects to the growing period that need to be considered and modeled through appropriate indices. The calculation procedures for both moisture-limited and temperature-limited growing period are explained in Annex 2.6.

4.7.1. Duration of the growing periods

In the study area both moisture regime and temperature are limiting factors to plant growth and crop production. Both the moisture-limited (Map 18) as the temperature-limited growing period (Map 19) follow an orographic pattern, in line with the considerable elevation differences within the study area. Nearly 70% of the area has a moisture-limited growing period of 150-240 days, 20% has a higher growing period. Also the temperature-limited growing period is reasonably high, with 95% of the study area in the range 180-300 days, and 70% in the range 210-270 days.

Whereas each type of growing period is quite long in its own right, the combinations of the two, indicating periods in which neither moisture nor temperature are limiting, are rather short, particularly for the rainfed areas (Map 20). In 95% of the study area the period without moisture or temperature limitations is limited to 30-120 days. The presence of irrigation makes a lot of difference. As Map 21 indicates, for the irrigated areas, which are located in lower-lying plains, the growing periods jump to 210-330 days.

4.7.2. Growing period onsets

The onset of the moisture-limited growing period is fairly uniform throughout the study area, with October the onset month in 82% of the area, for only 18% it is September (Map 22). These areas are located in the east, near the Caspian Sea watershed, and on the upper slopes of the Sabalan mountain.

The pattern of the onset of the temperature-limited growing period is again determined by the elevation differences within the study area (Map 23). The earliest onset month is February in the Moghan plain, followed by March in most (57%) of the study area, and April on the mountain slopes (31%). On the highest elevations of Sahand and Sabalan the growing periods start even later, between May and July, and on the very top of Sabalan there is no growing period at all.

The onset periods of the combined moisture-and temperature-limited growing periods show great variation, as shown in Table 1 and Maps 24 and 25.

Table 1. Onset months of the moisture-and temperature-limited growing period

Onset month	% of study area	Onset month	% of study area
February	4.62	October	41.54
March	27.64	June	0.23
April	15.73	July	0.03
May	1.17	August	0.12
September	8.88	November	0.05

4.7.3. Growing period ends

Whereas the onset of the moisture-limited growing period is rather uniform, the end shows great variation, ranging from March to June in about 94% of the study area, and even later at the highest levels of the mountains (Map 26).

In contrast, the end of the temperature-limited growing period shows little variation (Map 27), with November the end month in 72% of the study area, an earlier end (October) on the higher elevations of the Sahand and Sabalan mountains, and a later end (December) in the Mohan plain.

As for the start, due to the different dates for end of the moisture- and temperature-limited growing periods, there is a great variation in the end of the moisture-and temperature-limited growing periods (see Maps 28 and 29, and Table 2).

Table 2. End months of the moisture-and temperature-limited growing period

Onset month	% of study area	Onset month	% of study area
February	0.04	October	4.92
March	6.30	November	36.20
April	13.43	December	9.52
May	17.91	August	0.19
June	9.71	September	0.07
July	1.98		

It can therefore be concluded that crop calendars will have to be very location-specific in order to make use of the best periods in the year when both moisture and temperature are optimal.

4.8. Biomass productivity indices

It has been demonstrated (e.g. FAO, 1978 and Fischer et al., 2000) that the climatic growing period is a suitable indicator of potential biomass productivity. Biomass productivity indices, based solely on growing period characteristics, can be used as exploratory tools to assess in which parts of the region different crop types have a comparative advantage under either rainfed or irrigated conditions. The potential biomass productivity indices used in this study allow comparison of the relative performance of different crop groups (Table 3) in different parts of the study area.

Table 3. Adaptability ranges of different crop groups

Crop group	Crop types	Optimal temp. range	Examples	Biomass index
I	C3	15-20	Barley, bread wheat, chickpea, lentil, olive, sunflower, cabbage, oats, rye, grape, sugarbeet; temperate grasses; almost all trees	CBPI1
II	C3 adapted for higher temperatures	25-30	Cotton, groundnut, cowpea, soybean, tobacco, sunflower, sesame, rice, fig, grape, olive	CBPI2
III	C4	30-35	Maize, sorghum, sugarcane, all millets, fonio rice; tropical grasses	CBPI3
IV	C4 adapted for lower temperatures	20-30	Maize, sorghum, millets	CBPI4

For the calculation procedure of these climatic biomass indices is referred to Annex 2.

Maps 30-37 show the spatial distribution of the crop biomass productivity indices, for two situations, (i) under purely rainfed conditions, and (ii) considering current land use, under both rainfed and irrigated conditions. The results are summarized in Tables 4 and 5.

Table 4. Percentages of study area within specified CBPI values under rainfed conditions

CBPI Class	% for CBPI1	% for CBPI2	% for CBPI3	% for CBPI4
0 to 100	2.45	26.23	97.53	26.23
100 to 200	7.49	39.32	2.27	39.32
200 to 300	14.84	30.34	0.20	29.62
300 to 400	19.84	3.07		3.35
400 to 500	19.70	0.77		0.87
500 to 600	25.55	0.27		0.50
600 to 700	8.36			0.11
700 to 800	1.13			
800 to 900	0.61			
900 to1000	0.03			

Table 5. Percentages of study area within specified CBPI values under rainfed and irrigated conditions

CBPI Class	% for CBPI1	% for CBPI2	% for CBPI3	% for CBPI4
0 to 100	1.91	22.20	84.74	22.20
100 to 200	6.31	33.64	2.12	33.64
200 to 300	12.75	27.39	0.18	26.73
300 to 400	16.15	2.91	0.02	3.14
400 to 500	17.51	0.67	0.03	0.82
500 to 700	30.80	0.23	0.31	0.51
700 to 1000	1.60	0.01	3.63	0.01
1000 to 1300	0.00	0.06	1.15	0.03
1300 to 1600	0.00	0.30	2.15	0.05
1600 to 2000	1.86	3.87	1.68	0.98
2000 to 2500	11.06	2.99	3.98	6.07
2500 to 3000	0.05	5.75		5.84

The maps evidence the great variations in potential biomass productivity that exist in the study area, spatially but also in relation to the different crop groups, especially when both rainfed and irrigated conditions are compared.

Nevertheless it is also obvious that even under the most favourable conditions, irrigated land with the highest growing degree days in the study area, the biomass productivity indices are low in comparison to warmer areas, where BPI values of 5000-8000 are not unusual.

In terms of comparative advantage of the different crop groups, the CBPI values of Tables 4 and 5 indicate that the C3 crop group is climatically the best adapted to the study area. It has the highest percentages in higher CBPI classes, even under irrigated conditions. This finding is in line with the generally cold nature of the study area, as it was already evidenced from the temperatures of the warmer months, the low annual growing degree days, the importance of frost and the low potential evapotranspiration levels.

4.9. Climatic similarity

In similarity analysis the value of a climatic parameter or index at one location (the ‘match’ location) is compared with other locations (‘target’) locations in order to quantify the degree of similarity in climatic conditions. In this study ‘relative similarity’ is used, an approach in which the degree of similarity refers to the relative diversity within the study area. This approach only looks at the range of climatic conditions observed within this area, not outside, by ranking the differences between the different target locations and the match location.

Climatic similarity maps have been prepared, which show the degree of relative similarity in precipitation and temperature patterns with reference to three match locations, Moghan (Map 38), Maraghe (Map 39) and Ardabil (Map 40). The results are summarized in Table 6.

Table 6. Percentages of the study area in different similarity classes

Similarity Index	Similarity class	Ardabil	Maraghe	Moghan
0 to 0.1	Very low similarity	0.09	0.12	0.18
0.1 to 0.3	Low similarity	0.93	1.41	3.60
0.3 to 0.5	Moderate similarity	5.46	14.73	23.43
0.5 to 0.7	High similarity	44.83	68.55	53.82
0.7 to 1	Very high similarity	48.69	15.20	18.99

With 93% of the study area either ‘highly similar’ or ‘very highly similar’ to Ardabil, and nearly 50% in the ‘very high similarity’ class, this station is climatically the most representative for the entire area. With the exception of the west and north of the study area, high similarity scores are observed throughout the entire area. Maraghe, with nearly 84% in these two similarity classes, is also very representative, especially in the west of the study area, but the class ‘very high similarity’ is much smaller in area. Areas in the north of the study area have very high similarity with Moghan, but elsewhere similarity is much less. Unsurprisingly, the mountain areas have low similarity scores because all three match locations are situated in plain areas with warmer and drier climatic conditions.

4.10. Land use/land cover

The spatial distribution of the land use/land cover categories is shown in Map 41. Three land use categories dominate the study area: rangelands occupying 61%, rainfed crops with 24%, and irrigated crops with 13% of the study area. Saline areas occupy the edge of Lake Urumieh in the west, and there are wetlands (1%) in the Tabriz plain. Forests occupy a negligible area. Also land use shows a spatial pattern strongly influenced by the elevation. The crops are located in the warmer plains, with the irrigated crops in the deepest parts and the rainfed crops on higher, often more sloping land. The rangelands are mostly located on the higher, colder elevations with more strongly sloping land.

4.11. Topography

As evidenced by Map 42, there is a very wide range of elevations in the study area, with a elevation difference of nearly 4800 m between the lowest point, Bileh Savar in the Moghan plain, and the top of Sabalan mountain. As already obvious from earlier sections, elevation is the main factor that determines climate, and by association, is a key determinant of the potential for crops and land use systems in the area.

In total more than 80% of the area is above 1000 m elevation. About 58% of the study area is located between 1200 and 2000 m elevation, and an additional 15% is in the range 2000-2600 m.

With about 65% of the area having slopes below 8%, and 35% with slopes above, the study area is best described as an alternation of flat plains and sloping land (Map 43). The aspect map (Map 44) indicates that within the sloping land there is a slight dominance of the south-facing slopes (31%).

On the basis of elevation zones, slope and aspect classes a basic map of landforms was prepared (Map 45). The study area contains 32 combinations of 4 elevation classes (<800 m, 800-1200 m, 1200-1600 m, and >1600 m), 4 slope classes (0-2%, 2-12%, 12-30%, >30%), and 3 aspect classes (north, south and undifferentiated). Of these the following landform classes occupy 55% of the study area:

- Landform 310 (14%): high elevation (>1200-1600 m), flat to almost flat (0-2% slope)
- Landform 320 (13%): high elevation (>1200-1600 m), gently undulating to undulating (2-12% slope)
- Landform 420 (28%): very high elevation (>1600 m), gently undulating to undulating (2-12% slope)

The full legend of the landforms map is in Table 16 of Annex 1.

The aspect is also a factor that can modify the local climate. In general southern slopes are warmer than northern slopes. A procedure was developed to modify the temperature surfaces in function of the aspect (Annex 5). Map 46 shows the areas where the growing degree days have been adjusted in the positive or negative sense to take aspect into consideration.

4.12. Soils

Map 47 shows the soil distribution in the study area by means of associations of soil classification units. The 33 soil associations are mixtures of Soil Taxonomy units, for which the list and short concept descriptions are in Annex 3. At a higher level of classification, as was the case for the available soil map, Soil Taxonomy units are not very useful to guide soil management. For this reason they were reclassified into 11 ‘soil management domains’, which are more useful for land suitability studies. The map of soil management domains (Map 48) and Table 7 indicate that nearly 60% of the study area is occupied by only 2 soil management domains: SMD1 (27%) and SMD6 (33%).

Table 7. Distribution of soil management domains in the study area

SMD	Description	%
SMD 1	Predominantly soils without significant limitations for agriculture	26.98
SMD 2	Predominantly soils with better capability for grazing and/or forestry than for agriculture	0.49
SMD 3	Soils with high salinity	3.36
SMD 4	Poorly drained soils	0.64
SMD 5	Predominantly good agricultural soils with some limitations due to possible flooding	4.46
SMD 6	Predominantly shallow, stony or rocky soils	32.70
SMD 7	Mostly shallow, stony or rocky soils with a significant proportion of good agricultural soils	9.84
SMD 8	Association of shallow, stony or rocky soils, with poorly developed soils	9.71
SMD 9	Mostly poorly developed soils with a significant proportion of good agricultural soils	6.88
SMD 10	Mostly eroded and dissected 'badlands'	4.62
SMD 11	Soils of urbanized areas	0.31

4.13. Agroecological zones

Map 49 shows the distribution of the agroecological zones in the study area. There are 242 agroecological zones, ranging in size from a maximum of 1,852 km^2 to a minimum of 0.5 km^2. The ten largest AEZ occupy less than 39% of the study area, 48 AEZ cover 80% of the area, and 69 AEZ 90% of the area. There are 99 ‘niche’ AEZ with a total area of 10 km^2 or less. The relationship between number of AEZ and share of the study area is fully characterized by the cumulative curve in Figure 5.

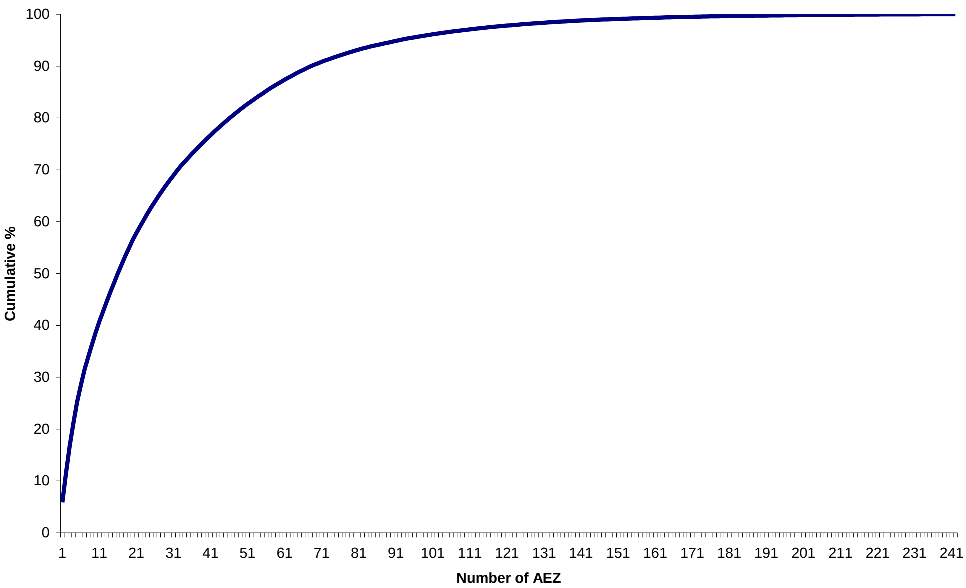

Figure 5. Area (%) occupied by a specified number of AEZ

These facts point again to a very high degree of ecological diversity in the project area. The full list of AEZ with their areas, percent of the study area, and short descriptions of their salient features is provided in Table 28 of Annex 4.

4.14. Land suitability

4.14.1 General

Using the methodology explained in Section 3 and Annex 5, a land suitability classification was undertaken for the following major field crops: barley, chickpea, lentil, olive, potato, sugarbeet, safflower, and wheat.

This resulted for each crop into a series of maps, with the following themes:

- Suitability of the thermal regime
- Suitability of the moisture regime
- Suitability of the climate
- Suitability of the topography
- Percentage of land with suitability class S1, S2, S3 and N (4 maps).

These maps are provided in Annex 1.

With the exception of olive, the annual growing degree days (AHU) served as the indicator for the thermal regime. Annual precipitation was used as indicator for the suitability of the moisture regime. For olive an additional suitability indicator, the minimum temperature of the coldest month, was used. For all crops the slope served as indicator for the suitability of topography.

4.14.2. Barley

Table 9[2]. Summary of suitability results for barley

Criteria	Ranges	Suitability unit	Limit. Code	Suitabil. Code	% of study area
Annual Precip (mm)	<150	Unsuitable, too dry	4	N	0
	150 to 225	Marginally suitable, too dry	3	S3	0.04
	225 to 300	Moderately suitable, too dry	2	S2	23.08
	300 to 800	Highly suitable	1	S1	76.88
	800 to 1100	Moderately suitable, too wet	2	S2	0
	> 1100	Unsuitable, too wet	4	N	0
AHU (°.days)	<900	Unsuitable, too cold	4	N	11.94
	900 to 1150	Marginally suitable, too cold	3	S3	19.38
	1150 to 1350	Moderately suitable, too cold	2	S2	27.43
	1350 to 2700	Highly suitable	1	S1	41.25
	2700 to 4000	Moderately suitable, too warm	2	S2	0
	> 4000	Unsuitable, too warm	4	N	0
Slope (%)	<4	Highly suitable	1	S1	40.69
	4 to 12	Moderately suitable	2	S2	39.20
	12 to 20	Marginally suitable	3	S3	14.63
	>20	Unsuitable	4	N	5.49
All criteria together		Highly suitable	1	S1	10.78
		Moderately suitable	2	S2	41.37
		Marginally suitable	3	S3	19.73
		Unsuitable	4	N	28.11

[2] Explanatory notes with the tables are at the end of this section

4.14.3. Chickpea

Table 10. Summary of suitability results for chickpea

Criteria	Ranges	Suitability unit	Limit. Code	Suitabil. Code	% of study area
Annual Precip (mm)	<200	Unsuitable, too dry	4	N	.09
	200 to 250	Marginally suitable, too dry	3	S3	11.11
	250 to 300	Moderately suitable, too dry	2	S2	65.58
	300 to 550	Highly suitable	1	S1	23.22
	550 to 800	Moderately suitable, too wet	2	S2	0
	800 to 1200	Marginally suitable, too wet	3	S3	0
	> 1200	Unsuitable, too wet	4	N	0
AHU (°.days)	<1200	Unsuitable, too cold	4	N	18.24
	1200 to 1650	Marginally suitable, too cold	3	S3	29.07
	1650 to 1950	Moderately suitable, too cold	2	S2	44.43
	1950 to 3000	Highly suitable	1	S1	8.26
	3000 to 3300	Moderately suitable, too warm	2	S2	0
	3300 to 3750	Marginally suitable, too warm	3	S3	0
	> 3750	Unsuitable, too warm	4	N	0
Slope (%)	<4	Highly suitable	1	S1	40.69
	4 to 10	Moderately suitable	2	S2	32.60
	10 to 15	Marginally suitable	3	S3	13.90
	>15	Unsuitable	4	N	12.82
All factors combined		Highly suitable	1	S1	2.75
		Moderately suitable	2	S2	29.50
		Marginally suitable	3	S3	31.72
		Unsuitable	4	N	36.03

4.14.4. Lentil

Table 11. Summary of suitability results for lentil

Criteria	Ranges	Suitability unit	Limitat. Code	Suitabil. Class	% of study area
Annual Precip (mm)	<230	Unsuitable, too dry	4	N	0.09
	230 to 280	Marginally suitable, too dry	3	S3	11.11
	280 to 400	Moderately suitable, too dry	2	S2	65.68
	400 to 800	Highly suitable	1	S1	23.22
	800 to 1200	Moderately suitable, too wet	2	S2	0
	1200 to 1500	Marginally suitable, too wet	3	S3	0
	> 1500	Unsuitable, too wet	4	N	0
AHU (°.days)	<1000	Unsuitable, too cold	4	N	18.29
	1000 to 1250	Marginally suitable, too cold	3	S3	26.48
	1250 to 1900	Moderately suitable, too cold	2	S2	42.26
	1900 to 4000	Highly suitable	1	S1	12.98
	3400 to 4500	Moderately suitable, too warm	2	S2	0
	> 4500	Unsuitable, too warm	4	N	0
Slope (%)	<4	Highly suitable	1	S1	40.69
	4 to 10	Moderately suitable	2	S2	32.60
	10 to 15	Marginally suitable	3	S3	13.90
	>15	Unsuitable	4	N	12.82
All factors combined		Highly suitable	1	S1	2.75
		Moderately suitable	2	S2	29.50
		Marginally suitable	3	S3	31.72
		Unsuitable	4	N	36.03

4.14.5. Olive

Table 12. Summary of suitability results for olive

Criteria	Ranges	Suitability unit	Limit. Code	Suitabil. Class	% of study area
Annual Precip (mm)	<150	Unsuitable, too dry	4	N	0
	150 to 300	Marginally suitable, too dry	3	S3	23.12
	300 to 400	Moderately suitable, too dry	2	S2	53.66
	400 to 1000	Highly suitable	1	S1	23.22
	1000 to 1200	Moderately suitable, too wet	2	S2	0
	1200 to 1400	Marginally suitable, too wet	3	S3	0
	> 1400	Unsuitable, too wet	4	N	0
Mean annual temp. (° C)	<13	Unsuitable, too cold	4	N	89.06
	13 to 14	Marginally suitable, too cold	3	S3	5.09
	14 to 15	Moderately suitable, too cold	2	S2	5.85
	15 to 22	Highly suitable	1	S1	0
	22 to 24	Moderately suitable, too warm	2	S2	0
	24 to 26	Marginally suitable, too warm	3	S3	0
	> 26	Unsuitable, too warm	4	N	0
Minimum temp. coldest month (° C)	<-1.2	Unsuitable, too cold	4	N	98.00
	-1.2 to 0.5	Marginally suitable, too cold	3	S3	2.00
	0.5 to 2.3	Moderately suitable, too cold	2	S2	0
	2.3 to 7.5	Highly suitable	1	S1	0
	7.5 to 9.2	Moderately suitable, too warm	2	S2	0
	9.2 to 11	Marginally suitable, too warm	3	S3	0
	>11	Unsuitable, too warm	4	N	0
Slope (%)	<8	Highly suitable	1	S1	64.88
	8 to 15	Moderately suitable	2	S2	22.30
	15 to 20	Marginally suitable	3	S3	7.33
	>20	Unsuitable	4	N	5.49
All factors combined		Highly suitable	1	S1	0.00
		Moderately suitable	2	S2	0.00
		Marginally suitable	3	S3	1.96
		Unsuitable	4	N	98.04

4.14.6. Potato/sugarbeet

Table 13. Summary of suitability results for potato/sugarbeet

Criteria	Ranges	Suitability unit	Limitat. Code	Suitabil. Class	% of study area
Irrigation	Not-irrigated	Not suitable	4	N	87.03
	Irrigated	Highly suitable	1	S1	12.97
AHU (°.days)	<1200	Unsuitable, too cold	4	N	87.04
	1200 to 1450	Marginally suitable, too cold	3	S3	0.08
	1450 to 1750	Moderately suitable, too cold	2	S2	3.40
	1750 to 3500	Highly suitable	1	S1	9.47
	3500 to 4750	Moderately suitable, too warm	2	S2	0
	> 4750	Unsuitable, too warm	4	N	0
Slope (%)	<2	Highly suitable	1	S1	22.63
	2 to 4	Moderately suitable	2	S2	18.05
	4 to 6	Marginally suitable	3	S3	13.55
	>6	Unsuitable	4	N	45.76
All factors combined		Highly suitable	1	S1	6.04
		Moderately suitable	2	S2	4.01
		Marginally suitable	3	S3	1.07
		Unsuitable	4	N	88.88

4.14.7. Safflower

Table 14. Summary of suitability results for safflower

Criteria	Ranges	Suitability unit	Limit. Code	Suitabil. Class	% of study area
Irrigation	Not-irrigated	Not suitable	4	N	87.03
	Irrigated	Highly suitable	1	S1	12.97
AHU (°.days)	<870	Unsuitable, too cold	4	N	87.09
	870 to 1320	Marginally suitable, too cold	3	S3	6.86
	1320 to 1590	Moderately suitable, too cold	2	S2	2.83
	1590 to 2460	Highly suitable	1	S1	3.21
	2460 to 2640	Moderately suitable, too warm	2	S2	0
	2640 to 3840	Marginally suitable, too warm	3	S3	0
	> 3840	Unsuitable, too warm	4	N	0
Slope (%)	<2	Highly suitable	1	S1	22.63
	2 to 4	Moderately suitable	2	S2	18.05
	4 to 6	Marginally suitable	3	S3	13.55
	>6	Unsuitable	4	N	45.76
All factors combined		Highly suitable	1	S1	6.00
		Moderately suitable	2	S2	3.95
		Marginally suitable	3	S3	1.02
		Unsuitable	4	N	88.88

4.14.8. Wheat

Table 15. Summary of suitability results for wheat

Criteria	Ranges	Suitability unit	Limit. Code	Suitabil. Class	% of study area
Annual Precip (mm)	<225	Unsuitable, too dry	4	N	0.04
	225 to 275	Marginally suitable, too dry	3	S3	8.33
	275 to 350	Moderately suitable, too dry	2	S2	44.46
	350 to 1200	Highly suitable	1	S1	47.18
	1200 to 1500	Moderately suitable, too wet	2	S2	0
	1500 to 1750	Marginally suitable, too wet	3	S3	0
	> 1750	Unsuitable, too wet	4	N	0
AHU (°.days)	<1000	Unsuitable, too cold	4	N	18.29
	1000 to 1250	Marginally suitable, too cold	3	S3	26.48
	1250 to 1500	Moderately suitable, too cold	2	S2	24.00
	1500 to 3000	Highly suitable	1	S1	31.24
	3000 to 4500	Moderately suitable, too warm	2	S2	0
	> 4500	Unsuitable, too warm	4	N	0
Slope (%)	<4	Highly suitable	1	S1	40.69
	4 to 10	Moderately suitable	2	S2	32.60
	10 to 15	Marginally suitable	3	S3	13.90
	>15	Unsuitable	4	N	12.82
All factors combined		Highly suitable	1	S1	5.11
		Moderately suitable	2	S2	30.92
		Marginally suitable	3	S3	27.97
		Unsuitable	4	N	35.98

Notes:
AHU: annual heat units
Limitation codes:
4: very severe limitation; 3: severe limitation; 2: moderate limitation; 1: no or slight limitation
Suitability classes:
N: unsuitable; S3: marginally suitable ; S2: moderately suitable; S1: highly suitable

5. CONCLUSIONS AND RECOMMENDATIONS

This study has generated a large dataset, mostly in the form of maps, on the agroecological conditions in the study area, on the basis of limited input data, consisting of climatic data (precipitation and temperature), a land use/land cover map, a digital elevation model and a soil map. Hence, an important lesson emerging from this study is that with a relatively small and widely available dataset a good knowledge can be obtained of many aspects of the agroecological conditions and crop suitabilities in different parts of Iran. However, one severe limitation, which has restricted the optimal use of the land suitability methods, is the lack of sufficiently detailed soil information. New approaches, making optimal use of already existing primary and secondary information, are necessary to improve the results by making them more soil-specific. This will be discussed further in this chapter.

The main outcomes of this study are an in-depth agroecological characterization of the study area and a number of possible crop options for which the chances of success have been identified through a land suitability classification process, based on the FAO Framework for Land Evaluation, and implemented in a GIS-based methodology, consisting of the following steps:

- Identification of land utilization types
- Creation of crop requirement tables
- Definition of homogeneous land units
- Matching requirements of land utilization types with land unit characteristics

This information can be used for developing land use recommendations and a land use plan at provincial level, but in the light of its biophysical bias, this study by itself does not provide all elements needed for such recommendations and plan development. In addition to a biophysical evaluation, it is necessary to collect sufficient socioeconomic background information to characterize the land utilization types of the area in sufficient detail. Rapid rural appraisals are necessary for problem identification related to land use.

Another limitation of the current study is that it is entirely *ex-ante* without verification of the results in the field. Validation could take several forms, such as sampling for yield, compiling production and yield data from experimental stations, or simply asking farmers for their opinions. Farmer involvement in land quality assessment characterization, whereby information is obtained from farmers about local agroecologies, is a novel approach, called *participatory agroecological characterization*. This rapid technique, based on joint transect studies with key informants (Cools et al., 2003), taps into the deep traditions of indigenous knowledge and allows a much better understanding of the variability of local environments, and helps researchers to develop optimal packages for these environments, using the methods of participatory technology development (PTD).

In the course of the study a number of issues emerged, which due to time and resource constraints could not be addressed, but deserve more attention in follow-up studies.
A first issue is drought, which is, as in most parts of Iran, a major problem in the study area. Concretely, the following approach would give rapid results in the study of drought:

- Characterization and mapping of drought, using monthly precipitation data, the Standardized Precipitation Index and ICARDA CLIMAP software for mapping the severity of drought;
- Risk assessment using daily precipitation data and the ICARDA Agroclimate Tool.

A second issue is land suitability for crops for which the ecological requirements are not well known or understood. In the current study, land suitability was confined to crops with well-known ecological requirements, but for many economically important crops (e.g. canola, saffron, pistachio, fruit trees etc.) this is not the case. A useful way to address this problem is through similarity mapping in relation to areas where these crops perform well and are high-yielding.

As mentioned earlier there is a need for better soil information. This is absolutely necessary for the site-specific location of resource constraints, such as shallow depth, stoniness, salinity, acidity, soil compaction, high erodibility, etc.

Whereas the irrigated areas in plains are well covered by semi-detailed soil surveys, the rainfed areas have been neglected and soil information about them is only available in the form of a 1:1,000,000 scale soil classification map linked to a database with soil profiles in a 10 x 10 km grid. Soils and their management properties can vary a lot within 100 km^2 blocks, and as new surveys are unlikely due to budget constraints, it will be necessary to generate new soil data by 'mining' the existing data using novel techniques.

A promising technology is a statistical approach leading to probabilistic maps of soil properties, based on the application in GIS of Bayesian statistics to a set of 'evidence layers' incorporating local and expert knowledge and using the following principles:

- Soil properties (e.g. depth, texture, organic carbon) are mapped instead of 'soil bodies', as in soil classification systems.
- The mapping is done in the same way a classical soil surveyor builds up a mental concept of soil distribution by exploiting relationships between soil occurrence and various environmental variables (e.g. elevation, rainfall, geology, slope), supported by a limited sample set, including real soil profiles.
- The mapping of individual soil properties is probabilistic, leading to fuzzy instead of crisp classifications (e.g. maps showing the probability of depth class 0-25 cm, 25-50 cm, 50-100 cm in pixel x instead of pixel x= class 0-25)
- The probabilities are calculated using Bayes Theorem by combining through expert knowledge all available evidence, as obtained from existing soil databases and known relationships between soil distribution and other environmental factors, such as land use/land cover, topography, climate, geology etc.

Currently a Ph.D. study is being finalized, based on the 'weights of evidence' method, as implemented by Corner et al. (2002) in the Expector software. The results of this study will be evaluated to assess its suitability for improving the existing soil maps with limited ground truthing.

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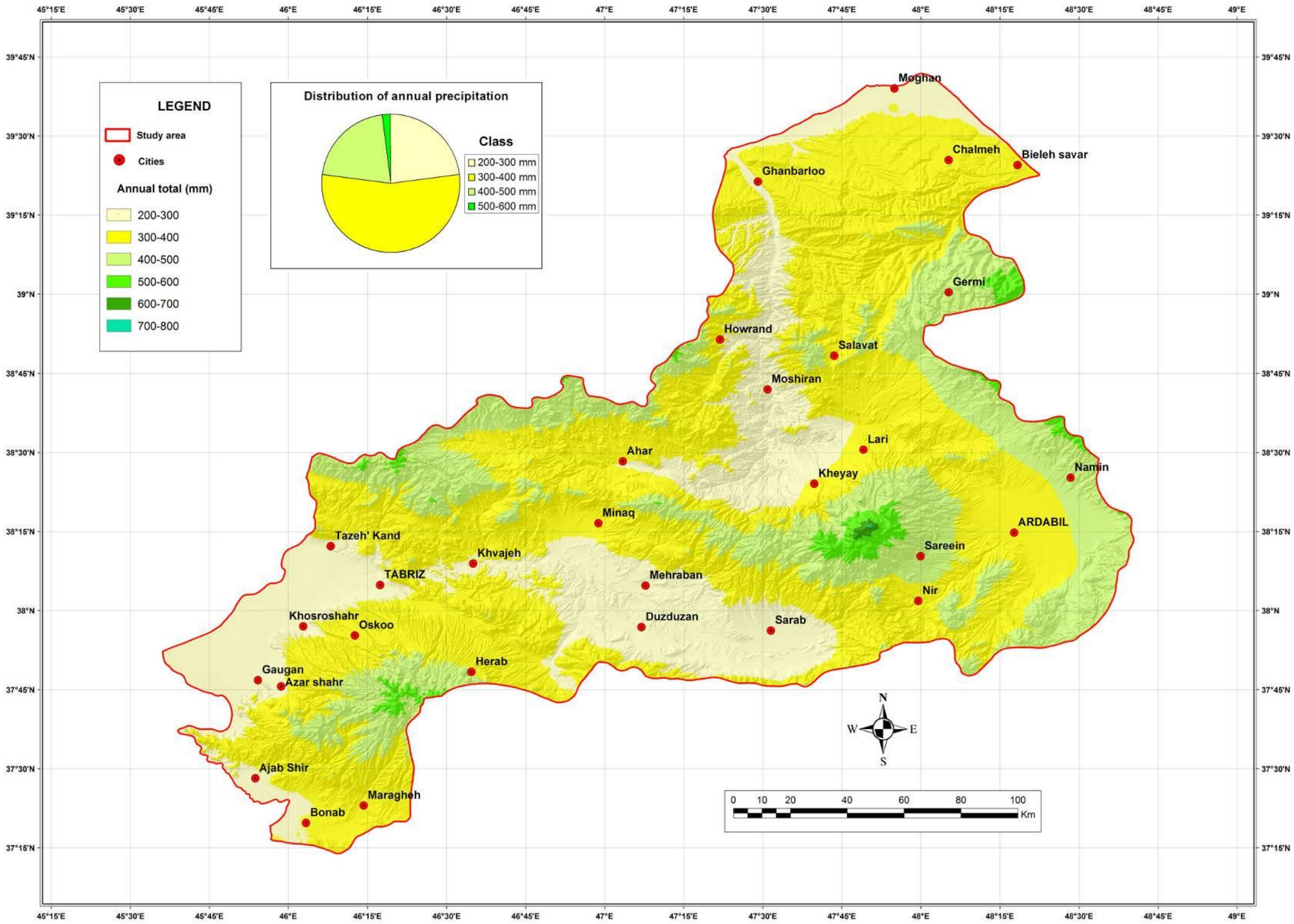
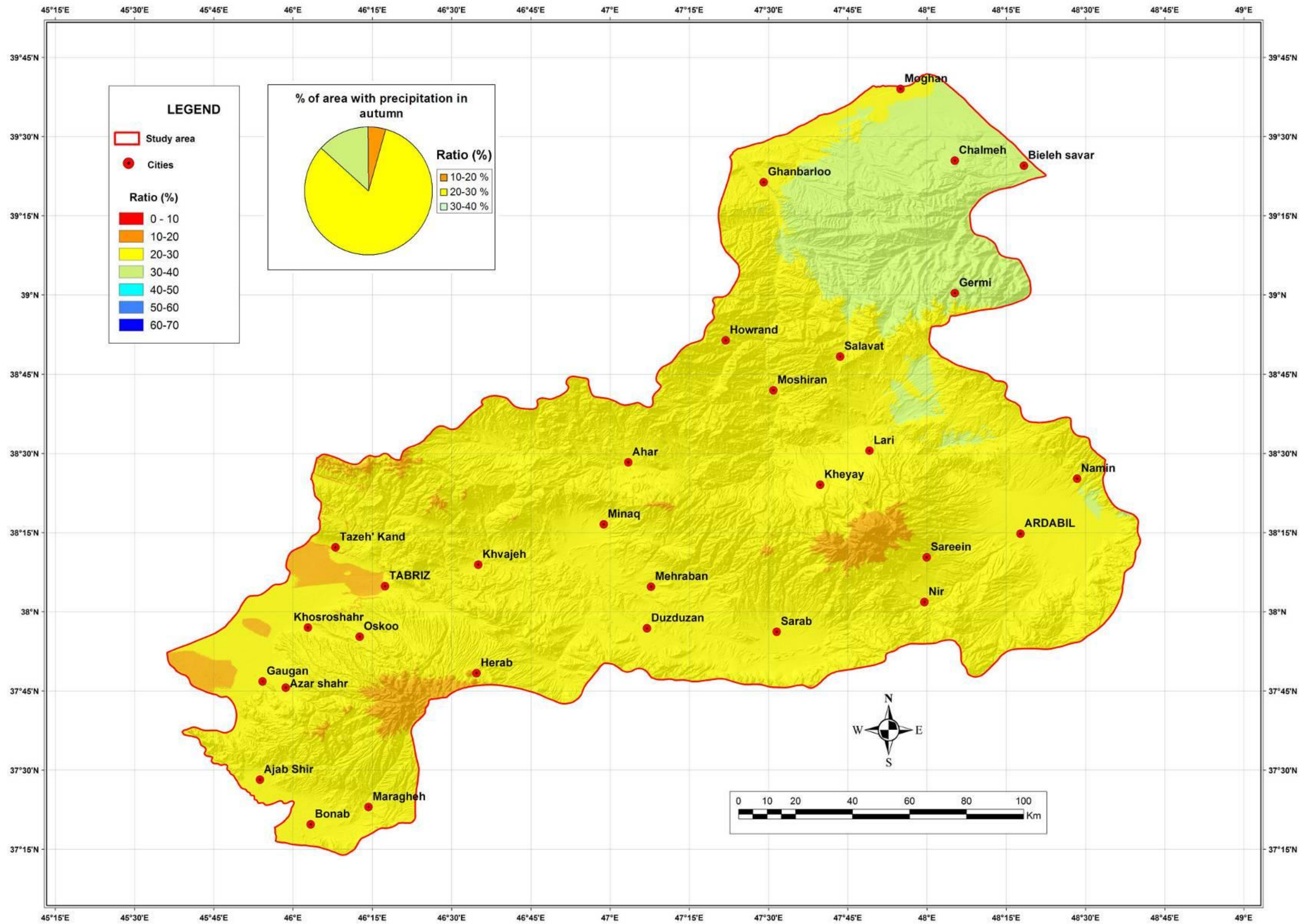
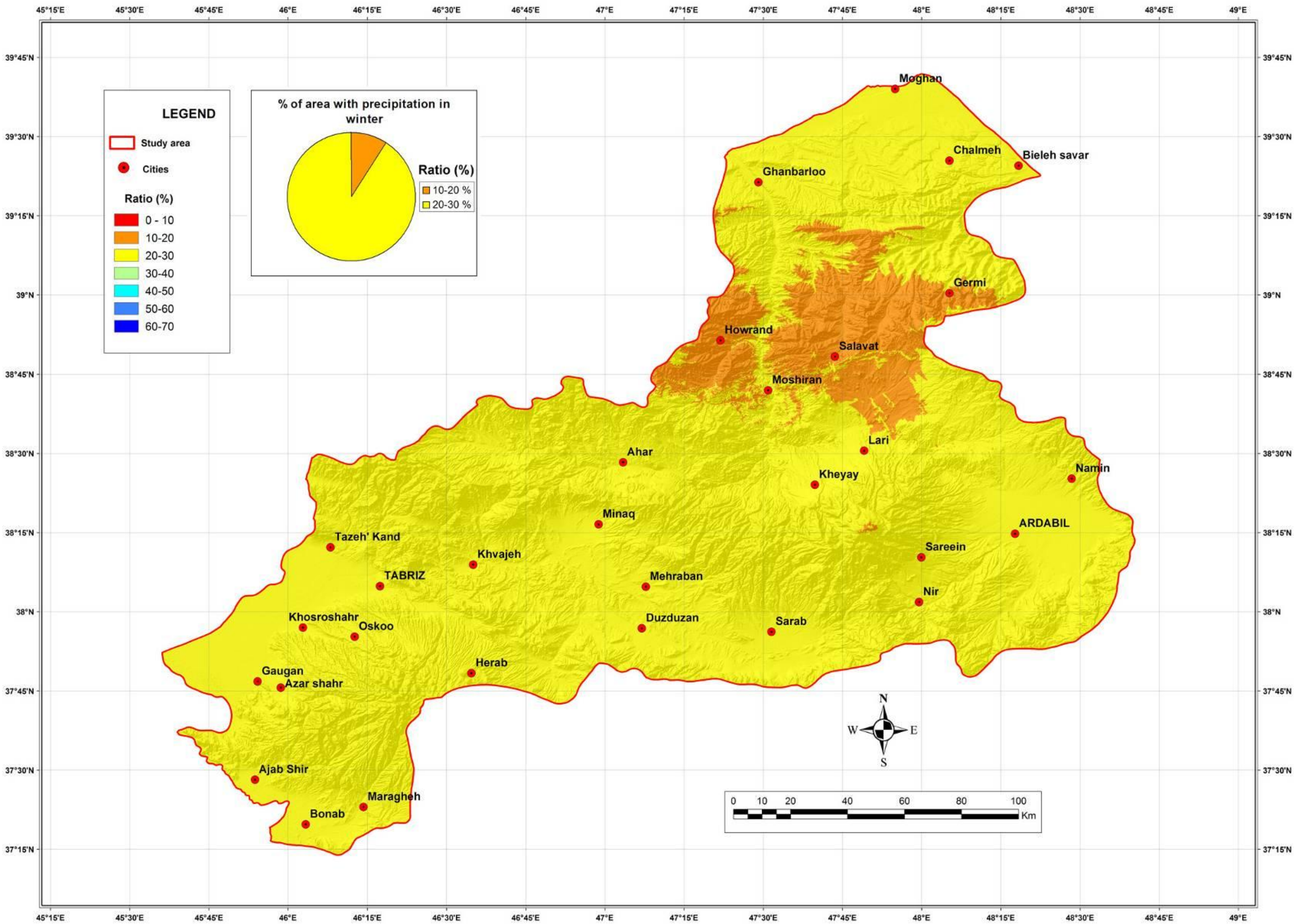
ANNEX 1. MAPS



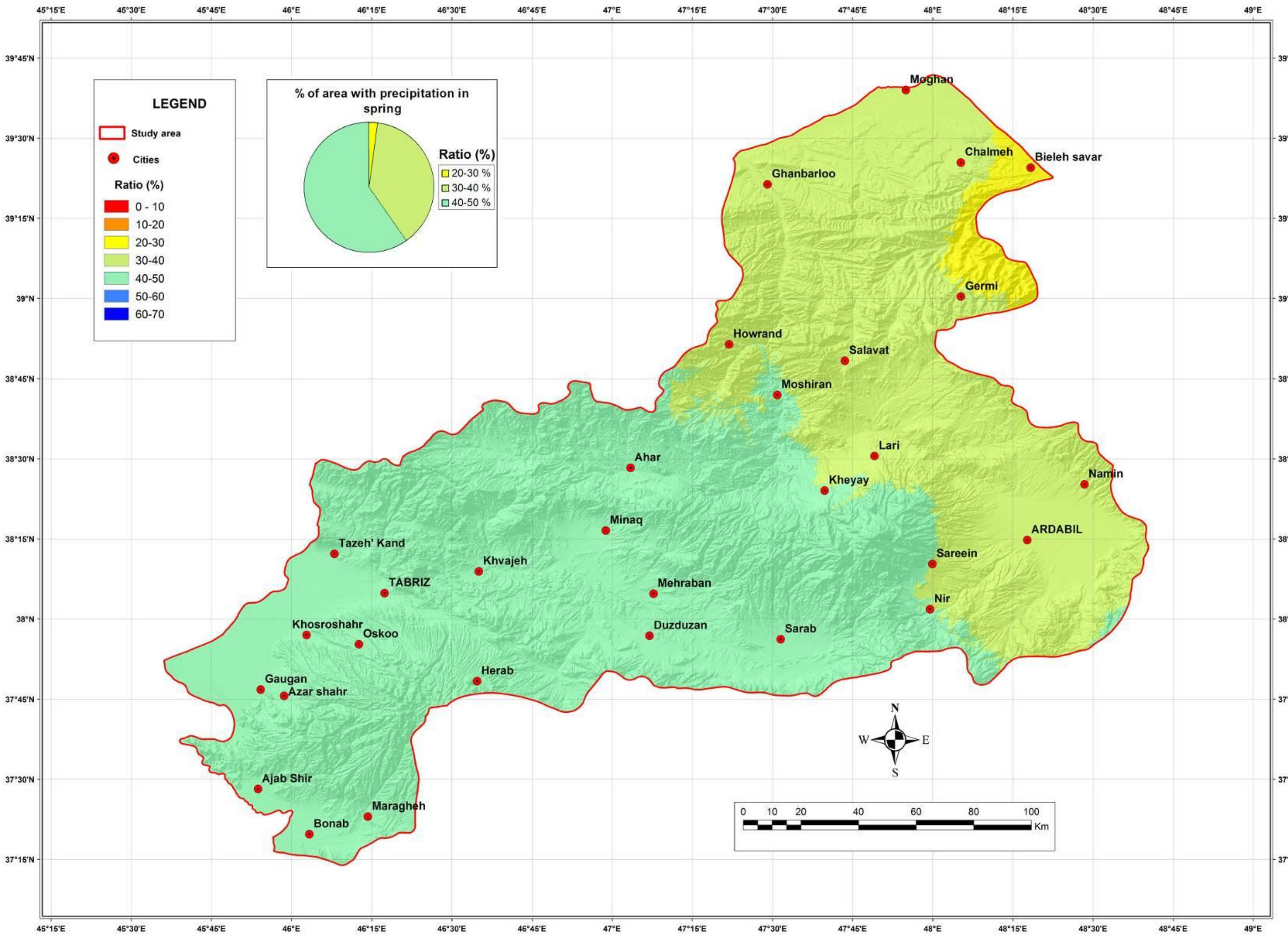
Map 1 Mean annual precipitation



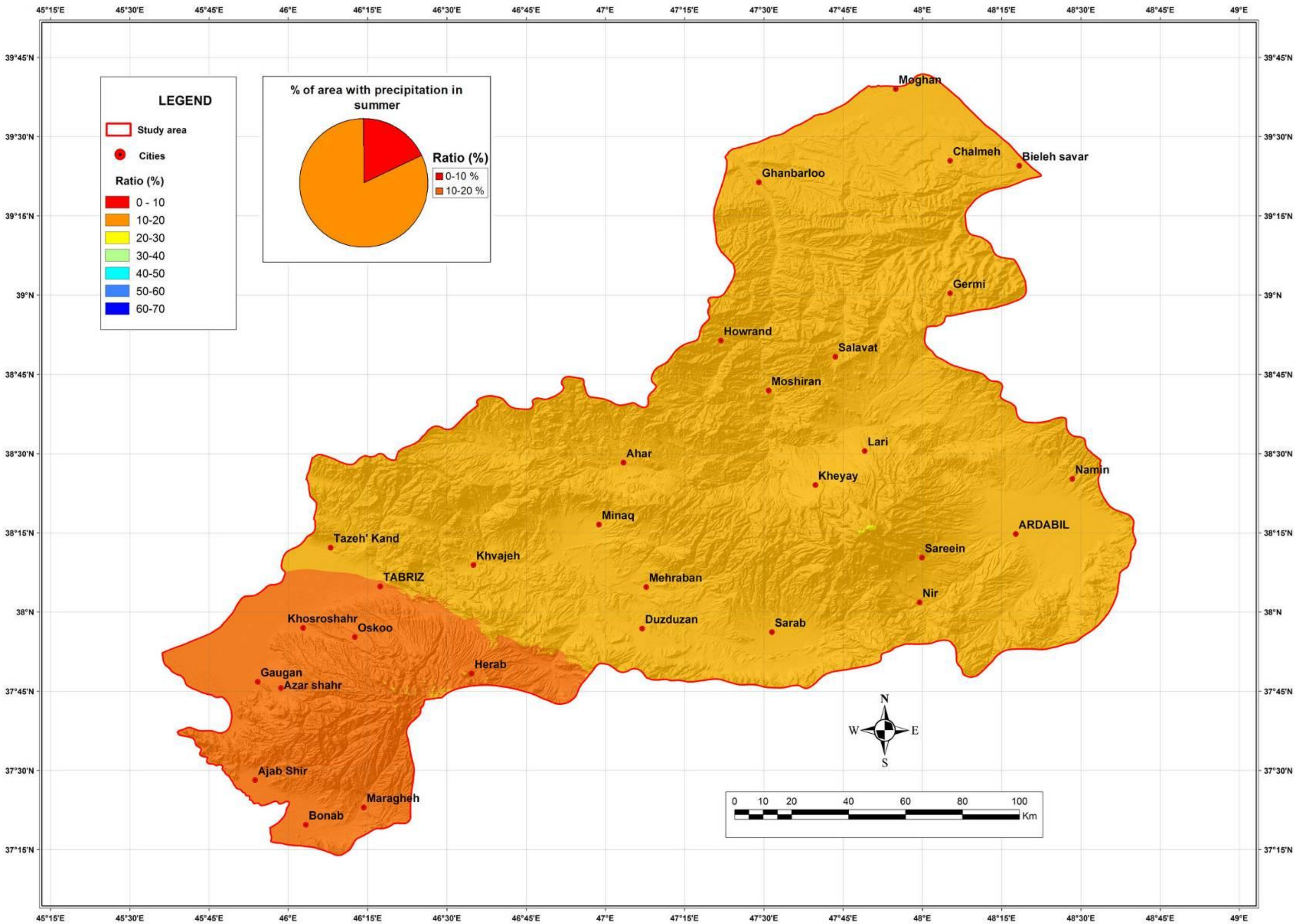
- Map 2. Seasonal distribution of precipitation: ratio of Autumn (September-November) to Annual Precipitation



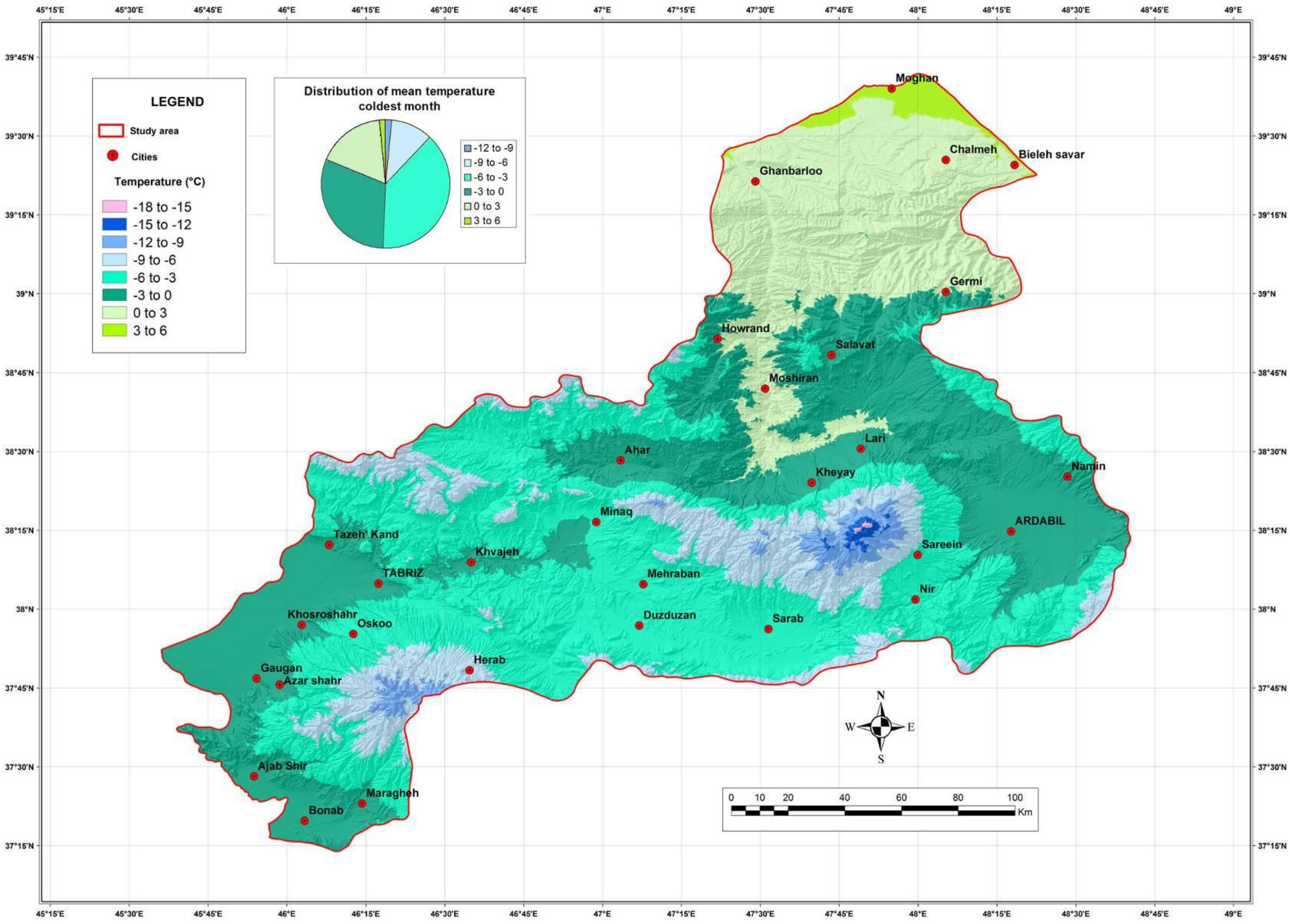
- Map 3. Seasonal distribution of precipitation: ratio of Winter (December- February) to Annual Precipitation



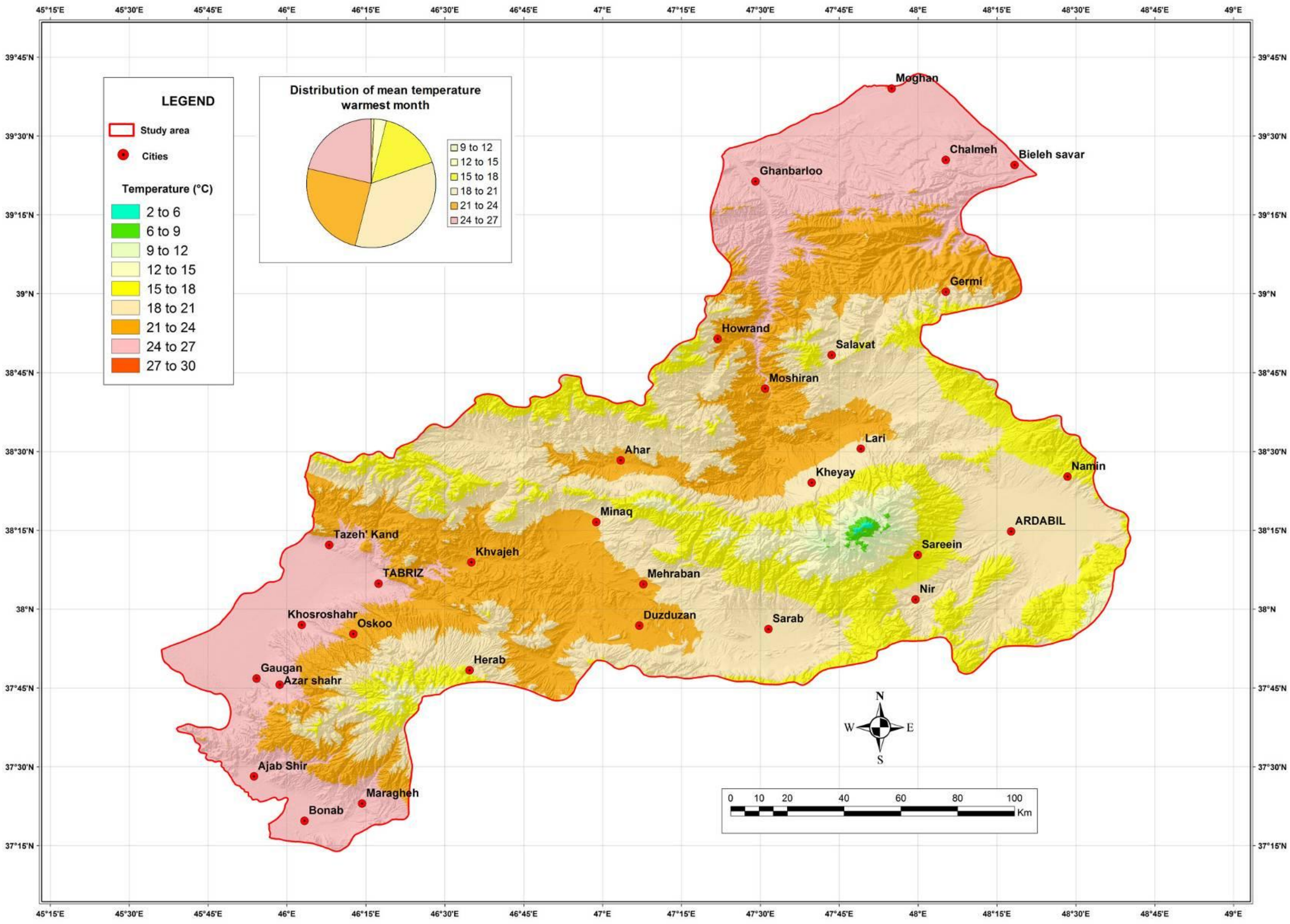
- Map 4. Seasonal distribution of precipitation: ratio of Spring (March-May) to Annual Precipitation



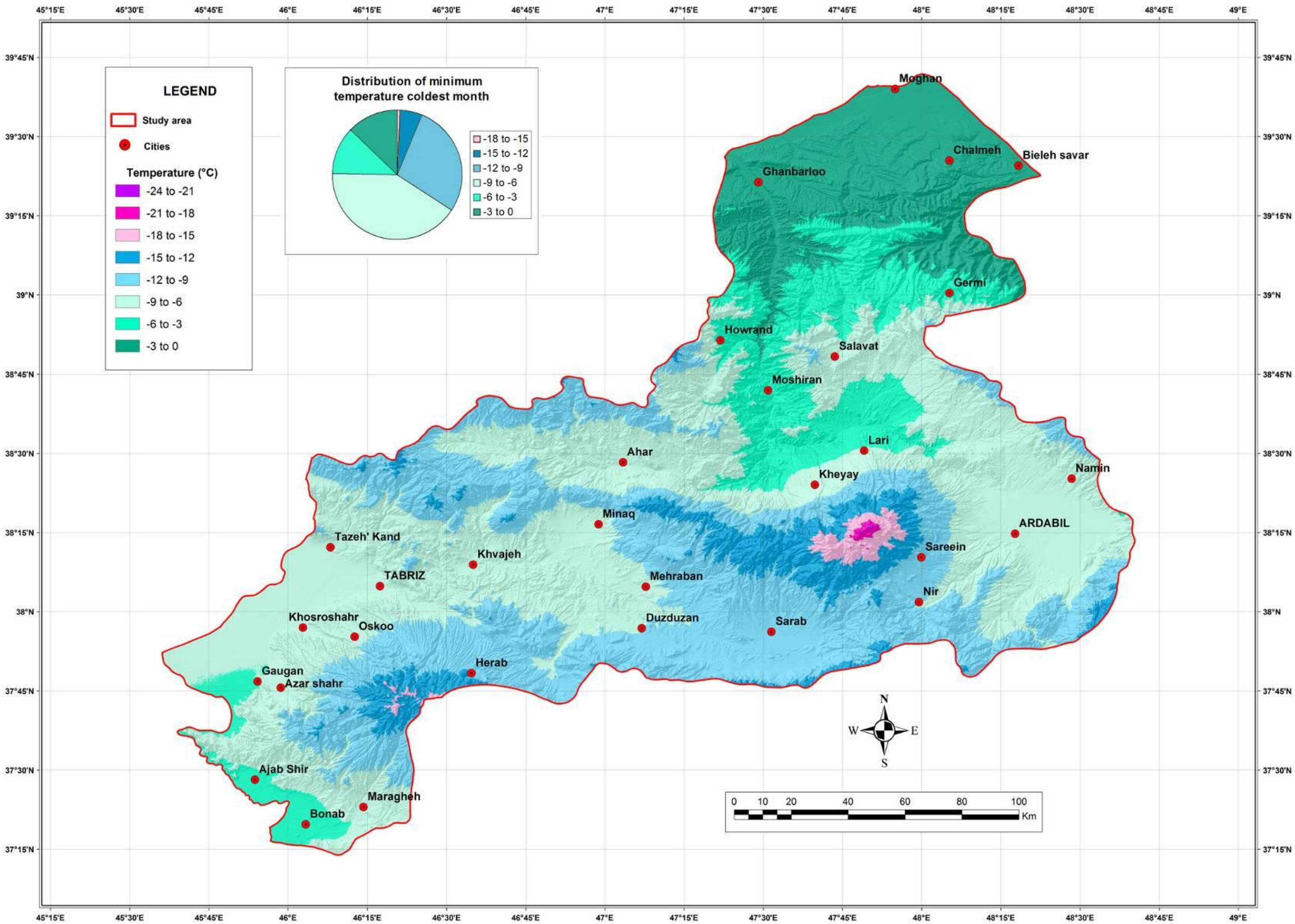
- Map 5. Seasonal distribution of precipitation: ratio of Summer (June- August) to Annual Precipitation



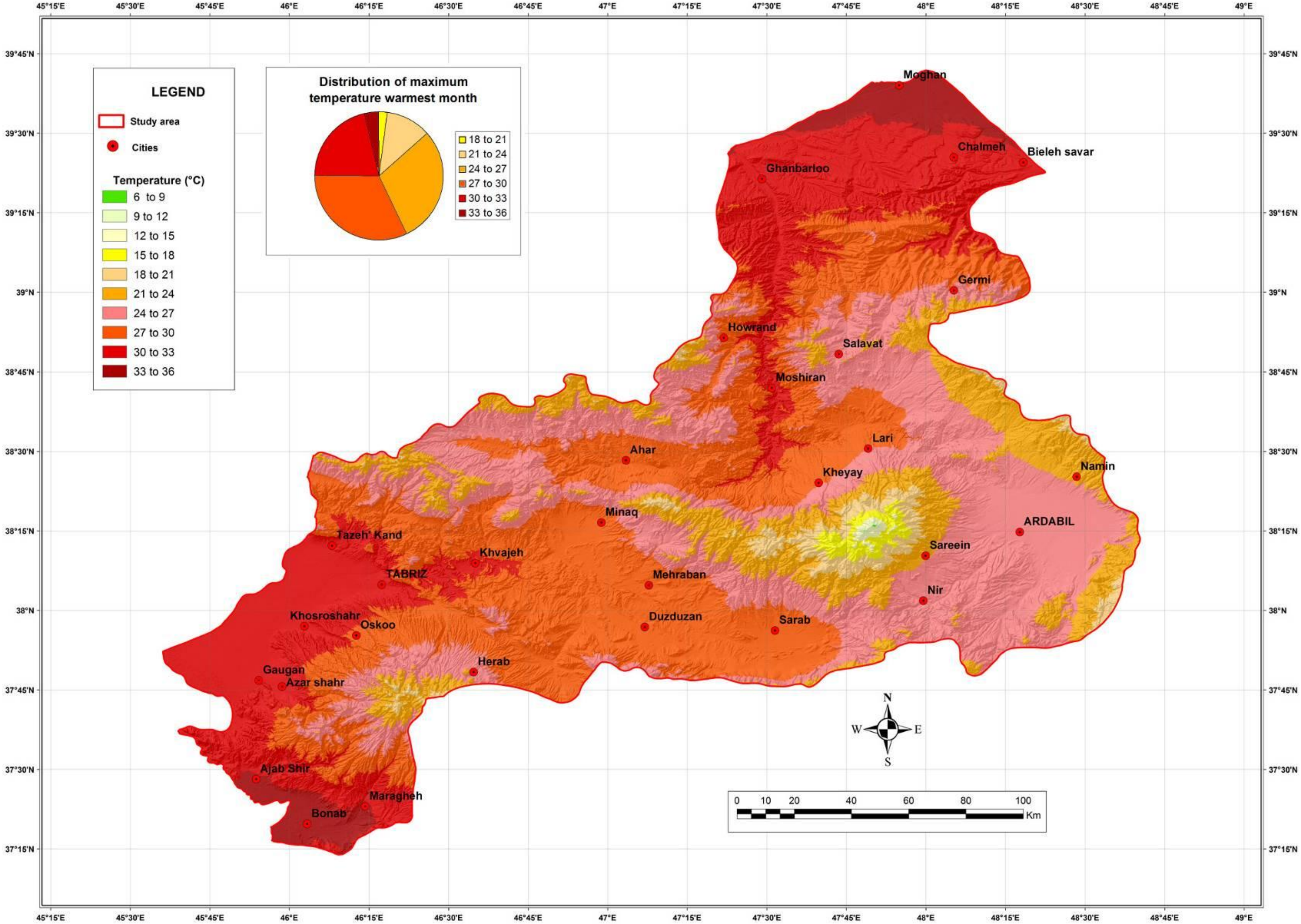
Map 6. Mean temperature of the coldest month



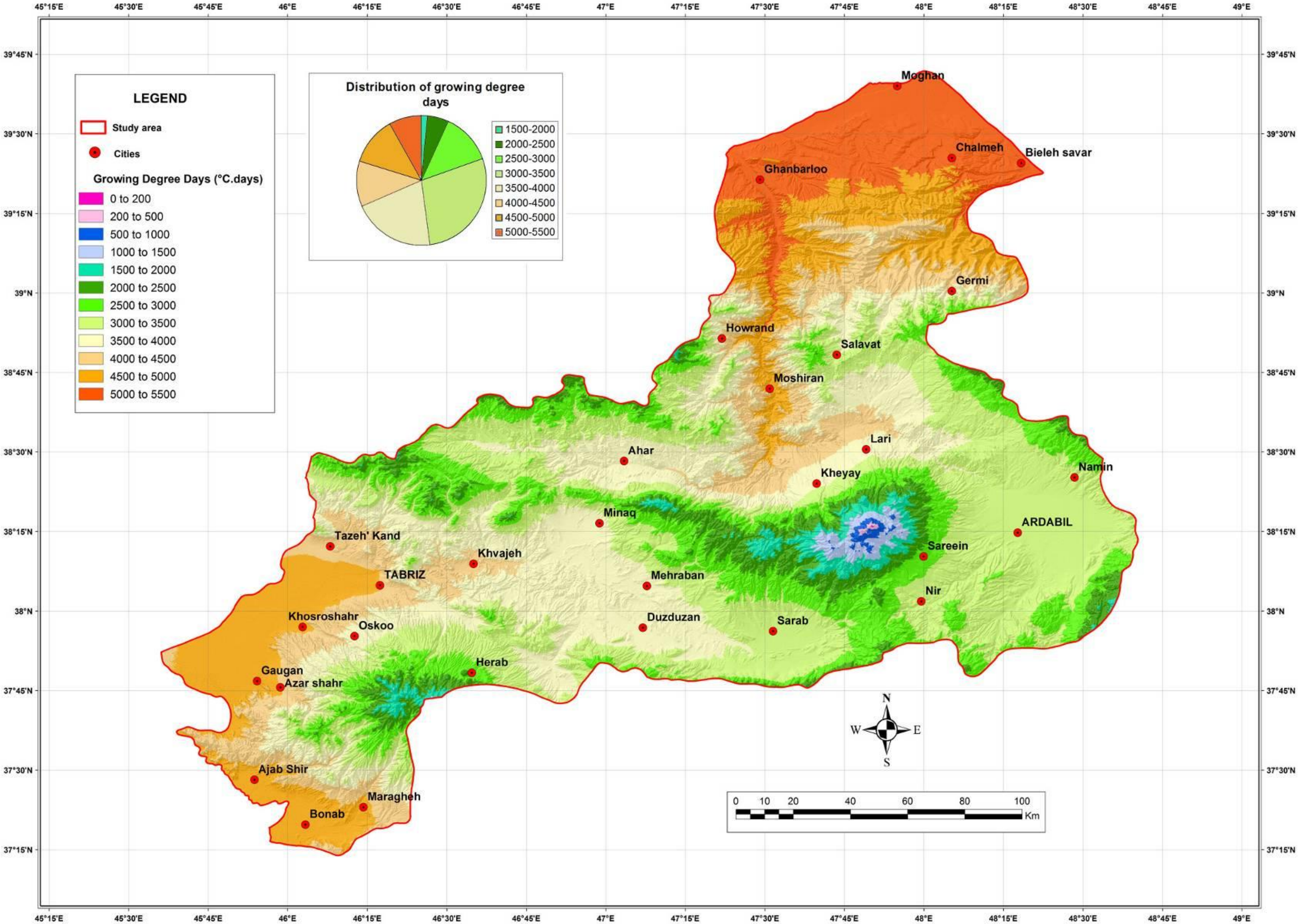
- Map 7. Mean temperature of the warmest month



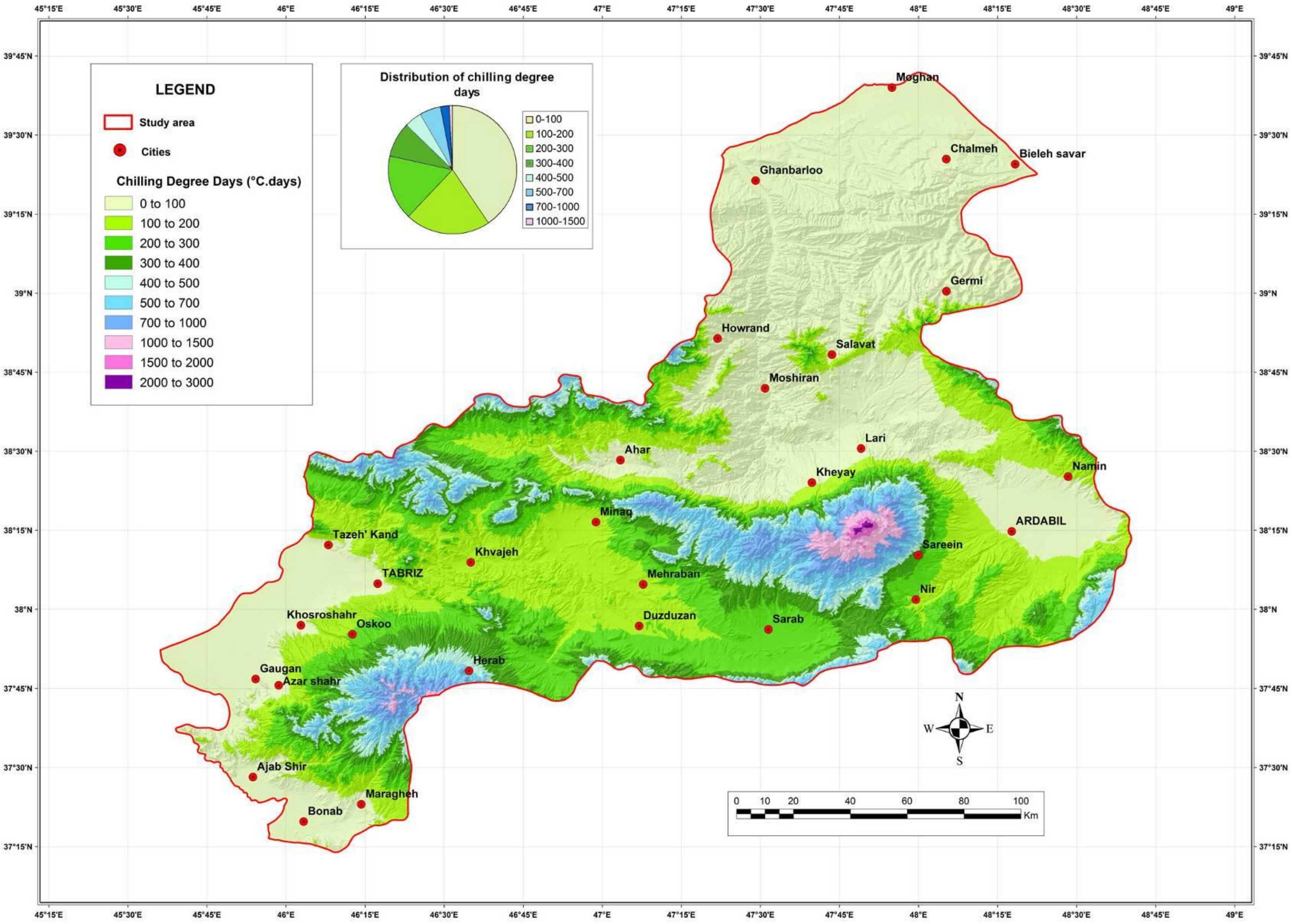
- Map 8. Mean minimum temperature of the coldest month



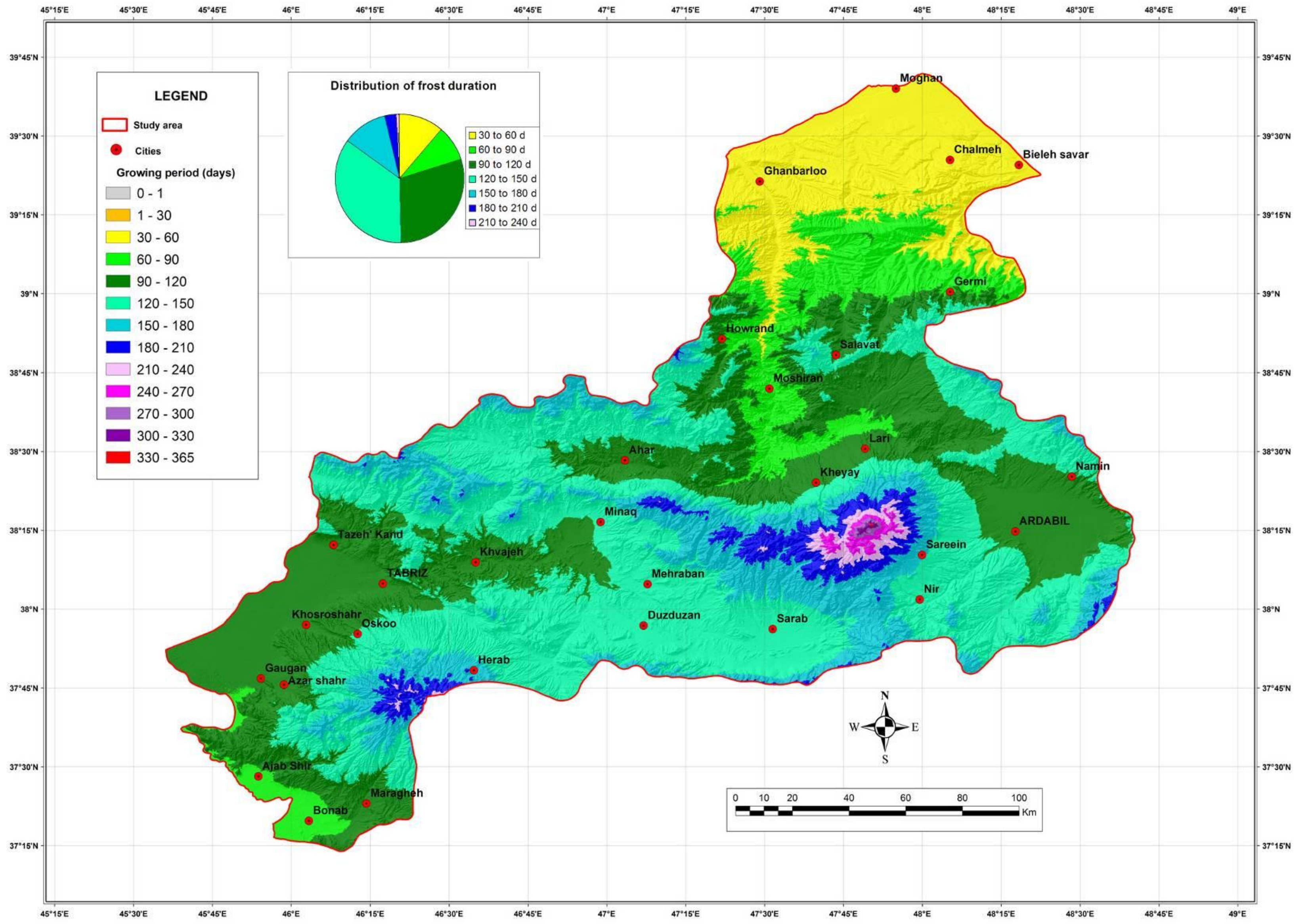
- Map 9. Mean maximum temperature of the warmest month



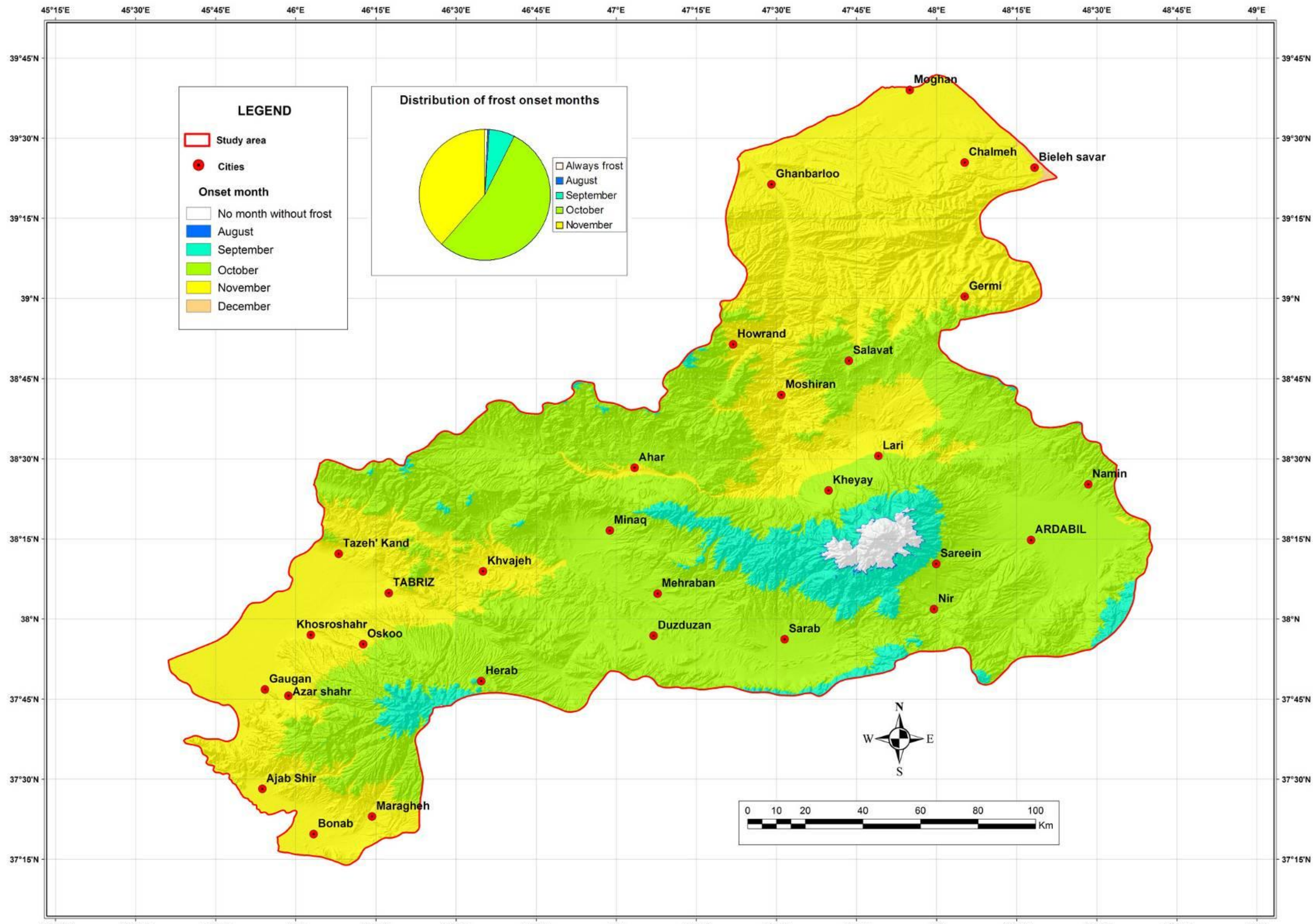
• Map 10. Annual growing degree days (above 0°C)



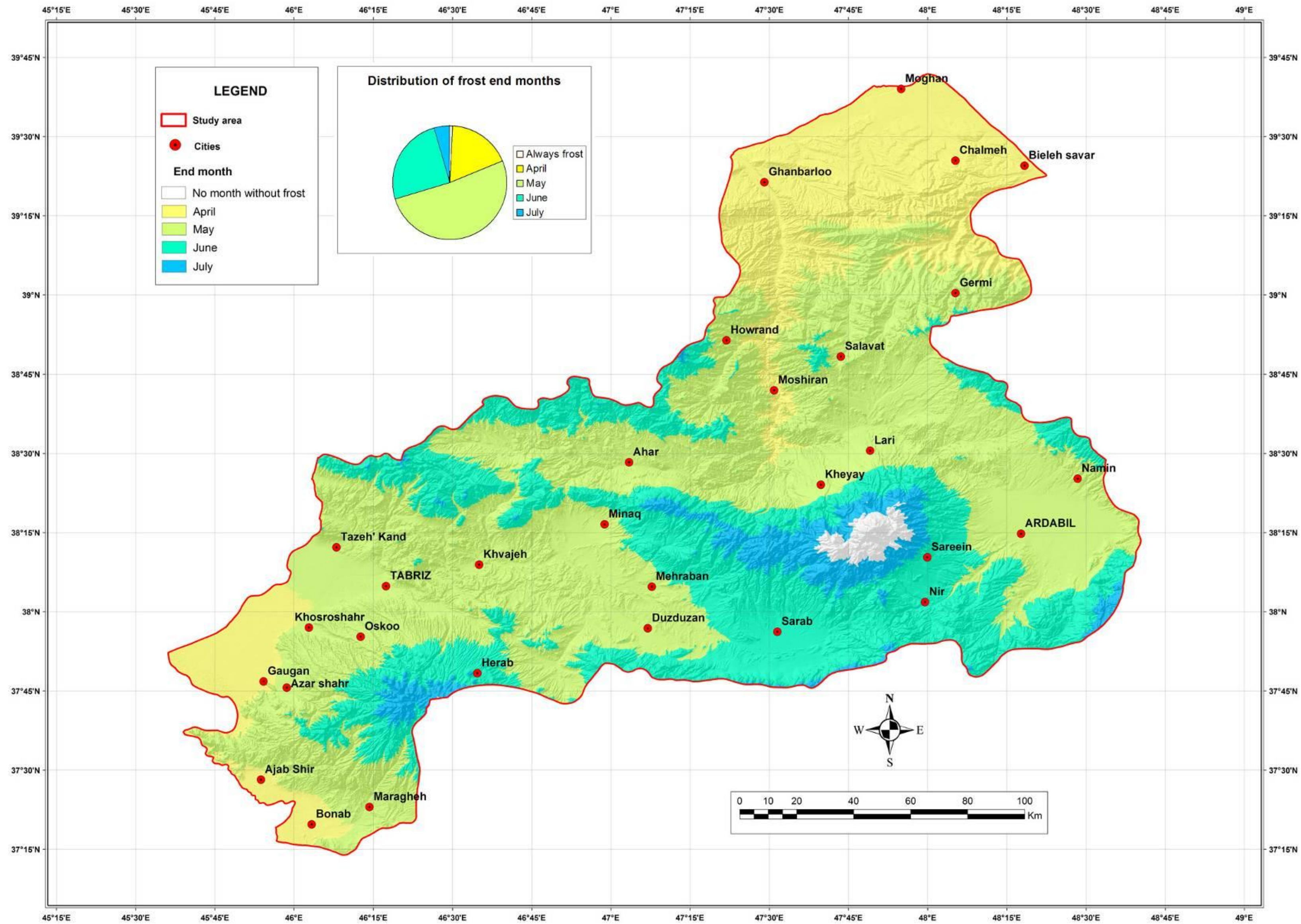
Map 11. Annual chilling degree days (below 0°C)



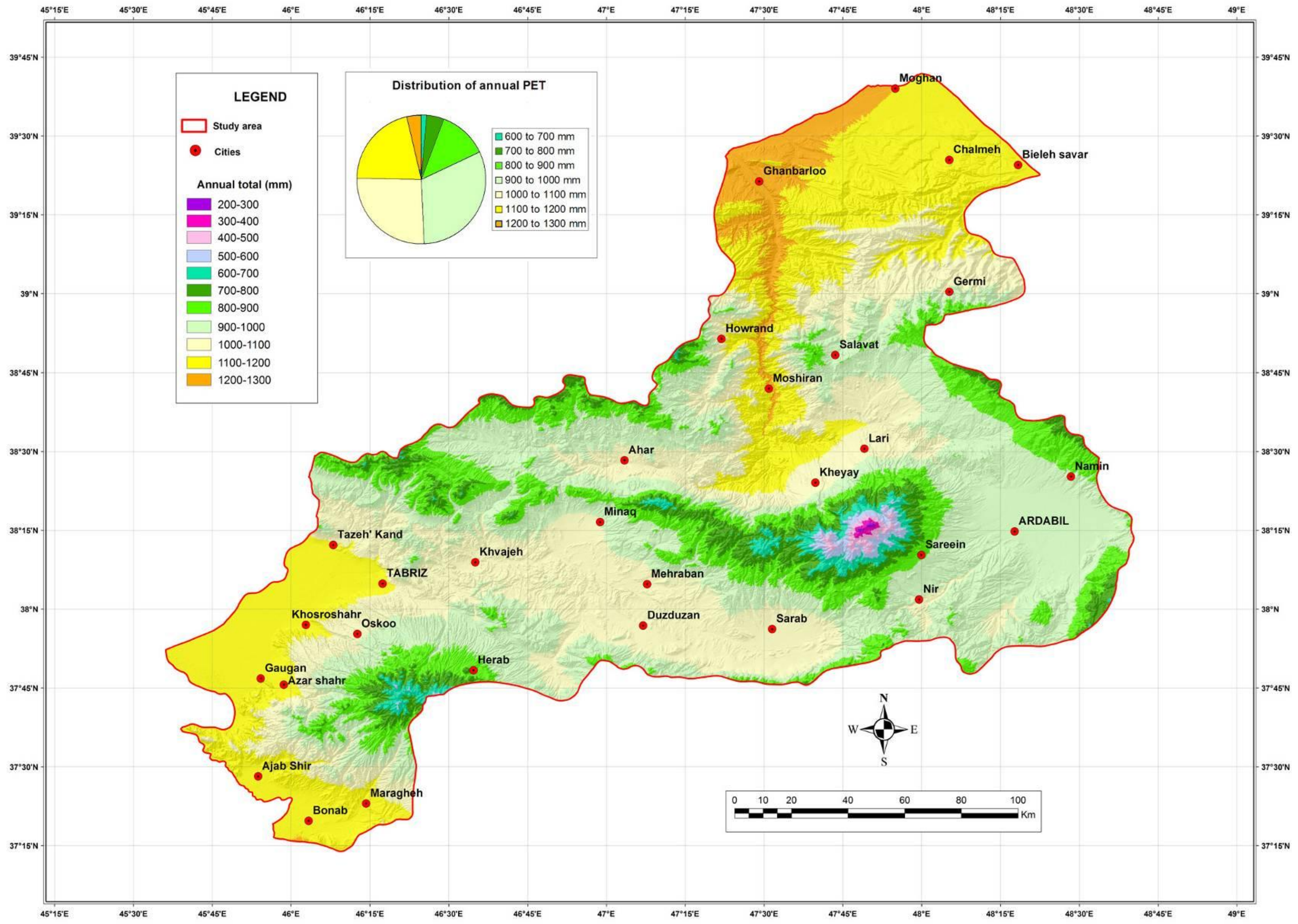
Map 12. Annual number of frost days



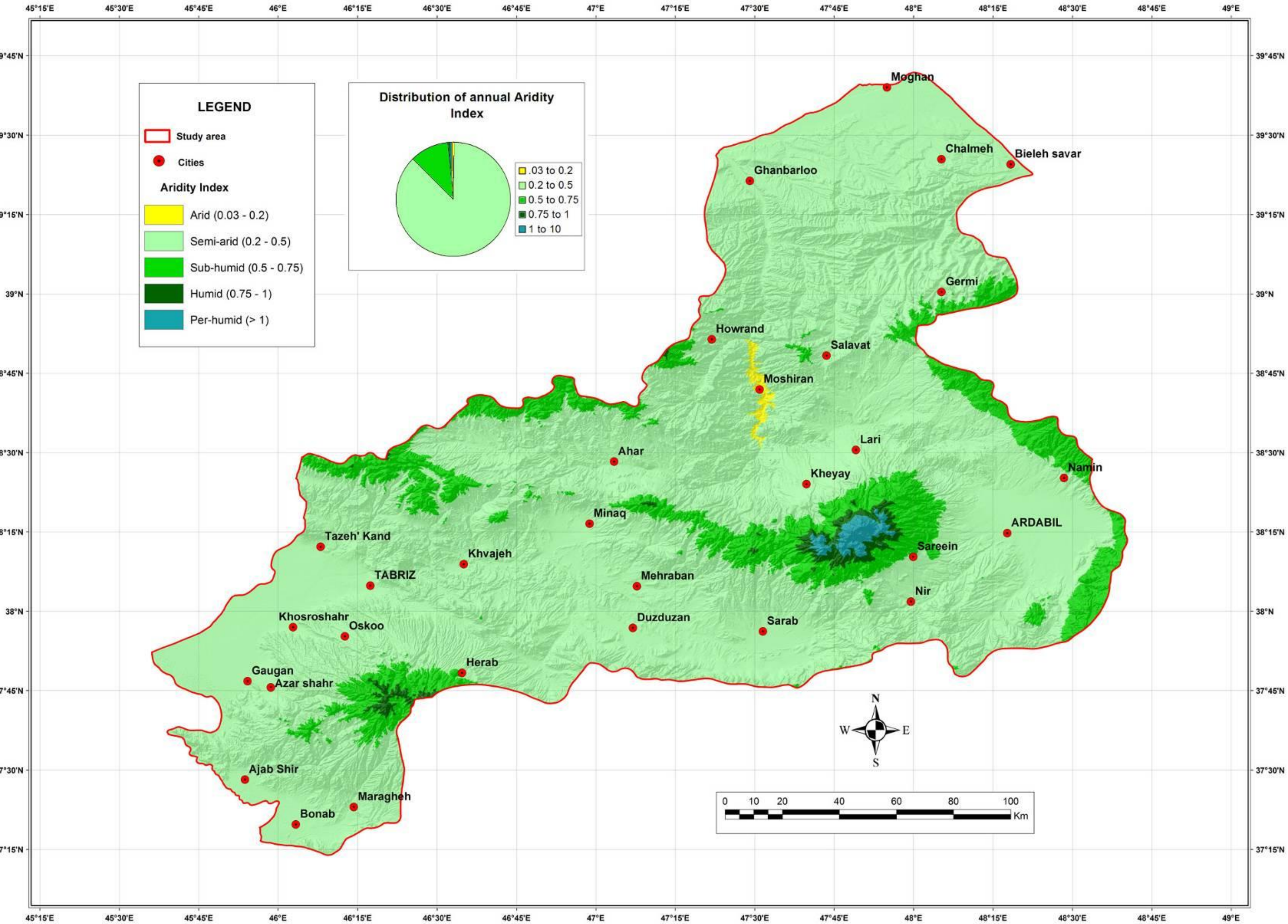
Map 13. Average onset month of frost



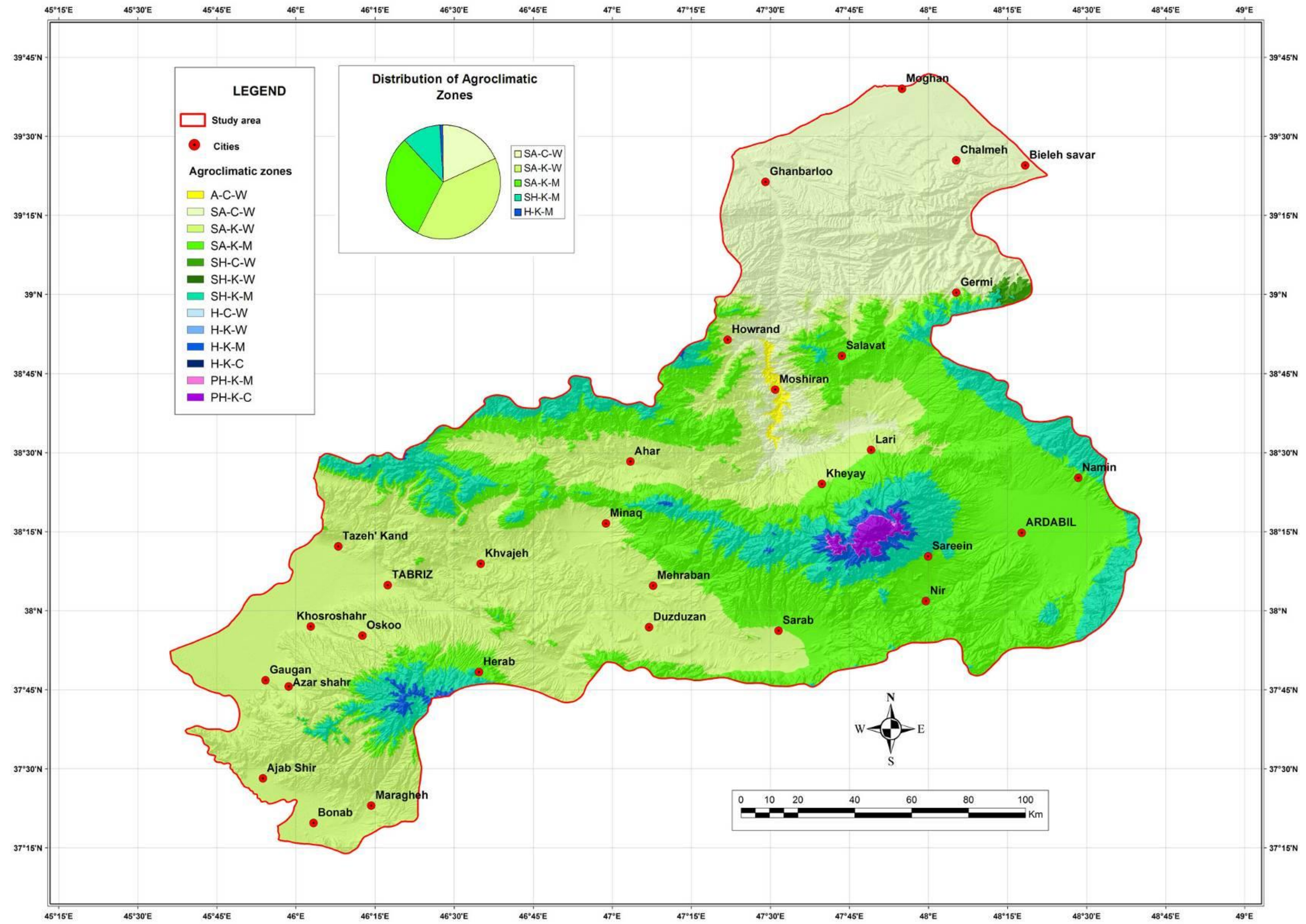
Map 14. Average end month of frost



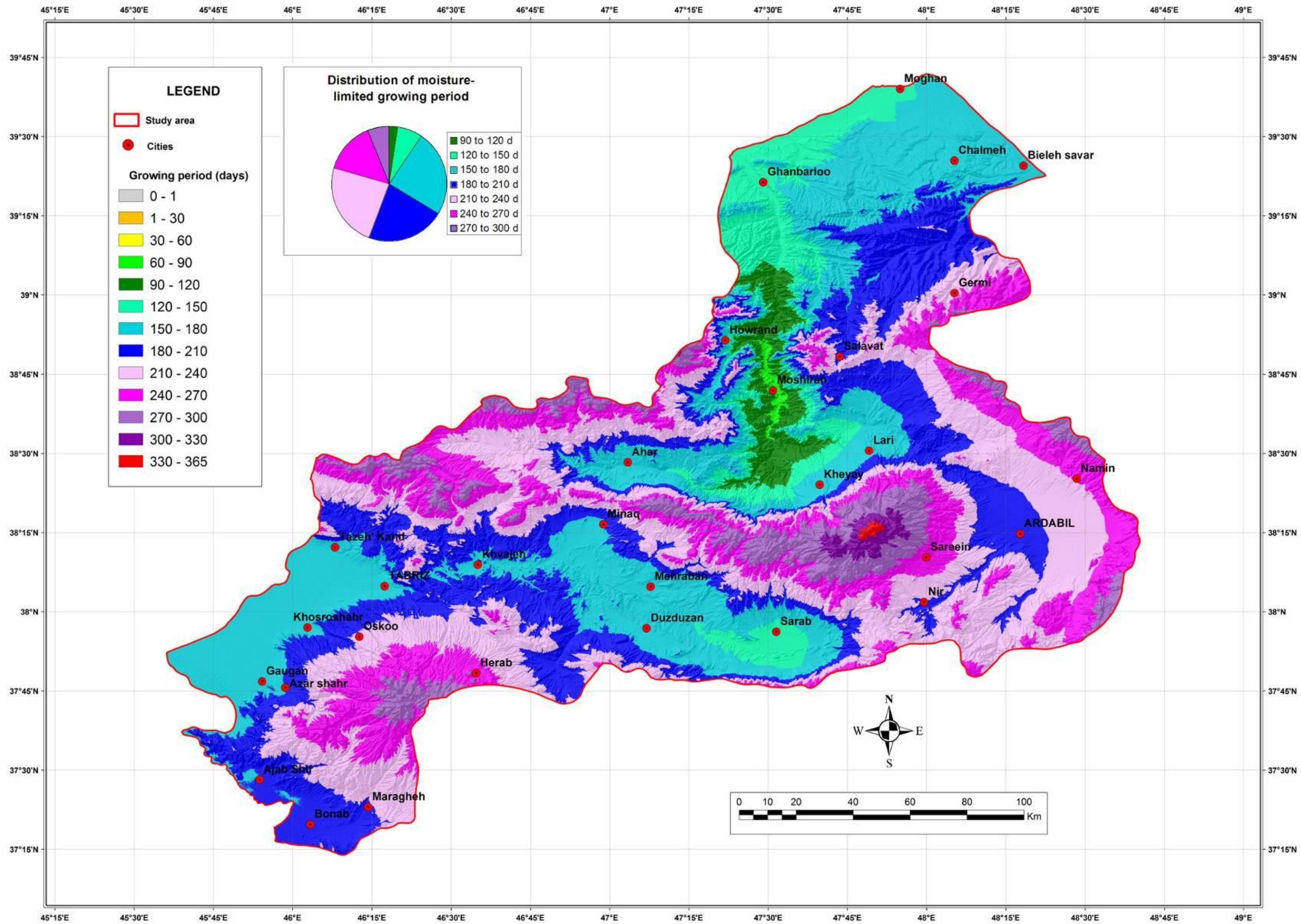
Map 15. Annual potential evapotranspiration



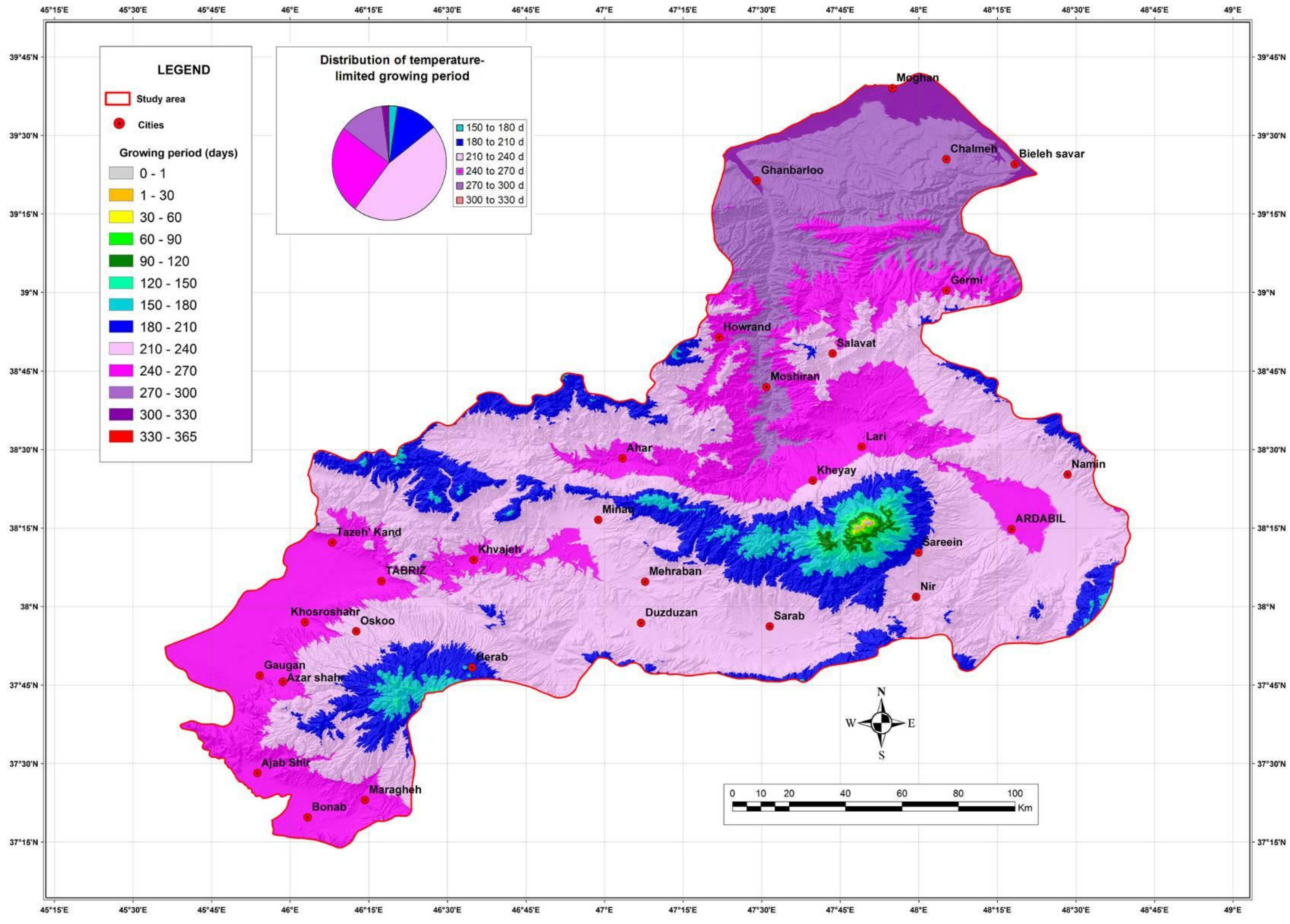
Map 16. Annual aridity index



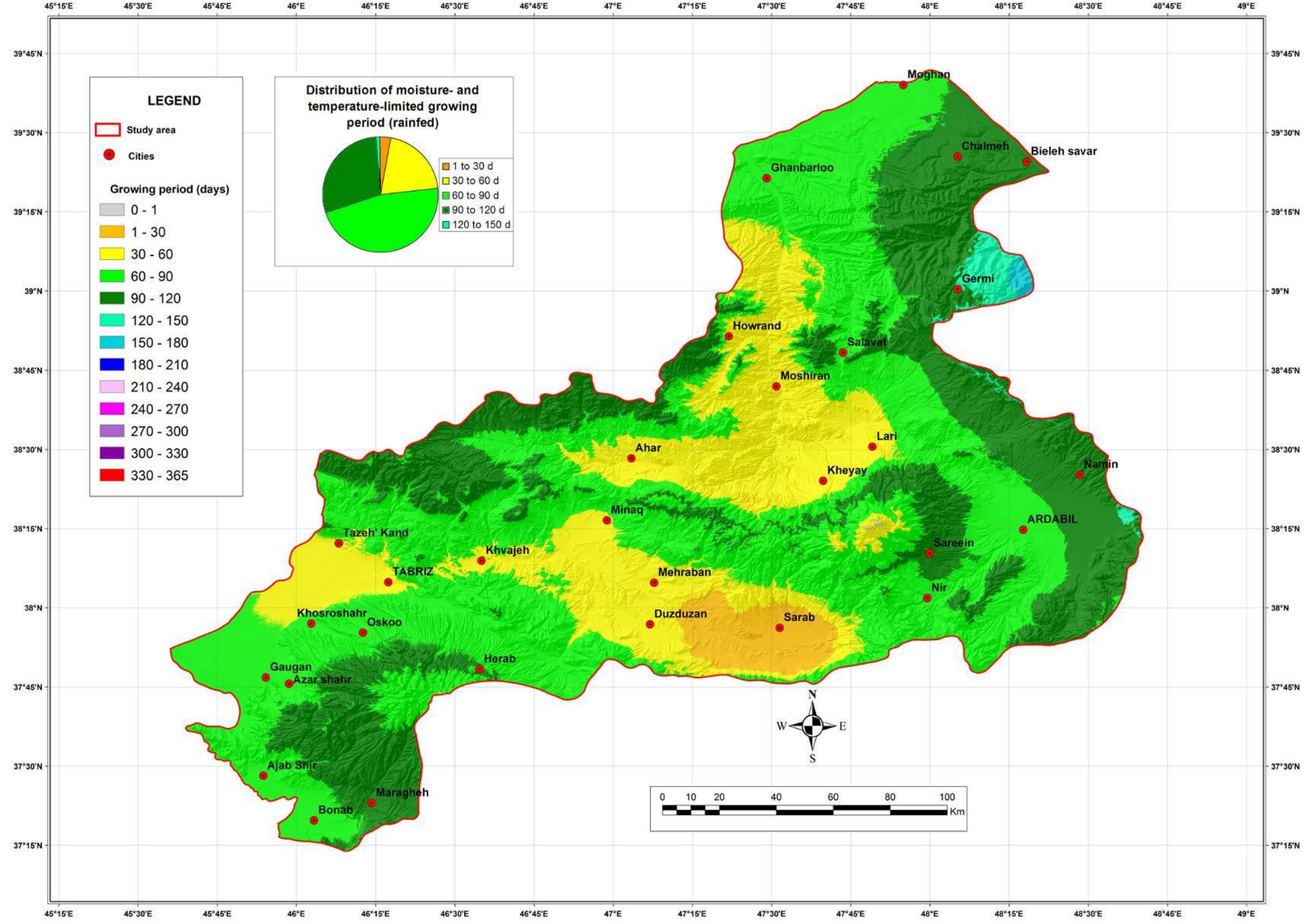
Map 17. Agroclimatic zones



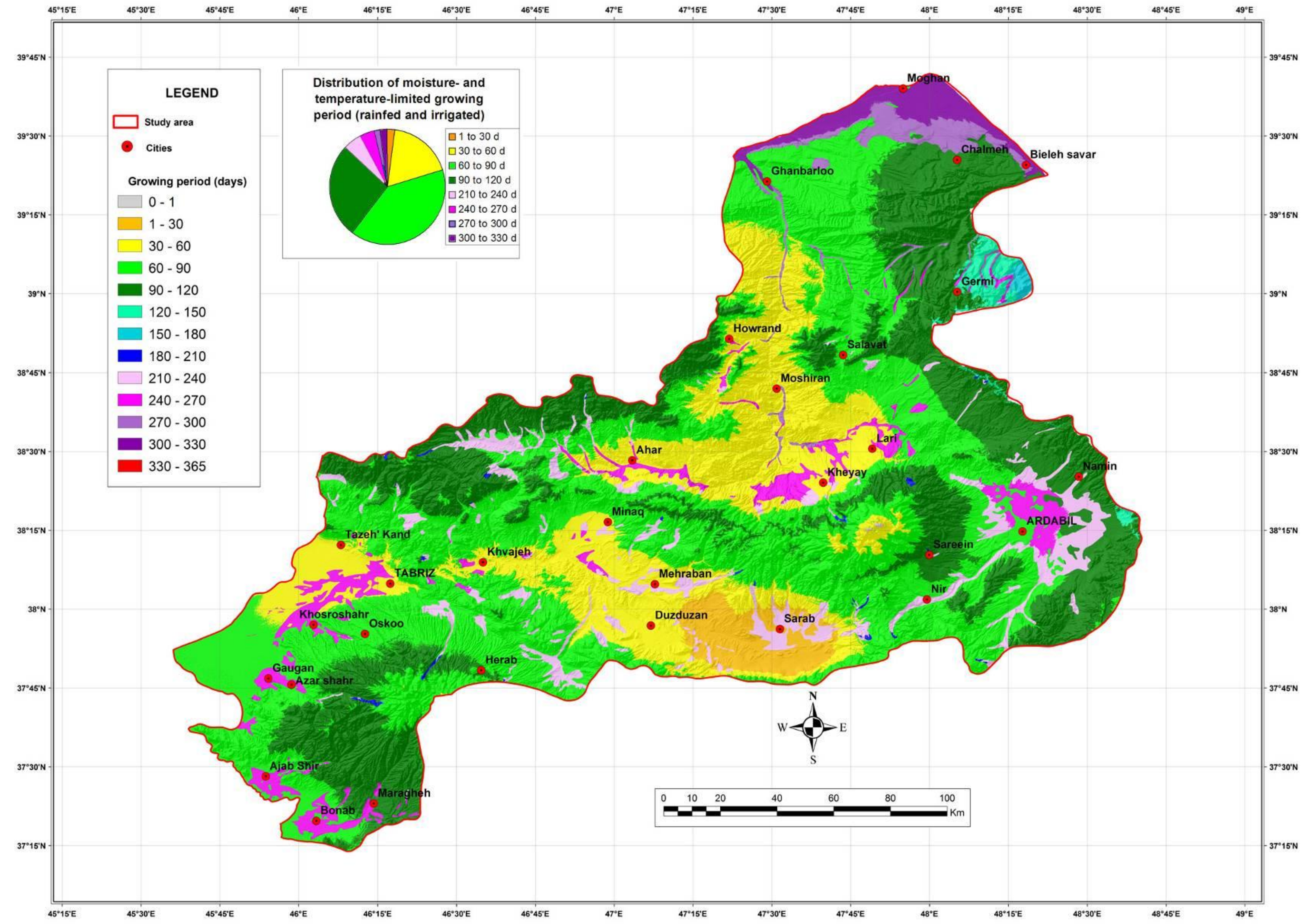
Map 18. Length of the moisture-limited growing period



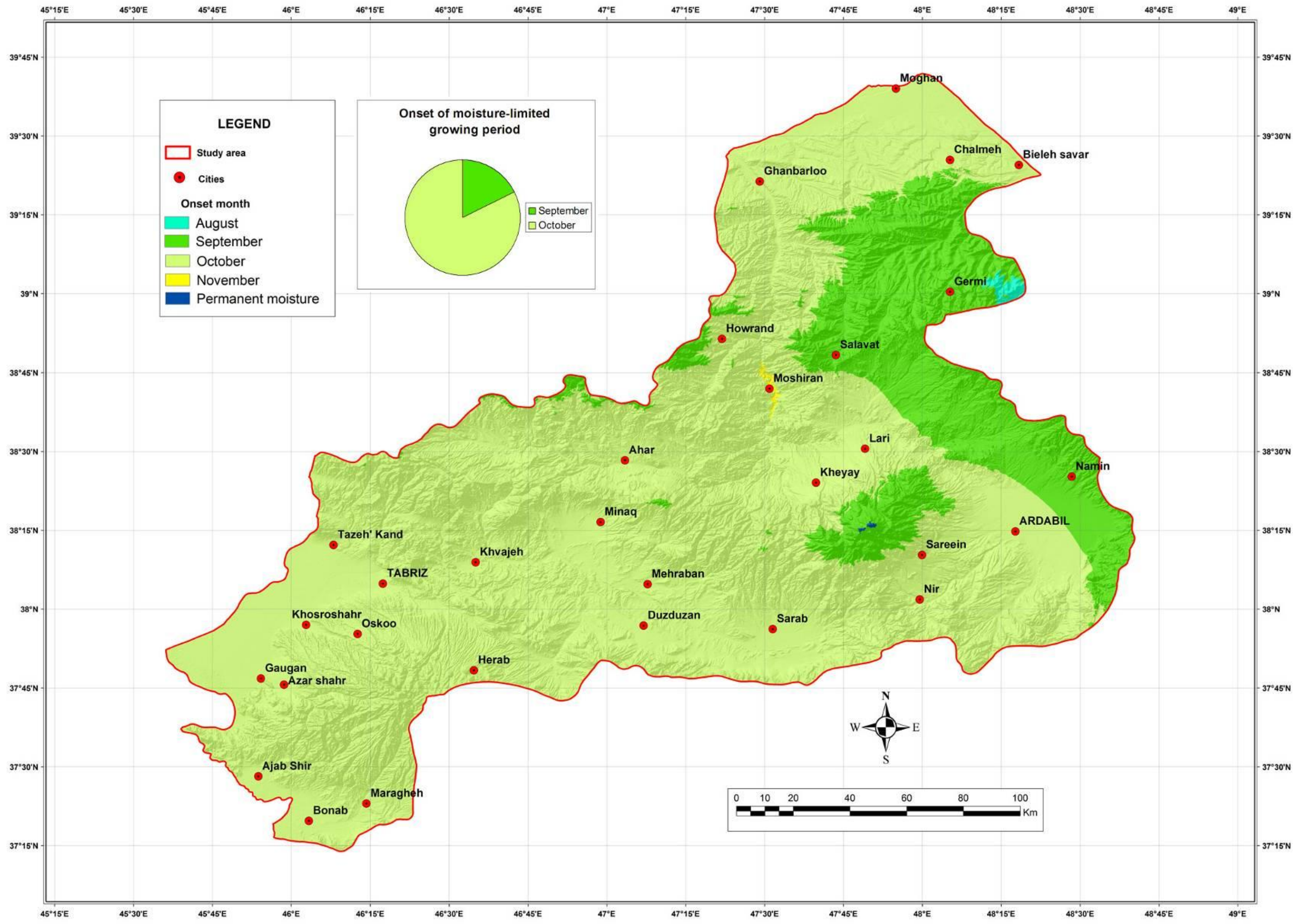
Map 19. Length of the temperature-limited growing period



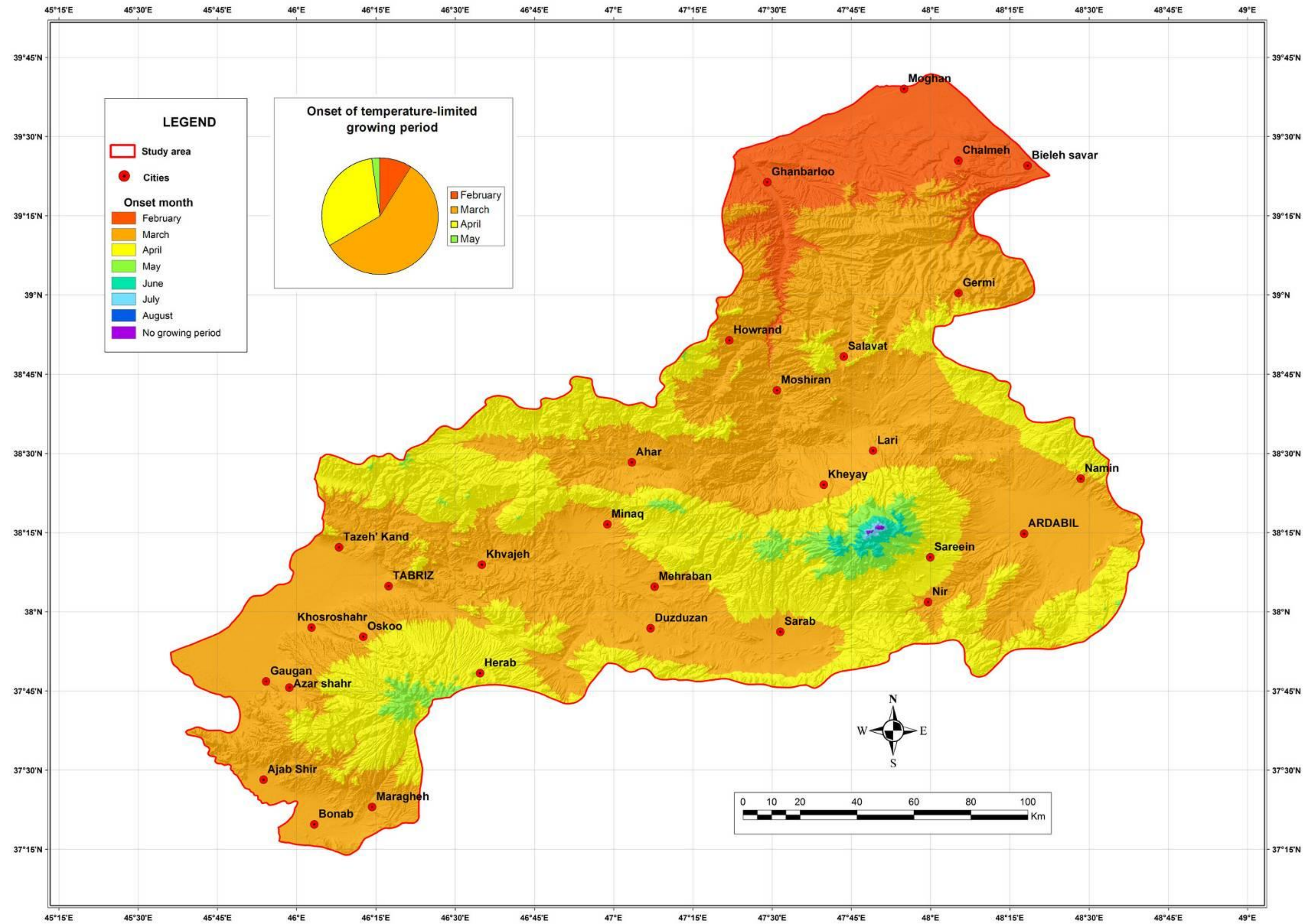
Map 20. Length of the moisture- and temperature-limited growing period under rainfed conditions



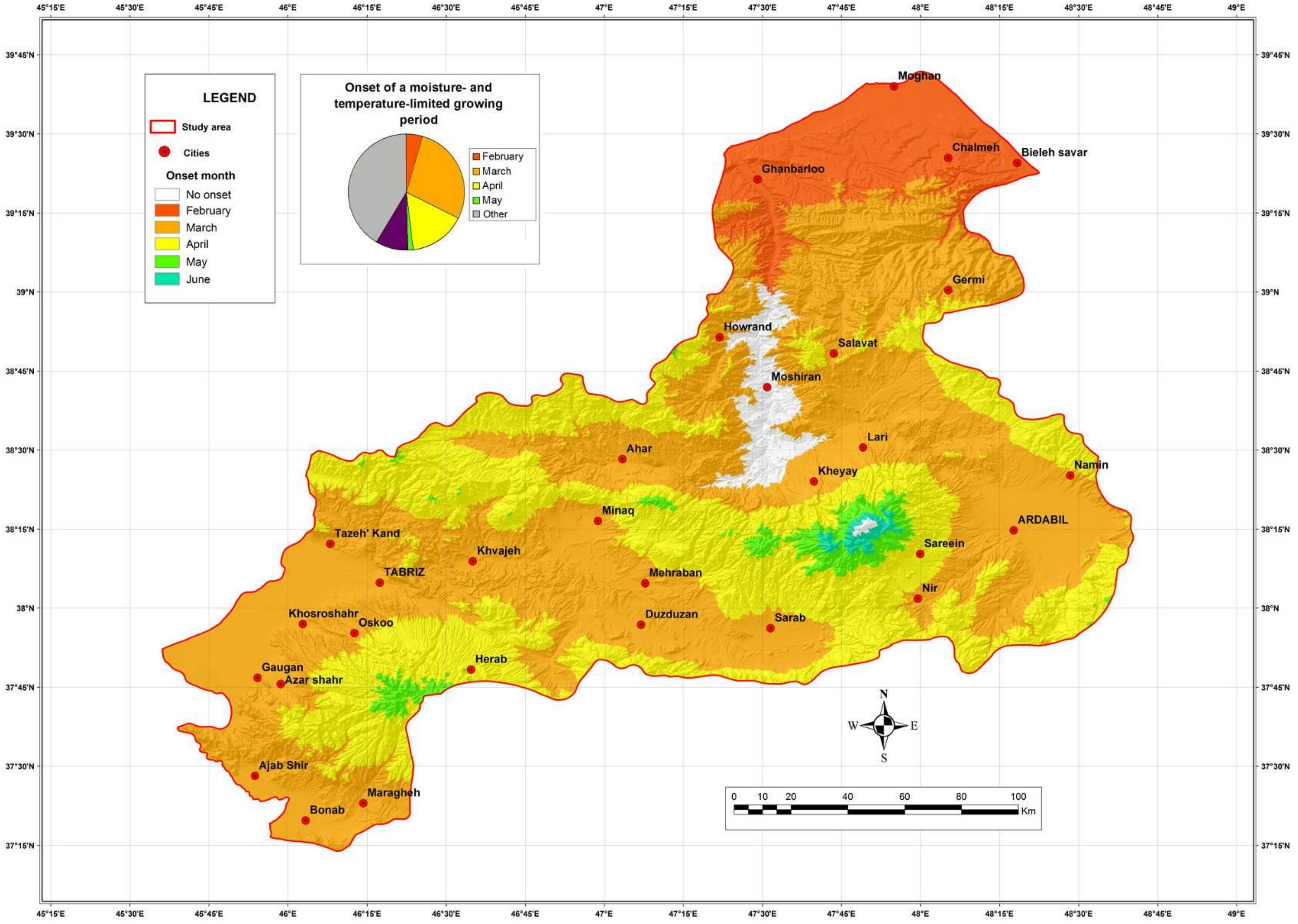
Map 21. Length of the moisture- and temperature-limited growing period under rainfed and irrigated conditions



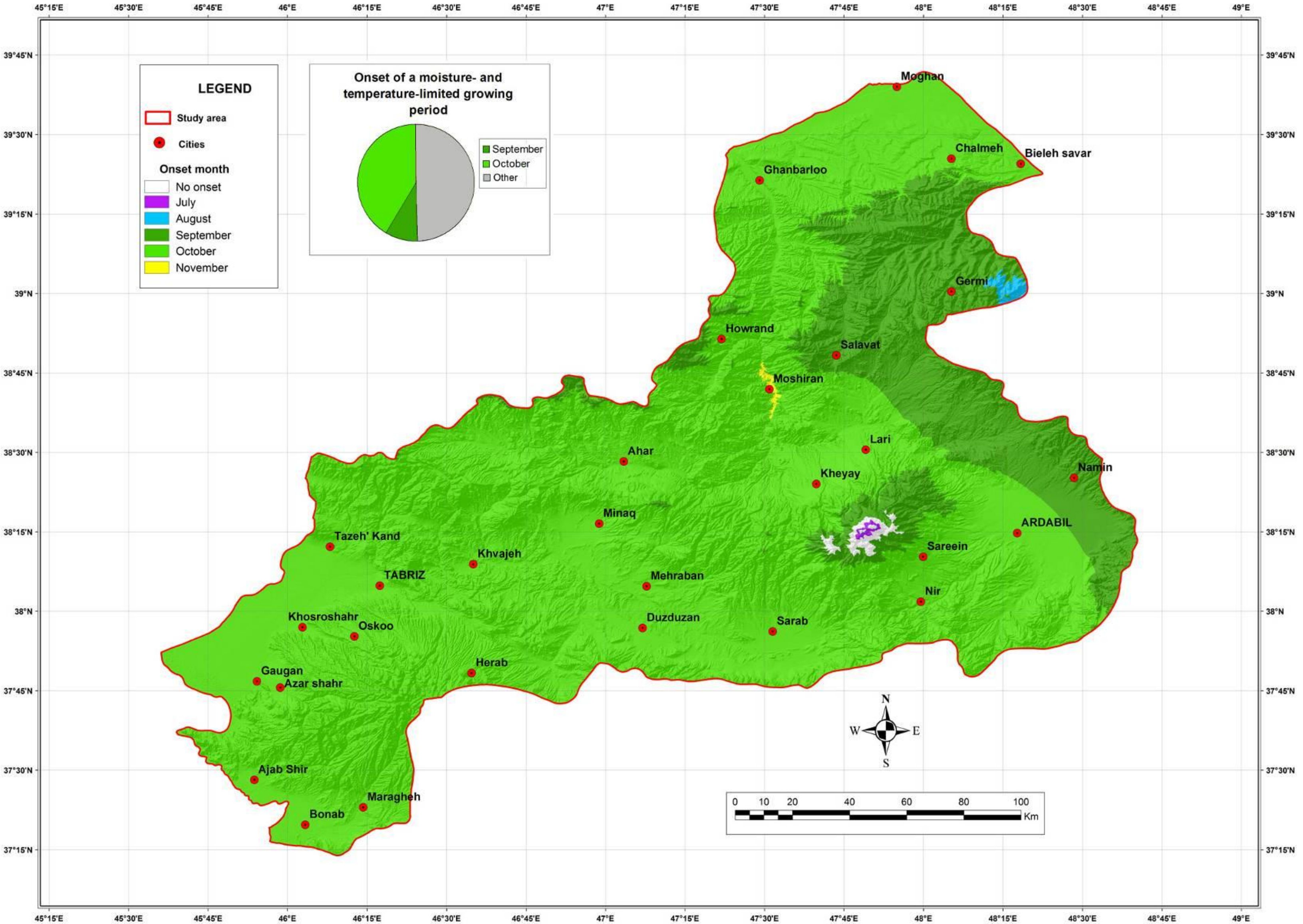
Map 22. Onset of the moisture-limited growing period



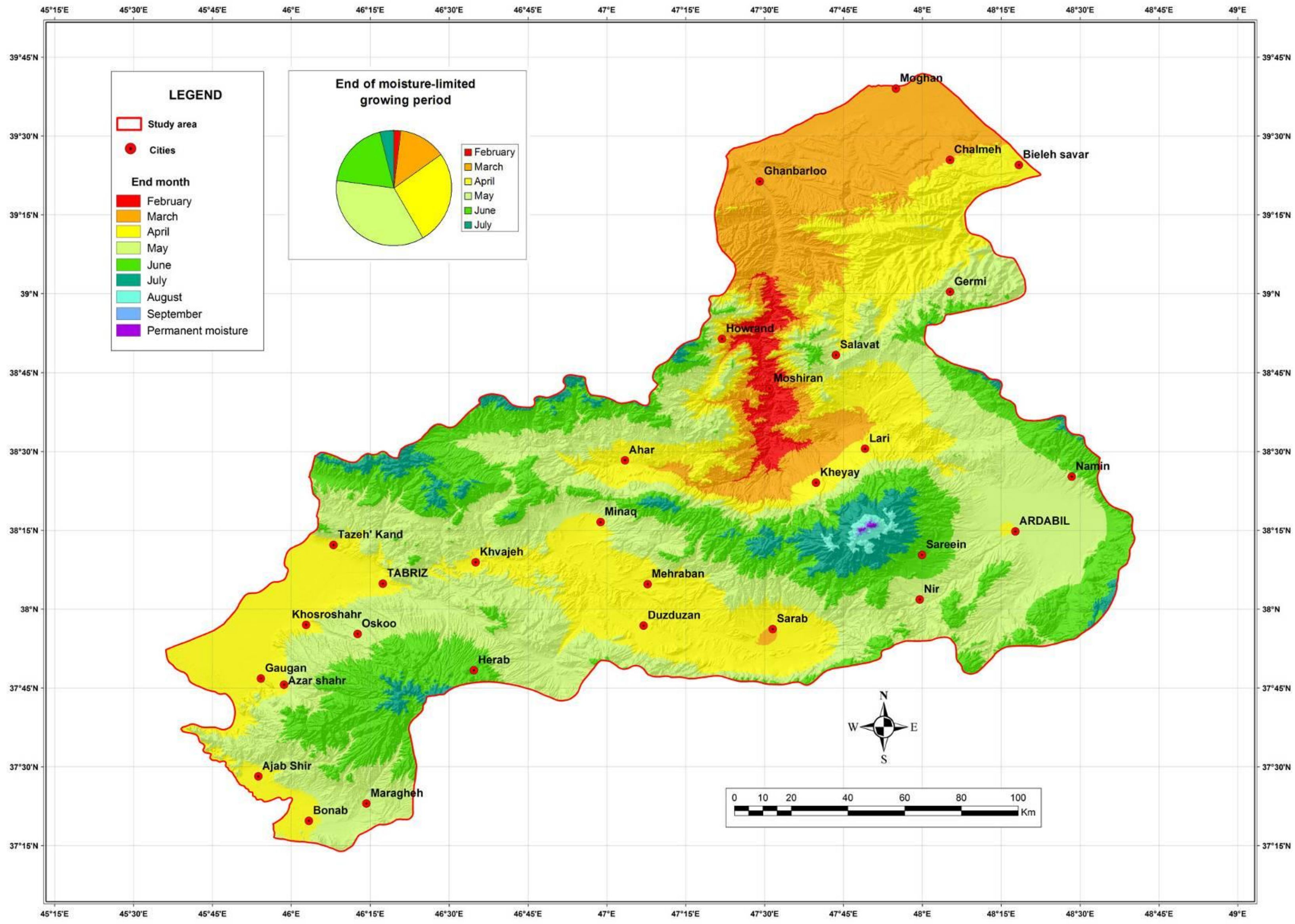
Map 23. Onset of the temperature-limited growing period



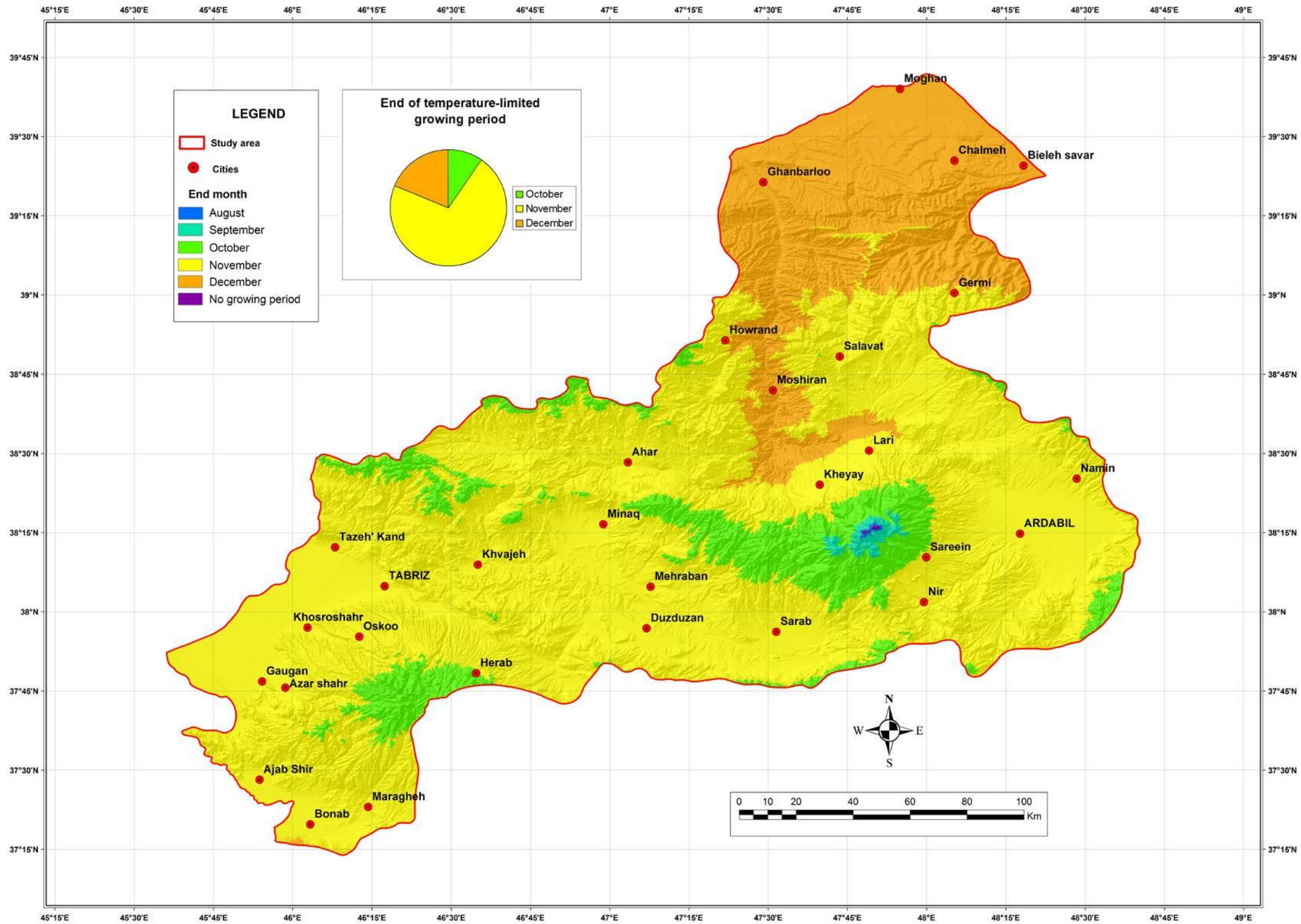
Map 24. Onset of the moisture- and temperature-limited growing period (January-June)



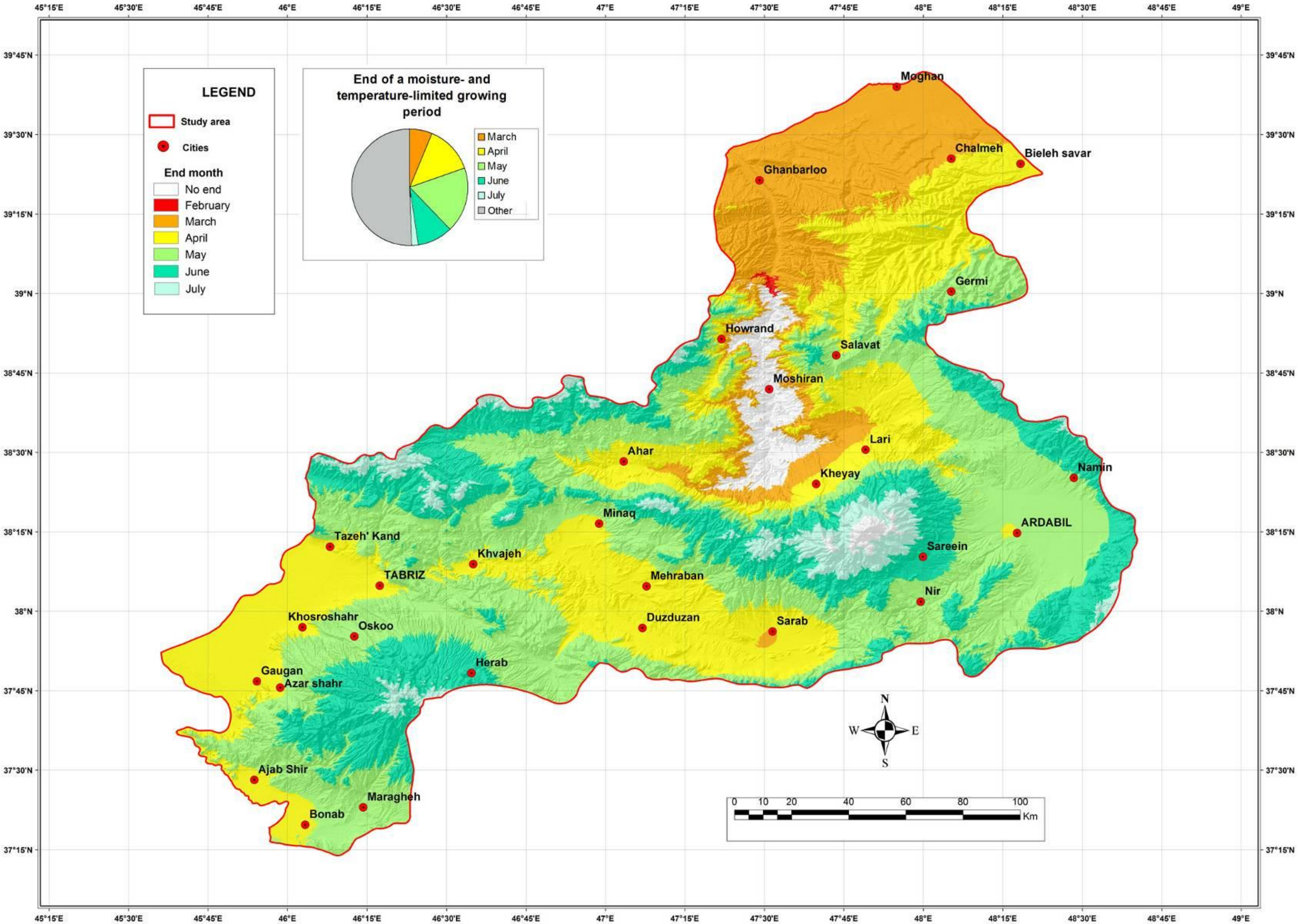
Map 25. Onset of the moisture- and temperature-limited growing period (July-December)



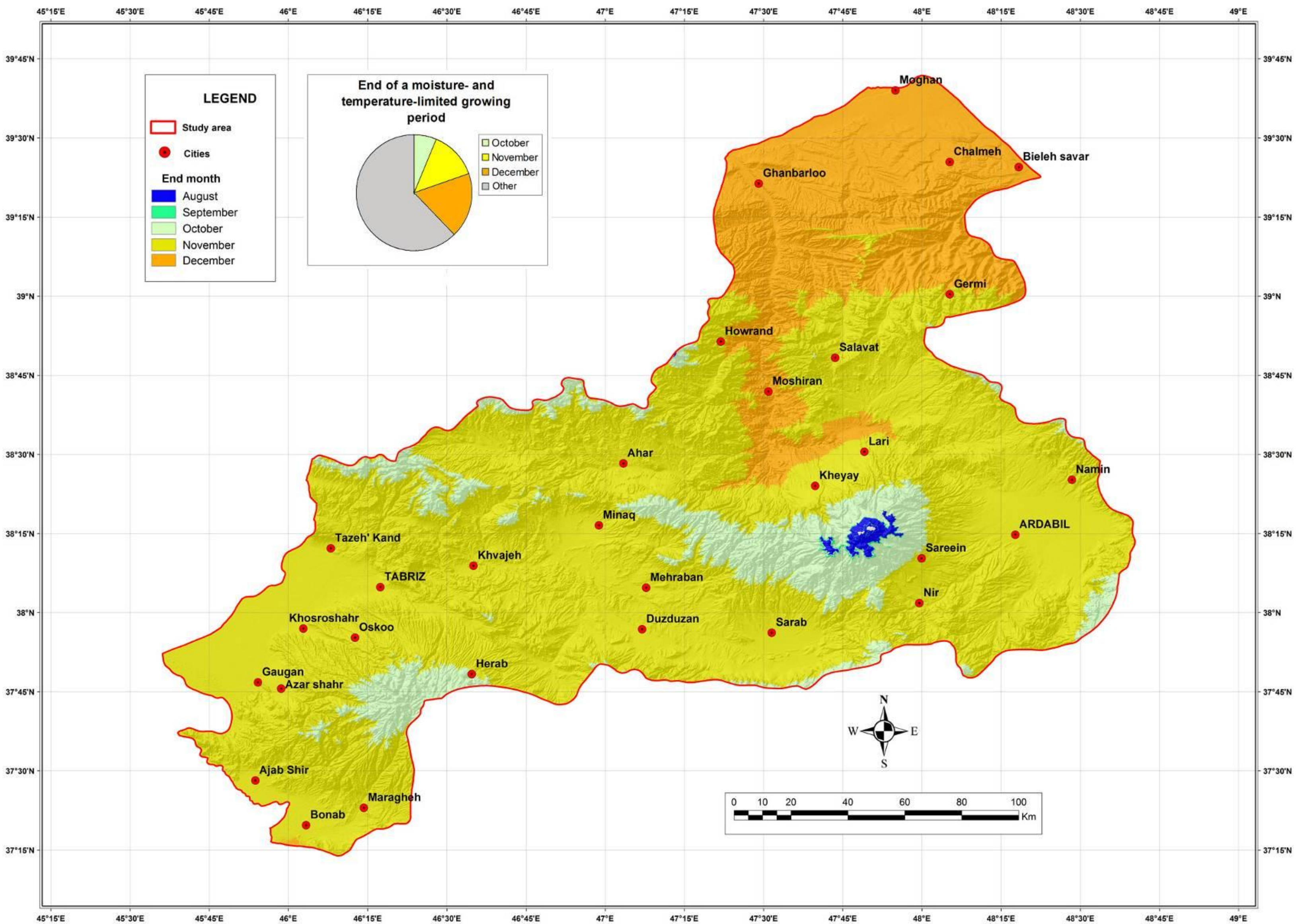
Map 26. End of the moisture-limited growing period



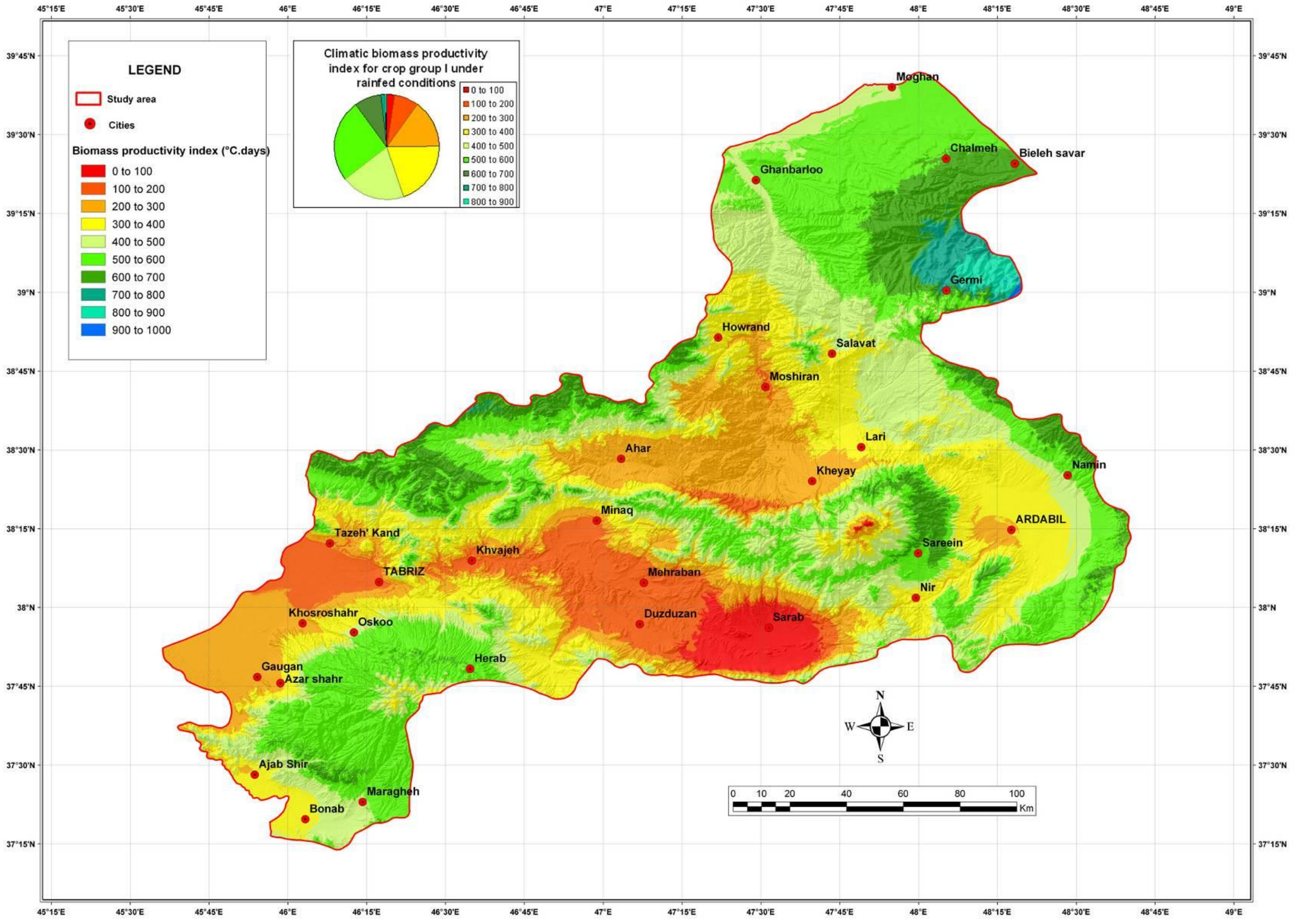
Map 27. End of the temperature-limited growing period



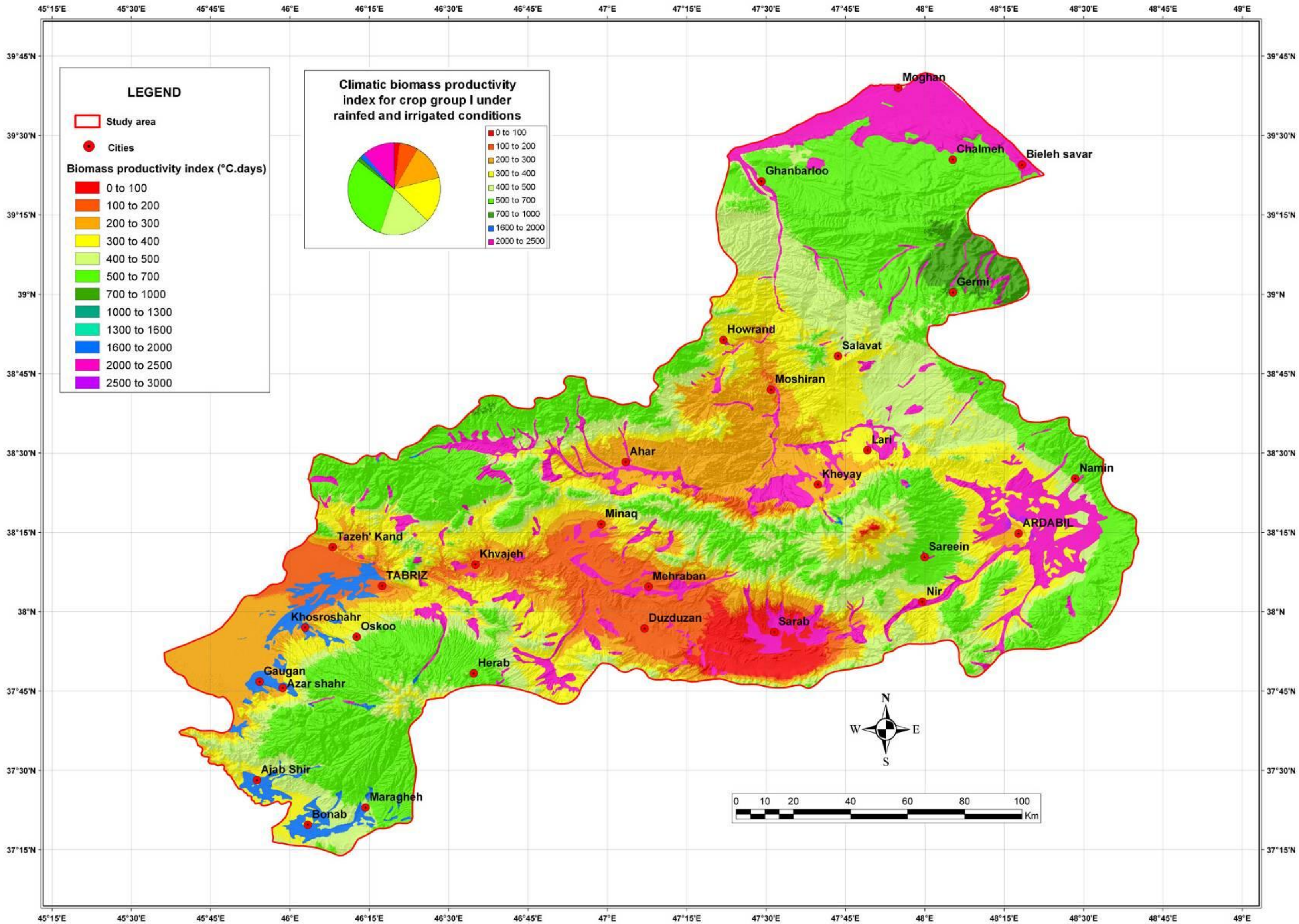
Map 28. End of the moisture- and temperature-limited growing period (January-July)



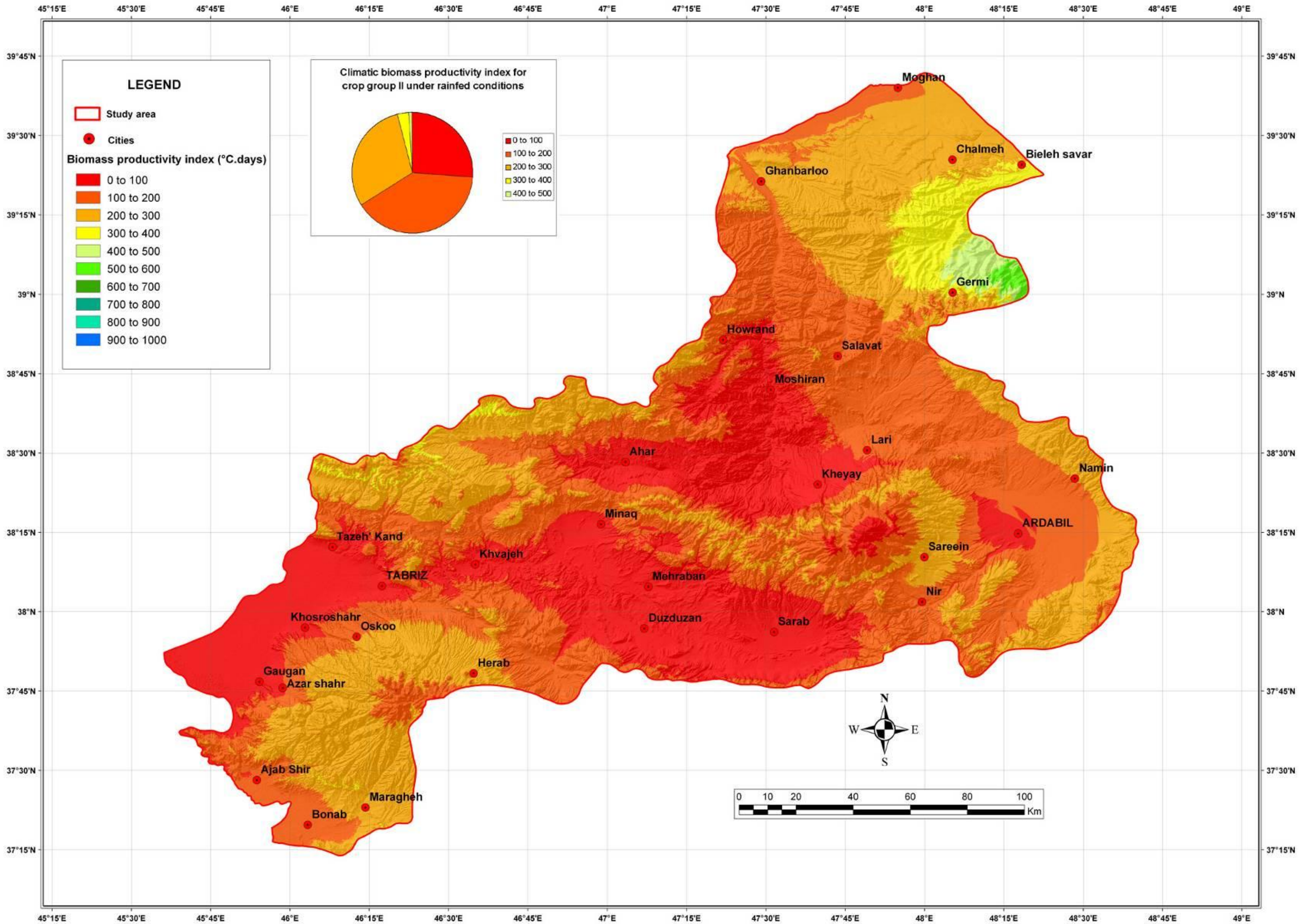
Map 29. End of the moisture- and temperature-limited growing period (August-December)



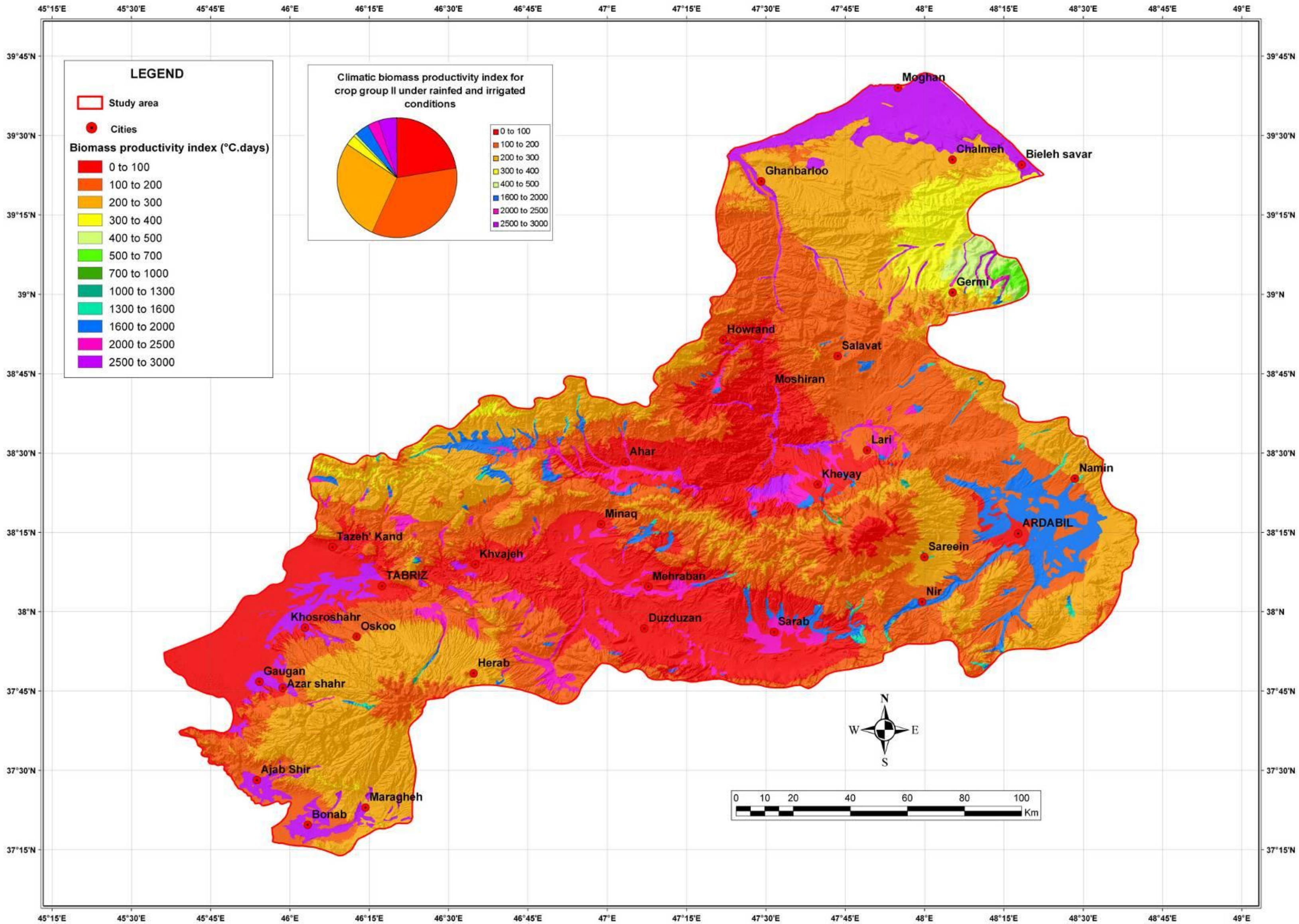
Map 30.Climatic biomass productivity index for crop group I under rainfed conditions



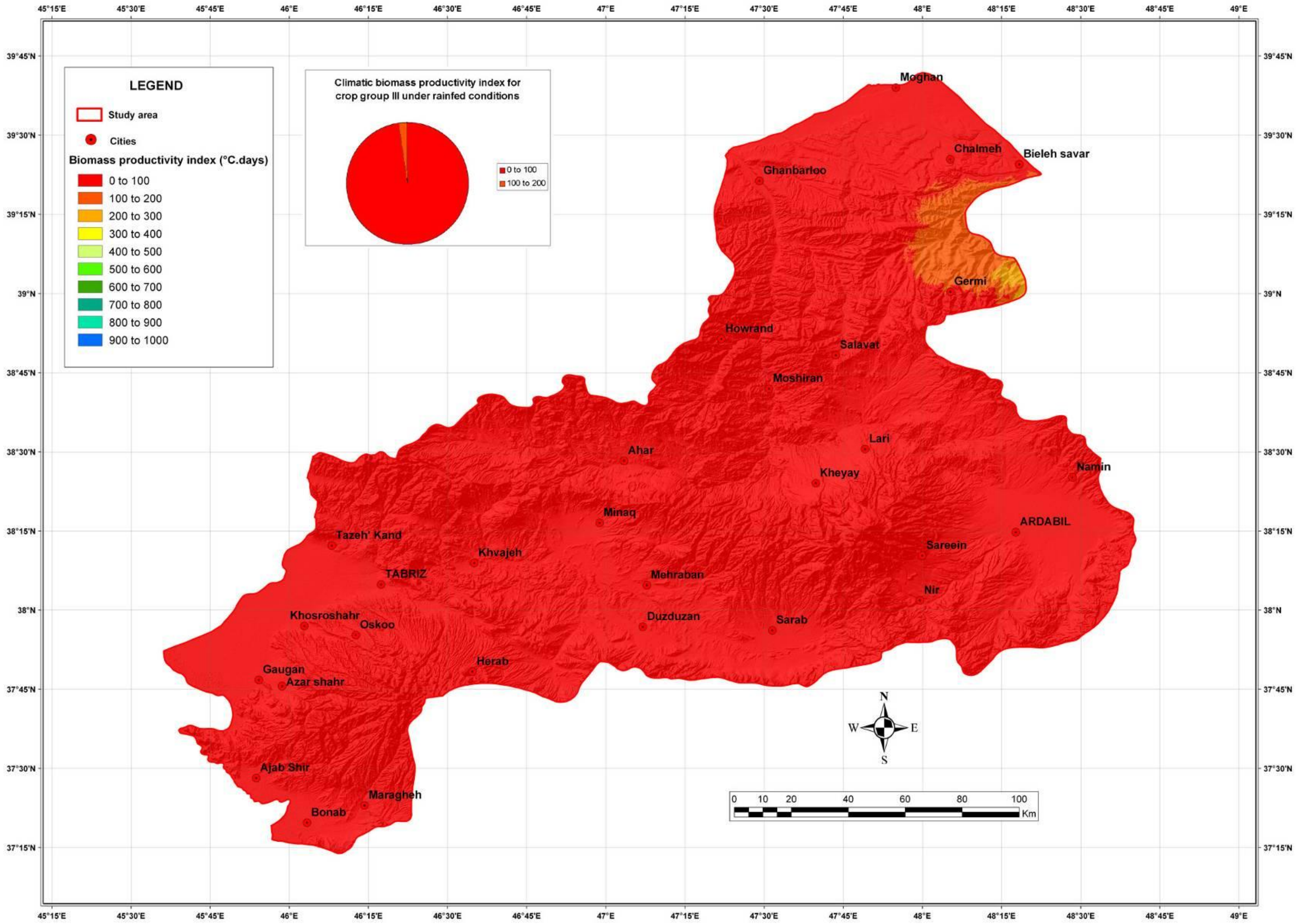
Map 31.Climatic biomass productivity index for crop group I under rainfed and irrigated conditions



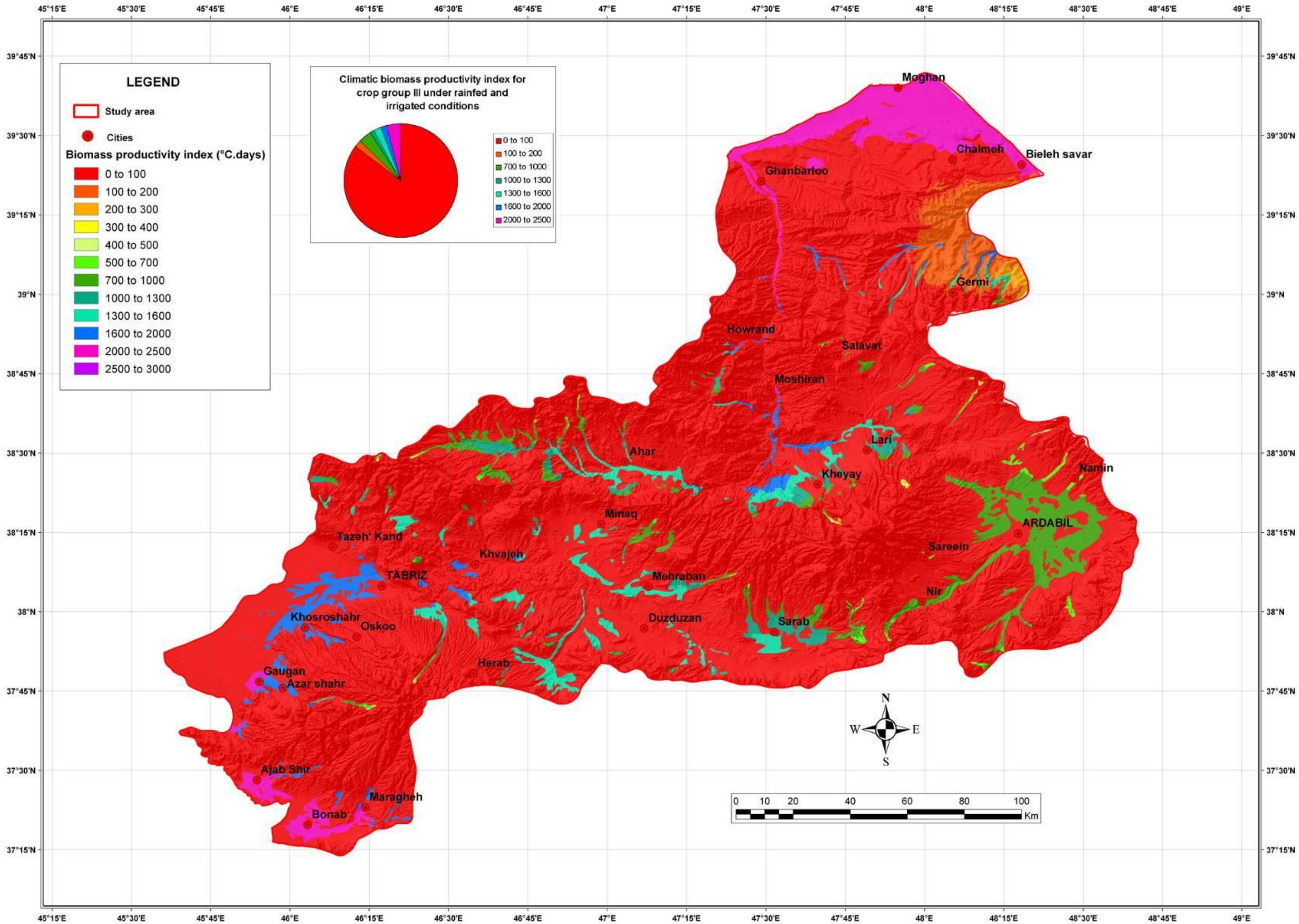
Map 32.Climatic biomass productivity index for crop group II under rainfed conditions



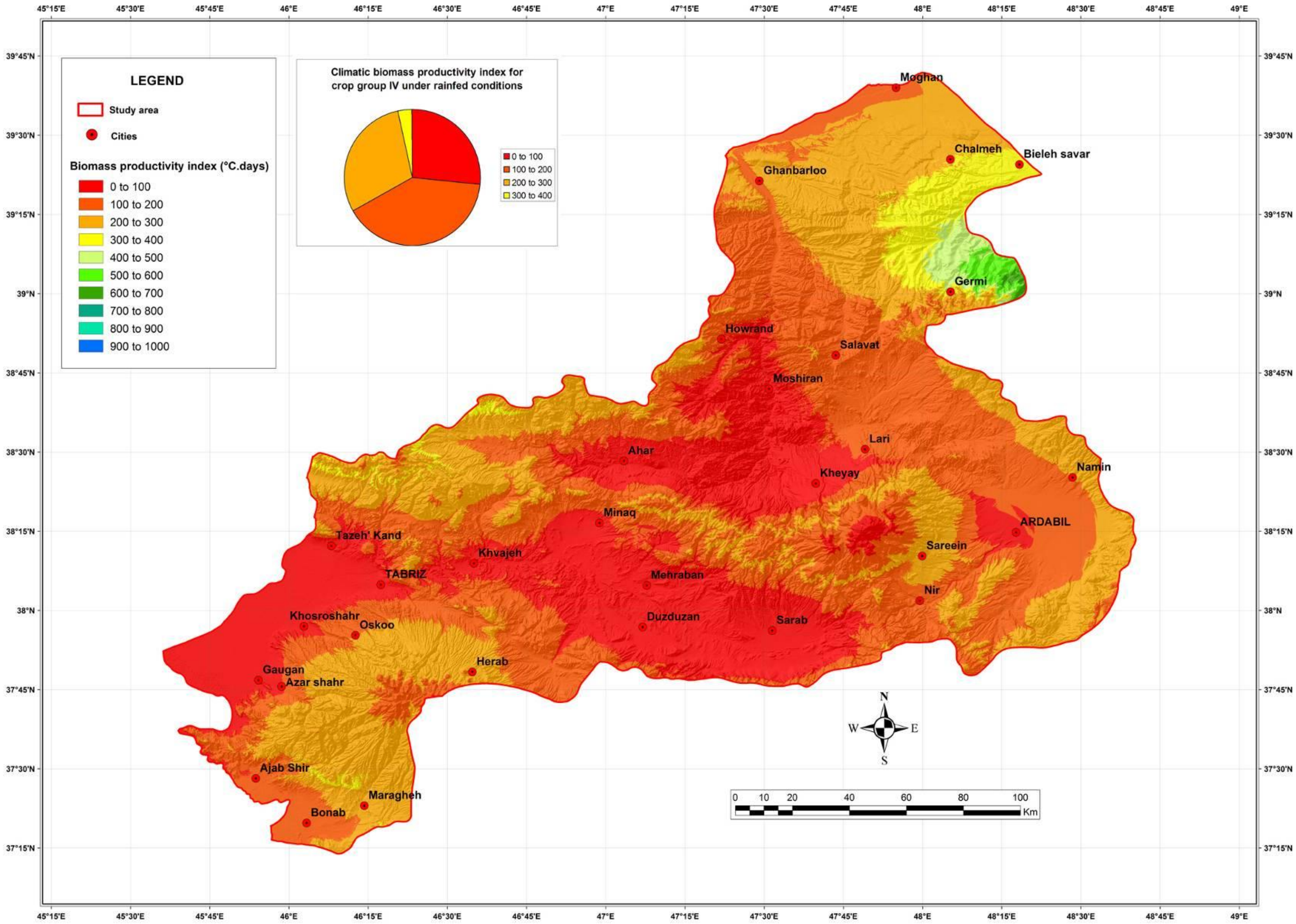
Map 33.Climatic biomass productivity index for crop group II under rainfed and irrigated conditions



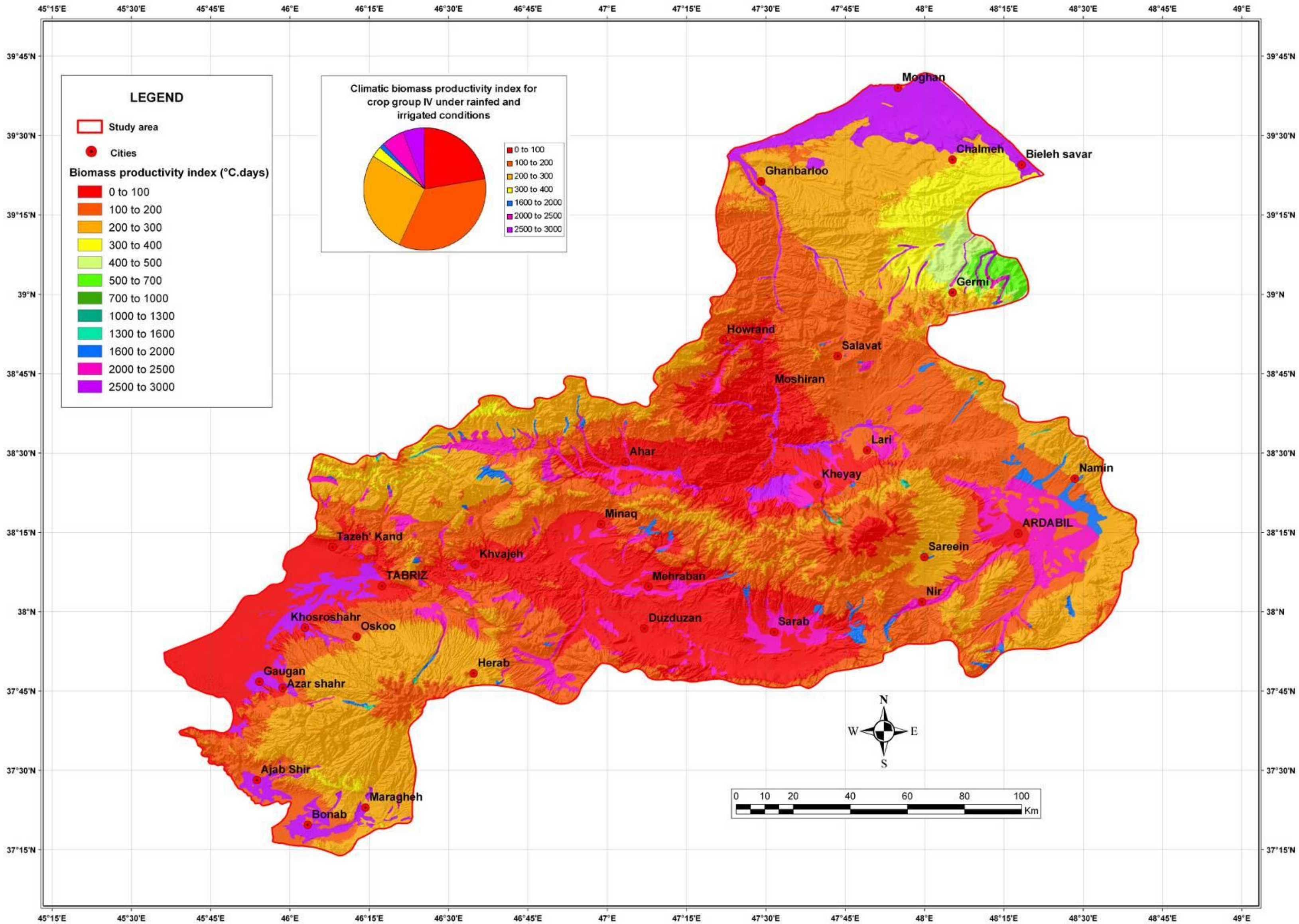
Map 34.Climatic biomass productivity index for crop group III under rainfed conditions



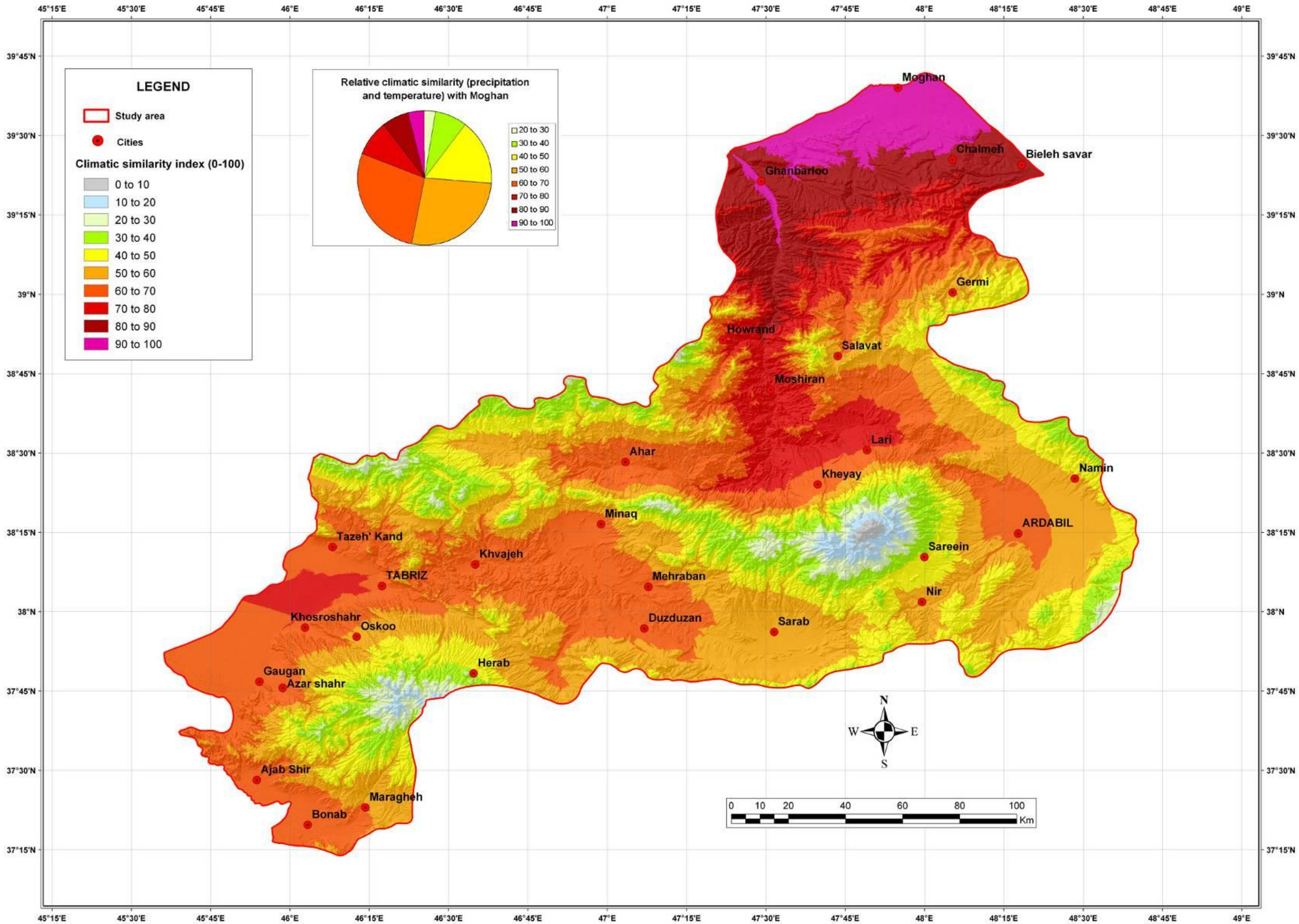
Map 35.Climatic biomass productivity index for crop group III under rainfed and irrigated conditions



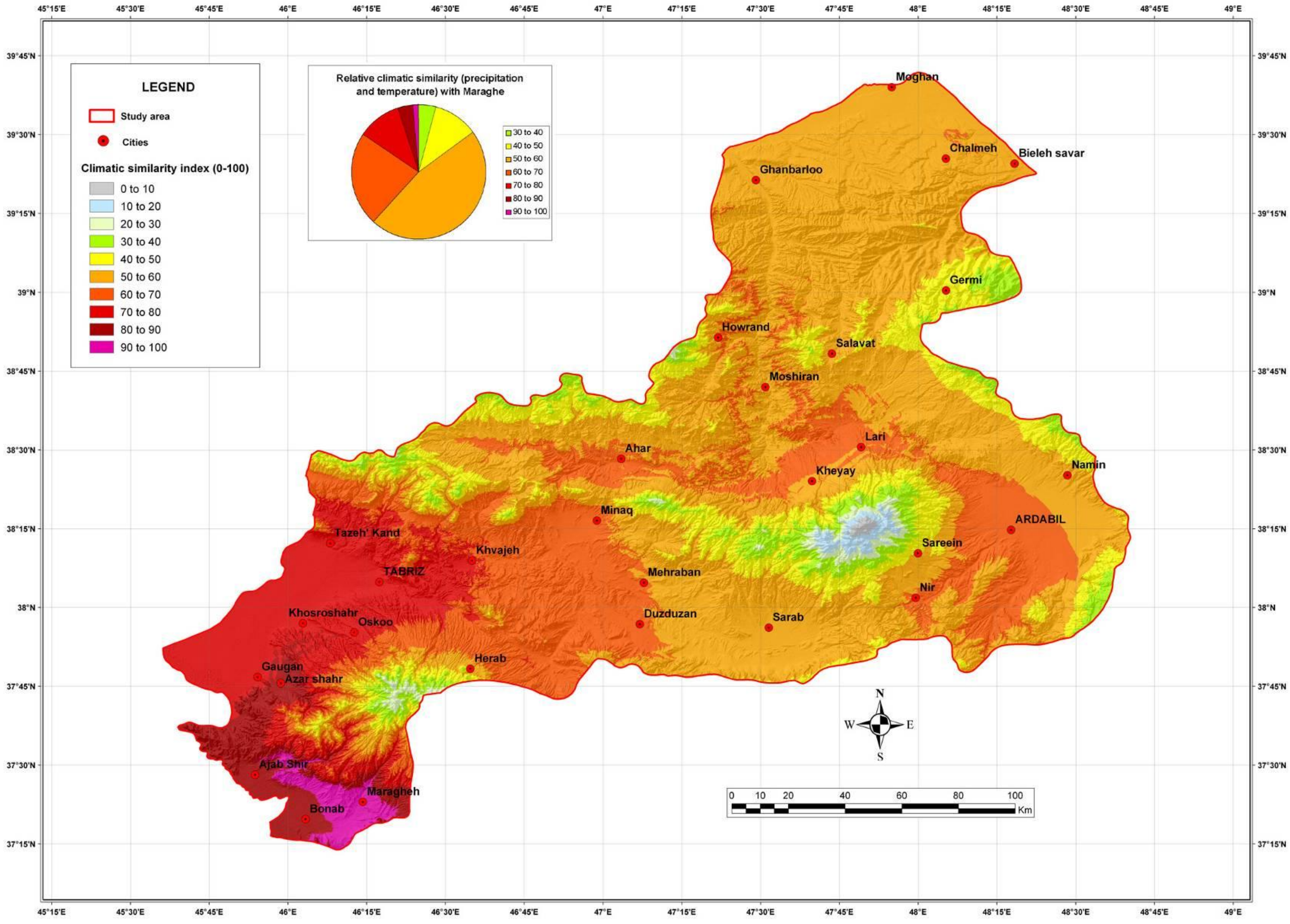
Map 36.Climatic biomass productivity index for crop group IV under rainfed conditions



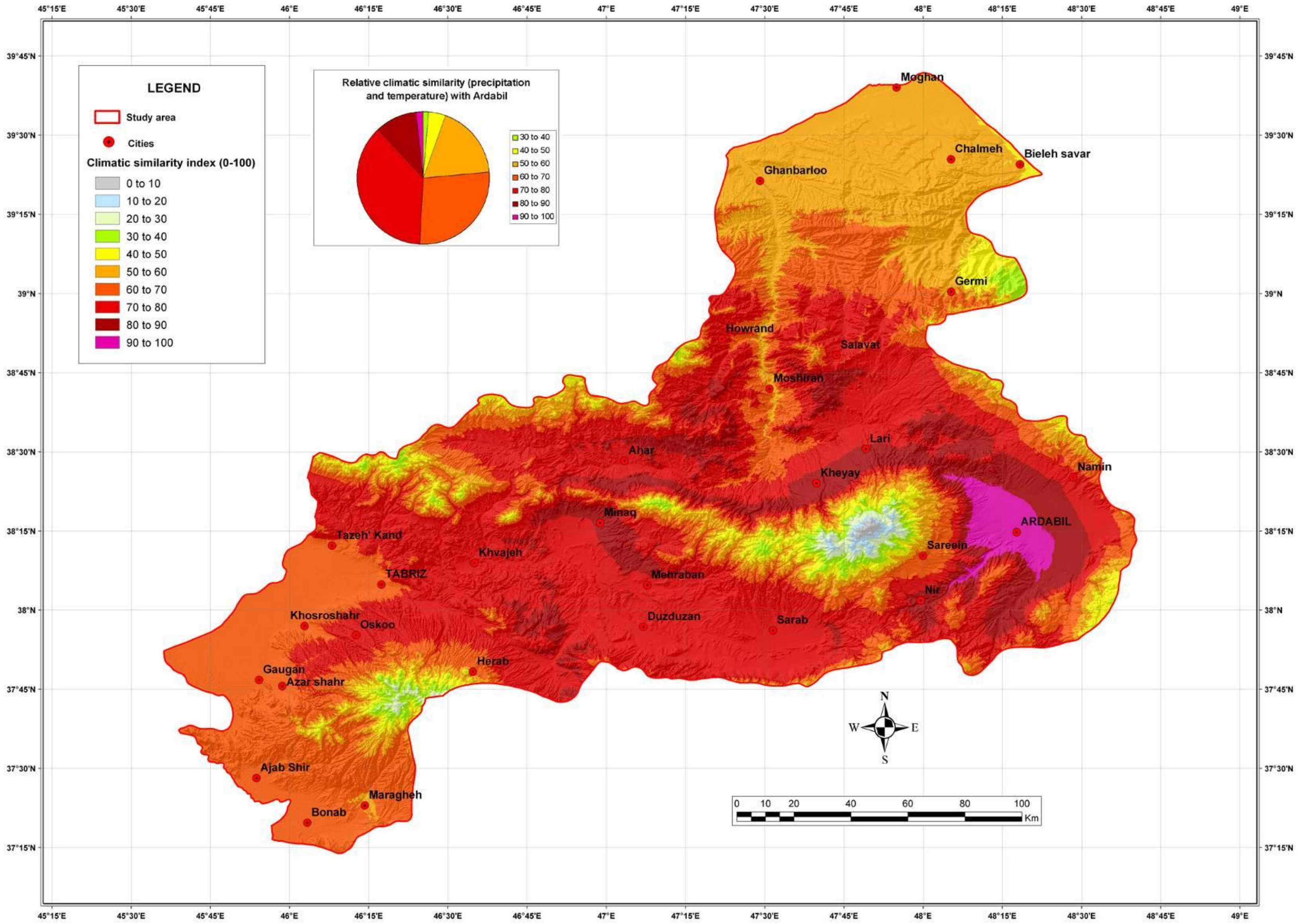
Map 37.Climatic biomass productivity index for crop group IV under rainfed and irrigated conditions



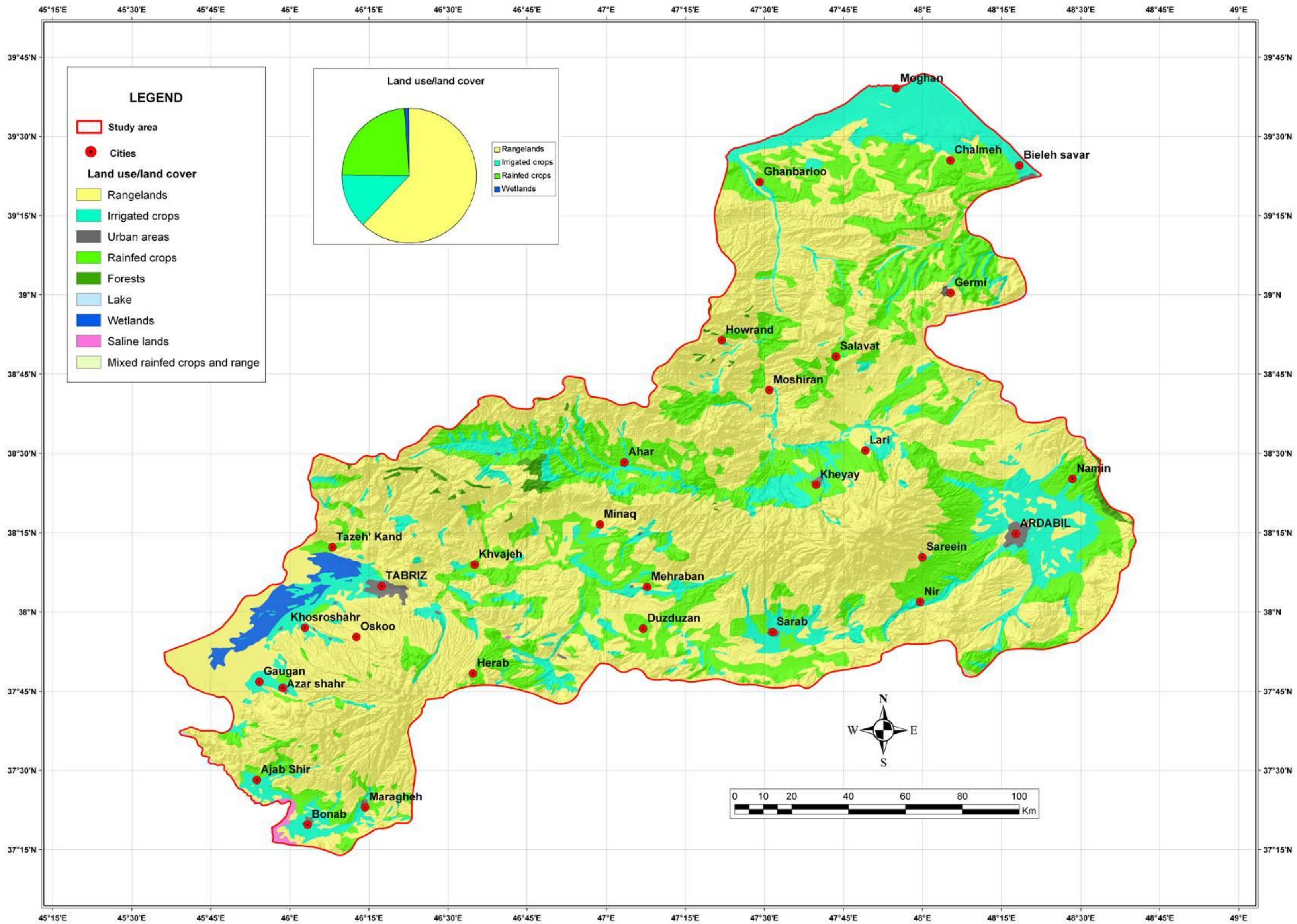
Map 38. Relative climatic similarity (precipitation and temperature) with Moghan



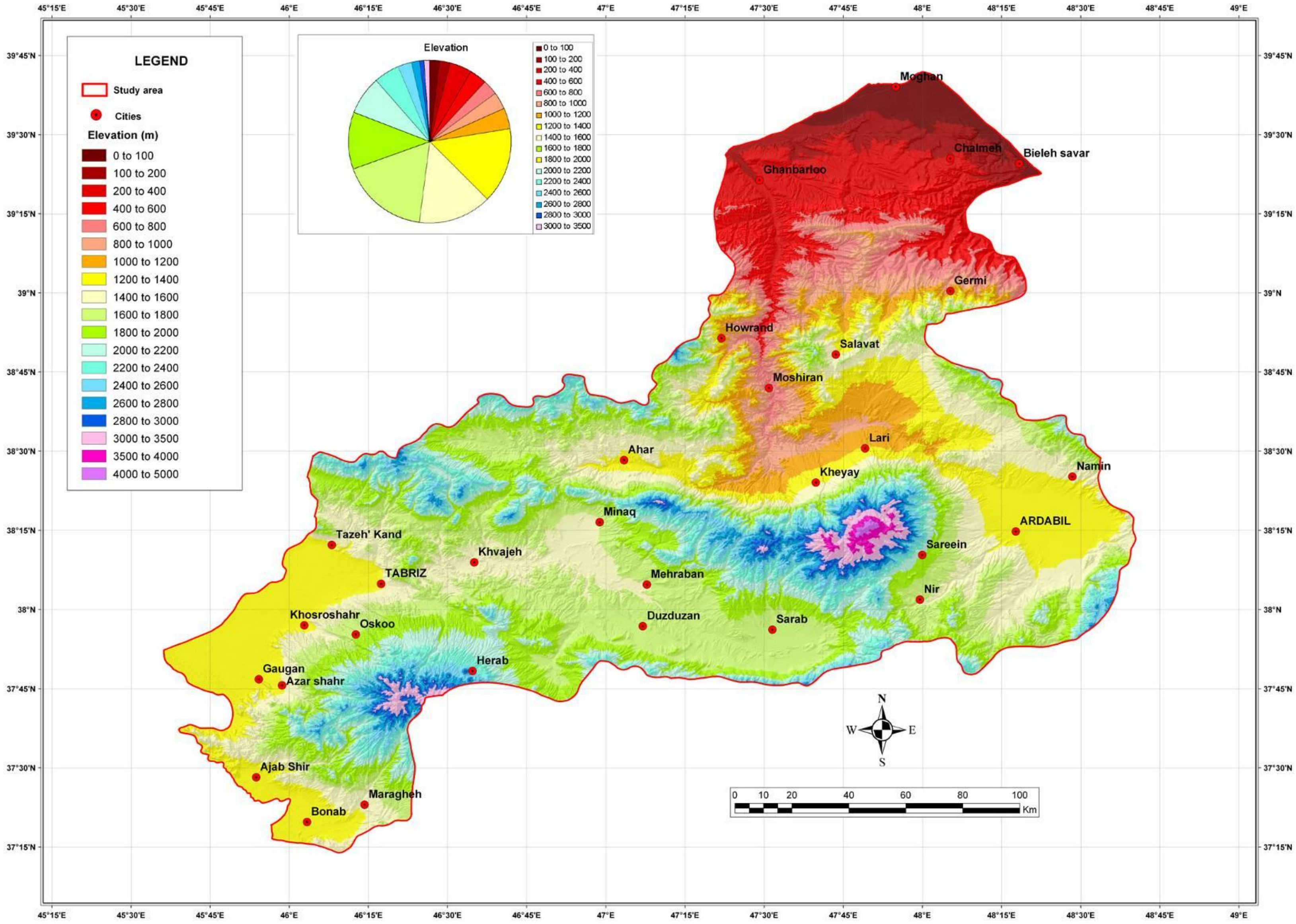
Map 39.Relative climatic similarity (precipitation and temperature) with Maraghe



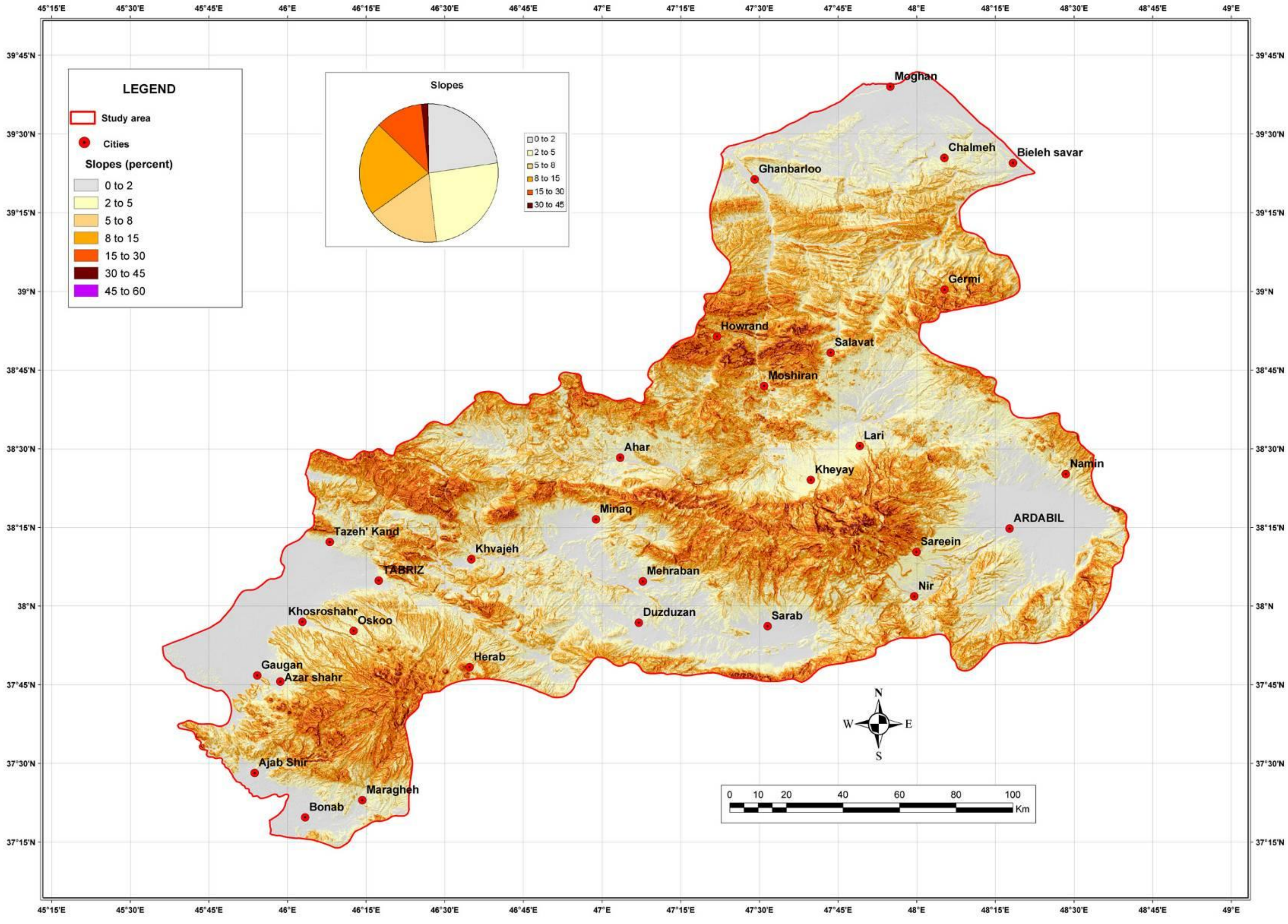
Map 40.Relative climatic similarity (precipitation and temperature) with Ardabil



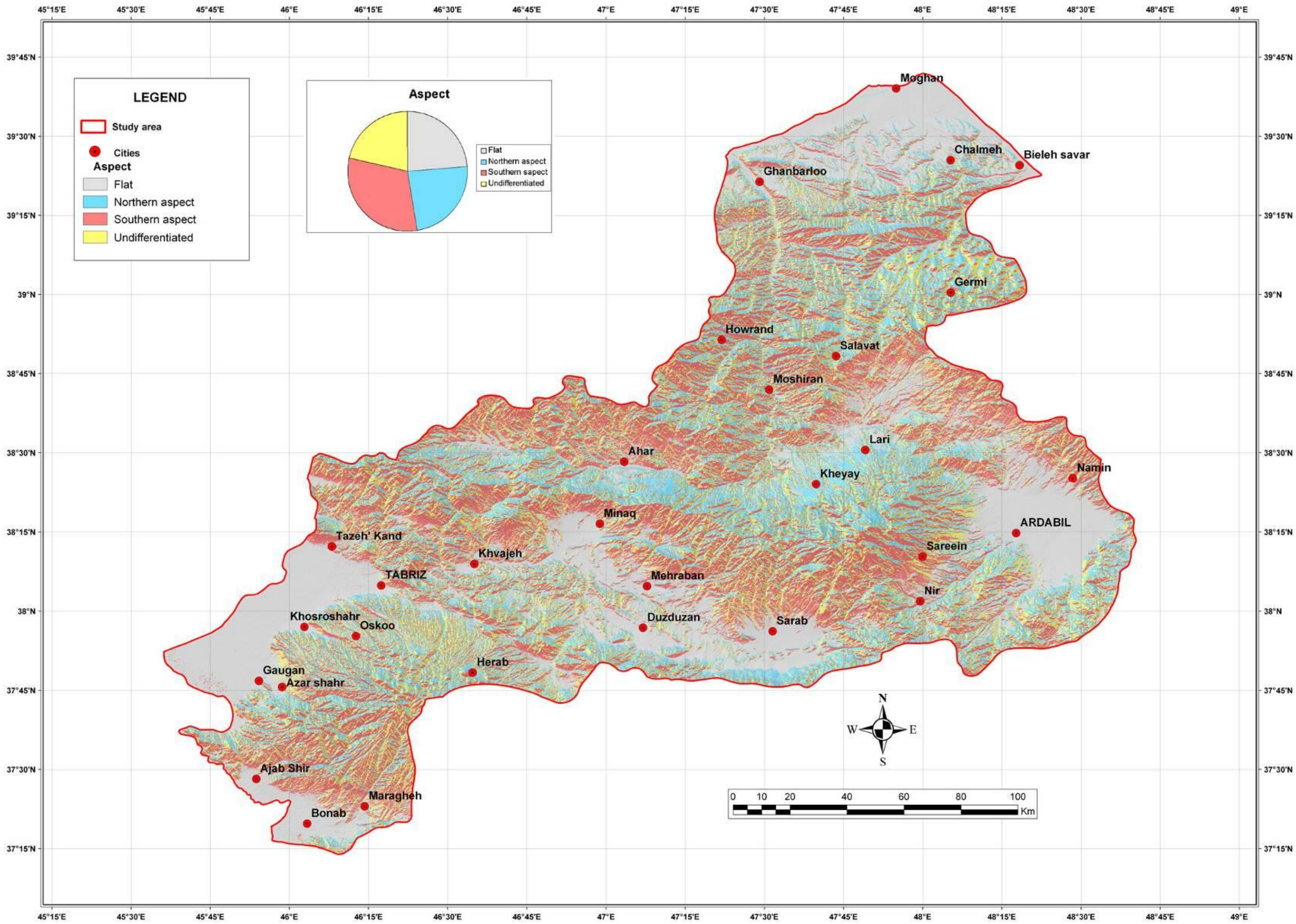
Map 41.Land use/land cover



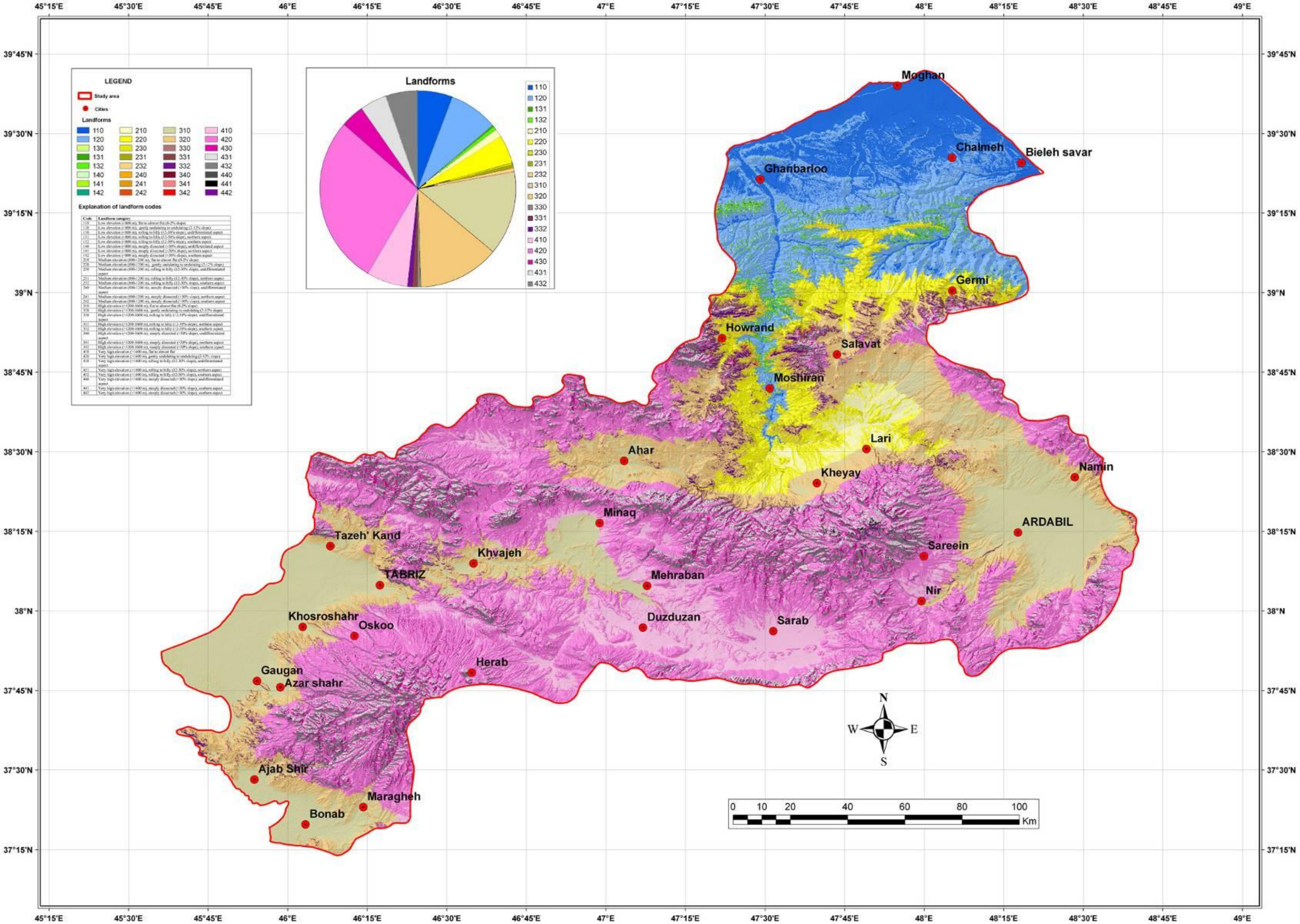
Map 42.Elevation



Map 43.Slopes



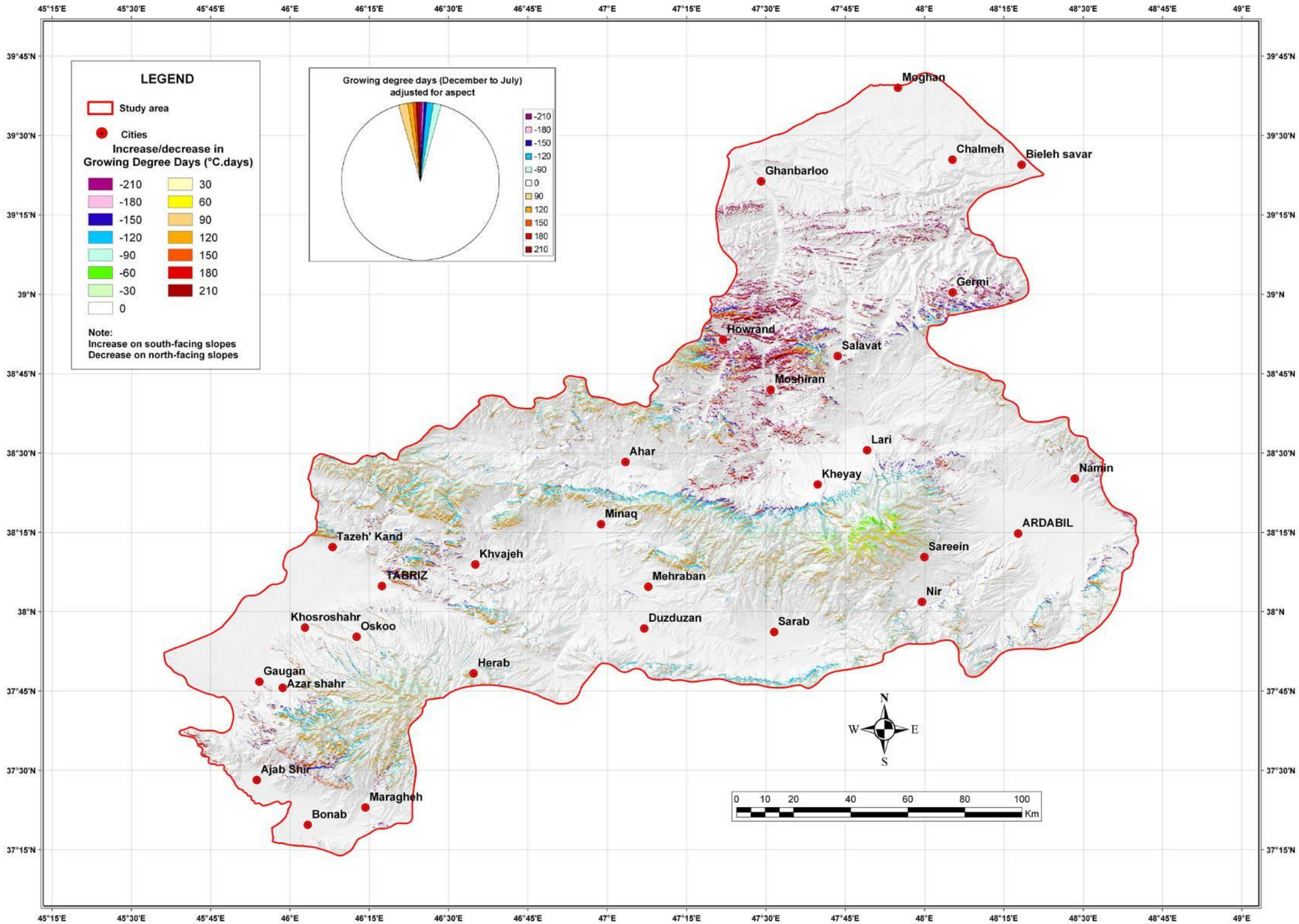
Map 44.Aspect



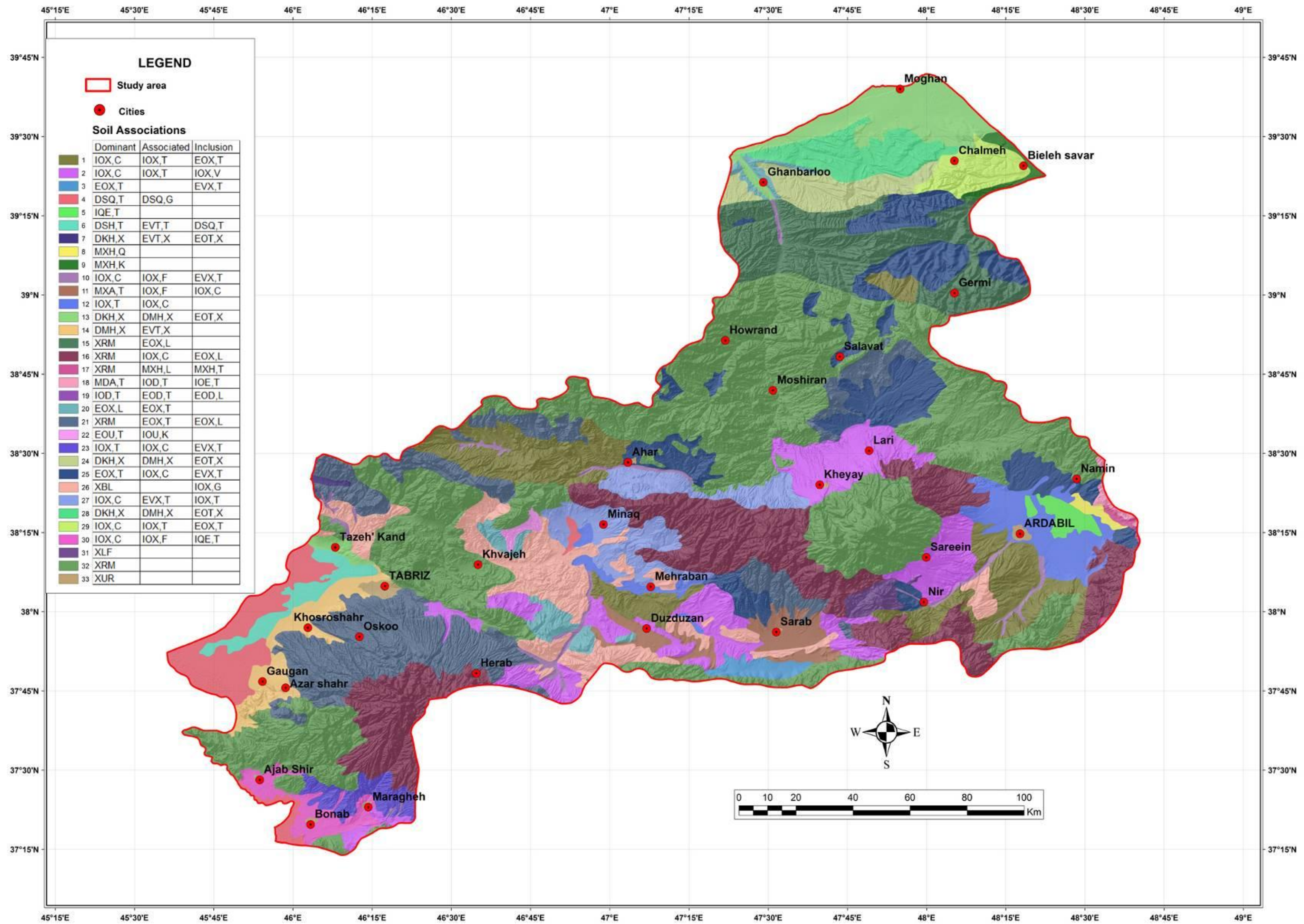
Map 45.Landforms

Table 16. Landform classes

Code	Landform category
110	Low elevation (<800 m), flat to almost flat (0-2% slope)
120	Low elevation (<800 m), gently undulating to undulating (2-12% 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 (800-1200 m), flat to almost flat (0-2% slope)
220	Medium elevation (800-1200 m), gently undulating to undulating (2-12% slope)
230	Medium elevation (800-1200 m), rolling to hilly (12-30% slope), undifferentiated aspect
231	Medium elevation (800-1200 m), rolling to hilly (12-30% slope), northern aspect
232	Medium elevation (800-1200 m), rolling to hilly (12-30% slope), southern aspect
240	Medium elevation (800-1200 m), steeply dissected (>30% slope), undifferentiated aspect
241	Medium elevation (800-1200 m), steeply dissected (>30% slope), northern aspect
242	Medium elevation (800-1200 m), steeply dissected (>30% slope), southern aspect
310	High elevation (>1200-1600 m), flat to almost flat (0-2% slope)
320	High elevation (>1200-1600 m), gently undulating to undulating (2-12% slope)
330	High elevation (>1200-1600 m), rolling to hilly (12-30% slope), undifferentiated aspect
331	High elevation (>1200-1600 m), rolling to hilly (12-30% slope), northern aspect
332	High elevation (>1200-1600 m), rolling to hilly (12-30% slope), southern aspect
340	High elevation (>1200-1600 m), steeply dissected (>30% slope), undifferentiated aspect
341	High elevation (>1200-1600 m), steeply dissected (>30% slope), northern aspect
342	High elevation (>1200-1600 m), steeply dissected (>30% slope), southern aspect
410	Very high elevation (>1600 m), flat to almost flat
420	Very high elevation (>1600 m), gently undulating to undulating (2-12% slope)
430	Very high elevation (>1600 m), rolling to hilly (12-30% slope), undifferentiated aspect
431	Very high elevation (>1600 m), rolling to hilly (12-30% slope), northern aspect
432	Very high elevation (>1600 m), rolling to hilly (12-30% slope), southern aspect
440	Very high elevation (>1600 m), steeply dissected (>30% slope), undifferentiated aspect
441	Very high elevation (>1600 m), steeply dissected (>30% slope), southern aspect
442	Very high elevation (>1600 m), steeply dissected (>30% slope), southern aspect



Map 46.Growing degree days (December to July) adjusted for aspect



Map 47. Soil associations

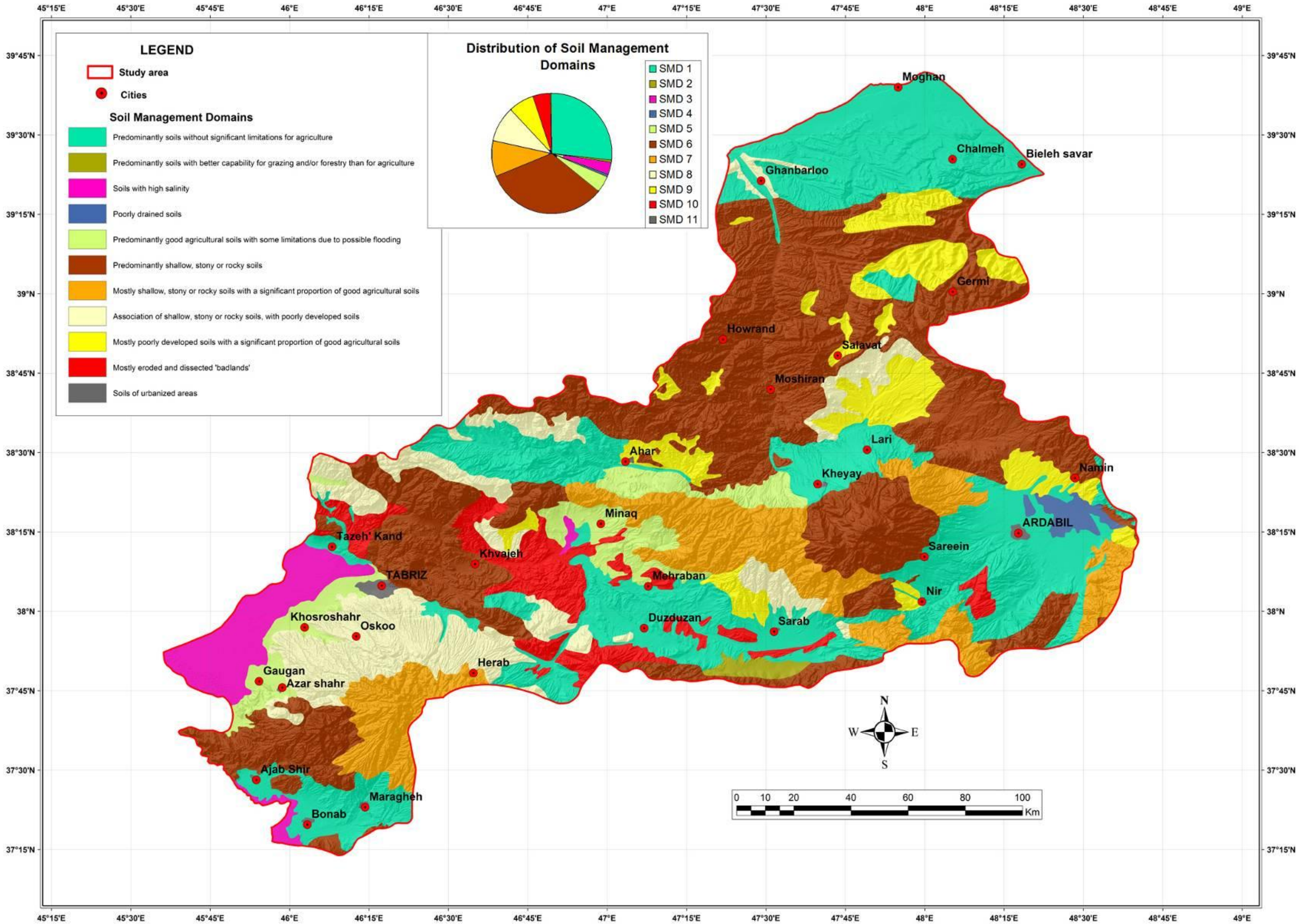


Figure 48. Soil Management Domains

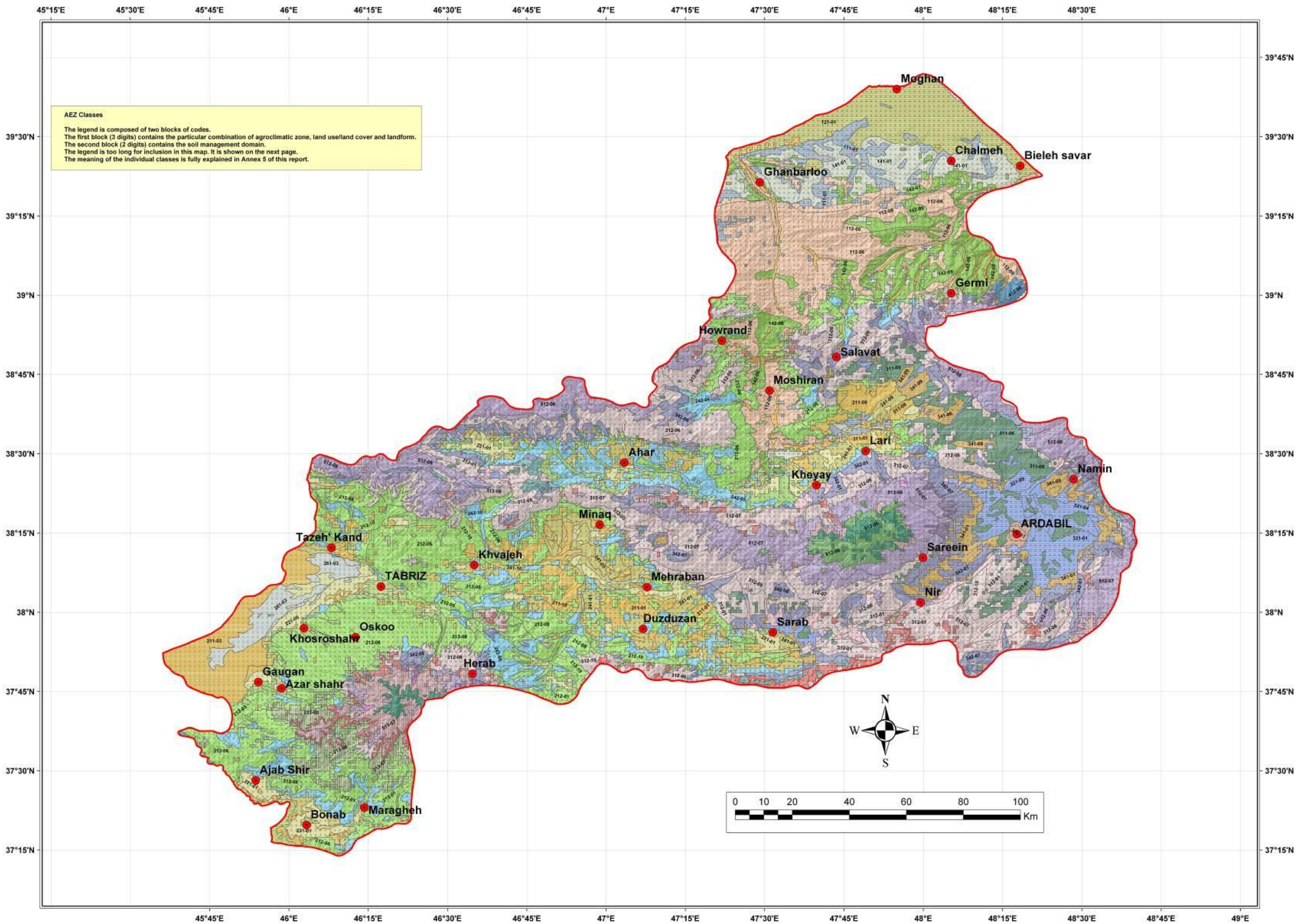
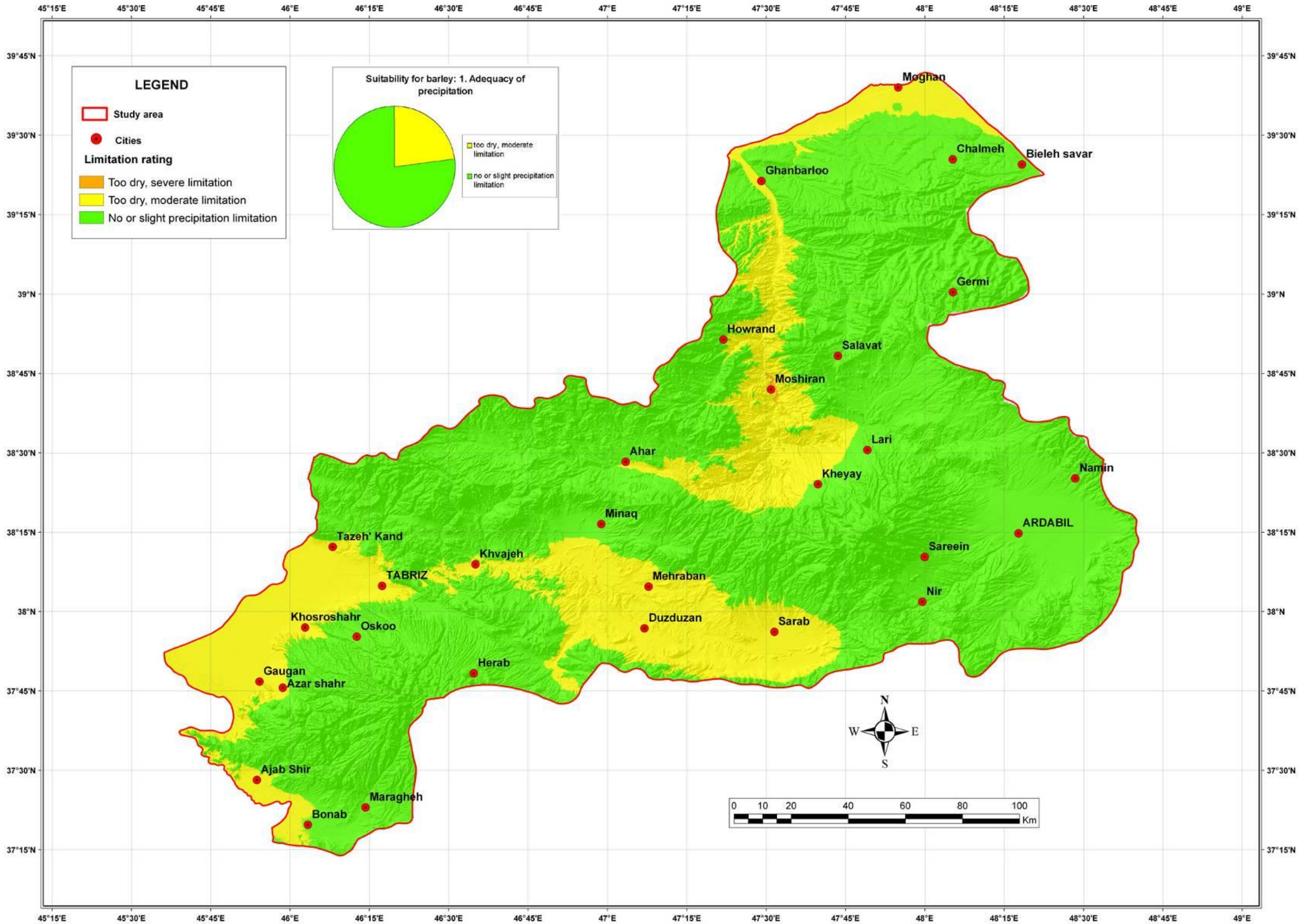
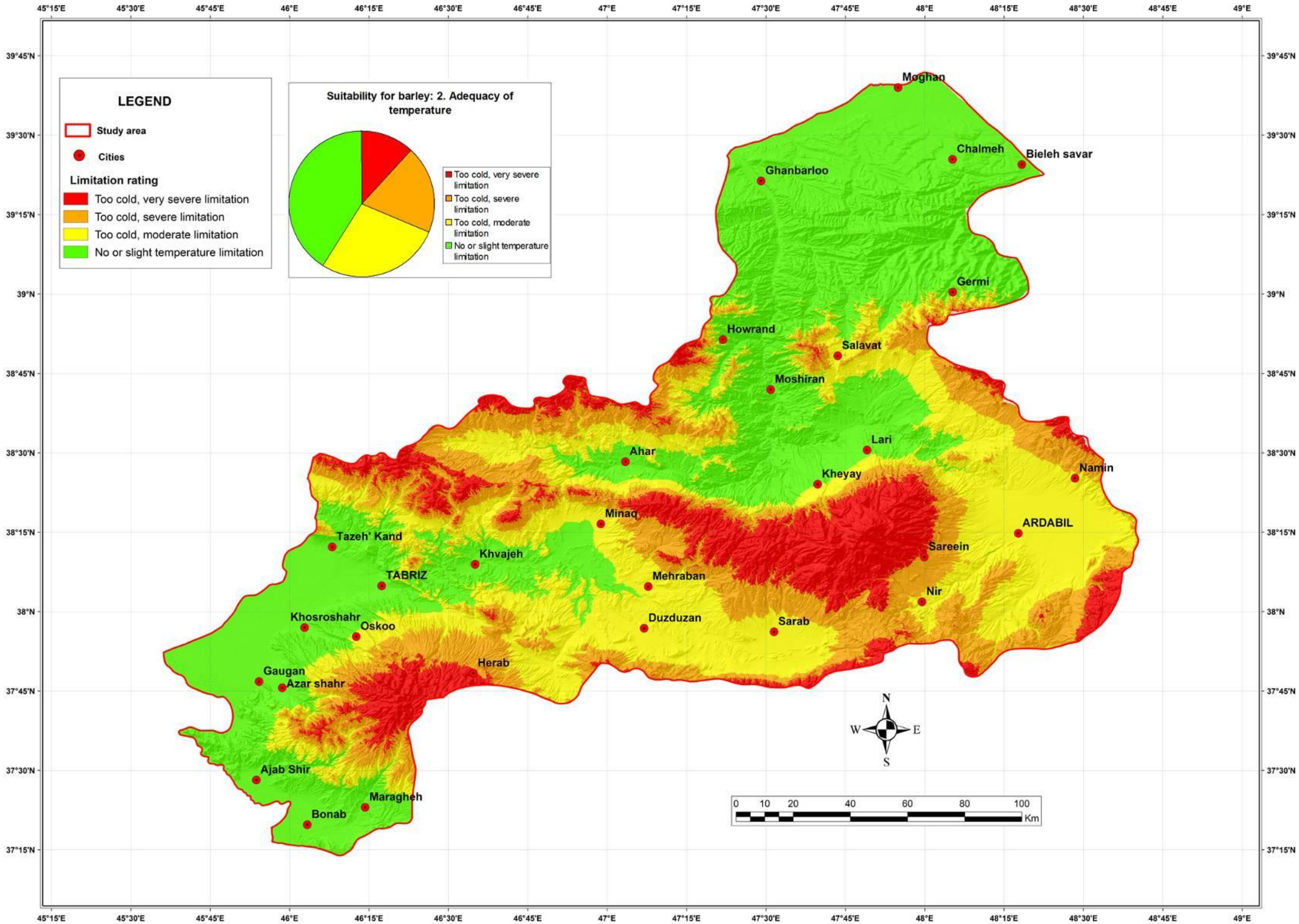


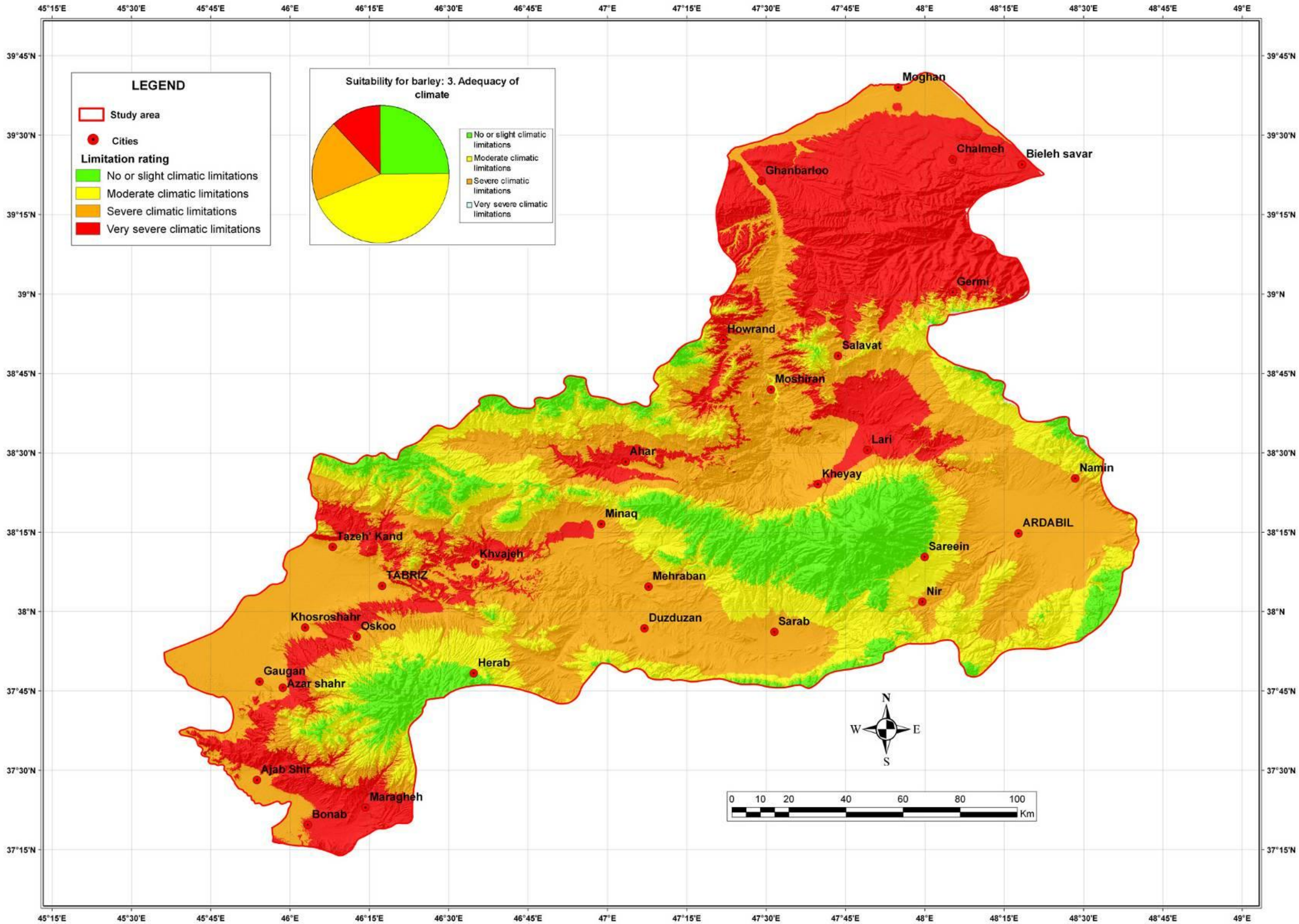
Figure 49. Agroecological zones



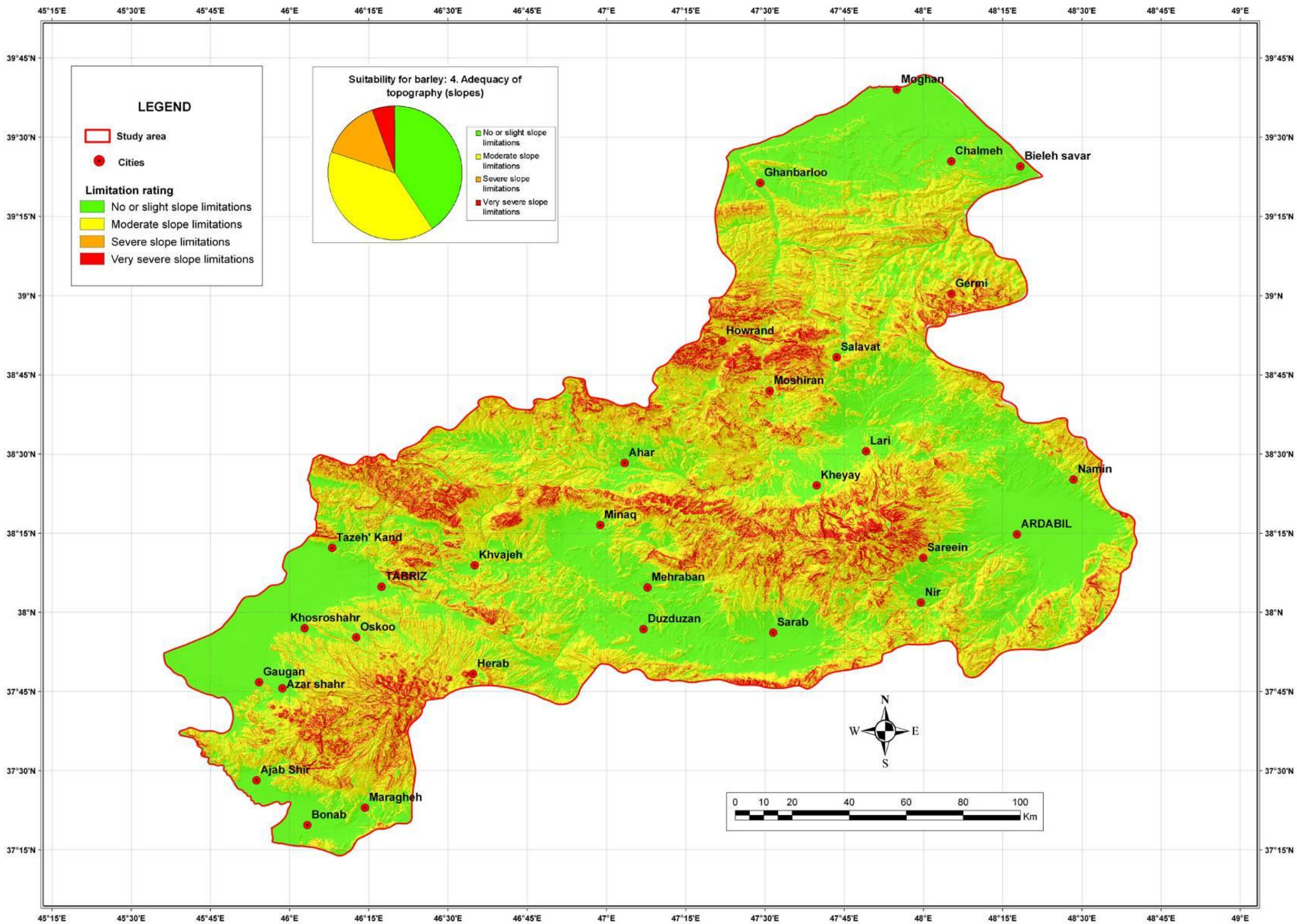
Map 50.Suitability for barley: 1. Adequacy of precipitation



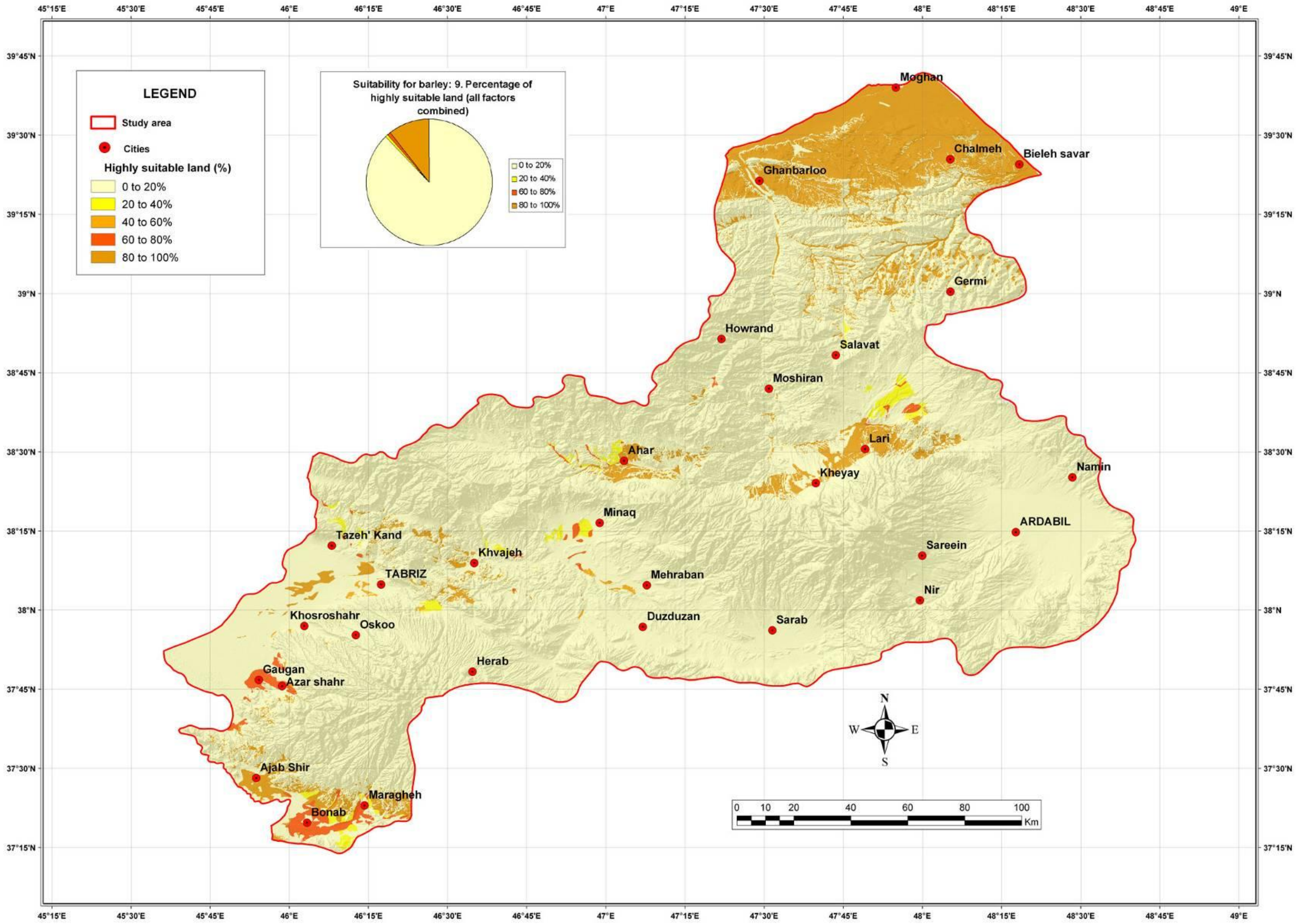
Map 51.Suitability for barley: 2. Adequacy of temperature



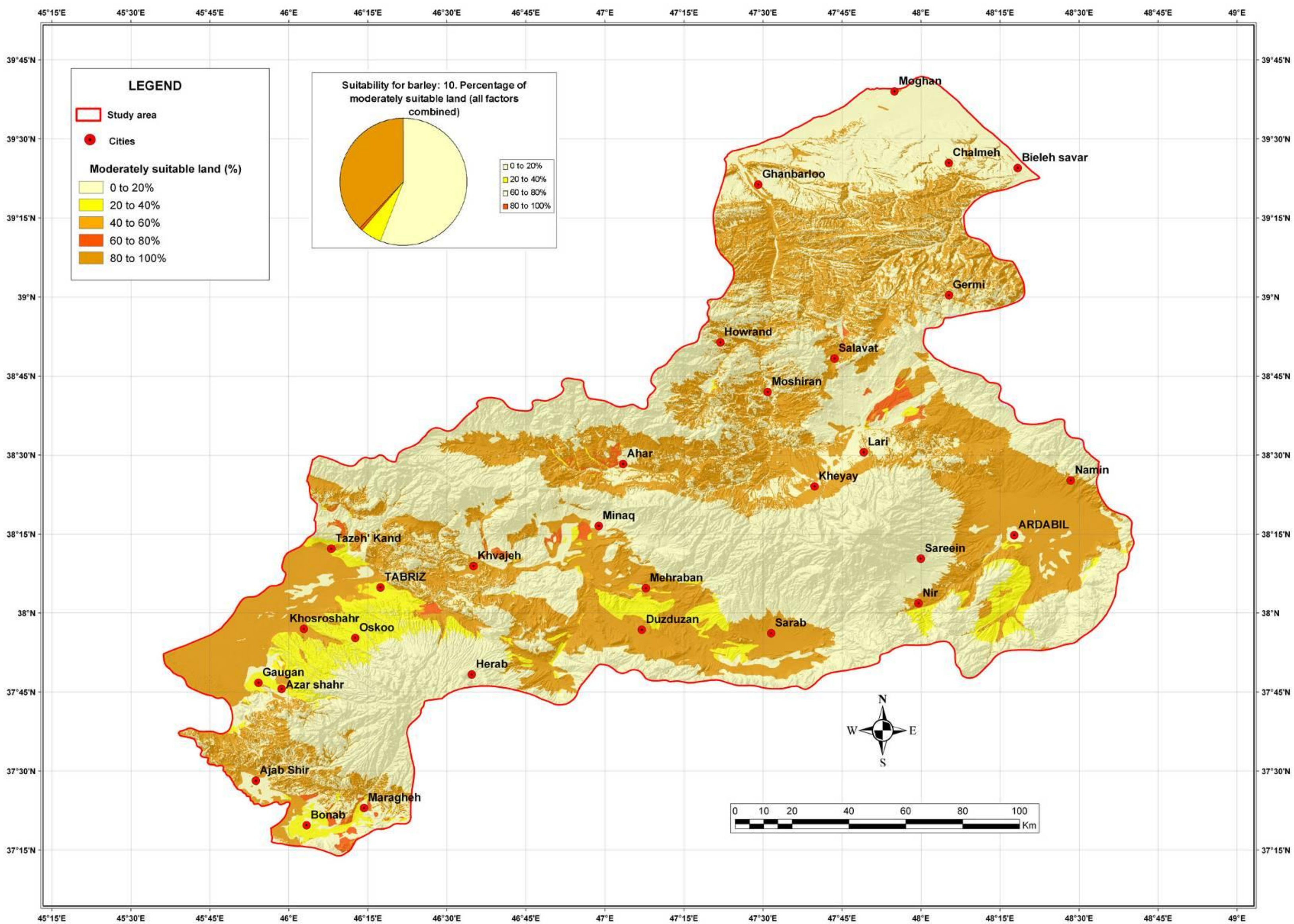
Map 52.Suitability for barley: 3. Adequacy of climate



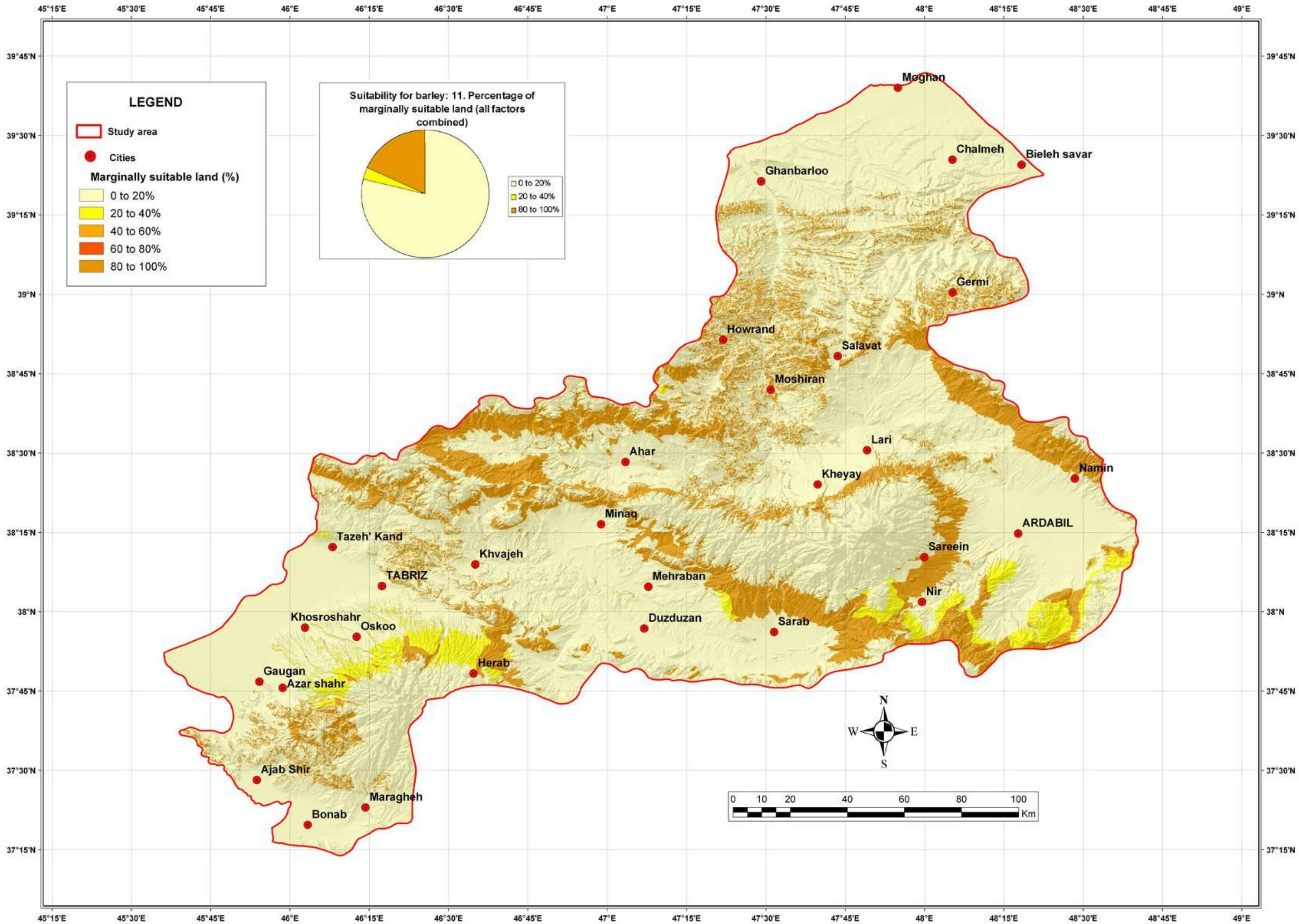
Map 53.Suitability for barley: 4. Adequacy of topography (slopes)



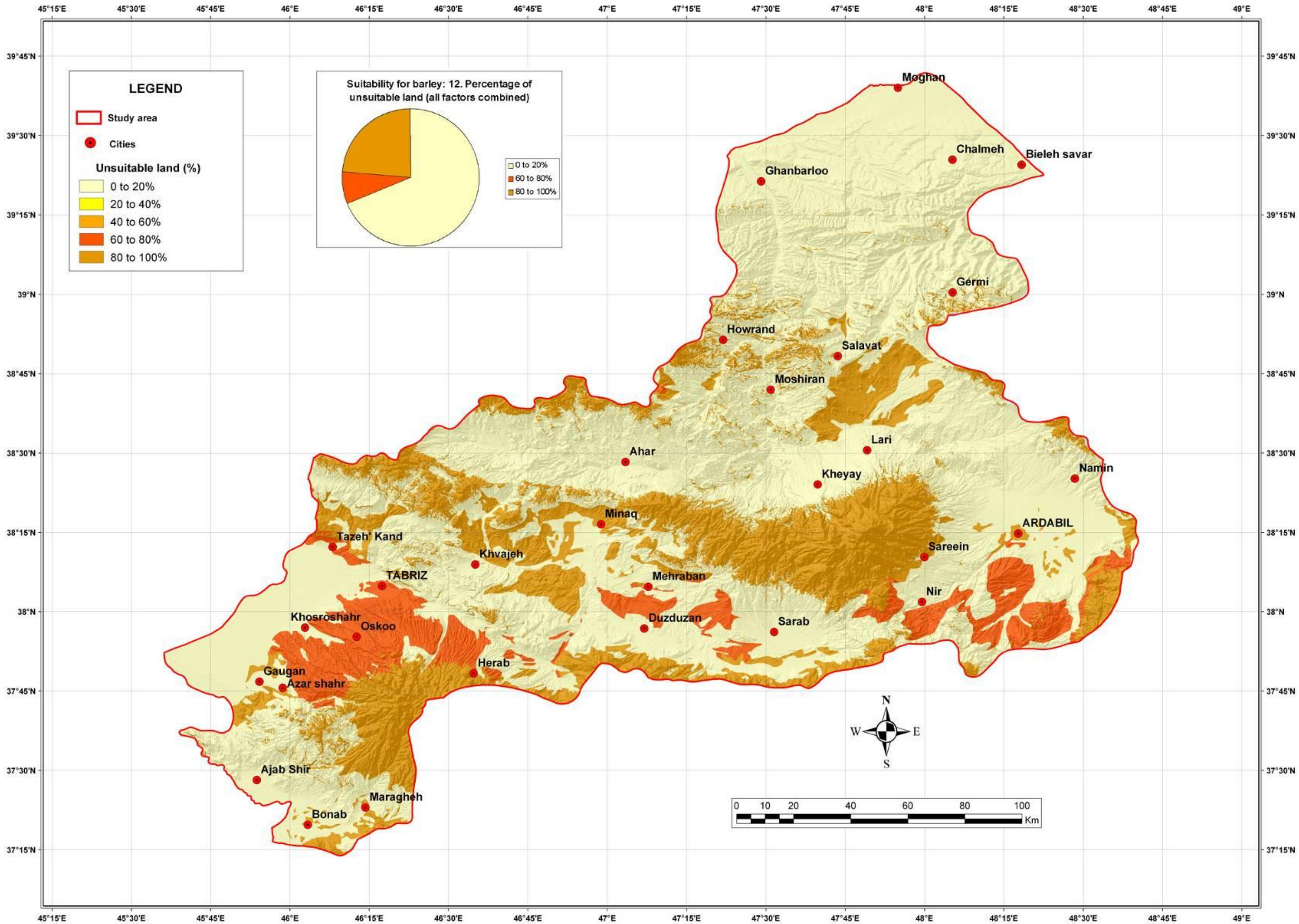
Map 54.Suitability for barley: 5. Percentage of highly suitable land (all factors combined)



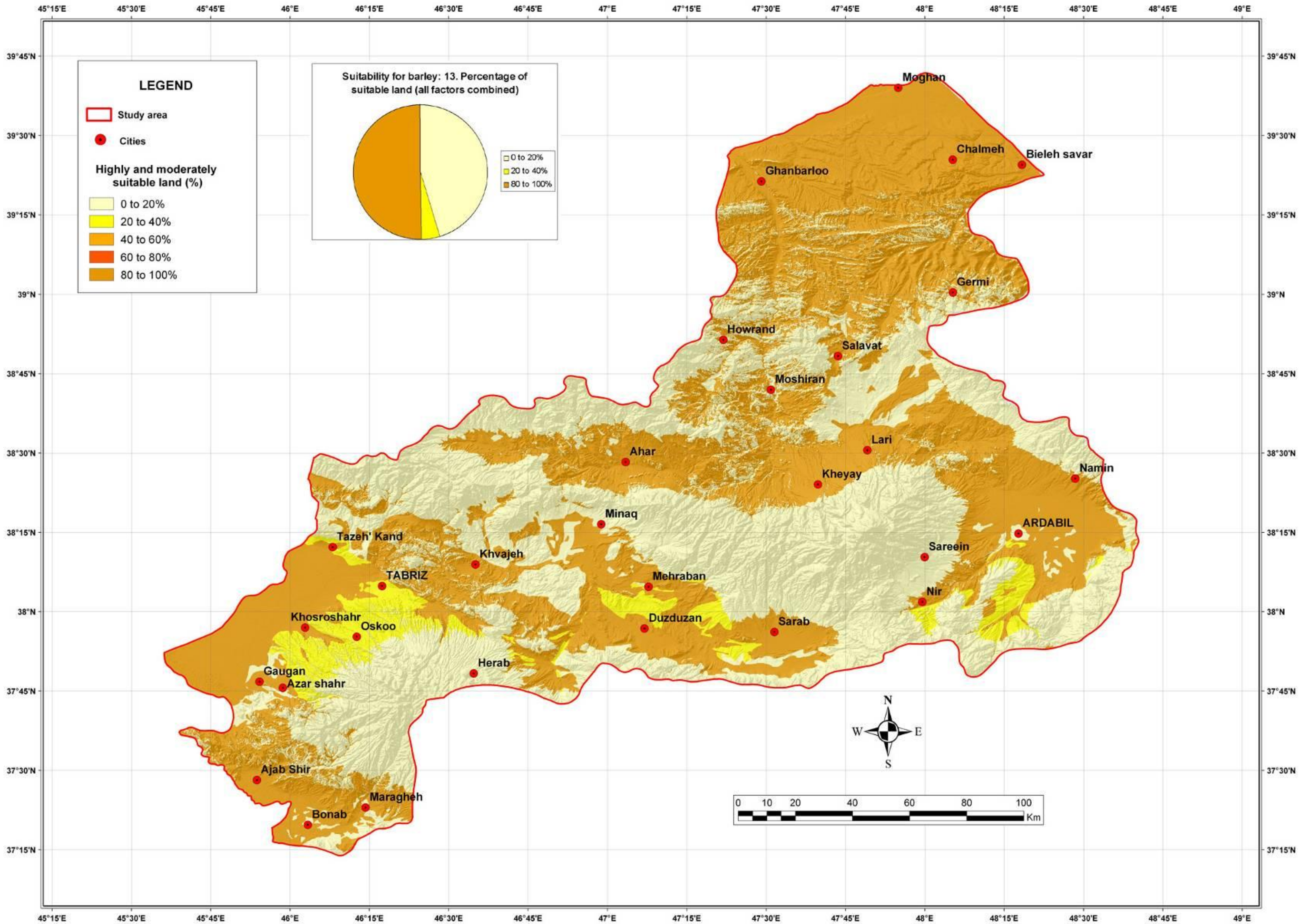
Map 55.Suitability for barley: 6. Percentage of moderately suitable land (all factors combined)



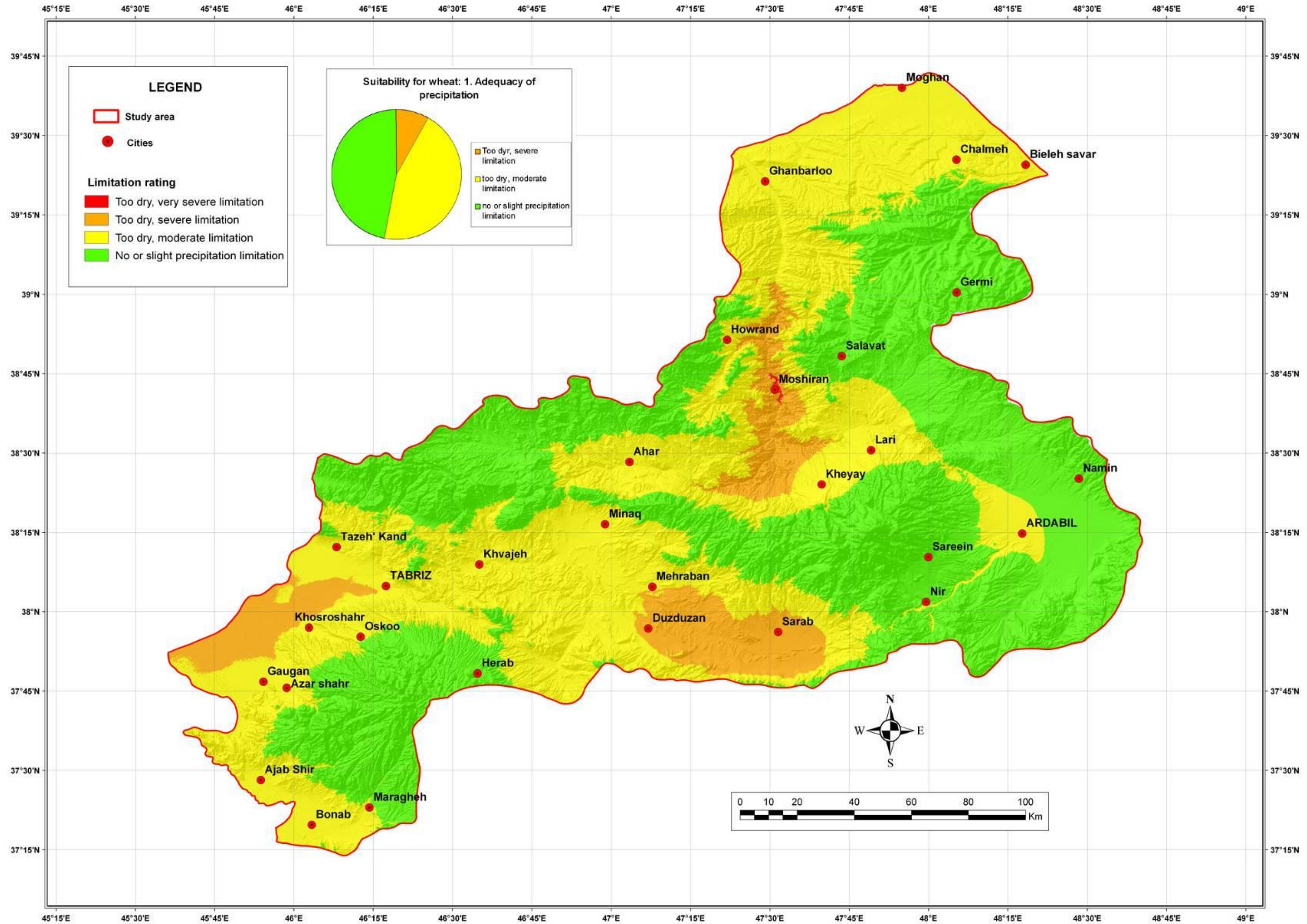
Map 56.Suitability for barley: 7. Percentage of marginally suitable land (all factors combined)



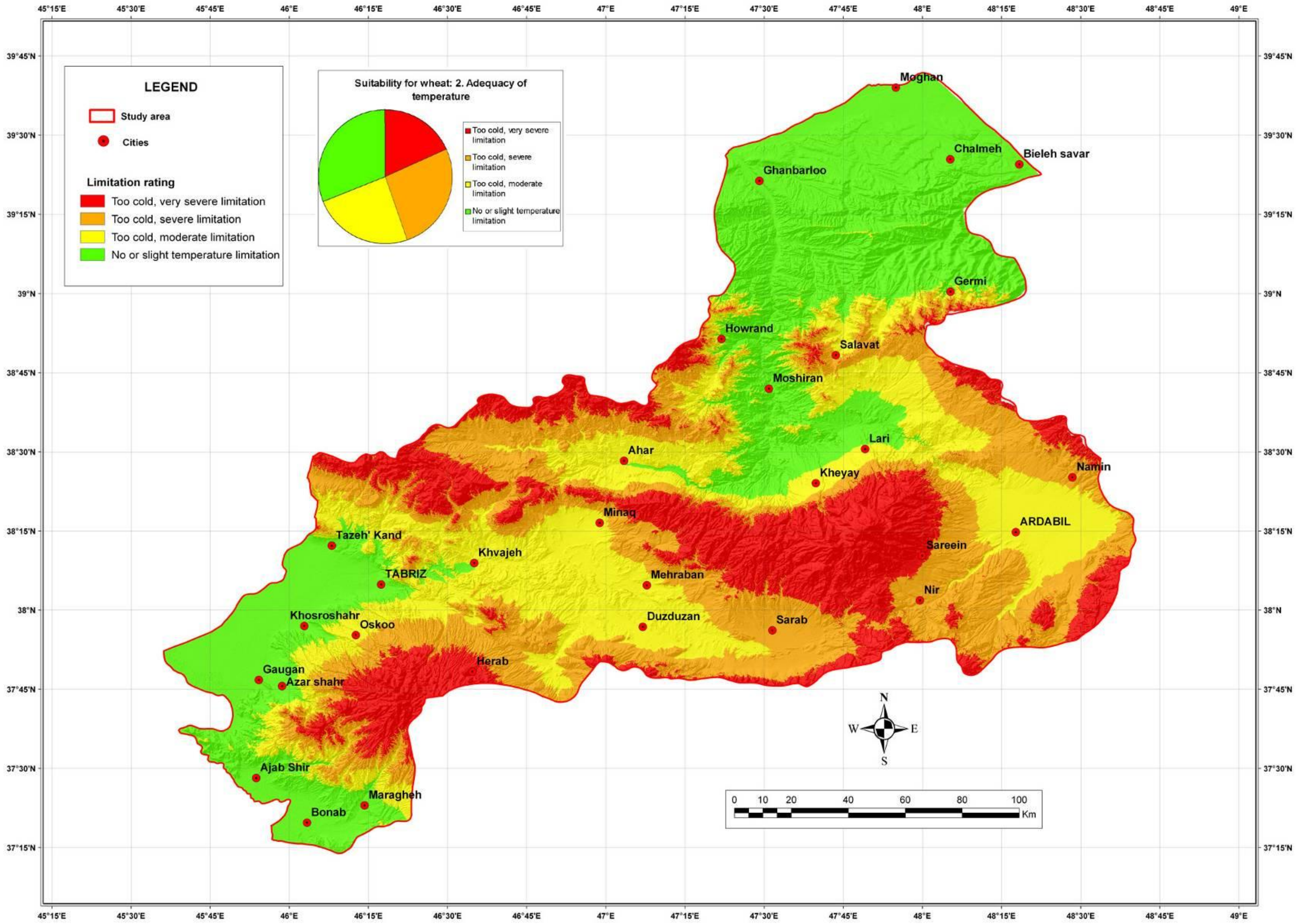
Map 57.Suitability for barley: 8. Percentage of unsuitable land (all factors combined)



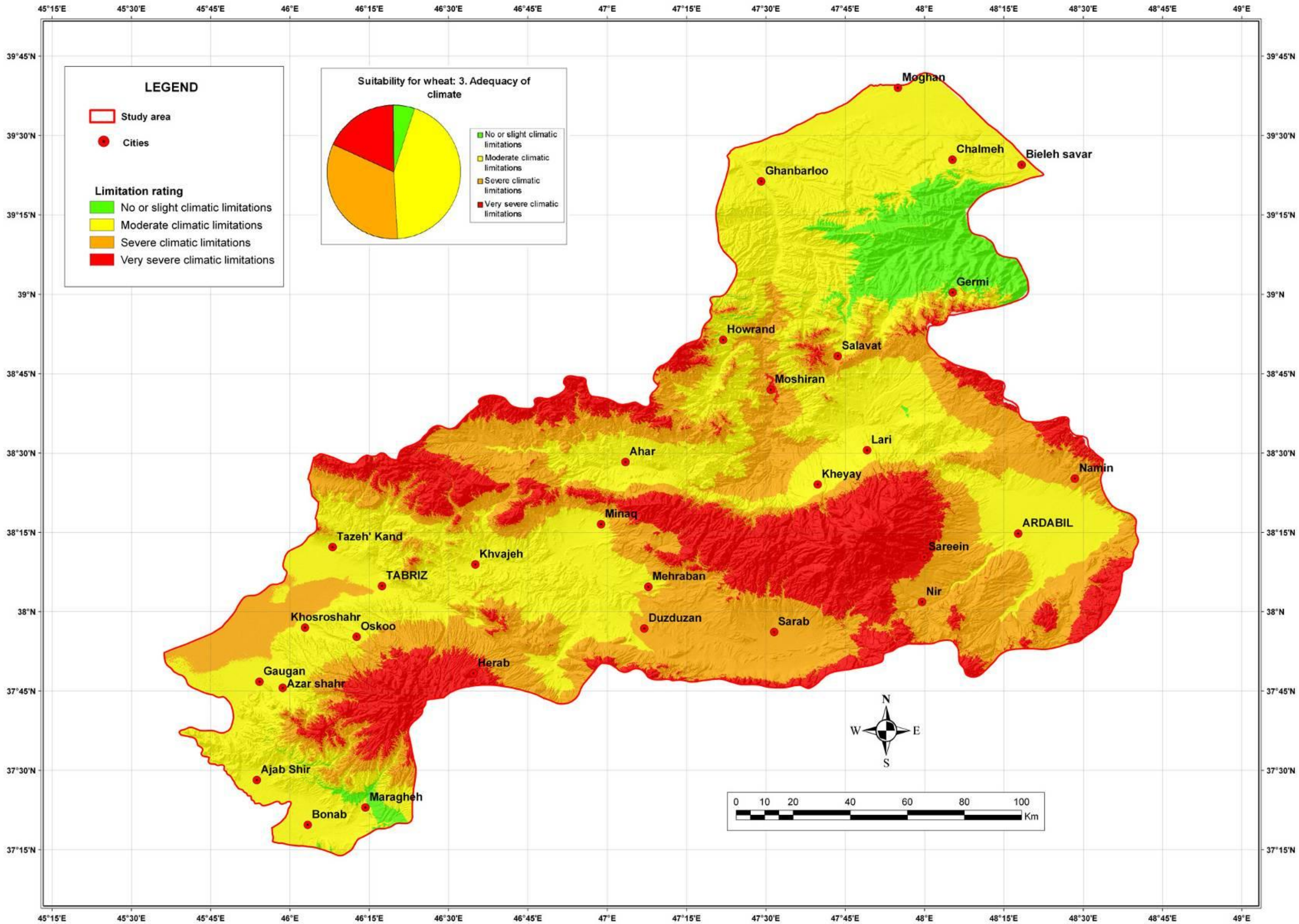
Map 58.Suitability for barley: 9. Percentage of suitable land (all factors combined)



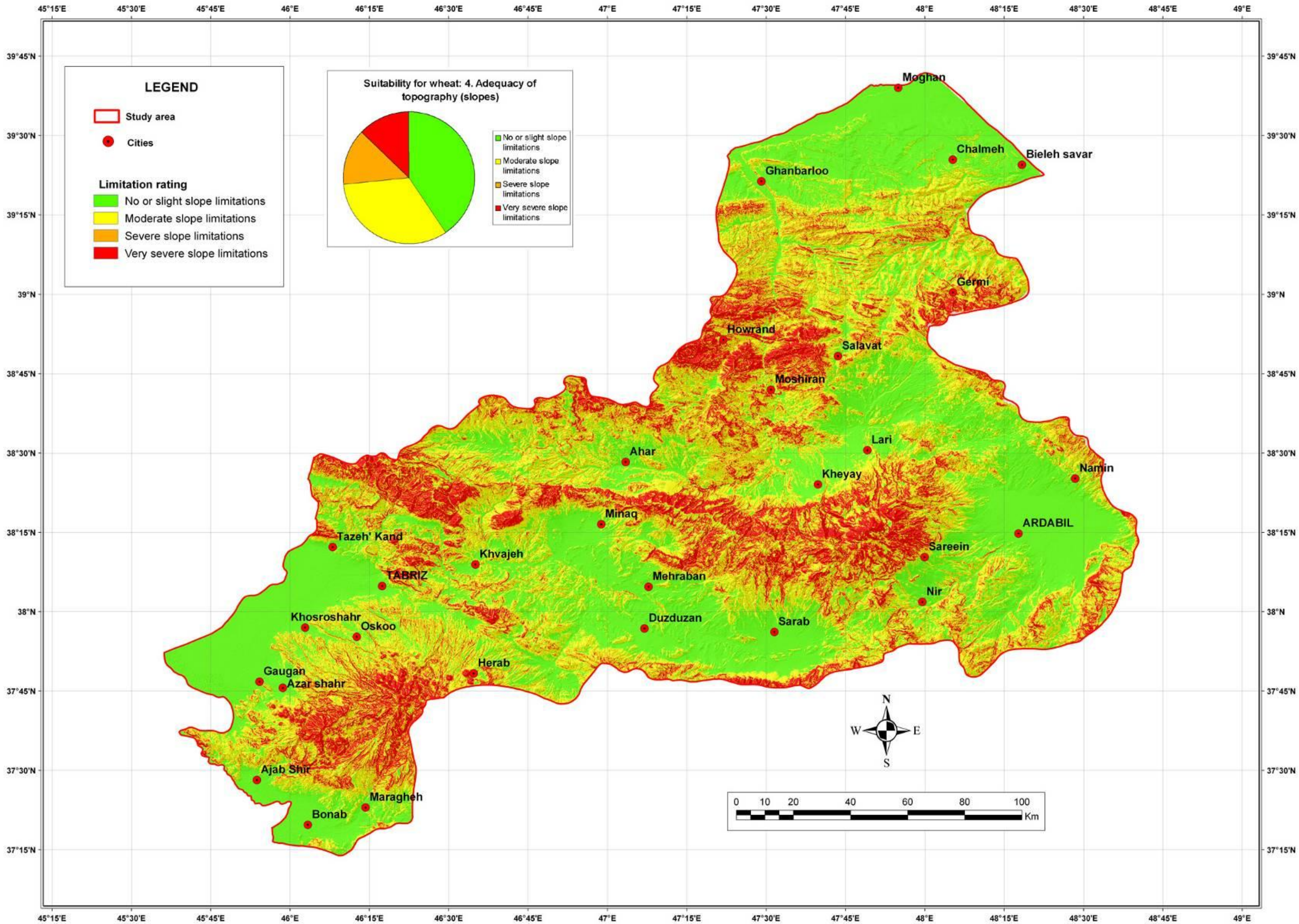
Map 59.Suitability for wheat: 1. Adequacy of precipitation



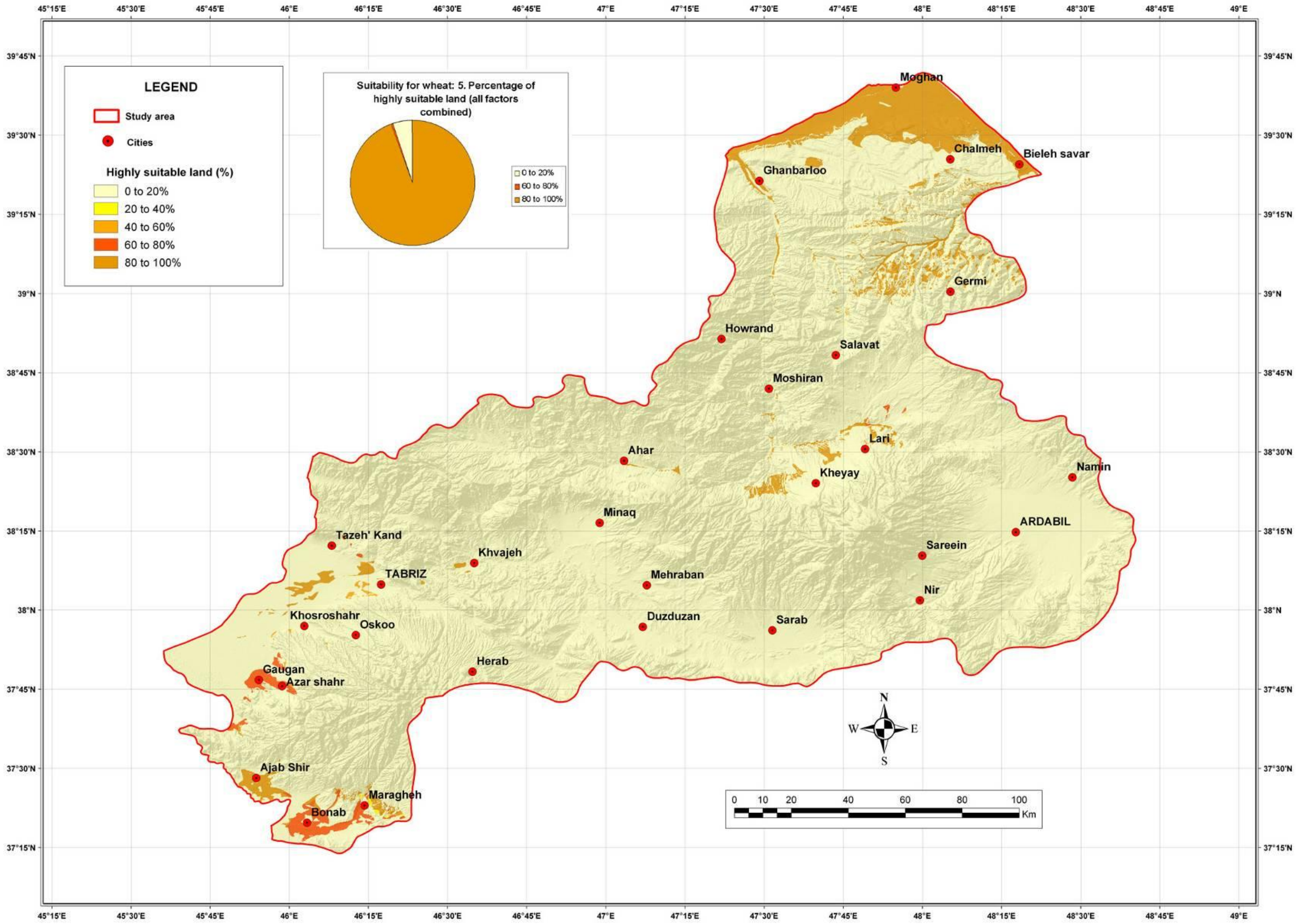
Map 60.Suitability for wheat: 2. Adequacy of temperature



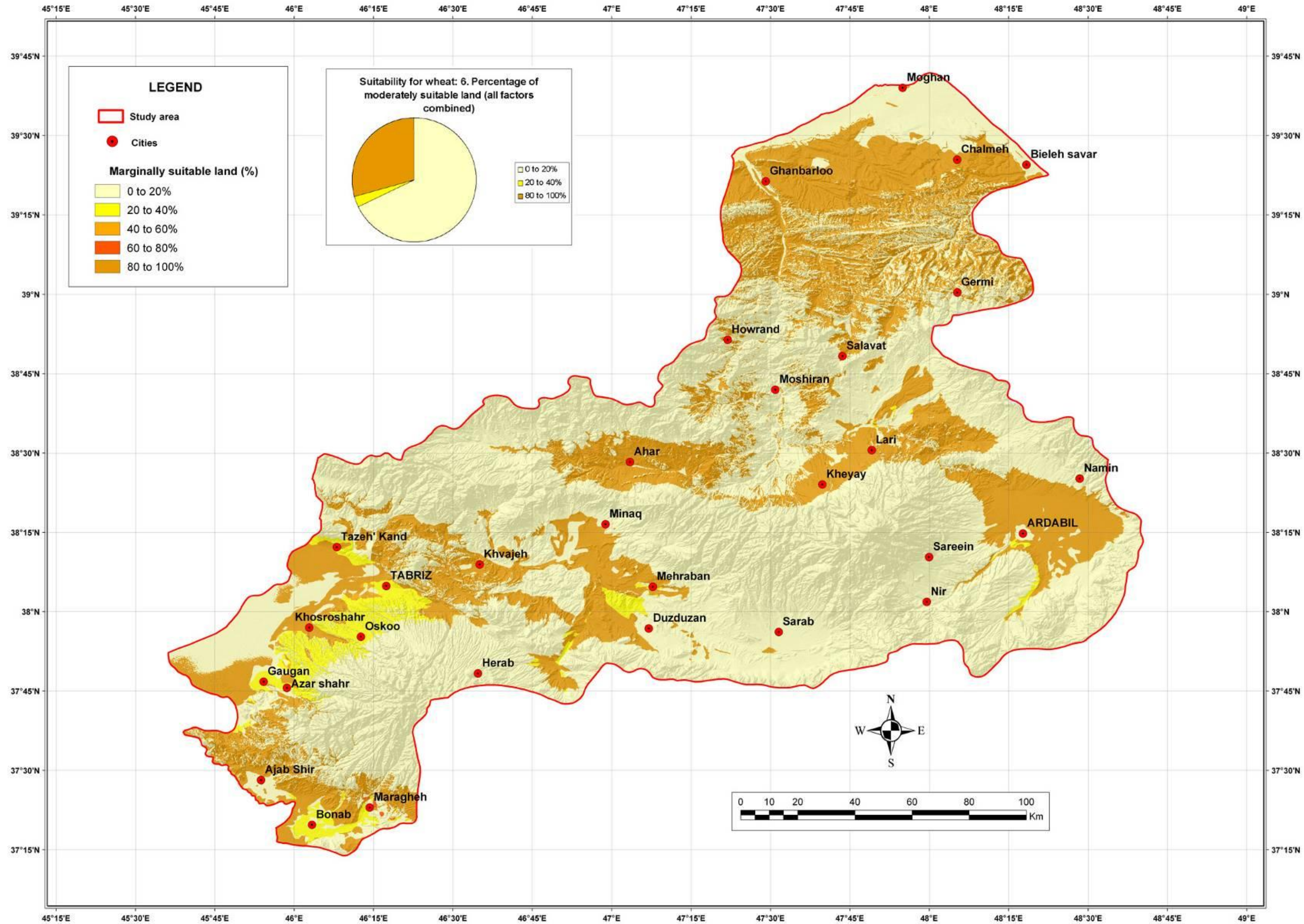
Map 61.Suitability for wheat: 3. Adequacy of climate



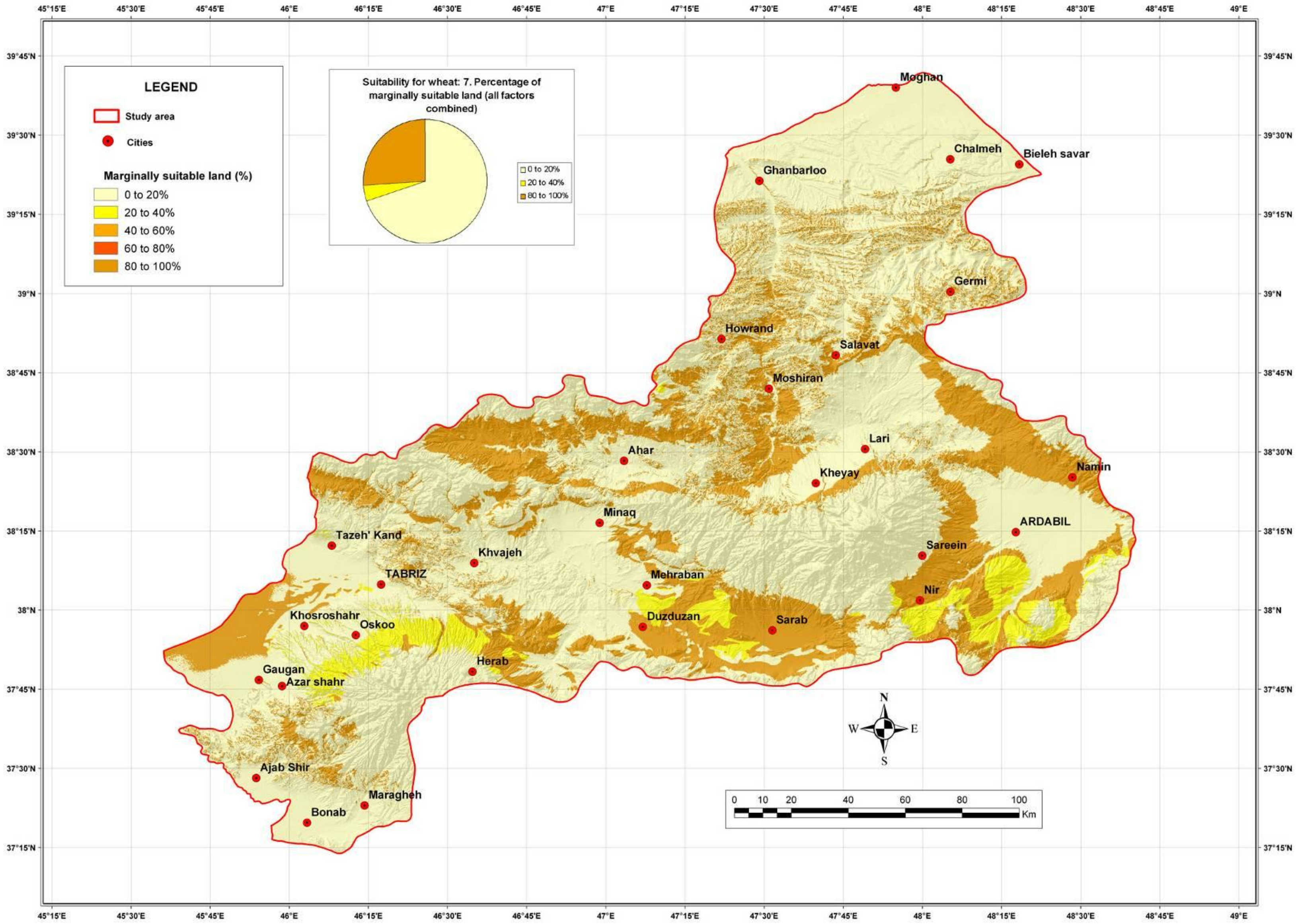
Map 62.Suitability for wheat: 4. Adequacy of topography (slopes)



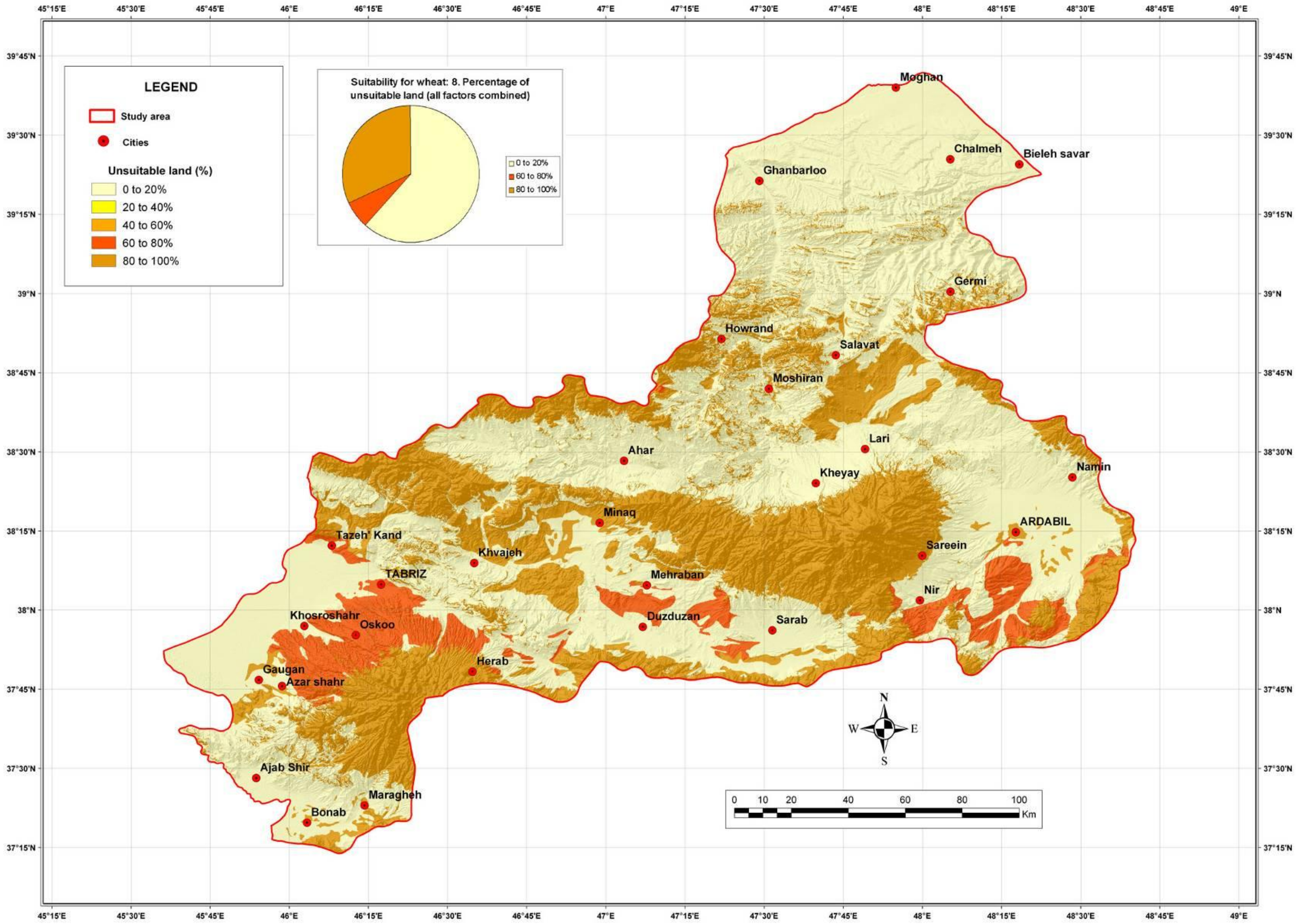
Map 63.Suitability for wheat: 5. Percentage of highly suitable land (all factors combined)



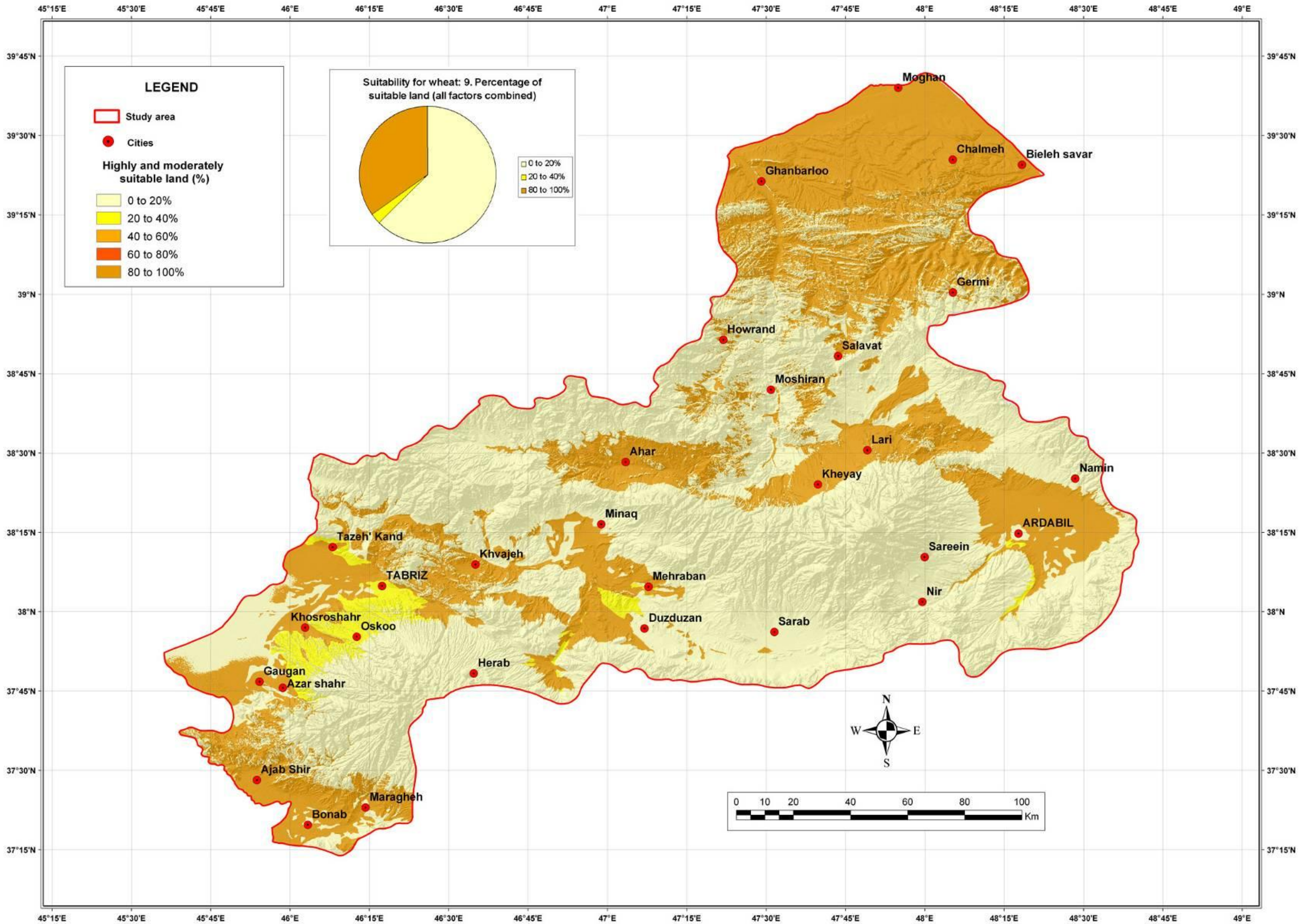
Map 64.Suitability for wheat: 6. Percentage of moderately suitable land (all factors combined)



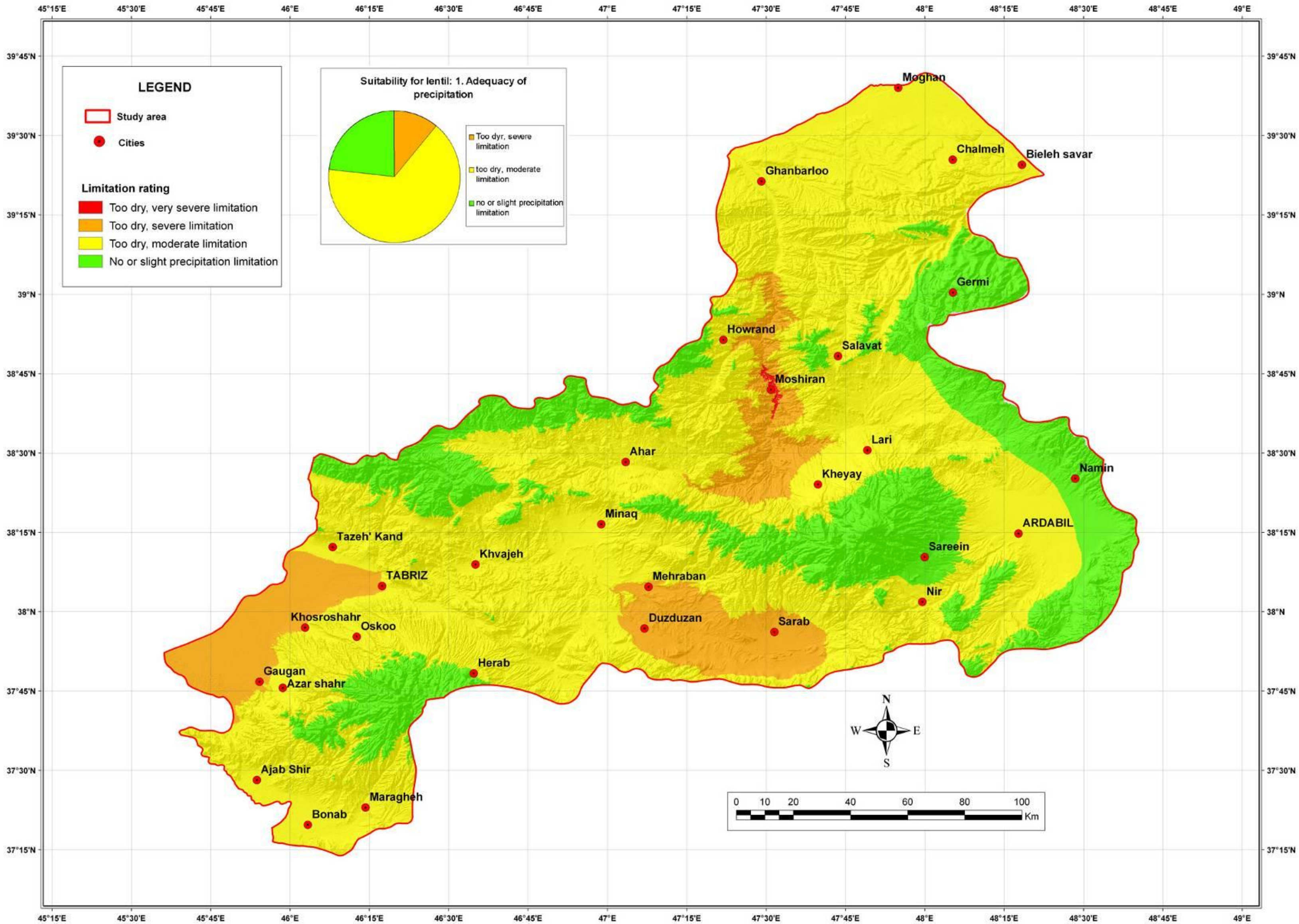
Map 65.Suitability for wheat: 7. Percentage of marginally suitable land (all factors combined)



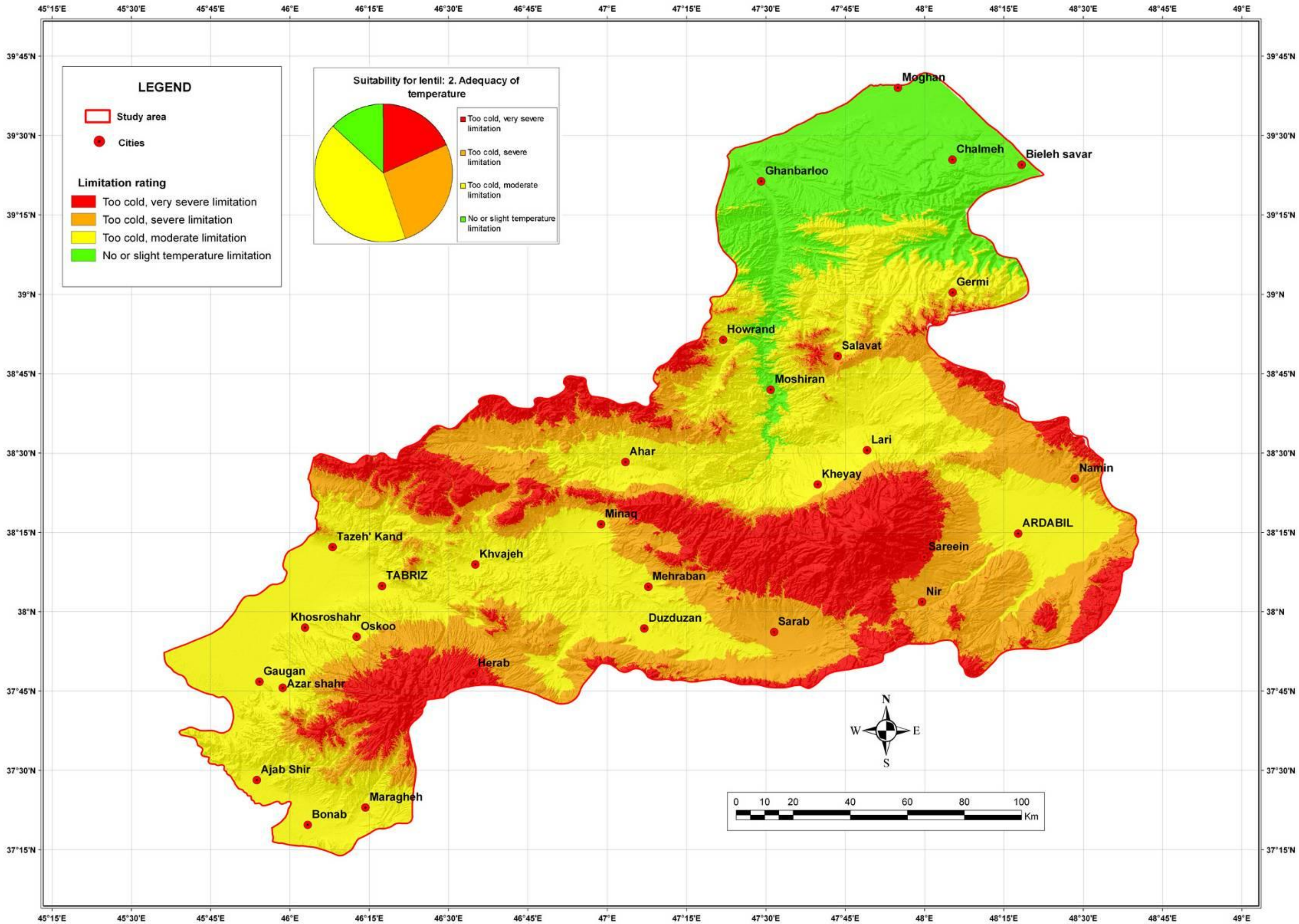
Map 66.Suitability for wheat: 8. Percentage of unsuitable land (all factors combined)



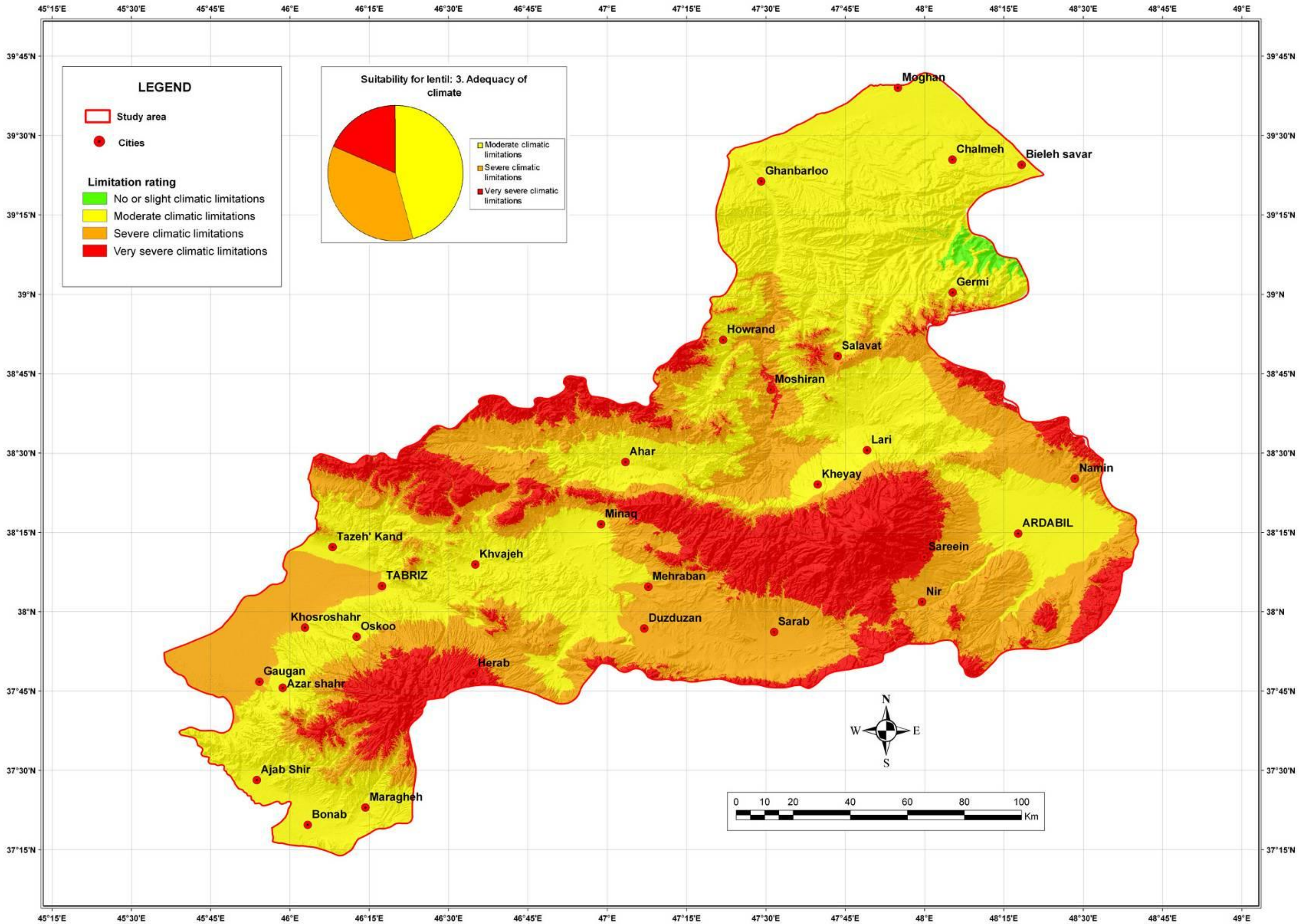
Map 67.Suitability for wheat: 9. Percentage of suitable land (all factors combined)



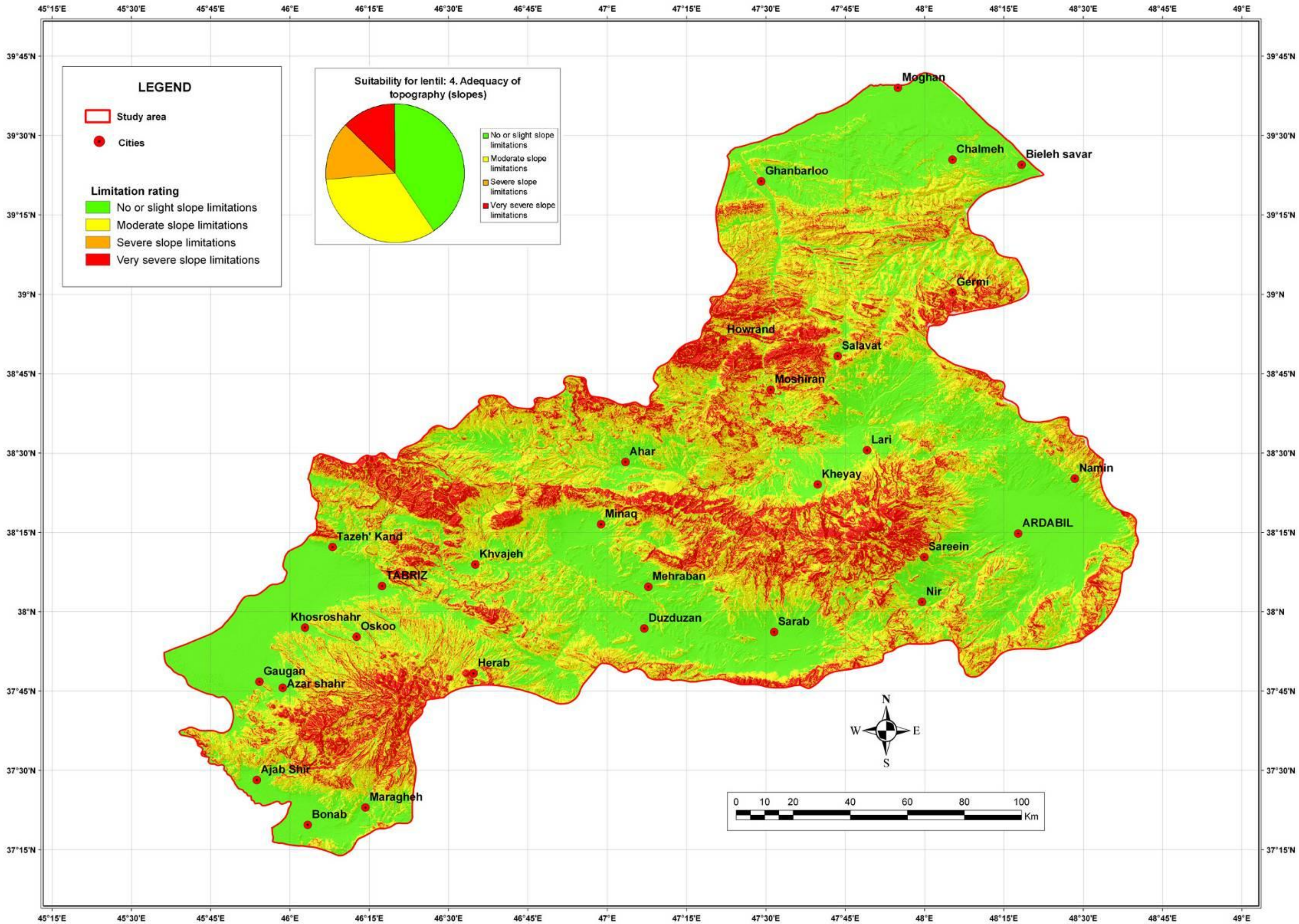
Map 68.Suitability for lentil: 1. Adequacy of precipitation



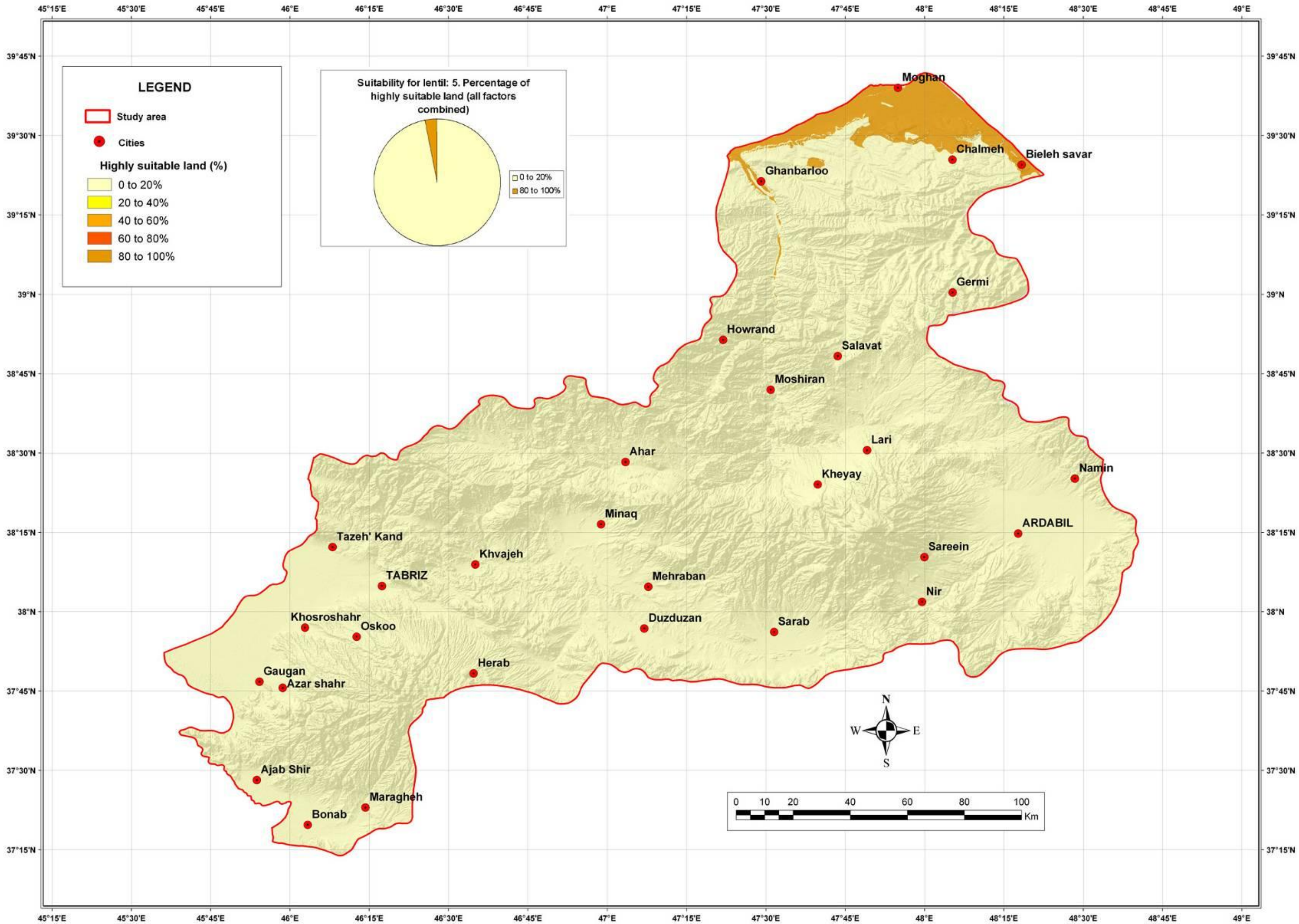
Map 69.Suitability for lentil: 2. Adequacy of temperature



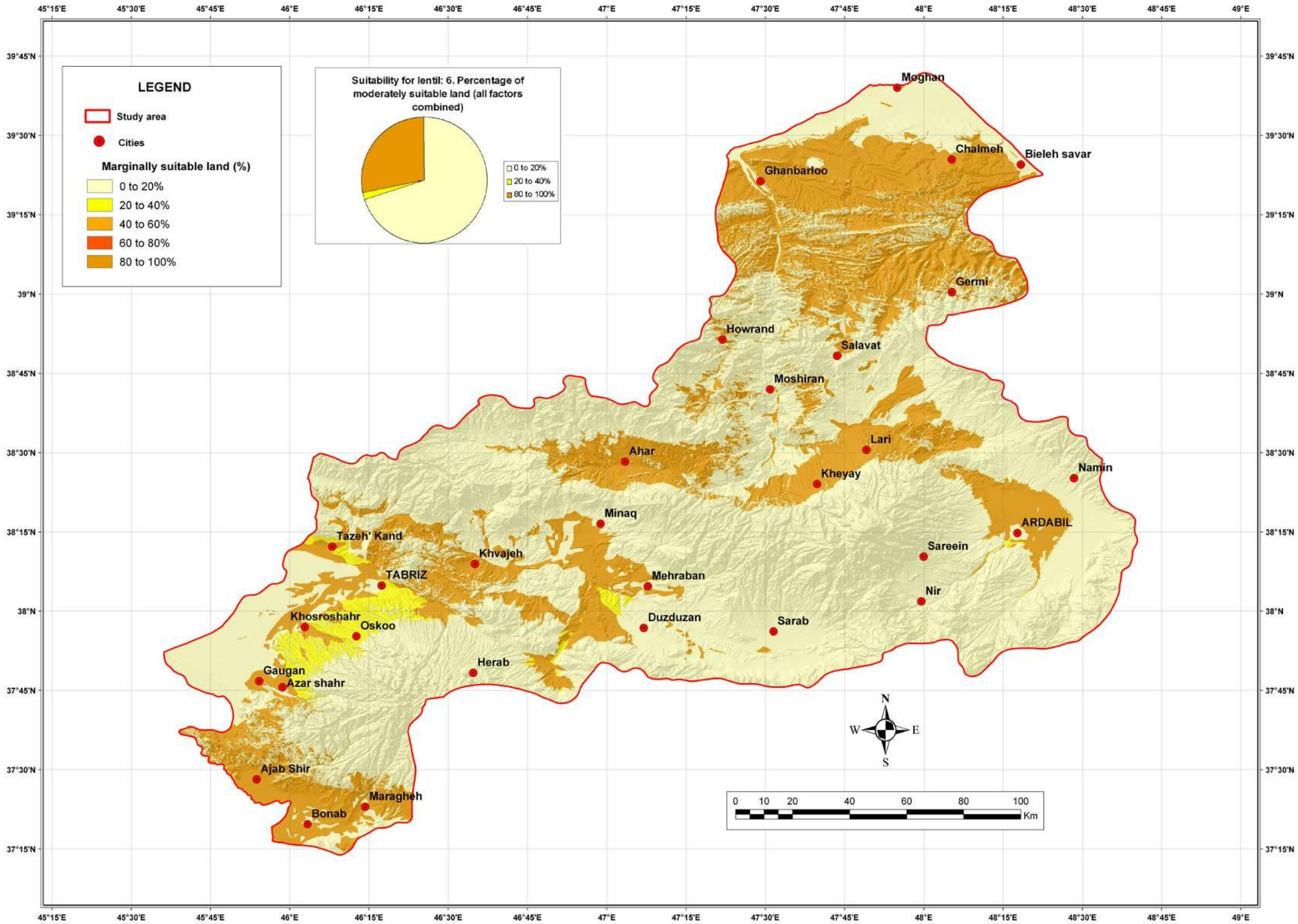
Map 70.Suitability for lentil: 3. Adequacy of climate



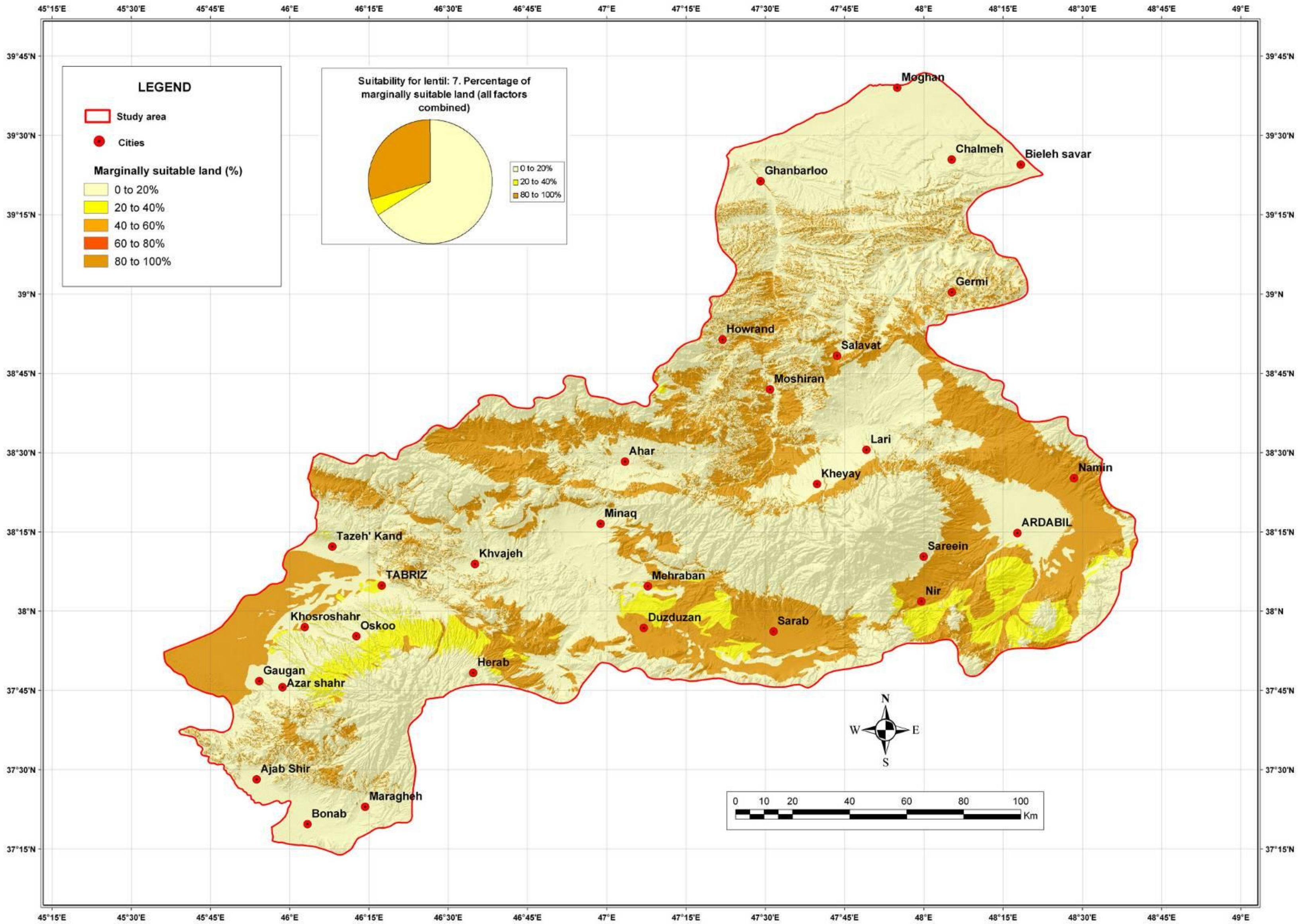
Map 71.Suitability for lentil: 4. Adequacy of topography (slopes)



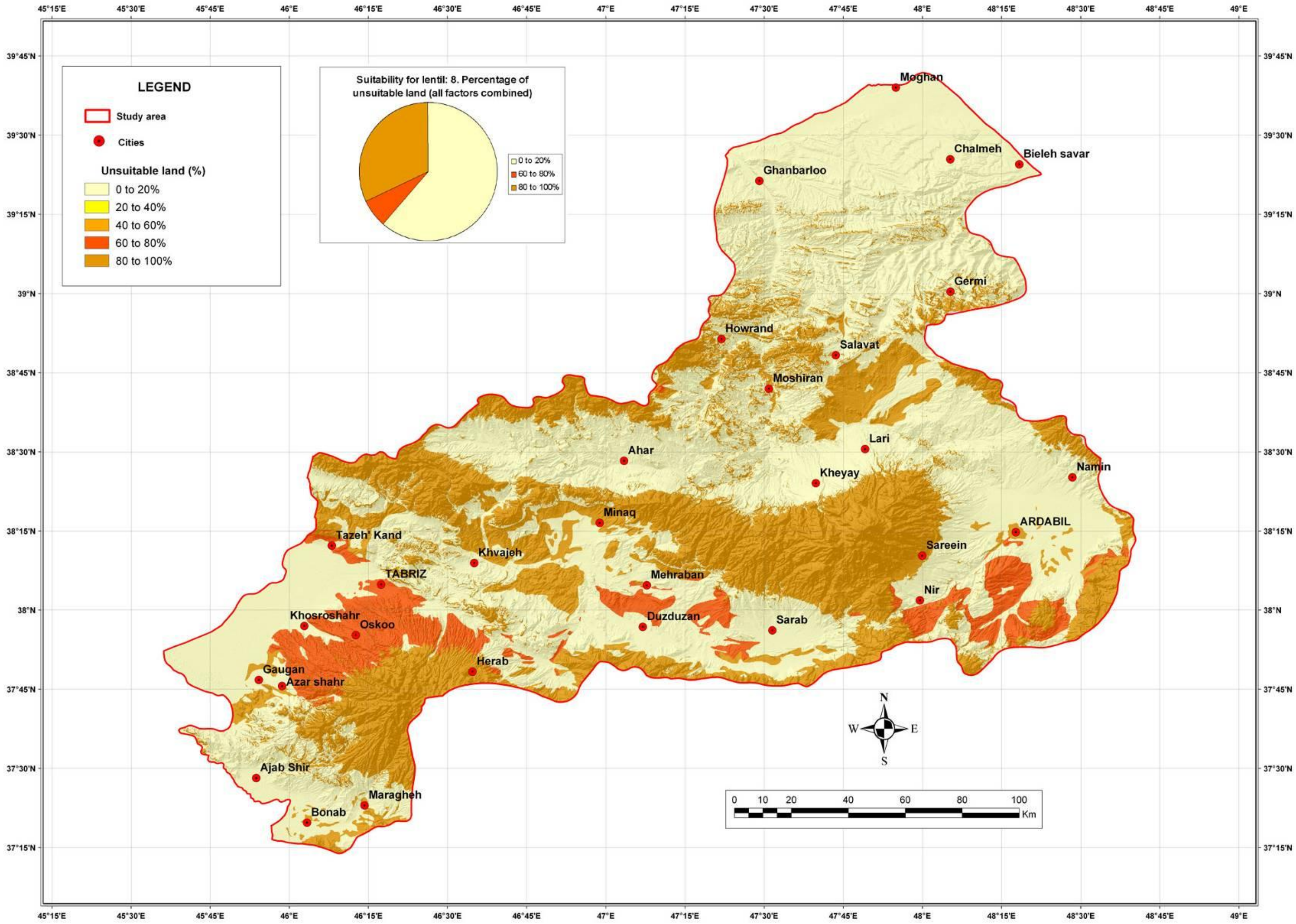
Map 72.Suitability for lentil: 5. Percentage of highly suitable land (all factors combined)



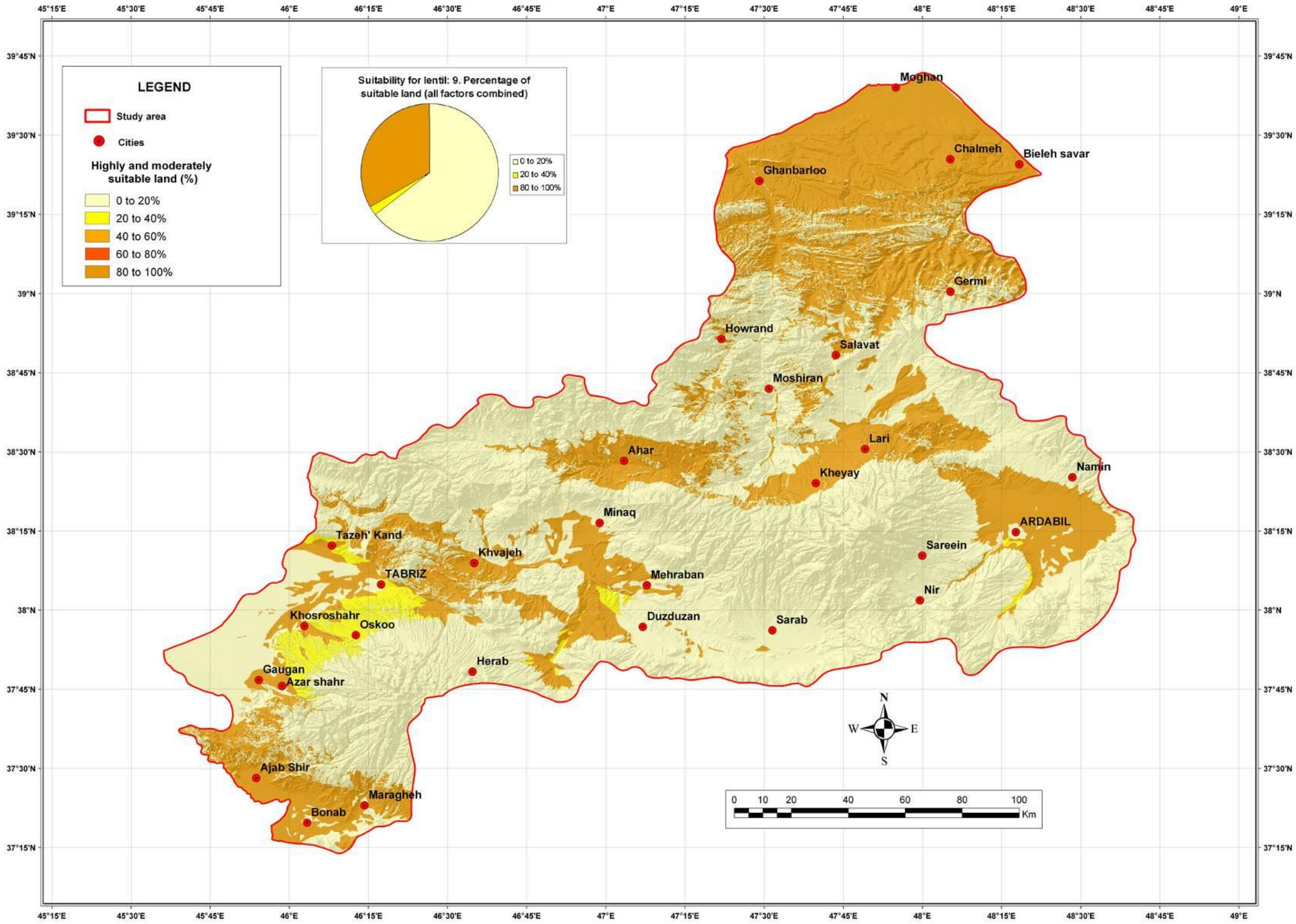
Map 73.Suitability for lentil: 6. Percentage of moderately suitable land (all factors combined)



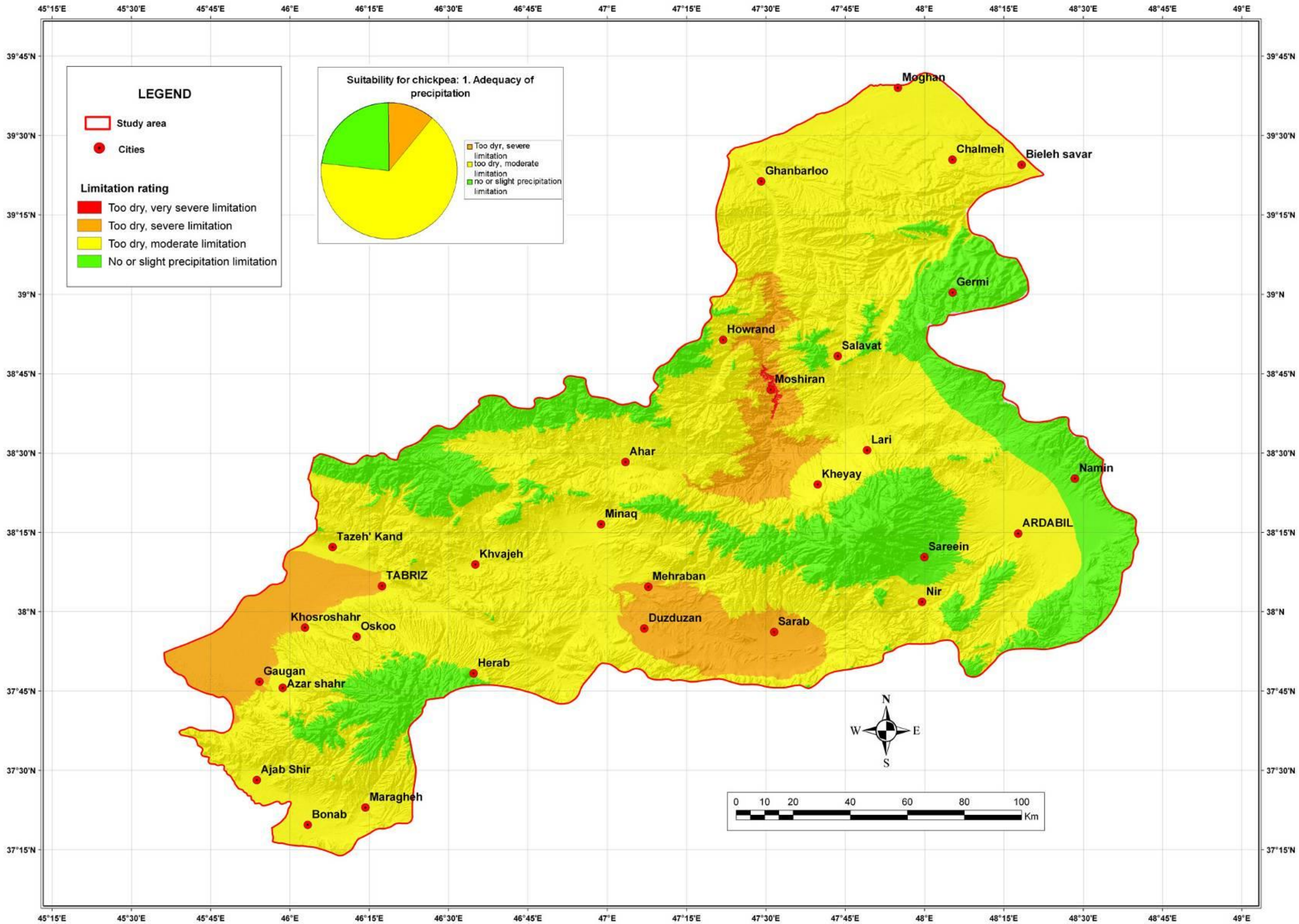
Map 74.Suitability for lentil: 7. Percentage of marginally suitable land (all factors combined)



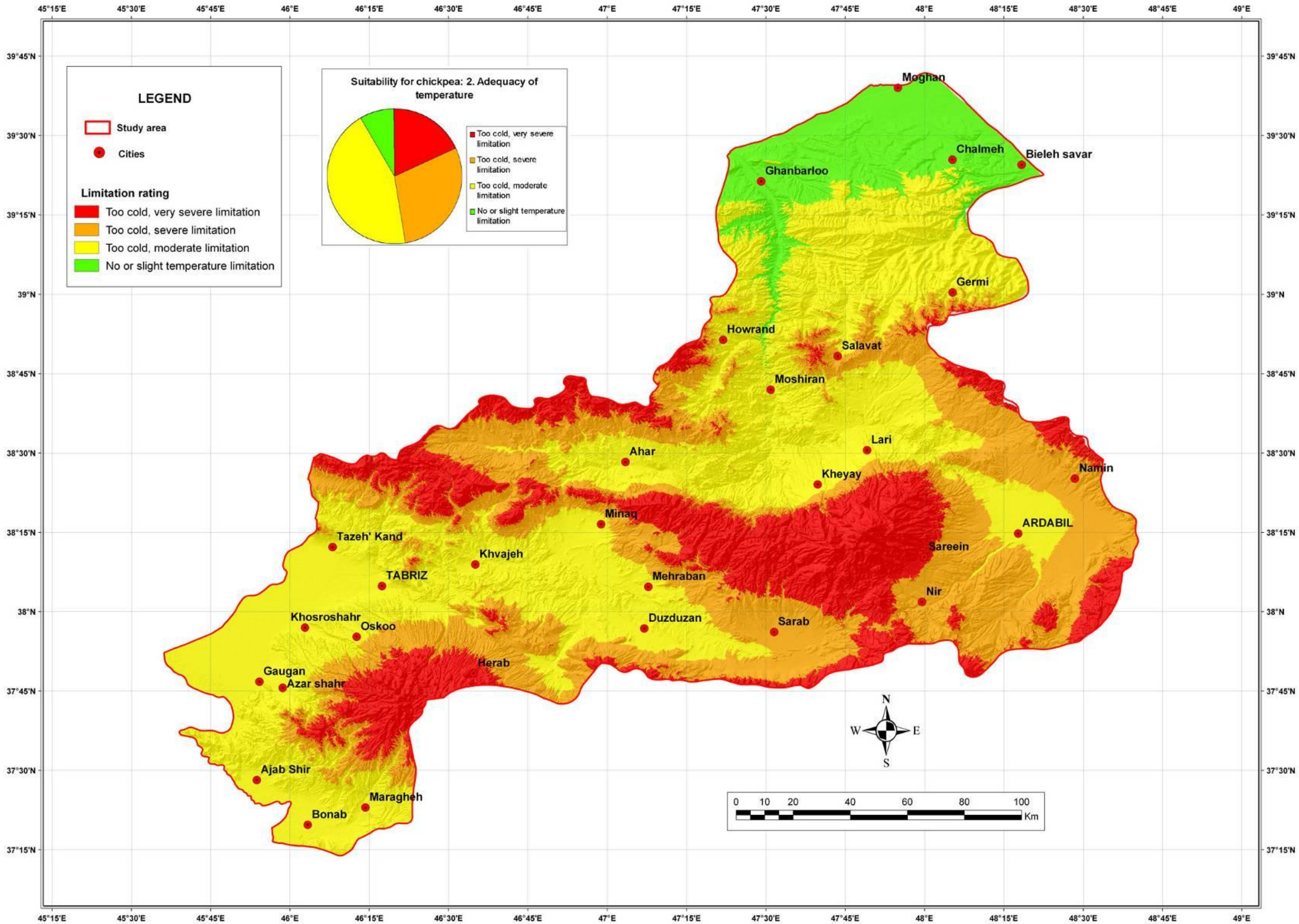
Map 75.Suitability for lentil: 8. Percentage of unsuitable land (all factors combined)



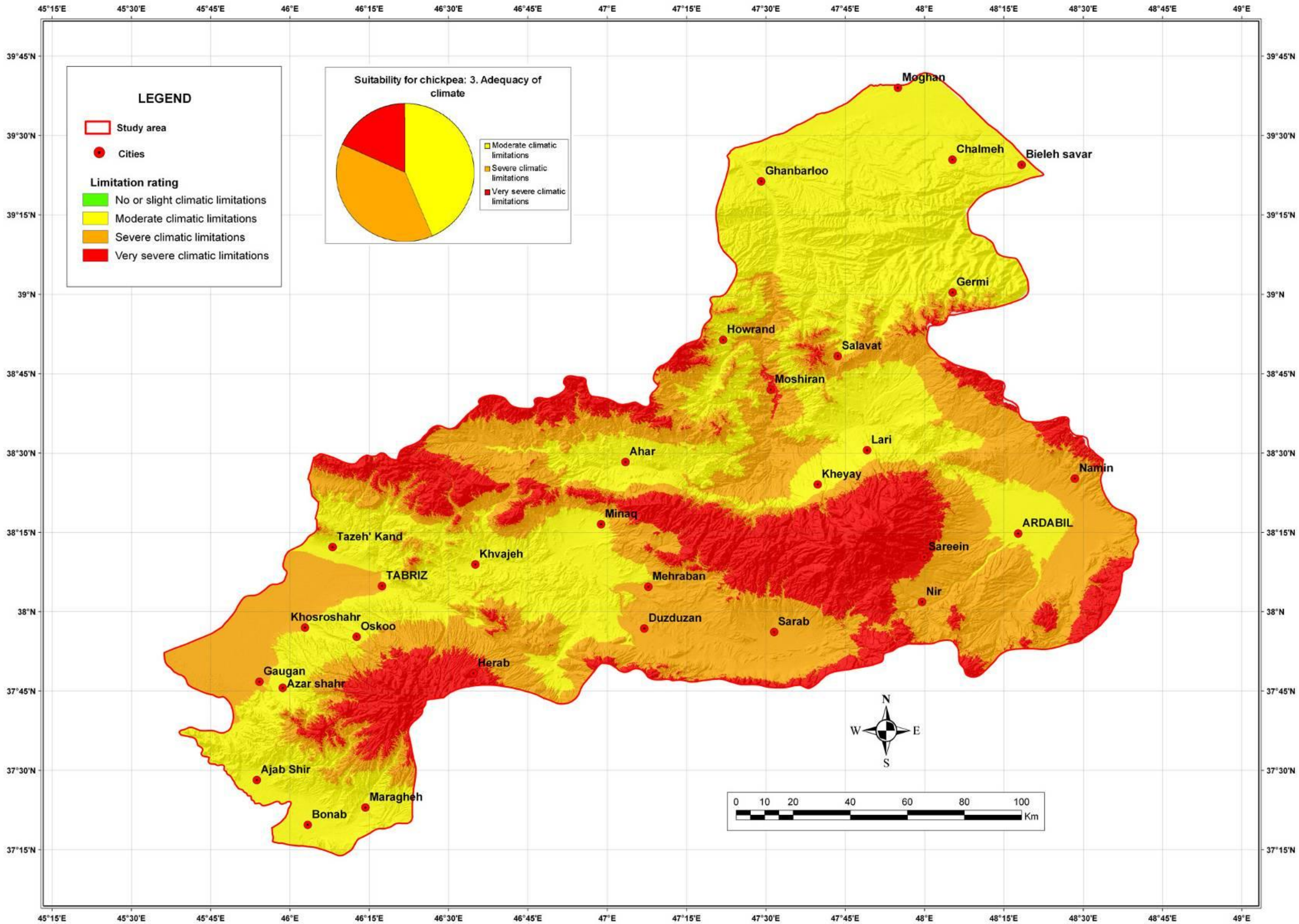
Map 76.Suitability for lentil: 9. Percentage of suitable land (all factors combined)



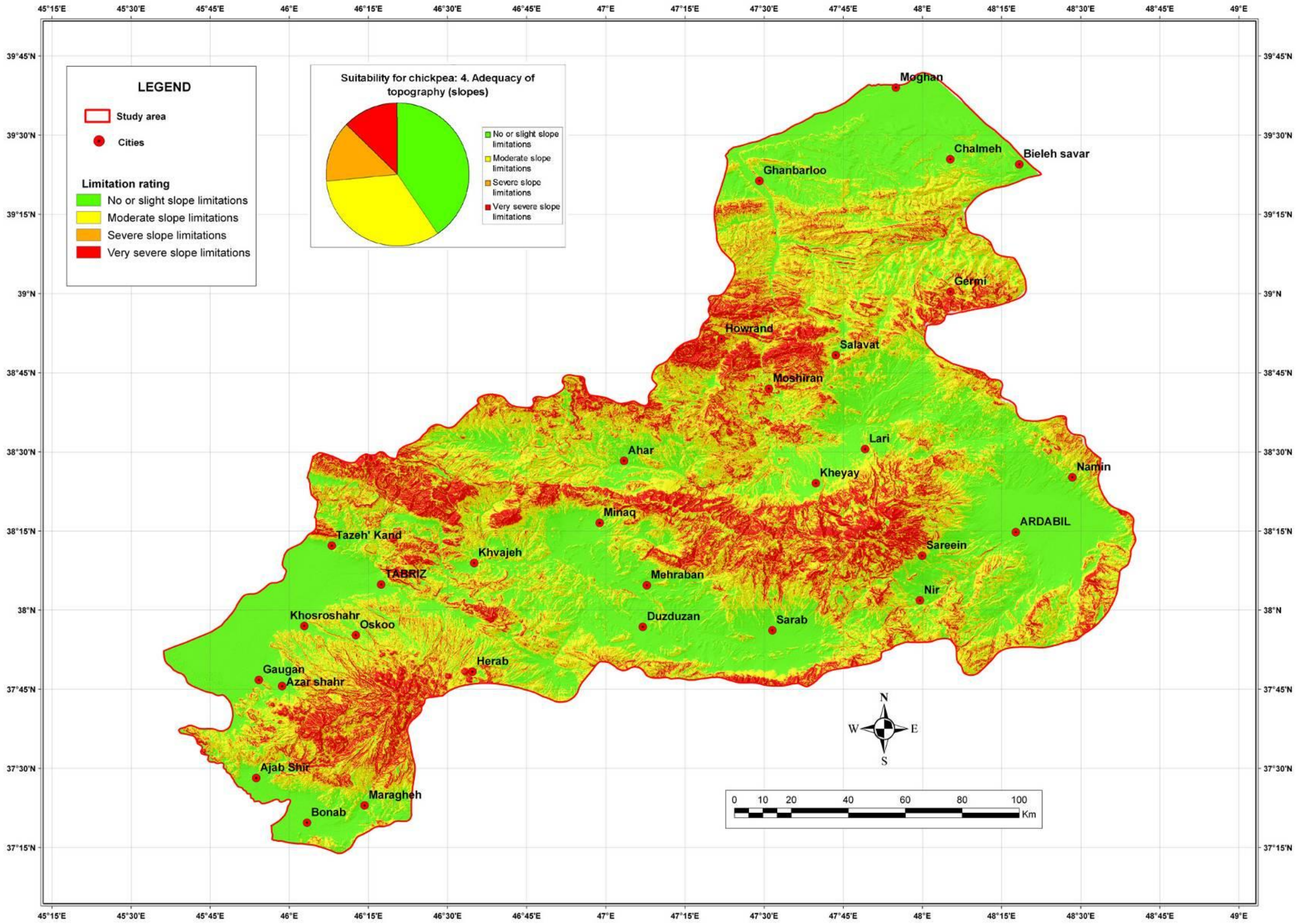
Map 77.Suitability for chickpea: 1. Adequacy of precipitation



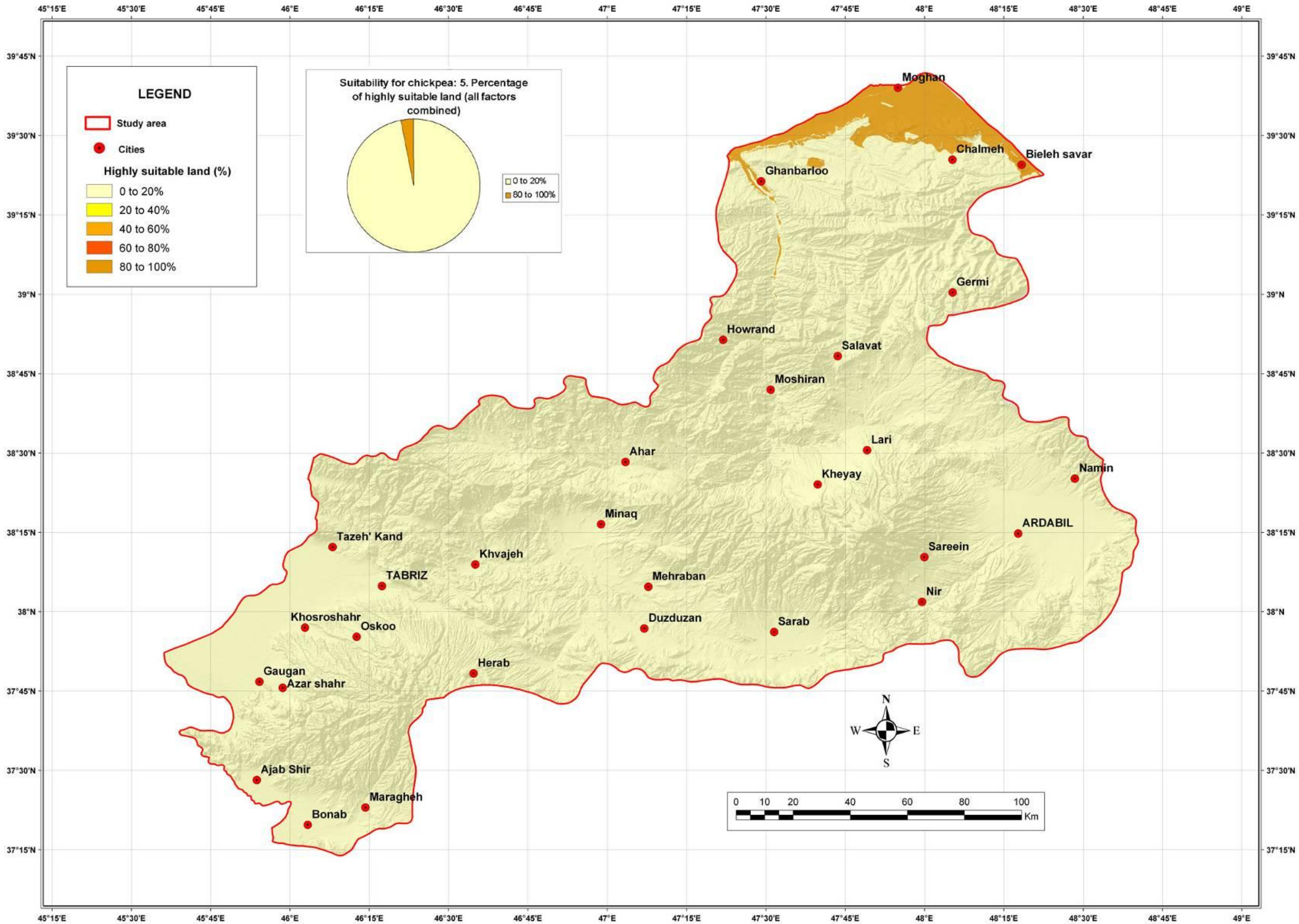
Map 78.Suitability for chickpea: 2. Adequacy of temperature



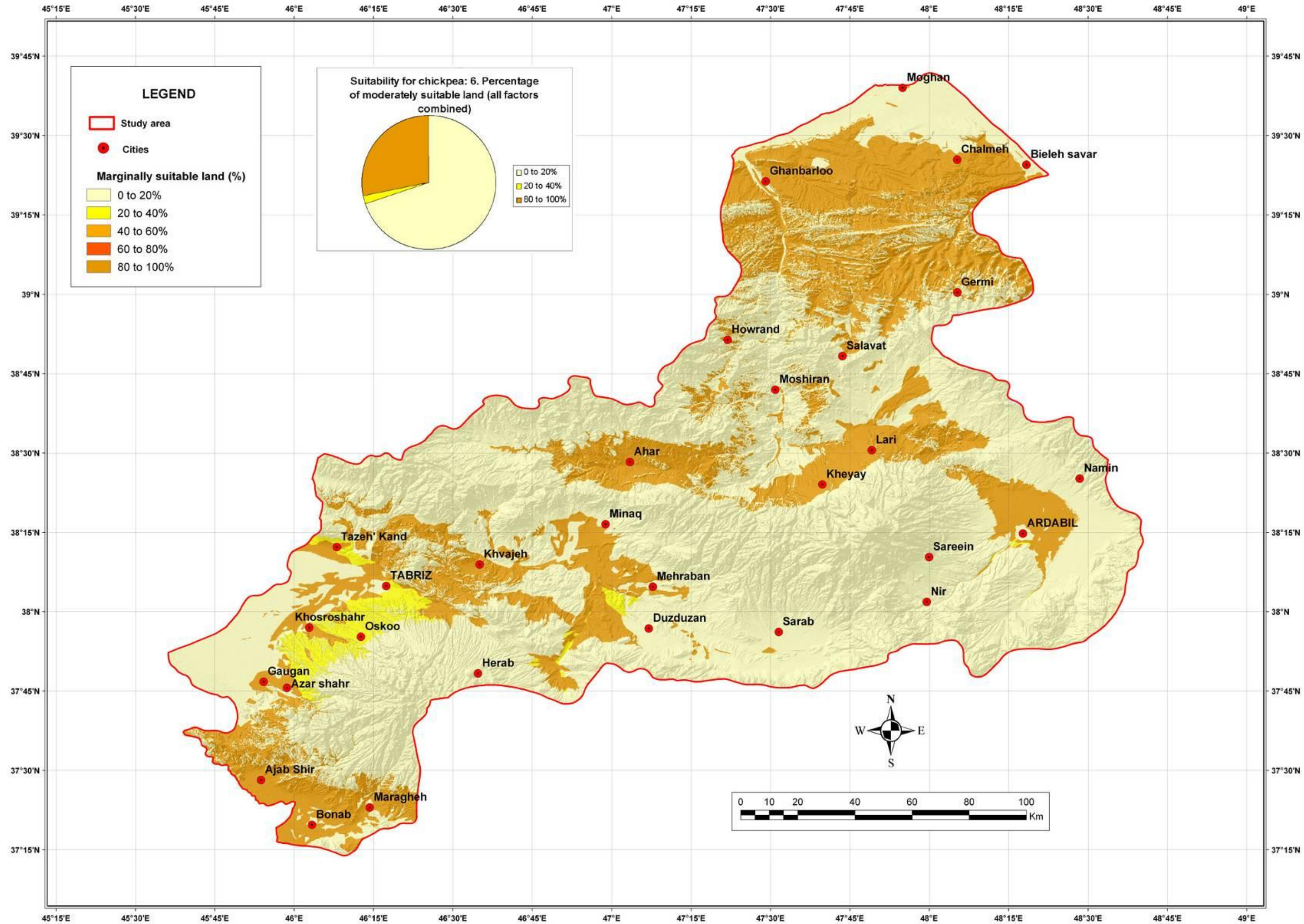
Map 79.Suitability for chickpea: 3. Adequacy of climate



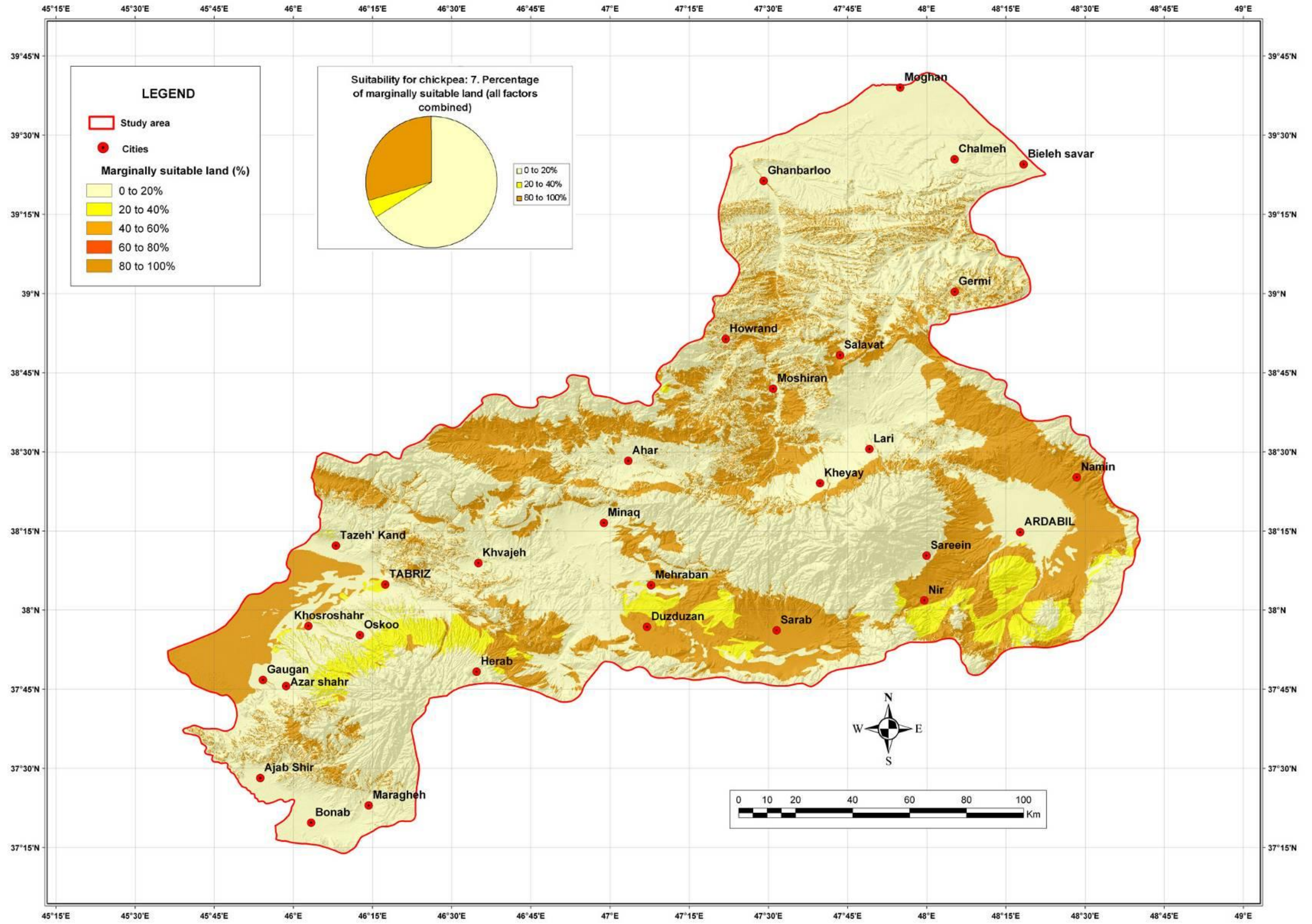
Map 80.Suitability for chickpea: 4. Adequacy of topography (slopes)



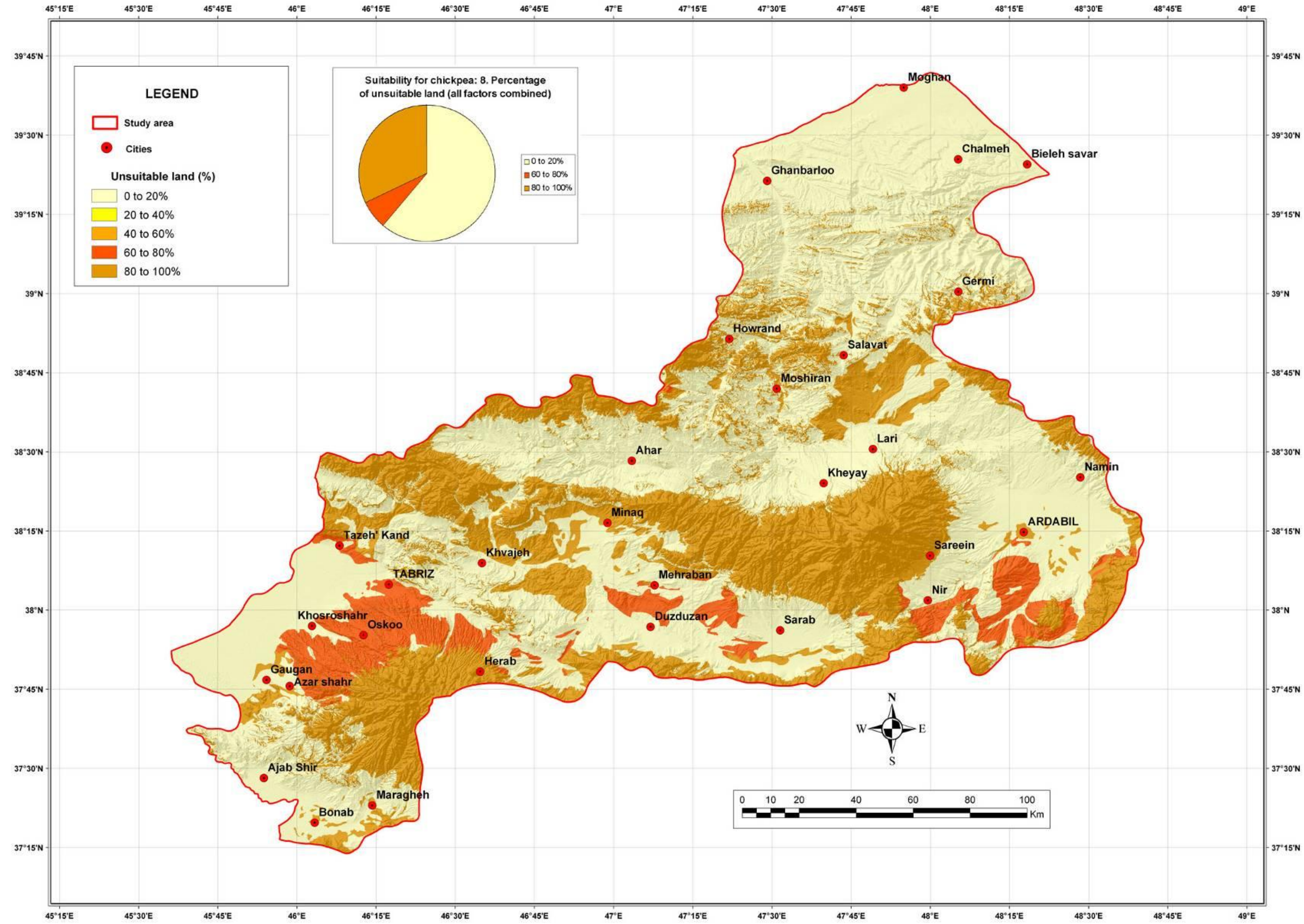
Map 81.Suitability for chickpea: 5. Percentage of highly suitable land (all factors combined)



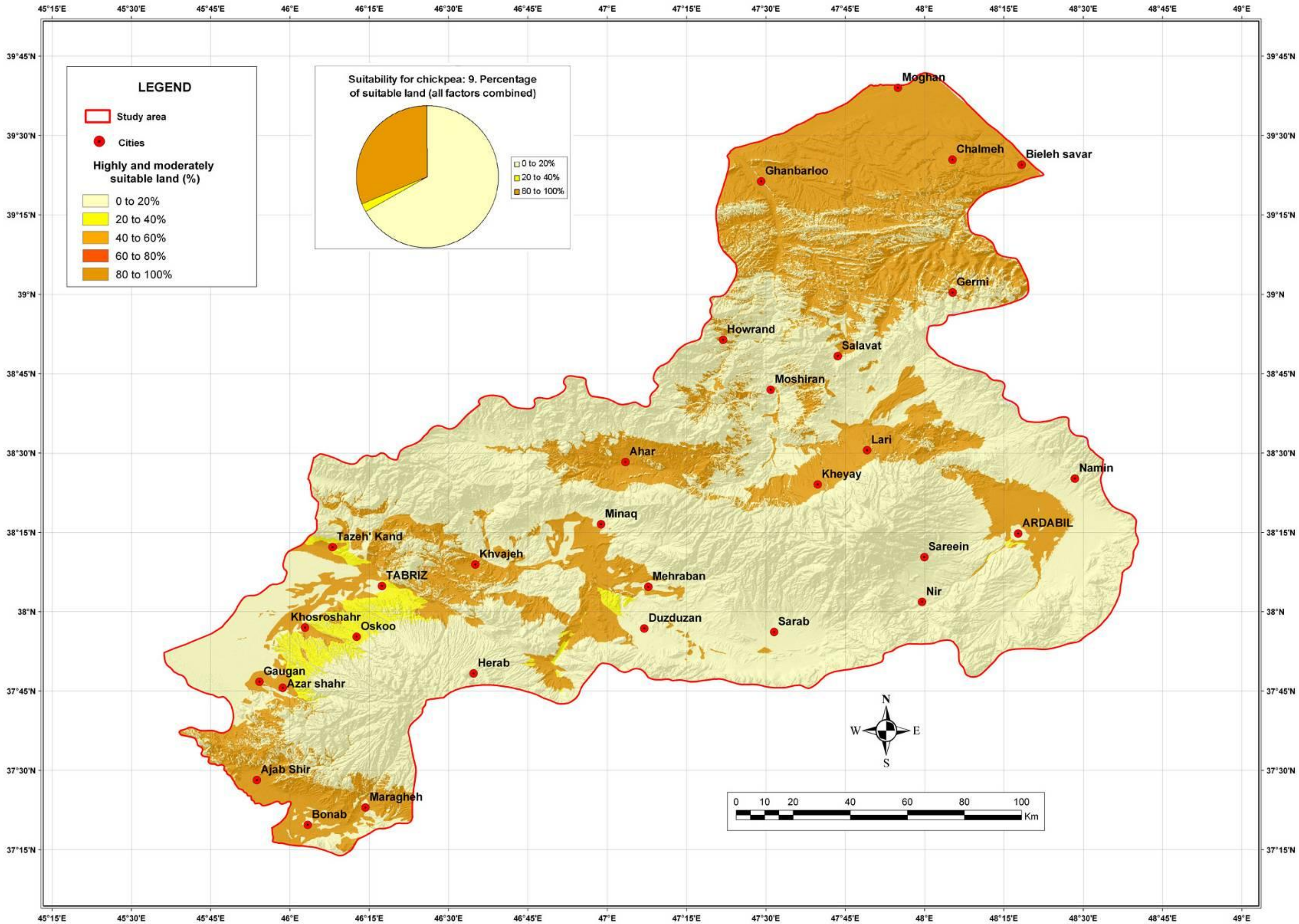
Map 82.Suitability for chickpea: 6. Percentage of moderately suitable land (all factors combined)



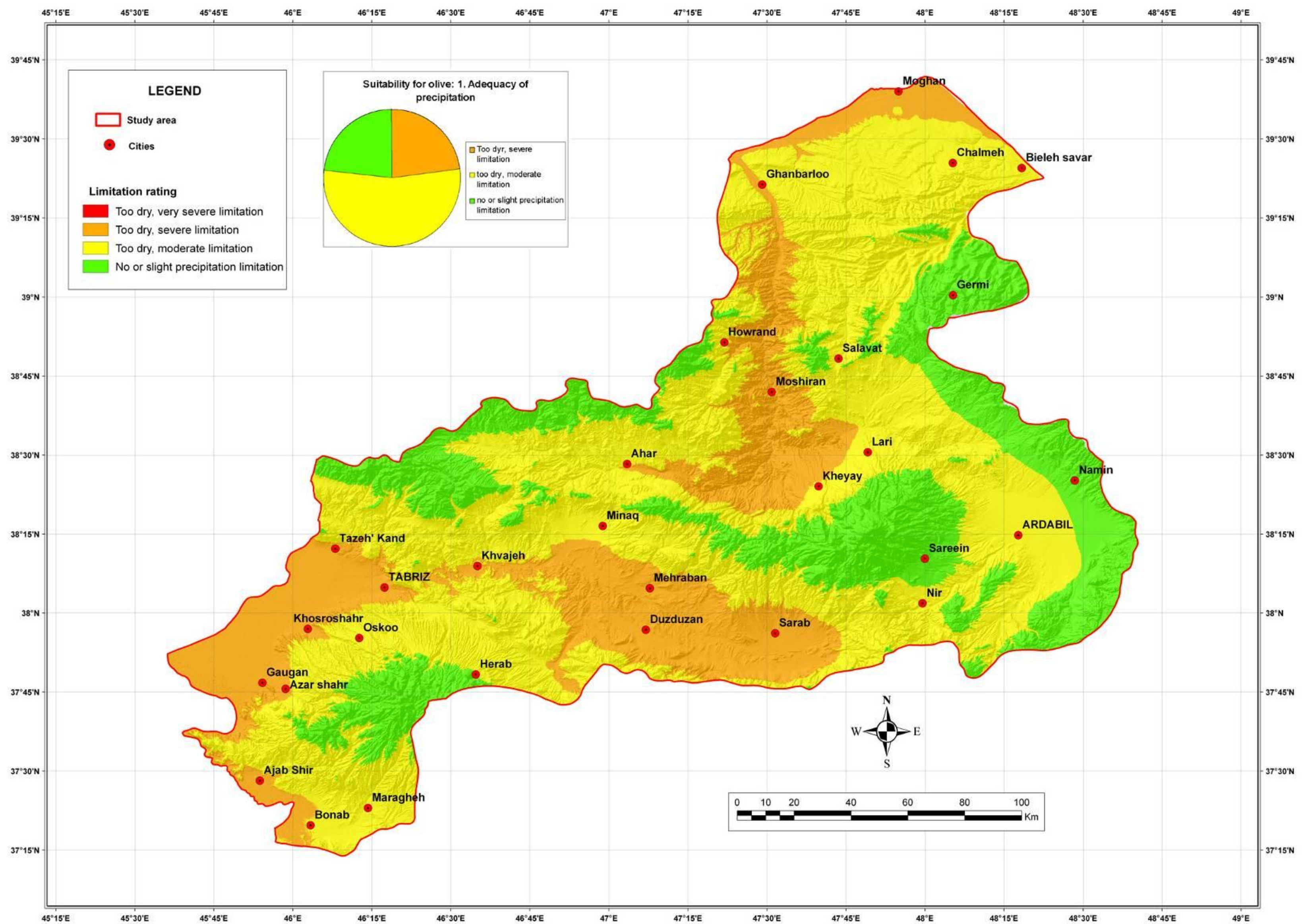
Map 83.Suitability for chickpea: 7. Percentage of marginally suitable land (all factors combined)



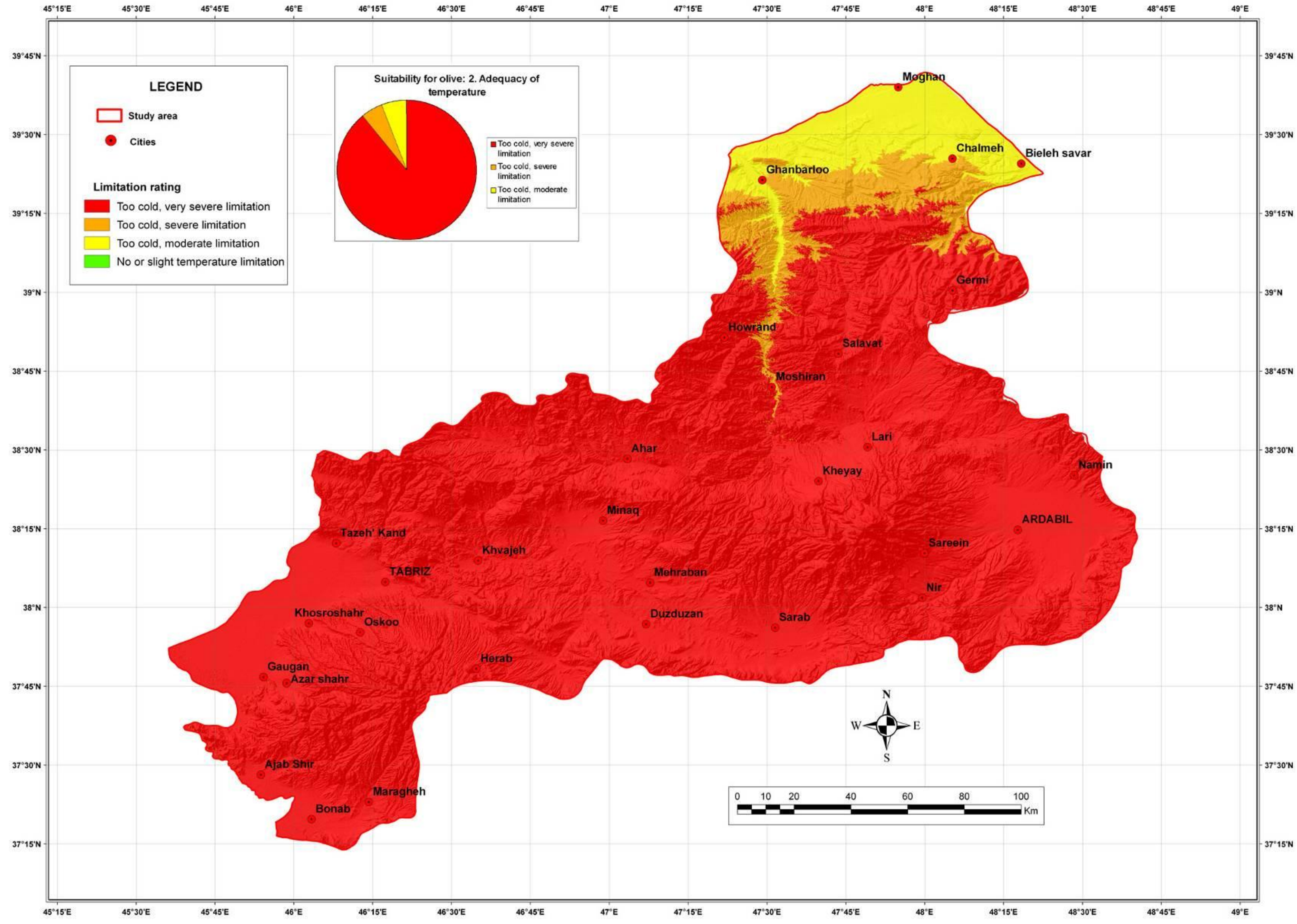
Map 84.Suitability for chickpea: 8. Percentage of unsuitable land (all factors combined)



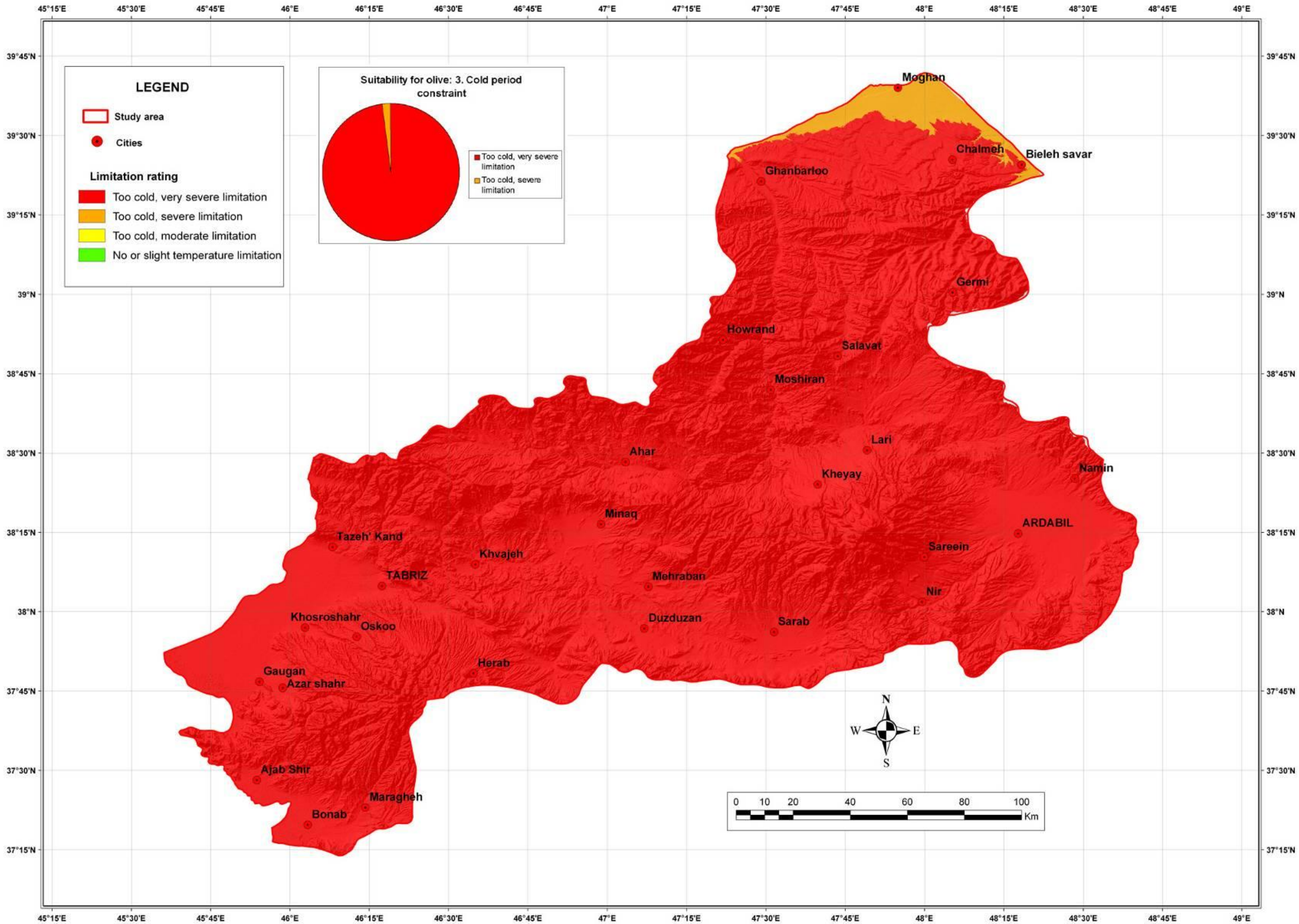
Map 85.Suitability for chickpea: 9. Percentage of suitable land (all factors combined)



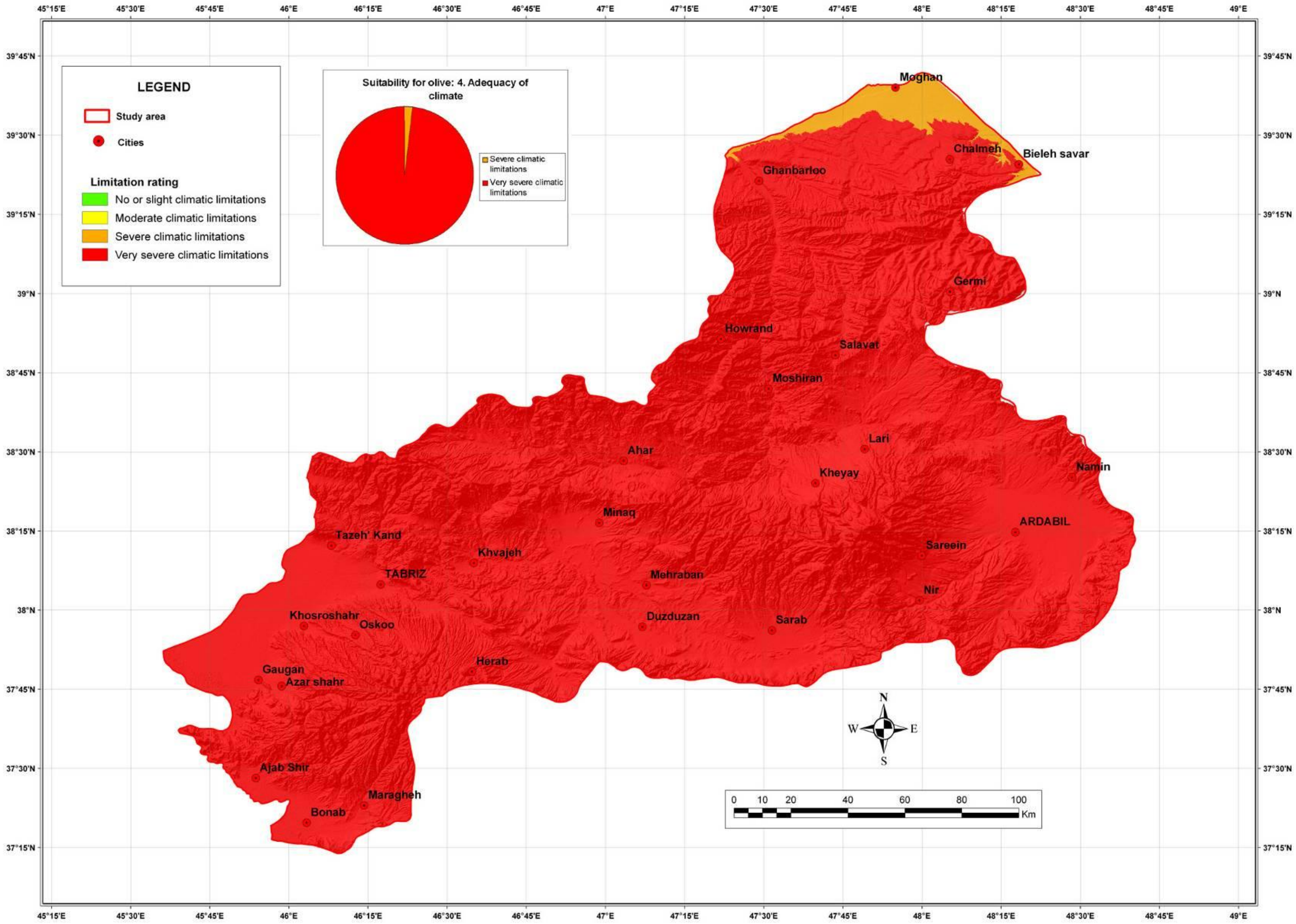
Map 86.Suitability for olive: 1. Adequacy of precipitation



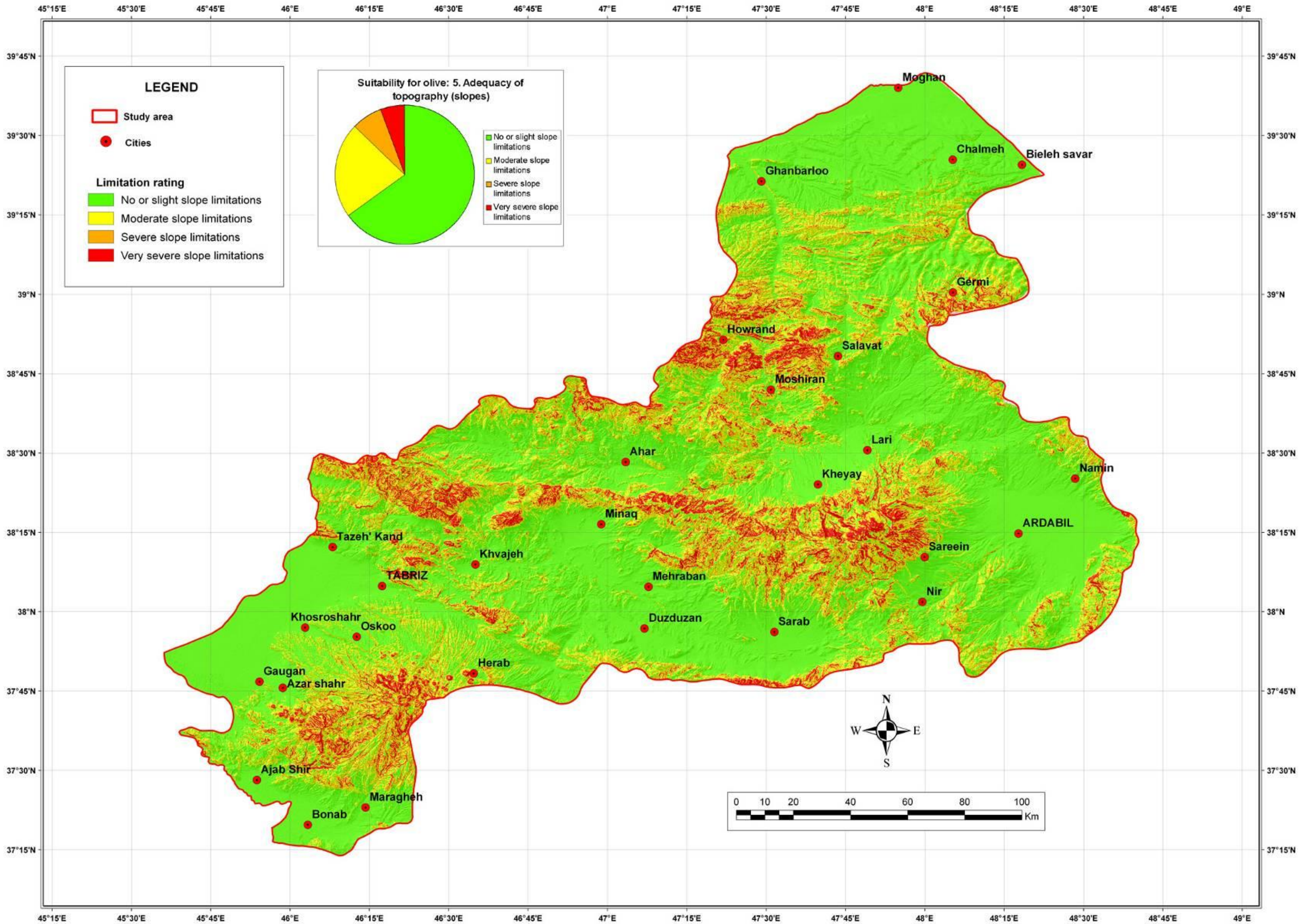
Map 87.Suitability for olive: 2. Adequacy of temperature



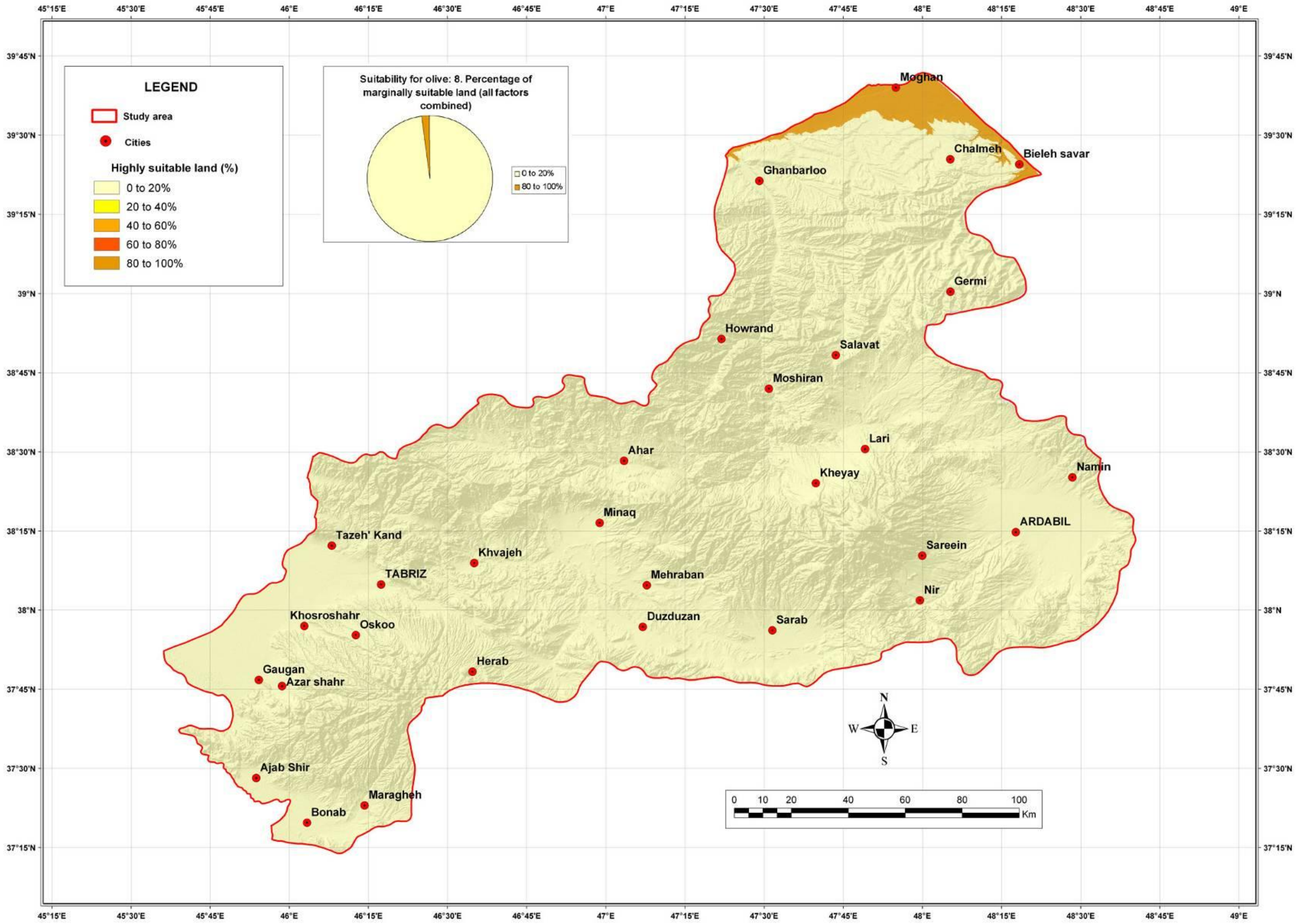
Map 88.Suitability for olive: 3. Cold period constraint



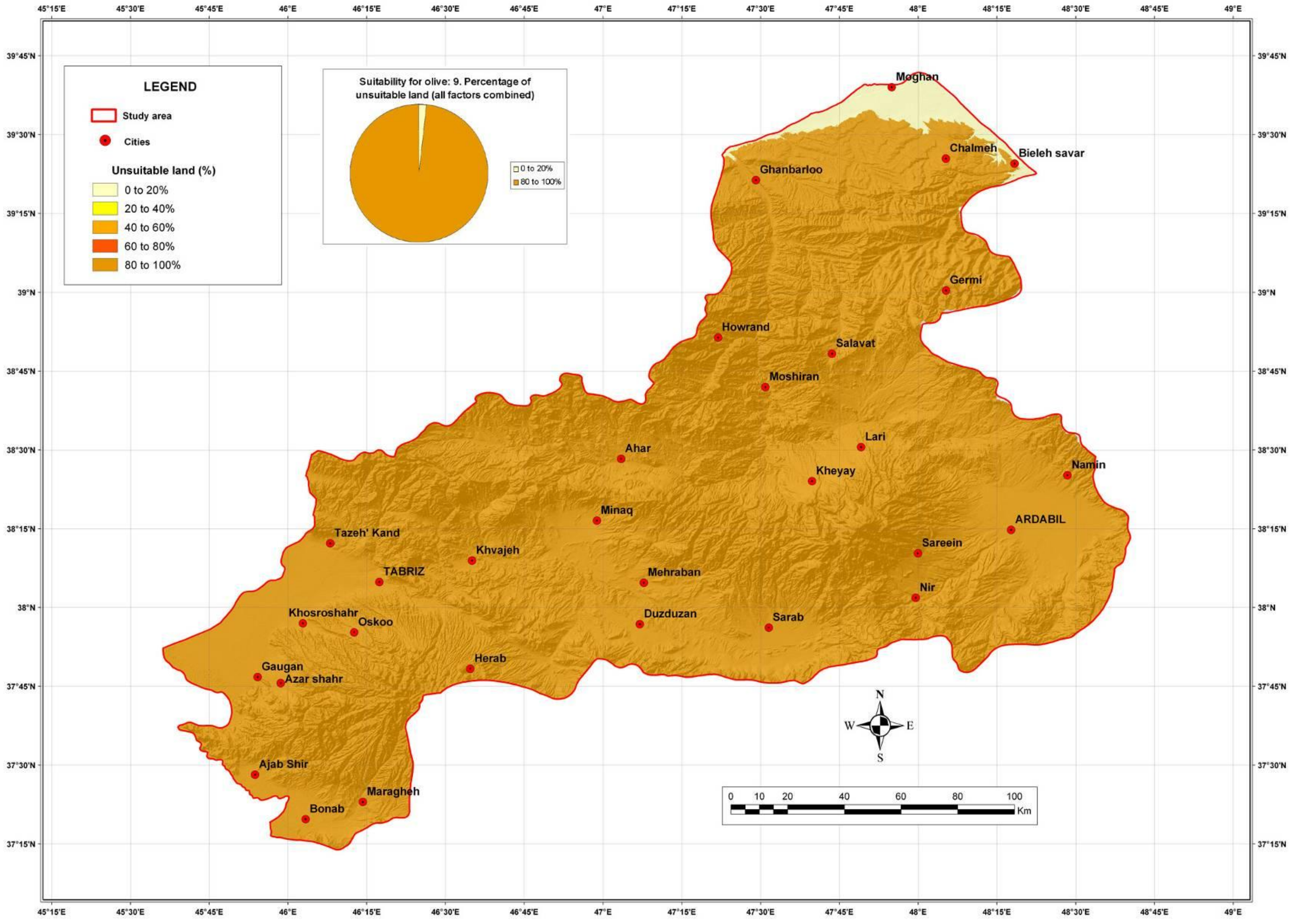
Map 89.Suitability for olive: 4. Adequacy of climate



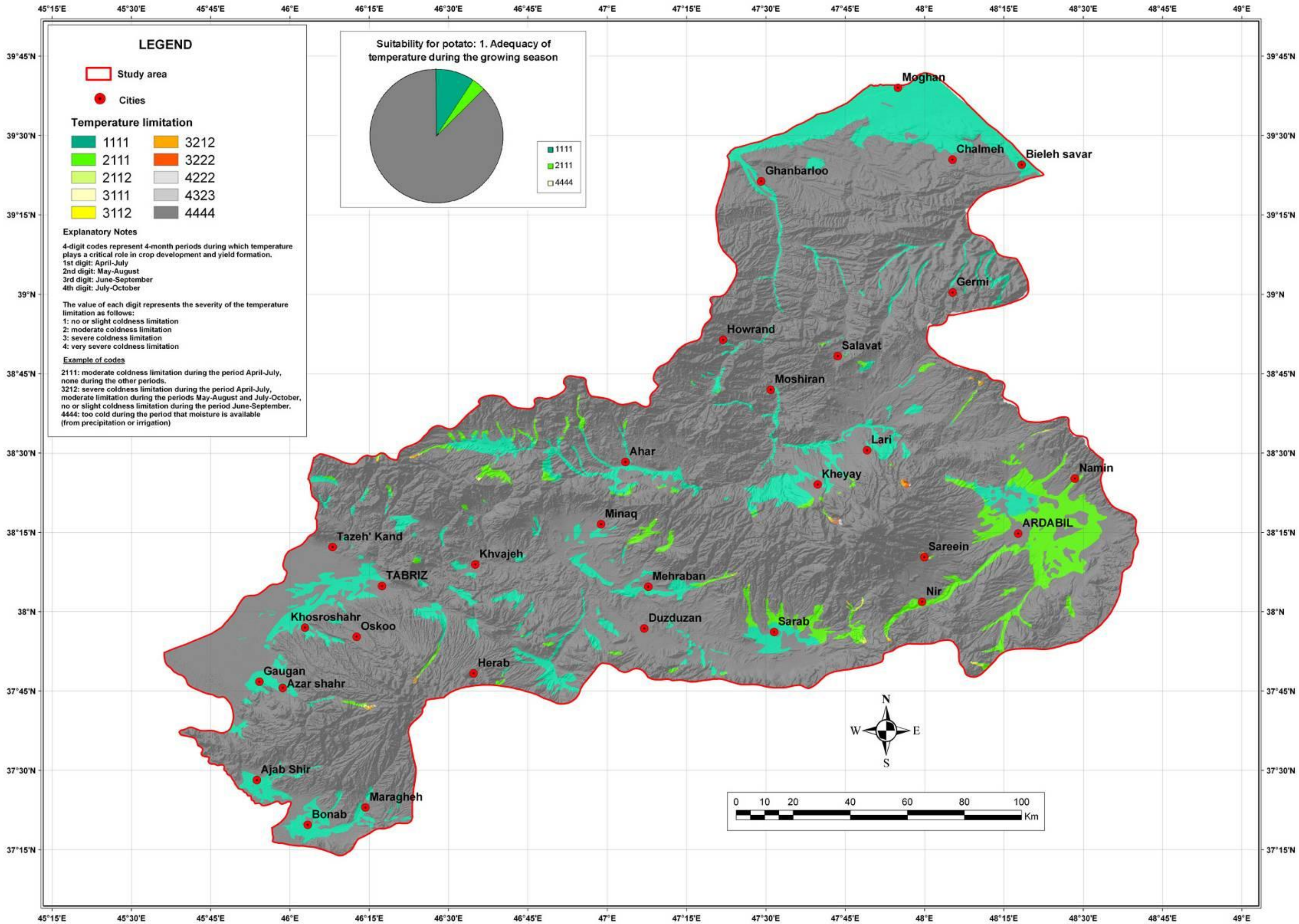
Map 90.Suitability for olive: 5. Adequacy of topography (slopes)



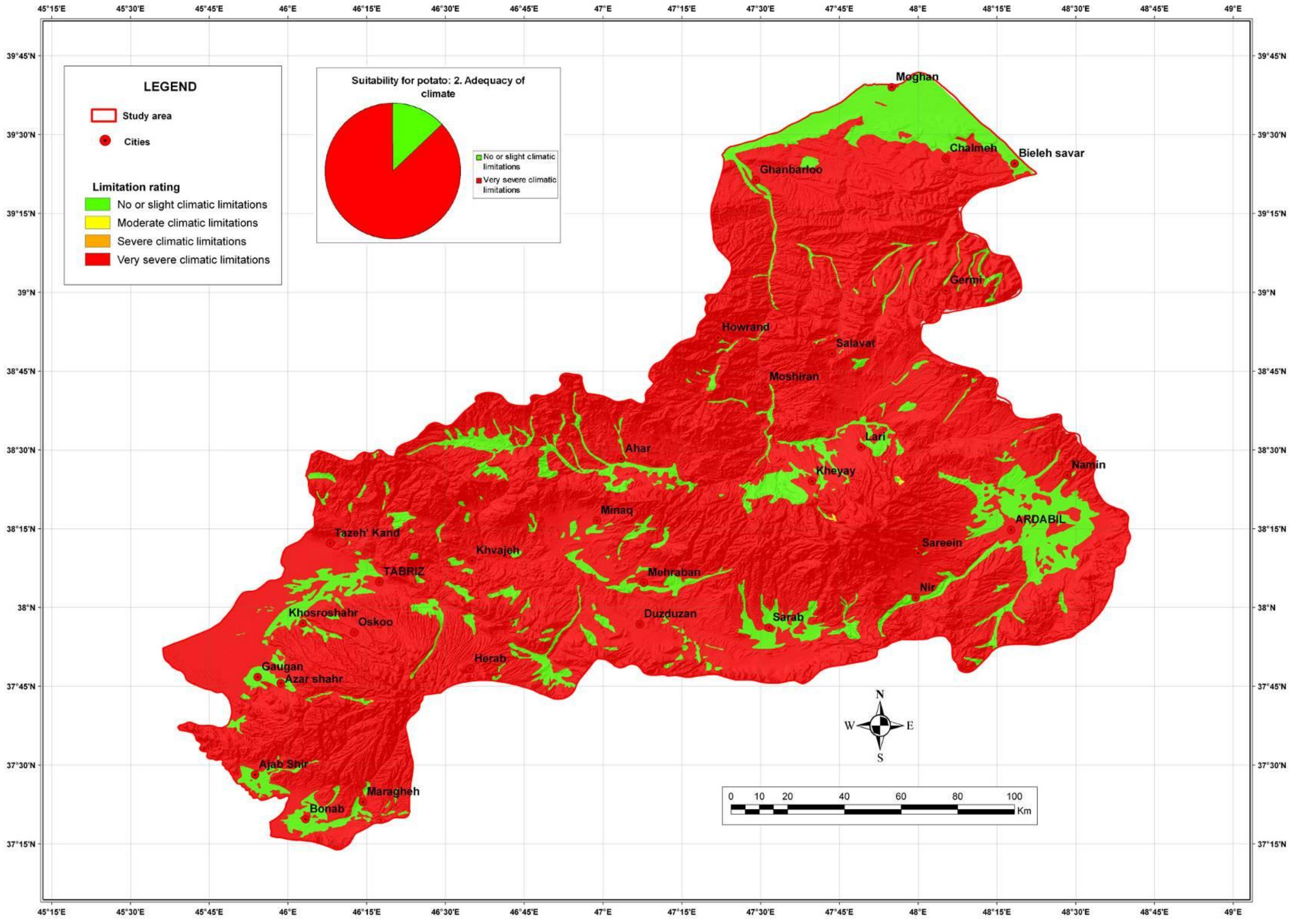
Map 91.Suitability for olive: 8. Percentage of marginally suitable land (all factors combined)



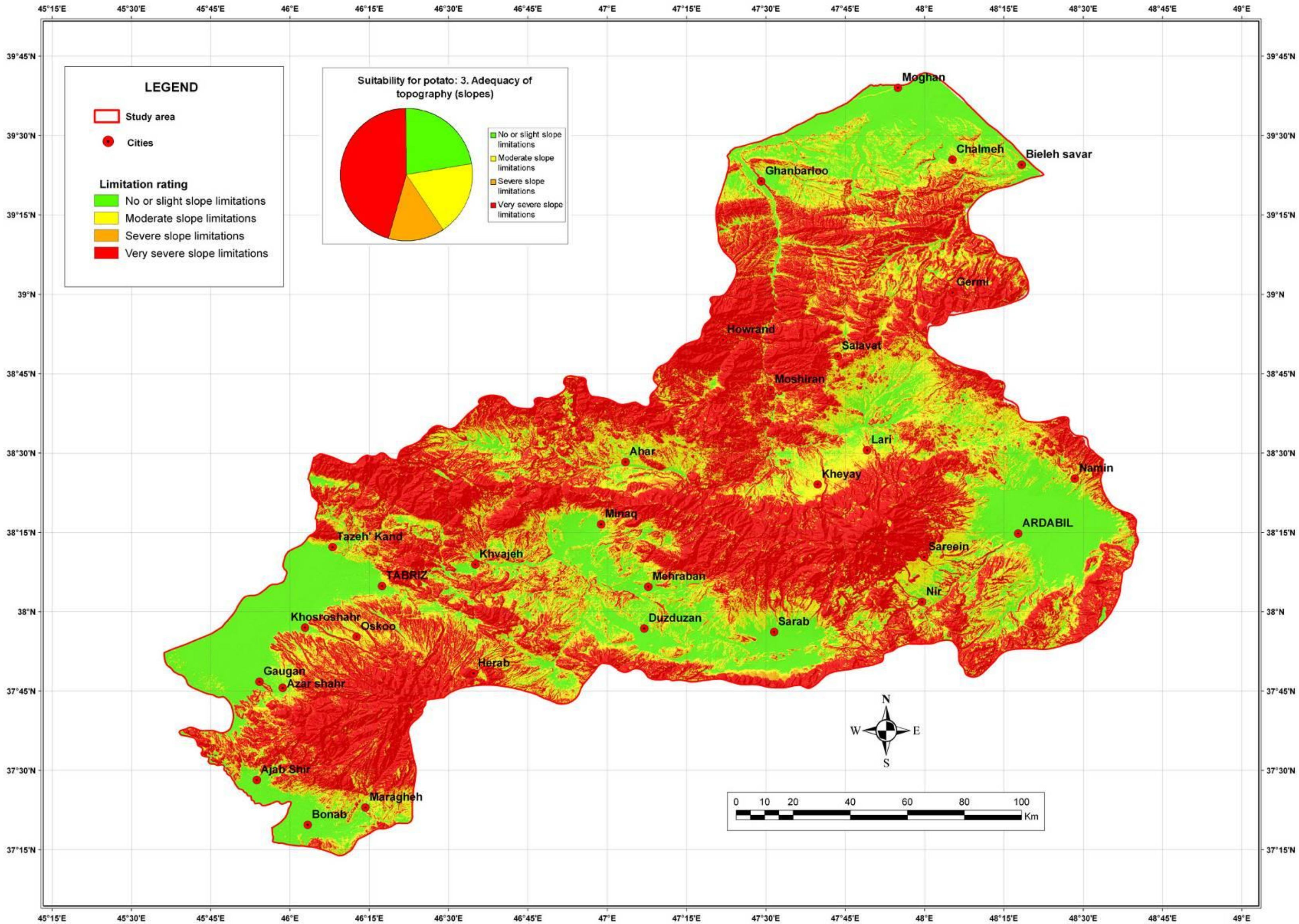
Map 92.Suitability for olive: 9. Percentage of unsuitable land (all factors combined)



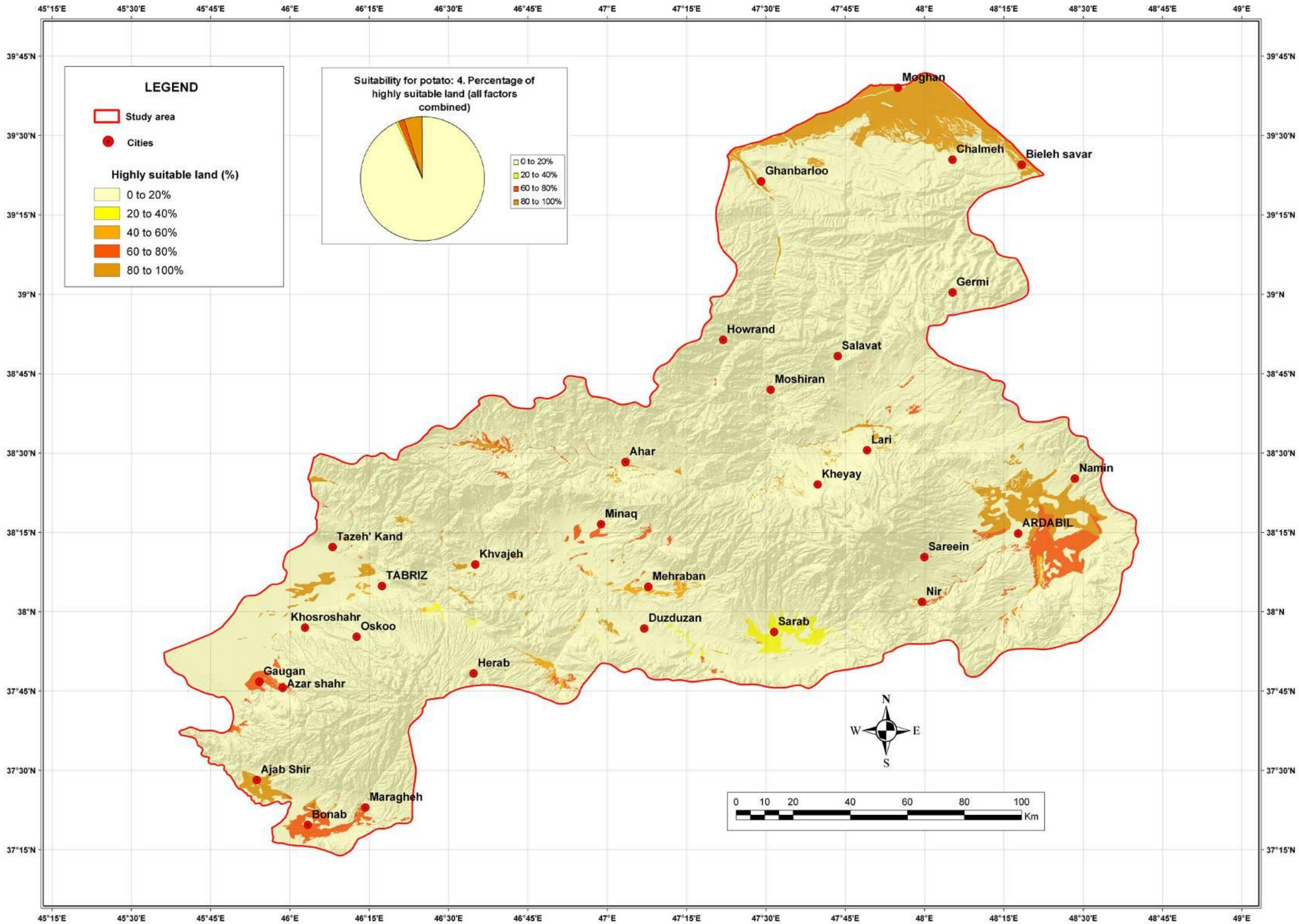
Map 93.Suitability for potato: 1. Adequacy of temperature during the growing season



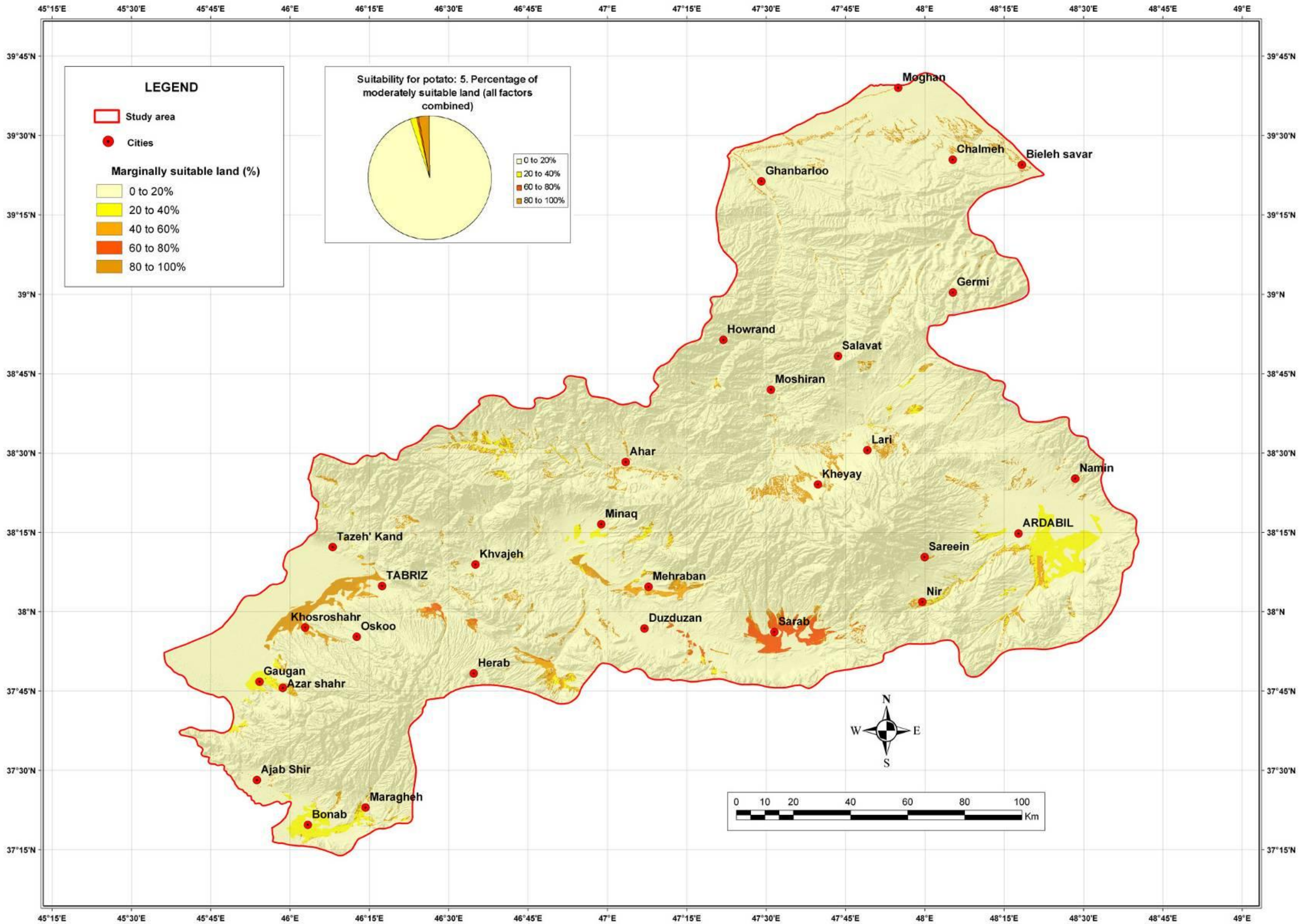
Map 94.Suitability for potato: 2. Adequacy of climate



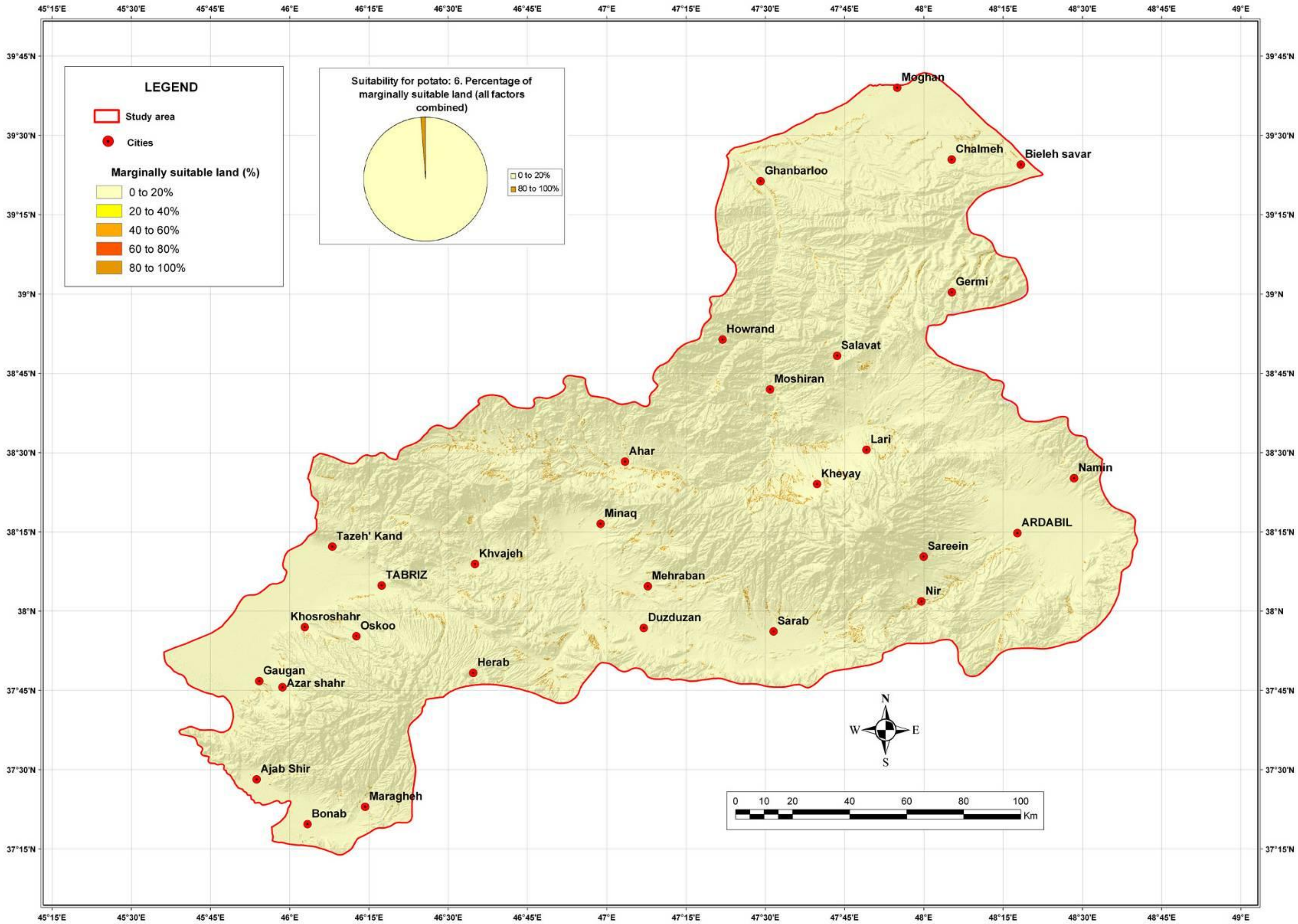
Map 95.Suitability for potato: 3. Adequacy of topography (slopes)



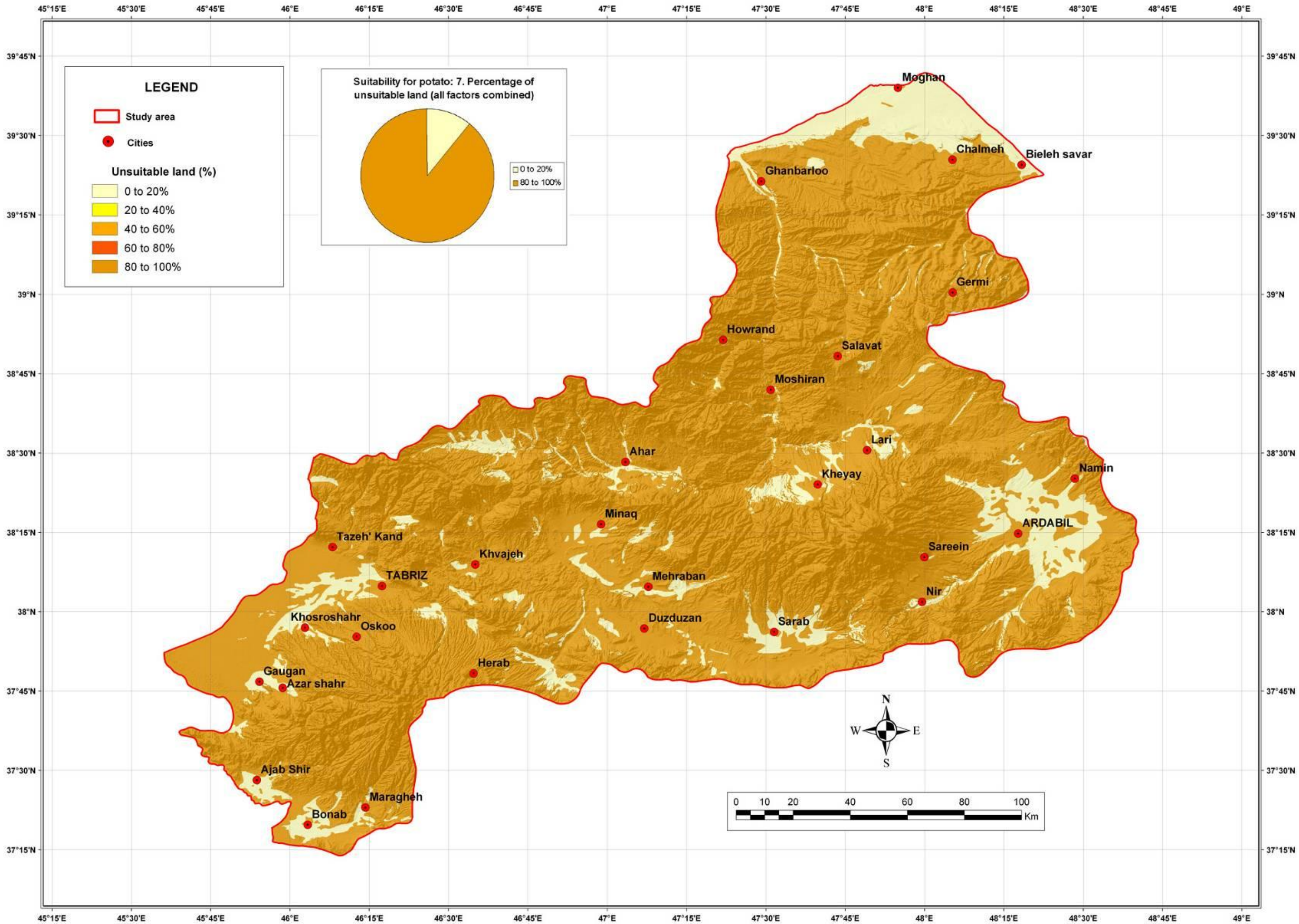
Map 96.Suitability for potato: 4. Percentage of highly suitable land (all factors combined)



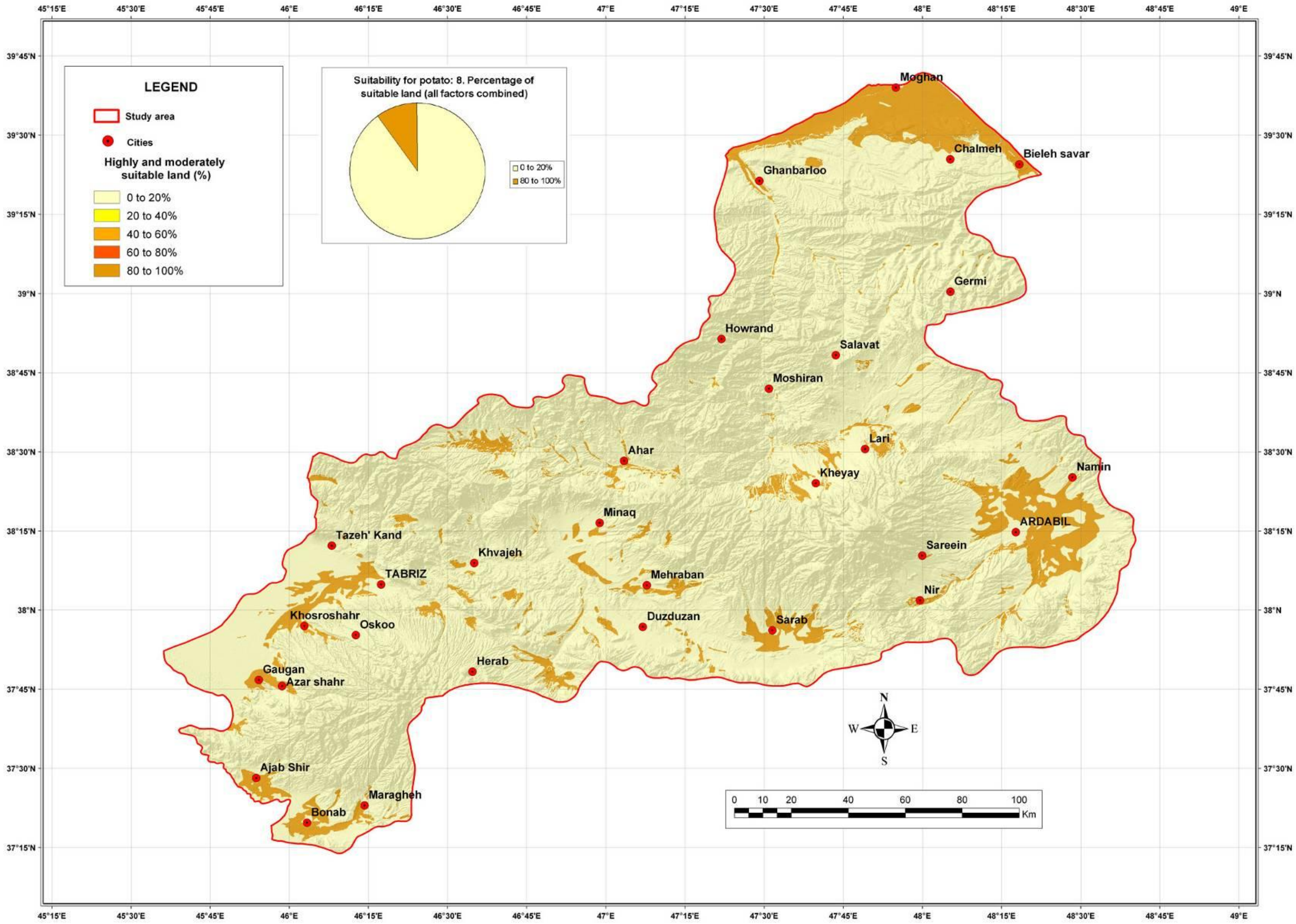
Map 97.Suitability for potato: 5. Percentage of moderately suitable land (all factors combined)



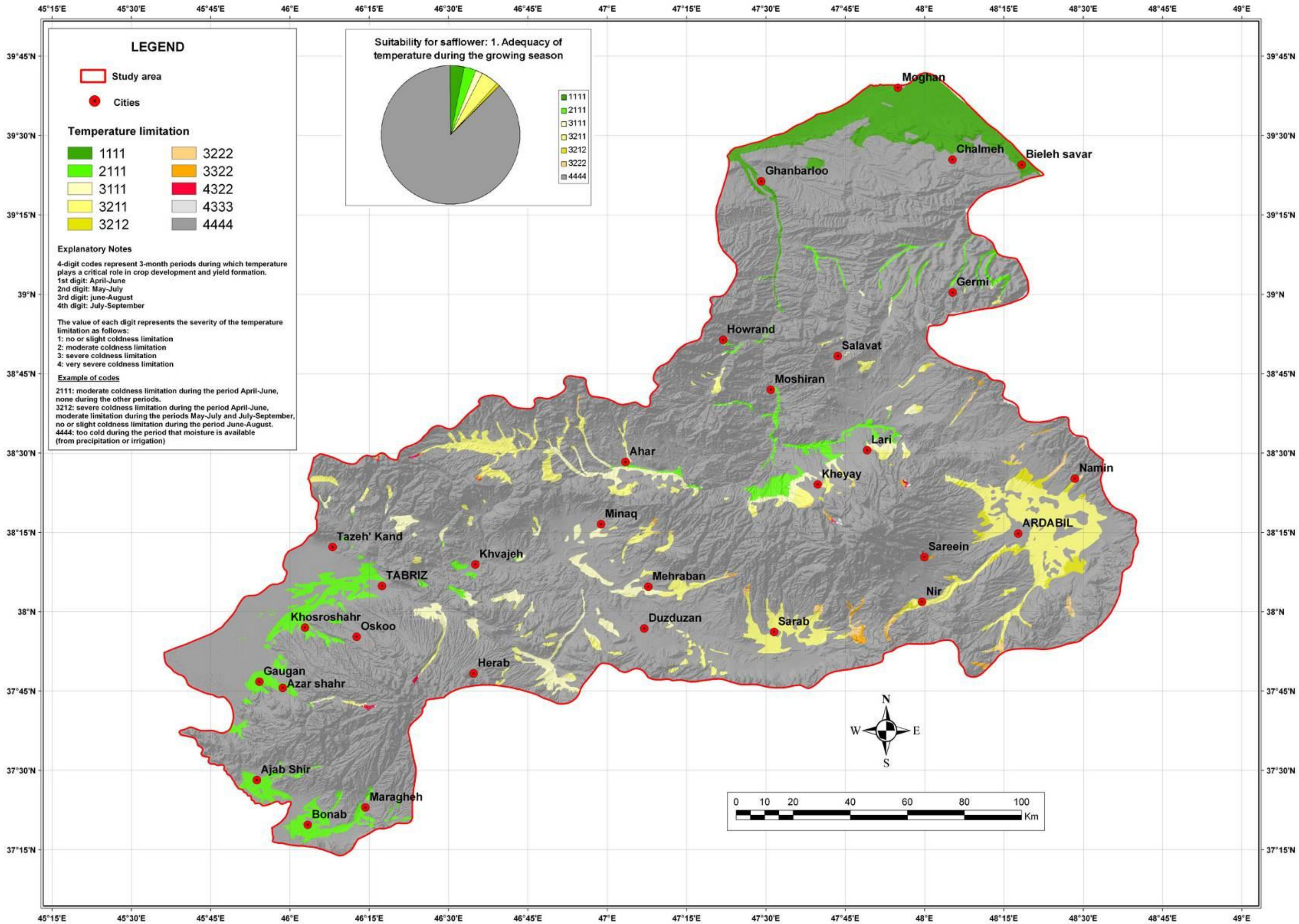
Map 98.Suitability for potato: 6. Percentage of marginally suitable land (all factors combined)



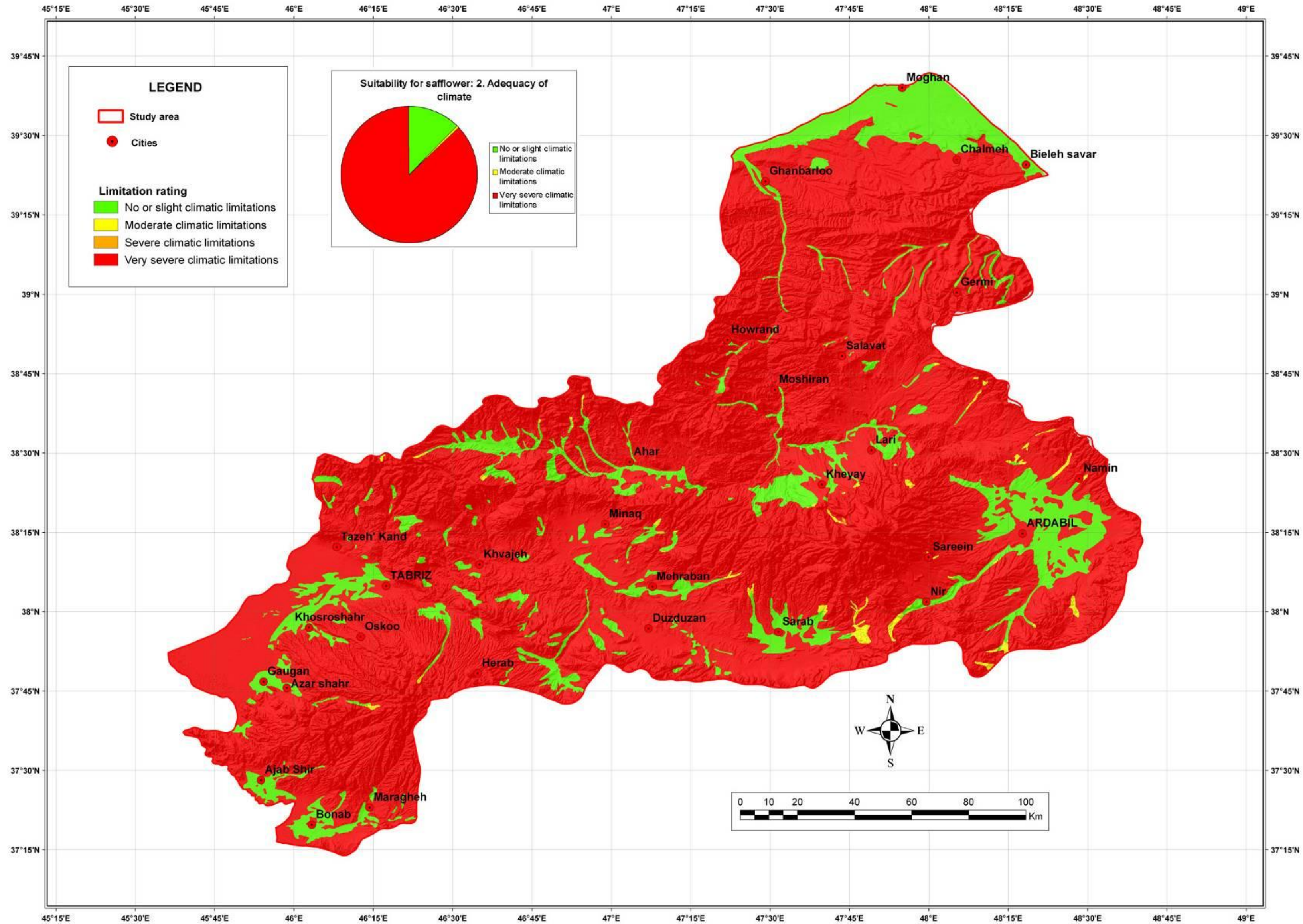
Map 99.Suitability for potato: 7. Percentage of unsuitable land (all factors combined)



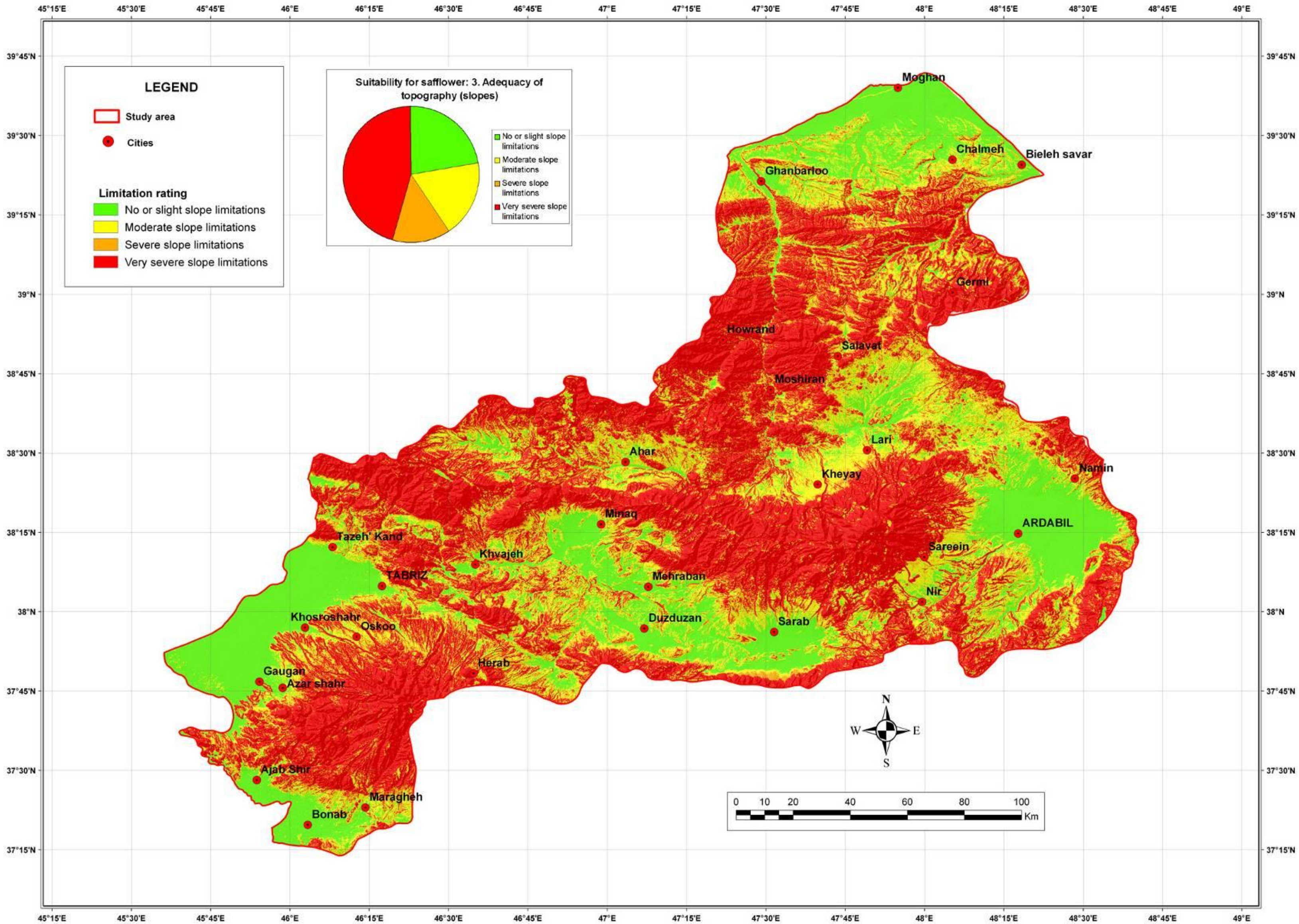
Map 100.Suitability for potato: 8. Percentage of suitable land (all factors combined)



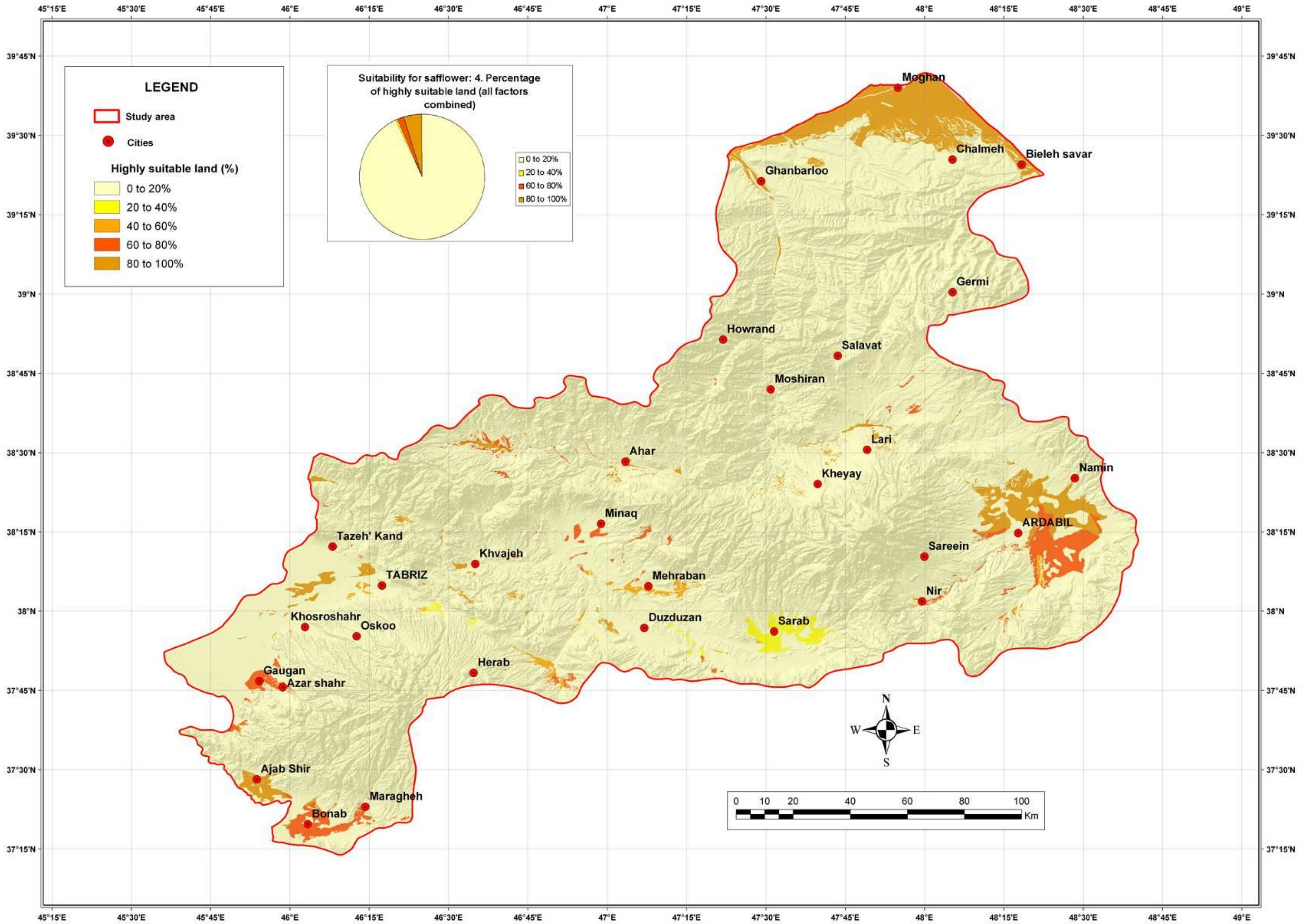
Map 101.Suitability for safflower: 1. Adequacy of temperature during the growing season



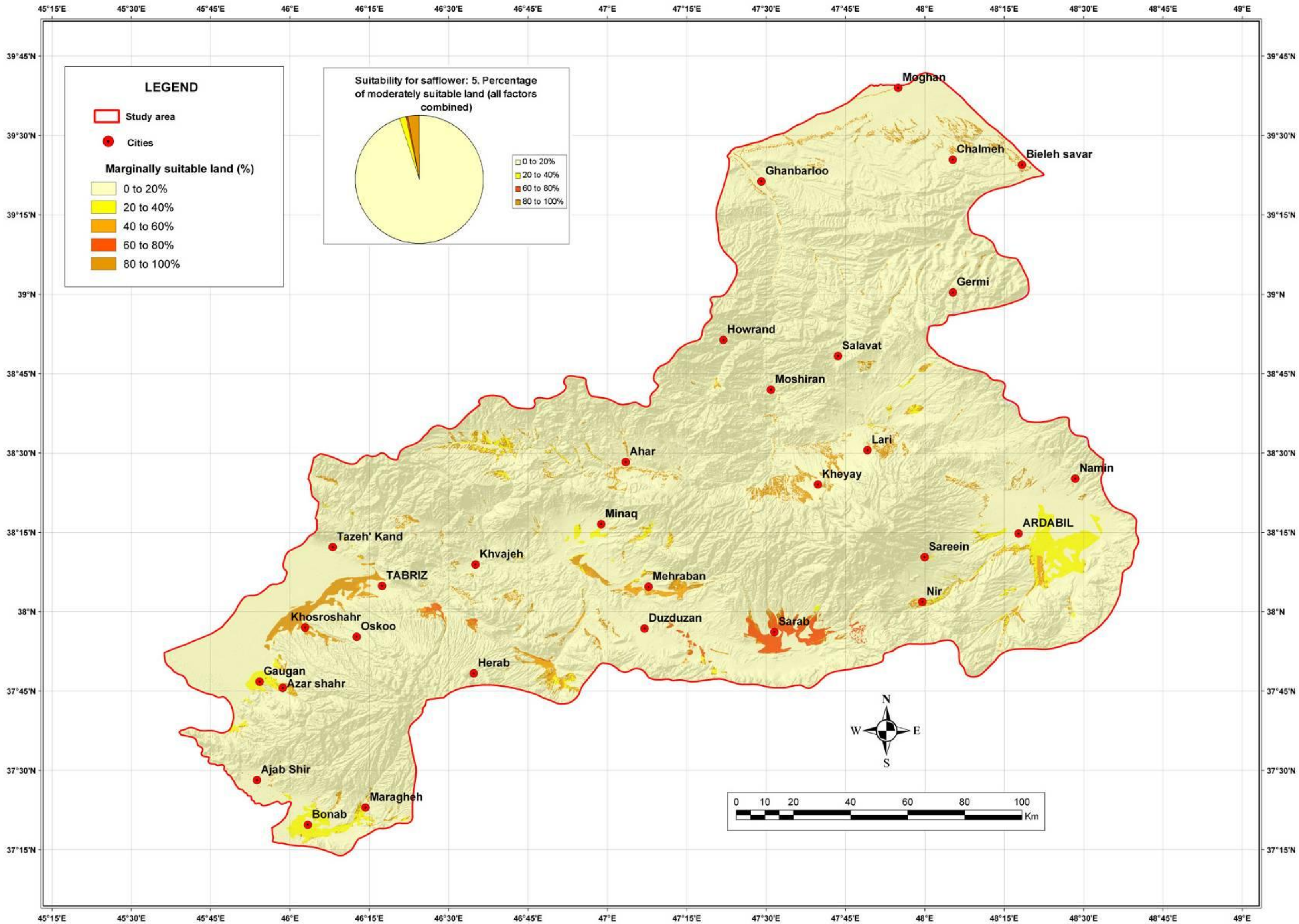
Map 102.Suitability for safflower: 2. Adequacy of climate



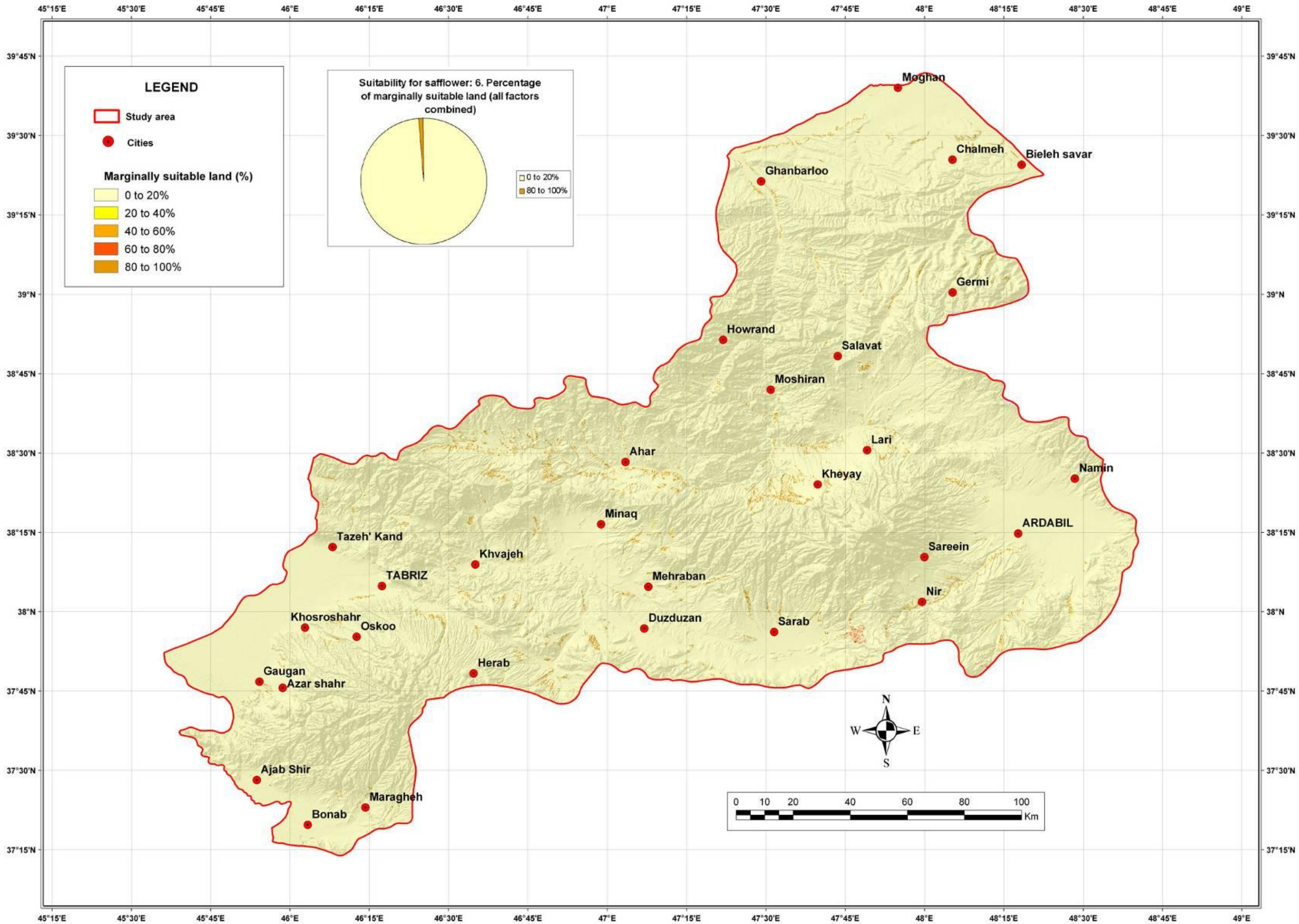
Map 103.Suitability for safflower: 3. Adequacy of topography (slopes)



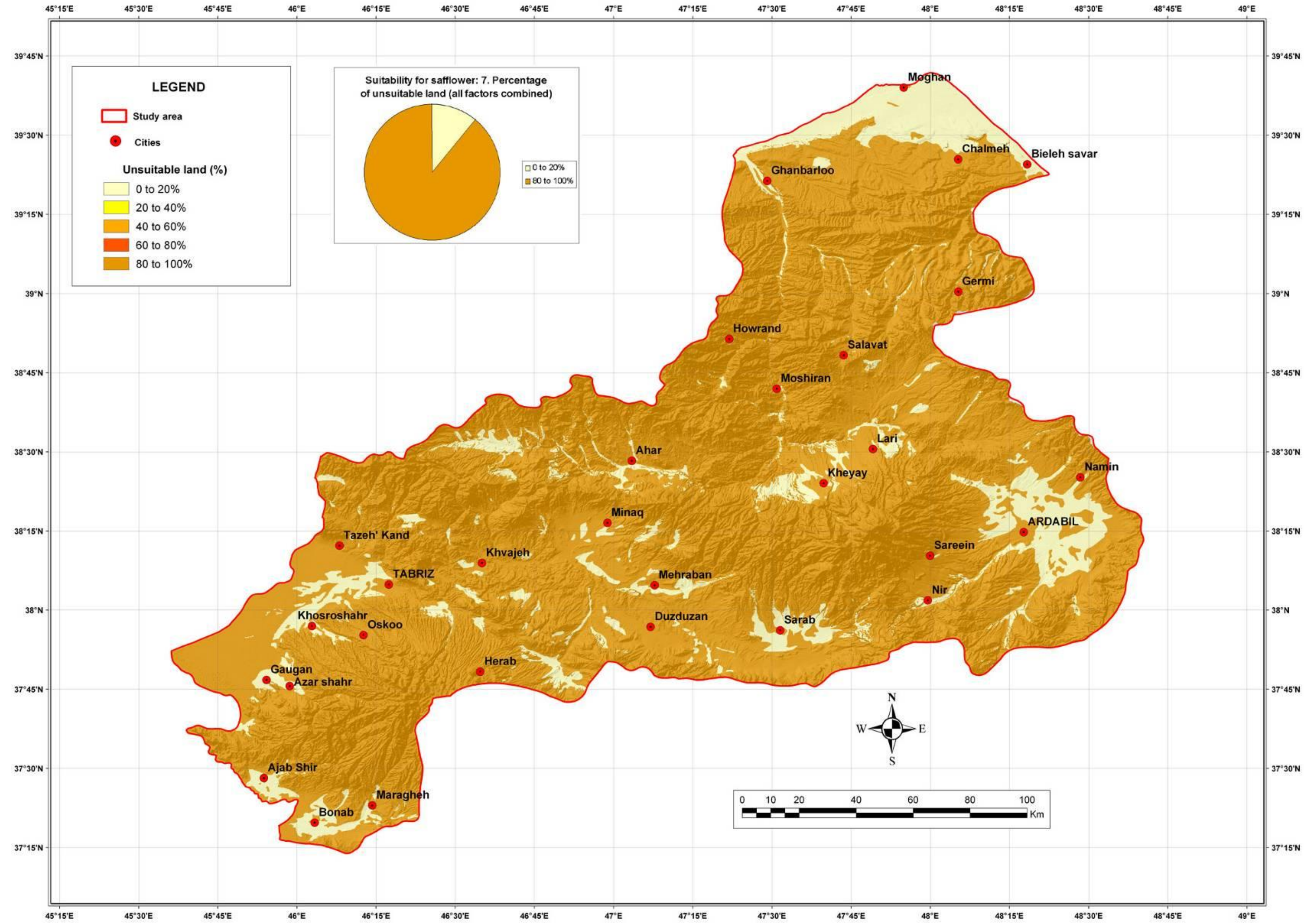
Map 104.Suitability for safflower: 4. Percentage of highly suitable land (all factors combined)



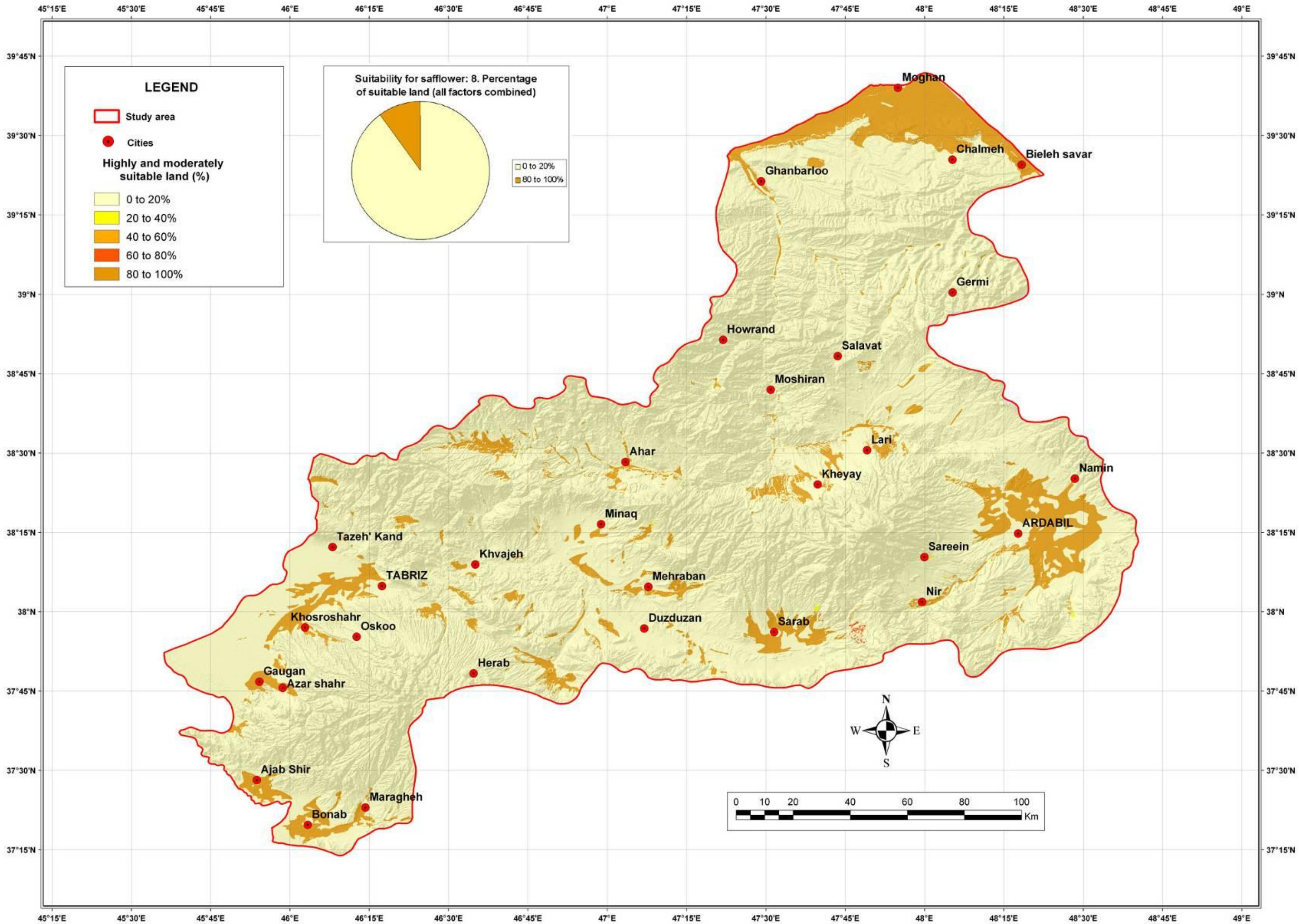
Map 105.Suitability for safflower: 5. Percentage of moderately suitable land (all factors combined)



Map 106.Suitability for safflower: 6. Percentage of marginally suitable land (all factors combined)



Map 107.Suitability for safflower: 7. Percentage of unsuitable land (all factors combined)



Map 108.Suitability for safflower: 8. Percentage of suitable land (all factors combined)

ANNEX 2. METHODS FOR GENERATING DERIVED CLIMATE SURFACES

A2.1. Seasonal precipitation

- Ratio of Autumn (September-November) to Annual Precipitation:

$$\frac{prec_{09} + prec_{10} + prec_{11}}{\sum_{i=1}^{12} prec_i}$$

- Ratio of Winter (December to February) to Annual Precipitation:

$$\frac{prec_{12} + prec_{01} + prec_{02}}{\sum_{i=1}^{12} prec_i}$$

- Ratio of Spring (March to May) to Annual Precipitation:

$$\frac{prec_{03} + prec_{04} + prec_{05}}{\sum_{i=1}^{12} prec_i}$$

- Ratio of Summer (June to August) to Annual Precipitation:

$$\frac{prec_{06} + prec_{07} + prec_{08}}{\sum_{i=1}^{12} prec_i}$$

with i: month number
prec: total precipitation during month i

A2.2. Derived temperature surfaces

- Mean temperature of the coldest month: Min ($Temp_{01}$, $Temp_{02}$, ….$Temp_{12}$)
- Mean temperature of the warmest month: Max ($Temp_{01}$, $Temp_{02}$, ….$Temp_{12}$)
- Minimum temperature of the coldest month: Min ($Tmin_{01}$, $Tmin_{02}$, ….$Tmin_{12}$)
- Maximum temperature of the warmest month: Max ($Tmax_{01}$, $Tmax_{02}$, ….$Tmax_{12}$)

with Min the lowest of the 12 monthly values
Max the highest of the 12 monthly values
Temp the mean average temperature in month i
Tmax the mean maximum temperature in month i
Tmin the mean minimum temperature in month i

- Annual growing degree days (also 'heat units', AHU):

If $Temp_i$>Threshold $HU_i = Temp_i * NumDays_i$
Else $HU_i = 0$

and $AHU = \sum_{i=1}^{12} HU_i$

with: $Temp_i$: mean monthly temperature (°C) during month i
HU_i: heat units during month i
NumDays: number of days in month i

Threshold: temperature below which no accumulation is done (in this study: 0°C)

- Annual chilling degree days (also 'cold units', ACU):

If $Temp_i$<Threshold $CU_i = Temp_i * NumDays_i$
Else $CU_i = 0$

And $ACU = \sum_{i=1}^{12} CU_i$

with: $Temp_i$: mean monthly temperature (°C) during month i
CU_i: cold units during month i
NumDays: number of days in month i
Threshold: temperature above which no accumulation is done (in this study: 0°C)

A2.3. Determining frost and frost-free periods

No direct data on frost and frost-free periods were available. To estimate these important factors for agriculture, an indirect procedure was used based on the temperature database, provided by the Iranian Meteorological Organization, which contains mean monthly minimum temperature and average number of frost days for more than 400 stations, totaling 5245 data points.

Duration of the frost and frost-free periods

For each station-month the number of frost days was plotted against the minimum temperature. The pattern is a clear sigmoid (Fig. 6).

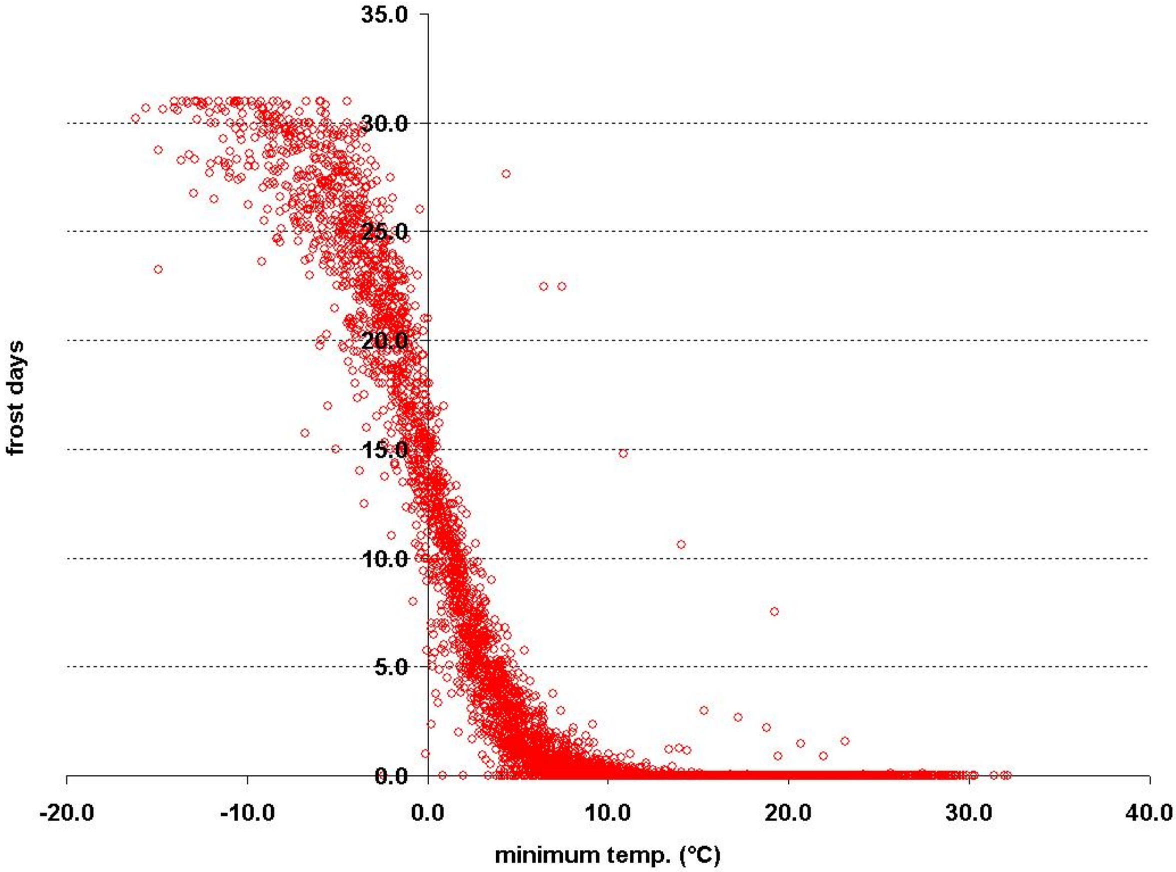


Figure 6. Pattern of frost days in relation to minimum temperature

For each station-month the actual number of frost days was then converted into a *proportion of frost days (FD)*, and into *proportion of frost-free days (FFD)*. A logarithmic transform on the FFD was then applied as follows:

$$\ln\frac{1-FFD}{FFD}$$

and plotted against the minimum temperature (Fig. 7).

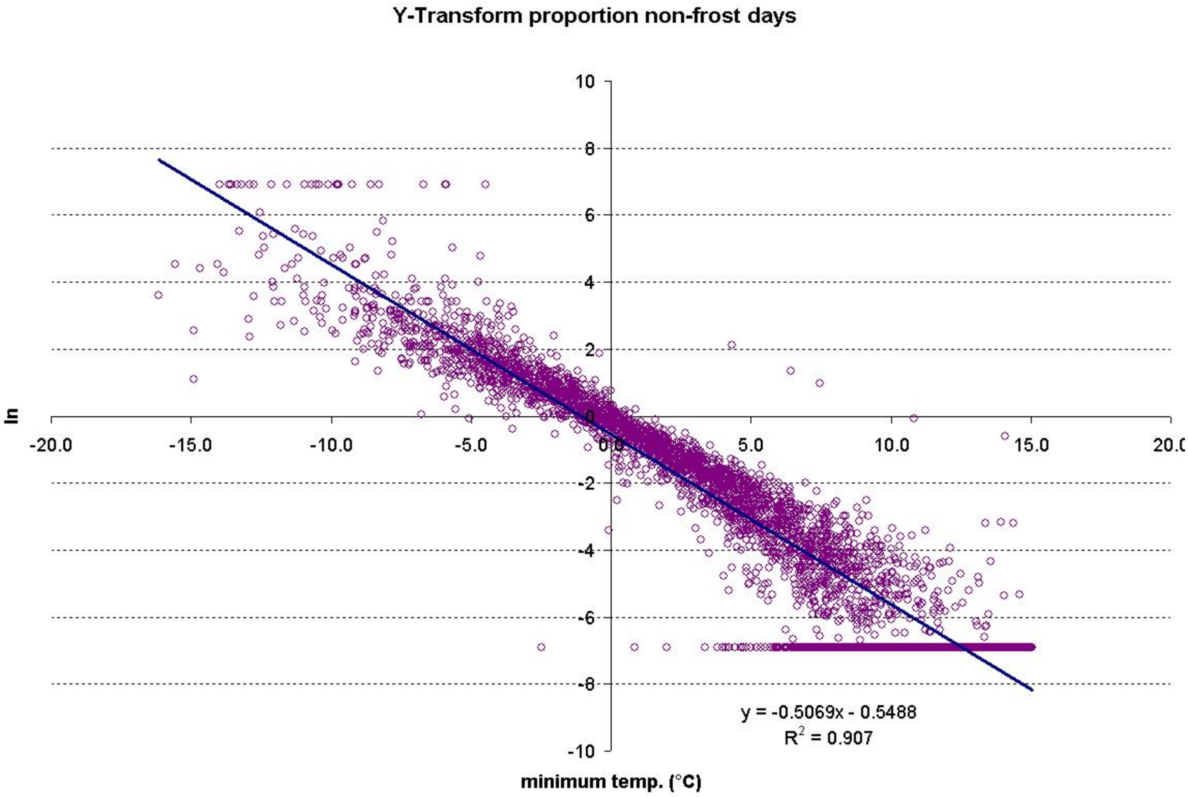


Figure 7. Y-transform proportion non-frost days

The coefficients of this regression equation were used to establish the following estimation equation of the proportion of non-frost days as a function of the minimum temperature (Fig. 8):

$$p_{nf} = \left(\frac{1}{1+e^{-0.5488-0.5069T\min}}\right) \quad (r^2{=}0.91)$$

With p=1 if the minimum temperature exceeds 15ºC

Repeated for every month of the year, the frost-free period was then estimated as follows:

$$FFP = \sum_{i=1}^{12} D_i\left(\frac{1}{1+e^{-0.5488-0.5069T\min}}\right)$$

And the frost period becomes:

$$FP = 365 - FFP$$

with FFP: frost-free period (in days per year); FP: frost period; D_i the number of days in each month, and T_{min}: the minimum temperature for the month.

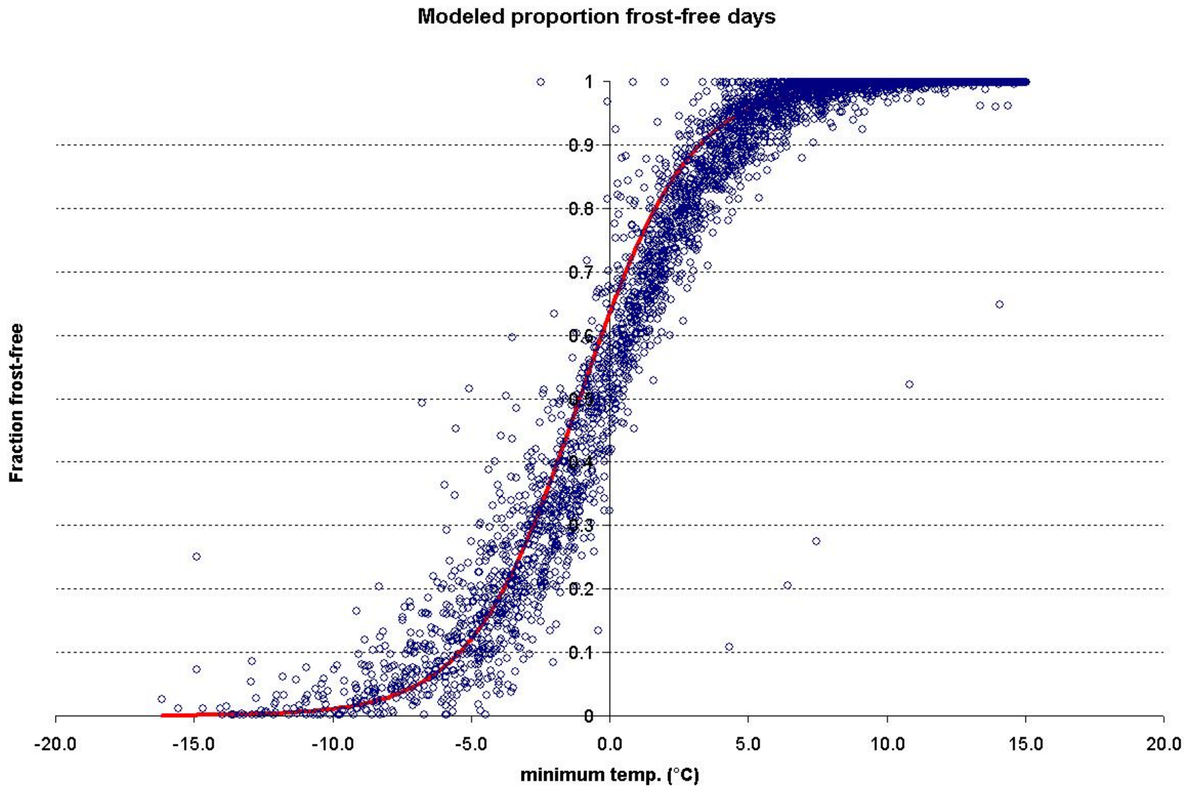


Figure 8. Modeled proportion frost-free days

Onset and end month of the frost period

Onset and end months of the frost period were determined from the 12 monthly grids of the proportion of frost days $[1-p_1]$, $[1-p_2]$, $[1-p_3]$, …$[1-p_{12}]$, by comparing two consequent months at a time.

If $[1-p_{i-1}]<>0$ and $[1-p_i]<>0$ then *no start/no end*. Value output file:0
If $[1-p_{i-1}] = 0$ and $[1-p_i] = 0$ then *no start/no end*. Value output file: 0
If $[1-p_{i-1}]<>0$ and $[1-p_i] = 0$ then *end*. Value output file: i
If $[1-p_{i-1}] = 0$ and $[1-p_i]<>0$ then *start*. Value output file: i.

Two maps were made, one for start, one for end.

Note:

As the equation for the proportion non-frost (p_{nf}) is asymptotic, it never reaches 1, and similarly p_f does not reach zero, hence it is possible to have frost even in the summer months and no start and end of the frost period! To avoid this, a limit needed to be put on the value of the proportion of frost days. This was achieved by the following condition:

If $p_f < 0.0324$ then $p_f = 0$

This corresponds with about 1 frost day in a month, the limit accepted for having a month with frost.

A2.4. 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. 9), a high degree of correlation can be established:

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

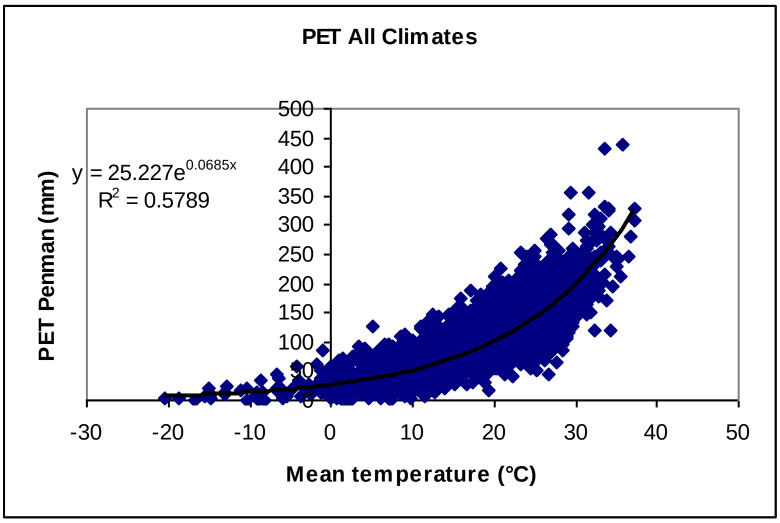


Figure 9. Correlation between PET Penman-Monteith and temperature (all climates combined)

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 $_{Penman-Monteith}$ from $PET_{Hargreaves}$ through regression (Fig. 10).

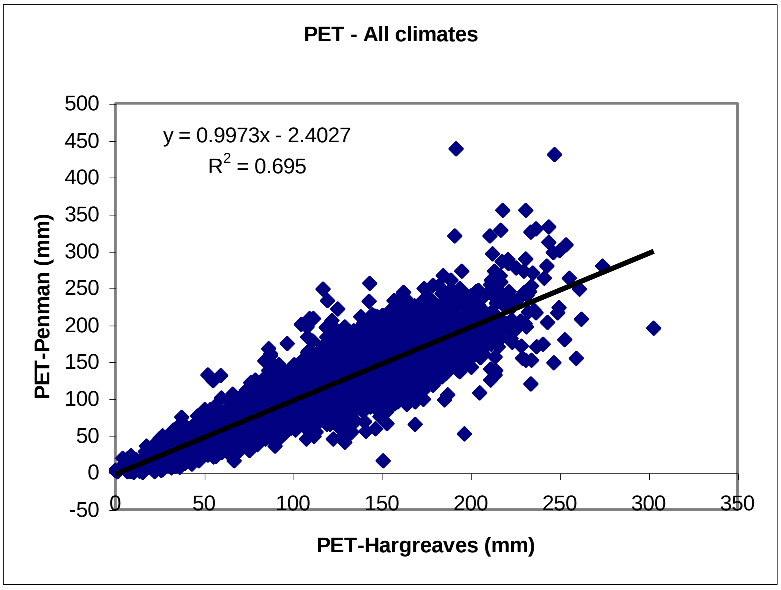


Figure 10. Correlation between PET Penman-Monteith and PET Hargreaves (all climates combined)

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):

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

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 17. 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

A2.5. Agroclimatic zones

The agroclimatic zones were mapped in accordance with the UNESCO classification system for arid zones (UNESCO, 1979). This system is based on three major criteria:

- Moisture regime;
- Winter type
- Summer type

In this classification system the *moisture regime* is determined by the ratio of annual rainfall over annual potential evapotranspiration, calculated according to the Penman method (see above). This ratio is also referred to as the *aridity index*. 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 (but also the same) classes may thus result depending on the values of the two terms.
The *winter type* is determined by the mean temperature of the coldest month.
The *summer type* is determined by the mean temperature of the warmest month .

Moisture regime, winter type and summer type, were combined in accordance with the classes of Table 18 (see also Fig.11).

Table 18. Moisture regime, winter type and summer type classes

Moisture regime	Aridity index
Hyper-arid (HA)	< 0.03
Arid (A)	< 0.2
Semi-arid (SA)	< 0.5
Sub-humid (SH)	< 0.7
Humid (H)	<1
Per-humid (PH)	≥ 1

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

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

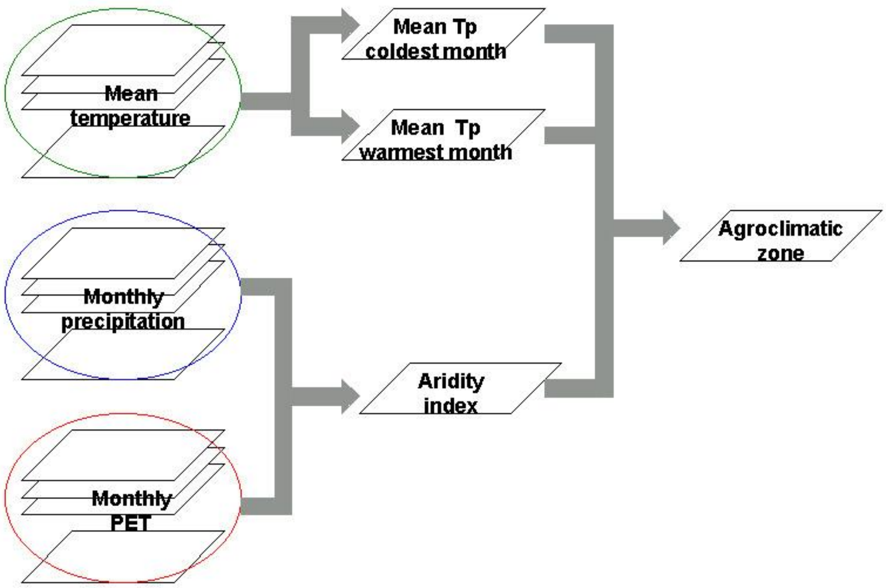


Figure 11. Combination of basic climate surfaces into agroclimatic zones

Originally designed for the differentiation of arid zones, the system has been extended to include also the more humid climates. For example, the moisture regime 'Per-humid' (aridity index >1) has not been defined in the original system, but has been added here in order to provide a better differentiation within the more humid zones not covered by the original UNESCO map.

A2.6. Growing periods

The climatic growing period is calculated by means of a model developed by the Food and Agriculture Organization of the United Nations (FAO, 1978) to estimate the length of growing period under either moisture-limiting or temperature-limiting conditions, or both. Under rainfed conditions, both moisture and temperature can be limited. Under irrigated conditions, only temperature is to be considered a limiting factor.

The criterion used for the definition of a *moisture-limited growing period* is the ratio of actual evapotranspiration (AET) to potential evapotranspiration (PET). If this ratio for any particular month is higher than a user-defined threshold (in this study 0.5), that month is part of a growing period; if it is not, that month is not part of the growing period. The start date of the growing period is obtained from linear interpolation of the AET/PET ratios between the last month that is part of the growing period, and the first month that is not part of the growing period. The end date, inversely, is obtained by linear interpolation of the AET/PET ratios between the last month that is part of the growing period, and the first one that is not part of the growing period.

The following model for estimating the length of the moisture-limited growing period is an adaptation of the FAO-model.

$$GP_{m,on} = M_{m,on} + NDays_m \frac{Thre_m - R_0}{R_1 - R_0}$$

$$GP_{m,end} = M_{m,end} + NDays2_m \frac{Thre_m - R_{n-1}}{R_n - R_{n-1}}$$

$$LGP_m = GP_{m,en} - GP_{m,on}$$

with: $GP_{m,on}$: onset date of the moisture-limited growing period
$GP_{m,end}$: end date of the moisture-limited growing period
LGP_m: length of moisture-limited growing period
$M_{m,on}$: the number of days from 1 January up to the end of the last month that is not part of the moisture-limited growing period
$M_{m,end}$: the number of days from 1 January up to the end of the month preceding the last month of the moisture-limited growing period
$NDays_m$: number of days in the first month of the moisture-limited growing period
$NDays2_m$: number of days in the last month of the moisture-limited growing period
$Thre_m$: AET/PET threshold for defining a moisture-limited growing period (user-defined; for this study set to 0 .5)
R_0: AET/PET ratio for the month preceding the first month of the moisture-limited growing period;
R_1: AET/PET ratio for the first month of the moisture-limited growing period;
R_{n-1}: AET/PET ratio for the month preceding the last month of the moisture-limited growing period;
R_n: AET/PET ratio for the last month of the moisture-limited growing period.

Similarly the temperature-limited growing period is calculated with reference to a temperature threshold, below which there is no growing period:

$$GP_{t,on} = M_{t,on} + NDays_t \frac{Thre_t - Temp_0}{Temp_1 - Temp_0}$$

$$GP_{t,end} = M_{t,end} + NDays2_t \frac{Thre_t - Temp_{n-1}}{Temp_n - Temp_{n-1}}$$

$$LGP_t = GP_{t,end} - GP_{t,on}$$

with: $GP_{t,on}$: onset date of the temperature-limited growing period
$GP_{t,end}$: end date of the temperature -limited growing period
LGP_m: length of temperature-limited growing period
$M_{t,on}$: the number of days from 1 January up to the end of the last month that is not part of the temperature-limited growing period
$M_{t,end}$: the number of days from 1 January up to the end of the month preceding the last month of the temperature -limited growing period
$NDays_t$: number of days in the first month of the temperature-limited growing period
$NDays2_t$: number of days in the last month of the temperature-limited growing period

$Thre_t$: temperature threshold for defining a temperature-limited growing period (user-defined; for this study set to 5°C)
$Temp_0$: Mean temperature for the month preceding the first month of the temperature-limited growing period;
$Temp_1$: mean temperature for the first month of the moisture-limited growing period;
$Temp_{n-1}$: mean temperature for the month preceding the last month of the moisture-limited growing period;
$Temp_n$: mean temperature for the last month of the moisture-limited growing period.

By combining the moisture-limited growing period with a temperature-limited growing period, length, onset and end of the growing period, limited by both moisture and temperature, can be calculated.

A2.7. Climate-determined biomass productivity indices

The biomass productivity indices listed in Table 3 are based on the concept of *accumulated temperature* as a proxy of radiation energy available for photosynthesis. The accumulation of temperature units only occurs within the moisture-limited growing period and is weighted according to the distance of the real daytime temperature from the optimal daytime temperature for each crop group:

$$CBPI_j = \sum_{i=GP_{m,on}}^{GP_{m,end}} (ATI)_{i,j}$$

with: CBPI: crop biomass productivity index
j: crop group
i: day number
ATI: adjusted thermal increment (°C) for each day inside the moisture-limited growing period
GPm,on: onset date of the moisture-limited growing period
GPm,end: end date of the moisture-limited growing period

In this model, the ATI depends on the daytime temperature and is:

$ATI = 0$ if $[T_{day} <= T_0$ or $T_{day} >= T_x]$
$ATI = T_{day} - T_0$ if $[T_{day} > T_0$ and $T_{day} < T_{opt1}]$
$ATI = (T_{opt1} + T_{opt2})/2 - T_0$ if $[T_{day} >= T_{opt1}$ and $T_{day} <= T_{opt2}]$
$ATI = T_x - T_{day}$ if $[T_{day} > T_{opt2}$ and $T_{day} < T_x]$

with T_0 : the daytime temperature below which no assimilation takes place (cold-limited);
T_{opt1} : the lower daytime temperature threshold above which maximum assimilation takes place;
T_{opt2} : the higher daytime temperature threshold above which assimilation rate declines;
T_x : the day-time temperature above which no assimilation takes place (heat-limited)

The temperature thresholds T0, Topt1, Topt2, and Tx depend on the particular crop group as shown in Table 19.

Table 19. Adaptability to temperature for different crop groups (adapted from FAO, 1978)

Crop group	T_0	T_{opt1}	T_{opt2}	T_x
I (C3 plants)	5	15	20	33
II (C3 plants for warm conditions)	10	25	30	45
III (C4 plants)	15	25	35	50
IV (C4 plants for cool conditions)	10	20	30	45

A2.8. Climatic similarity mapping

Similarity is assessed on the full precipitation and temperature record. Twelve monthly values of average temperature and total precipitation are used. Similarity is quantified by the sum of squared distances between the parameter values of the match and each target location, using a scale of 0 (or 0%, totally dissimilar) to 1 (or 100%, totally similar).
In order to avoid artificial dissimilarity due to different timing of growing periods (e.g. when comparing climates in different hemispheres), the temperature curves of the match and target locations are aligned first in such a way that the timing of the minimum and maximum temperatures coincides. Each parameter can be assessed in isolation, but also in combination. The contribution of each parameter can be manipulated by assigning weights (values between 0 and 1). This is useful, for example to express that a particular vegetation type or species is particularly sensitive to precipitation but less so to temperature, or vice versa.

Similarity can be expressed in a *relative* or *absolute* way.
In the first approach, the degree of similarity refers to the relative diversity within the study area. This approach only looks at the range of climatic conditions observed within this area, not outside, by ranking the distances between the different target locations and the match location. This approach effectively results in a form of contrast enhancement of similarity, since the 0-1 scale is maintained. This approach is useful when one is only interested in the range of variation within the study area and does not want to compare with external environments.
In the second approach, similarity is assessed through the absolute distance in either temperature, precipitation, or both. In this case the variation in climatic conditions within a study area is compared to external environments before it is translated into a measure of similarity. This approach results in a form of contrast reduction and is useful for the comparison of match and target locations in geographically separated areas.

The following procedure was used to quantify relative similarity analysis:

- The arrays of temperature ($\overline{Tm}$) and precipitation ($\overline{Pm}$) in the match location were obtained from the grid files through the match location's coordinates. The length of both arrays is twelve.
- For each cell in the target location grid (the study area) the arrays of temperature ($\overline{T}$) and precipitation ($\overline{P}$) were obtained from the study area grid files.
- The temperature array was shifted until the covariance:

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

reaches a maximum (phase). In a climatically homogeneous region (as in the study area) the phase is 0. The maximum possible phase is 11. If the phase is larger than zero, both the temperature and precipitation arrays are shifted by the phase.

- For each cell of the target location grid the following integers were calculated

$$Tr = \sum_{i=1}^{12}\left[10\left(Tm_i - T_i\right)\right]^2 \text{ and } Pr = \sum_{i=1}^{12}\left(Pm_i - P_i\right)^2$$

- All cell values of the arrays $\overline{Tr}$ and $\overline{Pr}$ were sorted in ascending order. The resulting arrays contains unique values, thus the number of elements can be somewhat smaller than the total number of cells in the input grids. The resulting length of $\overline{Tr}$ can be defined as N and the length of $\overline{Pr}$ as M.

- The temperature similarity in *j*-th cell was calculated as:

$$Ts_j = 100\left[1 - \frac{1 - rank\left(Tr_j, \overline{Tr}\right)}{N-1}\right],$$

and the precipitation similarity as:

$$Ps_j = 100\left[1 - \frac{1 - rank\left(Pr_j, \overline{Pr}\right)}{M-1}\right],$$

where $rank\left(b, \overline{A}\right)$ is a ranking number of *b* in an array $\overline{A}$.

- The combinations of 'temperature-precipitation' similarity (*S*) were calculated as:

$$S = 100\sqrt{\frac{\left(T_S W_T\right)^2 + \left(P_S W_P\right)^2}{W_T^2 + W_P^2}},$$

where the W_T and W_P are the weights assigned to respectively temperature and precipitation. In this case equal weight was given to temperature and precipitation.

ANNEX 3. SOIL ASSOCIATIONS, SOIL TAXONOMIC UNITS, SOIL MAP UNITS AND SOIL MANAGEMENT DOMAINS

The soil map of the study area consists of 33 soil associations (Table 20a) composed of an equal number of Soil Taxonomic units (Soil Survey Staff, 1999). Table 20b contains the explanations for the Taxonomy unit symbols.

Table 20a. Soil association listing and composition

Soil Association	Dominant	Associated	Inclusion
1	IOX,C	IOX,T	EOX,T
2	IOX,C	IOX,T	IOX,V
3	EOX,T		EVX,T
4	DSQ,T	DSQ,G	
5	IQE,T		
6	DSH,T	EVT,T	DSQ,T
7	DKH,X	EVT,X	EOT,X
8	MXH,Q		
9	MXH,K		
10	IOX,C	IOX,F	EVX,T
11	MXA,T	IOX,F	IOX,C
12	IOX,T	IOX,C	
13	DKH,X	DMH,X	EOT,X
14	DMH,X	EVT,X	
15	XRM	EOX,L	
16	XRM	IOX,C	EOX,L
17	XRM	MXH,L	MXH,T
18	MDA,T	IOD,T	IOE,T
19	IOD,T	EOD,T	EOD,L
20	EOX,L	EOX,T	
21	XRM	EOX,T	EOX,L
22	EOU,T	IOU,K	
23	IOX,T	IOX,C	EVX,T
24	DKH,X	DMH,X	EOT,X
25	EOX,T	IOX,C	EVX,T
26	XBL		IOX,G
27	IOX,C	EVX,T	IOX,T
28	DKH,X	DMH,X	EOT,X
29	IOX,C	IOX,T	EOX,T
30	IOX,C	IOX,F	IQE,T
31	XLF		
32	XRM		
33	XUR		

Table 20b. Explanation of symbols

Symbol	Soil Taxonomic Unit
DKH,X	Xeric Haplocalcid
DMH,X	Xeric Haplocambid
DSH,T	Typic Haplosalid
DSQ,G	Gypsic Aquisalid
DSQ,T	Typic Aquisalid
EOD,L	Lithic Udorthent
EOD,T	Typic Udorthent
EOT,X	Xeric Torriorthent
EOU,T	Typic Ustorthent
EOX,L	Lithic Xerorthent
EOX,T	Typic Xerorthent
EVT,T	Typic Torrifluvent
EVT,X	Xeric Torrifluvent
EVX,T	Typic Xerofluvent
IOD,T	Typic Dystrochrept
IOE,T	Typic Eutrochrept
IOU,K	Calcic Ustrochrept
IOX,C	Calcixerollic Xerochrept
IOX,F	Fluventic Xerochrept
IOX,G	Gypsic Xerochrept
IOX,T	Typic Xerochrept
IOX,V	Vertic Xerochrept
IQE,T	Typic Endoaquepts
MDA,T	Typic Argiudolls
MXA,T	Typic Argixeroll
MXH,K	Calcic Haploxeroll
MXH,L	Lithic Haploxeroll
MXH,Q	Aquic Haploxeroll
MXH,T	Typic Haploxeroll
XBL	Badlands
XLF	Lava flows
XRM	Rock outcrops
XUR	Soils of urban areas

Notes:
Dominant soils: occupy >50% of the soil association
Associated soils: occupy 20-50% of the soil association
Inclusions: occupy <20% of the soil association

Because soil classification units are conceptual soils, they have often little relationship to local conditions and, as evidenced by Table 20a, will therefore result in a very large proportion of impurities in the thus defined soil mapping units. Moreover, in view of their higher emphasis on soil taxonomic detail, they are not the most suitable way for mapping areas with similar soil management properties, and for this reason they are difficult to apply for mapping agroecological zones.

In order to establish spatial patterns of soil distribution that are more relevant to soil management, the following two-stage approach was taken:

- conversion of the Soil Taxonomic units into broader groupings ('soil management groups') that are relevant to their broad management properties (Table 21 and 22);
- establish the main spatial patterns of the soil management groups, or 'soil management domains' (Table 23).

Table 21. Soil Taxonomic units and regrouped soil management units

Symbol	Soil Taxonomy	Soil Taxonomy 1999	Concept	Soil management group
DKH,X	Xeric Haplocalcids	Xeric Haplocalcids	Strongly calcareous soils under arid Mediterranean climate. Micro-nutrient deficiencies can be expected under irrigation and cultivation.	**1a**
MXH,K	Calcic Haploxerolls	Calcic Haploxerolls	Moderately deep or deep, well-drained, calcareous soils with high OM content under Mediterranean climate. Can be used for either cropland, forest or grazing depending on slope	**1b**
IOX,C	Calcixerollic Xerochrepts	Humic Haploxerepts	Moderately deep or deep, well-drained calcareous soils with high OM content under Mediterranean climate. Can be used for either cropland, forest or grazing depending on slope	
MDA,T	Typic Argiudolls	Typic Argiudolls	Deep clayey soils with high OM content under humid climate. Mostly used for cropland	**2a**
MXA,T	Typic Argixerolls	Typic Argixerolls	Deep clayey soils with high OM content under Mediterranean climate. Mostly used for cropland	**2b**
MXH,T	Typic Haploxeroll	Typic Haploxerolls	Deep soils with high OM content under Mediterranean climate. Mostly used for cropland.	

Table 21. Continued

DMH,X	Xeric Haplocambids	Xeric Haplocambids	Deep, moderately deep to deep, neutral to mildly alkaline, clayey or silty soils with some profile development under dry Mediterranean climate. Can be used for cropping if water source for irrigation available.	**3a**
IOX,T	Typic Xerochrept	Typic Haploxerepts	Deep, moderately deep to deep, neutral to mildly alkaline, clayey or silty soils with some profile development under typical Mediterranean climate. Mostly used for cropland.	
IOX,F	Fluventic Xerochrept	Fluventic Haploxerepts	Deep, moderately deep to deep, neutral to mildly alkaline, stratified clayey or silty soils, with some profile development under Mediterranean climate. Mostly used for cropland	
IOE,T	Typic Eutrochrepts	TypicHaploxerepts	Deep, moderately deep to deep, neutral to mildly alkaline, clayey or silty soils, with some profile development and high base content under Mediterranean climate	
IOX,G	Gypsic Xerochrept	Gypsic Haploxerepts	Deep, moderately deep to deep, neutral to mildly alkaline, clayey or silty soils, with some profile development and gypsum under Mediterranean climate	
IOU,K	Calcic Ustrochrepts	Calcic Haplustepts	Strongly calcareous clayey or silty soils with some profile development	
IOD,T	Typic Dystrochrepts	Typic Dystroxerepts	Deep, clayey or silty , acid soils with some profile development. Mostly used for grazing or forest.	**3b**
EOX,T	Typic Xerorthents	Typic Xerorthents	Moderately deep or deep, poorly developed soils under Mediterranean climate. Mostly used for forest or grazing	**4**
EOU,T	Typic Ustorthents	Typic Ustorthents	Moderately deep or deep, poorly developed soils under wet&dry climate. Mostly used for forest or grazing.	
EOD,T	Typic Udorthents	Typic Udorthents	Moderately deep or deep, poorly developed soils under humid climate. Mostly used for forest or grazing	
EOT,X	Xeric Torriorthents	Xeric Torriorthents	Moderately deep or deep, poorly developed soils under arid Mediterranean climate. Mostly used for forest or grazing	

Table 21. Continued

MXH,Q	Aquic Haploxerolls	Aquic Haploxerolls	Poorly drained soils with moderately deep groundwater with high OM content under Med.climate.	**5**
IQE,T	Typic Endoaquepts	Typic Endoaquepts	Ponded soils (with groundwater near the surface), without salinity. Normally under natural vegetation.	
DSQ,T	Typic Aquisalids	Typic Aquisalids	Saline soils, with groundwater near or at the surface for part of the year	**6a**
DSQ,G	Gypsic Aquisalids	Gypsic Aquisalids	Saline soils, with groundwater near or at the surface for part of the year, with gypsum	
DSH,T	Typic Haplosalids	Typic Haplosalids	Saline soils, with better drainage	**6b**
XRM	Rock outcrops		Undifferentiated rock outcrops	**7**
XLF	Lava flows		Outcrops of volcanic rocks	**7a**
MXH,L	Lithic Haploxeroll	Lithic Haploxerolls	Shallow soils with high OM content under Mediterranean climate. Usually used for grazing.	**7b**
EOX,L	Lithic Xerorthents	Lithic Xerorthents	Poorly developed shallow or very stony soils under Mediterranean climate. Usually on sloping land and used for grazing.	
EOD,L	Lithic Udorthents	Lithic Udorthents	Shallow poorly developed soils under humid climate	
XBL	Badlands		Strongly eroded areas	**7c**
IOX,V	Vertic Xerochrept	Vertic Haploxerepts	Clayey calcareous soils with *vertic* properties. Commonly used as cropland.	**8**

Table 21. Continued

EVT,T	Typic Torrifluvents	Typic Torrifluvents	Stratified well-drained soils developed as alluvium by floods under arid climate. Driest moisture regime and flooding fairly rare. Could be used for irrigated crops or grazing depending on water source and topography.	**9**
EVT,X	Xeric Torrifluvents	Xeric Torrifluvents	Stratified well-drained soils developed as alluvium by floods under arid Mediterranean climate. Winter floods or rainfall additions. Could be used for irrigated crops or grazing depending on water source and topography.	
EVX,T	Typic Xerofluvents	Typic Xerofluvents	Stratified soils developed as alluvium by floods under Mediterranean climate. Mostly winter floods or spring floods from snowmelt on nearby mountains. Could be used for irrigated crops or grazing depending on water source and topography.	
XUR	Urban		Built-up areas	**10**

Notes: the labeling convention is OSG,B with O: order; S: sub-order; G: great group; B: sub-group and the symbols are as in the table below:

Orders	Sub-orders	Great groups	Sub-groups
D: Aridisols E: Entisols I: Inceptisols M: Mollisols X: Non-agricultural land	BL: Badlands D: Udolls K: Calcids LF: Lava flows M: Cambids O: Xerepts (if O=I) O: Orthents (If O=E) Q: Aquepts RM: Rock S: Salids UR: Urban X: Xerolls V: Fluvents (if O=E) O=Ustepts (if G=U)	A: Argiudolls (if S=D) A: Argixerolls (if S=X) D: Dystroxerepts E: Endoaquepts (for S=Q) H: Haplo- (for S=K,M,S,X) Q: Aquisalids U: Ustorthents X: Haploxerepts (if O=I) X: Xerorthents (if O=E) E: Haploxerepts (if O=I) U: Haplustepts	C: Calcixerollic K: Calcic L: Lithic T: Typic X: Xeric V: Vertic F: Fluventic

Table 22. Concepts of new soil units and their relationship with Soil Taxonomic units

Concept		Soil management group	Member 1	Member 2	Member 3
Strongly calcareous soils	With low OM	1a	DKH,X		
	With high OM	1b	MXH,K	IOX,C	
Deep well-developed clayey soils with high OM content	Humid climate	2a	MDA,T		
	Mediterranean.climate	2b	MXA,T	MXH,T	
Deep clayey or silty soils	Basic or neutral	3a	DMH,X IOX,G	IOX,T IOU,K	IOX,F IOE,T
	Acid	3b	IOD,T		
Poorly developed soils		4	EOX,T	EOU,T	EOD,T EOT,X
Poorly drained or ponded soils		5	MXH,Q	IQE,T	
Saline soils	Ponded	6a	DSQ,T	DSQ,G	
	Not poorly-drained	6b	DSH,T		
Very shallow soils or rock or strongly dissected land	Undifferentiated rocks	7	XRM		
	Volcanic rocks	7a	XLF		
	Shallow/v.stony	7b	EOX,L	EOD,L	MXH,L
	Badlands	7c	XBL		
Clayey soils with vertic properties		8	IOX,V		
Soils developed on recent alluvium		9	EVT,T	EVT,X	EVX,T
Soils of built-up areas		10	XUR		

Table 23. Soil management domains (SMD)

Soil Association	Dominant Soil Unit	Associated Soil Unit	Included Soil Unit	SMD	Soil Management Domain
1	1b	3a	4	1	Predominantly soils without significant limitations for agriculture
2	1b	3a	8	1	Predominantly soils without significant limitations for agriculture
3	4		9	2	Predominantly soils with better capability for grazing and/or forestry than for agriculture
4	6a	6a		3	Soils with high salinity
5	5			4	Poorly drained soils
6	6b	9	6a	3	Soils with high salinity and/or flooding
7	1a	9	4	5	Predominantly good agricultural soils with some limitations due to possible flooding
8	5			4	Poorly drained soils
9	1b			1	Predominantly soils without significant limitations for agriculture
10	1b	3a	9	1	Predominantly soils without significant limitations for agriculture
11	2b	3a	1b	1	Predominantly soils without significant limitations for agriculture
12	3a	1b		1	Predominantly soils without significant limitations for agriculture
13	1a	3a	4	1	Predominantly soils without significant limitations for agriculture
14	3a	9		5	Predominantly good agricultural soils with some limitations due to possible flooding
15	7	7b		6	Predominantly shallow, stony or rocky soils
16	7	1b	7b	7	Mostly shallow, stony or rocky soils with a significant proportion of good agricultural soils
17	7	7b	2b	6	Predominantly shallow, stony or rocky soils
18	2a	3b	3a	1	Predominantly soils without significant limitations for agriculture
19	3b	4	7b	9	Mostly good agricultural soils, with some acidity, and poorly developed soils
20	7b	4		8	Association of shallow, stony or rocky soils, with poorly developed soils
21	7	4	7b	8	Association of shallow, stony or rocky soils, with poorly developed soils
22	4	3a		9	Mostly poorly developed soils with a significant proportion of good agricultural soils
23	3a	1b	9	1	Predominantly soils without significant limitations for agriculture

Table 23. Continued

24	1a	3a	4	1	Predominantly soils without significant limitations for agriculture
25	4	1b	9	9	Mostly poorly developed soils with a significant proportion of good agricultural soils
26	7c		3a	10	Mostly eroded and dissected 'badlands'
27	1b	9	3a	5	Predominantly good agricultural soils with some limitations due to possible flooding
28	1a	3a	4	1	Predominantly soils without significant limitations for agriculture
29	1b	3a	4	1	Predominantly soils without significant limitations for agriculture
30	1b	3a	5	1	Predominantly soils without significant limitations for agriculture
31	7a			6	Predominantly shallow, stony or rocky soils
32	7			6	Predominantly shallow, stony or rocky soils
33	10			11	Soils of urbanized areas

ANNEX 4. SPECIAL PROCEDURES FOR MAPPING AGROECOLOGICAL ZONES

Simplification of input data layers

The following layers were used to generate the AEZ map:

- Agroclimatic zones
- Land use/land cover
- Landforms
- Soil management domains

Tables 24-25 show for the ACZ and LULC themes the equivalences between the old classes and the ones created for the AEZ map.

Agroclimatic zones

Table 24. Correlation between ACZ classes and (new) classes for AEZ map

Old ACZ class		Classes for AEZ	
Code	Label	Code	Label
20	A-C-W	1	A/SA-C-W
33	SA-C-W	1	
37	SA-K-W	2	SA-K-W
38	SA-K-M	3	SA-K-M
46	SH-C-W	4	SH-C/K-W
50	SH-K-W	4	
51	SH-K-M	5	SH-K-M
64	H-K-M	6	H/PH-K-M/C
77	PH-K-M	6	
78	PH-K-C	6	

Land use/land cover

Table 25. Correlation between LULC classes and (new) LULC classes for AEZ map

Old LULC class		Classes for AEZ	
Code	Label	Code	Label
1	Rangelands	1	Rangelands
2	Irrigated crops	2	Irrigated crops
3	Urban	3	Other use
4	Rainfed crops	4	Rainfed crops
5	Forests	5	Forests
6	Lake	6	Water bodies and wetlands
7	Wetlands	6	
8	Saline lands	3	Other use
9	Mixed rainfed crops and range	4	Rainfed crops

Landforms

GTOPO30, a low-resolution DEM (0.008333 decimal degree grid cell size, or approximately 1 km resolution) was used to derive landforms through a simplified 3-class system, based on the concept of 'relief intensity'. 'Relief intensity' is derived from the maximum elevation difference between two neighbouring pixels and classified as follows:

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

Soil management domains (SMD)

Table 26 shows the new soil classes used for defining the AEZ.

Table 26. New soil classes: Soil management domains

SMD Code	SMD description
1	Predominantly soils without significant limitations for agriculture
2	Predominantly soils with better capability for grazing and/or forestry than for agriculture
3	Soils with high salinity
4	Poorly drained soils
5	Predominantly good agricultural soils with some limitations due to possible flooding
6	Predominantly shallow, stony or rocky soils
7	Mostly shallow, stony or rocky soils with a significant proportion of good agricultural soils
8	Association of shallow, stony or rocky soils, with poorly developed soils
9	Mostly poorly developed soils with a significant proportion of good agricultural soils
10	Mostly eroded and dissected 'badlands'
11	Soils of urbanized areas

Table 27 shows the equivalences between the soil associations of the soil map, their composition in terms of soil management groups, and the soil management domains

Table 27. Correlation between soil associations and soil management domains

Soil Assoc.	Dom.	Assoc.	Incl.	SMD code	Soil management domain
1	1b	3a	4	1	Predominantly soils without significant limitations for agriculture
2	1b	3a	8	1	Predominantly soils without significant limitations for agriculture
3	4		9	2	Predominantly soils with better capability for grazing and/or forestry than for agriculture
4	6a	6a		3	Soils with high salinity
5	5			4	Poorly drained soils
6	6b	9	6a	3	Soils with high salinity and/or flooding
7	1a	9	4	5	Predominantly good agricultural soils with some limitations due to possible flooding
8	5			4	Poorly drained soils
9	1b			1	Predominantly soils without significant limitations for agriculture

Table 27. Continued

10	1b	3a	9	1	Predominantly soils without significant limitations for agriculture
11	2b	3a	1b	1	Predominantly soils without significant limitations for agriculture
12	3a	1b		1	Predominantly soils without significant limitations for agriculture
13	1a	3a	4	1	Predominantly soils without significant limitations for agriculture
14	3a	9		5	Predominantly good agricultural soils with some limitations due to possible flooding
15	7	7b		6	Predominantly shallow, stony or rocky soils
16	7	1b	7b	7	Mostly shallow, stony or rocky soils with a significant proportion of good agricultural soils
17	7	7b	2b	6	Predominantly shallow, stony or rocky soils
18	2a	3b	3a	1	Predominantly soils without significant limitations for agriculture
19	3b	4	7b	9	Mostly poorly developed soils with a significant proportion of good agricultural soils
20	7b	4		8	Association of shallow, stony or rocky soils, with poorly developed soils
21	7	4	7b	8	Association of shallow, stony or rocky soils, with poorly developed soils
22	4	3a		9	Mostly poorly developed soils with a significant proportion of good agricultural soils
23	3a	1b	9	1	Predominantly soils without significant limitations for agriculture
24	1a	3a	4	1	Predominantly soils without significant limitations for agriculture
25	4	1b	9	9	Mostly poorly developed soils with a significant proportion of good agricultural soils
26	7c		3a	10	Mostly eroded and dissected 'badlands'
27	1b	9	3a	5	Predominantly good agricultural soils with some limitations due to possible flooding
28	1a	3a	4	1	Predominantly soils without significant limitations for agriculture
29	1b	3a	4	1	Predominantly soils without significant limitations for agriculture
30	1b	3a	5	1	Predominantly soils without significant limitations for agriculture
31	7a			6	Predominantly shallow, stony or rocky soils
32	7			6	Predominantly shallow, stony or rocky soils
33	10			11	Soils of urbanized areas

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 Management Domain Code

For the pilot area, the Climate Code, Land Use/Cover Code and Landform Code can be represented by 1 digit, whereas the SMD Code requires 2 digits, leading to 5-digit codes with **CULSS** format. By overlaying the 4 themes the AEZ codes are generated using the appropriate multipliers and summation method.

Thus e.g. the AEZ code **31206** is the result of the combination of:
- Climate code: 3 (multiplier 10000)
- Land use/cover code: 1 (multiplier 1000)
- Landform code: 2 (multiplier 100)
- Soil management domain code: 6 (multiplier 1)

The full description of the code is then: *Semi-arid moisture regime, cold winters and mild summers, rangelands on hills, predominantly shallow, stony or rocky soils*.

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:

- Isolate the class containing fragmented pixels using a logical expression (e.g. AEZ=220). This creates a layer with binary values (0 or 1).
- Apply '**SetNull**' function (e.g. SetNull(Temp=0,Temp)), which creates a grid with Value=1 and the zeros become 'No Data'.
- 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.
- 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)
- Mask out the chosen pixels, using the '**SetNull**' function to replace the values 1 by NoData.
- Apply the '**Nibble**' function to replace the areas in the AEZ layer corresponding to the mask with the values of nearest neighbors.

Figure 12 shows the steps for removing noisy pixels.

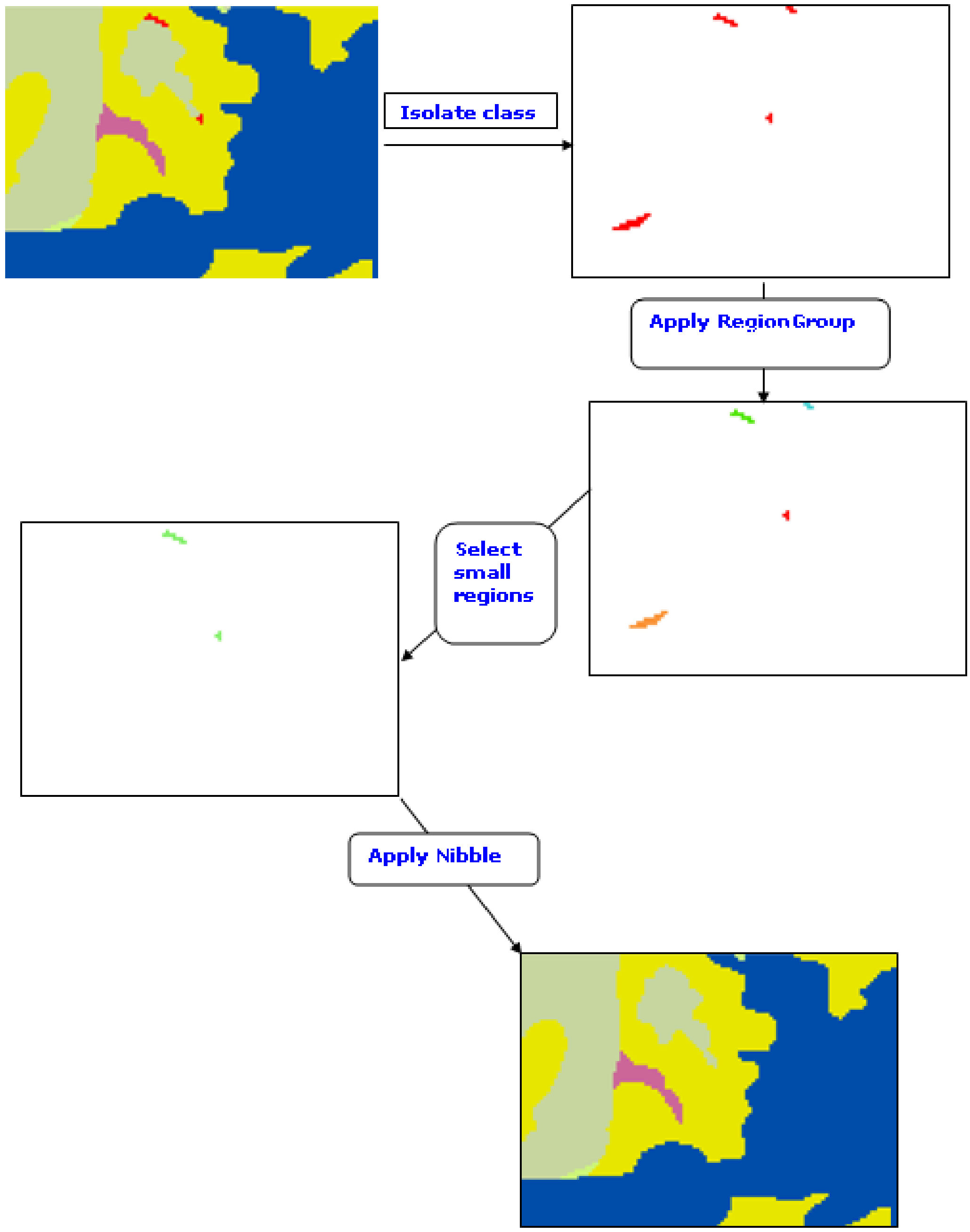


Figure 12. Steps for removal of noisy pixels

The results from this procedure are summarized in Table 28, which provides a listing of all AEZ, with their areas in km2 and as a percentage of the total study area, as well as short descriptions of climate, land use/land cover, landforms and soils.

Table 28. Description of Agroecological Zones (ranked according to area)

AEZ Code	Area (km2)	Area (%)	Climate	Land Use	Landform	SMD
21206	1,852	5.85	Semi-arid moisture regime, cold winters and warm summers	Rangelands	Hills	Predominantly shallow, stony or rocky soils
31206	1,801	5.69	Semi-arid moisture regime, cold winters and mild summers	Rangelands	Hills	Predominantly shallow, stony or rocky soils
11206	1,629	5.15	Arid or semi-arid moisture regime, cool winters and warm summers	Rangelands	Hills	Predominantly shallow, stony or rocky soils
51206	1,385	4.37	Subhumid moisture regime, cold winters and mild summers	Rangelands	Hills	Predominantly shallow, stony or rocky soils
21208	1,338	4.23	Semi-arid moisture regime, cold winters and warm summers	Rangelands	Hills	Association of shallow, stony or rocky soils, with poorly developed soils
31207	997	3.15	Semi-arid moisture regime, cold winters and mild summers	Rangelands	Hills	Mostly shallow, stony or rocky soils with a significant proportion of good agricultural soils
12101	940	2.97	Arid or semi-arid moisture regime, cool winters and warm summers	Irrigated crops	Plains	Predominantly soils without significant limitations for agriculture
51207	816	2.58	Subhumid moisture regime, cold winters and mild summers	Rangelands	Hills	Mostly shallow, stony or rocky soils with a significant proportion of good agricultural soils
31201	745	2.35	Semi-arid moisture regime, cold winters and mild summers	Rangelands	Hills	Predominantly soils without significant limitations for agriculture
14101	721	2.28	Arid or semi-arid moisture regime, cool winters and warm summers	Rainfed crops	Plains	Predominantly soils without significant limitations for agriculture
24201	675	2.13	Semi-arid moisture regime, cold winters and warm summers	Rainfed crops	Hills	Predominantly soils without significant limitations for agriculture
21103	629	1.99	Semi-arid moisture regime, cold winters and warm summers	Rangelands	Plains	Soils with high salinity
34201	605	1.91	Semi-arid moisture regime, cold winters and mild summers	Rainfed crops	Hills	Predominantly soils without significant limitations for agriculture
21201	582	1.84	Semi-arid moisture regime, cold winters and warm summers	Rangelands	Hills	Predominantly soils without significant limitations for agriculture
24101	577	1.82	Semi-arid moisture regime, cold winters and warm summers	Rainfed crops	Plains	Predominantly soils without significant limitations for agriculture
21210	559	1.77	Semi-arid moisture regime, cold winters and warm summers	Rangelands	Hills	Mostly eroded and dissected 'badlands'
32101	524	1.65	Semi-arid moisture regime, cold winters and mild summers	Irrigated crops	Plains	Predominantly soils without significant limitations for agriculture
31208	521	1.65	Semi-arid moisture regime, cold winters and mild summers	Rangelands	Hills	Association of shallow, stony or rocky soils, with poorly developed soils
14206	501	1.58	Arid or semi-arid moisture regime, cool winters and warm summers	Rainfed crops	Hills	Predominantly shallow, stony or rocky soils
22101	490	1.55	Semi-arid moisture regime, cold winters and warm summers	Irrigated crops	Plains	Predominantly soils without significant limitations for agriculture
24206	410	1.29	Semi-arid moisture regime, cold winters and warm summers	Rainfed crops	Hills	Predominantly shallow, stony or rocky soils

AEZ Code	Area (km2)	Area (%)	Climate	Land Use	Landform	SMD
11101	408	1.29	Arid or semi-arid moisture regime, cool winters and warm summers	Rangelands	Plains	Predominantly soils without significant limitations for agriculture
21101	401	1.27	Semi-arid moisture regime, cold winters and warm summers	Rangelands	Plains	Predominantly soils without significant limitations for agriculture
34206	395	1.25	Semi-arid moisture regime, cold winters and mild summers	Rainfed crops	Hills	Predominantly shallow, stony or rocky soils
51307	369	1.17	Subhumid moisture regime, cold winters and mild summers	Rangelands	Mountains	Mostly shallow, stony or rocky soils with a significant proportion of good agricultural soils
31106	352	1.11	Semi-arid moisture regime, cold winters and mild summers	Rangelands	Plains	Predominantly shallow, stony or rocky soils
14209	349	1.10	Arid or semi-arid moisture regime, cool winters and warm summers	Rainfed crops	Hills	Mostly poorly developed soils with a significant proportion of good agricultural soils
34101	323	1.02	Semi-arid moisture regime, cold winters and mild summers	Rainfed crops	Plains	Predominantly soils without significant limitations for agriculture
22201	319	1.01	Semi-arid moisture regime, cold winters and warm summers	Irrigated crops	Hills	Predominantly soils without significant limitations for agriculture
21306	319	1.01	Semi-arid moisture regime, cold winters and warm summers	Rangelands	Mountains	Predominantly shallow, stony or rocky soils
26103	293	0.93	Semi-arid moisture regime, cold winters and warm summers	Wetlands and water bodies	Plains	Soils with high salinity
11209	288	0.91	Arid or semi-arid moisture regime, cool winters and warm summers	Rangelands	Hills	Mostly poorly developed soils with a significant proportion of good agricultural soils
21110	285	0.90	Semi-arid moisture regime, cold winters and warm summers	Rangelands	Plains	Mostly eroded and dissected 'badlands'
34207	255	0.81	Semi-arid moisture regime, cold winters and mild summers	Rainfed crops	Hills	Mostly shallow, stony or rocky soils with a significant proportion of good agricultural soils
21205	241	0.76	Semi-arid moisture regime, cold winters and warm summers	Rangelands	Hills	Predominantly good agricultural soils with some limitations due to possible flooding
31101	240	0.76	Semi-arid moisture regime, cold winters and mild summers	Rangelands	Plains	Predominantly soils without significant limitations for agriculture
14201	238	0.75	Arid or semi-arid moisture regime, cool winters and warm summers	Rainfed crops	Hills	Predominantly soils without significant limitations for agriculture
61206	233	0.73	Humid or per-humid moisture regime, cold winters and mild or cool summers	Rangelands	Hills	Predominantly shallow, stony or rocky soils
51208	226	0.72	Subhumid moisture regime, cold winters and mild summers	Rangelands	Hills	Association of shallow, stony or rocky soils, with poorly developed soils
22105	222	0.70	Semi-arid moisture regime, cold winters and warm summers	Irrigated crops	Plains	Predominantly good agricultural soils with some limitations due to possible flooding
32201	216	0.68	Semi-arid moisture regime, cold winters and mild summers	Irrigated crops	Hills	Predominantly soils without significant limitations for agriculture
31306	214	0.68	Semi-arid moisture regime, cold winters and mild summers	Rangelands	Mountains	Predominantly shallow, stony or rocky soils
34208	205	0.65	Semi-arid moisture regime, cold winters and mild summers	Rainfed crops	Hills	Association of shallow, stony or rocky soils, with poorly developed soils

AEZ Code	Area (km2)	Area (%)	Climate	Land Use	Landform	SMD
22205	204	0.65	Semi-arid moisture regime, cold winters and warm summers	Irrigated crops	Hills	Predominantly good agricultural soils with some limitations due to possible flooding
31209	201	0.63	Semi-arid moisture regime, cold winters and mild summers	Rangelands	Hills	Mostly poorly developed soils with a significant proportion of good agricultural soils
21109	192	0.61	Semi-arid moisture regime, cold winters and warm summers	Rangelands	Plains	Mostly poorly developed soils with a significant proportion of good agricultural soils
11201	186	0.59	Arid or semi-arid moisture regime, cool winters and warm summers	Rangelands	Hills	Predominantly soils without significant limitations for agriculture
24210	186	0.59	Semi-arid moisture regime, cold winters and warm summers	Rainfed crops	Hills	Mostly eroded and dissected 'badlands'
31109	182	0.58	Semi-arid moisture regime, cold winters and mild summers	Rangelands	Plains	Mostly poorly developed soils with a significant proportion of good agricultural soils
24205	173	0.55	Semi-arid moisture regime, cold winters and warm summers	Rainfed crops	Hills	Predominantly good agricultural soils with some limitations due to possible flooding
24105	165	0.52	Semi-arid moisture regime, cold winters and warm summers	Rainfed crops	Plains	Predominantly good agricultural soils with some limitations due to possible flooding
31307	164	0.52	Semi-arid moisture regime, cold winters and mild summers	Rangelands	Mountains	Mostly shallow, stony or rocky soils with a significant proportion of good agricultural soils
24208	161	0.51	Semi-arid moisture regime, cold winters and warm summers	Rainfed crops	Hills	Association of shallow, stony or rocky soils, with poorly developed soils
31210	155	0.49	Semi-arid moisture regime, cold winters and mild summers	Rangelands	Hills	Mostly eroded and dissected 'badlands'
34109	154	0.49	Semi-arid moisture regime, cold winters and mild summers	Rainfed crops	Plains	Mostly poorly developed soils with a significant proportion of good agricultural soils
24110	154	0.49	Semi-arid moisture regime, cold winters and warm summers	Rainfed crops	Plains	Mostly eroded and dissected 'badlands'
51306	151	0.48	Subhumid moisture regime, cold winters and mild summers	Rangelands	Mountains	Predominantly shallow, stony or rocky soils
61306	142	0.45	Humid or per-humid moisture regime, cold winters and mild or cool summers	Rangelands	Mountains	Predominantly shallow, stony or rocky soils
34209	136	0.43	Semi-arid moisture regime, cold winters and mild summers	Rainfed crops	Hills	Mostly poorly developed soils with a significant proportion of good agricultural soils
21207	130	0.41	Semi-arid moisture regime, cold winters and warm summers	Rangelands	Hills	Mostly shallow, stony or rocky soils with a significant proportion of good agricultural soils
32104	130	0.41	Semi-arid moisture regime, cold winters and mild summers	Irrigated crops	Plains	Poorly drained soils
31205	129	0.41	Semi-arid moisture regime, cold winters and mild summers	Rangelands	Hills	Predominantly good agricultural soils with some limitations due to possible flooding
24209	123	0.39	Semi-arid moisture regime, cold winters and warm summers	Rainfed crops	Hills	Mostly poorly developed soils with a significant proportion of good agricultural soils
24109	123	0.39	Semi-arid moisture regime, cold winters and warm summers	Rainfed crops	Plains	Mostly poorly developed soils with a significant proportion of good agricultural soils
21105	118	0.37	Semi-arid moisture regime, cold winters and warm summers	Rangelands	Plains	Predominantly good agricultural soils with some limitations due to possible flooding

AEZ Code	Area (km2)	Area (%)	Climate	Land Use	Landform	SMD
21209	110	0.35	Semi-arid moisture regime, cold winters and warm summers	Rangelands	Hills	Mostly poorly developed soils with a significant proportion of good agricultural soils
21307	109	0.34	Semi-arid moisture regime, cold winters and warm summers	Rangelands	Mountains	Mostly shallow, stony or rocky soils with a significant proportion of good agricultural soils
34106	106	0.33	Semi-arid moisture regime, cold winters and mild summers	Rainfed crops	Plains	Predominantly shallow, stony or rocky soils
21108	104	0.33	Semi-arid moisture regime, cold winters and warm summers	Rangelands	Plains	Association of shallow, stony or rocky soils, with poorly developed soils
12206	87	0.27	Arid or semi-arid moisture regime, cool winters and warm summers	Irrigated crops	Hills	Predominantly shallow, stony or rocky soils
22206	86	0.27	Semi-arid moisture regime, cold winters and warm summers	Irrigated crops	Hills	Predominantly shallow, stony or rocky soils
54206	85	0.27	Subhumid moisture regime, cold winters and mild summers	Rainfed crops	Hills	Predominantly shallow, stony or rocky soils
32109	83	0.26	Semi-arid moisture regime, cold winters and mild summers	Irrigated crops	Plains	Mostly poorly developed soils with a significant proportion of good agricultural soils
31108	77	0.24	Semi-arid moisture regime, cold winters and mild summers	Rangelands	Plains	Association of shallow, stony or rocky soils, with poorly developed soils
61307	76	0.24	Humid or per-humid moisture regime, cold winters and mild or cool summers	Rangelands	Mountains	Mostly shallow, stony or rocky soils with a significant proportion of good agricultural soils
12201	76	0.24	Arid or semi-arid moisture regime, cool winters and warm summers	Irrigated crops	Hills	Predominantly soils without significant limitations for agriculture
22103	75	0.24	Semi-arid moisture regime, cold winters and warm summers	Irrigated crops	Plains	Soils with high salinity
22208	73	0.23	Semi-arid moisture regime, cold winters and warm summers	Irrigated crops	Hills	Association of shallow, stony or rocky soils, with poorly developed soils
21308	70	0.22	Semi-arid moisture regime, cold winters and warm summers	Rangelands	Mountains	Association of shallow, stony or rocky soils, with poorly developed soils
24106	67	0.21	Semi-arid moisture regime, cold winters and warm summers	Rainfed crops	Plains	Predominantly shallow, stony or rocky soils
21106	64	0.20	Semi-arid moisture regime, cold winters and warm summers	Rangelands	Plains	Predominantly shallow, stony or rocky soils
34205	63	0.20	Semi-arid moisture regime, cold winters and mild summers	Rainfed crops	Hills	Predominantly good agricultural soils with some limitations due to possible flooding
51201	58	0.18	Subhumid moisture regime, cold winters and mild summers	Rangelands	Hills	Predominantly soils without significant limitations for agriculture
32206	56	0.18	Semi-arid moisture regime, cold winters and mild summers	Irrigated crops	Hills	Predominantly shallow, stony or rocky soils
11109	53	0.17	Arid or semi-arid moisture regime, cool winters and warm summers	Rangelands	Plains	Mostly poorly developed soils with a significant proportion of good agricultural soils
31104	51	0.16	Semi-arid moisture regime, cold winters and mild summers	Rangelands	Plains	Poorly drained soils
22210	51	0.16	Semi-arid moisture regime, cold winters and warm summers	Irrigated crops	Hills	Mostly eroded and dissected ‘badlands’
11106	50	0.16	Arid or semi-arid moisture regime, cool winters and warm summers	Rangelands	Plains	Predominantly shallow, stony or rocky soils

AEZ Code	Area (km2)	Area (%)	Climate	Land Use	Landform	SMD
32205	50	0.16	Semi-arid moisture regime, cold winters and mild summers	Irrigated crops	Hills	Predominantly good agricultural soils with some limitations due to possible flooding
35201	49	0.16	Semi-arid moisture regime, cold winters and mild summers	Forests	Hills	Predominantly soils without significant limitations for agriculture
54207	49	0.15	Subhumid moisture regime, cold winters and mild summers	Rainfed crops	Hills	Mostly shallow, stony or rocky soils with a significant proportion of good agricultural soils
41206	48	0.15	Subhumid moisture regime, cool or cold winters and warm summers	Rangelands	Hills	Predominantly shallow, stony or rocky soils
31308	47	0.15	Semi-arid moisture regime, cold winters and mild summers	Rangelands	Mountains	Association of shallow, stony or rocky soils, with poorly developed soils
14109	45	0.14	Arid or semi-arid moisture regime, cool winters and warm summers	Rainfed crops	Plains	Mostly poorly developed soils with a significant proportion of good agricultural soils
32209	40	0.13	Semi-arid moisture regime, cold winters and mild summers	Irrigated crops	Hills	Mostly poorly developed soils with a significant proportion of good agricultural soils
32207	40	0.13	Semi-arid moisture regime, cold winters and mild summers	Irrigated crops	Hills	Mostly shallow, stony or rocky soils with a significant proportion of good agricultural soils
23103	38	0.12	Semi-arid moisture regime, cold winters and warm summers	Other use	Plains	Soils with high salinity
24202	38	0.12	Semi-arid moisture regime, cold winters and warm summers	Rainfed crops	Hills	Predominantly soils with better capability for grazing and/or forestry than for agriculture
12209	37	0.12	Arid or semi-arid moisture regime, cool winters and warm summers	Irrigated crops	Hills	Mostly poorly developed soils with a significant proportion of good agricultural soils
54201	37	0.12	Subhumid moisture regime, cold winters and mild summers	Rainfed crops	Hills	Predominantly soils without significant limitations for agriculture
24108	35	0.11	Semi-arid moisture regime, cold winters and warm summers	Rainfed crops	Plains	Association of shallow, stony or rocky soils, with poorly developed soils
24102	35	0.11	Semi-arid moisture regime, cold winters and warm summers	Rainfed crops	Plains	Predominantly soils with better capability for grazing and/or forestry than for agriculture
22110	32	0.10	Semi-arid moisture regime, cold winters and warm summers	Irrigated crops	Plains	Mostly eroded and dissected 'badlands'
34306	32	0.10	Semi-arid moisture regime, cold winters and mild summers	Rainfed crops	Mountains	Predominantly shallow, stony or rocky soils
23111	32	0.10	Semi-arid moisture regime, cold winters and warm summers	Other use	Plains	Soils of urbanized areas
14208	29	0.09	Arid or semi-arid moisture regime, cool winters and warm summers	Rainfed crops	Hills	Association of shallow, stony or rocky soils, with poorly developed soils
32208	29	0.09	Semi-arid moisture regime, cold winters and mild summers	Irrigated crops	Hills	Association of shallow, stony or rocky soils, with poorly developed soils
14108	29	0.09	Arid or semi-arid moisture regime, cool winters and warm summers	Rainfed crops	Plains	Association of shallow, stony or rocky soils, with poorly developed soils
35206	28	0.09	Semi-arid moisture regime, cold winters and mild summers	Forests	Hills	Predominantly shallow, stony or rocky soils
55206	27	0.09	Subhumid moisture regime, cold winters and mild summers	Forests	Hills	Predominantly shallow, stony or rocky soils

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51106	27	0.08	Subhumid moisture regime, cold winters and mild summers	Rangelands	Plains	Predominantly shallow, stony or rocky soils
33101	25	0.08	Semi-arid moisture regime, cold winters and mild summers	Other use	Plains	Predominantly soils without significant limitations for agriculture
34107	25	0.08	Semi-arid moisture regime, cold winters and mild summers	Rainfed crops	Plains	Mostly shallow, stony or rocky soils with a significant proportion of good agricultural soils
31110	25	0.08	Semi-arid moisture regime, cold winters and mild summers	Rangelands	Plains	Mostly eroded and dissected ‘badlands’
31301	25	0.08	Semi-arid moisture regime, cold winters and mild summers	Rangelands	Mountains	Predominantly soils without significant limitations for agriculture
34202	24	0.08	Semi-arid moisture regime, cold winters and mild summers	Rainfed crops	Hills	Predominantly soils with better capability for grazing and/or forestry than for agriculture
34104	22	0.07	Semi-arid moisture regime, cold winters and mild summers	Rainfed crops	Plains	Poorly drained soils
21102	22	0.07	Semi-arid moisture regime, cold winters and warm summers	Rangelands	Plains	Predominantly soils with better capability for grazing and/or forestry than for agriculture
11306	22	0.07	Arid or semi-arid moisture regime, cool winters and warm summers	Rangelands	Mountains	Predominantly shallow, stony or rocky soils
33111	21	0.07	Semi-arid moisture regime, cold winters and mild summers	Other use	Plains	Soils of urbanized areas
11208	21	0.07	Arid or semi-arid moisture regime, cool winters and warm summers	Rangelands	Hills	Association of shallow, stony or rocky soils, with poorly developed soils
22109	19	0.06	Semi-arid moisture regime, cold winters and warm summers	Irrigated crops	Plains	Mostly poorly developed soils with a significant proportion of good agricultural soils
23211	19	0.06	Semi-arid moisture regime, cold winters and warm summers	Other use	Hills	Soils of urbanized areas
34108	19	0.06	Semi-arid moisture regime, cold winters and mild summers	Rainfed crops	Plains	Association of shallow, stony or rocky soils, with poorly developed soils
22106	19	0.06	Semi-arid moisture regime, cold winters and warm summers	Irrigated crops	Plains	Predominantly shallow, stony or rocky soils
32107	18	0.06	Semi-arid moisture regime, cold winters and mild summers	Irrigated crops	Plains	Mostly shallow, stony or rocky soils with a significant proportion of good agricultural soils
55208	17	0.05	Subhumid moisture regime, cold winters and mild summers	Forests	Hills	Association of shallow, stony or rocky soils, with poorly developed soils
23101	17	0.05	Semi-arid moisture regime, cold winters and warm summers	Other use	Plains	Predominantly soils without significant limitations for agriculture
21301	17	0.05	Semi-arid moisture regime, cold winters and warm summers	Rangelands	Mountains	Predominantly soils without significant limitations for agriculture
24103	16	0.05	Semi-arid moisture regime, cold winters and warm summers	Rainfed crops	Plains	Soils with high salinity
51308	16	0.05	Subhumid moisture regime, cold winters and mild summers	Rangelands	Mountains	Association of shallow, stony or rocky soils, with poorly developed soils
32307	15	0.05	Semi-arid moisture regime, cold winters and mild summers	Irrigated crops	Mountains	Mostly shallow, stony or rocky soils with a significant proportion of good agricultural soils

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26105	15	0.05	Semi-arid moisture regime, cold winters and warm summers	Wetlands and water bodies	Plains	Predominantly good agricultural soils with some limitations due to possible flooding
14106	14	0.04	Arid or semi-arid moisture regime, cool winters and warm summers	Rainfed crops	Plains	Predominantly shallow, stony or rocky soils
24306	14	0.04	Semi-arid moisture regime, cold winters and warm summers	Rainfed crops	Mountains	Predominantly shallow, stony or rocky soils
21202	13	0.04	Semi-arid moisture regime, cold winters and warm summers	Rangelands	Hills	Predominantly soils with better capability for grazing and/or forestry than for agriculture
34105	13	0.04	Semi-arid moisture regime, cold winters and mild summers	Rainfed crops	Plains	Predominantly good agricultural soils with some limitations due to possible flooding
52206	12	0.04	Subhumid moisture regime, cold winters and mild summers	Irrigated crops	Hills	Predominantly shallow, stony or rocky soils
14306	12	0.04	Arid or semi-arid moisture regime, cool winters and warm summers	Rainfed crops	Mountains	Predominantly shallow, stony or rocky soils
51209	12	0.04	Subhumid moisture regime, cold winters and mild summers	Rangelands	Hills	Mostly poorly developed soils with a significant proportion of good agricultural soils
32108	12	0.04	Semi-arid moisture regime, cold winters and mild summers	Irrigated crops	Plains	Association of shallow, stony or rocky soils, with poorly developed soils
54307	11	0.04	Subhumid moisture regime, cold winters and mild summers	Rainfed crops	Mountains	Mostly shallow, stony or rocky soils with a significant proportion of good agricultural soils
22209	11	0.03	Semi-arid moisture regime, cold winters and warm summers	Irrigated crops	Hills	Mostly poorly developed soils with a significant proportion of good agricultural soils
22111	10	0.03	Semi-arid moisture regime, cold winters and warm summers	Irrigated crops	Plains	Soils of urbanized areas
31202	10	0.03	Semi-arid moisture regime, cold winters and mild summers	Rangelands	Hills	Predominantly soils with better capability for grazing and/or forestry than for agriculture
61207	10	0.03	Humid or per-humid moisture regime, cold winters and mild or cool summers	Rangelands	Hills	Mostly shallow, stony or rocky soils with a significant proportion of good agricultural soils
34307	9	0.03	Semi-arid moisture regime, cold winters and mild summers	Rainfed crops	Mountains	Mostly shallow, stony or rocky soils with a significant proportion of good agricultural soils
34308	9	0.03	Semi-arid moisture regime, cold winters and mild summers	Rainfed crops	Mountains	Association of shallow, stony or rocky soils, with poorly developed soils
32105	8	0.03	Semi-arid moisture regime, cold winters and mild summers	Irrigated crops	Plains	Predominantly good agricultural soils with some limitations due to possible flooding
34210	8	0.03	Semi-arid moisture regime, cold winters and mild summers	Rainfed crops	Hills	Mostly eroded and dissected ‘badlands’
13101	8	0.02	Arid or semi-arid moisture regime, cool winters and warm summers	Other use	Plains	Predominantly soils without significant limitations for agriculture
13206	8	0.02	Arid or semi-arid moisture regime, cool winters and warm summers	Other use	Hills	Predominantly shallow, stony or rocky soils
11108	8	0.02	Arid or semi-arid moisture regime, cool winters and warm summers	Rangelands	Plains	Association of shallow, stony or rocky soils, with poorly developed soils

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31302	8	0.02	Semi-arid moisture regime, cold winters and mild summers	Rangelands	Mountains	Predominantly soils with better capability for grazing and/or forestry than for agriculture
42206	8	0.02	Subhumid moisture regime, cool or cold winters and warm summers	Irrigated crops	Hills	Predominantly shallow, stony or rocky soils
23208	7	0.02	Semi-arid moisture regime, cold winters and warm summers	Other use	Hills	Association of shallow, stony or rocky soils, with poorly developed soils
12208	7	0.02	Arid or semi-arid moisture regime, cool winters and warm summers	Irrigated crops	Hills	Association of shallow, stony or rocky soils, with poorly developed soils
32106	7	0.02	Semi-arid moisture regime, cold winters and mild summers	Irrigated crops	Plains	Predominantly shallow, stony or rocky soils
26101	7	0.02	Semi-arid moisture regime, cold winters and warm summers	Wetlands and water bodies	Plains	Predominantly soils without significant limitations for agriculture
24207	7	0.02	Semi-arid moisture regime, cold winters and warm summers	Rainfed crops	Hills	Mostly shallow, stony or rocky soils with a significant proportion of good agricultural soils
23108	7	0.02	Semi-arid moisture regime, cold winters and warm summers	Other use	Plains	Association of shallow, stony or rocky soils, with poorly developed soils
55201	7	0.02	Subhumid moisture regime, cold winters and mild summers	Forests	Hills	Predominantly soils without significant limitations for agriculture
52307	7	0.02	Subhumid moisture regime, cold winters and mild summers	Irrigated crops	Mountains	Mostly shallow, stony or rocky soils with a significant proportion of good agricultural soils
31310	6	0.02	Semi-arid moisture regime, cold winters and mild summers	Rangelands	Mountains	Mostly eroded and dissected ‘badlands’
54209	6	0.02	Subhumid moisture regime, cold winters and mild summers	Rainfed crops	Hills	Mostly poorly developed soils with a significant proportion of good agricultural soils
31107	6	0.02	Semi-arid moisture regime, cold winters and mild summers	Rangelands	Plains	Mostly shallow, stony or rocky soils with a significant proportion of good agricultural soils
41209	6	0.02	Subhumid moisture regime, cool or cold winters and warm summers	Rangelands	Hills	Mostly poorly developed soils with a significant proportion of good agricultural soils
52208	6	0.02	Subhumid moisture regime, cold winters and mild summers	Irrigated crops	Hills	Association of shallow, stony or rocky soils, with poorly developed soils
23205	5	0.02	Semi-arid moisture regime, cold winters and warm summers	Other use	Hills	Predominantly good agricultural soils with some limitations due to possible flooding
23201	5	0.02	Semi-arid moisture regime, cold winters and warm summers	Other use	Hills	Predominantly soils without significant limitations for agriculture
35208	5	0.02	Semi-arid moisture regime, cold winters and mild summers	Forests	Hills	Association of shallow, stony or rocky soils, with poorly developed soils
21203	5	0.02	Semi-arid moisture regime, cold winters and warm summers	Rangelands	Hills	Soils with high salinity
35106	5	0.02	Semi-arid moisture regime, cold winters and mild summers	Forests	Plains	Predominantly shallow, stony or rocky soils

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31105	5	0.01	Semi-arid moisture regime, cold winters and mild summers	Rangelands	Plains	Predominantly good agricultural soils with some limitations due to possible flooding
25201	5	0.01	Semi-arid moisture regime, cold winters and warm summers	Forests	Hills	Predominantly soils without significant limitations for agriculture
54106	5	0.01	Subhumid moisture regime, cold winters and mild summers	Rainfed crops	Plains	Predominantly shallow, stony or rocky soils
32210	4	0.01	Semi-arid moisture regime, cold winters and mild summers	Irrigated crops	Hills	Mostly eroded and dissected 'badlands'
32301	4	0.01	Semi-arid moisture regime, cold winters and mild summers	Irrigated crops	Mountains	Predominantly soils without significant limitations for agriculture
44206	4	0.01	Subhumid moisture regime, cool or cold winters and warm summers	Rainfed crops	Hills	Predominantly shallow, stony or rocky soils
23105	4	0.01	Semi-arid moisture regime, cold winters and warm summers	Other use	Plains	Predominantly good agricultural soils with some limitations due to possible flooding
54101	4	0.01	Subhumid moisture regime, cold winters and mild summers	Rainfed crops	Plains	Predominantly soils without significant limitations for agriculture
22108	4	0.01	Semi-arid moisture regime, cold winters and warm summers	Irrigated crops	Plains	Association of shallow, stony or rocky soils, with poorly developed soils
26206	3	0.01	Semi-arid moisture regime, cold winters and warm summers	Wetlands and water bodies	Hills	Predominantly shallow, stony or rocky soils
24111	3	0.01	Semi-arid moisture regime, cold winters and warm summers	Rainfed crops	Plains	Soils of urbanized areas
12108	3	0.01	Arid or semi-arid moisture regime, cool winters and warm summers	Irrigated crops	Plains	Association of shallow, stony or rocky soils, with poorly developed soils
22202	3	0.01	Semi-arid moisture regime, cold winters and warm summers	Irrigated crops	Hills	Predominantly soils with better capability for grazing and/or forestry than for agriculture
51109	3	0.01	Subhumid moisture regime, cold winters and mild summers	Rangelands	Plains	Mostly poorly developed soils with a significant proportion of good agricultural soils
21310	3	0.01	Semi-arid moisture regime, cold winters and warm summers	Rangelands	Mountains	Mostly eroded and dissected 'badlands'
32308	3	0.01	Semi-arid moisture regime, cold winters and mild summers	Irrigated crops	Mountains	Association of shallow, stony or rocky soils, with poorly developed soils
21111	3	0.01	Semi-arid moisture regime, cold winters and warm summers	Rangelands	Plains	Soils of urbanized areas
22211	3	0.01	Semi-arid moisture regime, cold winters and warm summers	Irrigated crops	Hills	Soils of urbanized areas
21211	3	0.01	Semi-arid moisture regime, cold winters and warm summers	Rangelands	Hills	Soils of urbanized areas
22308	3	0.01	Semi-arid moisture regime, cold winters and warm summers	Irrigated crops	Mountains	Association of shallow, stony or rocky soils, with poorly developed soils
34305	3	0.01	Semi-arid moisture regime, cold winters and mild summers	Rainfed crops	Mountains	Predominantly good agricultural soils with some limitations due to possible flooding
51107	3	0.01	Subhumid moisture regime, cold winters and mild summers	Rangelands	Plains	Mostly shallow, stony or rocky soils with a significant proportion of good agricultural soils
32110	3	0.01	Semi-arid moisture regime, cold winters and mild summers	Irrigated crops	Plains	Mostly eroded and dissected 'badlands'

AEZ Code	Area (km2)	Area (%)	Climate	Land Use	Landform	SMD
22306	3	0.01	Semi-arid moisture regime, cold winters and warm summers	Irrigated crops	Mountains	Predominantly shallow, stony or rocky soils
32211	2	0.01	Semi-arid moisture regime, cold winters and mild summers	Irrigated crops	Hills	Soils of urbanized areas
54306	2	0.01	Subhumid moisture regime, cold winters and mild summers	Rainfed crops	Mountains	Predominantly shallow, stony or rocky soils
23206	2	0.01	Semi-arid moisture regime, cold winters and warm summers	Other use	Hills	Predominantly shallow, stony or rocky soils
24307	2	0.01	Semi-arid moisture regime, cold winters and warm summers	Rainfed crops	Mountains	Mostly shallow, stony or rocky soils with a significant proportion of good agricultural soils
32306	2	0.01	Semi-arid moisture regime, cold winters and mild summers	Irrigated crops	Mountains	Predominantly shallow, stony or rocky soils
55306	2	0.01	Subhumid moisture regime, cold winters and mild summers	Forests	Mountains	Predominantly shallow, stony or rocky soils
12106	2	0.01	Arid or semi-arid moisture regime, cool winters and warm summers	Irrigated crops	Plains	Predominantly shallow, stony or rocky soils
12306	2	0.01	Arid or semi-arid moisture regime, cool winters and warm summers	Irrigated crops	Mountains	Predominantly shallow, stony or rocky soils
23109	2	0.01	Semi-arid moisture regime, cold winters and warm summers	Other use	Plains	Mostly poorly developed soils with a significant proportion of good agricultural soils
51301	2	0.01	Subhumid moisture regime, cold winters and mild summers	Rangelands	Mountains	Predominantly soils without significant limitations for agriculture
52306	2	0.01	Subhumid moisture regime, cold winters and mild summers	Irrigated crops	Mountains	Predominantly shallow, stony or rocky soils
23210	2	0.01	Semi-arid moisture regime, cold winters and warm summers	Other use	Hills	Mostly eroded and dissected 'badlands'
22203	2	0.01	Semi-arid moisture regime, cold winters and warm summers	Irrigated crops	Hills	Soils with high salinity
54208	2	0.01	Subhumid moisture regime, cold winters and mild summers	Rainfed crops	Hills	Association of shallow, stony or rocky soils, with poorly developed soils
34110	2	0.01	Semi-arid moisture regime, cold winters and mild summers	Rainfed crops	Plains	Mostly eroded and dissected 'badlands'
25206	2	0.01	Semi-arid moisture regime, cold winters and warm summers	Forests	Hills	Predominantly shallow, stony or rocky soils
31305	2	0.01	Semi-arid moisture regime, cold winters and mild summers	Rangelands	Mountains	Predominantly good agricultural soils with some limitations due to possible flooding
35306	2	0.01	Semi-arid moisture regime, cold winters and mild summers	Forests	Mountains	Predominantly shallow, stony or rocky soils
35101	2	0.01	Semi-arid moisture regime, cold winters and mild summers	Forests	Plains	Predominantly soils without significant limitations for agriculture
61208	2	0.01	Humid or per-humid moisture regime, cold winters and mild or cool summers	Rangelands	Hills	Association of shallow, stony or rocky soils, with poorly developed soils
42209	2	0.01	Subhumid moisture regime, cool or cold winters and warm summers	Irrigated crops	Hills	Mostly poorly developed soils with a significant proportion of good agricultural soils
34204	2	0.00	Semi-arid moisture regime, cold winters and mild summers	Rainfed crops	Hills	Poorly drained soils
22207	2	0.00	Semi-arid moisture regime, cold winters and warm summers	Irrigated crops	Hills	Mostly shallow, stony or rocky soils with a significant proportion of good agricultural soils
14205	1	0.00	Arid or semi-arid moisture regime, cool winters and warm summers	Rainfed crops	Hills	Predominantly good agricultural soils with some limitations due to possible flooding

AEZ Code	Area (km2)	Area (%)	Climate	Land Use	Landform	SMD
52201	1	0.00	Subhumid moisture regime, cold winters and mild summers	Irrigated crops	Hills	Predominantly soils without significant limitations for agriculture
26203	1	0.00	Semi-arid moisture regime, cold winters and warm summers	Wetlands and water bodies	Hills	Soils with high salinity
41301	1	0.00	Subhumid moisture regime, cool or cold winters and warm summers	Rangelands	Mountains	Predominantly soils without significant limitations for agriculture
51210	1	0.00	Subhumid moisture regime, cold winters and mild summers	Rangelands	Hills	Mostly eroded and dissected 'badlands'
24301	1	0.00	Semi-arid moisture regime, cold winters and warm summers	Rainfed crops	Mountains	Predominantly soils without significant limitations for agriculture
12109	1	0.00	Arid or semi-arid moisture regime, cool winters and warm summers	Irrigated crops	Plains	Mostly poorly developed soils with a significant proportion of good agricultural soils
22302	1	0.00	Semi-arid moisture regime, cold winters and warm summers	Irrigated crops	Mountains	Predominantly soils with better capability for grazing and/or forestry than for agriculture
33105	1	0.00	Semi-arid moisture regime, cold winters and mild summers	Other use	Plains	Predominantly good agricultural soils with some limitations due to possible flooding
35307	1	0.00	Semi-arid moisture regime, cold winters and mild summers	Forests	Mountains	Mostly shallow, stony or rocky soils with a significant proportion of good agricultural soils
35301	1	0.00	Semi-arid moisture regime, cold winters and mild summers	Forests	Mountains	Predominantly soils without significant limitations for agriculture
23306	1	0.00	Semi-arid moisture regime, cold winters and warm summers	Other use	Mountains	Predominantly shallow, stony or rocky soils
35207	1	0.00	Semi-arid moisture regime, cold winters and mild summers	Forests	Hills	Mostly shallow, stony or rocky soils with a significant proportion of good agricultural soils
55209	1	0.00	Subhumid moisture regime, cold winters and mild summers	Forests	Hills	Mostly poorly developed soils with a significant proportion of good agricultural soils
22102	1	0.00	Semi-arid moisture regime, cold winters and warm summers	Irrigated crops	Plains	Predominantly soils with better capability for grazing and/or forestry than for agriculture
32202	1	0.00	Semi-arid moisture regime, cold winters and mild summers	Irrigated crops	Hills	Predominantly soils with better capability for grazing and/or forestry than for agriculture
33201	1	0.00	Semi-arid moisture regime, cold winters and mild summers	Other use	Hills	Predominantly soils without significant limitations for agriculture
34302	1	0.00	Semi-arid moisture regime, cold winters and mild summers	Rainfed crops	Mountains	Predominantly soils with better capability for grazing and/or forestry than for agriculture
23106	1	0.00	Semi-arid moisture regime, cold winters and warm summers	Other use	Plains	Predominantly shallow, stony or rocky soils
21302	1	0.00	Semi-arid moisture regime, cold winters and warm summers	Rangelands	Mountains	Predominantly soils with better capability for grazing and/or forestry than for agriculture
54308	1	0.00	Subhumid moisture regime, cold winters and mild summers	Rainfed crops	Mountains	Association of shallow, stony or rocky soils, with poorly developed soils
32111	0	0.00	Semi-arid moisture regime, cold winters and mild summers	Irrigated crops	Plains	Soils of urbanized areas

ANNEX 5. SPECIAL PROCEDURES FOR MAPPING LAND SUITABILITY

5.1. Use of aspect to adjust the temperature grid

To adjust the temperature surfaces used in the land suitability mapping for aspect, the following decision rules were adopted:

1) If temperature data were used (e.g. for olive), the temperature surfaces were adjusted as follows:

- If slope>threshold and aspect is S (112.5-247.5): **add 1°C**
- If slope>threshold and aspect is N (0-67.5; 292.5-360): **subtract 1°C**

2) If growing degree days data were used (for all other crops), the growing degree day surfaces were adjusted as follows:

- If slope>threshold and temperature> -0.5° and aspect is S (112.5-247.5): **add 30 growing degree days**
- If slope> threshold and temperature> -0.5° and aspect is N (0-67.5; 292.5-360): **subtract 30 growing degree days**

In this study 15% was taken as slope threshold for differentiating aspect. In both cases (temperature and growing degree days), there was no change in values if the slope was less than the threshold value or the aspect was neither north nor south.

5.2. Use of a land use map to adjust soil suitability assessment

The limited detail of the soil map necessitated the use of the more accurate land use/land cover map to correct the soil suitability ratings based on the prior interpretation of the soil map.
The following decision rules have been adopted for soil suitability:

- If the LULC category is 'irrigated', the % N (non suitable) or % S3 (marginally suitable) is reset as follows:
  the total % (N and S3) becomes 75% S1, 25% S2
- If the LULC category is 'rainfed', the % N or % S3 is reset as follows:
  The total % (N and S3) becomes 25% S1, 75% S2

<u>Example:</u>
Soil map unit 6 (Table 29) has, before adjustment, the following proportions of suitability classes:
S1: 30%; S2: 0%; S3: 0%; N: 70%

If the land use is 'irrigated', according to the first rule, 75% of S3 and N (70%) becomes S1 (52.5%) and 25% of S3 and N becomes S2 (17.5%).
After adjustment, we get:
S1 : 30% + 52.5% = 82.5%
S2: 0% + 17.5% = 17.5%
S3: 0%
N: 0%

Table 29. Adjustment of soil suitability percentages according to land use-based decision rules

Soil Unit	%S1	%S2	%S3	%N	%S1	%S2	%S3	%N	%S1	%S2	%S3	%N
1	90	10	0	0	90	10	0	0	90	10	0	0
2	100	0	0	0	100	0	0	0	100	0	0	0
3	10	90	0	0	10	90	0	0	10	90	0	0
4	0	0	0	100	75	25	0	0	25	75	0	0
5	0	0	0	100	75	25	0	0	25	75	0	0
6	30	0	0	70	82.5	17.5	0	0	47.5	52.5	0	0
7	90	10	0	0	90	10	0	0	90	10	0	0
8	0	0	100	0	75	25	0	0	25	75	0	0
9	100	0	0	0	100	0	0	0	100	0	0	0
10	100	0	0	0	100	0	0	0	100	0	0	0
11	100	0	0	0	100	0	0	0	100	0	0	0
12	100	0	0	0	100	0	0	0	100	0	0	0
13	90	10	0	0	90	10	0	0	90	10	0	0
14	100	0	0	0	100	0	0	0	100	0	0	0
15	0	35	0	65	48.75	51.25	0	0	16.25	83.75	0	0
16	0	0	0	100	75	25	0	0	25	75	0	0
17	30	10	0	60	75	25	0	0	45	55	0	0
18	10	30	0	60	55	45	0	0	25	75	0	0
19	100	0	0	0	100	0	0	0	100	0	0	0
20	60	40	0	0	60	40	0	0	60	40	0	0
21	0	100	0	0	0	100	0	0	0	100	0	0
22	0	40	0	60	45	55	0	0	15	85	0	0
23	90	10	0	0	90	10	0	0	90	10	0	0
24	35	65	0	0	35	65	0	0	35	65	0	0
25	100	0	0	0	100	0	0	0	100	0	0	0
26	40	60	0	0	40	60	0	0	40	60	0	0
27	0	10	0	90	67.5	32.5	0	0	22.5	77.5	0	0
28	100	0	0	0	100	0	0	0	100	0	0	0
29	90	10	0	0	90	10	0	0	90	10	0	0
30	90	10	0	0	90	10	0	0	90	10	0	0
31	90	0	0	10	97.5	2.5	0	0	92.5	7.5	0	0
32	0	0	0	100	75	25	0	0	25	75	0	0
33	0	0	0	100	75	25	0	0	25	75	0	0
34	90	10	0	0	90	10	0	0	90	10	0	0

Notes: yellow background: unadjusted soil suitabilities; blue background: values adjusted if ‘irrigated’; green background: values adjusted if ‘rainfed’

If the land use is ‘rainfed’, according to the second rule, 25% of S3 and N (70%) becomes S1 (17.5%) and 75% of S3 and N becomes S2 (52.5%).
After adjustment, we get:
S1 : 30% + 17.5% = 47.5%
S2: 0% + 52.5% = 52.5%
S3: 0%
N: 0%

5.3. Crop requirement tables

Soil information was inadequate to allow a crop-specific differentiation of thresholds for different soil properties (e.g. salinity, stoniness, depth). For this reason the same soil suitability ratings were used for all the soil map units, irrespective of the crop, as shown in Table 29. However, the soil suitability ratings are specific for three land use situations (irrigated, rainfed, all other). For the other criteria, such as precipitation, temperature, slope, the thresholds are crop-specific.

Table 30[3]. Suitability criteria and threshold for barley

Criteria	Ranges	Suitability unit	Limitat. Code	Suitability Code
Annual Precip (mm)	<150	Unsuitable, too dry	4	N
	150 to 225	Marginally suitable, too dry	3	S3
	225 to 300	Moderately suitable, too dry	2	S2
	300 to 800	Highly suitable	1	S1
	800 to 1100	Moderately suitable, too wet	2	S2
	> 1100	Unsuitable, too wet	4	N
AHU (°.days)	<900	Unsuitable, too cold	4	N
	900 to 1150	Marginally suitable, too cold	3	S3
	1150 to 1350	Moderately suitable, too cold	2	S2
	1350 to 2700	Highly suitable	1	S1
	2700 to 4000	Moderately suitable, too warm	2	S2
	> 4000	Unsuitable, too warm	4	N
Slope (%)	<4	Highly suitable	1	S1
	4 to 12	Moderately suitable	2	S2
	12 to 20	Marginally suitable	3	S3
	>20	Unsuitable	4	N

[3] Explanatory notes with the tables are at the end of this section

Table 31. Suitability criteria and thresholds for wheat

Criteria	Ranges	Suitability unit	Limitation Code	Suitability Class
Annual Precip (mm)	<225	Unsuitable, too dry	4	N
	225 to 275	Marginally suitable, too dry	3	S3
	275 to 350	Moderately suitable, too dry	2	S2
	350 to 1200	Highly suitable	1	S1
	1200 to 1500	Moderately suitable, too wet	2	S2
	1500 to 1750	Marginally suitable, too wet	3	S3
	> 1750	Unsuitable, too wet	4	N
AHU (°.days)	<1000	Unsuitable, too cold	4	N
	1000 to 1250	Marginally suitable, too cold	3	S3
	1250 to 1500	Moderately suitable, too cold	2	S2
	1500 to 3000	Highly suitable	1	S1
	3000 to 4500	Moderately suitable, too warm	2	S2
	> 4500	Unsuitable, too warm	4	N
Slope (%)	<4	Highly suitable	1	S1
	4 to 10	Moderately suitable	2	S2
	10 to 15	Marginally suitable	3	S3
	>15	Unsuitable	4	N

Table 32. Suitability criteria and thresholds for olive

Criteria	Ranges	Suitability unit	Limitati on Code	Suitability Class
Annual Precip (mm)	<150	Unsuitable, too dry	4	N
	150 to 300	Marginally suitable, too dry	3	S3
	300 to 400	Moderately suitable, too dry	2	S2
	400 to 1000	Highly suitable	1	S1
	1000 to 1200	Moderately suitable, too wet	2	S2
	1200 to 1400	Marginally suitable, too wet	3	S3
	> 1400	Unsuitable, too wet	4	N
Mean annual temp. (° C)	<13	Unsuitable, too cold	4	N
	13 to 14	Marginally suitable, too cold	3	S3
	14 to 15	Moderately suitable, too cold	2	S2
	15 to 22	Highly suitable	1	S1
	22 to 24	Moderately suitable, too warm	2	S2
	24 to 26	Marginally suitable, too warm	3	S3
	> 26	Unsuitable, too warm	4	N
Minimum temp. coldest month (° C)	<-1.2	Unsuitable, too cold	4	N
	-1.2 to 0.5	Marginally suitable, too cold	3	S3
	0.5 to 2.3	Moderately suitable, too cold	2	S2
	2.3 to 7.5	Highly suitable	1	S1
	7.5 to 9.2	Moderately suitable, too warm	2	S2
	9.2 to 11	Marginally suitable, too warm	3	S3
	>11	Unsuitable, too warm	4	N
Slope (%)	<8	Highly suitable	1	S1
	8 to 15	Moderately suitable	2	S2
	15 to 20	Marginally suitable	3	S3
	>20	Unsuitable	4	N

Table 33. Suitability criteria and thresholds for lentil

Criteria	Ranges	Suitability unit	Limitation Code	Suitability Class
	<230	Unsuitable, too dry	4	N
	230 to 280	Marginally suitable, too dry	3	S3
Annual	280 to 400	Moderately suitable, too dry	2	S2
Precip	400 to 800	Highly suitable	1	S1
(mm)	800 to 1200	Moderately suitable, too wet	2	S2
	1200 to 1500	Marginally suitable, too wet	3	S3
	> 1500	Unsuitable, too wet	4	N
	<1000	Unsuitable, too cold	4	N
	1000 to 1250	Marginally suitable, too cold	3	S3
AHU	1250 to 1900	Moderately suitable, too cold	2	S2
(°.days)	1900 to 4000	Highly suitable	1	S1
	3400 to 4500	Moderately suitable, too warm	2	S2
	> 4500	Unsuitable, too warm	4	N
	<4	Highly suitable	1	S1
Slope	4 to 10	Moderately suitable	2	S2
(%)	10 to 15	Marginally suitable	3	S3
	>15	Unsuitable	4	N

Table 34. Suitability criteria and thresholds for chickpea

Criteria	Ranges	Suitability unit	Limitation Code	Suitability Class
	<200	Unsuitable, too dry	4	N
	200 to 250	Marginally suitable, too dry	3	S3
Annual	250 to 300	Moderately suitable, too dry	2	S2
Precip	300 to 550	Highly suitable	1	S1
(mm)	550 to 800	Moderately suitable, too wet	2	S2
	800 to 1200	Marginally suitable, too wet	3	S3
	> 1200	Unsuitable, too wet	4	N
	<1200	Unsuitable, too cold	4	N
	1200 to 1650	Marginally suitable, too cold	3	S3
	1650 to 1950	Moderately suitable, too cold	2	S2
AHU	1950 to 3000	Highly suitable	1	S1
(°.days)	3000 to 3300	Moderately suitable, too warm	2	S2
	3300 to 3750	Marginally suitable, too warm	3	S3
	> 3750	Unsuitable, too warm	4	N
	<4	Highly suitable	1	S1
Slope	4 to 10	Moderately suitable	2	S2
(%)	10 to 15	Marginally suitable	3	S3
	>15	Unsuitable	4	N

Table 35. Suitability criteria and thresholds for potato and sugarbeet

Criteria	Ranges	Suitability unit	Limitation Code	Suitability Class
Irrigation	Not-irrigated	Not suitable	4	N
	Irrigated	Highly suitable	1	S1
AHU (°.days)	<1200	Unsuitable, too cold	4	N
	1200 to 1450	Marginally suitable, too cold	3	S3
	1450 to 1750	Moderately suitable, too cold	2	S2
	1750 to 3500	Highly suitable	1	S1
	3500 to 4750	Moderately suitable, too warm	2	S2
	> 4750	Unsuitable, too warm	4	N
Slope (%)	<2	Highly suitable	1	S1
	2 to 4	Moderately suitable	2	S2
	4 to 6	Marginally suitable	3	S3
	>6	Unsuitable	4	N

Table 36. Suitability criteria and thresholds for safflower

Criteria	Ranges	Suitability unit	Limitation Code	Suitability Class
Irrigation	Not-irrigated	Not suitable	4	N
	Irrigated	Highly suitable	1	S1
AHU (°.days)	<870	Unsuitable, too cold	4	N
	870 to 1320	Marginally suitable, too cold	3	S3
	1320 to 1590	Moderately suitable, too cold	2	S2
	1590 to 2460	Highly suitable	1	S1
	2460 to 2640	Moderately suitable, too warm	2	S2
	2640 to 3840	Marginally suitable, too warm	3	S3
	> 3840	Unsuitable, too warm	4	N
Slope (%)	<2	Highly suitable	1	S1
	2 to 4	Moderately suitable	2	S2
	4 to 6	Marginally suitable	3	S3
	>6	Unsuitable	4	N

Notes:
AHU: annual heat units
Limitation codes:
4: very severe limitation; 3: severe limitation; 2: moderate limitation; 1: no or slight limitation
Suitability classes:
N: unsuitable; S3: marginally suitable ; S2: moderately suitable; S1: highly suitable