Desertification Information System to Support National Action Programmes in the Mediterranean (DIS/MED)

Thematic and sensitivity mapping on desertification and drought : climatic sensitivity to desertification

Technical paper

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1. Introduction

The climate is a leading agent in promoting the desertification process because it sets the condition in which soil erosion and land degradation occur. High rainfall variability, high intensity rainfall, high temperature variability, seasonal droughts, wind intensity are all climate factors which can easily cause desertification if associated with the wrong conditions such as poor and highly erodible soils, low plant cover and excessive human activity.

The present technical paper aims to suggest a proper methodology for the definition of the hydrological balance esteem, in terms of desertification and drought, due to the climate factors for the Mediterranean area. In other words the objective is to point out desertification based on the two main terms of an hydrological balance esteem: the precipitation and the evapotranspiration.

DISMED Tamanrasset workshop agreed that the first step of development of the regional mapping should be based on the elaboration of a minimum set of indicators to assess the structural sensitivity to desertification. With reference to the cartography of climatic sensitivity to desertification the basic layer it was agreed to be the aridity index. The terms of reference for the elaboration of the Aridity Index analysis were presented at the technical session of WG1 held in Rome in November 2002 in parallel to the CRIC. Terms of reference have been discussed and agreed by WG1 participants.

Therefore the main output of the document is the cartography of Aridity index for all the Mediterranean area (1:1,000,000); the aridity index as been defined as the ratio between the precipitation and the evapotranspiration.

As stated during the various workshops all country partners will provide the FMA with climatic data and information relevant to the elaboration of the desertification sensitivity map. Therefore the methodology will allow the FMA, throughout a standard procedure for the calculations of the aridity index values for all the Mediterranean area, to achieve various targets.

First of all we will handle a tool capable of a continuous, homogeneous and coherent view of the desertification process all over the Mediterranean area: this is only possible adopting a standard procedure for spatialising temperature and rainfall data and a standard method for calculating the evapotranspiration and aridity index. In second hand all the desertification analysis at national level, based on different methodologies, will be overcome and all country partners could use the relevant DISMED information to understand the desertification process related to the climate phenomena even in border line region were data are usually rare or unavailable.

In order to provide a structural analysis, the reference 30 years 1961-1990 period has been chosen, accordingly with IPCC (Intergovernmental Panel on Climate Changes) structural analysis time series.

The present document has been divided in chapter showing the steps undertaken to define the aridity index and to produce the relevant cartography of Aridity index:

Chapter 2: In this chapter are reported the selection criteria for defining the extent of the area of study, and all the basic background databases needed for the further calculation as the latitude, longitude, altitude and sea distance databases.
Chapter 3 and 4: Description of the temperature and precipitation databases available (FAOCLIM-2 and IPCC). The spatialisation procedures over the area of study are also described.

Chapter 5: The methods to calculate the potential evapotranspiration are reported and compared (Penman-Monteith, Hargreaves, Thornthwaite).
Chapter 6: This chapter describes the selection of the aridity index as climate indicators for desertification. Also it explains the classification of the aridity index in the final cartography.
Chapter 7: Conclusions.
Annex 1: This annex provides the software scripts used to perform the calculations for our methodology.
Annex 2: This annex provides the aridity index cartography for each country partner.

Once the structural analysis of the climatic index will be achieved for the reference 30 years 1961-1990 period then the standard procedure will be applied to the period 1991- 2000 (current analysis). The further steps will be undertaken in assessing the desertification trend, in terms of aridity index, comparing the two historical series.

2. The Area of study

The area of study to define the effects of desertification for the Mediterranean area has been selected based on the following assumptions/criteria:

- The country partners taking part to the DISMED projects which supply the essential meteorological databases in terms of temperature and rainfall;
- All other Mediterranean countries which information allow continuity, in terms of climatic database, in the desertification analysis;
- The sub-Saharan countries such as Mauritania which meteorological data can supply important information on the Sahara-Mediterranean interaction effects;
- Northern European countries which meteorological data can supply important information on the North Europe-Mediterranean interaction effects and can effectively support the aridity index representation for the Mediterranean region.

Therefore the area of study is located within the following coordinates: N +47°, S +18°, E +45°, W –18°.

Also in this chapter the procedure to define all the necessary databases, functional to the future calculations and spatialisation (temperature, rainfall, evapotranspiration and aridity index), and relative raster output are reported in term of:

- The elevation database;
- The latitude database;
- The longitude database;
- The sea distance database.

2.1. The Elevation Database

The elevation data for the area of study have been obtained from “The Land Processes Distributed Active Archive Center”. The Land Processes DAAC was established as part of NASA's Earth Observing System (EOS) Data and Information System (EOSDIS) initiative to process, archive, and distribute land-related data collected by EOS sensors, thereby promoting the inter-disciplinary study and understanding of the integrated Earth system.

The Land Processes DAAC supplies GTOPO30 which is a global digital elevation model (DEM) with a horizontal grid spacing of 30 arc seconds (approximately 1 kilometer to the equator). GTOPO30 was derived from several raster and vector sources of topographic information, such as Digital Terrain Elevation Data, Digital Chart of the world, International Map of the World, etc.

The DEM horizontal grid spacing is 30-arc seconds (0.008334 degrees). The horizontal coordinate system is decimal degrees of latitude and longitude referenced to WGS84. The vertical units represent elevation in meters above mean sea level. The elevation values range from -407 to 8,752 meters. In the DEM, ocean areas have been masked as "no data" and have been assigned a value of -9999.

On the DACC internet site the GTOPO30 has been divided into tiles for an easier distribution. The following tiles have been downloaded and then merged using ARCVIEW 3.2: tileW020N90 (Europe), E020N90 (Euro-Asia), W020N40 (West Africa) and E020N40 (East Africa). Then an elevation raster file (elevation layer) has been extrapolated for the relevant area of study.

2.2. The Latitude and Longitude Databases

The latitude and longitude databases have been originated using Perl Programming Software. The procedure simply consisted in the creation of two raster files which included respectively the latitude and the longitude.
The latitude raster for the area of interest has been created using the imlat.pl file (see Annex 1). The raster file is formed by 4530 rows and 7630 columns; the maximum latitude value of 52.4910720 degrees is used as starting point. All matrix values are calculated detracting a constant value of 0.008334 corresponding to a 30-arc seconds. The output file is latdismed.rst. This type of data are binary which is the ideal format for the IDRISI Software (GIS).

The longitude raster for the area of interest has been created using Perl Software script the imlong.pl file (see Annex 1). The raster is a 4530 by 7630 matrix; the minimum longitude value of -18.2960780 degrees is used as starting point. All matrix values are calculated adding a constant value of 0.008334. The output file is londismed.rst.

2.3. The sea distance Database

First step has consisted in defining the original coast shape for the Mediterranean area. This has been achieved using the Digital Chart of the World DCW database 1:1,000,000. The merging of different frames of the DCW database and the creation of the topology have been executed with ARCVIEW 3.2 software. Then the coast shape layer for the area of study has been saved in a vector file (renamed Shp_coste.shp) also using ARCVIEW 3.2.

The coast shape file has been elaborated in the ARCVIEW 3.2 GIS software and then, applying the Find Distance function in the Analysis Tools, a sea distance raster has been automatically originated based on a number of cells of 4530 by 7630 and an output grid cell size value of 0.008334 corresponding to a 30-arc seconds.

Therefore it is absolutely clear then the sea distance raster is homogeneous, in term of number of cells, with the elevation, longitude and latitude raster files which are used for the further calculations (see chapter 3).

3. The Temperature Events

The main objective of this chapter is to describe the series of operations and the methodology to obtain an uniform distribution of temperature data (temperature spatialisation) for the Mediterranean area under examination. The main outputs are 12 mean monthly temperature raster files with a resolution value of 30-seconds arc.

3.1. Temperature Database

As discussed during the first validation workshop in Algeria all country partners have been invited to provide the selected organization with data and information relevant to the elaboration of the desertification sensitivity map.

At the time being all available data have been collected, mainly from the FAOCLIM database, and a data query and harmonization has been carried out: the first assumptions and results are that (i) stations with less then 25 years of data over the period 1961-90 have not been considered, (ii) mean historical values for temperature and rainfall have been calculated and (iii) a geographic layer for the meteorological station have been produced.

The table 3.1 shows the inventory of meteorological stations with consistent time series for monthly mean temperature over the period 1961-90 from the FAOCLIM database.

It is understood that the temperature database will be continuously updated by the FMA using the relevant country partners climatic information on temperature and rainfall. Then the methodology, presented in this document, will be applied to the revised set of information by an automatic procedure.

Tab 3.1 – Meteorological Stations

Country	**temperature stations**
ALGERIA	10
EGYPT	8
FRANCE	18
GREECE	7
ITALY	42
LIBYAN_AR.JAMAHIRIYA	7
MOROCCO	5
PORTUGAL	11
SPAIN	17
TUNISIA	5
TURKEY	138
Total	**268**

It is not clear at the moment if the FAOCLIM data will be completely discharged and eliminated form the procedure. This will depend mainly from the amount of information supplied by the country partners.

All temperature data with other essential information are included in FAOCLIM database. The main information included in the database are summarized in the following table.

Tab 3.2 – Temperature Database

Field name	Field Type	Width	Decimal	Description
Station_id	CHAR	16	0	Meteorological station FAOCLIM2 ID
Stat_name	CHAR	31	0	Name of the station
Wmo_code	NUMBER	14	0	Station WMO code
Country	CHAR	16	0	Country
X_coord	NUMBER	18	5	Longitude in decimal degrees
Y_coord	NUMBER	18	5	Latitude in decimal degrees
Elevation	NUMBER	14	0	Elevation (meters)
Sea_dist	NUMBER	16	0	Distance form the sea (meters)
Tm_years	NUMBER	12	0	Length of mean temperature time series over the period 1961-90
Tm_jan	NUMBER	13	2	January mean temperature (C°) over the time series
Tm_feb	NUMBER	13	2	February mean temperature (C°) over the time series
Tm_mar	NUMBER	13	2	March mean temperature (C°) over the time series
Tm_apr	NUMBER	13	2	April mean temperature (C°) over the time series
Tm_may	NUMBER	13	2	May mean temperature (C°) over the time series
Tm_jun	NUMBER	13	2	June mean temperature (C°) over the time series
Tm_jul	NUMBER	13	2	July mean temperature (C°) over the time series
Tm_aug	NUMBER	13	2	August mean temperature (C°) over the time series
Tm_sep	NUMBER	13	2	September mean temperature (C°) over the time series
Tm_oct	NUMBER	13	2	October mean temperature (C°) over the time series
Tm_nov	NUMBER	13	2	November mean temperature (C°) over the time series
Tm_dec	NUMBER	13	2	December mean temperature (C°) over the time series

3.2. Data spatialisation

The first step for the data spatialisation has been to extend the punctual real data to all the interested area. In other words it is to find a way to be able to estimate the temperature for every cell of a spatial grid starting from a reduced amount of real data.
Based on the data available, it has been decided to directly relate the temperature value, using the multiple linear regression theory, to the latitude, longitude, elevation and sea distance values. In mathematical terms the temperature, which is assumed as the dependent variable, can be expressed, using a regression equation, as a function of 4 independent variables (lat., long, elevation, sea elevation):

$$Tm_i = m_{1i} * X\_coord + m_{2i} * Y\_coord + m_{3i} * Elevation + m_{4i} * Sea\_dist + c_{0i} \quad (3.1)$$

Where

i = month from 01 (Gen) to 12 (Dec);
Tm_i = Average monthly temperature (C°);
X_coord = Longitude in decimal degrees;
Y_coord = Latitude in decimal degrees;
Elevation = Elevation (m)
Sea_dist = Sea distance (m);
m_{1i}, m_{2i}, m_{3i}, m_{4i} = Regression Coefficients;
c_{0i} = Constant;

The regression coefficient are calculated using an ordinary method of least squares.

The procedure consisted of feeding the FAOCLIM database, which includes 12 columns of monthly mean temperature (each month of the year), latitude, longitude, elevation and sea distance values, into a Matlab software script (mregress.m); the Matlab file calculates a constant (c_{0i}) and four regression coefficients (m_{1i}, m_{2i}, m_{3i}, m_{4i}) for each set of monthly mean temperature. Before feeding the data into the Matlab script a cleaning exercise has been applied to eliminate all useless data, such as the missing data which are esteemed with a value of –9999 in the FAOCLIM database.

The real spatialisation exercise is realized producing a temperature raster for the whole Mediterranean area and for each month so that each cell of the raster has got assigned a mean monthly temperature value.

This has been achieved using a Perl software routine (regre_lin.pl as in Annex 1) which create a binary temperature raster with a regression equation using the correlation coefficients and the constants, calculated as described previously, and the latitude, longitude, elevation, and sea distance rasters as described in chapter 2. The Temperature raster can be read by IDRISI.

The final outputs are twelve (one for each month) mean monthly temperature raster files (from temp_01.rst to temp_12.rst), relative to the historical series ‘60–‘91, inclusive of values (binary mode) for all the area of interest (4530 by 7630).

Figure 3.1 shows the mean yearly temperature values of the reference 30 years 1961-1990 period for the Mediterranean area.

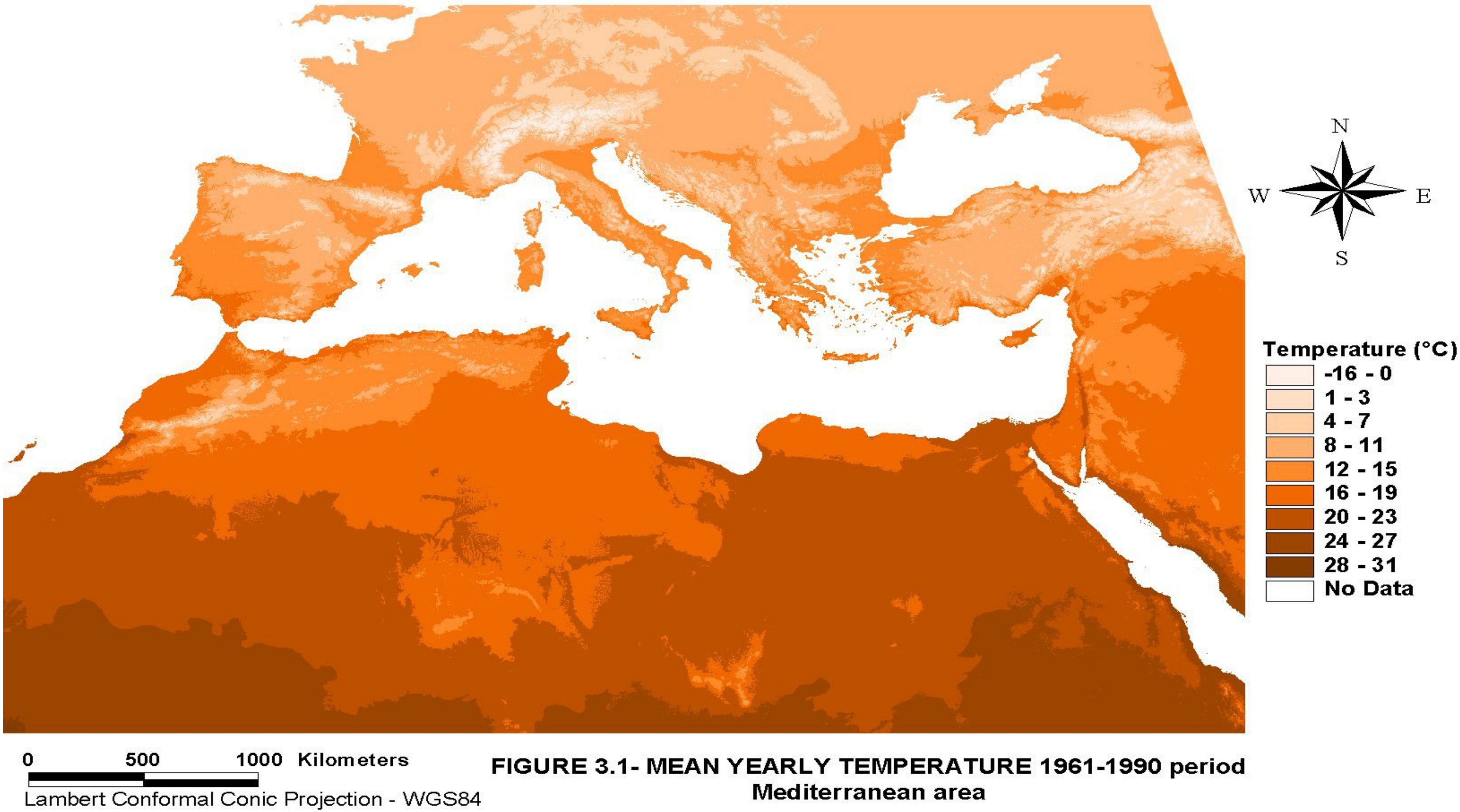

FIGURE 3.1- MEAN YEARLY TEMPERATURE 1961-1990 period
Mediterranean area

4 – The rainfall events

The main objective of this chapter is to describe the series of operations to obtain an uniform distribution of rainfall data (rainfall spatialisation) for the Mediterranean area under examination. The main outputs are 12 mean monthly rainfall raster files with a resolution value of 30-seconds arc.

4.1. Rainfall Databases

The rainfall spatialisation has presented a higher degree of difficulty compared to the temperature spatialisation. This has been due to the nature of the existing database supplied by the FAOCLIM. In mathematical terms it has not been possible to create a satisfactory correlation between rainfall values and other set of possible independent variables such as latitude, longitude, sea distance or elevation. Therefore two databases have been used and finally merged:

- FAOCLIM database;
- IPCC - CRU (Intergovernmental Panel on Climate Change – Climate Research Unit) Global Climate Dataset 0.5 degrees 1961-90 Mean Monthly Climatology.

Table 4.1 shows the inventory of meteorological stations with consistent time series for monthly mean rainfall over the period 1961-90 from the FAOCLIM database.

It is understood that the rainfall database will be continuously updated by the FMA using the relevant country partners climatic information on temperature and rainfall. Then the methodology, presented in this document, will be applied to the revised set of information by an automatic procedure.

Tab 4.1 – Meteorological Stations – FAOCLIM2

Country	**rainfall stations**
ALGERIA	38
EGYPT	31
FRANCE	36
GREECE	32
ITALY	58
LIBYAN_AR.JAMAHIRIYA	16
MOROCCO	26
PORTUGAL	22
SPAIN	38
TUNISIA	8
TURKEY	188
Total	**493**

It is not clear, at the moment, if the IPCC and FAOCLIM data will be completely discharged and eliminated form the procedure. This will depend mainly from the amount of information supplied by the country partners.

All precipitation data and other essential information are included in the FAOCLIM database. The main information included in the database are summarized in the following table.

Tab 4.2 – Rainfall Database

Field name	Field Type	Width	Decimal	Description
Station_id	CHAR	16	0	Meteorological station FAOCLIM2 ID
Stat_name	CHAR	31	0	Name of the station
Wmo_code	NUMBER	14	0	Station WMO code
Country	CHAR	16	0	Country
X_coord	NUMBER	18	5	Longitude in decimal degrees
Y_coord	NUMBER	18	5	Latitude in decimal degrees
Elevation	NUMBER	14	0	Elevation (meters)
Sea_dist	NUMBER	16	0	Distance form the sea (meters)
Rm_years	NUMBER	13	0	Length of rainfall time series over the period 1961-90
Rm_jan	NUMBER	9	2	January mean rainfall (mm) over the time series
Rm_feb	NUMBER	9	2	February mean rainfall (mm) over the time series
Rm_mar	NUMBER	9	2	March mean rainfall (mm) over the time series
Rm_apr	NUMBER	9	2	April mean rainfall (mm) over the time series
Rm_may	NUMBER	9	2	May mean rainfall (mm) over the time series
Rm_jun	NUMBER	9	2	June mean rainfall (mm) over the time series
Rm_jul	NUMBER	9	2	July mean rainfall (mm) over the time series
Rm_aug	NUMBER	9	2	August mean rainfall (mm) over the time series
Rm_sep	NUMBER	9	2	September mean rainfall (mm) over the time series
Rm_oct	NUMBER	9	2	October mean rainfall (mm) over the time series
Rm_nov	NUMBER	9	2	November mean rainfall (mm) over the time series
Rm_dec	NUMBER	9	2	December mean rainfall (mm) over the time series

The IPCC Data Distribution Centre provides observed global climate data sets which include a gridded terrestrial climatology of mean monthly data for 1961-90 on a 0.5º latitude/longitude grid (XYZ file). The variables will include precipitation, mean temperature, diurnal temperature range, frequency of wet days, frequency of ground frost days, vapour pressure, sunshine hours, cloud cover and wind speed. For our task the monthly mean precipitation for the 1961-90 period has been used.

The climate surfaces have been constructed from a new dataset of station 1961–90 climatological normals, numbering between 19 800 (precipitation) and 3615 (wind speed). The station data were interpolated as a function of latitude, longitude, and elevation using thin-plate splines. The accuracy of the interpolations are assessed using cross validation and by comparison with other climatologies. The original thin-plate spline fitting technique was described by Wahba (1979) whereas Hutchinson (1995) provides a theoretical description of their application to surface climate variable as precipitation. Thin-plate splines are defined by minimizing the roughness of the interpolated surface, subject to the data having a predefined residual.

Tab 4.3 – IPCC data

Country	rainfall data
ALGERIA	846
EGYPT	362
FRANCE	250
GREECE	51
ITALY	129
LIBYAN_AR.JAMAHIRIYA	591
MOROCCO	158
PORTUGAL	39
SPAIN	214
TUNISIA	59
TURKEY	323
Total	**3022**

4.2 – Data spatialisation

The overall task for the rainfall spatialisation consisted of 'downscaling' the IPCC mean monthly precipitation data supplied on a 0.5º latitude/longitude grid, to the standard grid spacing of 30-arc seconds (0.008334 degrees) as assumed in the present project. Before doing so, the FAOCLIM database has been merged into the IPCC database, the last one (IPCC) being the more continuous and consistent in term of data over the area of interest.

Then the rainfall spatialisation has been achieved in two steps due to the following reasons: (i) the precipitation file dimension (IPCC + FAOCLIM data) and (ii) the number of complex computing calculations needed to extrapolate the final grid:

- First spatialisation from a grid spacing of 0.5 degrees (approx. 100 km resolution) down to a grid spacing of 0.08334 degrees (approx. 8 km resolution) using the Kriging method on Surfer Software;
- Second spatialisation from a grid spacing of 0.08334 degrees (approx. 8 km resolution) down to a grid spacing of 0.008334 degrees (approx. 1 km resolution) using TIN method (Triangular interpolation Network) on Surfer Software.

Kriging is a geostatistical gridding method. This interpolation method has been used to estimate the precipitation values on a regular grid using irregularly (and regularly) spaced starting data. The Kriging geostatistical approach to interpolation has been chosen based on the following reasons:

- Kriging is preceded by an analysis of the spatial structure of the data. The representation of the average spatial variability is integrated into the estimated procedure in the form of a variogram model.
- Ordinary Kriging interpolates exactly: when a sample value is available at the location of interest, the Kriging solution is equal to that value.
- Kriging as a statistical method, provides an indication of the estimation error (the kriging standard deviation).
- With moderate-sized data sets, Triangulation with Linear Interpolation is fast and creates a good representation of your data. The Kriging method produces a better final data representations (even if produces the grids more slowly) than other interpolation methods such as the Triangulation with Linear Interpolation.

Kriging can be custom-fit to a data set by specifying the appropriate variogram model. Within Surfer, Kriging can be either an exact or a smoothing interpolator depending on the user-specified parameters. It incorporates anisotropy and underlying trends in an efficient and natural manner. Surfer 7 includes an extensive variogram modelling subsystem. With the precipitation data set during the first spatialisation, the ordinary Kriging with the default linear variogram has shown being the most effective.

Given that for larger data sets the Kriging interpolation method can be rather slow (if not possible as find out during the elaboration), the second step spatialisation has been run on Surfer Software using Triangulation with Linear Interpolation (TIN); for large datasets the Triangulation with Linear Interpolation is quite fast (faster than the Kriging method) and produces a good final data representations. In other hand the Triangulation with Linear Interpolation works best when data are evenly distributed over the grid area as achieved by the first spatialisation using the Kriging method.

The Triangulation with Linear Interpolation method on Surfer Software uses the optimal Delaunay triangulation. The algorithm creates triangles by drawing lines between data points. The original points are connected in such a way that no triangle edges are intersected by other triangles. The result is a patchwork of triangular faces over the extent of the grid. This method is an exact interpolator. Each triangle defines a plane over the grid nodes lying within the triangle, with the tilt and elevation of the triangle determined by the three original data points defining the triangle. All grid nodes within a given triangle are defined by the triangular surface. Because the original data are used to define the triangles, the data are honored very closely.

The final output files are twelve (one for each month) XYZ Surfer files with longitude, latitude and mean monthly precipitation values (binary mode) for all the area of interest (4530 by 7630 by 3 matrix). The 12 files are then imported with the IDRISI Software and converted in raster format (from pio_01.rst to pio_12.rst).

Figure 4.1 shows the mean yearly precipitation values of the reference 30 years 1961-1990 period for the Mediterranean area.

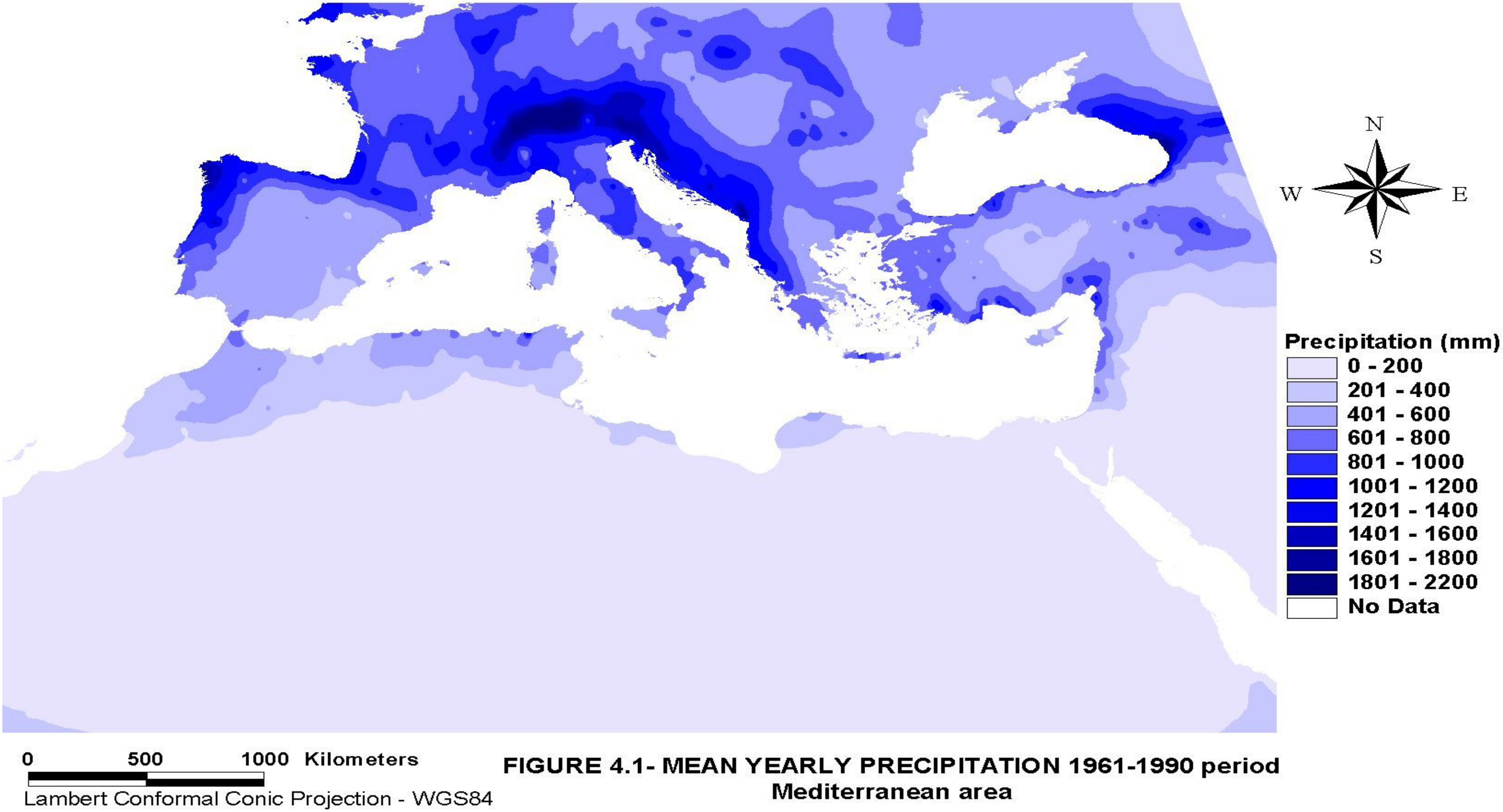

FIGURE 4.1- MEAN YEARLY PRECIPITATION 1961-1990 period Mediterranean area

5 – Evapotranspiration

5.1 .Introduction

Besides precipitation, the most significant component of the hydrologic budget is evapotranspiration. Evapotranspiration is the water lost to the atmosphere by two processes: evaporation and transpiration. Evaporation is the loss from open bodies of water, such as lakes and reservoirs, wetlands, bare soil, and snow cover; transpiration is the loss from living-plant surfaces. Several factors other than the physical characteristics of the water, soil, snow, and plant surface also affect the evapotranspiration process. The more important factors include net solar radiation, surface area of open bodies of water, wind speed, density and type of vegetative cover, availability of soil moisture, root depth, reflective land-surface characteristics, and the seasons.

Owing to the difficulty of obtaining accurate field measurements, ET is commonly computed from weather data. During the last fifty years, a large number of empirical methods have been developed and used to estimate ET_0 (potential evapotranspiration) from meteorological data. Some methods are only valid under specific climatic and agronomic conditions and cannot be applied to scenarios different from those under which they were originally developed. Testing the accuracy of these methods, under a new environment, has proved to be costly, time consuming and to have a limited global validity. In addition, this requires lysimeters and well-trained personnel.

In this chapter various evapotranspiration model will be described starting from (i) the Thornthwaite method, which is the final temperature method adopted for the calculation in this report and passing throughout (ii) the Penmam-Monteith method, and (iii) the Hargreaves method. It has to be stated that the "FAO Irrigation and Drainage Paper 56" recommends Penman-Monteith method as the sole standard method.

All the methods calculate the reference evapotranspiration ETo. The real evapotranspiration for a selected area is usually lower than the reference evapotranspiration ETo due to a series of factors as the type of soil and the type of vegetation which can be taken into account assuming correction coefficients (as assumed in the "FAO Irrigation and Drainage Paper 56" for the Penmam-Monteith method).

The following paragraphs give an overview on several evapotranspiration methods: Thornthwaite method, Penman-Monteith method, Hargreaves method. The Thornthwaite method has been adopted and used in the DISMED project for the following reasons:

- it has been continuously used and verified in the Mediterranean area and it has given satisfactory results in various projects and studies due to the extensive local calibration;
- it uses an easily available data input as the average monthly temperature which is also the standard parameter in the FAOCLIM database.

The Penman-Monteith method has not been adopted for the lack of critical information and database such as the air temperature, humidity, radiation and wind speed, which are already difficult to define for small area and definitely impossible to collect for an area as wide as the Mediterranean. The Hargreaves method has been dismissed mainly for the lack of specific data as the maximum and minimum temperature.

5.1 – The Thornthwaite method

The Thornthwaite method estimates the potential evapotranspiration only based on average monthly temperature data. This is like assuming that the air temperature represents the integrated effects of radiation, wind, humidity, vegetation, soil, etc. The basic equations are:

$EP_0 = 16 \times c \times (T \times 10/I)^a$; (5.1)

$a = 0.49239 + 1.792\ E\text{-}2 \times I + 7.711\ E\text{-}5 \times I^2 + 6.75\ E\text{-}7 \times I^3$ (5.2)

$c = h_{light} / 12$ (5.3)

$I = \sum_{I=1,12} (T_i / 5)^{1.514}$ (5.4)

Where:
EP_0 = Monthly average evapotranspiration (in mm);
T = mean air temperature of the *i*-th month (°C);
I = annual heat index;
a = Thornthwaite correction factor;
c = correction factor for monthly sunshine duration;
h_{light} = average hours of day light for month.

For temperature values equal or lower than zero degree centigrade a standard value of zero is assumed.

Temperature-based methods were developed in the mid-latitude continental region (i.e. mid-western USA) as a climatic index, not as a method for calculating ET. Outside such region, the methods may result in significant errors.

5.2. Other methods

5.2.1. Penman-Monteith method

The Penman-Monteith method calculates the evapotraspiration throughout an equation that combines the energy balance with the mass transfer method from an open water surface from standard climatological records of sunshine, temperature, humidity and wind speed and extending it to cropped surfaces by introducing resistance factors.
The resistance nomenclature distinguishes between aerodynamic resistance and surface resistance factors. The surface resistance parameters are often combined into one parameter, the 'bulk' surface resistance parameter which operates in series with the aerodynamic resistance. The surface resistance, r_s, describes the resistance of vapour flow through stomata openings, total leaf area and soil surface. The aerodynamic resistance, r_a, describes the resistance from the vegetation upward and involves friction from air flowing over vegetative surfaces. Although the exchange process in a vegetation layer is too complex to be fully described by the two resistance factors, good correlations can be obtained between measured and calculated evapotranspiration rates, especially for a uniform grass reference surface.

From the original Penman-Monteith equation the FAO Penman-Monteith method to estimate ET_0 is:

$$ET_o = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T+273} u_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34 u_2)} \qquad (5.5)$$

where:
ET_o reference evapotranspiration [mm day^{-1}],
R_n net radiation at the crop surface [MJ m^{-2} day^{-1}],
G soil heat flux density [MJ m^{-2} day^{-1}],
T air temperature at 2 m height [°C],
u_2 wind speed at 2 m height [m s^{-1}],
e_s saturation vapour pressure [kPa],
e_a actual vapour pressure [kPa],
e_s - e_a saturation vapour pressure deficit [kPa],
Δ slope vapour pressure curve [kPa $°C^{-1}$],
γ psychrometric constant [kPa $°C^{-1}$].

Most of the parameters are measured or can be readily calculated from weather data.

5.2.2. Hargreaves method

The Hargreaves method calculates the reference evapotranspiration based on a simple temperature dependent equation:

$$ET_o = 0.0023(T_{mean} + 17.8)(T_{max} - T_{min})^{0.5} R_a \qquad (5.6)$$

Where:
R_a extraterrestrial radiation [MJ m^{-2} d^{-1}] which is the solar radiation received at the top of the earth's atmosphere on a horizontal surface,
T_{max} maximum air temperature [°C],
T_{min} minimum air temperature [°C],

This method has been adopted by “FAO IRRIGATION AND DRAINAGE PAPER 56” in case of lack of meteorological data..

The equation (5.23) has a tendency to under-predict the ET_o under high wind conditions (u_2 > 3 m/s) and to over-predict it under conditions of high relative humidity.

5.3. Evapotranspiration Calculations and raster creation

The calculation of the mean monthly evapotranspiration values of our 30 year series has been made, adopting the Thornthwaite method, using the twelve mean monthly temperature raster files obtained as described in chapter 3.

The initial step has been to calculate the average hours of day light during each month in way to assess the correction factor for monthly sunshine duration (a). This operation has been made for each 30 second degree cell of the study area using a Perl software script, sun_lut.pl (see Annex 1): the data input are the latitude raster file (latdismed.rst) as defined in chapter 1, and the Julian day number identifying the representative day of each month in terms of numbers of hours of day light. It has to be noticed that this assumption could underestimate the number of hours of day light in December and overestimate it in June but the error produced is practically irrelevant. The output are 12 raster files (formed by 4530 rows and 7630 columns) with number of hours per day for each month of the year (from sun_lat_01.rst to sun_lat_12.rst).

Then the final task step is to calculate the evapo-transpiration for each 30 second degree cell of the Mediterranean area for each month of the year using a Perl Software script, etp2.pl (see Annex 1), throughout the following steps:

- Importing of the twelve mean monthly temperature raster files (from temp_01.rst to temp_12.rst);
- Importing of the raster file for hours of day light of the month for which the ET is calculated (for example December ⬇ sun_lat_12.rst);
- Calculation of the annual heat index, I, as described in equation 5.4;
- Calculation of the Thornthwaite correction factor, a, as described in equation 5.2;
- Calculation of the correction factor for monthly sunshine duration, c, as described in equation 5.3;
- Calculation of the Thornthwaite evapotranspiration, EP_0, as described in equation 5.1;
- Outputing of a evapotranspiration raster file (for example etp_12.rst for December).

This procedure has been run for each month of the years obtaining 12 raster files (formed by 4530 rows and 7630 columns) with evapotranspiration data for each month of the year (from etp_01.rst to etp_12.rst).

5.5 – Correction factors for the Thornthwaite method

The Thornthwaite method is known to underestimate the potential evapotranspiration in comparison to other evapotranspiration methods (Santo, Bugalho, "Climatic variability and desertification risk in Portugal" European Commission, 1996. Mediterranean Desertification Research results and policy implications, Proceedings Vol.2, EUR 19303).

Also the Thornthwaite method is known to systematically underestimate PET in more arid regions and seasons (Deichmann, U. and L. Eklundh 1991, Global digital datasets for land degradation studies: A GIS approach, GRID Case Study Series No. 4, Global Resource Information Database, United Nations Environment Programme, Nairobi).

The methods based upon air temperature work best in the regions for which they were developed, namely, mid-latitude continental climates, where air temperature is a fairly good index of net radiation. In the tropics, however, these methods often give erroneous results, and may seriously underestimate the amplitude of seasonal fluctuations of water demand.

The use of the empirical Thornthwaite formula outside of climatic regions for which they were developed often result in errors (Riquier J., Formules d'Évapotranspiration, I.R.S.M. Tananarive). When used for such purposes, the empirical methods should be checked against direct measurements or energy-balance methods. Therefore a further step would be to identify a possible correlation between the Thornthwaite method and the Penman-Monteith method. This could be done based on the following steps:

- Acquisition of meteorological data for various station within a country;
- Calculation, for each station,of the Thornthwaite evapotranspiration ET_0 value;
- Calculation, for each station, of the Penman-Monteith evapotranspiration ET_0 value;
- Definition of a relationship between the two sets of evapotranspiration values in way to obtain an empirical correlation (for example a linear regression).
- Adoption of an evapotranspiration method as standard (Penman-Monteith or Thornthwaite);
- Review of the evapotranspiration value.

Figure 5.1 shows the mean yearly evapotranspiration values of the reference 30 years 1961-1990 period for the Mediterranean area.

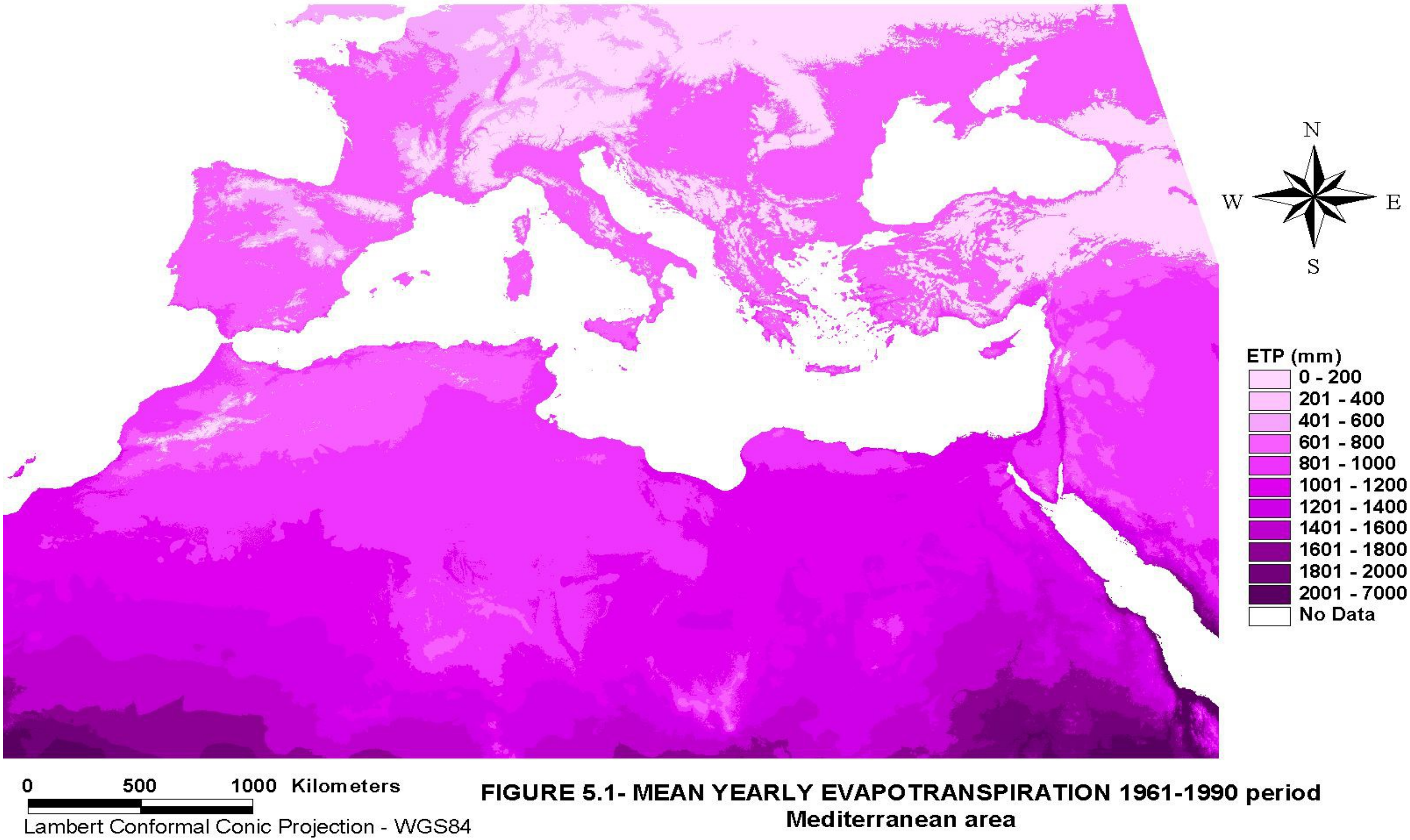

FIGURE 5.1- MEAN YEARLY EVAPOTRANSPIRATION 1961-1990 period
Mediterranean area

6 – Desertification: The Climate factor

6.1. Introduction

The threat posed by desertification to human welfare is internationally recognized and was the stimulus behind agreement of the International Convention to Combat Desertification in 1992. UNEP define desertification as "land degradation in arid, semi-arid and dry sub-humid areas resulting from various factors, including climatic variations and human activities" (ICCD, 1994).

Desertification can be estimated assuming a series of indicators which are able to give a synthetic image of the degree of degradation of a certain area and which can help defining the environmental policy and assimilate the environmental aspects in a wider political social and economical frame.

The indicator, we are looking for, should be capable of giving us a synthetic image of the state of desertification but also should be proficient in monitoring continuously the desertification process over the time at regular, or fixed, intervals. Others are the requirement for a reliable indicator*:* desirably quantitative, sufficiently sensitive to provide an early warning of change, distributed over a broad geographical area (widely applicable), relatively independent of sample size, easy and cost-effective to measure, collect, assay, and/or calculate, able to assess the present status, able to assess the trend, able to differentiate between natural cycles or trends and those induced by anthropogenic stress, relevant to ecologically significant phenomena.

The objective of the DISMED cartography was defined by Djerba Workshop (March 2002) as follows:
“The representation of actual status and dynamics of desertification and drought as related to bio-physics and socio-economic systems”.

In particular DISMED Djerba workshop, taking into account the shortage of homogeneous data over the all region, agreed on the utilization of simplified models of the desertification process mainly based on the combination of the synthesis parameters relevant to:

- Soil;
- Vegetation;
- Climate;
- management of the territory and of its resources.

The main objective of the DISMED cartography is to highlight the land sensibility to desertification based on climatic factors. This mean that we are not trying to shown desert zones “as intended in the popular way” but zones which are more sensible to be interested by a desertification process.
Those, taking into account the other parameters (soil, vegetation, human management), can be then classified as area with lower or higher degree of degradation.

The DISMED Tamanrasset workshop agreed that the basic climate indicator for the cartography of climatic sensitivity to desertification had to be the Aridity Index as defined by the UNEP (United Nation Environmental Program).

6.2. Climate indicators for Desertification: an overview

6.2.1. UNEP aridity index

This aridity index has been proposed by the UNCCD to identify arid, semi-arid, dry sub-humid areas, potentially at risk of desertification, as specified by ANPA – Enne & Zucca (2000) (Desertification indicators for the European Mediterranean Region – Stat of the art and possible methodological approaches, Ed. ANPA, Roma). It provides a measure of the average water available for plants and the relation between mean annual precipitations and mean annual evapotranspiration calculated with the Penman equation. Based on the above ratio (P/ETP) five classes have been determined by the UNEP: hyper arid (< 0.05), arid (0.05-0.2), semiarid (0.2-0.5), sub-humid (0.5-0.65) and humid (>0.65).

6.2.2. DISMED aridity index

The DISMED aridity index calculation has been developed by the FMA (in cooperation with the Institute of Biometeorology of the Italian National Research Council - IBIMET) and is fairly similar to the on discussed in paragraph 6.2.1. The main difference has been the method to determine the evapotranspiration term; as specified in chapter 5 the evapotranspiration has been calculated using the Thornthwaite equation instead of the Penman equation. So the aridity index equation is:

$$Ai = (\sum_{i=1,n} P_i+10)/ (\sum_{i=1,n} ETP_i+10) \quad (6.1)$$

Where:
P_i = mean monthly rainfall event (mm);
ETP_i = mean monthly evapotranspiration (mm);

A standard value of 10 has been added to the nominator and the denominator of the equation to calculate the aridity index; this has been done to avoid an undetermined value of the aridity index when the evapotranspiration (denominator) is equal to zero. For the Thornthwaite method the evapotranspiration is null when the temperature is zero or below.

Based on the above ratio, five classes were determined: hyper arid (< 0.1), arid (0.1-0.4), semiarid (0.4-0.7), sub-humid (0.7-1.1) and humid (>1.1). The reasons of this new classification is described in the next paragraphs.

The criteria to define the DISMED aridity index classification, as previously stated, are:

- the aridity index values are higher if calculated using the Thornthwaite method for the evapotranspiration; this is because the ETP is underestimated in particularly hot areas;
- It has been decided to adopt a classification which could properly describe the desertification process all over the wide region of interest; using the UNEP classification the desertification distribution over the European Countries would have been completely flat.

6.2.3. Bagnouls-Gaussen aridity index

The Bagnoouls-Gaussen aridity index is defined according to the formula:

$$BG= \sum_{i=1,n} (2ti - Pi)\, k \quad (6.2)$$

Where:

ti = the average air temperature during month i (°C)
Pi = the total monthly rainfall (mm);
k = the percentage of months in which 2ti –Pi>0.

An example of application of this index has been made during the ESA project (Kosmas et al., 1999) where 6 classes of aridity have been identified (<50,50-75,75-100,100-125,125-150,>150).

6.3. Aridity index Calculations and Aridity index map

The average yearly aridity index for our 30 year series (‘61-‘90) has been calculated applying the equation 6.2 to the twelve mean monthly rainfall raster files (from pio_01.rst to pio_12.rst) and the mean monthly Thornthwaite evapotranspiration (from etp_01.rst to etp_12.rst) throughout a Perl Software script (i_drov3.pl - see Annex 1). The script file operates directly with the raster files and therefore gives a raster output file (readable with IDRISI32) named I_DROU.rst where at each cell, with a resolution value of 30-arc seconds (approx. 1 km resolution), is assigned a average yearly aridity index (‘61-’90).

Tab 6.1 – DISMED Aridity Index classes

	DISMED
hyper arid	<0.1
Arid	0.1 - 0.4
semi-arid	0.4 - 0.7
sub-humid	0.7 - 1.1
Humid	>1.1

The main reason for using the DISMED classification, instead of the UNEP classification, has been the nature of data available (only temperature data) which only allowed to calculate the aridity index throughout the ET_0 with the Thornthwaite method.

Figure 6.1 shows the mean yearly aridity index values of the reference 30 years 1961-1990 period for the Mediterranean area (aridity index presented in 5 classifications).

In Annex 2 the cartography of the Sensitivity to Desertification Structural Analysis 1961-1990 - Aridity Index for each of the following countries of the Mediterranean area is shown: Algeria, Egypt, France, Greece, Italy, Libya, Morocco, Portugal, Spain, Tunisia, Turkey.

6.3. Aridity index for the Mediterranean Countries

A more detailed analysis of the desertification process in the Mediterranean can be obtained calculating the land surface included in each AI class (arid, semi-arid, etc.) for each country. The following two tables, 6.2 and 6.3, show the land surface (in percentage) held in each aridity class for all Mediterranean countries involved in the DISMED project, using respectively the DISMED and the UNEP Aridity Index classification.

Tab 6.2 - DISMED Aridity Index classification %

	Hyper arid	**Arid**	**Semi Arid**	**Sub-Humid**	**Humid**
	<0.1	**0.1 - 0.4**	**0.4 - 0.7**	**0.7 - 1.1**	**>1.1**
Algeria	64.07	22.17	7.69	5.89	0.18
Egypt	72.95	27.04	0.00	0.00	0.01
France	0.00	0.00	0.00	0.40	99.60
Greece	0.00	0.00	0.32	56.30	43.38
Italy	0.00	0.00	0.14	17.91	81.95
Libya	67.39	29.47	3.05	0.09	0.00
Morocco	0.00	21.03	45.46	29.33	4.17
Portugal	0.00	0.00	0.00	28.65	71.35
Spain	0.00	0.58	3.94	60.67	34.81
Tunisia	0.31	53.17	24.81	21.37	0.36
Turkey	0.00	0.00	3.75	28.34	67.91

Tab 6.2 - UNEP Aridity Index classification %

	Hyper arid	**Arid**	**Semi Arid**	**Sub-Humid**	**Humid**
	<0.05	**0.05 - 0.2**	**0.2 - 0.5**	**0.5 - 0.65**	**>0.65**
Algeria	39.57	39.69	9.20	6.06	5.48
Egypt	34.52	61.31	4.17	0.00	0.01
France	0.00	0.00	0.00	0.00	100.00
Greece	0.00	0.00	0.00	0.77	99.23
Italy	0.00	0.00	0.00	0.21	99.79
Libya	54.52	30.84	13.55	1.03	0.06
Morocco	0.00	8.11	25.22	36.13	30.54
Portugal	0.00	0.00	0.00	0.00	100.00
Spain	0.00	0.00	0.70	4.75	94.55
Tunisia	0.00	12.60	51.54	16.77	19.09
Turkey	0.00	0.00	0.00	4.72	95.28

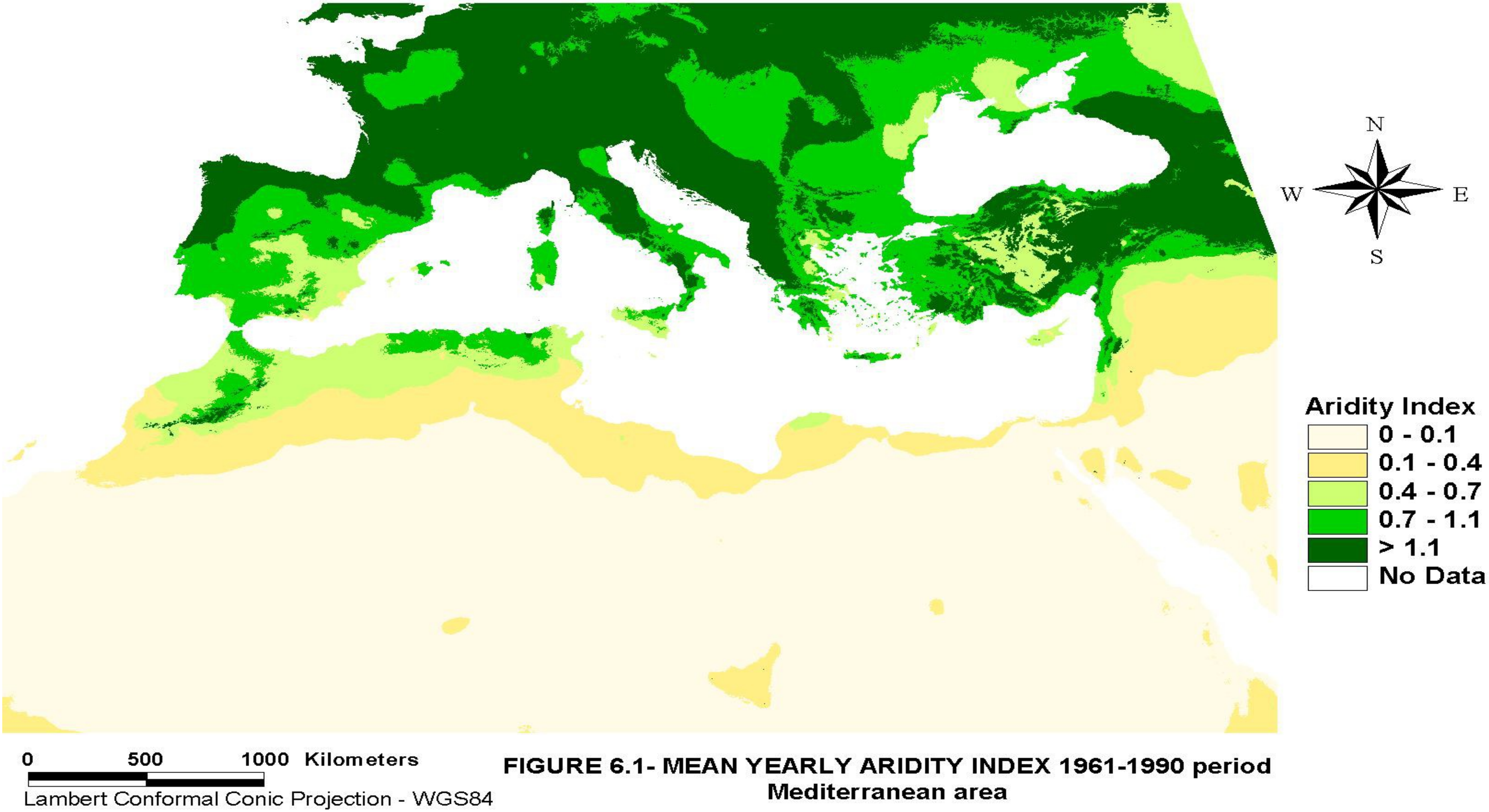

FIGURE 6.1- MEAN YEARLY ARIDITY INDEX 1961-1990 period
Mediterranean area

7 - Conclusions

It has to be underlined that this document has to be considered as a "process approach", a methodology, to identify the sensitivity to desertification for the Mediterranean area. In other words more than to achieve a final cartography on desertification, the main target has been defining a standard procedure which can be run each time new dataset from the partner countries are received. Therefore the cartography, produced up to now, has to be considered a sort of "work in progress". So once the procedure has been validated either from a theoretical than a practical point of view, the effort of all country partners, in supplying the relevant information, is fundamental to achieve a reliable final cartography of the desertification process.

Anyway a first study of the final cartography of "the Sensitivity to Desertification Structural Analysis 1961-1990 - Aridity Index" for the Mediterranean region has been attempted and the main conclusions are:

- Italy presents few zones with high sensitivity to desertification as the Southern areas of Sicily and Sardinia and other areas with lower sensitivity as the Puglia and Basilicata regions and the borderline area between Lazio and Tuscany.

- Spain presents few zones with high sensitivity to desertification as the Andalusia, the Murcia and the Comunidad Valenciana regions.

- In Spain also the region presents an area sensitive to desertification below the Pyrenees mountains; this could be an anomaly due to the lack of climatic information. Further research should be done in this area.

- Greece presents few zones with high sensitivity to the desertification process as the Macedonia central/ Tessalya regions and the Attica area.

- The Creta situation has to be high lighted because the island presents higher values of the aridity index compared to areas with similar latitude (Cyprus, Sicily, Tunisia, etc.). This is due to the higher amount of precipitation.

- The north west areas of Algeria present lower values of the aridity index compared to the border countries such as Tunisia and Marocco. This could be an underestimation of the methodology due to the lack of climatic information (only few stations) for this region.

- Portugal presents a zone with medium sensitivity to the desertification process as Algarve/Planicies (as confirmed by the Portugal authorities).

- Turkey presents few zones with high sensitivity to desertification as the Cappadocia and the Central Anatolia.

- The island of Cyprus is characterised by an high sensitivity to desertification.

- In Egypt the Nile river valley is not highlighted being the aridity index only a climatic water balance.

Once the structural analysis of the climatic index will be achieved for the reference 30 years 1961-1990 period with all the databases from the country partners then the standard procedure will be applied to the period 1991- 2000 (current analysis). The further steps will be undertaken in assessing the desertification trend, in terms of aridity index, comparing the two historical series.

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ANNEX 1 – Software scripts

imlat.pl

```
($file,$rig,$col,$maxlat,$res)=@ARGV;

print STDOUT "$rig\t$col\n";
print STDOUT "\t$minlat\n";
print STDOUT "\t$minlon\n";

open(lat,">$file") or die "Non apre file !!";
binmode(lat);
$val=$maxlat;

for($i=0;$i<$rig;$i++)
    {
        for($j=0;$j<$col;$j++)
        {$valbin=pack('f',$val);
        print lat "$valbin";
      }
    $val=$val-$res;
    }
```

imlong.pl

```
($file,$rig,$col,$minlon,$res)=@ARGV;

print STDOUT "\t$rig\t$col\n";

print STDOUT "\t$minlon\n";

open(lon,">$file") or die "Non apre file !!";

binmode(lon);
$val=$minlon;

for($i=0;$i<$rig;$i++)
    {
        for($j=0;$j<$col;$j++)
        { $val=$val+$res;
         $valbin=pack('f',"$val");
         print lon $valbin;
       }
    $val=$minlon;
    }
```

mregress.m

```
function [Coefficients, S_err, XTXI, R_sq, F_val, Coef_stats, Y_hat, residuals,
covariance] ...
        = mregress(Y, X, INTCPT)
% MREGRESS  Performs multiple linear regression analysis of X (independent) on Y
(dependent).
%  Usage:
% [Coefficients, S_err, XTXI, R_sq, F_val, Coef_stats, Y_hat, residuals, covariance]
%                                              = mregress(Y, X, INTCPT)
%      INTCPT = 1; include a y-intercept in the model
%        INTCPT = 0; DO NOT include a y-intercept in the model
%        Returns:
%   Coefficients  - Regression coefficients
%   S_err          - Standard error of estimate
%   XTXI           - inverse of X' * X
%   R_sq           - R-squared
%   F_val         - F-value for the regression and siginificance level (p-value for F)
%  Coef_stats     - Coefficients with their standard deviations, T-values, and p-values
%         Y_hat              - Fitted values
%         residuals           - Residuals
%      covariance          - Covariance matrix ( XTXI * S_err^2 )
% G. Anthony Reina
% Motor Control Lab
% The Neurosciences Institute
% Created: 4 Aug 1998
% Last Update: 10/8/1998 by GAR
% Please note that for the case when the intercept of the model equals zero, the
% definition of R-squared and the F-statistic change mathematically. For a linear
% model containing the y-intercept, R-squared refers to the amount of variance
around% the mean of the dependent variable (y) which is explained by the variance
around the mean of the independent variables (x). For a linear model NOT containing
the% y-intercept, R-squared measures the amount of variance around ZERO of the
dependent
% variable which is explained by the variance around ZERO of the independent
variable.
% If the same equation for R-squared is used for both with and without a y-intercept
% (namely R-squared = [Sum of Squares of the Regression] / [ Total sum of the
squares]),
% then R-squared may be a NEGATIVE value for some data. For this reason,
% this subroutine will calculate R-squared using the total un-corrected sum of the
% squares. In effect, this approach avoids negative R-squares but may lack any
% meaningful interpretation for the "goodness-of-fit" in the model. It has been
% suggested by some texts that a more useful approach is to always use the case
% where y-intercept is included in the model. However, as with all statistical
% analyses, it is prudent to simply be aware of what your data "looks" like and
% what your statistical tools are actually measuring in order to generate a useful
% analysis.
% For further reading on regression through the origin (i.e. without a y-intercept),
% please refer to:
%    Neter J, Kutner MH, Nachtsheim CJ, and Wasserman W. "Applied Linear
%           Statistical Models" 4th ed. Irwin publishing (Boston, 1996), pp 159-163.
%    Myers R, "Classical and Modern Regression with Applications" Duxbury Press
%           (Boston, 1986), p. 30.
```

regre_lin.pl

```
($fileout,$c1,$file1,$m1,$file2,$m2,$file3,$m3,$file4,$m4)=@ARGV;

# messaggi a video
print STDOUT "Elaboro i file: ";
print STDOUT "$file1\t$file2\t$file3\t$file4\n";
print STDOUT "il file di output e ";
print STDOUT "$fileout";
# apro in lettura i 4 file
########################################################################
open(file1,"<$file1") or  "Non apre $file1 !!";
open(file2,"<$file2") or  "Non apre $file2 !!";
open(file3,"<$file3") or  "Non apre $file3 !!";
open(file4,"<$file4") or  "Non apre $file4 !!";
binmode(file1);
binmode(file2);
binmode(file3);
binmode(file4);
########################################################################
open(fileout,">$fileout") or  "Non apre $fileout !!";
binmode(fileout);
########################################################################
  while (!eof(file1)){
                    read(file1, $data_file1, 4);
                $val_data_file1=unpack('f',$data_file1);
                    read(file2, $data_file2, 4);
                $val_data_file2=unpack('f',$data_file2);
                    read(file3, $data_file3, 4);
                $val_data_file3=unpack('f',$data_file3);
                    read(file4, $data_file4, 4);
                $val_data_file4=unpack('f',$data_file4);
$datares=$val_data_file1*$m1+$val_data_file2*$m2+$val_data_file3*$m3+
$val_data_file4*$m4+$c1;
                  $valbin=pack('f',$datares);
                  print fileout $valbin;
               }
########################################################################
```

sun_lat.pl

```
($file_sun_lat,$file_lat,$julianday)=@ARGV;

open(sun_lat,">$file_sun_lat") or die "Non apre file !!";
open(file_lat,"<$file_lat") or die "Non apre file !!";

binmode(sun_lat);
binmode(file_lat);

while (!eof(file_lat))
     {
       read(file_lat, $latbin,4);
       $lat=unpack('f',$latbin);
       $val=&durataday($julianday,$lat);
       $valbin=pack('f',$val);
       print sun_lat "$valbin";
       undef $latbin;
      }
######################################################################
sub durataday {
             my ($jday, $lat_sub) = @_;
             my $pi=3.14159265;
             my $adelt,$tem1,$tem2,$ahou, $ahdy;
             $lat_sub=$lat_sub*($pi/180);
             $adelt=0.4014*sin((2*$pi)*($julianday-77)/365);
             $tem1=1-((-&tang($lat_sub)*($adelt))**2);
             $tem1=sqrt($tem1);
             $tem2=(-&tang($lat_sub)*&tang($adelt));
             $ahou=atan2($tem1,$tem2);
             $ahdy=($ahou/$pi)*24;
             return $ahdy;
            }
######################################################################
sub tang {
         my $val = shift(@_);
         my $tang;
         $tang=sin($val)/cos($val);
         return $tang;
        }
```

etp2.pl

```
($file_out,
$file_temp1,$file_temp2,$file_temp3,$file_temp4,$file_temp5,$file_temp6,$file_temp
7,$file_temp8,$file_temp9,$file_temp10,$file_temp11,$file_temp12,$file_h_sun)=@A
RGV;
#
open(file_out,">$file_out") or die "Non apre file !!";
open(file_temp1,"<$file_temp1") or die "Non apre file !!";
open(file_temp2,"<$file_temp2") or die "Non apre file !!";
open(file_temp3,"<$file_temp3") or die "Non apre file !!";
open(file_temp4,"<$file_temp4") or die "Non apre file !!";
open(file_temp5,"<$file_temp5") or die "Non apre file !!";
open(file_temp6,"<$file_temp6") or die "Non apre file !!";
open(file_temp7,"<$file_temp7") or die "Non apre file !!";
open(file_temp8,"<$file_temp8") or die "Non apre file !!";
open(file_temp9,"<$file_temp9") or die "Non apre file !!";
open(file_temp10,"<$file_temp10") or die "Non apre file !!";
open(file_temp11,"<$file_temp11") or die "Non apre file !!";
open(file_temp12,"<$file_temp12") or die "Non apre file !!";
open(file_h_sun,"<$file_h_sun") or die "Non apre file !!";
#
binmode(file_out);
binmode(file_temp1);
binmode(file_temp2);
binmode(file_temp3);
binmode(file_temp4);
binmode(file_temp5);
binmode(file_temp6);
binmode(file_temp7);
binmode(file_temp8);
binmode(file_temp9);
binmode(file_temp10);
binmode(file_temp11);
binmode(file_temp12);
binmode(file_h_sun);#

#ATTENZIONE IL CICLIO è FATTO SUL FILE TEMP1, QUINDI è DI QUESTO CHE
SI OTTIENE L'ETP; PASSARE BENE I PARAMETRI!!!
while (!eof(file_temp1))
                {
#lettura dei valori di temperatura
                read(file_temp1, $val_temp1_bin,4);
      $val_temp1=unpack('f',$val_temp1_bin);
                read(file_temp2, $val_temp2_bin,4);
      $val_temp2=unpack('f',$val_temp2_bin);
                read(file_temp3, $val_temp3_bin,4);
      $val_temp3=unpack('f',$val_temp3_bin);
                read(file_temp4, $val_temp4_bin,4);
      $val_temp4=unpack('f',$val_temp4_bin);
                read(file_temp5, $val_temp5_bin,4);
      $val_temp5=unpack('f',$val_temp5_bin);
                read(file_temp6, $val_temp6_bin,4);
      $val_temp6=unpack('f',$val_temp6_bin);
```

```
                read(file_temp7, $val_temp7_bin,4);
        $val_temp7=unpack('f',$val_temp7_bin);
                read(file_temp8, $val_temp8_bin,4);
        $val_temp8=unpack('f',$val_temp8_bin);
                read(file_temp9, $val_temp9_bin,4);
        $val_temp9=unpack('f',$val_temp9_bin);
                read(file_temp10, $val_temp10_bin,4);
        $val_temp10=unpack('f',$val_temp10_bin);
                read(file_temp11, $val_temp11_bin,4);
        $val_temp11=unpack('f',$val_temp11_bin);
                read(file_temp12, $val_temp12_bin,4);
        $val_temp12=unpack('f',$val_temp12_bin);

#calcolo di i_mensile partendo dai dati di temperatura mensili
        $val_i_mens1=($val_temp1/5)**(1.514);
        $val_i_mens2=($val_temp2/5)**(1.514);
        $val_i_mens3=($val_temp3/5)**(1.514);
        $val_i_mens4=($val_temp4/5)**(1.514);
        $val_i_mens5=($val_temp5/5)**(1.514);
        $val_i_mens6=($val_temp6/5)**(1.514);
        $val_i_mens7=($val_temp7/5)**(1.514);
        $val_i_mens8=($val_temp8/5)**(1.514);
        $val_i_mens9=($val_temp9/5)**(1.514);
        $val_i_mens10=($val_temp10/5)**(1.514);
        $val_i_mens11=($val_temp11/5)**(1.514);
        $val_i_mens12=($val_temp12/5)**(1.514);

#calcolo di i_annuo partendo dai dati di temperatura mensili
$val_i_annuo=$val_i_mens1+$val_i_mens2+$val_i_mens3+$val_i_mens4+
$val_i_mens5+$val_i_mens6+$val_i_mens7+$val_i_mens8+$val_i_mens9+
$val_i_mens10+$val_i_mens11+$val_i_mens12;
#calcolo del fattore a di thornthwaite partendo da i_annuo
                $val_a_tor=(6.75*0.0000001)*($val_i_annuo**3)-
(7.711*0.00001)*($val_i_annuo**2)+(1.792*0.01)*$val_i_annuo+0.49239;

#lettura del valore h_sun (ore di illuminazione)
                read(file_h_sun, $val_h_sun_bin,4);
        $val_h_sun=unpack('f',$val_h_sun_bin);
#calcolo del fattore di correzione partendo da h_sun
                $val_corr=$val_h_sun/12;
#calcolo etp di thornthwaite
                $val=(16*(($val_temp1*10/$val_i_annuo)**$val_a_tor))*$val_corr;
#               compio un'operazione matemat.; se il risultato non cambia significa
che $val non è un numero
                $val_new=$val+$val;
                if ($val_new == $val) {
                #$val non è un numero
                                $val=0;
                } else {
                #nessuna operazione $val va bene
                                }
#scrittura su file di output
                $valbin=pack('f',$val);
        print file_out "$valbin";
                }
```

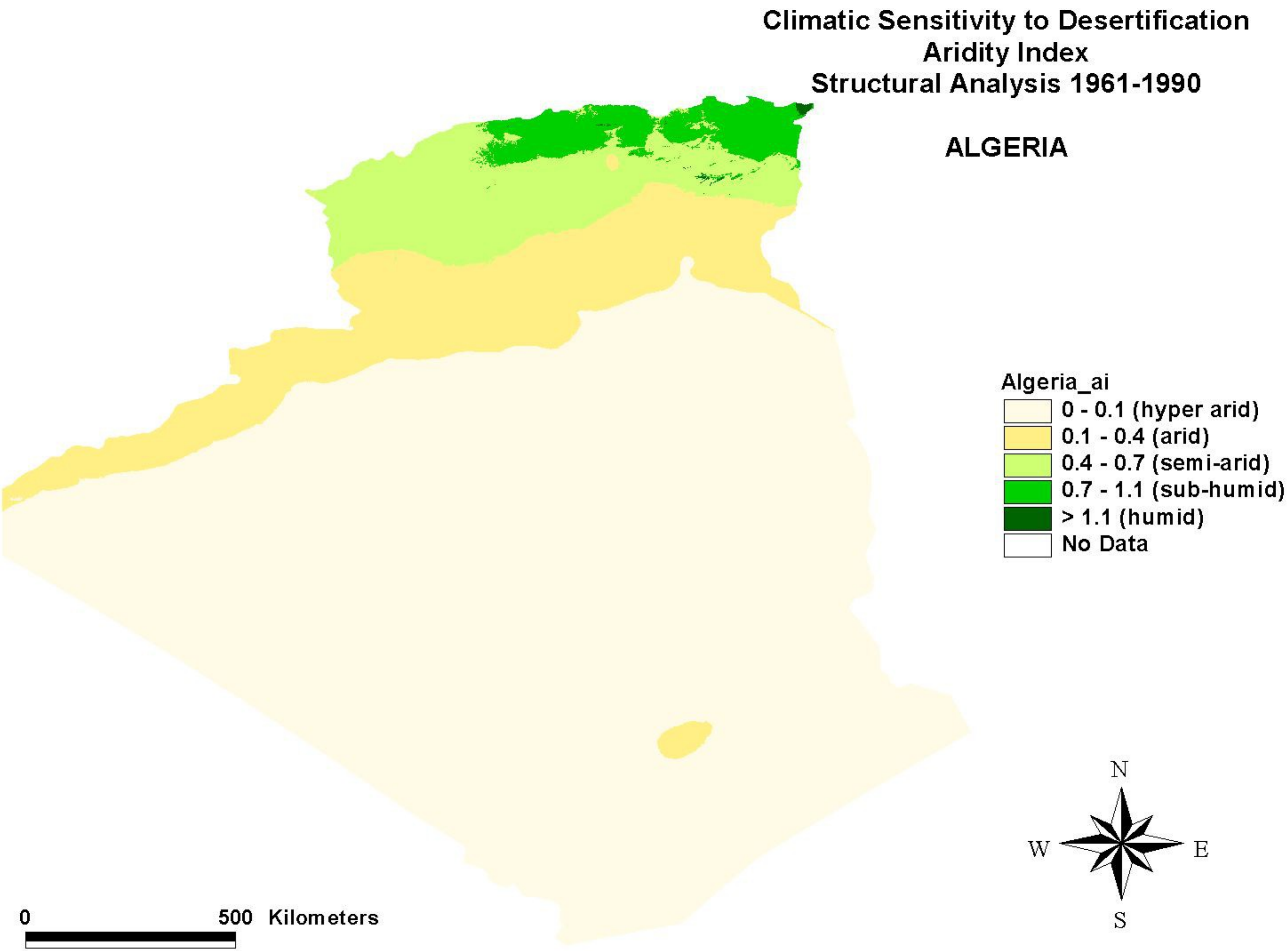
i_drov3.pl

```
($file_out,
$file_pio_01,$file_pio_02,$file_pio_03,$file_pio_04,$file_pio_05,$file_pio_06,$file_pio
_07,$file_pio_08,$file_pio_09,$file_pio_10,$file_pio_11,$file_pio_12,$file_etp_01,$fil
e_etp_02,$file_etp_03,$file_etp_04,$file_etp_05,$file_etp_06,$file_etp_07,$file_etp_
08,$file_etp_09,$file_etp_10,$file_etp_11,$file_etp_12)=@ARGV;
#
open(file_out,">$file_out") or die "Non apre file !!";
#
open(file_pio_01,"<$file_pio_01") or die "Non apre file !!";
open(file_pio_02,"<$file_pio_02") or die "Non apre file !!";
open(file_pio_03,"<$file_pio_03") or die "Non apre file !!";
open(file_pio_04,"<$file_pio_04") or die "Non apre file !!";
open(file_pio_05,"<$file_pio_05") or die "Non apre file !!";
open(file_pio_06,"<$file_pio_06") or die "Non apre file !!";
open(file_pio_07,"<$file_pio_07") or die "Non apre file !!";
open(file_pio_08,"<$file_pio_08") or die "Non apre file !!";
open(file_pio_09,"<$file_pio_09") or die "Non apre file !!";
open(file_pio_10,"<$file_pio_10") or die "Non apre file !!";
open(file_pio_11,"<$file_pio_11") or die "Non apre file !!";
open(file_pio_12,"<$file_pio_12") or die "Non apre file !!";
open(file_etp_01,"<$file_etp_01") or die "Non apre file !!";
open(file_etp_02,"<$file_etp_02") or die "Non apre file !!";
open(file_etp_03,"<$file_etp_03") or die "Non apre file !!";
open(file_etp_04,"<$file_etp_04") or die "Non apre file !!";
open(file_etp_05,"<$file_etp_05") or die "Non apre file !!";
open(file_etp_06,"<$file_etp_06") or die "Non apre file !!";
open(file_etp_07,"<$file_etp_07") or die "Non apre file !!";
open(file_etp_08,"<$file_etp_08") or die "Non apre file !!";
open(file_etp_09,"<$file_etp_09") or die "Non apre file !!";
open(file_etp_10,"<$file_etp_10") or die "Non apre file !!";
open(file_etp_11,"<$file_etp_11") or die "Non apre file !!";
open(file_etp_12,"<$file_etp_12") or die "Non apre file !!";
#
binmode(file_out);
binmode(file_pio_01);
binmode(file_pio_02);
binmode(file_pio_03);
binmode(file_pio_04);
binmode(file_pio_05);
binmode(file_pio_06);
binmode(file_pio_07);
binmode(file_pio_08);
binmode(file_pio_09);
binmode(file_pio_10);
binmode(file_pio_11);
binmode(file_pio_12);
binmode(file_etp_01);
binmode(file_etp_02);
binmode(file_etp_03);
binmode(file_etp_04);
binmode(file_etp_05);
```

```
binmode(file_etp_06);
binmode(file_etp_07);
binmode(file_etp_08);
binmode(file_etp_09);
binmode(file_etp_10);
binmode(file_etp_11);
binmode(file_etp_12);
#
$dieci=10;
while (!eof(file_pio_01))
                {
#lettura dei valori di pioggia
                read(file_pio_01, $val_pio_01_bin,4);
    $val_pio_01=unpack('f',$val_pio_01_bin);
                read(file_pio_02, $val_pio_02_bin,4);
    $val_pio_02=unpack('f',$val_pio_02_bin);
                read(file_pio_03, $val_pio_03_bin,4);
    $val_pio_03=unpack('f',$val_pio_03_bin);
                read(file_pio_04, $val_pio_04_bin,4);
    $val_pio_04=unpack('f',$val_pio_04_bin);
                read(file_pio_05, $val_pio_05_bin,4);
    $val_pio_05=unpack('f',$val_pio_05_bin);
                read(file_pio_06, $val_pio_06_bin,4);
    $val_pio_06=unpack('f',$val_pio_06_bin);
                read(file_pio_07, $val_pio_07_bin,4);
    $val_pio_07=unpack('f',$val_pio_07_bin);
                read(file_pio_08, $val_pio_08_bin,4);
    $val_pio_08=unpack('f',$val_pio_08_bin);
                read(file_pio_09, $val_pio_09_bin,4);
    $val_pio_09=unpack('f',$val_pio_09_bin);
                read(file_pio_10, $val_pio_10_bin,4);
    $val_pio_10=unpack('f',$val_pio_10_bin);
                read(file_pio_11, $val_pio_11_bin,4);
    $val_pio_11=unpack('f',$val_pio_11_bin);
                read(file_pio_12, $val_pio_12_bin,4);
    $val_pio_12=unpack('f',$val_pio_12_bin);

#calcolo valore totale di pio
$val_pio_tot=$val_pio_01+$val_pio_02+$val_pio_03+$val_pio_04+$val_pio_05+
$val_pio_06+$val_pio_07+$val_pio_08+$val_pio_09+$val_pio_10+$val_pio_11+
$val_pio_12;

#lettura dei valori di etp
                read(file_etp_01, $val_etp_01_bin,4);
    $val_etp_01=unpack('f',$val_etp_01_bin);
                read(file_etp_02, $val_etp_02_bin,4);
    $val_etp_02=unpack('f',$val_etp_02_bin);
                read(file_etp_03, $val_etp_03_bin,4);
    $val_etp_03=unpack('f',$val_etp_03_bin);
                read(file_etp_04, $val_etp_04_bin,4);
    $val_etp_04=unpack('f',$val_etp_04_bin);
                read(file_etp_05, $val_etp_05_bin,4);
    $val_etp_05=unpack('f',$val_etp_05_bin);
                read(file_etp_06, $val_etp_06_bin,4);
    $val_etp_06=unpack('f',$val_etp_06_bin);
```

```
		read(file_etp_07, $val_etp_07_bin,4);
	$val_etp_07=unpack('f',$val_etp_07_bin);
		read(file_etp_08, $val_etp_08_bin,4);
	$val_etp_08=unpack('f',$val_etp_08_bin);
		read(file_etp_09, $val_etp_09_bin,4);
	$val_etp_09=unpack('f',$val_etp_09_bin);
		read(file_etp_10, $val_etp_10_bin,4);
	$val_etp_10=unpack('f',$val_etp_10_bin);
		read(file_etp_11, $val_etp_11_bin,4);
	$val_etp_11=unpack('f',$val_etp_11_bin);
		read(file_etp_12, $val_etp_12_bin,4);
	$val_etp_12=unpack('f',$val_etp_12_bin);

#calcolo valore totale di etp
$val_etp_tot=$val_etp_01+$val_etp_02+$val_etp_03+$val_etp_04+$val_etp_05+
$val_etp_06+$val_etp_07+$val_etp_08+$val_etp_09+$val_etp_10+$val_etp_11+
$val_etp_12;

#calcolo del valore di aridità
		#if ($val_etp_tot==0) {
		#				$indice++;
		#				print stdout "i pixel a etp zero
sono $indice\n";
		#					}
	  $val=($val_pio_tot+$dieci)/($val_etp_tot+$dieci);

#calcolo indice di aridità
#		if ($val_etp_tot>0) {
#		  $val=$val_pio_tot/$val_etp_tot
#		  } else {
#		  $val=9999
#			}

#scrittura su file di output
		$valbin=pack('f',$val);
	print file_out "$valbin";
		}
```

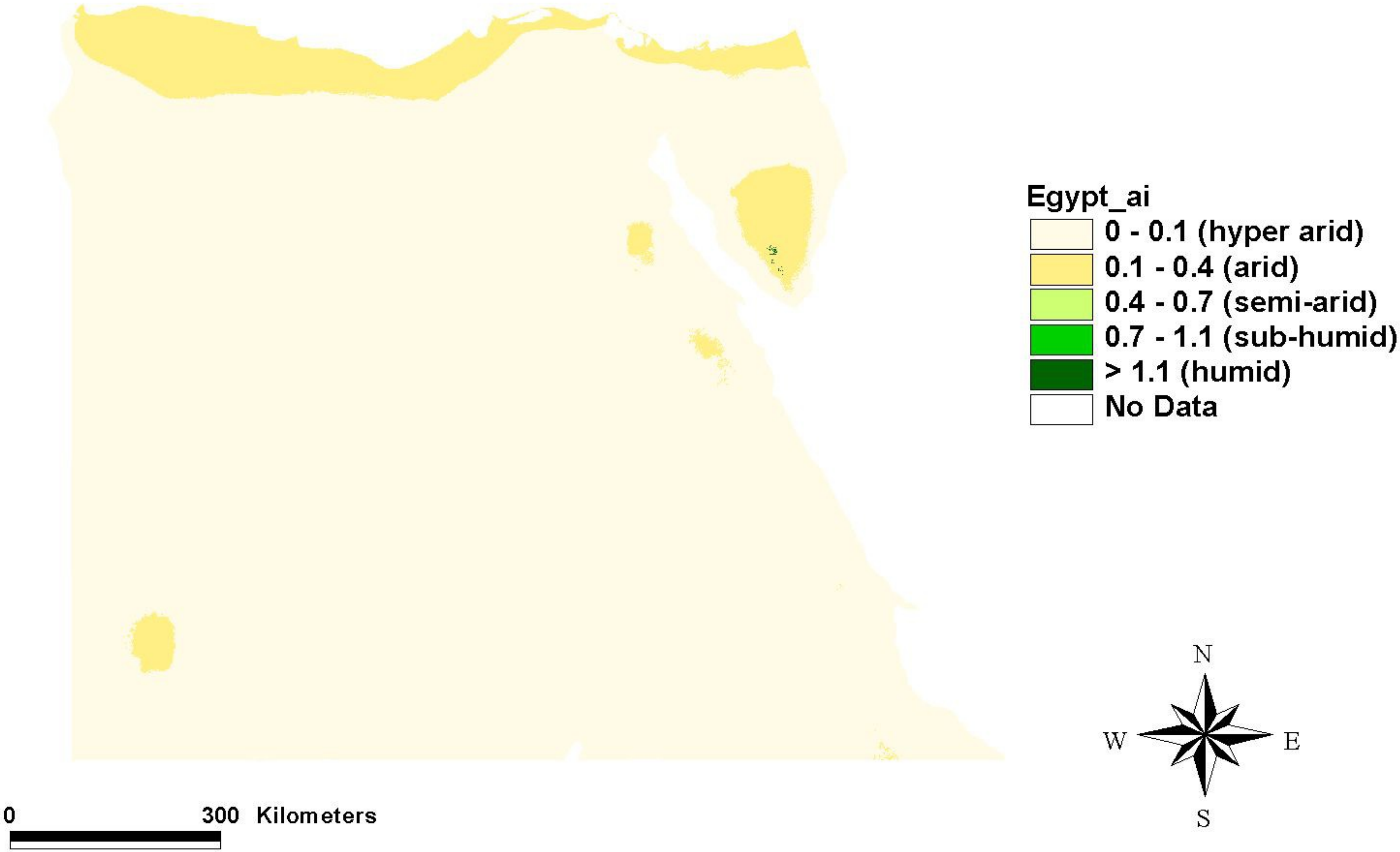
ANNEX 2 - Aridity Index for each country partner

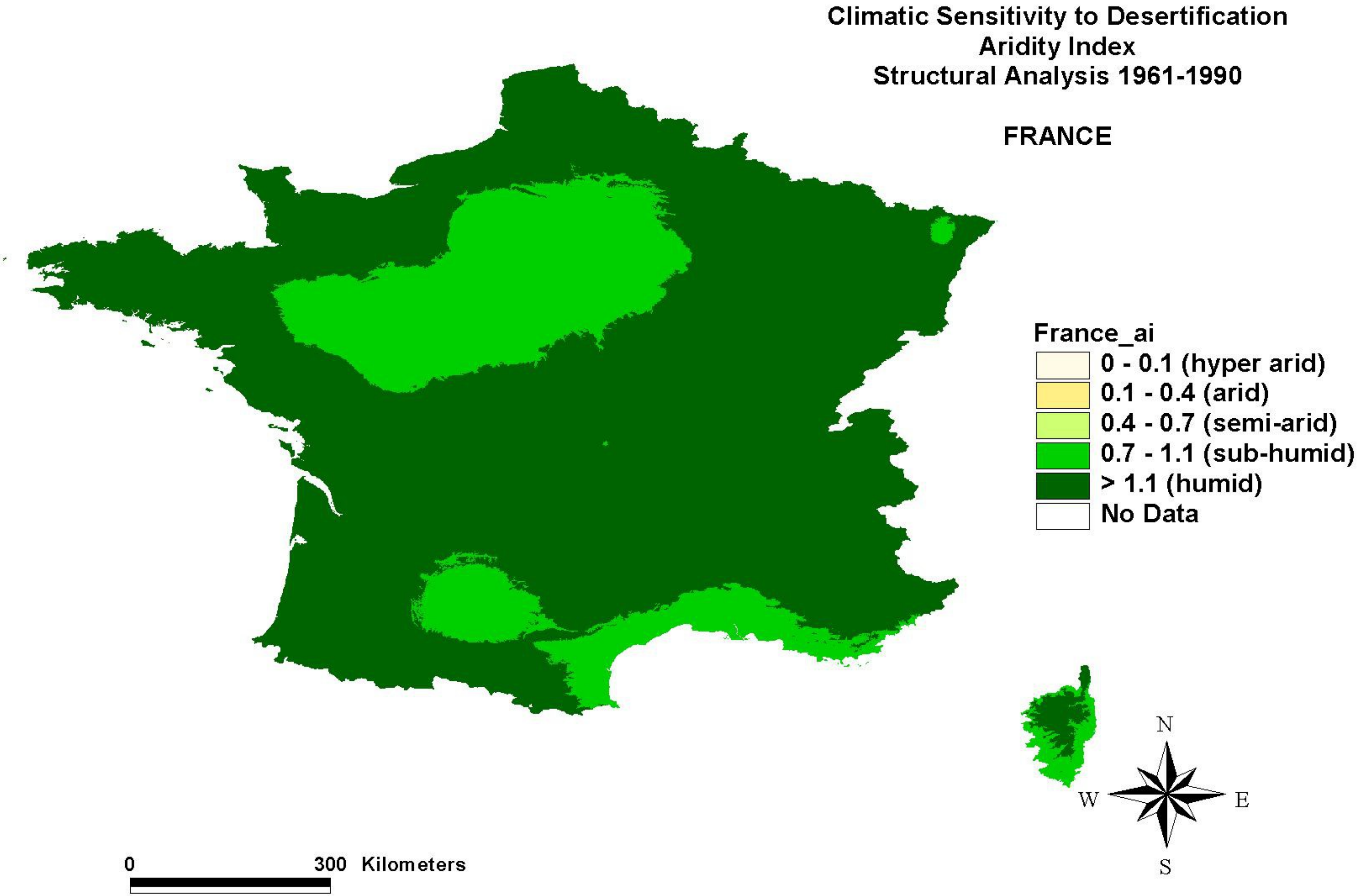


Climatic Sensitivity to Desertification
Aridity Index
Structural Analysis 1961-1990
ALGERIA
Algeria_ai
0 - 0.1 (hyper arid)
0.1 - 0.4 (arid)
0.4 - 0.7 (semi-arid)
0.7 - 1.1 (sub-humid)
> 1.1 (humid)
No Data
N
W
E
S
0
500 Kilometers

Climatic Sensitivity to Desertification
Aridity Index
Structural Analysis 1961-1990

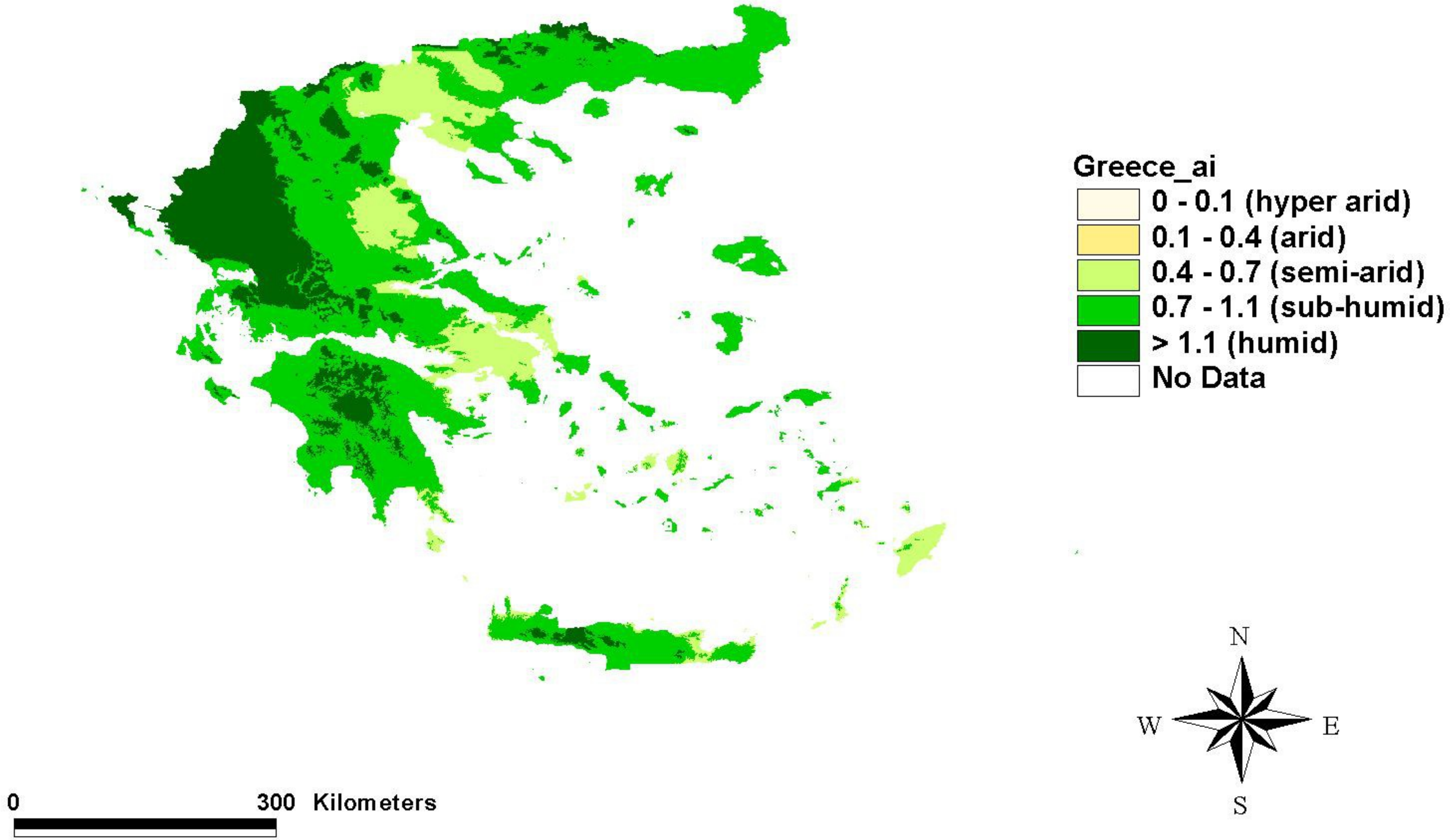
EGYPT

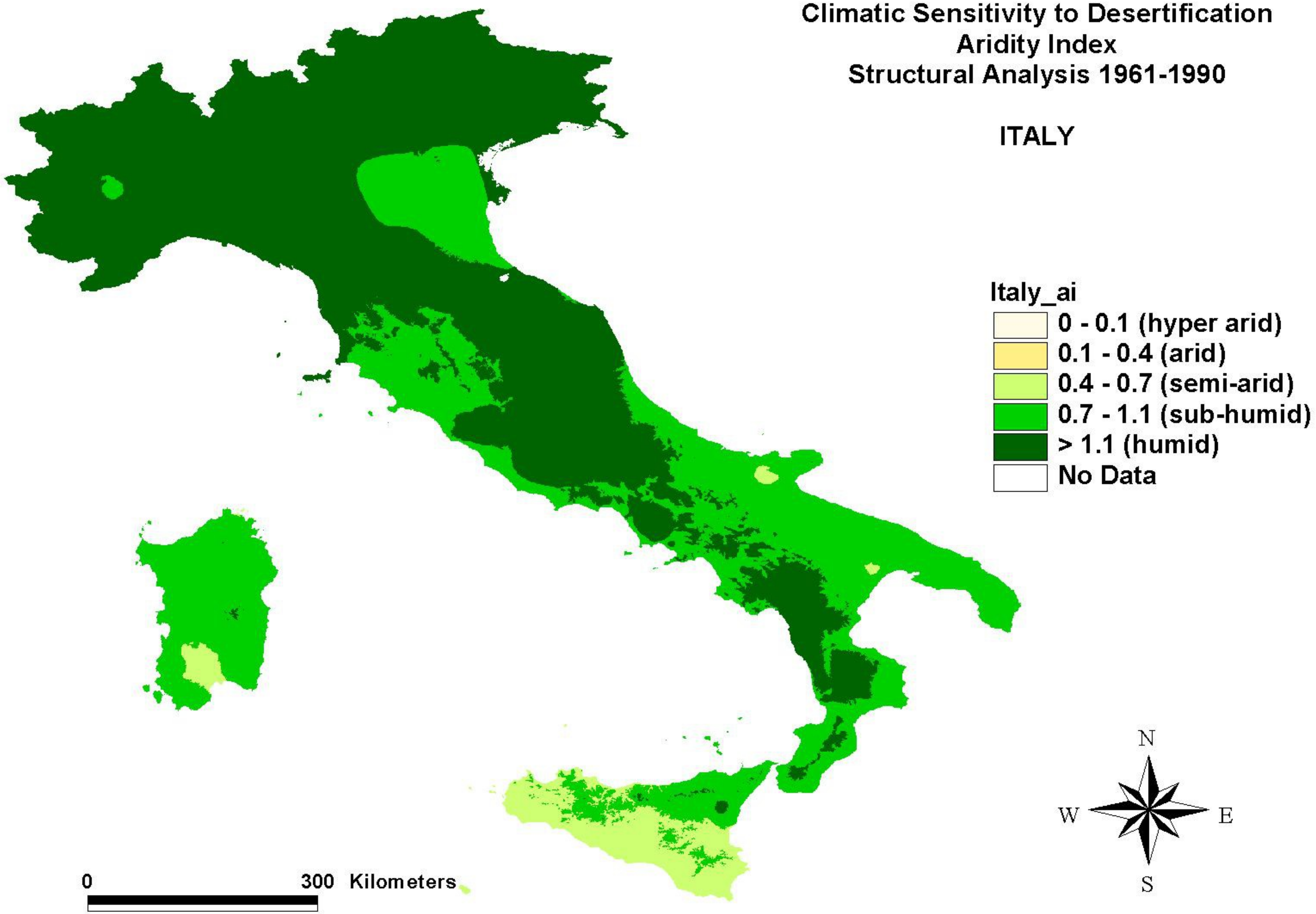



Climatic Sensitivity to Desertification
Aridity Index
Structural Analysis 1961-1990
FRANCE
France_ai
0 - 0.1 (hyper arid)
0.1 - 0.4 (arid)
0.4 - 0.7 (semi-arid)
0.7 - 1.1 (sub-humid)
> 1.1 (humid)
No Data
N
W
E
S
0
300 Kilometers

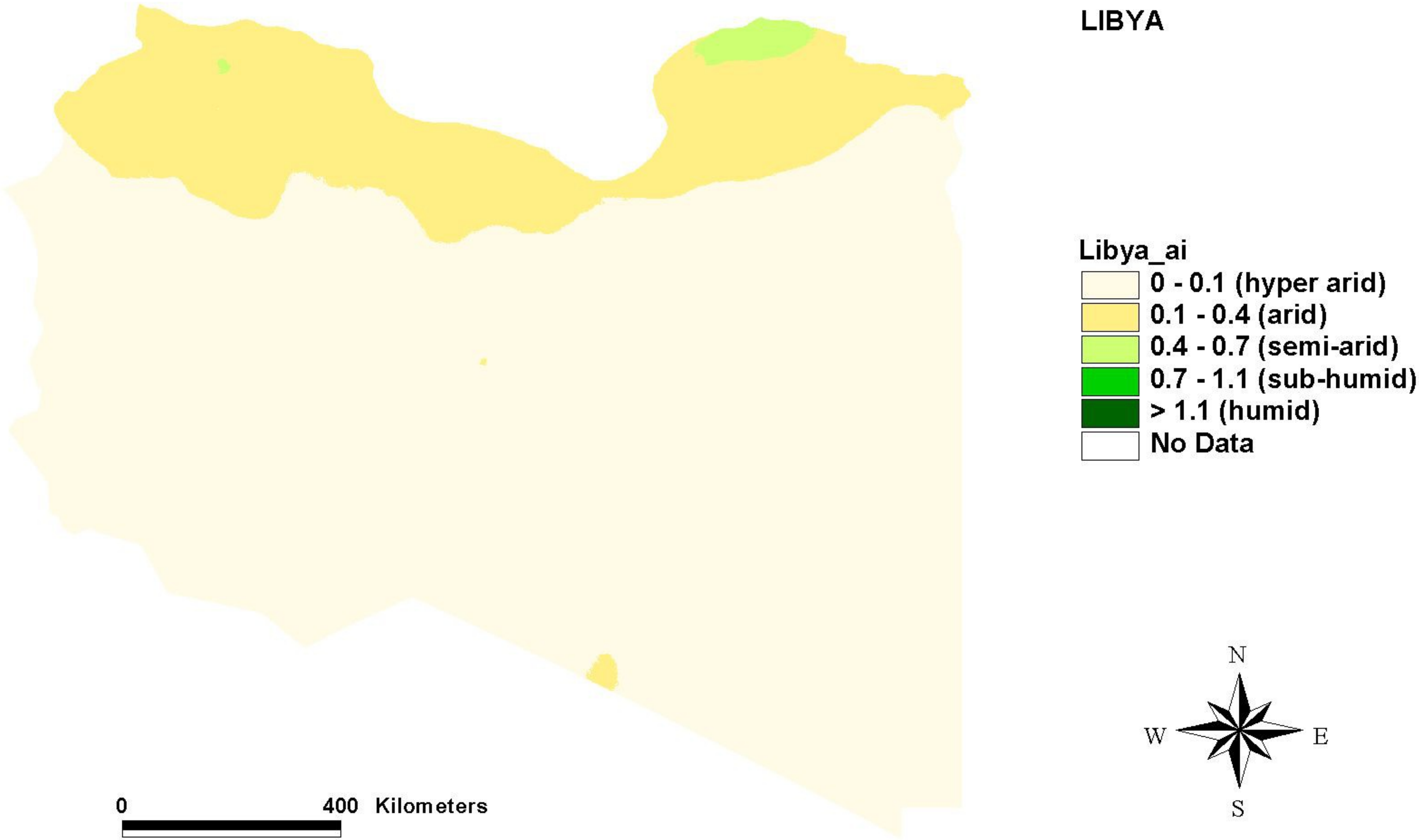
Climatic Sensitivity to Desertification
Aridity Index
Structural Analysis 1961-1990

GREECE



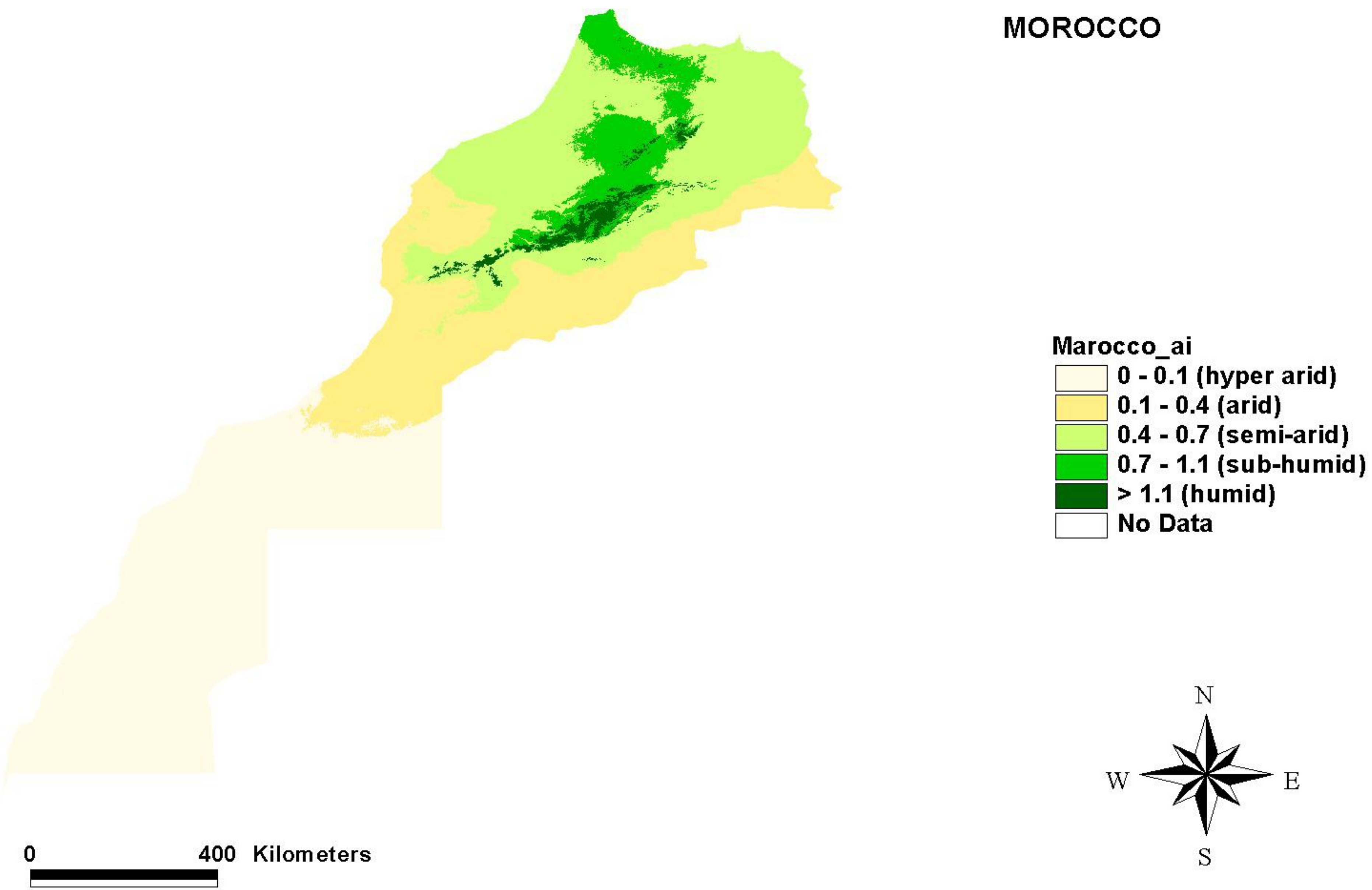

Climatic Sensitivity to Desertification
Aridity Index
Structural Analysis 1961-1990
ITALY
Italy_ai
0 - 0.1 (hyper arid)
0.1 - 0.4 (arid)
0.4 - 0.7 (semi-arid)
0.7 - 1.1 (sub-humid)
> 1.1 (humid)
No Data
N
W
E
S
0
300 Kilometers

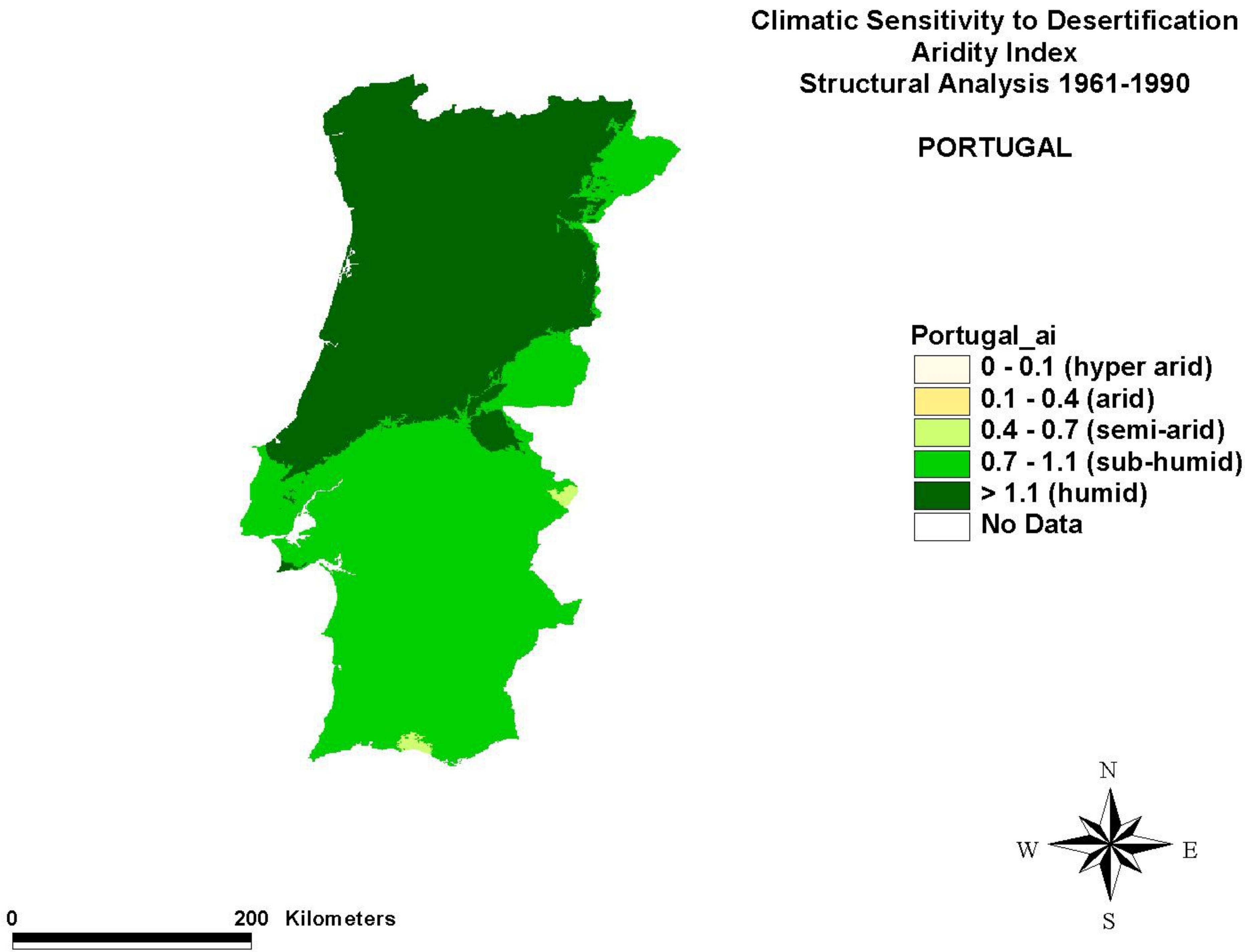
Climatic Sensitivity to Desertification
Aridity Index
Structural Analysis 1961-1990



Climatic Sensitivity to Desertification
Aridity Index
Structural Analysis 1961-1990

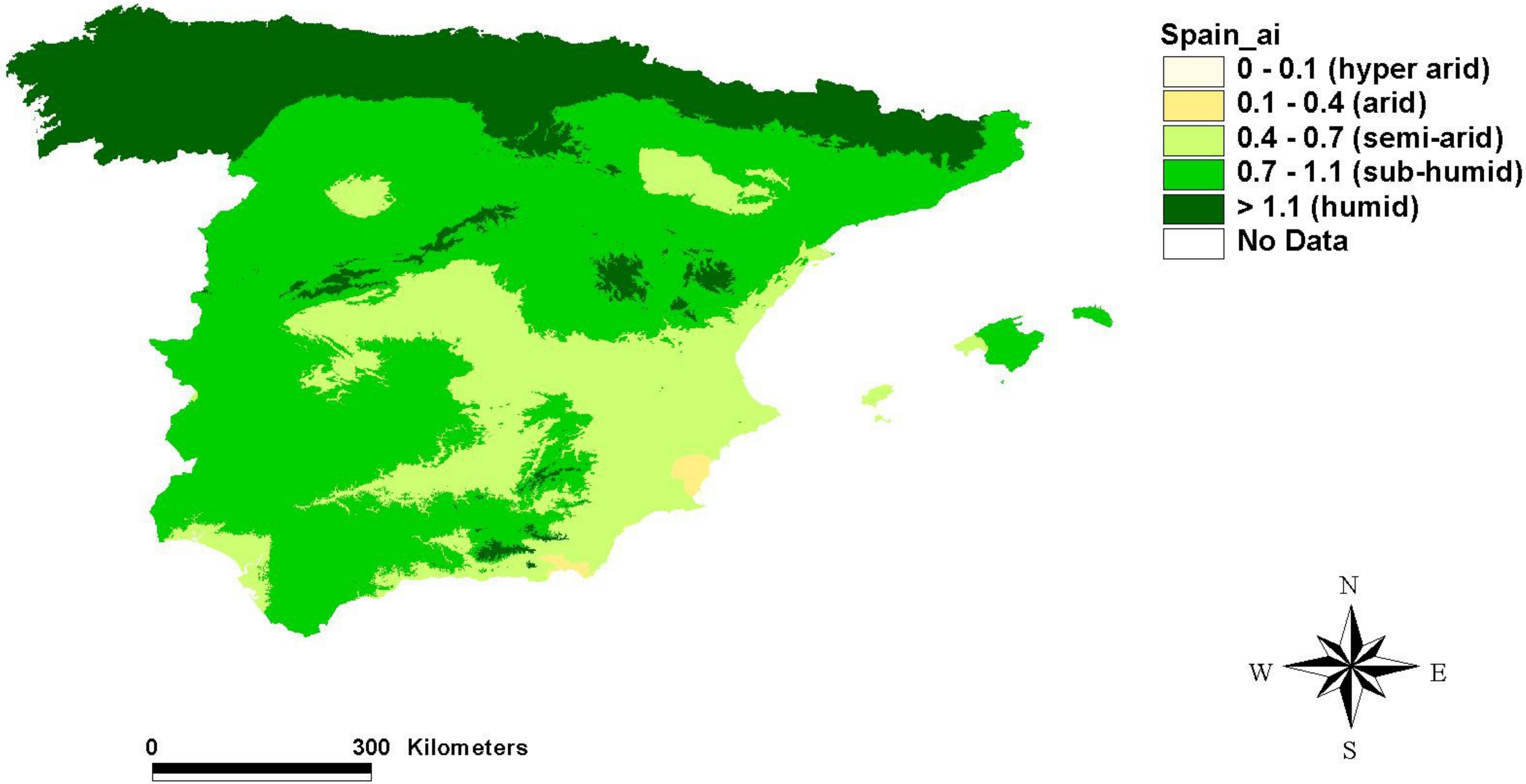
MOROCCO

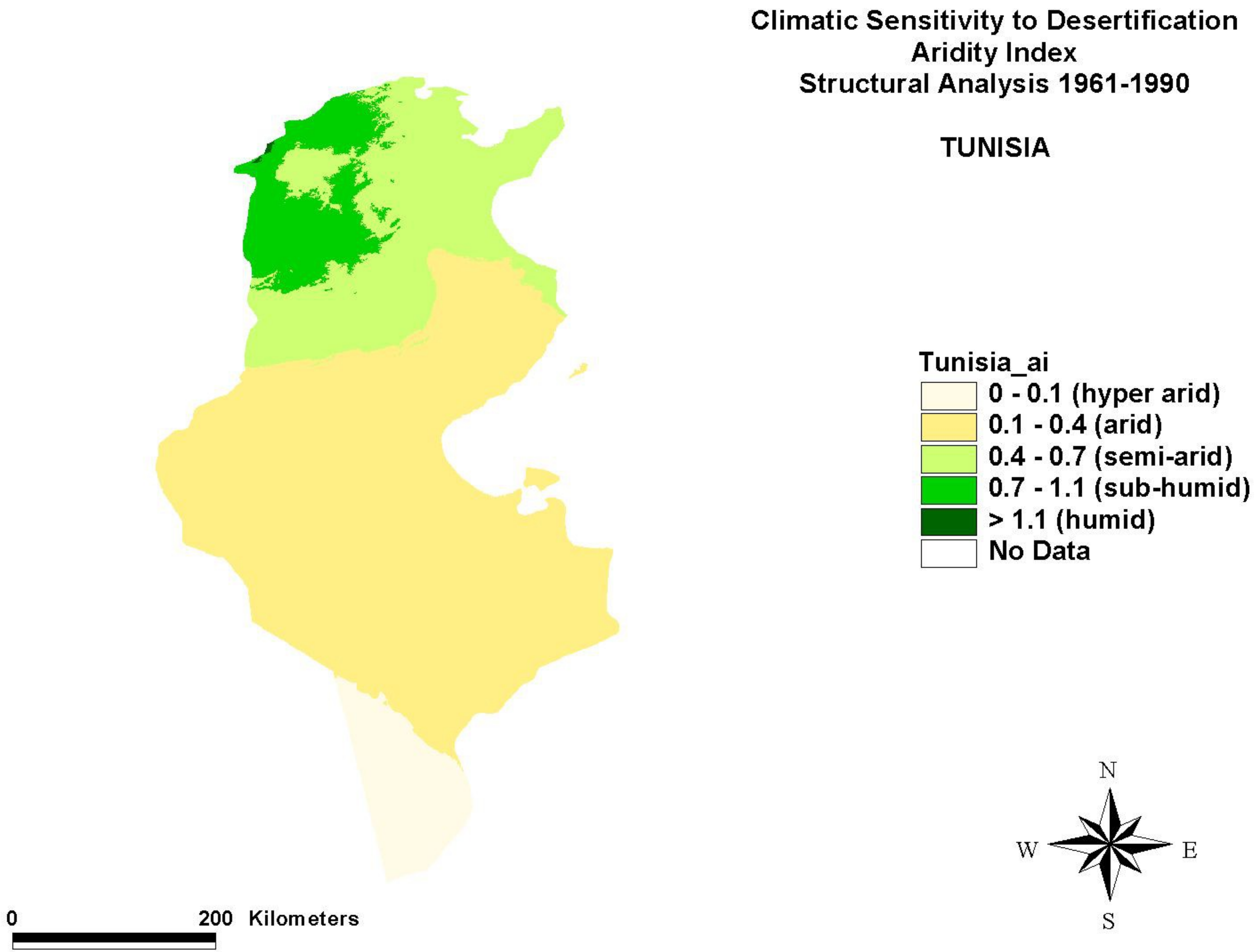



Climatic Sensitivity to Desertification
Aridity Index
Structural Analysis 1961-1990
PORTUGAL
Portugal_ai
0 - 0.1 (hyper arid)
0.1 - 0.4 (arid)
0.4 - 0.7 (semi-arid)
0.7 - 1.1 (sub-humid)
> 1.1 (humid)
No Data
N
W
E
S
0
200 Kilometers

Climatic Sensitivity to Desertification
Aridity Index
Structural Analysis 1961-1990

SPAIN




Climatic Sensitivity to Desertification
Aridity Index
Structural Analysis 1961-1990
TUNISIA
Tunisia_ai
0 - 0.1 (hyper arid)
0.1 - 0.4 (arid)
0.4 - 0.7 (semi-arid)
0.7 - 1.1 (sub-humid)
> 1.1 (humid)
No Data
N
W
E
S
0
200 Kilometers

Climatic Sensitivity to Desertification
Aridity Index
Structural Analysis 1961-1990

TURKEY