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High Resolution Climatic Surfaces of Nallıhan Ecosystem in Turkey; a Convenient Methodology to Create Climate Maps

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Abstract: In this study, a new methodology, based upon Local Climate Estimator (LOCCLIM) free software of Food and Agricultural Organization (FAO) of the United Nations (UN), was developed to create the climatic maps of Nallıhan Region in Turkey. Suggested methodology improves the spatial resolution quality of the derived climatic data and contains the steps that show how climatic surfaces can be established in geographic information system (GIS) environment. For this purpose, total 570 points (sites) were established with 0.01 decimal degree (~1000 m) grid intervals on the map of study area. Then, climatic variables (temperature, precipitation and potential evapotranspiration) of each point was derived by using LOCCLIM and (user defined) digital elevation model (DEM) with 1/25000 scale. Finally, climatic maps were developed by using derived point data and Inverse Distance Weighted Average (IDWA) method in GIS. To test the developed climatic surface maps, linear regression analyses were conducted with the original climatic data. Additional climatic surfaces were produced by using regression equations, DEM and map calculation functions of GIS. All developed climatic maps originated from LOCCLIM were subtracted from the corresponding regressed surface maps. The differences were found low for temperature variables, when some great differences were detected for the other climatic variables. Results showed that LOCCLIM supplied a strong background as a worldwide database source and software and proposed methodology could be a good solution to create the temperature related continuous surfaces. On the other hand, it is concluded that users should be cautious when they are working with precipitation and potential evapotranspiration variables.

Key words: Climate maps, GIS, LOCCLIM, FAO, Nallıhan

INTRODUCTION

Climate data in long-term norms, especially prevailing temperature and precipitation, are important for the studies related to plant populations (Reid, 1980; Coffin and Lauenroth, 1990; Lauenroth *et al.*, 1993; Molles, 1999). Estimates that belong to the amount and spatial distribution of climatic variables are also critical inputs for a variety of ecosystem modeling studies (Reid, 1980; Running and Coughlan, 1988; Agren *et al.*, 1991; Yeakley *et al.*, 1994). Consequently, there is an increasing demand for high-resolution climate maps that provide reliable estimates over broad geographic areas (McKenney *et al.*, 2006). Depending on its importance, numerous techniques that estimate climatic surfaces have been developed. Inverse distance weighting (Jones *et al.*, 1986) and nearest neighbor assignment (Cooter *et al.*, 2000), for example, are the techniques that based solely on values at nearby stations. Moreover spatial models have been developed to explain more complex climatic situations considering the effects of elevation and proximity to large water bodies (Seglenieks and Soulis, 2000, Daly *et al.*, 2002).

Considering the data access and evaluating problems, some of the organizations started to develop some software to estimate local climate variables by using long-term climatic records. Food and Agriculture Organization (FAO) of the United Nations is one of these organizations that maintain a worldwide climatic database (FAOCLIM). FAO also developed free software called LOCCLIM which is a powerful local climate estimator. LOCCLIM presents an estimate of the climate at any location in the world by employing the Inverse Distance Weighted Average (IDWA) approach (Grieser, 2002). For each estimate, LOCCLIM uses either its elevation database produced from NOAA (1 km resolution) or user-defined elevation database. This flexibility makes possible to produce more accurate estimates, if detailed elevation data is available.

In this study, a new methodology was developed to create high resolution climatic surfaces of Nallıhan ecosystem in Turkey. General approach and objectives within this frame can be summarized as; aggregating reliable climatic database for a given region, taking consideration of elevation effects on climatic variables, evaluating derived climatic database to develop climatic surfaces and testing the developed surfaces. The developed methodology based on the aggregation of geo-referenced climatic data in LOCCLIM and evaluation of this data in Geographic Information Systems (GIS). To increase the accuracy, user defined elevation model (1/25000 scale) was employed instead of LOCCLIM`s elevation database. Consequently, high resolution climatic surfaces of the region that belongs to temperature, precipitation and potential evapotranspiration variables were produced in 2002.

MATERIALS AND METHODS

The study area is located in Nallıhan administrative district of Ankara province in Turkey (Fig. 1) and covers 327.31 km^2 surface area. The general topographical layout of the study area shows mountainous characters and elevation changes between 150 and 1750 m. According to Koppen-Geiger climate system; dry mid-latitude climate characteristics (BSk) under the effects of Mediterranean climate (CSa) were recognized in the area (Strahler and Strahler, 1996). In respect of Emberger classification system; the climate of the study area showed Semi-arid Upper Mediterranean Bioclimate characteristics with cold winters (Akman and Daget, 1971; Akman, 1999). Basically, four seasons are recognized in the study area. Precipitation is mostly in rain form throughout the year except winters and total number of snowy days does not exceed 20 days.

The methodology given in Fig. 2 was developed to produce the climatic surfaces of the study area. The point data (X and Y coordinates) text file was firstly produced in LOCCLIM software and converted to dbf format in Microsoft Excel. Before producing this point data, desired latitude and longitude values were entered. Then, LOCCLIM produced a point data text file which includes 570 sites within the study area with 0.01 decimal degree (~1000 m) intervals. By setting the locations of these 570 sites, LOCCLIM automatically determined the nearest 20 climatic stations that will be considered for the calculations.

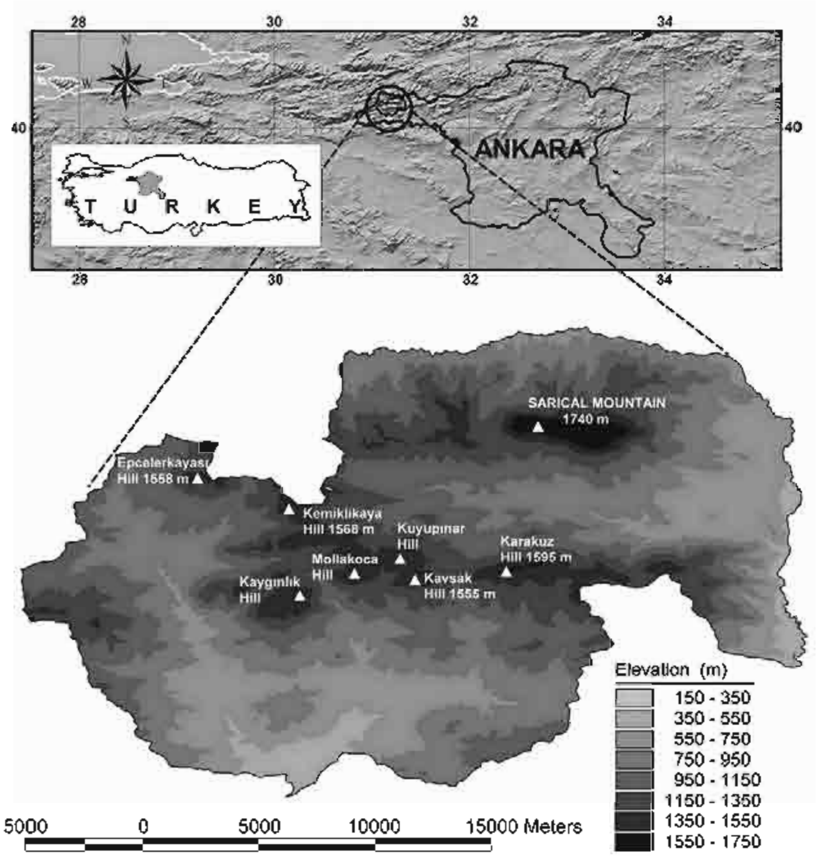

Fig. 1: Geographical location and topography of the study area (projection is geographic with international 1909 European datum and scale is 1/25000)

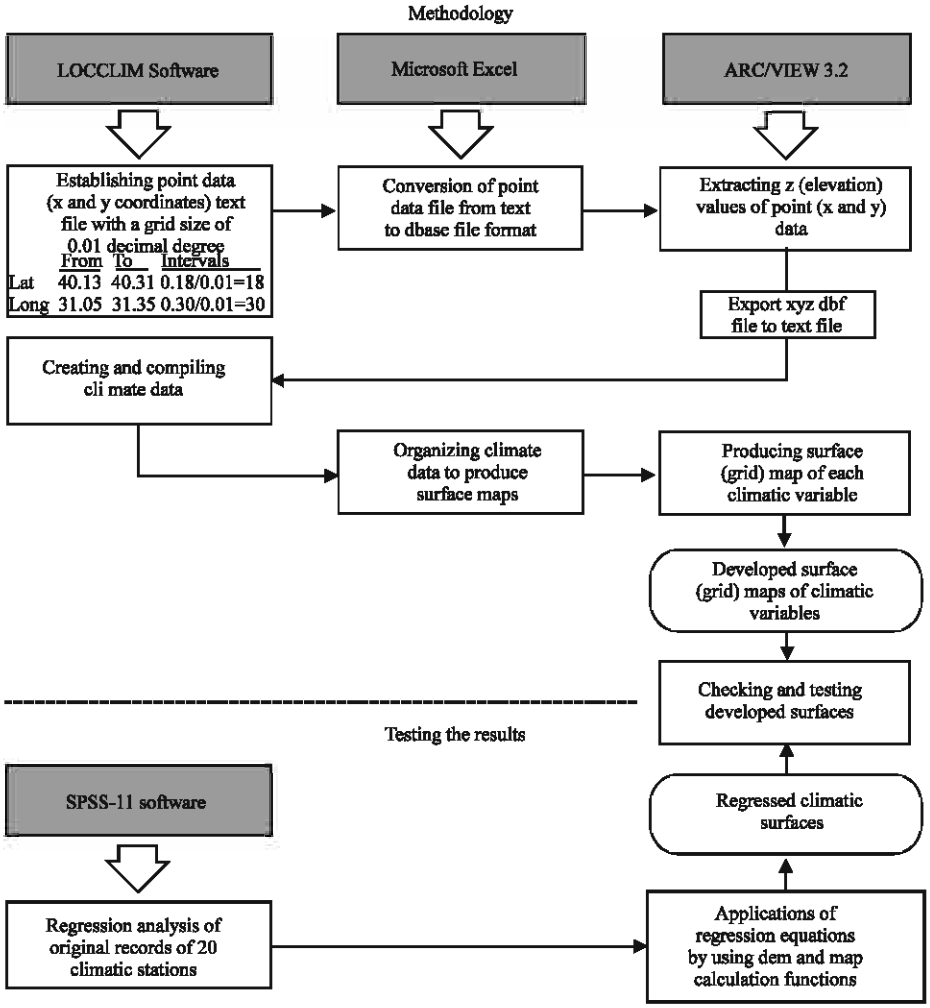

Fig. 2: The flowchart of the methodology (the rectangles indicate the analyses and processes, rounded rectangles show output products)

Overlaying the established dbf file on the elevation grid map with 1/25000 scale, elevation (Z) values of each point was extracted by Arc/View 3.2 software (ESRI, 1996). Resulting final dbf file including the coordinates and elevations of established points was organized and exported to text file format in Arc/View 3.2. Setting locations of established XYZ text file, desired climatic variables (max-min-mean temperatures, precipitation, evapotranspiration, etc.), outputs (best estimates and confidence intervals 90 or 95%) and other parameters (don't consider over 2000 m, user defined elevation, max stations in nearby (1-20) and etc.) were defined in the option menu of LOCCLIM. After defining all desired options, the best estimates of all determined points automatically calculated and saved in separate files by LOCCLIM. All produced LOCCLIM files were firstly opened and organized in Microsoft Excel and saved in dbf file format in which Arc/View 3.2 software can utilize. To produce the surface maps, grid and spatial analysis extensions of Arc/View 3.2 were employed. Then, each climatic point data file in dbf format was converted to climatic surface maps. Throughout the creation of all climatic surfaces, Inverse Distance Weighted Average (IDWA) method was applied. In basic, IDWA is an interpolation method that estimates cell values by averaging the values of sample data points in the neighborhood of each processing cell. The closer a point is to the centre of the cell being estimated, the more influence, or weight, it has in the averaging process. This method supposes that the variable being mapped decreases in influence with distance from its sampled location (ESRI, 1996).

In order to test the developed surfaces, linear regression analysis with entering method was conducted by using original climatic data of 20 stations in SPSS software (SPSS, 2001). Elevation was determined as

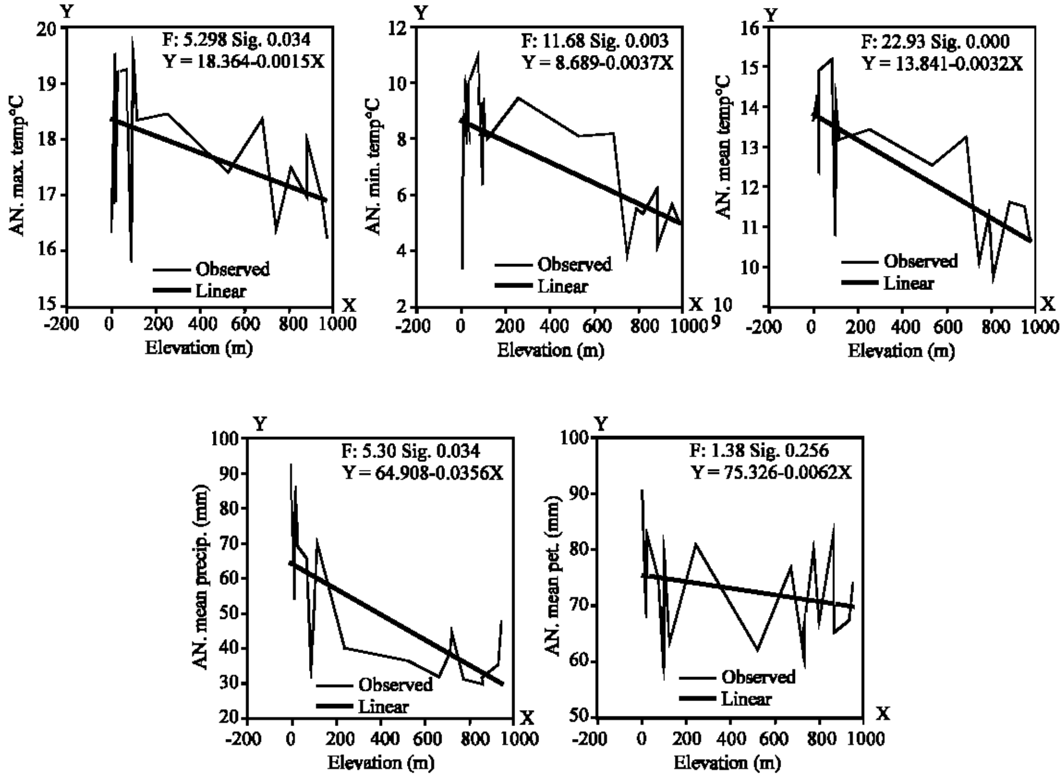

Fig. 3: Linear curve estimations and developed regression equations derived from original climate (20 stations) data

independent variable in each case of regression analysis. Therefore, all climatic variables were formulated as a function of elevation at the end of this process (Fig. 3). Using determined regression equations and digital elevation model; additional (regressed) climatic surfaces were produced in Arc/View 3.2. Finally, all developed climatic maps originated from LOCCLIM were subtracted from the corresponding regressed surface maps by employing the map calculation functions of Arc/View 3.2. Resulting difference maps were utilized to interpret where the developed methodology works adequately.

RESULTS AND DISCUSSION

The locations of the determined climatic stations and established points were given in Fig. 4a and b, respectively. Considering the determined climatic stations and elevation values, the best estimates of the focused climatic variables were calculated for each established point (Fig. 4b) in LOCCLIM. Evaluating the point data, the surface (grid) maps of each climatic variable were produced with the grid resolution of 30 m in Arc/View 3.2 software. At the end of this process, five climatic variables including (1) maximum temperature, (2) minimum temperature, (3) mean temperature, (4) precipitation and (5) potential evapotranspiration (PET) were mapped in annual mean basis. Resulting climatic surface maps in annual basis were given in Fig. 5. Consequently, an important spatial database set that is ready to further spatial analyzes was created.

In order to test the developed surfaces (Fig. 5), five linear curve estimations with corresponding regression equations were determined by using the original climatic data of 20 stations (Fig. 4a) in SPSS software. Regressed climatic surfaces, shown in Fig. 6, were produced by using developed regression equations (Fig. 3), DEM and map calculation functions of GIS. Difference maps which were obtained by subtracting the surface maps of all (LOCCLIM originated) climatic variables from the corresponding regressed (calculated) surface maps were given in Fig. 7.

It is reasonable to compare the LOCCLIM climatic surface maps with the regressed climatic surface maps in order to test the reliability of developed methodology, because main climatic variables are mostly controlled by altitude. Temperature, for example, varies with location and season and decreases 6.5°C per 1000 m increase in altitude on a global average (Lutgens and Tarbuck, 1995). On the other hand, precipitation increases with higher elevations (Hevesi *et al*., 1992; Daly *et al*., 1994) and

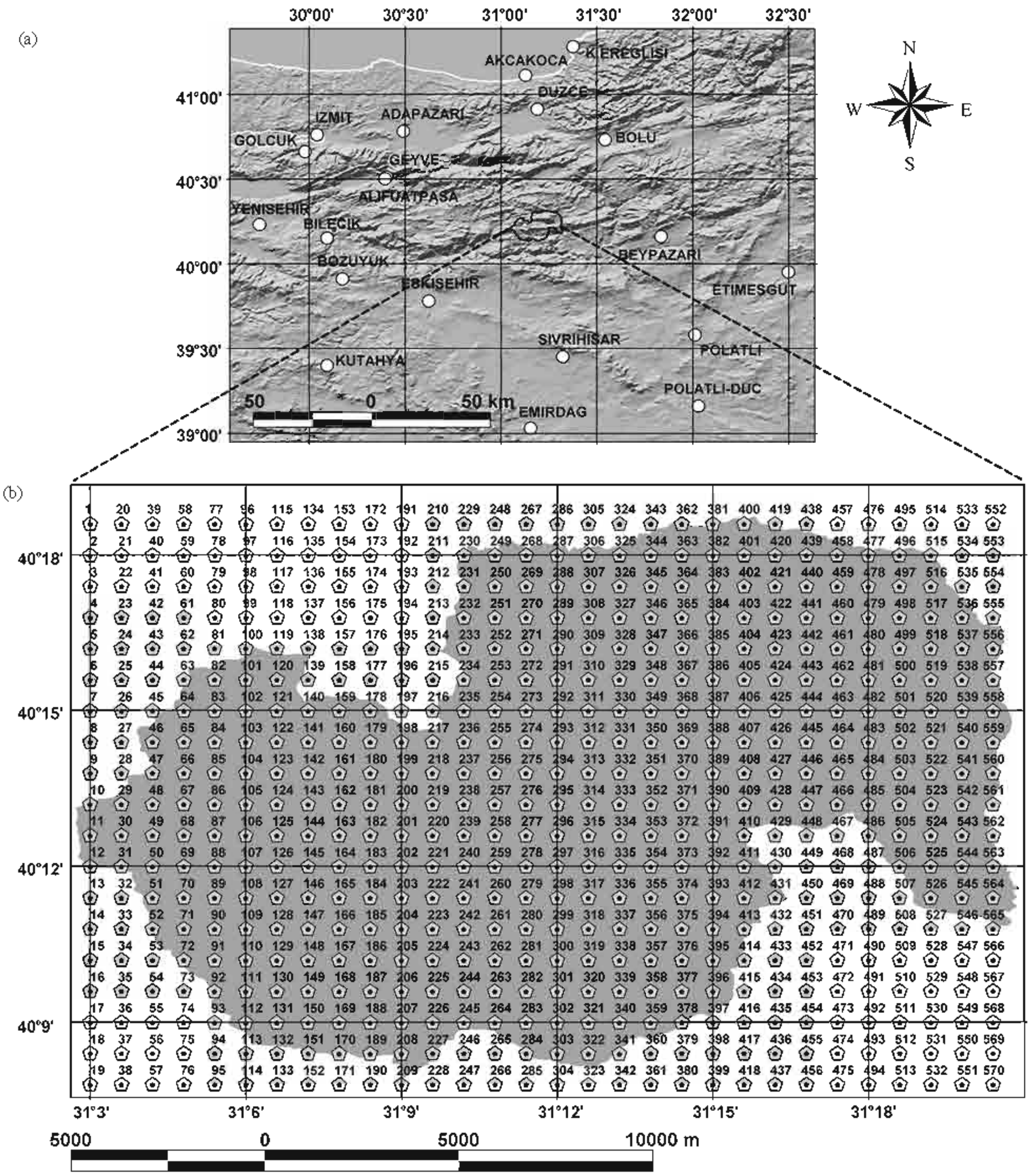

Fig. 4: Determined climatic stations (a) and grid points (b) for climatic data aggregation in LOCCLIM

potential evapotranspiration is controlled by temperature, radiation, humidity and wind speed. Lower temperature values at higher elevations could possibly indicate high precipitation and low potential evapotranspiration values. Consequently, climatic variables may be modeled as a function of elevation and climatic surface maps might be produced by utilizing developed models and DEM in GIS environment (Goodale *et al.*, 1998).

In this study, inverse relationships between elevation and temperature related variables are the common characteristic in all produced surfaces (Fig. 5b-d and 6a-c). At a first glance, the developed temperature maps by the introduced methodology (Fig. 5b-d) showed parallelism with the temperature maps developed by regression analysis (Fig. 6a-c). The difference maps (Fig. 7a-c) also supported this parallelism in quantitative way and they

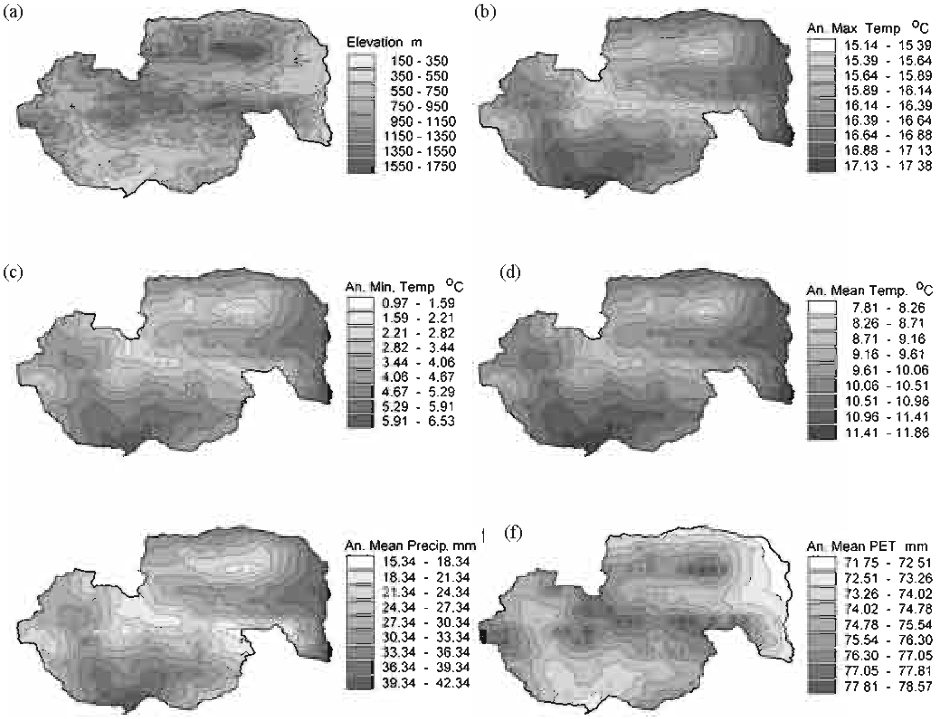

Fig. 5: Elevation (a) and climatic surface maps of maximum temperature (b), minimum temperature (c), mean temperature (d), precipitation (e) and potential evapotranspiration (f) (NOTE: All surface maps were produced in annual mean basis)

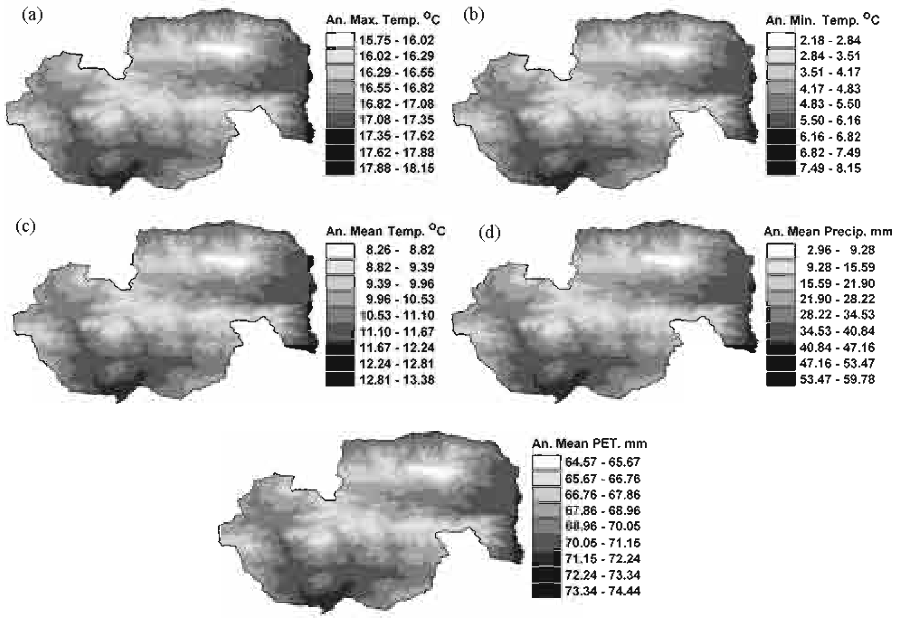

Fig. 6: Regressed climatic surfaces: annual maximum temperature (a), annual minimum temperature (b), annual mean temperature (c), annual mean precipitation (d) and annual mean PET (e) (NOTE: All maps have identical shape with different values (legends) because all of them were derived from the elevation map by applying different regression models)

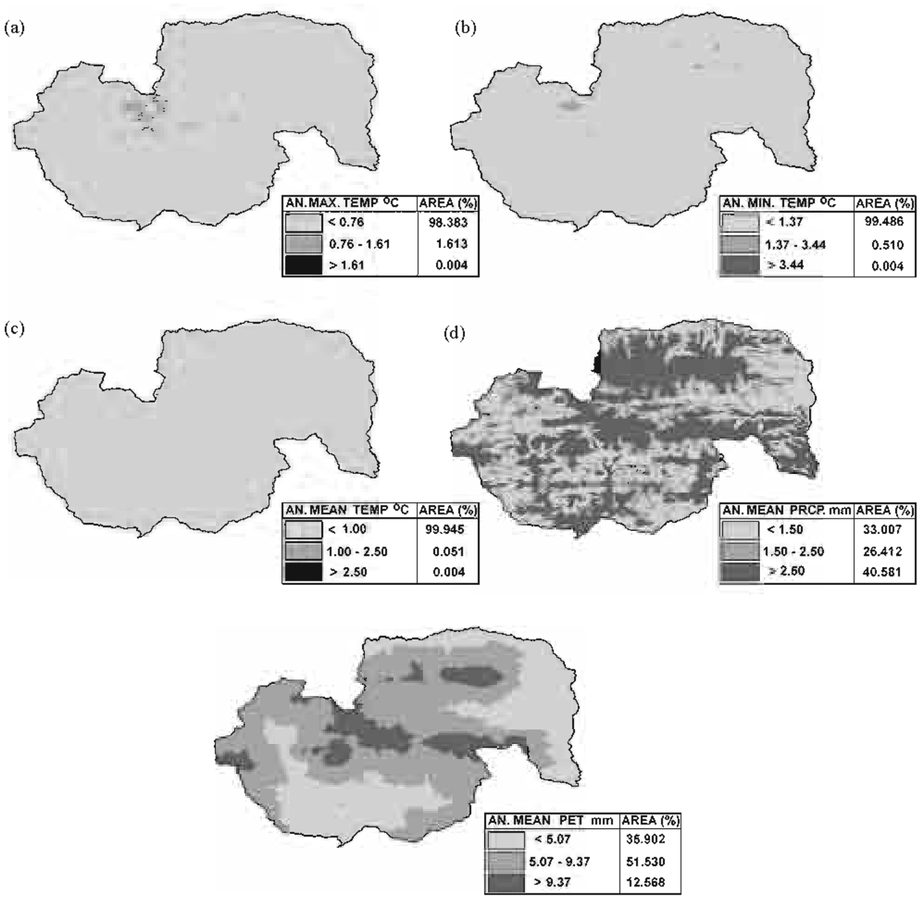

Fig. 7: Difference maps: annual maximum temperature (a), annual minimum temperature (b), annual mean temperature (c), annual mean precipitation (d) and annual mean PET (e)

indicated that the differences between the temperature surface maps originated from the two different applications are very small (0.76-1.37°C) in majority (> 99%) of the study area. Considering this parallelism, the best results were obtained for the variables related to temperature. As a result, it might be concluded that the introduced methodology is valid for temperature variables.

Although an inverse relationship was discovered between elevation and precipitation in both applications (Fig. 5e and 6d), the difference map of precipitation (Fig. 7d) revealed the serious dissimilarities (> 2.50 mm) in 40.58% of the total area. Furthermore, lower precipitation values at higher elevations might indicate a conflict. Regarding the results of PET variable (Fig. 5f and 6e), some disagreements were also determined. The first discordance was detected about the characteristics of the relationship between the elevation and PET. A direct relationship between elevation and PET was detected in the map originated from LOCCLIM (Fig. 5f), when an inverse relationship was determined in the map originated from regression analysis (Fig. 6e). Secondly, the difference between the two PET maps (Fig. 7e) were found great (> 5.07 mm) in 35.90% of the total area.

The interpolation of climatic data of mountainous regions leaved some problems to obtain spatial data and direct interpolation without topographical data can not capture the spatial climatic variability unless an unrealistically high station density is available (Thomas and Herzfeld, 2004). Elevation information only improved results (Fleming *et al.*, 2000; Goovaerts, 2000; New *et al.*, 2002). Considering the overall results, the introduced methodology might not be appropriate to develop climatic surfaces related to precipitation and potential evapotranspiration variables. These kinds of problems could be related to insufficient number of weather stations. To catch the good precipitation and PET gradient, more weather stations at different elevations should have been distributed very well in the nearby area. This can be solved by adding the new records of small climatic stations into the LOCCLIM`s database.

CONCLUSION

The results proved that any coordinated climatic data aggregated by LOCCLIM could be converted to grid maps by using the power of GIS. Established grid maps supplied not only surface data for modeling studies but also good visualization that is important to catch the spatial change of climatic variables at a glance. Consequently, application of the developed methodology might increase the value of the climatic data. Results showed that some problems could appear in the aggregated climatic data such as precipitation and potential evapotranspiration variables. Users should be cautious at this point. The main cause of these kinds of problems might be related to insufficient number of climatic stations in some of countries. Small disagreements between the produced climatic data and reality could be fixed by adding and updating new stations into the climatic database of LOCCLIM.

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