Spatial Modeling of Climatic Parameter Fluctuation
Mapping Temperature Variation in the Bermejo Basin from 1901 to 2000

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Abstract

Understanding the spatial and temporary variations in climate within a zone, and their relationships with other factors, is important in activities related to climate change and the management of the natural resources, such as environmental planning, land-use planning, watershed management and territorial ordering. Even when these variations are sometimes reported in maps, the values represented there are presently often obtained by the straight application of subjective criteria, seldom supported or replaced by the systematic use of computerized techniques of spatial data analysis and modeling.

In this study, a method is presented for mapping and analyzing the temporary variations of climatic parameters linked to the global climate change. This method focuses on the use of geographic information systems (GIS) and is tested in producing temperature variation maps of the Bermejo Basin, in northwest Argentina, between 22 and 27°S, and 58 and 66°W.

To produce these maps, temperature and rainfall data of meteorological stations were first summarized for different periods from 1873 to 2000 to build up a tabular database, and a digital elevation model was produced from topographic data using GIS capabilities. Tabular and elevation data were then linked in a GIS environment to produce air temperature maps following the presented method, and maps showing temperature variations from 1901 to 2000 were derived. Ranges of air temperature most probably correlated with land-use suitability were selected, and two maps showing thermal zones were produced. These maps were crossed and a map showing the shift of the thermal zones was developed, illustrating the consequent spatial

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shift of land use and farming types agroclimatic suitability. Isopleths were derived from maps showing temperature and thermal zones variations, and these lines were plotted onto land-use and vegetation maps to allow the visual assessment of temperature variations within different land cover types. This led to the identification of areas most likely affected by temperature variations within different cartographic units. In addition, the original grid maps showing temperature variations were used to quantify the magnitude of these variations within each land cover type, to report them statistically and to relate these magnitudes to the degrees of the occurred impacts within each unit.

The geo-database developed during this mapping process, consisting of tables, formulae, maps and their relationships, is built up using dependency links among objects. Consequently, when input source maps, tables or formulae are improved, the dependent output maps and/or tables can be automatically recalculated. The geo-database will be also used for the development of scenarios to represent future trends of air temperature under different local and global conditions, and to locate and analyze the dynamic variation of other climatic parameters, contributing to the study of climate change and land use planning at different scales.

Introduction

The Problem

Understanding the spatial and temporary variations in climate within a zone, and their relationships with other factors, like topography and geographic location, is important in activities related to climate change and the management of the natural resources, such as land-use planning, watershed management and territorial ordering. Even when these variations are sometimes reported in maps, the values represented there are presently often obtained by the straight application of subjective criteria, seldom supported or replaced by the systematic use of computerized techniques of spatial data analysis and modeling. On the other hand, the scarce use of these techniques has limited largely not only the possibilities to map the temporary variations of climatic parameters, but also to assess their spatial relationships with other environmental factors.

Objectives

The main emphasis in this study is on presenting a method for mapping and analyzing the temporary variations of climatic parameters linked to the global climate change. This method focuses on the use of Geographic Information Systems (GIS) and the development of a georeferenced database, and is applied in producing air temperature and thermal zones temporal variation maps of the Bermejo Basin, in northwest Argentina, and in assessing their spatial relationships with land-cover types.

The Argentinian Sector of the Bermejo Basin

The Bermejo Basin, shared by Argentina and Bolivia, is part of the macro-region of the Plata Basin. It embraces a surface area of 123,162 km^2 and its main watercourse has a length of more than 1,300 km (Strategic Action Program for the Binational Basin of the Bermejo River, 2000). This study is done at a reconnaissance scale 1: 500,000 on the argentinian sector of Bermejo Basin, covering about 90% of its total surface. This sector embraces portions of the provinces of Chaco, Formosa, Jujuy and Salta, between 22 and 27^{o}S, and 58 and 66^{o}W. Because of its characteristics, the Bermejo Basin is divided into the Upper Basin and the Lower Basin.

The Upper Basin is located in the west, between 300 and 5,700 m.a.s.l., in the Eastern Range of the Andes and the Sub Andean Ridge, where the dominant relief is undulating to very steep (area represented in Figure 3). The climate presents a sharp rainfall gradient, from 2,200 to 200 mm annually, with high seasonal variations, while mean temperatures decrease with elevation from 23^{o}C to below 0^{o}C in the higher mountains.

The (semi)natural vegetation varies from closed and exuberant forests in the lowlands, between 300 and 1,500 meters, to woodland shrubs, open grasslands and sparse cactus deserts in the highlands, above 1,500 meters. The main land-use varies from dry-land farming in the highlands, to forestry and livestock in the lowlands with irrigated and rain fed agriculture in the lowest sectors. Living conditions show extreme variations with broad sectors having a precarious economic existence.

The Lower Basin is located in the east, between 40 and 350 m.a.s.l., in the Chaco Plain, where the dominant relief is flat to very flat. Annual rainfall varies from 1,500 mm in the east, with moderate seasonality, to 700 mm in the west, where seasonality is sharp. Annual mean temperatures vary from 21 to 24^{o}C, showing poor relation with elevation.

The (semi)natural vegetation varies from grasslands, forests, and swampy herbaceous communities to shrubby mosaics. The main land use is forestry and livestock, with important sectors under rain fed agriculture and smaller areas under irrigated agriculture. In general, population density is low to very low and living conditions extremely precarious.

Methodology

Temperature variation maps were produced following an approach based on the following guidelines to assess climate change effects on anthropic and (semi)natural ecosystems:

1. Define major climatic variables that condition the existence of (semi)natural and anthropic ecosystems;
2. Compile statistical data of selected climatic variables of stations within and close to the study area;
3. Analyze historic trends, fluctuation and extreme values for each selected parameter;

4. Compile cartographic and descriptive information about ecosystems to be assessed;
5. Obtain satellite imagery or aerial photos of one or more dates at a suitable spatial resolution to map ecosystems and their variation areas;
6. Model the spatial and temporal variations of selected climatic parameters;
7. Quantify the magnitude of climatic parameter variations for each ecosystem;
8. Map ecosystem areas where climatic parameter values are lying out of their original distribution ranges to identify potential impact areas;
9. Build up alternative spatial scenarios showing expected climatic parameters variations and their potential impacts on ecosystems;
10. Define potential implications of changes in ecosystems distribution.

The method presented here focuses on step 6 and part of steps 7 and 8 of the guidelines. This method (Figure 1) is applied to the production of maps showing annual mean air temperature variation in the argentinian sector of Bermejo Basin from 1901 to 2000.

The method starts by building up a tabular database from long-term climatic data and producing a digital elevation model (DEM) from topographic data using GIS capabilities. Then, regression analysis between air temperature and elevation are carried out and lapse rates derived. Lapse rates are validated/adjusted from instantaneous soil temperature readings at different elevations, at the depth(s) showing the best correlation with mean air temperature. Data from secondary stations have also to be used for this purpose.

Air temperatures at sea level are estimated for different periods for each meteorological station applying the obtained lapse rates, and the differences between these estimates and the ordinates (constant terms) obtained from the regression formulas are derived. Air temperature differences at sea level obtained for each station are interpolated to the rest of the area using GIS capabilities. For this, the area is assumed to be flat and at sea level during this step. Simultaneously, preliminary air temperature maps are obtained for the different periods by the straight application of the regression formulas to the DEM.

Final air temperature maps are obtained for different periods by adding the values contained on the two previous maps: air temperature differences at sea level and air temperatures derived from lapse rates, as proposed by De Fina and Sabella (1959) and De Fina (1992). Final temperature maps are used to calculate temperature variation between two periods by subtracting the values obtained for the last period to the values obtained for the first.

Simultaneously, estimated temperature values for each period are grouped into ranges most closely linked to (agro)ecological zones boundaries, and the obtained temperature differences for each couple of consecutive periods are also grouped into ranges. All maps obtained in the GIS environment until this step present a raster format, with individual values stored in individual square cells.

Vector maps showing thermal zones and isotherms for different periods, and isopleths of air temperature temporal variation for each couple of periods are derived from the classified raster maps obtained in the previous step. This is done in the GIS by applying a raster to vector conversion, followed by line smoothing and short segment removal. Vector maps are final products for results presentation and are also used for visual analysis of climatic parameter fluctuation within anthropic and (semi)natural ecosystems, by plotting vector lines onto land-use and vegetation maps. Finally, the two maps showing thermal zones were crossed and a map showing the shift of the thermal zones was developed, while the original raster maps showing temperature temporal variations were used to assess relationships with land cover types statistically.

Results

The first product obtained was a tabular database built up from temperature and rainfall data of 35 meteorological stations summarized for different periods from 1873 to 2000 (main stations location is shown in Figure 4). For this, the following sources were consulted: Gould (1882), Davis (1889 and 1895), SMN (1958a, 1958b, 1963, 1981 and 1992), CIRHMET (1993), Arias and Bianchi (1996), Olivares *et al* (1995), and preliminary decennial data from 1991-2000 were obtained from the Biblioteca Nacional de Meteorologia del Servicio Meteorologico Nacional (Buenos Aires, Argentina). A Digital Elevation Model (DEM) produced from topographic data in a previous study (Zuviria 2002) was already available.

Even when tabular data are not reported here, the comparative data analysis of annual mean, maximum mean and minimum mean temperatures and annual rainfall carried out for stations presenting values recorded during 1901-1950 and 1951-2000, allowed to extract the following conclusions for this period: 1) annual mean temperature decreased (0 to 0.8°C), as reported by IPCC (1998) and in opposition to assumptions erroneously taken within the Bermejo Basin (Seoane and Moyano 1999); 2) annual maximum mean temperature decreased more than the annual mean (0.4 to 2.2°C); 3) annual minimum temperature increased in most of the area, showing a slight decrease in a small sector (-0.2 to 1.5^{o}C); 4) thermal amplitude decreased (0.5 to 3.4^{o}C); and 5) annual rainfall increased (5 to 26%), showing a high correlation ($R^2 = 0.85$) with annual maximum mean temperature decreasing. The formulas obtained from the regression analysis between annual air temperature (Tx; ^{o}C) and elevation (E; meters $*$ 100) for the periods 1901-1950 and 1951-2000 are the following:

$$\mathbf{Tx_{1901\text{-}1950} = 23.6 - 0.44\ E}$$

$$\mathbf{Tx_{1951\text{-}2000} = 22.5 - 0.38\ E}$$

From the straight application of these formulas, it results that annual air temperature decreased within the area below 1,800 m.a.s.l. and increased above this limit. Lapse rates obtained from linear regression between annual mean air temperature and elevation were highly correlated with elevation ($R^2 > 0.94$), as expected from a previous study (Zuviria and Burgos 1986). This correlation is higher within the hilly and mountainous sectors of the Upper Basin while in the flat Lower Basin temperature correlation with elevation is poor. This is because lapse rates are also associated within this area, but in a lower degree, with rainfall, cloudiness and latitude, as indicated by Bianchi *et al* (1994). These influences are accounted in the maps showing air temperature differences at sea level. Lapse rates were validated using data from secondary stations but, even when it was planned to take soil temperature measurements to complete this validation, as done in a previous study (Zuviria 1992), it could not be done here.

ILWIS (Nijmeijer *et al*, 2001) GIS was used for the mapping process, and maps showing thermal zones (FAO 1997) and their spatial shift from 1901-1950 to 1951-2000 were produced (Figure 2), taking ranges of air temperature most probably correlated with land-use suitability, as recommended by Parry (1990). Maps presenting annual mean isotherms for the mentioned periods and isopleths of air temperature temporal variation were also produced and used to visualize air temperature fluctuation in a fragile ecosystem, the transition forest (Figure 3) and on main land-use types (Figure 4). Tabular results from the geostatistical analysis are also presented in the last figure, showing mean temperature variation (X var) and standard deviation (SD) within each land-use type from 1901-1950 to 1951-2000.

The geo-database developed during this mapping process, consisting of tables, formulae, maps and their relationships, is built up using dependency links among objects. Consequently, when input source maps, tables or formulae are improved, the dependent output maps and/or tables can be automatically recalculated. This geo-database is currently used for the development of scenarios to represent future trends of air temperature under different local and global conditions, and to locate and analyze the dynamic variation of other climatic parameters, contributing to the study of climate change and land use planning at different scales.

Conclusions

The major aim of this study, the development of a method for mapping and analyzing the temporary variations of climatic parameters linked to the global climate change, is achieved. This method focuses on the use of geographic information systems (GIS) and was used to produce temperature variation maps of the Bermejo Basin, in northwest Argentina.

The application of this method has led to the procurement of the following products: 1) a digital long-term climatic database of the Bermejo Basin; 2) annual mean air temperature maps for different periods; 3) maps showing annual mean temperature temporal variation between two consecutive periods; 4) thermal zones maps for different periods; 5) maps showing thermal zones shift between two consecutive periods; 6) combined maps presenting land-use and/or vegetation types together with temperature temporal variations between two consecutive periods; 7) the geo-database of Bermejo Basin, built up using dependency links among objects.

The implementation of dependency links among objects in the geo-database developed during this mapping process, consisting of tables, formulae, maps and their relationships, allows the automated recalculation of any dependent output maps and/or tables when input source maps, tables or formulae are improved. This ability facilitates the use of this geo-database for spatial model testing and other analytical purposes, what will lead to further improvement on the results and on the production of maps representing variations of other climatic parameters.

The method presented allowed the visual assessment of temperature variations within different land cover types, what led to the identification of areas most likely affected by temperature variations within different cartographic units, to quantify the magnitude of these variations within each unit, to report them statistically, and to relate these magnitudes to the degrees of the occurred impacts within each unit.

This method is regarded as a contribution to the study of climate change, to be also used at smaller scales together with general circulation models (GCM), as a complementary approach for simulating the distribution of present and potential climate change.

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