CLIMATE CHANGE IMPACTS ON HYDROMETEOROLOGICAL VARIABLES AT LAKE KARLA WATERSHED

TZABIRAS J.[1], VASILIADES L.[1], SIDIROPOULOS P.[1], PAPAIOANNOU G.[1], LOUKAS A. [1] and MYLOPOULOS N.[1]

[1] Laboratory of Hydrology and Aquatic Systems Analysis, Department of Civil Engineering, University of Thessaly, Greece
E-mail: aloukas@uth.gr

ABSTRACT

The effects of climate change on meteorology, hydrology and ecology have become a priority area, both for process research and for water management strategies. General circulation models (GCMs) are the main tools today for simulating present and future climate conditions. However, the outputs of the current general circulation models (GCMs) cannot be used for analysis at local extent due to their coarse spatial resolution. This paper is dealing with the assessment of climate change scenarios on selected meteorological variables at the Lake Karla watershed, central Greece and it is a contribution to the “HYDROMENTOR” research project. A statistical downscaling method has been employed to estimate monthly precipitation and temperature time series for historical and future climate periods. The methodology is based on multiple linear regressions of GCM predictand variables with observed areal precipitation and temperature as well as on the application of a stochastic time series model for precipitation and temperature residuals simulation. The outputs of the Canadian Centre for Climate Modeling Analysis Global Circulation Model CGCM3 were applied for three socioeconomic scenarios, namely SRES B1, SRES A1B and SRES A2 for the assessment of climate change impact on precipitation and temperature. The methodology has been developed for the historical period 1980-2000. The analysis was conducted for two future periods 2030–2050 and 2080–2100. Historical and future periods were compared for monthly and annual basis using various statistical criteria such as the mean, standard deviation, minimum and maximum values and first order autocorrelation coefficient. Results showed that climate change will have minor impacts on precipitation and even smaller impacts on temperature. The changes follow the logical assumptions of the scenarios given that the SRES B1 is the least intensive scenario, the SRES A1B is a moderate climate change scenario and the SRES A2 is the most intensive.

Keywords: climate change, statistical downscaling, precipitation, temperature

1. Introduction

It is widely accepted that the increasing concentration of greenhouse gases in the atmosphere will very likely lead to the change of climate. Globally averaged mean evaporation, temperature, and rainfall intensity will probably increase in response to increased concentrations of greenhouse gases (IPPC, 2001). This shift toward higher global temperature and more intense rainfall is of great concern for assessing climate change impacts on water resources due to potential effects on extreme events such as floods and droughts. The risk of increase in the frequency of extremes is clear but the potential consequences in particular regions need to be assessed (SWCS, 2003). This is required because this information may lead to practices that should be taken in order to protect local societies from probable catastrophic environmental changes.

General circulation models (GCMs) are the main tools today for simulating present and future climate conditions. These models have shown their efficiency to simulate the large-scale variables of historical climate and that’s why they are widely employed to study the impacts of greenhouse gases increasing concentrations on the global climate. CGMs include representations of surface hydrology, sea ice, cloudiness, convection, atmospheric radiation and other processes (Grotch and MacCracken 1991). Though differences between model formations may exist, most models project relevant results on a global extent. However in regional climate schemes they appear restrictions and large discrepancies are detected among models.

Various techniques have been developed to downscale information from GCMs to regional scales. Downscaling is the process of transforming information from climate models at coarse spatial resolution to a fine spatial resolution. Downscaling is necessary, as the underlying processes described by the environmental impact models are very sensitive to local climate, and the drivers of local climate variations, such as topography, are not captured at coarse scales. There are two broad categories of downscaling: dynamic (which simulates physical processes at fine scales) and statistical (which transforms coarse-scale climate projections to a finer scale based on observed relationships between the climate at the two spatial resolutions) (IPCC, 2007).

2. Study area and database

Lake Karla basin (Fig.1a) is an intensively cultivated agricultural region lying between latitude 39°20′56′ to 39°45′15′ N and longitude 22°26′10″ to 23°0′27″ E, which is the eastern part of Thessaly, Greece. The climate is typical Mediterranean with an average temperature of 16–17° C and mean annual relative humidity of 67–72 %. The average precipitation is 500–700 mm and occurs mainly in autumn, winter and spring. Most of the aquifer area is plain with an altitude ranging from 45 to 65 m.

The study watershed experienced severe, extreme and persistent droughts during the period from mid to late 1970s and the period from late 1980s to early 1990s. The prolonged and significant decrease of monthly and annual precipitation adversely affected the natural vegetation, the agriculture of the region and the available water resources (Vasiliades *et al*., 2009).

Monthly precipitation and temperature data of uniform distributed rain gauges across the watershed were available for 20 hydrological years from October 1980 to September 2000. Monthly areal precipitation and temperature of the basin were estimated by the Thiessen polygon method modified by the monthly gradients using the stations (Fig. 1b), which are within or in the vicinity of the watershed.

(a) (b)

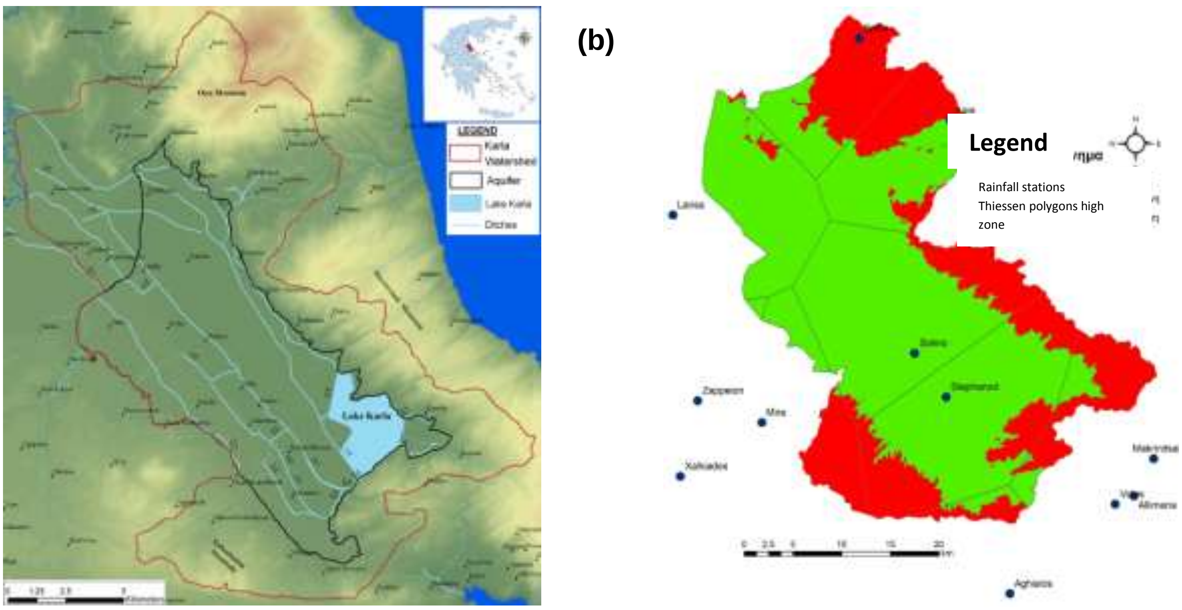

Figure 1: a) Lake Karla watershed b) Thiessen polygons for Lake Karla watershed

3. Methodology

The aim of this study is to develop a statistical downscaling method for monthly precipitation and temperature using a GCM and an impact model for three socioeconomic scenarios, namely SRES B1, SRES A1B and SRES A2. A statistical downscaling method with stochastic bias correction is developed using the outputs of the CGCM3 for the base historical period (1980-2000), and used to estimate monthly precipitation and temperature time series for two future periods (2030-2050 and 2080-2100) at the watershed level.

3.1. Statistical downscaling

The third generation GCM (CGCM3.1) of the Canadian centre for climate monitoring and analysis was used for the choice of predictor variables in downscaling procedure, a spectral model with resolution 3.75^o latitude and 3.75^o longitude (Flato and Boer, 2001). CGCM3 outputs are downscaled using multiple regression equations between GCM predictor output variables and areal monthly precipitation and temperature. The equations are developed for the historical 1980-2000 period.

Forward selection stepwise regression technique showed that the most important predictors for logarithmically transformed precipitation data are the Toa outgoing longwave flux (Rlut in w/m2) and the surface downward eastward stress (Tauu in Pa) while for temperature are the surface downwelling shortwave flux in air (Rsds in w/m2) and the geopotential height at 50hPa (Zg_50 in m). Dummy variables (a set of categorical variables assigned to the 12 months of the year) are used to account for the effect of the “month” on precipitation and temperature values. These can be viewed as a noise component, statistically independent of the large-scale climate (Vasiliades *et al*., 2009). In the formula:

$$P = P_{MLR} + P_{residual} \quad (1)$$

with P = observed monthly precipitation, P_{MLR} = monthly precipitation explained by multiple linear regression and $P_{residual}$ = residuals of MLR. If this operation is carried out on the estimated series of the regression fitting period (October 1980–September 2000), the result is the observed series. For the climate scenarios, P_{MLR} is obtained by downscaling the GCM outputs while $P_{residual}$ remains unchanged. In this way, the problem of limited correlation between predictor and predictand variables may be tackled. However, in order to estimate the uncertainty of the downscaling method, stochastic timeseries modelling was applied for the treatment of the residuals. Stochastic monthly disaggregation timeseries models applied for the annual precipitation and temperature residuals. In this study, the modified method of synthetic fragments proposed by Maheepala and Perera (1996) has been applied for generate synthetic monthly climate residual data and to preserve the cross-correlation between the two variables (downscaled residual precipitation and temperature).

Application of the modified method of fragments generated 100 synthetic climate residual timeseries each one of length equal to the length of historical data (20 years). The generated residual climate timeseries were added to the statistically downscaled climate results to reproduce the observed annual and monthly climate pattern. Finally, the developed MLR equations for temperature and rainfall were applied to estimate GCM derived future climate timeseries for the future periods 2030-2050 and 2080-2100, and then the 100 replicates of the present climate were added to GCM derived future timeseries assuming that the climate residual timeseries in the future have the same statistical characteristics of the historical period.

4. Results

Application of the statistical downscaling method for future periods and estimation of future precipitation and temperature timeseries showed small changes relative to the historical period. For the low elevation zone of Lake karla watershed (Fig.3a) mean annual precipitation for the historical period 1980-2000 is 466.78 mm and ranges from a minimum value of 345.90 mm to a maximum one of 616.00 mm. Climate change scenarios indicate that for the short-term future period 2030-2050 small changes of precipitation are expected. Mean annual rainfall for the

SRES B1 scenario is likely to increase by 0.7% while for the SRES A1B and SRESA2 scenarios is projected to decrease from 1.1% to 2.5%, respectively. For the future period 2080-2100 the changes of rainfall are more clearly identified. Mean annual precipitation is decreased for all the climate change scenarios from to 1.28% (SRES B1) to 5.59% (SRES A2). Mean annual temperature of the low elevation zone of Lake Karla watershed for the historical period 1980-2000 is 14.93 °C with a range from 12.73 °C to 17.18 °C. Mean annual temperature for SRES B1 is increased by 1.00% while for SRES A1B by 1.49% and for SRES A2 by 1.39% at the short-term future period. Similar increases are also observed for the long-term future period (increase of mean annual temperature by 1.96%, 3.00% and 4.10% for SRES B1, A1B and A2, respectively). Similar precipitation and temperature patterns are observed for the high elevation zone of Lake Karla watershed.

5. Concluding remarks

A hybrid statistical downscaling procedure was applied at the Lake Karla watershed for the assessment of climate change impacts on meteorological variables. Future meteorological schemes were developed for three socioeconomic scenarios and two future periods. The stochastically generated results of areal precipitation and temperature, as well as potential evapotranspiration which was calculated from the temperature timeseries showed that climate change scenarios project mild changes for the short-term period and moderate for the long-term period. Future work may be focused in the use of this process in climate change impact assessments with employment of a larger number of GCMs.

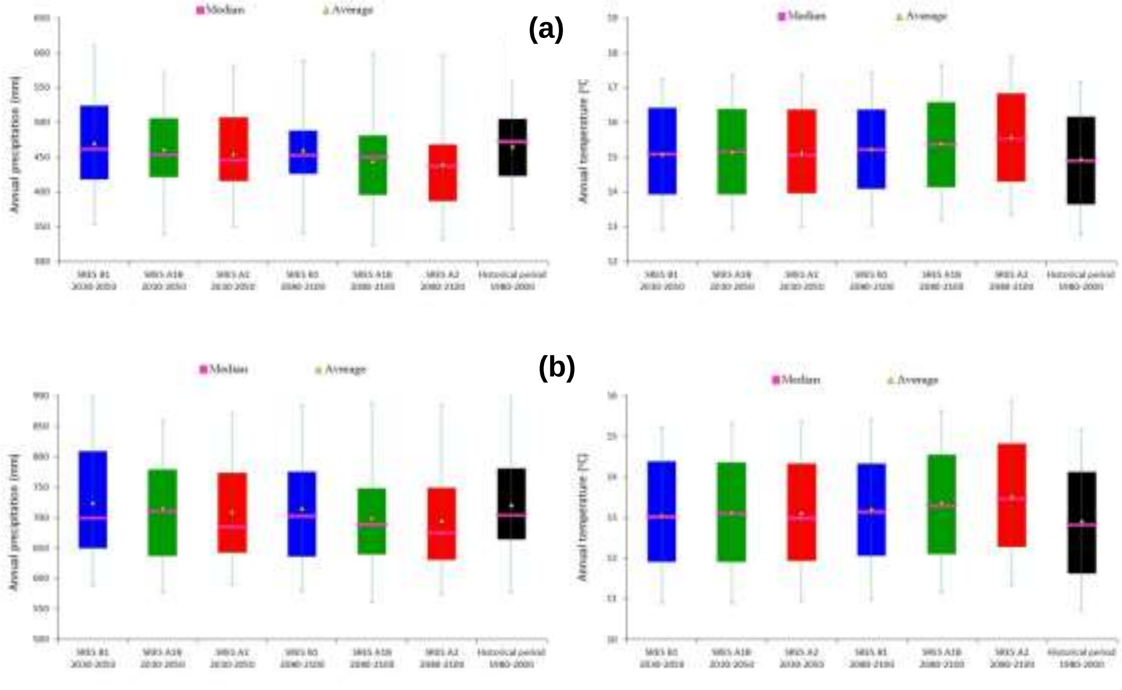

Figure 2: Historical and downscaled precipitation and temperature for: (a) low elevation zone of the Lake Karla watershed, and (b) high elevation zone of the Lake Karla watershed

ACKNOWLEDGEMENTS

This study has been financially supported by the research project "Hydromentor" funded by the Greek General Secretariat of Research and Technology in the framework of the E.U. co-funded National Action "Cooperation".

REFERENCES

1. IPCC (2001), Climate Change 2001 - The Scientific Basis. Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change (IPCC), Houghton, J. T. Ding, Y., Griggs, D.J., Noguer, M., van der Linden, P. J., and D. Xiaosu (Eds.), Cambridge University Press, UK, 881 pp, 2001.
2. SWCS. Conservations implications of climate change: Soil erosion and runoff from cropland.A Report from the Soil and Water Conservation Society. Soil and water Conservation Society, Ankeny, Iowa.http://www.swcs.org/docs/climate change-final.pdf. 2003
3. Grotch, S. and MacCracken, M.C. (1991), The use og general circulation models to predict region climate change.Int.J.climatology.,4 , 286-303, 1991.
4. Vasiliades, L., Loukas, A. and Patsonas, G. (2009), Evaluation of a statistical downscaling procedure for the estimation of climate change impacts on droughts. Nat. Hazards Earth Syst. Sci.; 9: 879-894.
5. Flato, G.M., Boer, G.J.: 2001, Warming asymmetry in climate change simulations. Geoph. Res. Lett.; 28: 195-198.
6. Intergovernmental Panel on Climate Change, (IPCC): Climate Change (2007), The physical Science Basis, in: Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, edited by: Solomon, S., Qin, D., Manning, M., Chen, Z., Marquis, M., Averyt, K. B., Tignor, M., andMiller, H. L. (2007), Cambridge University Press, Cambridge.
7. Maheepala, S. and Perera, C.J.C. (1996), Monthly hydrologic data data generation by disaggregation. J. Hydrol.; 178: 277-291