Article

Evaluation of extreme dry and wet conditions using climate and hydrological indices in the upper part of the Gallikos River Basin

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Abstract: Climate changes in the Mediterranean region especially those related to changes in rainfall distribution and occurrence of extreme events affect local economies. Agriculture is a sector strongly affected by climate conditions and concerns the majority of the Greek territory. The Gallikos river basin is an area of great interest regarding climate change impacts since it is an agricultural area depended on surface water resources and an area in which extreme events relatively often take place (e.g. floods). Long time series precipitation (27 years) and temperature data derived from measurement stations along with reanalysis data (ERA INTERIM) were used for the estimation of water availability and climate type over time in the area. The Standardized Precipitation Index and De Martonne aridity index was employed. The water flow measurements were correlated in order to investigate the interrelation between the different river branches and the extent of the meteorological changes effect in the basin. Descriptive statistics and cumulative curves were applied to check homogeneity of data. The results revealed that the climate type varies from semi arid to very wet and water availability ranges from moderately dry to extremely wet years. Reanalysis data overestimate precipitation. The meteorological changes affect at the same time the entire basin since the flow rate peaks occur simultaneously in the hydrographic network at different areas.

Keywords: Gallikos; Standarized Precipitation Index; De Martonne Aridity Index; Floods;

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1. Introduction

The Intergovernmental Panel on Climate Change (IPCC) since 2008 has highlighted the vulnerability of freshwater resources against the observed climate change and pointed out the consequences on humans and ecosystems [1]. Climate change is a global phenomenon and many areas will be affected worldwide as well as in Europe [2]. Mediterranean basin is considered to be one of the most prone areas to the impacts of climate change as it is mentioned by many researchers in their publications starting from the previous decade [3, 4]. The impacts of climate change on water resources, environment and main economical sectors is a critical issue that constitutes a matter of concern for the Greek researchers [5, 6, 7, 8, 9, 10, 11]. In the year 2009, the Interdisciplinary Climate Change Impacts Study Committee was set (CCISC) up by the Bank of Greece for studying these impacts indicating the awareness of the Greek scientific society about climate change.

The climate of Greece is predominantly classified as Mediterranean [12] ranging locally to different climate types due to the geography, the extended coastlines and the large number of islands. According to the Hellenic National Meteorological Service (HNMS) the main climate types that occur in Greece are Bsk, Bsh, Cfa, Csa [13]. The first two aforementioned climate types correspond to semi arid types and therefore the areas belonging to these zones are suffering from long dry periods during the summer and are subjected to severe stress due to the agricultural and touristic activities. The spatial distribution of the climate in relation to water resources and crops has been investigated over the last decades using climate indices and relative thematic maps that depict the climate zonation for the Greek extent have been designed [14, 15].

The Gallikos river basin is an agricultural area and a significant percentage of the residents are employed in this sector. The main crops are corn, tobacco, cotton and sunflower that have high irrigation demands. Groundwater exploitation along the river banks is the main source in order to meet these demands. River is the main recharge source of the aquifers. Surface water abstractions for irrigation purposes take place by the construction of very small scale dams or by direct abstractions. Extreme flooding events have been recorded over the last decades inundating large areas resulting in human losses, infrastructure and agriculture damages [16]. The most recent events were recorded during the years 2004, 2014 and 2015. According to HNMS the climate of the studied area is characterised as cold semi-arid (Bsk). Therefore, the Gallikos study area was selected as an indicative and representative case study for the investigation of the climate characteristics and its hydrological behaviour under extreme conditions.

2. Materials and Methods

Regional setting

The upper part of Gallikos river basin is located in northern Greece and has an a extent of 868km^2. The river length within the boundaries of the study area is 45km. A very dense hydrographic network is developed in the area (see Figure 1). The water flow has a seasonal character [17]. The main geological formations that outcrop in the basin are Quaternary and Tertiary sediments, limestone and dolomites and crystalline bedrock formations (gneiss, quartzites, schists) [18].

Data collection and analysis

Precipitation and temperature data were derived from reanalysis data base ERA-Interim (spatial resolution 12.5km×12.5km) for the time period 1980-2006. Data from rain gauges and temperature measurement stations that were operating in the area for the same time period under the supervision of the competent authorities were also evaluated. During the years 2004 to 2006 the river water flow rate was measured at different major branches of the hydrographic network (see Figure 1) at specific time intervals and after rainfall events [19]. Descriptive statistics were applied on data. The Standarized Precipitation Index (SPI) and de Martonne Index was applied to investigate water availability and aridity of the studied region over the years.

SPI is a widely used index to characterize meteorological drought by quantifying precipitation deficit [20]. Depending on the SPI timescale range, drought impacts reflect the water availability on different water resources (e.g. soil moisture for short timescales, groundwater and reservoir storage for long timescales). In the present paper a 12month timescale SPI was calculated for reanalysis and raw data.

The de Martonne aridity index is utilized as a measure of the aridity of an area at a local level [15]. Both annual and monthly values were calculated in the present study for reanalysis and raw data.

Annual cumulative curves are used in order to investigate the homogeneity of the measurements between the different rain gauges comparing each station with the others. The coincidence of the points on a straight line, could mean that there is dependence between the rain gauges.

3. Results

The mean precipitation and temperature for the entire basin was estimated for the period 1980-2006. The results that are depicted in Table 1 showed that the reanalysis data overestimate the precipitation values, while the temperature values are quite similar. The homogeneity tests that were conducted between the data showed that all the measurements are quite reliable since the cumulative curves form straight lines with very high dependence.

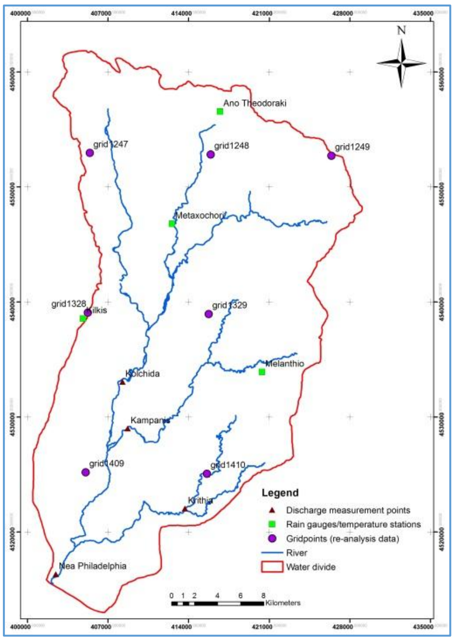

Figure 1. Map of the upper part of the Gallikos river basin

Table 1. Mean annual precipitation and temperature for period 1980-2006 of the upper part of Gallikos basin.

	Mean annual
Precipitation (mm)	
grid1409	603.90
grid1410	600.82
grid1328	609.44
grid 1329	608.2
grid1247	614.06
grid1248	618.08
grid1249	620.38
Re-analysis data	**610.7**
Kilkis	429.55
Ano Theodoraki	442.91
Melanthio	592.37
Metaxochori	516.24
Raw data	**495.26**
Temperature (°C)	
grid1409	13.65
grid1410	13.79
grid1328	13.37
grid 1329	13.48
grid1247	12.98
grid1248	13.05
grid1249	13.11
Re-analysis data	**13.35**
Ano Theodoraki	13.37
Melanthio	13.00
Metaxochori	14.97
Raw data	**13.78**

In Figure 2 the river discharge fluctuation is depicted for the years 2004 to 2006 at four different locations (see Figure 1). The distribution of the values seems to follow a typical hydrological pattern for Greece. During summer months the lowest values are recorded. An increasing trend appears at the end of autumn along with precipitation increase and in winter (after January) that soil is saturated the discharge has a continuous increase till the early summer months that starts to reduce as it is expected. The curves that illustrate discharge are parallel. Peaks and low values occur at the same time. The different branches of the river are recharged mainly from rain (only a small number of springs with very small contribution to the river flow rate occur in the area) and drain distinct parts of the basin apart from Nea Philadelphia that is the receiver of the entire network discharge. The similarity of the fluctuation indicates, as a general rule, that the meteorological events (e.g. rainfall incidents or drought periods) affect the hydrographic network of the entire basin the same way.

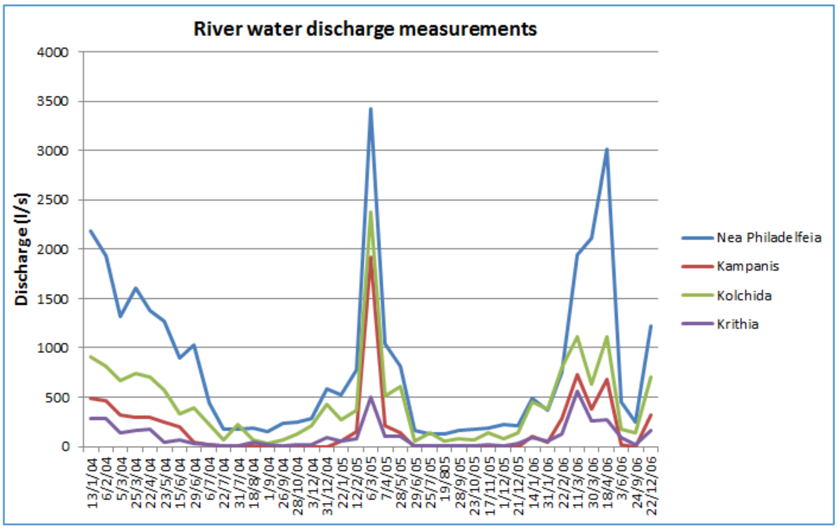

Figure2. Fluctuation of discharge (2004-2006)

De Martonne aridity index for raw data showed a variation of the climate categories from semi dry to humid climates. More specific for the 27 years, the climate percentages were: Semi dry 40.8%, Mediterranean 25.9%, Semi humid 14.8% and Humid 18.5%. It is noticeable that five consecutive years (1990-1994) were recorded as semi dry period while the most humid period was between 2002-2006. The corresponding percentages for the reanalysis data were: Semi dry 7.4%, Mediterranean 22.2%, Semi humid 25.9%, Humid 33.3% and Very Humid 11.2%. These results suggest that the reanalysis data present much more wetter years compared to the raw data. According to the monthly de Martonne index of raw data for the time period 1980-2006, the land needs to be irrigated during the months June, July, August and September.

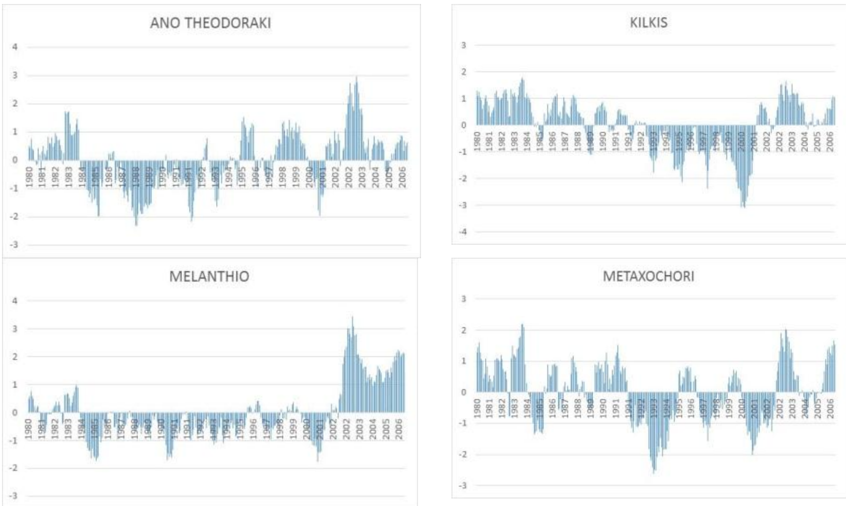

Figure 3. SPI -12 results for raw data.

The results of SPI index for 12month timescale for raw and reanalysis data are depicted in Figure 3 and Figure 4, respectively.

As shown in Figure 3, there is a continuous change between wet and dry periods. The Melanthio rain gauge appeared to have the longest drought period, from 1984 to 2002, while for the Ano Theodoraki station the dry period was from 1984 to 1995. The drought period for the Kilkis and Metaxochori stations was shifted to 1991 and 2001 showing a delay of approximately 10 years. The SPI values based on the reanalysis precipitation data are closer to the two northern stations (Ano

Theodoraki and Metaxochori). All grid points showed that the period 1991 to 1995 was the driest one which is in accord with the De Martonne results.

Figure 4. SPI -12 results for reanalysis data.

4. Discussion and Conclusions

Water resources of Gallikos basin are under severe stress as it is revealed by the application of SPI and de Martonne indices due to the long drought periods that last even for decades. The agricultural sector is depended on water resources and therefore the economy of the area. The water resources managers that are involved in the area should act as soon as possible in order to prevent and reverse the existing and upcoming impacts from climate change and extreme conditions. Indicative set of measures could include change of cultivation types, construction of infrastructures for the exploitation of surface water (such as dams or implementation of artificial recharge), change of irrigation methods and sufficient presence of the state control mechanisms.

Abbreviations

The following abbreviations are used in this manuscript:

IPCC: Intergovernmental Panel on Climate Change
CCISC: Climate Change Impacts Study Committee
HNMS: Hellenic National Meteorological Service
SPI: Standarized Precipitation Index

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Conflicts of Interest: The authors declare no conflict of interest.