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# IMPACT OF CHANGING RAINFALL CONDITIONS ON SURFACE AND GROUNDWATER RESOURCES IN AN EXPERIMENTAL WATERSHED IN GREECE

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**ABSTRACT**
The present study concerns the impact of a change in the rainfall regime on surface and groundwater resources in an experimental watershed. The research is conducted in a gauged mountainous watershed (15.18 km$^2$) that is located on the eastern side of Penteli Mountain, in the prefecture of Attica, Greece and the study period concerns the years from 2003 to 2008. The decrease in the annual rainfall depth during the last two hydrological years 2006-2007, 2007-2008 is 10% and 35%, respectively, in relation to the average of the previous years. In addition, the monthly distribution of rainfall is characterized by a distinct decrease in winter rainfall volume. The field measurements show that this change in rainfall conditions has a direct impact on the surface runoff of the watershed, as well as on the groundwater reserves. The mean annual runoff in the last two hydrological years has decreased by 56% and 75% in relation to the average of the previous years. Moreover, the groundwater level follows a declining trend and has dropped significantly in the last two years.

**KEYWORDS**: Hydrometric stations, raingauges, field measurements, runoff.

## 1. INTRODUCTION

Human-induced warming of the climate system is widespread and can be detected in temperature observations taken at the surface, in the troposphere and in the oceans (Hegerl *et al.,* 2007), with a serious impact on the hydrogeological conditions of a region. Manabe *et al.*, 2004 used a coupled atmosphere-ocean-land model to explore the response of the global water cycle to an increase in carbon dioxide, focusing on river discharge and soil moisture. Their results suggest that water is going to be more plentiful in those regions of the world that are already 'water-rich'. However, water stresses will increase significantly in regions and seasons that are already relatively dry. Some parts of the globe will get hotter and drier while other parts will get hotter and wetter. Wetherald and Manabe (2002) investigated the change in water availability which is expected to occur by the middle of the 21st century under the IS92a scenario (Houghton *et al.*, 1992). Eastern Europe is expected to experience increasing temperature and decreasing precipitation in summer (Chang *et al.,* 2002; Panagoulia *et al.,* 2008; Oikonomou *et al.,* 2008).

Although climate change occurs at a global scale, its impacts are sensitive to a particular scenario and a region being examined and there has been an increasing trend for the investigation on a regional basis (Lekkas *et al.*, 2008; Courbis *et al.*, 2008). Lange *et al.,* 2008 assess the climate change impacts in the Barents Sea Region. River discharge and freshwater runoff to the Barents Sea under changing climate was investigated by Dankers and Middelkoop (2008). The results of their model (BarentsFlow) clearly indicate that the hydrological characteristics of the sub-arctic environment studied will change considerably. This is mainly due to a reduction of the snow season by 30 to 50 days and increased evapotranspiration in the summer (Stathis and Myronidis, 2009).

Moraes *et al*. (1998) detected the changes in the patterns of flow in a subtropical river basin located in the southeastern region of Brazil and its possible relation to man-induced changes. Statistical analyses were performed on records of precipitation, evapotranspiration and streamflow, from 1947 to 1991. From eight streamflow gauge stations, half showed significant decreasing trend. Chang *et al.,* 2002 assessed the regional impact of climate change on runoff in a mountainous region of southwestern Bulgaria. A GIS-based distributed hydrologic model and two climate change scenarios – HadCM2 and CCC – were employed for years around 2025 and 2085. Results from both scenarios demonstrated the sensitivity of runoff to climate change, which produce significant spatial and temporal changes in the basin's water yield with maximum runoff shift into early spring and further decreases in summer runoff.

The meteorological conditions and especially the annual rainfall volume, as well as the temporal distribution of rainfall exert a great influence on the hydrogeological conditions of a region. The present study concerns the impact, on a regional basis, of a substantial change in the rainfall regime during the last two hydrological years, on surface and groundwater resources in an experimental mountainous watershed in Attica, Greece. Rainfall-runoff data of the last five year period (2003-2008) were analyzed in order to determine the changes in rainfall characteristics and then associate them with stream runoff at the outlet of the experimental watershed, as well as with the groundwater resources. The analysis of groundwater level data resulted in important conclusions regarding the trend of the groundwater reserves in the area.

## 2. STUDY AREA

The experimental watershed (Figure 1) is located on the eastern side of Penteli Mountain, in the prefecture of Attica, Greece. The total area of the watershed is 15,18 $km^2$, its geometric figure is oblong in the North-South direction and the mean, minimum and maximum altitudes are 430, 146 and 950 m, respectively. The watershed is characterized by steep slopes; the mean slope is equal to 21%. The prevailing type of landcover is pasture areas. The vegetation is dense, consisting mainly of small bushes. A significant percentage (29%) of the total watershed area comprises of the rapidly developing settlement of Drafi, which is located on the southern part of the watershed. The landuses and the respective percentages are shown in Table 1.

Geologically, the study area consists approximately of 60% schists, 23% conglomerates, 9% marls and marly limestones and 8% marbles. The geologic formations that prevail in the northern part are Schists with marble intercalations and marbles. The small percentage of marbles is characterized by high water capacity and very low to zero runoff coefficient, owing to the numerous fractures that have been extended by the karstic process. A karstic aquifer is located on the northeastern part of the watershed, at the altitude zone between 500 and 800 m. It contributes significantly to the baseflow, which is constant throughout the year. In the southern part of the watershed, there are compact conglomeratic formations in alterations with clay and marl layers. This structure leads to the formation of successive aquifers in the water permeable layers of conglomerates and marly limestones. Groundwater level measurements are made once a month at three municipal bores and twice a year (in high season; late March and low season; late September) at selected residential bores.

The installed equipment consists of a dense raingauge network that has been operating since October 2003 and two hydrometric stations. The raingauge network consists of three gauges that are properly installed at sites of different altitude; 203, 383 and 630 m, respectively. The gauges' records have a ten-minute time step. The first hydrometric station has been operating since January 2003 and is located on the watershed's outlet, where stage-discharge measurements are made for the derivation of the stage-discharge equation. The second hydrometric station (spillway construction) has been operating since January 2005. It is installed at the outlet of the northern subwatershed (in Figure1), which constitutes about 51% of the extent of the total watershed. The water level is recorded at ten-minute intervals at both hydrometric stations.

The length of the main channel is 7.456 m and the density of the channel network is 3.72 km $km^{-2}$, which implies very good drainage. The baseflow reaches a minimum value in late summer and a maximum in spring. The climate in the prefecture of Attica is Mediterranean and most of the rainfall events occur between October and March.

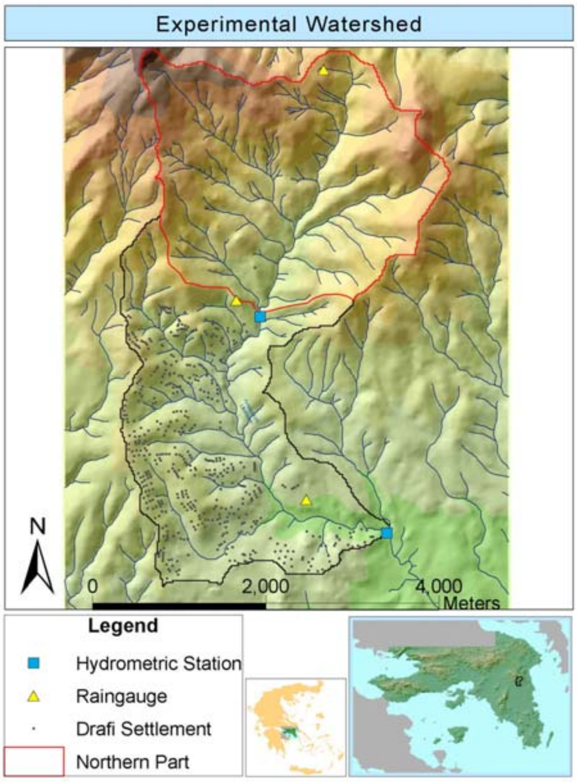


*Figure 1.* The study area

*Table 1.* The landuses of the experimental watershed

| Landuse | Area ($m^2$) | Percentage % |
|---|---|---|
| Pasture | 10.657.896 | 70,2 |
| Wood | 113.247 | 0,7 |
| Inhabited area (Drafi) | 4.411.657 | 29,1 |
| SUM | 15.182.800 | 100 |

## 3. DATA ANALYSIS

All data that were used in this paper are publicly available via the website: http://www.xbasin.chi.civil.ntua.gr. The rainfall data on a ten-minute time step of the period 2003-2008 were processed for the derivation of the daily, monthly and annual surface values. The Thiessen Polygon method (Wride *et al.,* 2004; NRCS, 1993) was used for that purpose.

The stage-discharge equation, compiled from the field measurements at the outlet of the watershed, was used for the calculation of runoff on a ten minute time step, using the Stout water level correction method. The mean daily runoff values were calculated on the next step and finally the mean monthly values. The absolute altitude of groundwater level was calculated at each bore from the measured water depth and the altitude of each measurement site.

## 4. RESULTS AND DISCUSSION

### 4.1 Decrease in rainfall depth and change in the monthly distribution of rainfall

The annual surface rainfall depth for the hydrological years from 2003-2004 until present is depicted in Figure 2. As shown, there is not any extraordinary change in the annual rainfall depth in the area during the first three years (from 2004 to 2006), while a drop is observed in the last two years, 2007 and 2008. The decrease in the annual rainfall for each of the last two years is 10% and 35%, respectively, in relation to the average value of the previous years. It must be noted that the calculation of the average value was made from the first and the third hydrological year. If the exceptionally high rainfall depth (881mm) of the year 2004-2005 was taken into account, then the average value would be greater and would lead to the calculation of greater drops in rainfall depth. The calculation of the annual rainfall of the present hydrological year was made until May 2008. It is not expected to increase substantially in the next few months until the end of the hydrological year.

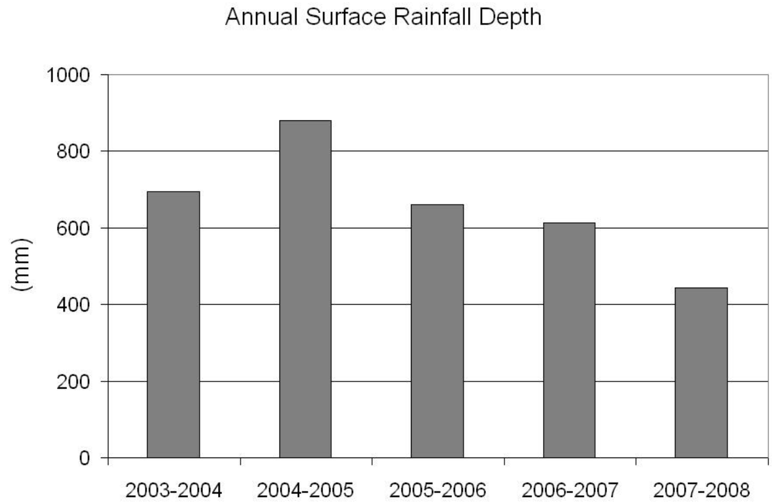


*Figure 2.* The annual surface rainfall in the study area

A thorough search into the monthly distribution of rainfall (Figure 3) shows that there is a distinct decrease in the winter (especially December and January) rainfall depth during the last three years. Concerning December, the average monthly rainfall depth of the hydrological years 2003-2004, 2004-2005 is 200 mm. The decrease in December rainfall depth for the next three hydrological years is dramatic, reaching 83, 89 and 53%, respectively. Regarding the monthly rainfall depth of January, the average value for the hydrological years 2003-2004, 2004-2005 is 243 mm. The decrease in the rainfall depth of January in the next three hydrological years is substantial; it is 56, 97 and 86%, respectively.

Moreover, it is worth noting that the snowfall height in the area during the study period is not remarkable; it is about 15 cm, with an exception in the winter of 2004 and 2008, when the total snowfall height reached about 55 cm.

The change in the monthly distribution of rainfall is especially important for water resources management, since the rainfall that more effectively contributes to the enrichment of groundwater reserves and furthermore to the watershed's baseflow is that occurring in winter period. This is owed, among other factors, to the fact that in winter the rainfall type is characterized by long duration and low rainfall intensity, allowing a greater percentage of water to percolate into the ground. Moreover, the losses due to evapotranspiration are lower. The significant decrease in winter rainfall depth during the last three years is partly compensated from an increase in rainfall in the spring months. However, the storm type in this time period is characterized by greater rainfall intensity and shorter duration, while the losses due to evapotranspiration are greater. Consequently, the change in the monthly distribution of rainfall results in considerable decrease of the water amount that percolates into the ground.

**4.2 Effect of the altered rainfall regime on runoff**

The change in the rainfall conditions has a direct impact on the surface runoff of the watershed. The mean annual runoff at the outlet of the watershed is depicted in Figure 4. As shown, the mean annual runoff of the first three hydrological years remains about the same (0.081 $m^3$ $s^{-1}$). However, the mean annual runoff of the hydrological year (2006-2007) has decreased by 56% in relation to the average value of the first three years. Furthermore, in the current hydrological year (2007-2008) and under the optimistic scenario that the monthly runoff of June, July, August and September will remain steady at the value of May, the decrease in the mean annual runoff reaches 75% in relation to the average value of the first three years.

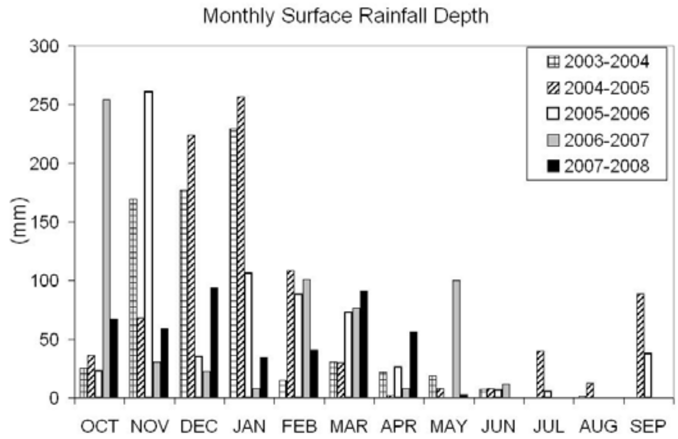


*Figure 3.* Monthly distribution of rainfall in the study area

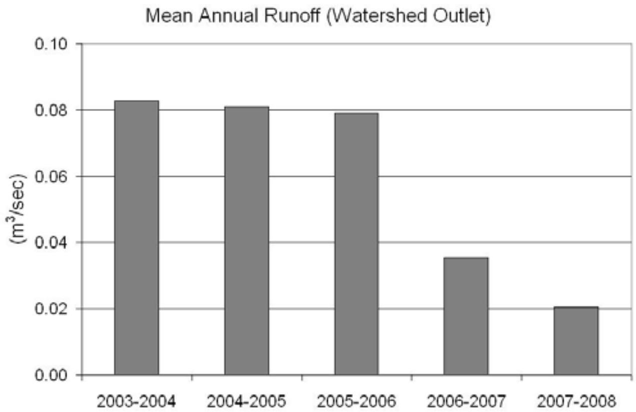


*Figure 4.* The mean annual runoff at the watershed outlet

Regarding the monthly distribution of runoff, the mean monthly runoff for each hydrological year is depicted in Figure 5. As shown, the mean monthly runoff in each successive hydrological year gradually decreases, with the more distinct changes observed in the winter months of the last two years. The mean runoff in March has also decreased, despite the fact that the rainfall in this month has increased during the last three years in relation to the previous years. This is mainly owed to the descending baseflow that directly depends on the precipitation of the previous months. The decrease in surface water resources is alarming. If the present rainfall conditions continue in the next few years, the stream baseflow will undoubtedly decrease to zero.

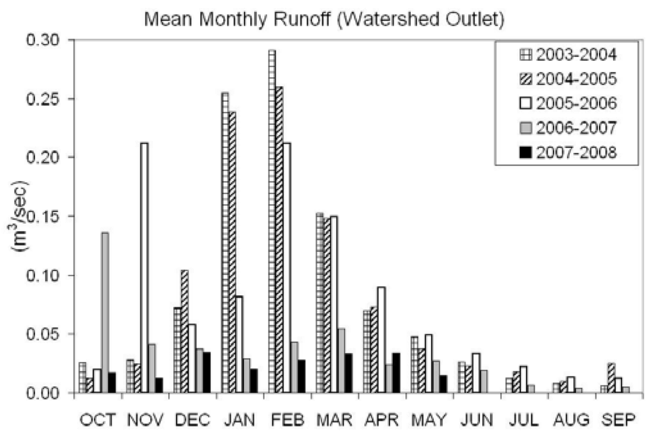


*Figure 5.* Monthly distribution of runoff at the watershed outlet

**4.3 Effect of the altered rainfall regime on groundwater reserves**

The decrease in the annual rainfall depth and the change in the monthly distribution of rainfall volume have a great impact on groundwater reserves. The monthly groundwater level measurements at a municipal bore located near the centre of the southern part of the watershed, during the time period (2004-2008), are depicted in Figure 6. The particular site was chosen, since this municipal bore is rarely used and is relatively isolated, away from the effect of nearby residential bores. Thus, the measurements at the particular site have the greatest possible reliability. As illustrated, a steady dropdown rate (of 0.5 m $year^{-1}$) of the high season (March) groundwater level is observed at the particular site. The comparison with data at other measurement sites showed a common feature, which is the decrease in the high season groundwater level during the last two hydrological years, 2006-2007 and 2007-2008, in relation to the measurements of the two previous years. The decrease at the other measurement sites is more abrupt, due to the regular water pumping for residential use. According to the data, the spatially averaged groundwater level of March 2008 has dropped about 3 m, in relation to the respective value of March 2006.

Except from the aquifers in the southern part, a decrease in the groundwater reserves is also remarked in the northern part of the watershed. This is indirectly observed through the discharge of the springs that are formed at the contact between schists and marbles. The total flow rate of these springs is measured through the hydrometric station at the outlet of the uninhabited northern subwatershed. The stream flow data at this measurement site show that the base flow gradually decreases; for instance, the mean baseflow of May 2008 was 17 l $sec^{-1}$, while the respective value two years ago was 39 l $sec^{-1}$.

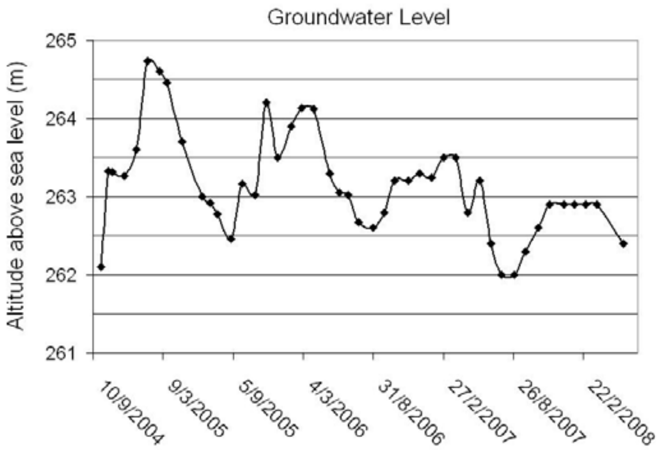


*Figure 6.* The dropdown of groundwater level at a measurement site in the southern part of the watershed

**5. CONCLUSIONS**

The present research shows that there is a significant change in the rainfall conditions in the study area of the experimental watershed. A remarkable decrease in the annual rainfall depth is observed in the last two years, reaching 10% and 35%, respectively, in relation to the average value of the previous years. In addition, there is a substantial change in the monthly distribution of rainfall, characterized by distinct decrease in the winter rainfall depth.

This change in rainfall conditions has a direct impact on the surface runoff of the watershed. The decrease in the annual runoff in the last two years is 56% and 75% in relation to the average value of the previous years. Concerning the groundwater reserves, the measurements at bores in the southern part of the watershed show that the high season groundwater level has dropped about 3 m, spatially averaged, in relation to the measurements of the hydrological years 2004-2005, 2005-2006.

The persistence of the rainfall conditions of the two last two years in the future will gradually lead to the critical reduction in the groundwater reserves of the northern part of the watershed and consequently to the total lack of the watershed’s baseflow. The drop of the groundwater level will continue in the inhabited southern part, perhaps with a faster rate, due to the lack of feed of the aquifers from the stream baseflow. Concerning the measures that could be taken, firstly, a rational exploitation of the existing groundwater reserves is necessary from the local community. This is feasible through restrictions on the maximum water volume pumped from each bore. Another, long-term, measure is the reforestation of the area for the increase in the infiltrated amount of water.

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