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Nicolaos Lambrakis
George Stournaras
Konstantina Katsanou *Editors*

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Climate Change Implications on Groundwater in Hellenic Region

G. Stournaras, G. Yoxas, Emm. Vassilakis, P.T. Nastos

Faculty of Geology and Geoenvironment, University of Athens, GR 157 84, Greece.
stournaras@geol.uoa.gr

Abstract There is a general consensus that climate change is an ongoing phenomenon. This will inevitably bring about numerous environmental problems, including alterations to the hydrological cycle, which is already heavily influenced by anthropogenic activity. The available climate scenarios indicate areas where rainfall may increase or diminish, but the final outcome with respect to man and environment will, generally, be detrimental. The research is focused on the climate change implications to the underground water tables of the mainland in Greece, excluding the island complex. It is based on regional climate models (RCMs) simulations under emission scenarios (SRES) A1B (3.5 ^{o}C), A2 (4.5 ^{o}C) and B2 (3.1 ^{o}C), for specific climatic zones of the Greek area during the period 2011-2100, which were estimated by the third report of IPCC.

1 Introduction

Climate change in combination with increased anthropogenic activities will affect water resources throughout the world. This paper gives information concerning the impacts of climate change on water resources, and particularly groundwater. Climate variability and change can affect the quantity and quality of various components in the global hydrologic cycle (Milly et al. 2005).

The Intergovernmental Panel on Climate Change (IPCC 2007) estimates that the global mean surface temperature has increased 0.6 ± 0.2 ^{o}C since 1861, and predicts an increase of 2 to 4 ^{o}C over the next 100 years. Global sea levels have risen between 10 and 25 cm since the late 19th century. As a direct consequence of warmer temperatures, the hydrologic cycle will undergo significant impact with accompanying changes in the rates of precipitation and evaporation. Predictions include higher incidences of severe weather events, a higher likelihood of flooding, and more droughts. The impact would be particularly severe in the tropical areas, which mainly consist of developing countries (Kumar 2005).

Although the most noticeable impacts of climate change could be fluctuations in surface water levels and quality, the greatest concern of water managers is the potential decrease and quality of groundwater supplies, as it is the main available

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potable water supply source for human consumption and irrigation of agriculture produce worldwide (Stournaras 2008). Because groundwater aquifers are recharged mainly by precipitation or through interaction with surface water bodies, the direct influence of climate change on precipitation and surface water ultimately affects groundwater systems.

Bearing the complexity of the linkage between climate change and groundwater in mind, it is necessary to adapt groundwater management accordingly and to consider the best options for developing and safeguarding groundwater resources. Main scope of this paper is to estimate the flux of groundwater's infiltration volume due to climate change.

2 Climate Scenarios

Fundamental cause forecasted at the future of anthropogenic changes of climate in world scale is the increase of greenhouse gases (GHG) due to human activities. For this aim, according to the third report of IPCC (2001) a big number of scenarios (in total 40) relative with the future development of emissions of greenhouse gases (Nakićenović et al. 2000) were made.

The total of scenarios covers the main uncertainties for the forecast of future emissions GHG based on the running knowledge and the initial "basic histories". Each one of the emission scenarios (SRES) constitutes simply a likely version of development of greenhouse gases. The simulations of the used regional climate models (RCMs) were carried out under SRES A1B, A2 and B2 respectively.

SRES A1B concerns economic growth that will be continued rapidly. The changes in the land use will not be enormous whilst the world population continues increasing rapidly up to year 2050 when it reaches about 9 billion and afterwards decreasing progressively. The main sources of energy that will be used are coming either from mining fuels or alternative sources which will have an impact of increase of CO_2 emissions within the 21^{st} century, reaching the concentration of 720 ppm until the year of 2100.

SRES A2 refers in medium scale increase of income and particularly intense consumption of energy. The world population will continue increasing rapidly. The technological growth will be slow and partial, while medium to low changes in land use will take place. The increase of CO_2 emissions in the atmosphere will be rapid within the 21^{st} century reaching the concentration 850 ppm, at the year 2100.

SRES B2 reports in continuation of world economic growth while the technological changes are lower compared with them of SRES A1. The increase of CO_2 concentration in the atmosphere will continue within the 21^{st} century reaching 620 ppm until the year 2100.

3 Division of Greece in 12 climate zones

The climate of Greece shows high spatial variability due to intensive vertical partitioning and land/sea interaction. For this reason and taking into account that the spatial resolution of the RCMs data used in this study are quite satisfactory for describing the relief of Greece, climate change study was applied not only throughout the entire Greek peninsula as a whole but also for each one from the 12 climate zones that Greece has been divided according to Zanis et al. 2009. The 12 zones are the following (Fig.1): a) Mainland climate zones: Western Greece (WG), Central and Eastern Greece (CEG), Western and Central Macedonia (WCM), Eastern Macedonia-Thrace (EMT), Western Peloponnesus (WP) and Eastern Peloponnesus (EP), and b) Island complex climate zones: Crete (C), Dodecanese (D), Cyclades (CY) Eastern Aegean (EA), North Aegean (NA) and Ionian.

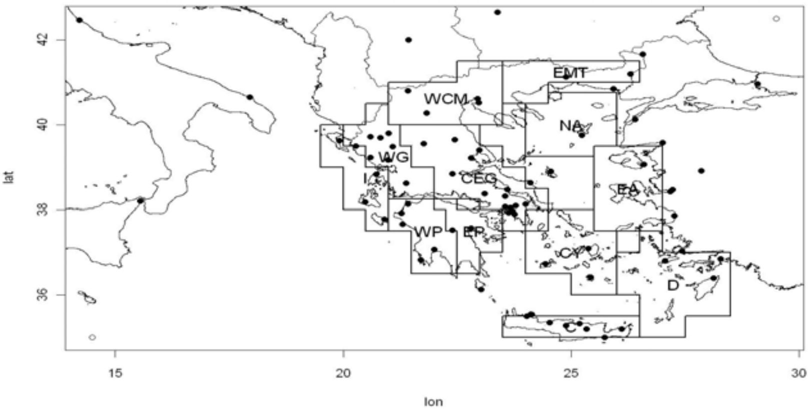

Fig. 1. The climate zones in which Greece was divided in. The black dots represent the 57 meteorological stations (from HNMS) used for the analysis (Zanis et al. 2009).

The above mentioned division was based on several climate and geographic criteria, the most important of which are the following: i) Pindos mountain range, which splits the mainland in the wet western area and the dry eastern area, ii) the frequency of either the tropical maritime or the polar continental air masses affect each area, which shows significant increase from south to north, especially during winter but also during the transitional seasons. Therefore the temperature shows high gradation along the north-south axis, iii) the high temperature variation between the island complex and the mainland areas, iv) the precipitation variation between the Eastern Aegean Islands and the Dodecanese where high values are recorded in contrast to extremely low precipitation values throughout the Cyclades Island complex (the climatic data concerning air temperature and precipitation totals from the 57 meteorological stations were acquired from Hellenic National Meteorological Service (HNMS).

4 Current Conditions

The status of Greece due to water reservation and management seems to be quite interesting, showing some peculiarities which indicate the level of true development and organization. From the water reservation point of view, Greece can be identified as a relatively rich territory concerning the rest Mediterranean frame (Stournaras 1998). The main reasons which are responsible for being identified as rich territory are related to the regime of the atmospheric precipitation. The precipitation totals in Greece shows an average value of 700 mm, which is rather interesting for the Mediterranean basin (Scoullos 2009). This is highly, related to the general factors which are responsible for the Greek climate and the weather phenomena, but also to the topography variation since the high relief near the coastline results in precipitation at mountainous areas. The most significant factor on this matter is the nearly north-south orientation of Pindos mountain range, the elevation of which in many cases exceeds 2,000 m. The wet air masses coming from the west (due to west atmospheric circulation) are blocked by this mountain range causing much more precipitation along the western than the eastern part of the country (Stournaras 2010). Additionally, due to the high relief contrast of the Greek peninsula, a dense drainage network pattern has been shaped leading the surface water to relatively large rivers which drain also the ground water in cases of additional surface discharge through springs. The cases of Transboundaries Rivers of northern Greece are referred as special cases as their entrance in Greece is being correlated with neighbor countries before their flow into north Aegean, e.g. Evros (Bulgaria, Turkey), Nestos, Strymon (Bulgaria), Axios (FYROM). The single case of reverse flow is represented by the river Aoos which starts from Greece and flows into Albania.

The underground water circulation is also a quite interesting matter since a large part of the Greek territory is consisted of permeable rocks, which accept the water through primary or secondary infiltration procedures and form the shape and the characters of the aquifers (Soulios 2010). Such cases can be identified in large continental basins or deltaic fans, the carbonate rocks of karst water tables (limestone, dolomites, marbles, and gypsum) and in extended igneous and metamorphic massifs (Stournaras et al. 2007).

Despite the fact that none of the 14 Water Districts (WD) of the country has not reported any problem for immediate water shortage according to Ministry of Development of Greece (2003), there are indications that the national water potential is decreasing, which is in agreement with the IPCC general findings for the climate change. Additionally, according to the results of the research project ENSEMBLES (http://www.ensembles-eu.org) the precipitation in central and northern Greece is gradually decreased during the last five decades. The reduction starts from 30 mm and regionally reaches 150 mm per decade. Also, the comparison between the river water flows for the periods 1900-1970 and 1971-1998 shows decreased water amount percentages between 5%-10% for the territory of

Greece in general, with the exception of Epirus District where the decrease percentages are not more than 2%-5% (Milly et al. 2005).

5 Observations and concessions for the estimation of water resources in Greece due to climate change

In order to estimate the country's expected water resources changes until the year 2100, several hydrological balance estimations were carried out for the periods 2021-2050 and 2071-2100. The main information came from the use of climate change modeling (precipitation and evapotranspiration in mm respectively). Specifically the simulations of the used RCMS were carried out for SRES A1B, B2 and A2.

Table 1. Modeling results for the main hydrologic balance parameters' change (R, I) of Greece's climate zones (CZ) and Water Districts (WD) for the periods 2021-2050 and 2071-2100 under different SRES scenarios.

A1B		2021-2050			2071-2100		
WD	CZ	R (hm^3)	I (hm^3)	Total (hm^3)	R (hm^3)	I (hm^3)	Total (hm^3)
1	WP	2455.32	1303.90	3759.22	2090.98	1208.15	3299.13
2	I	n/a	n/a	n/a	n/a	n/a	n/a
3	EP	-267.13	1214.01	946.89	-378.04	1091.76	713.72
4,5	WG	8247.09	6248.78	14495.86	7224.69	5936.71	13161.39
6,7,8	CEG	1875.80	2095.48	3971.28	2147.40	2064.74	4212.14
9,10	WCM	1018.33	1341.53	2359.86	1035.22	1330.11	2365.32
11,12	EMT	4239.73	1454.83	5694.56	3419.28	1335.75	4755.03
13	C	-142.94	471.34	328.41	-169.87	449.90	280.03
total				31556.08			28786.76

B2		2021-2050			2071-2100		
WD	CZ	R (hm^3)	I (hm^3)	Total (hm^3)	R (hm^3)	I (hm^3)	Total (hm^3)
1	WP	-528.02	436.98	-91.03	-256.60	420.48	163.88
2	I	n/a	n/a	n/a	n/a	n/a	n/a
3	EP	225.91	1543.55	1769.46	87.76	1345.88	1433.64
4,5	WG	2856.74	4315.04	7171.77	1625.28	3455.71	5080.99
6,7,8	CEG	3241.63	2224.22	5465.85	2567.20	1937.18	4504.38
9,10	WCM	72.06	1341.15	1413.21	34.37	1151.90	1186.27
11,12	EMT	2102.01	1260.46	3362.47	1144.64	1023.94	2168.57
13	C	-376.39	334.18	-42.21	-255.21	337.32	82.11
total				19049.52			14619.84

A2		2021-2050			2071-2100		
WD	CZ	R (hm^3)	I (hm^3)	Total	R (hm^3)	I (hm^3)	Total (hm^3)
1	WP	-528.02	436.99	-91.03	-254.82	388.75	133.93
2	I	n/a	n/a	n/a	n/a	n/a	n/a
3	EP	225.91	1543.55	1769.46	-41.55	1151.53	1109.98
4,5	WG	2856.74	4315.04	7171.77	2214.68	3487.28	5701.96
6,7,8	CEG	3241.63	2224.22	5465.85	1984.71	1655.22	3639.93
9,10	WCM	72.06	1341.15	1413.21	-70.43	1062.74	992.31
11,12	EMT	2102.01	1260.46	3362.47	1195.73	967.33	2163.06
13	C	-376.40	334.18	-42.21	-206.13	291.74	85.60
total				19049.52			13826.77

The interpretation of the results led to estimations of hydrologic balance parameters (Table 1) such as infiltration (I) and runoff (R) for the 2021-2050 and 2071-2100 period respectively.

It is obvious, according to the above estimations that the main parameters of hydrologic balance, which control the amount of groundwater, show a decrease correlated with current situation (Ministry of Development, 2003). Additionally, in some regions the runoff values are being described by a negative sign which means that they are showing a deficit character.

In order to describe the estimated change for every parameter of the hydrologic balance for the period of 2021-2100, a comparison of the results was made. The comparative results for all the described SRES scenarios led to the following conclusions (Table 2):

Table 2. Comparative results of the estimated change for every parameter of the hydrologic balance under different SRES scenarios (in %). (V: Precipitation, Etr: Evapotranspiration, I: Infiltration, R: Run off).

A1B				B2				A2			
V	Etr	I	R	V	Etr	I	R	V	Etr	I	R
- 5	- 2	- 5	- 12	- 15	- 12	- 16	- 35	- 22	- 20	- 21	- 37

According to the above resulted values at each SRES scenario, there is a clear decrease in groundwater's amount, due to climate change. The total precipitation amount is decreasing and subsequently the total infiltrating water is very likely to decrease from 5% (A1B) to 21% (A2) than today levels, and the total runoff will decrease from 12% (A1B) to 37% (A2) respectively throughout the mainland of Greece.

6 Estimations of groundwater decrease

In order to depict the correlation of rain volume V (hm^3) and volume of infiltrated water I (hm^3) cross plots diagrams were constructed (Fig 2 a, b, c), according to above resulted values at each scenario for the period 2011 - 2100. According to these diagrams it is obvious that due to precipitation's decrease the affection in ground water is instant.

Additionally, between 2011 and 2050 period the flux of infiltration water is rougher than between the period 2050 and 2100 respectively.

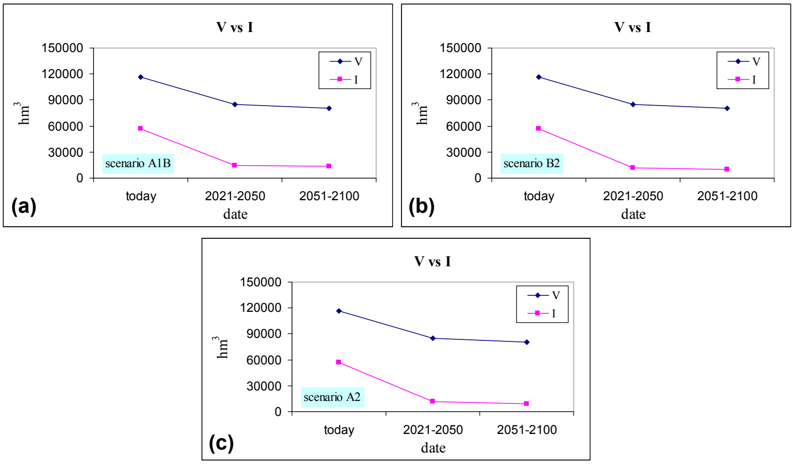

Fig. 2. Cross-plot diagrams showing the flux of precipitation's volume (V) versus volume of infiltrated water (I), (a) SRES A1B, (b) SRES B2, (c) SRES A2.

7 Conclusions

The implications of climate change on water systems in Greece and especially on groundwater systems can be summed up as following:

i. Decreased inflow and renewal of the aquifer water due to precipitation decrease and evapotranspiration increase.

ii. Increased salinization of the coastal and submarine water tables, especially the karstic ones and its advancing towards the mainland because of the land water decreasing potential due to less feeding and over pumping.

iii. Increased polluted load concentration in the coastal and sea water bodies due to less rarefaction.

iv. Intense disorganization of the deltaic fan areas as a result of either dam construction along the upstream zone (less flow, full deposition) and technical interference across the delta (leading the eroded material at a single mouth).

v. Pollution or exsiccation or the coastal wetlands.
vi. Aggravation of desertification phenomena due to water shortage and soil alterations (condensation etc.).

These conclusions should be combined with the fact that almost 75%-80% of the total water resources of the country are used for irrigation; it is more than obvious that these changes will have direct consequences on the type and extent of the cultivating areas along with the change of the agricultural methodologies.

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References

IPCC (2001) Climate Change 2001: The Scientific Basis, Contributions of Working Group 1 to the Third Assessment Report of the Intergovernmental Panel on Climate Change. In: Houghton J. T, Ding Y, Griggs D J, Noguer M, Van der Linden P J, Dai X Maskell K, Johnson C.A. (eds.) Cambridge University Press, Cambridge, UK

IPCC (2007) Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. In: Solomon S, Qin D Manning M, Chen Z, Marquis M, Averyt K B, Tignor M, Miller H L (eds.) Cambridge University Press, Cambridge, UK and New York, NY, USA, 966

Kumar K (2005) High-resolution climate change scenarios for India for the 21st century. Current Science 90, 334-345

Milly P C D, Dunne K A, Vecchia A V (2005) Global pattern of trends in streamflow and water availability in a changing climate, Nature 438, 347–350

Ministry Of Development (2003) Water Master Plan of Water Resources Management of Greece, Athens (in Greek)

Nakicenovic N, Alcamo J, Davis G, De Vries B, Fenhann J, Gaffin S, Gregory K, Grubler A, Yong Jung T, Kram T, Lebre La Rovere E, Michaelis L, Mori S, Morita T, Pepper W, Pitcher H, Price L, Riahi K, Roehrl A, Rogner H-H, Sankovski A, Schlesinger M, Shukla P, Smith S, Swart R, Van Rooijen S, Victor N and Dadi Z (2000) Emissions scenarios. Special Report of the Intergovernmental Panel on Climate Change, Cambridge University Press

Skoullos M (2009) Climate change in the Mediterranean region: Possible threats and responses in “Water Management”, Water Security and Climate Change Adaptation: Early Impacts and Essential Responses By Sadoff Cn and Muller M, GWP, TEC background papers No 14

Soulios G (2010) General Hydrogeology. Volume 1, Unioversity Studio Press, Thessaloniki

Stournaras G (1998). Hydrology of Greece, Papyrus – Larousse Encyclopaedia, Volume: Greece

Stournaras G, Migiros G, Stamatis G, Evelpidou N, Botsialas C, Antoniou V, Vasilakis E (2007) The fractured rocks in Hellas, Groundwater Hydrology SV

Stournaras G (2008) Hydrogeology and vulnerability of limited extension fissured rocks islands, Ecohydrology & Hydrobiology 8, No 2-4, 391-399

Stournaras G (2010) The water in Mediterranean, in “Losing Paradise”: The Water Crisis in the Mediterranean, Ashgate Publishing Ltd, UK

Zanis P, Kapsomenakis I, Philandras C, Douvis K, Nikolakis D, Kanelopoulou E, Zerefos C, Repapis C (2009) Analysis of an ensemble of present day and future regional climate simulations for Greece. Int. J. Climatol. 29, 1614-1633, doi:10.1002/joc

www.ensembles-eu.org. Research Project, EU