CLIMATE CHANGE IMPACT UPON WATER RESOURCES IN THE BUZĂU AND IALOMIȚA RIVER BASINS

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Key-words: climate change impact, hydrology, water resources.

L'impact de changements climatiques sur les ressources d'eau dans les basins versants des rivières Buzău et Ialomița. L'objectif de notre étude a été l'évaluation d'impacts de changement climatique sur l'hydrologie, en utilisant différentes simulations de changement climatique, dans les basins hydrographiques des rivières Buzău et Ialomița. La modélisation hydrologique basée sur des scénarios de changement climatique globale et régionale a indiqué des changements saisonniers remarquables dans l'écoulement des rivières. Ces changements étaient localement spécifiques, apparemment dans la connexion avec la position géographique et l'altitude des sous-bassins. Dans les mois d'hiver et printaniers, un écoulement augmenté et temporellement modifié a été modelé aux parties significatives de sous-basins situés dans les régions montagneuses. Pour les sous-bassins de plaine, la diminution d'écoulement est survenue pendant hiver et printemps.

1. INTRODUCTION

Information regarding the impact of climate change in hydrology and water management at regional and local scales is required in order to develop adaptation measures and mitigation strategies at national and regional level.

The aim of this study was to evaluate impacts of the future projected climate change impact on water resources of the Buzău and Ialomița rivers and also their tributary streams.

Covering an area of 14,392 km², Buzău and the Ialomița river basins are located outside the of Curvature Carpathian Mountains (Fig. 1) into an area characterized by the presence of a wide diversity of relief represented by mountains (31%), hills (34%) and plains (35%), varying from the heights of Bucegi Mountains (2,500 m) to the Romanian Plain, where the elevation is about 8 m.

The total hydrographical network of these two rivers basins has a length of 5,919 km and the reception area, represent about 6.6% of the country's surface.

Ialomița River, with a total length of 417 km and a general flow direction NW-SE, drains directly into the Danube River and has as main tributaries Prahova and Cârcinov rivers. A tributary of the Siret River, the Buzău River, with a length of 303 km, has the same general flow direction like Ialomița River and in turn has a number of tributaries with lower reception areas.

Morphology of these river basins and the climatic factors lead to a variation of vegetation and soils with the altitude. Also, in conformity of altitude, the annual precipitation varied from 1,400 mm/year, in the mountainous area to 400 mm/year in the plane area and the evapotranspiration between 500 mm/year in the high area to 850 mm/year in the plane area. However, due to a very high variability of weather conditions, droughts as well as excessive humidity periods occur in the course of a year.

In this area there are 8 reservoirs: Bolboci, Pucioasa, Dridu, Paltinu, Măneciu in Ialomița river basin and Siriu, Cândesti, Cireşu in Buzău river basin.

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Data series of 17 meteorological stations have used to estimate precipitation, air temperature, relative air humidity, wind speed and sunshine duration. In addition for precipitation are used data series of 89 rain gauging stations. In the analysed area the hydrological database includes data of 50 runoff gauging-stations.

Due to very big differences in data sets, the period from 1970 until 2000 was chosen because in this period for the most part of gauging stations there are continuous series of measured discharges.

For this study the mean monthly discharges at 4 gauging stations from the Buzău river basin and 13 gauging stations from Ialomiţa river basin are used for the analyse of flow modification in this area.

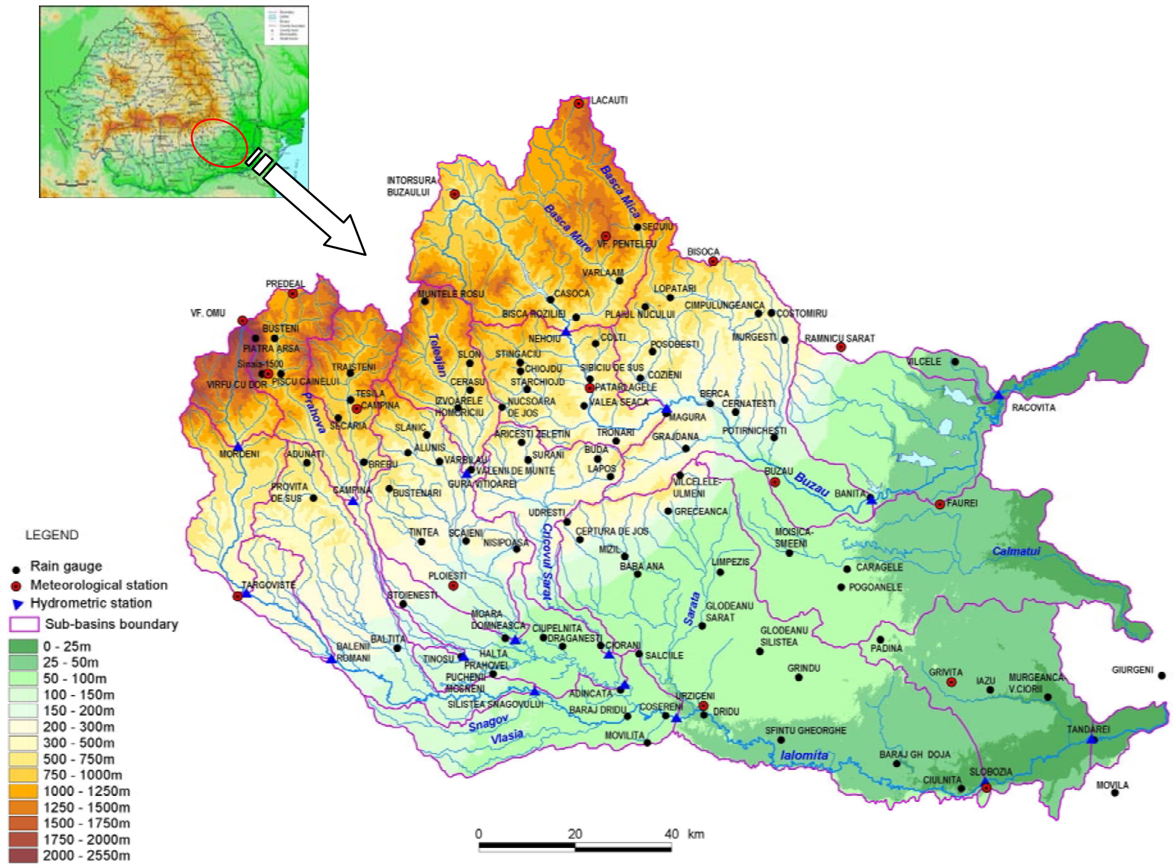


Fig. 1 – Buzău and Ialomiţa river basins and the analysed cross-sections.

The analysis of monthly river flow in future climate conditions derived from already existent simulations with global and regional climate models was achieved. A regional climate model (RegCM3) with two spatial resolutions (25 km and 15 km) was considered, the higher spatial resolution (10 km) simulations being achieved within the CECILIA project (http://www.cecilia-eu.org/).

The river flow analysis in different cross-sections of selected area was undertaken in order to describe the modifications of the surface water resources, in climate change conditions, from the upper parts of the basin towards the lowlands.

Evaluation of river flow is based on mathematical modelling of the precipitation-runoff process with the conceptual, spatially lumped water balance model WATBAL *(Yates, 1994)*.

The model calibration, based on historical data, is presented in section 2. Sections 4 and 5 show the results regarding the climate change impact on water resources based on simulations achieved with global climate models (GCMs) and regional climate model RegCM3, respectively. The conclusions are summarised in section 6.

2. MODEL CALIBRATION

For modelling the response of river basins to potential climate change, the WatBal model was used, a water balance model combined with the Priestley-Taylor method for computing potential evapotranspiration. The integrated tool designed in the EXCEL 5.0 is simple to use and takes advantage of IIASA's mean monthly hydrological data *(Yates, 1994)*.

The WatBal model will be adjusted to the local conditions of a specific region before modelling river basin water balance. In order to complete this task, the hydrological model was calibrated, for each analysed sub-basin, using the observed climatic data for the reference period 1971-2000. Climate input data used for the calibration of hydrological model were: total monthly precipitation and monthly mean of temperature, relative humidity, wind speed, sunshine duration or solar radiation. The observed series from the meteorological stations (and the rain stations in case of precipitation) corresponding of each sub-basin were used for computing the average values of mentioned climatic parameters.

The errors between the measured and simulated discharges were estimated by means of the following numerical criteria:

- The root mean square error (RMSE):

$$\mathrm{RMSE} = \sqrt{\frac{\mathrm{F}}{\mathrm{N}}} \tag{1}$$

with: $F = \sum_{i=1}^{N} \left(O_i - \hat{O}_i\right)^2$, where: O_i are the measured discharges; $\hat{O}_i$ - the simulated discharges; F - the residual variation; N - the number of discharge values.

- The NTD criterion *(Nash & Sutcliffe, 1970)*, which compares the residual variance with initial one, because a universal criterion was required, which does not depend on the value of the data and on the length of the series.

$$NTD = 1 - \frac{F}{F_0} \tag{2}$$

where the initial variance is calculated with the relation:

$$F_0 = \sum_{i=1}^{N} \left(O_i - \overline{O}\right)^2 \tag{3}$$

with $\overline{O}$ the mean of the measured discharges.

The mean monthly discharges at 4 gauging stations from the Buzău river basin and 13 gauging stations from the Ialomiţa river basin were used for the analysis of flow modification in study area. The calibration of the WATBAL model for each of the 17 analysed sub-basins was accomplished by the simulation of monthly discharge hydrograph at the outlets of sub-basins and using, as input data, the average values (1971–2000) of observed climatic parameters corresponding to each sub-basin. As example, in Fig. 2 are presented the observed and simulated mean monthly discharge hydrographs during the period of calibration 1971–2000 at the Ţăndărei gauging station, situated at the outlet of the Ialomiţa River.

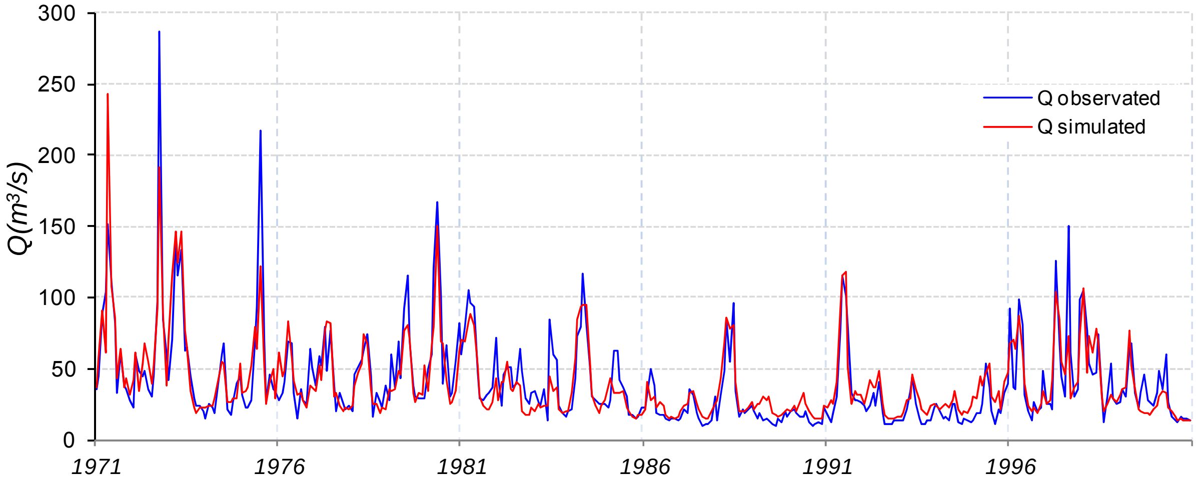


Fig. 2 – Observed and simulated mean monthly discharge at Ţăndărei gauging station on the reference period (1971–2000).

The results of the numerical criteria above mentioned, applied for the period 1971–2000, for the all analysed cross-sections of Buzău and Ialomiţa river basins, indicate a variation of RMSE, in concordance with the river basin surface, between 1.0 and 16.0 m^3/s. Nash-Sutcliffe criterion ranged between 0.66 and 0.79 (Table 1).

Table 1

The values of the assessment criteria of deviations between discharges in the period 1971–2000 for the considered sections within Buzău and Ialomiţa river basins.

River basin	River	Section	Surface of sub-basin (km^2)	RMSE (m^3/s)	NTD
Buzău	Buzău	Nehoiu	1572	9.94	0.66
		Măgura	2290	10.19	0.76
		Baniţa	3997	11.67	0.74
		Racoviţa	5066	12.97	0.73
Ialomiţa	Ialomiţa	Moroeni	263	2.76	0.58
		Târgovişte	686	3.57	0.73
		Bălenii Români	924	4.21	0.73
		Siliştea Snagovului	1885	4.97	0.77
	Prahova	Câmpina	476	2.42	0.79
		Halta Prahova	978	4.37	0.72
		Adâncata	3682	8.49	0.79
	Teleajen	Gura Vitioarei	491	2.49	0.67
		Moara Domnească	1398	3.49	0.75
	Cricovul Sărat	Ciorani	601	1.0	0.73
	Ialomiţa	Coşereni	6265	15.63	0.76
		Slobozia	9154	15.97	0.75
		Ţăndărei	10309	15.43	0.77

Even if it is a simplified model, the obtained results show that WatBal model behaves well. This is confirmed by the NTD parameter values that, except for three gauging stations (Nehoiu on Buzău River, Moroeni on Ialomița River and Gura Vitioarei on Teleajen River), are above 0.7. In addition, the model WatBal turns out to be very sensitive to the effective precipitation establishment, so a temperature variation of 1–2°C can be significant in determining the quantity of water resulting from snow melting. WatBal model testifies its performance for the monthly time step especially where precipitation was relatively uniform during the year (melting process is insignificant) and the flow changes are due especially to the evapo-transpiration.

3. CLIMATE PROJECTIONS

The climate change scenarios were developed using (i) the pattern scaling techniques applied to the outputs of 3 global climate models (GCMs) under various emission scenarios and (ii) outputs of the regional model RegCM *(Giorgi et al., 1993)* with two spatial resolutions under A1B IPCC emission scenario: 25km (achieved within the ENSEMBLES project, *Van der Linden & Mitchell, 2009),* referred in the following as *RegCM3–25*) and 10 km (achieved within the CECILIA project, referred in the following as *RegCM3–10*). The *RegCM3–25* has been developed at the ICTP, Trieste *(Van den Linden, 2005)* and is driven by the ECHAM5-r3 global climate model (developed at the Max-Planck Institute for Meteorology, *(Busuioc et al., 2010a)* while *RegCM3–10* is driven by the *RegCM3-25* and has been developed at the National Meteorological Administration (NMA). The performance of the both RegCM3 versions in terms of their ability to reproduce the temperature and precipitation characteristics over Romania has been analysed in *Busuioc et al. (2010a)*. More details for the RegCM3 are presented in *Busuioc et al. (2010b)*. It was found that, in average over Romania, the *RegCM3–25* overestimates the temperature in winter and underestimates it in rest of the year; the precipitation is generally overestimated, except for summer when it is underestimated.

For all analysed river basins, the climatic input parameters for the future periods used in hydrological modelling were obtained by correcting the measured values over the calibration period with the changes simulated by each model. Mean monthly temperatures used as input data to hydrological simulations were obtained by addition of temperature increase, in climate change hypothesis, to the actual temperatures, and the others climatic parameters by addition of monthly deviations to the mean monthly climatic parameters.

In the first step, the climatic parameters of three global climate models (GCMs) ECHAM, HadCM and NCAR (noted below with E, H and N, respectively), (Table 2), for three future time horizons (i.e. 2025, 2050, and 2100) and three emission scenarios were used (*Dubrovsky et al., 2005*). The three emission scenarios are the following: LO (low estimate of climate sensitivity - optimistic emission scenario), MI (mean estimate of climate sensitivity - mean emission scenario), HI (high estimate of climate sensitivity - high emission scenario). Therefore, a total of 27 climate scenarios were constructed specifically for each sub-basin.

Table 2

GCM simulations used in the determination of standardised scenarios (according to Dubrovsky *et al*. 2005)

Model	Acronym	Atmospheric resolution
ECHAM4 / OPYC3	ECHAM	2.8×2.8°
HadCM2	HadCM	2.5×3.75°
NCAR DOE-PCM	NCAR	2.8×2.8°

The projected mean ± optimistic/pessimistic annual changes in temperature, precipitation, solar radiation, and wind speed estimated by the three GCMs for three future time horizons, compared to the reference period 1971–2000, for Ialomiţa and Buzău river basins, are presented in Fig. 3.

There was a consistent increase in mean annual temperature in Buzău and Ialomiţa river basins in all three models (Fig. 3). An increasing of temperature was projected by all models in target river basins area, with mean increases of 0.7–1.0°C, 1.3–2.1°C, and 2–3°C in 2025, 2050, and 2100, respectively. The optimistic changes were lower by ~50% than these mean values but the pessimistic changes were higher by up to ~100%.

The precipitation amounts decreased in all model projections for all time horizons. The solar radiation change showed almost a mirror pattern compared to the precipitation both in the long-term averages and the seasonality. Also the projected wind speed changes were relatively small and of different sign between the models.

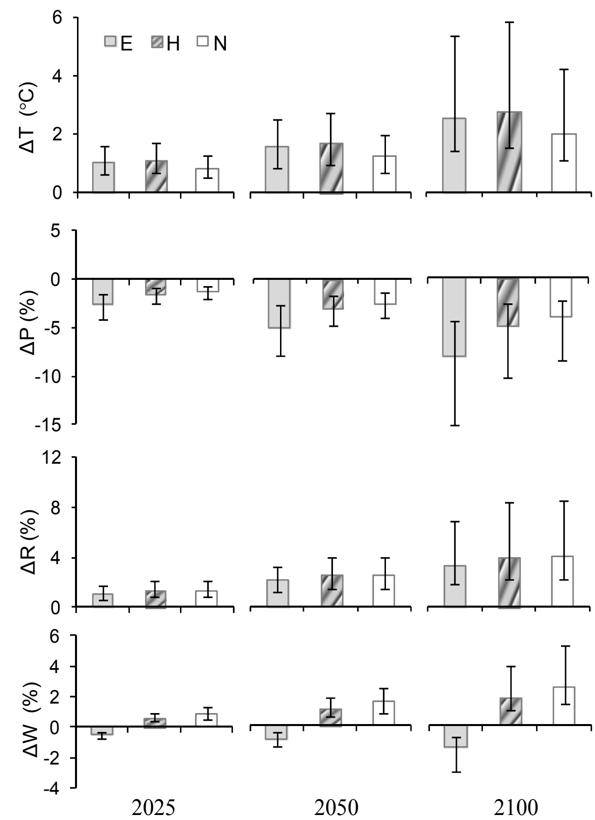


Fig. 3 – Mean annual changes of climatic parameters, simulated by three GCMs (E – ECHAM, H – HadCM, N – NCAR) for middle ± optimistic/ pessimistic (vertical lines) climate change scenarios, in Buzău and Ialomiţa river basins.

Fig. 4 shows the projected changes of mean monthly temperature and precipitation. For all models and times horizons an important increasing of temperature in summer (month of July and August, especially) was estimated, which could reach 4–5°C in 2100. Regarding mean monthly precipitation, it will decrease for the ECHAM model during February to November, HadCM model during May to October and NCAR model during June to November. It is noted so that for all models and times horizons precipitation will decrease during June to October. In the rest of the year, precipitation will increase.

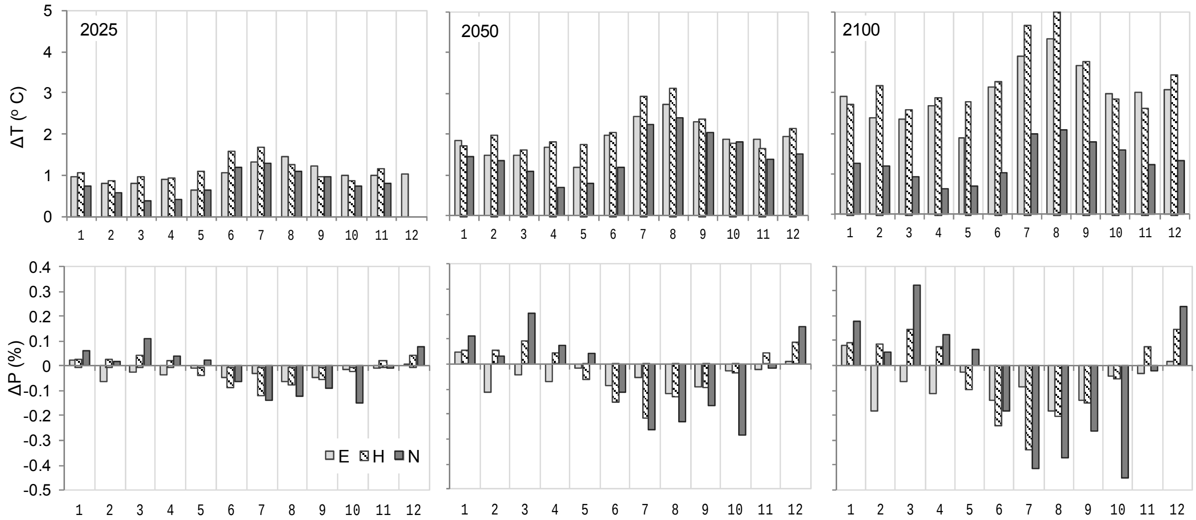
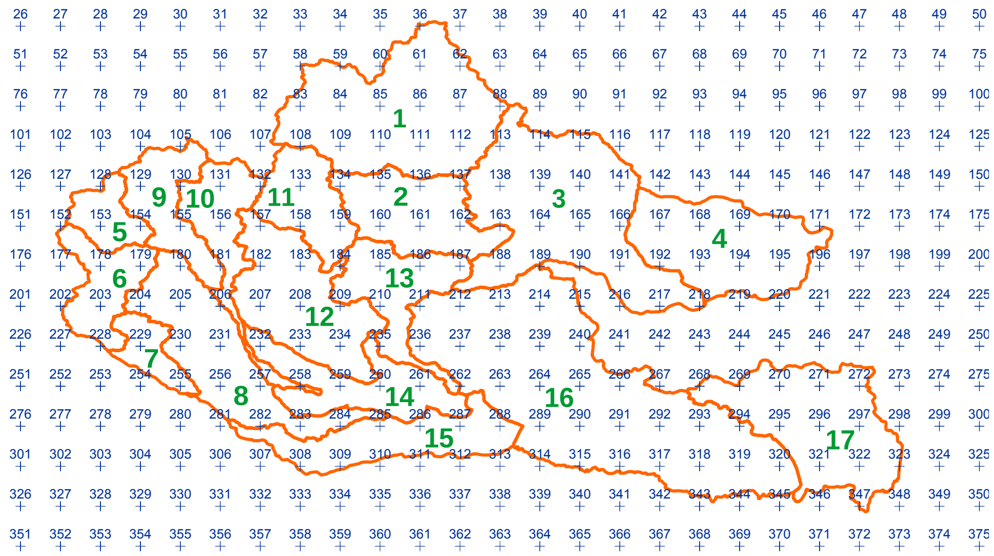


Fig. 4 – Mean monthly changes of temperature and precipitation, simulated by three GCMs (E – ECHAM, H – HadCM, N – NCAR) for middle climate change scenarios, in Buzău and Ialomiţa river basins.

The high-resolution regional climate projections of the RegCM3 (*RegCM3–25*, *RegCM3–10*) under the A1B scenario were also used for hydrological simulations in the analyzed area. For both RegCM3 spatial resolutions, the estimated changes of the main climatic parameters were calculated as differences between climatic parameters corresponding to the two periods 2021–2050 and 2071–2100 and to the reference period 1971–2000, for each calendar month. These changes are supplied in each model grid point. The average spatial change over each sub-basin is then computed. Fig. 5 shows the nodes used for each of 17 analysed sub-basins.



Buzău river basin: *Nehoiu: 1; Măgura: 1+2; Baniţa: 1+2+3; Racoviţa: 1+2+3+4*

Ialomiţa river basin: *Moroeni: 5; Târgovişte: 5+6; Bălenii Romani: 5+6+7; Siliştea Snagovului: 5+6+7+8; Câmpina: 9; Halta Prahova: 9+10; Gura Vitioarei: 11; Moara Domnească: 11+12; Ciorani: 13; Adâncata: 9+...+14; Coşereni: 5+...+15; Slobozia: 5+...+16; Ţăndărei: 5+...+17.*

Fig. 5 – Nodes of grid climatic model (+) and limits of sub-basins (—).

The results regarding temperature and precipitation changes simulated by the two resolutions of RegCM3 model, for the near and remote periods, in case of Buzău and Ialomiţa river basins, are illustrated in Fig. 6. The temperature is projected to increase about 0.8–1.5 °C over 2021–2050 and about 2.8–3.1°C over 2071–2100, with higher values in the summer and autumn months. The RegCM3 temperature changes on Buzău and Ialomiţa river basins are similar to those obtained from GCM simulations presented above.

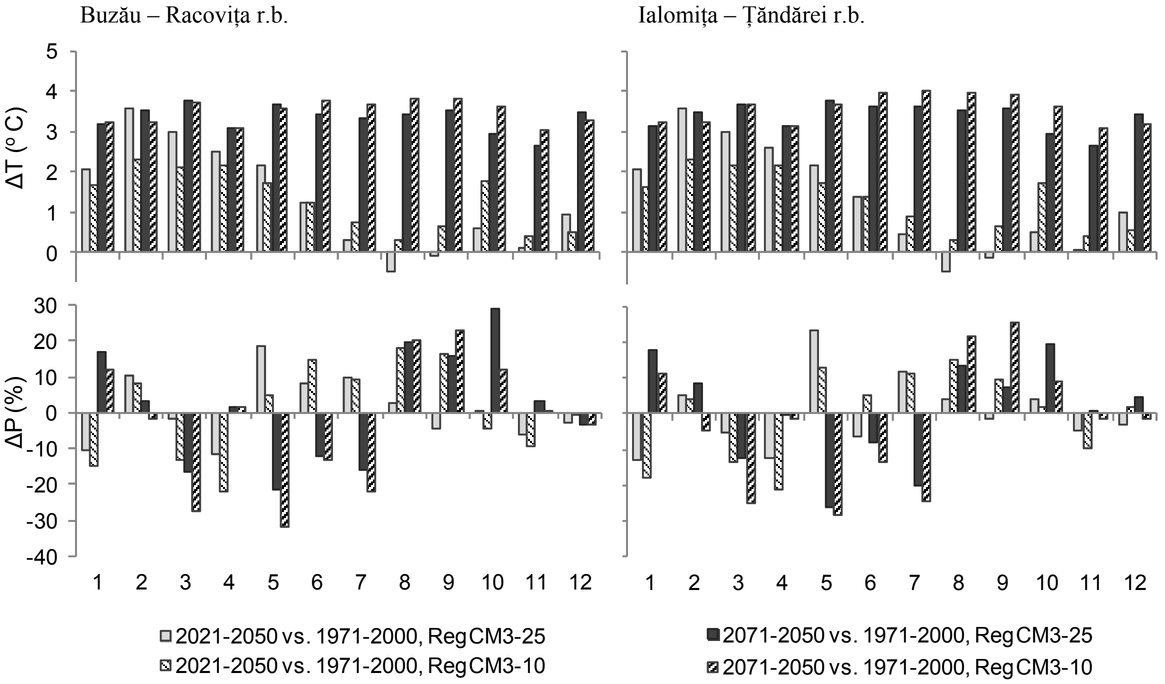


Fig. 6 – Monthly differences between the values of temperature and precipitation simulated with RegCM3 model, for the future periods 2021–2050 and 2071–2100 in comparison with the reference period 1971–2000.

The precipitation amounts decreased in most RegCM3 projections. Notable differences existed between the two spatial resolutions (25 km and 10 km) in the seasonal distribution of precipitation. The *RegCM3–10* outputs show small seasonal changes in the near future period (2021–2050) and a significant decrease in summer precipitation in the far future period (2071–2100) by contrast to the *RegCM–25* outputs that had an increased precipitation in winter and spring months but deficits in the summer and autumn.

4. ASSESSMENT OF CLIMATE CHANGE IMPACT ON WATER RESOURCES BASED ON THE OUTPUTS OF GLOBAL CLIMATE MODELS (GCMS)

The simulated flow using WatBal model (*Yates, 1994*) in current and forthcoming climate change conditions allows the assessment of climate change impact in water resources of the Buzău and Ialomiţa river basins.

Taking into account the new values of the climatic parameters for each of the 17 analyzed sub-basins were simulated the mean monthly flows and then were calculated the relative deviations between the mean monthly discharges in current regime and in simulated ones, in the hypothesis of the climate change. For the comparison of the modified regime of flow, as a result of climate changes, with the current multi-annual monthly hydrological regime, the mean monthly discharges with middle +/- optimistic/pessimistic (error bars) GCM scenarios for time periods 2025, 2050 and 2100 are presented in Fig. 7, for two gauging stations: Moroeni and Țăndărei on Ialomița River. We can observe a less modification of monthly discharge in the case of Moroeni gauging station, this being a characteristic of all the catchments with high mean altitude (Carpathian and Subcarpathian area).

The largest increase in the seasonal flow variability is observed at Țăndărei gauging station, which is characteristic for all cross sections corresponding to the river basins with low mean altitude (plain sector). The uncertainty in the runoff predictions increased with time and in the time horizon of 2100 it occupied a very wide range of runoff values. In the summer and autumn months this uncertainty belt was narrower because the results of the three models were more coincident and the decrease in runoff seems to be doubtless.

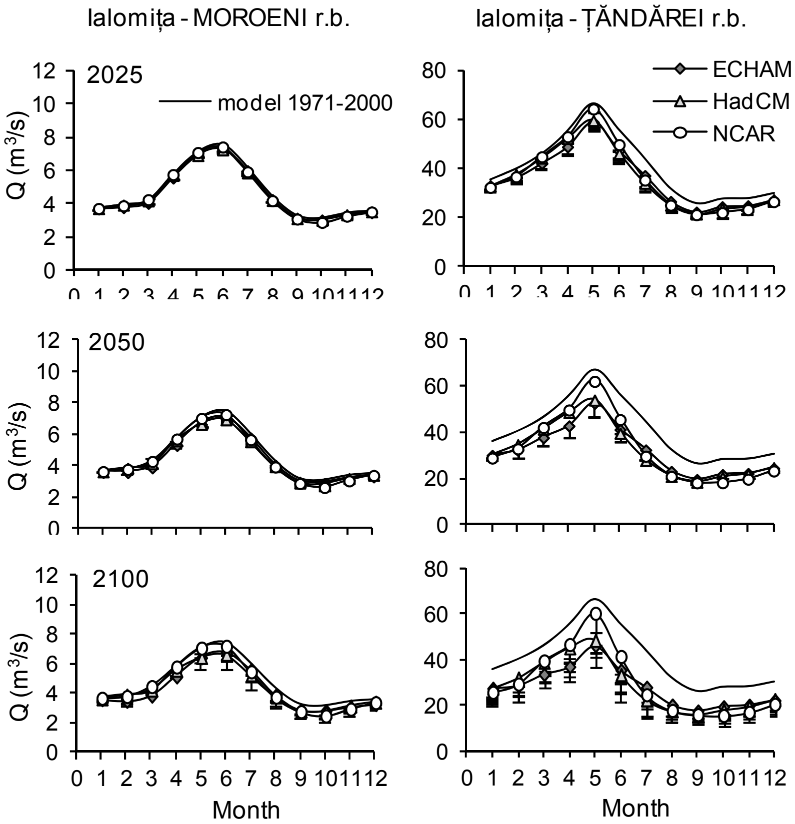


Fig. 7 – Variation of current and simulated mean monthly discharges for time periods 2025, 2050 and 2100 and middle +/- optimistic/pessimistic (error bars) global temperature change scenarios at the Moroeni and Țăndărei gauging stations on Ialomița River.

Also, in Fig. 8 can be seen that the mean annual discharge decreases in climate change conditions. The relative errors to the current regime are larger for all climate models, especially for the time horizon 2100 and they reach 30% in case of river basins with lower mean altitudes.

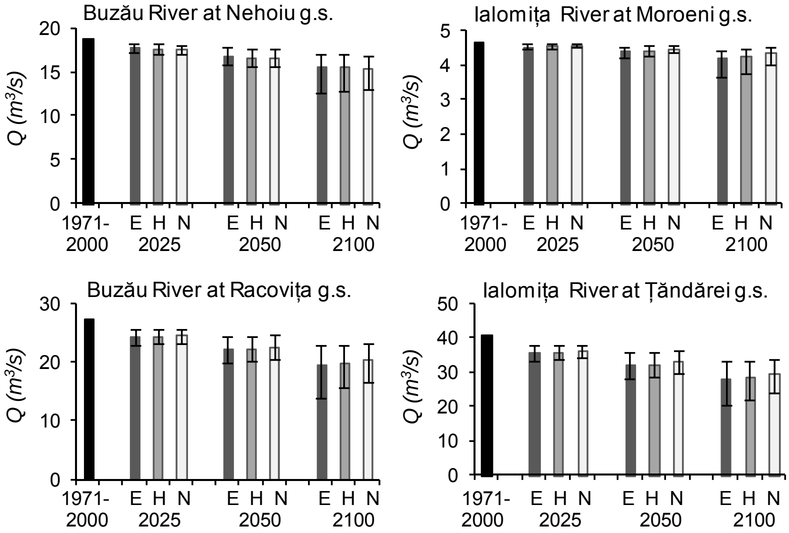


Fig. 8 – The mean annual discharges for reference period and for the middle +/- optimistic/pessimistic (error bars) GCMs scenarios for Nehoiu and Racoviţa gauging stations on Buzău River and for Moroeni and Ţăndărei gauging stations on Ialomiţa River.

5. ASSESSMENT OF CLIMATE CHANGE IMPACT ON WATER RESOURCES BASED ON THE OUTPUTS OF REGIONAL CLIMATE MODELS

The assessment of climate change impact on water resources in the selected basins, using the RegCM3–25 and RegCM3–10 simulations under the A1B scenario, was the second stage in the analysis of the impact of climate change on hydrological regime presented in this paper.

With the changed input climate data, the monthly discharge series were simulated at all 17 gauging stations from the Buzău and Ialomiţa river basins, for the above mentioned time horizons. The changes of mean monthly runoff and differences in the seasonal runoff distribution in the reference period (1971–2000) and future time horizons 2021–2050 and 2071–2100 were estimated and compared.

The Fig. 9 shows the simulated monthly average discharges at the outlet of Buzău and Ialomiţa river basins for the future time horizons in comparison with the reference period.

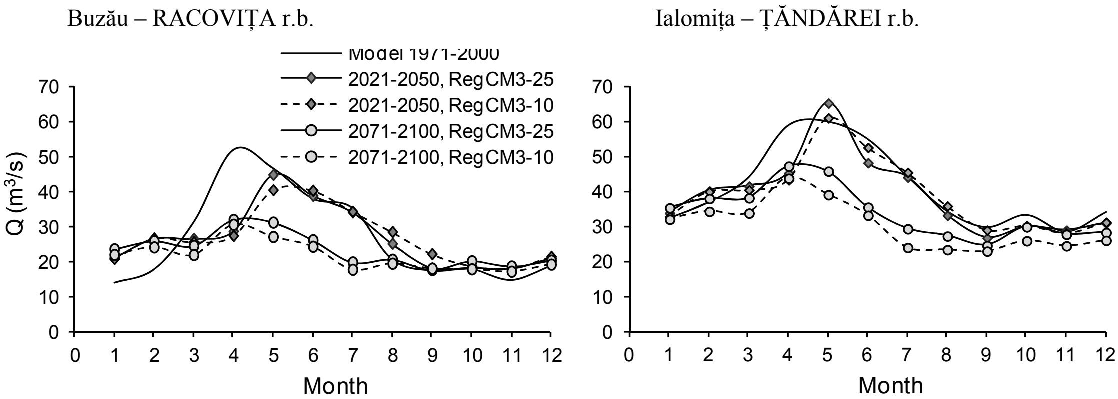


Fig. 9 – Comparison of mean monthly discharges modification
in climate change conditions due by RegCM3 with 25km and 10km spatial resolutions.

The analysis of the hydrological scenarios results shows that in all analysed areas the mean annual flow decreases as the time horizon is larger.

Generally, it can be concluded that the hydrological modelling based on the regional climate models indicate notable seasonal changes of the flow in all pilot basins for both of the investigated time horizons.

During the winter and early spring periods, it can be observed an increase in the long-term of mean monthly flow. The period of increasing in flow could have occured from November/December to February/March. This increase could be caused by the increase in air temperature and a shift of the snow melting period from spring months to the winter period. These changes were locally specific, apparently in connection with the geographical position and altitude of the catchment.

During the months of winter and spring, an increasing of flow was modelled at those river profiles where significant parts of catchments are situated in mountainous areas.

At lowland river sections, the decreases of flow occurred in winter and spring in all the river basins. In the months of summer and autumn, a significant reduction in river flow was modelled for all climatic models in all sub-basins, apparently due to the increase in evapotranspiration. In addition to the general drop in runoff, the predicted climate change induced also amplification in the seasonal inequality of flow, which might have important implication for the management of water resources.

Also, for each sub-basin, the mean annual discharge was computed in climate change condition and compared with the mean annual discharge of the reference period (Fig. 10). The mean annual discharge will decrease, especially at the end of the XXI century. The decreasing is more accentuated to the sub-basins having a lower mean altitude.

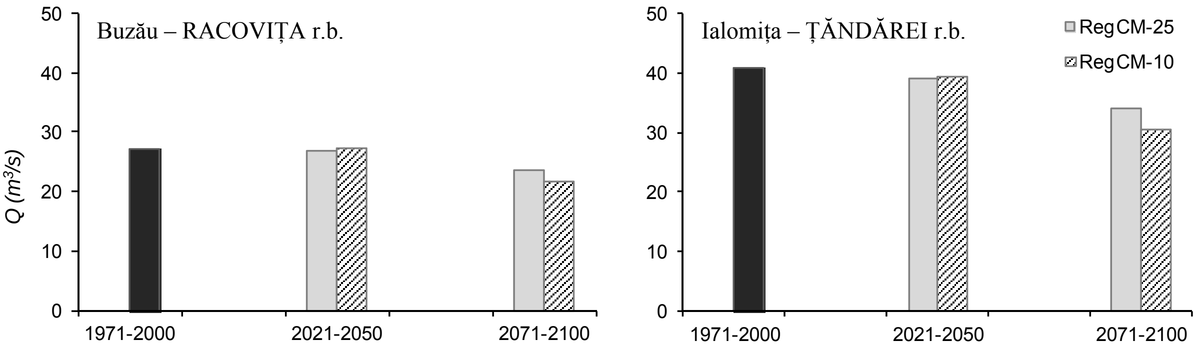


Fig. 10 – Comparison of mean annual flow modification in climate change conditions due by RegCM3 with 25 km and 10 km spatial resolutions.

6. CONCLUSIONS

Climate change impacts on hydrology were analysed in Buzău and Ialomiţa river basins using different climate projections.

The hydrological modelling based on the global and regional climate models indicated notable seasonal changes in the river discharges in all studied sub-basins. In parallel with it global decreasing variation these changes were locally specific, apparently in connection with the geographical position and mean altitude of the sub-basins.

For the sub-basins with high mean altitude (Carpathian and Subcarpathian area) or those sub-basins where significant parts were situated in mountainous areas an increased and temporally modified flow patterns were modelled especially in the winter and spring months. These modifications of flow can be explained as a result of the decreasing of the snow depth and duration of snow coverage due to the air temperature increasing in winter time.

For the lowland cross-sections (situated in the plain) the flow presents in general a largest decrease in worm season and an increasing in winter and early spring time. The important increasing simulated in winter and early spring results from earlier occurrence of floods produced by snow-melt and reduction of spring combined floods (snow-melt and rain) through the desynchronisation between the snow-melt and spring rain occurrence.

Mean multiannual discharge, when using global climate models as well as regional, will decrease as the time horizon is larger. Using global climate models led at the river basins with lower mean altitudes to a decrease which can reach 30%.

When using regional climatic models, regardless of their resolution, simulated discharges for the period 2021–2050 are comparable, while, hydrological simulation results for the period 2071–2100 show a decrease in mean multiannual discharge, in the case of the use the changes in climatic parameters resulting from the regional climate model with resolution of 10 km *(RegCM-10)*, that could reach 20%.

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