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Procedia Engineering 162 (2016) 246 – 253

Procedia Engineering

www.elsevier.com/locate/procedia

International Conference on Efficient & Sustainable Water Systems Management toward Worth Living Development, 2nd EWaS 2016

Water accounting in the Po River Basin applied to climate change scenarios

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Abstract

The influence of humans on the earth's temperature and climate is a fact recognised by scientific community and it is mainly caused by deforestation and burning fossil fuels. Mediterranean area is turning drier, becoming more vulnerable to wildfires and drought. In the coming years, it is expected that the increasing water demand in combination with water scarcity due to climate change would intensify the current water stress. The Po is the longest river in Italy, with a length of 652 km and it is also the largest river with an average discharge of 1540 m^3/s. The Po Valley covers the economically most important area of Italy, and a population of more than 16 million which produces 40% of the national Gross Domestic Product. As other Mediterranean areas, this river basin is subject to high flow variation, frequent floods and periods of low flows that may be amplified in the coming years. The main objective of this study is to apply a modelling chain for the development of water accounting analysis in the Po River Basin, including the impact of climate change on the region. To do this, the climate change impacts have been obtained under the Intergovernmental Panel on Climate Change scenario RCP 4.5. The hydrological/hydraulic components are simulated through a physically based distributed model (TOPKAPI) and a water balance model at basin scale (RIBASIM). The accounting approach has been the SEEA-W. The results show that, in future scenarios, the application of measures will be required to mitigate climate change maintaining water allocations.

Peer-review under responsibility of the organizing committee of the EWaS2 International Conference on Efficient & Sustainable
Water Systems Management toward Worth Living Development

Keywords: Climate change; water accounting; System of Environemtal-Economic Accounting for Water (SEEA-W); Po River Basin

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Peer-review under responsibility of the organizing committee of the EWaS2 International Conference on Efficient & Sustainable Water Systems
Management toward Worth Living Development
doi:10.1016/j.proeng.2016.11.051

1. Introduction

The influence of humans on the earth's temperature and climate is a fact recognised by scientific community, and it is mainly caused by deforestation and burning fossil fuels. All regions around the world are affected by climate change. According to European Commission [1] heat waves, forest fires and drought events are becoming frequent phenomena in Southern and Central Europe, while Mediterranean area is turning drier, becoming more vulnerable to wildfires and drought. The most important fact is that these impacts may be intensified in the coming years. In fact, several authors have reviewed climate change and land use impacts on water resources in European and Mediterranean areas manifesting that the increasing water demand in combination with water scarcity due to climate change would intensify the current water stress [2, 3].

To overcome this situation, adaptation actions are preventing the damage climate change can cause, saving lives and money later. Some examples of adaptation measures are adapting building codes to future climate conditions and extreme events, building flood defences, developing drought tolerant crops or the more efficiently use of scarce water resources [1]. Regarding the last, in this sense, the Blueprint to safeguard Europe's water resources [4] recognizes water accounting as a useful tool to supply basic information with the aim of providing support to decision-makers in water resource management [5, 6].

To assess the impacts of climate change on water resources management, the Po River Basin (PRB) in North Italy, has been selected as a case study, because of its importance, dimensions, availability of data, and the increased severity of drought and flood episodes in recent years. Other studies have been used as a basis for the development of this research. Vezzoli et al. [7] studied the climate change impacts on the whole PRB under RCP 4.5 scenario to 2040 applying the bias correction to the outputs of impact model and not to climate data, showing a reduction on discharges. Afterwards, Vezzoli et al. [3] simulations are extended to 2100 under RCP 4.5 and RCP 8.5 scenarios to evaluate water availability in the PRB.

This work is presented as follows: Section 2 summarises the methodology of the approach; Section 3 describes briefly the climate and hydrology of the PRB; in Section 4 the asset accounts for the considered scenarios are presented; Section 5 presents the discussion; and finally in Section 6 the main conclusions are drawn.

2. Methodology

The target of implementing climate and hydrological simulations is to assess the impacts of climate change and also the capability of PRB to adapt to new conditions. The methodology proposed consists on the application of four consecutive stages: 1) a module for the climate; 2) a fully distributed physically-based rainfall-runoff model (TOPKAPI); 3) a water resources management model (RIBASIM) for simulating the behaviour of river basins during varying hydrologic conditions, and 4) the building of the required databases to connect the two latest models to organize the information to obtain the asset accounts under SEEA-W methodology.

The climate change impacts on the period 2001-2100 have been simulated under the Intergovernmental Panel on Climate Change (IPCC) Representative Concentration Pathways (RCP) 4.5 [8]. The hydrological model is composed by TOPKAPI (TOPographic Kinematic Approximation and Integration) model [9], a fully-distributed physically-based rainfall-runoff model that can provide high resolution information on the hydrological state of a catchment. Once obtained the runoff, this is the input to RIBASIM (River Basin Simulation Model) [10], a water balance model to simulate the behaviour of river basins during varying hydrologic conditions (see Figure 1). More detailed information about the application of these models in the case study are described in Vezzoli et al. [7] and Vezzoli et al. [3].

The accounting approach applied in this research has been the System of Environmental-Economic accounting for Water (SEEA-W) [11]. As other accounting approaches, SEEA-W was developed with the objective of standardizing concepts and methods in water accounting for organizing economic and hydrological information permitting a consistent analysis of the contribution of water to the economy and the impact of the economy on water resources. SEEA-W comprises five categories of accounts, this research is focused on obtaining asset accounts.

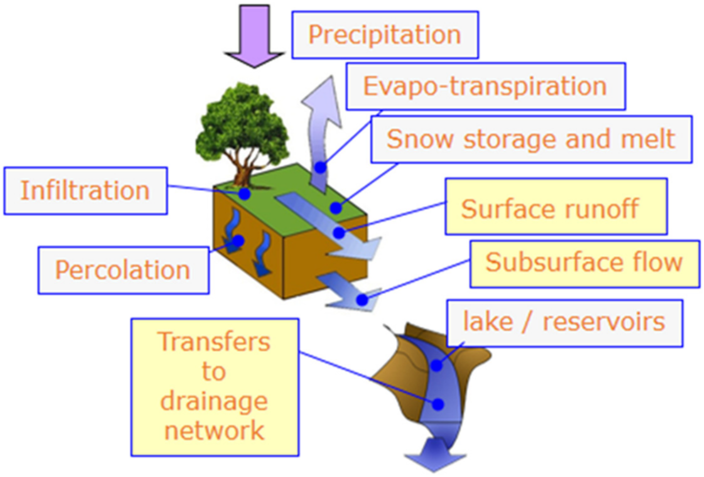

Fig. 1. Scheme of the water resources assessment in the Po River Basin

3. Description of the case study: the Po River Basin

The Po is the longest river in Italy, with a length of 652 km from its source in Cottian Alps (at Pian del Re) to its mouth in the Adriatic Sea, in the north of Ravenna (see figure 2). It is also the largest river with an average discharge of 1540 m^3/s. The river basin area extends on about 71.000 km^2 in Italy, and about 3000 km^2 in Switzerland and France.

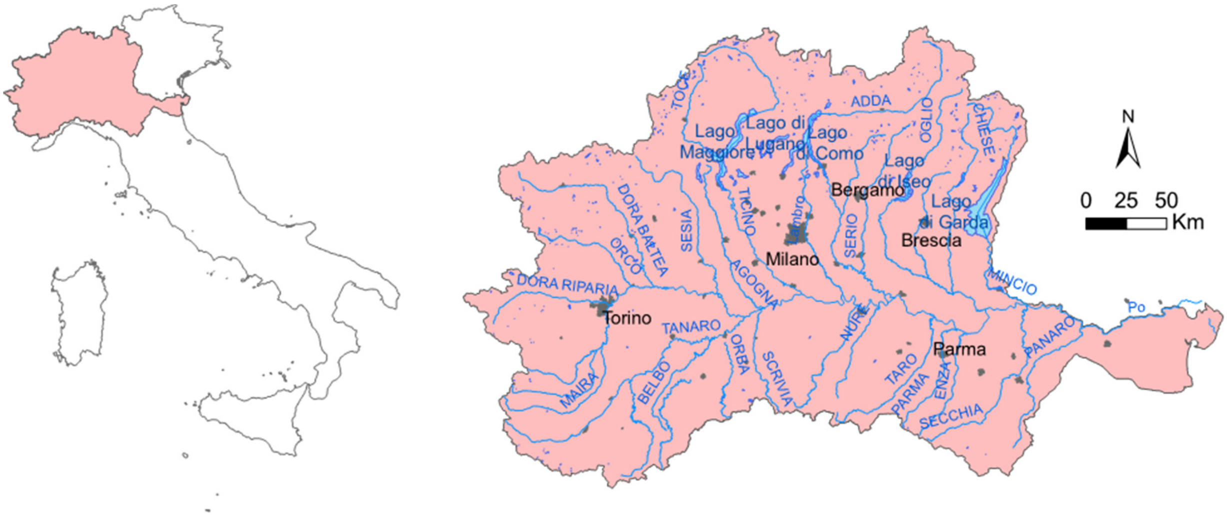

Fig. 2. Location of the Po River Basin

Discharges are characterized by two maxima, in spring and autumn, and two minima, in winter and summer. On the one hand, the regime of Alpine tributaries responds to temperature pattern; late spring and summer discharges are the results of snow and glacier melting processes with a maximum in summer and a minimum in winter. On the other hand, the regime of Apennines tributaries are driven by precipitation, showing two maxima and two minima. In the Alpine area, there are 4 natural big lakes and 174 reservoirs, of which 143 are artificial reservoirs for hydropower production; furthermore, the basin comprises over 600 km2 of glacier areas.

Climate conditions in the Po area are changing in a sensitive way: from 1960 to present an increase of the annual mean temperature of about 2°C has been observed, with a relevant increase of the linear trend which leads to forecasting an increase of the annual mean temperature close to 3-4 °C at the end of the century. The decrease of precipitation is not so evident, nevertheless, an increase in the intensity of the single rainfall events, but an overall decrease in the total number of the rainfall events can be observed, resulting in a decrease of the annual mean precipitation of about 20% observed during the last thirty years. The decrease is more evident during spring and summer seasons (when a maximum decrease of about 50% can be noticed) whereas the inter-annual variability increases. Furthermore, due to the strong negative correlation between the decreasing snow coverage and the increasing air temperature, a constant retreatment of the alpine glaciers is expected.

The PRB covers the economically most important area of Italy, and a population of more than 16 million which produces 40% of the national Gross Domestic Product (GDP). Water uses within the PRB come from the electricity sector, from inland navigation and for an irrigation based agriculture. The river is subject to high flow variation, frequent floods and periods of low flows. Total water abstraction account to more than 20.5 billion m^3 per year, most part of which (16.5 billion m^3) is used in agriculture/irrigation, 2.5 billion m^3 for drinking water and 1.5 billion m^3 for industrial uses. Abstractions account for 14.5 billion m^3 for surface waters and for 6 billion m^3 for groundwater.

In this research, we concentrate on Pontelagoscuro station, which is representative of the water cycle on the whole PRB.

4. Results

Water accounts enable us to compare hydrological information at temporal scale. As an example of the applicability of the model chain, the following sections show the asset accounts in the current scenario, taking as a reference the hydrological year 2010/11; and in the RCP 4.5 scenario to consider the effects of climate change, taking as a reference the time horizon 2040/41. The simulation of the current scenario has been driven by climate observations and it is used as a reference. For the scenario RCP 4.5, the simulations of precipitation and temperature until 2100 were provided by the Euro-Mediterranean Centre on Climate Change (CMCC). These simulations were obtained from the regional model COSMO-CLM model-driven global CMCC-CM [12]. RCP 4.5 scenario considers a stabilization of the entire radioactive forcing by 2100 through the adaptation of technologies and strategies to reduce greenhouse gas emissions [3]. This scenario assumes an increase in CO_2 emissions until 2040 and a later decrease to less than the present, approximately 4.2 PgC / Yr.

4.1. Current scenario

As we observe in table 1, at the beginning of the year the volume of reserves are over 95 km3, while closing stocks include over 93 km^3. The values of snow and groundwater volumes at opening and closing stocks are explained by the principle of superposition [13]. In other words, we must pay attention to the changes in volumes and not in the volumes themselves. During 2010/11 precipitation represents more than 80 km3, mainly in the form of rain. The volume abstracted for water uses comes from the intakes located in the river. It is also relevant that the amount of evapotranspiration from soil is twice than the water abstracted for water uses. On the other hand, the outflows to the sea exceeds 50 km^3. Other changes in volume are considered to close the balance, being explained the uncertainties such as variation in the river levels or aquifers and representing an error of 5% in the whole river basin. According to table 2, the main exchanges of flows between water resources are those between soil water and rivers.

4.2. Scenario RCP 4.5

Table 3 shows as at the beginning of the time horizon 2040/41 the volume of reserves are over 72 km^3, and closing stocks are over 67 km^3. The main differences are in the volume of snow reserves, which have been considerably reduced due to the increase of temperatures. During this year, precipitation represents more than 57 km^3, mainly in the form of rain. It is also noteworthy that the amount of evapotranspiration from soil is three times the water abstracted for water uses (twice for the current scenario). Moreover, outflows to the sea have been reduced to around 33 km^3. As we observe in the matrix of flows for the current scenario, table 4 shows that the main exchanges of flows between water resources are those between soil water to rivers.

Table 1. Asset accounts in the Po River Basin in 2010/11 (km^3/year)

	EA.131. Surface water						
	EA. 1311 Artificial reservoirs	EA. 1312 Lakes	EA. 1313 Rivers	EA. 1314 Snow, ice and glaciers	EA. 132 Groundwater	EA. 133 Soil water	Total
1. Opening stocks		1.21		75.25	0.47	18.68	95.53
Increases in stocks							
2. Returns			0.88		4.92		5.79
3. Precipitation				4.80		77.56	82.37
4. Inflows							
4.a. From upstream territories							
4.b. From other resources in the territory			66.73		19.40	5.59	91.71
Decreases in stocks							
5. Abstraction			14.69				14.69
6. Evapotranspiration/actual evapotranspiration						28.60	28.60
7. Outflows							
7.a. To downstream territories			0.34				0.34
7.b. To the sea			52.19				52.19
7.c. To other resources in the territory			14.55	5.59	14.25	57.32	91.71
8. Other changes in volume			14.18		-10.11	0.89	4.96
9. Closing stocks		1.21		74.46	0.42	16.74	92.83

Table 2. Matrix of flows between water resources in the Po River Basin in 2010/11 (km^3/year)

	EA.131. Surface water						Outflows to other resources in the territory
	EA. 1311 Artificial reservoirs	EA. 1312 Lakes	EA. 1313 Rivers	EA. 1314 Snow, ice and glaciers	EA. 132 Groundwater	EA. 133 Soil water	
EA.1311 Artificial reservoirs							
EA. 1312 Lakes							
EA. 1313 Rivers					14.55		**14.55**
EA. 1314 Snow, ice and glaciers						5.59	**5.59**
EA. 132 Groundwater			14.25				**14.25**
EA. 133 Soil water			52.48		4.84		**57.32**
Inflows from other resources in the territory			**66.73**		**19.40**	**5.59**	**91.71**

Table 3. Asset accounts in the Po River Basin in time horizon 2040/41 (km^3/year)

	EA.131. Surface water						
	EA. 1311 Artificial reservoirs	EA. 1312 Lakes	EA. 1313 Rivers	EA. 1314 Snow, ice and glaciers	EA. 132 Groundwater	EA. 133 Soil water	Total
1. Opening stocks		1.21		53.63	0.38	17.04	72.27
Increases in stocks							
2. Returns			0.28		3.07		3.34
3. Precipitation				3.34		54.29	57.62
4. Inflows							
4.a. From upstream territories							
4.b. From other resources in the territory			42.91		12.11	4.49	59.50
Decreases in stocks							
5. Abstraction			8.31				8.31
6. Evapotranspiration/actual evapotranspiration						22.16	22.16
7. Outflows							
7.a. To downstream territories			0.28				0.28
7.b. To the sea			32.91				32.91
7.c. To other resources in the territory			9.61	4.49	9.74	35.66	59.50
8. Other changes in volume			7.93		-5.50	-4.61	-2.18
9. Closing stocks		1.21		52.48	0.32	13.39	67.40

Table 4. Matrix of flows between water resources in Po River Basin in time horizon 2040/41 (km^3/year)

	EA.131. Surface water						Outflows to other resources in the territory
	EA. 1311 Artificial reservoirs	EA. 1312 Lakes	EA. 1313 Rivers	EA. 1314 Snow, ice and glaciers	EA. 132 Groundwater	EA. 133 Soil water	
EA.1311 Artificial reservoirs							
EA. 1312 Lakes							
EA. 1313 Rivers					9.61		9.61
EA. 1314 Snow, ice and glaciers						4.49	4.49
EA. 132 Groundwater			9.74				9.74
EA. 133 Soil water			33.17		2.49		35.66
Inflows from other resources in the territory			42.91		12.11	4.49	59.50

5. Discussion

Despite all the uncertainties introduced by the assumptions associated in each step of the simulation chain [7], TOPKAPI and RIBASIM have been found to be a robust and powerful tool for the application of water accounting in the case study. As noted by Momblanch et al. [5], water balances cannot be more precise than the available records and observations in the basin.

As we know, future is uncertain and we use IPCC climatological scenarios in order to help water end users to prepare for the future. These scenarios are coherent and consistent descriptions about how climate on the Earth can change in the future. Figure 3 is presented below in order to show how the evolution of water resources in the future could be. The indicator named Total Actual Renewable Water Resources (TARWR) represents the maximum theoretical amount of water actually available at a given moment. A priori, figure 3a shows that the TARWR in RCP 4.5 scenario during the time horizons 2020/21, 2040/41 and 2099/00 is in the same order of magnitude than for the current scenario (2010/11). But, as it is observed high flows in spring due to snow melting processes become more frequent in RCP 4.5 scenario also with the intensification of low flows in summer. In the same way, figure 3b shows a reduction in the volume of snow stored in the river basin. It is noteworthy to highlight that as the total volume is unknown, we consider an initial volume of 100 km^3 of snow and this amount reduces over the time horizons.

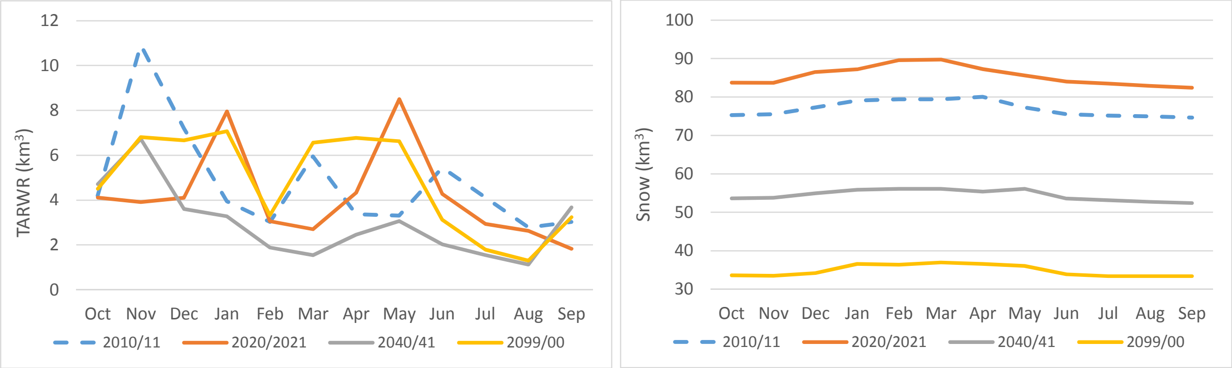

Fig. 3. (a) Total Actual Renewable Water Resources (TARWR) and (b) volume of snow reserves for RCP 4.5 scenario in selected time horizons

The consequences of polar ice sheets and glaciers melting may cause an increase in river levels, resulting in flooding and erosion along the river banks and causing damage to properties and infrastructures.

6. Conclusions

The main objective of this study has been, on the one hand, the improvement of knowledge of the system itself and, on the other hand, the development of the methodological tools for the development of water accounting analysis in the Po River Basin, analysing the impact of climate change on the region.

The main conclusion obtained from this research is the fact that TOPKAPI and RIBASIM are reliable tools that provide information enough for asset accounts under the SEEA-W methodology, allowing the collection of those parameters of water cycle that can not be obtained by monitoring.

This work has represented a first approximation of the development of water accounting, since new improvements in the chain model will allow us to consider the changes in the volumes and the amount of evaporation in reservoirs and lakes, the supply to groundwater demands, among others. Future works are aimed at including the economic issues in order to use this modelling chain as a predictive instrument for the implementation of measures required to improve the use of water resources according to the indications of the Blueprint.

Acknowledgements

The authors would like to express our gratitude to the ARPA-Emilia Romagna for providing data to develop this study. We also wish to thank the Spanish Ministry of Economy and Competitiveness for its financial support through the NUTEGES project (CGL2012-34978) and the European Community's Seventh Framework Program in financing the project ENHANCE (FP7-ENV-2012, 308438), LIFE ALBUFERA (LIFE12 ENV/ES/000685), IMPREX (H2020-WATER-2014-2015, 641811) and SWICCA (ECMWF's ITT C3S_441 Lot 1 Volume V). As well by the supporting of "Pioneers into Practice Program" of Climate-KIC for creating opportunities and the framework for innovators to address climate change and shape the world's next economy.

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