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Anthropogenic and Climate Change Contributions to Uncertainties in Hydrological Modeling of Small Rivers Watershed Runoff

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Abstract: The movement and storage of water on watershed scales is a complex system affected by climatic, geologic, soil, land use, anthropogenic and other factors. The nature of processes inherent in surface and subsurface hydrology is best investigated by hydrologic models simulating these processes over different spatio-temporal scales and physiographical conditions. In 2014-2015 the SWAT (Soil and Water Assessment Tool) model was used as a basis for the follow-up investigations of Moldova small rivers' potential streamflow in current and likely future climate. Actuality of this research was caused by the observed and expected deficit of water resources, necessary for the sustainable functioning of the country's economy. The study showed that SWAT, being useful for design purposes, is less powerful in modeling the flow of small anthropogenically altered streams when the simulated runoff, which eventually enter to the river stream, does not reflect water losses resulted from human activities in their watersheds. In particular, the observed three-year streamflow of a pilot river was only between 10 and 20 percents of the corresponding modeled runoff. The likely alterations of rivers streamflow in the conditions of climate change were estimated according to the latest high resolution climate change projections based on new approaches to accounting for the greenhouse gas concentrations – the so-called Representative Concentration Pathways, which assume different radiative forcings in the current century. The SWAT modeling of the future runoff from three small rivers' watersheds, as a function of the projected values of local air temperature and precipitation, has demonstrated a possible reduction in the water yields that could reach in Moldova, depending on a time horizon and radiative forcing, from about 2% to 21%, causing additional uncertainties in water supply planning.

Key words: climate change, hydrological modeling, Moldova, SWAT, uncertainties

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1. Introduction

Water is critical for sustainable development, being used to energize all sectors and levels of society; the robust water resources management builds resilient economies (Jägerskog et al., 2015). Healthy, flowing rivers are ‘lifelines’ of our planet. In common with catchments they sustain the rich variety of life, reduce the impacts of extreme natural events, recharge groundwater supplies and maintain the ecological integrity of local ecosystems. At the same time, rivers and riverine ecosystems are among the most threatened in the world, and in many basins, due to the combined effects of natural and anthropogenic factors, in the past 50 years the amount of runoff flowing into rivers has substantially changed (Yan and Pottinger, 2013). The water insecurity, manifested as a lack of proper water quantity and quality in a given space and time, poses significant risks for many countries, and the global-scale impairment of aquatic ecosystems becomes increasingly documented and articulated (e.g., Le Quesne et al., 2010).

The primary challenge in achieving a water security is our ability to make decisions in the present that sufficiently account for needs of the future (Ray & Brown, 2015). Moreover, Rolf et al. (2015, p.1) emphasize an urgent need in a broader conception of *sustainable water resource management* that maintains key ecological functions supporting the long-term provision of biodiversity, ecosystem goods, services and values, thereby “…formulating environmental health as a necessary ingredient for water security and the social well-being it supports”. Under this judgment and in the light of accelerating stressors from population growth and economic development, any securing of fresh water supply and its equitable allocation to support human well-being, while sustaining healthy and functioning ecosystems, is now a grand environmental challenge. Additional challenges in the sustainable management of water resources are posed by *hydrological uncertainties* and *climate change*.

The last years have demonstrated dramatic shifts in water decision-making. On the background of growing demands in the changing word, an increasing *uncertainty* about water availability and quality will further strengthen significance of risks posed by an energy-water-food nexus (WEC, 2016). Although water managers have essentially two alternatives for addressing the burning risks, assuming that either the recent past or the hydrological modeling could safely predict future risks pattern, both these approaches, as Joan Matthews (2015) suggests, are not satisfactory in relation to climate change, especially for quantitative water management. In particular, the past can mask important trends and novel patterns in precipitation, their seasonality, water use and other variables, and when these uncertainties are connected to economic, institutional, demographic, and urbanization trends, ‘the envelope of uncertainty’ rapidly increases (Matthews & Mauroner, 2015).

Nevertheless, the nature of processes inherent in surface and subsurface hydrology is rather well investigated by the hydrologic modeling that can simulate these processes over different spatio-temporal intervals and physiographical conditions. In recent years, a number of conceptual hydrological models have been developed and increasingly used by hydrologists and water resource managers to understand and address the extensive array of water resource problems, including those related to watersheds, streamflow and reservoir management, as well as to human activities that affect these processes. Numerous review studies, which provide comparisons either of complete modeling hydrologic packages or their specific components, with varying levels of input/output data and their structural complexity, have been done by different authors (Daniel et al., 2011; Refsgaard et al., 2010; Van Liew et al., 2005). These and other studies demonstrate the fact that movement and storage of water on watershed scales is a complex system affected by climatic, geologic, soil, land use, anthropogenic and other factors, accompanied by their inherent uncertainties. Moreover, available scenarios of their future trends are usually very limited and incomplete; this makes any planning, resource management, strategies development and infrastructure design/operations more challenging, especially in the developing world (Matthews & Mauroner, 2015).

We can assume that this conclusion is also valid for other aspects of fresh water modeling.

The long-standing intensive human use and alteration of lakes, rivers, and wetlands resulted in many negative impacts historically (Yan & Pottinger, 2013). However, the quickening ‘pulse’ of climate change is especially important for waters, since the rate of change is not only uncertain, but also fast, while many aspects of water decision-making – infrastructure, ecosystems, management agreements, etc. – are lasting over climate-relevant timescales. Water is also a naturally variable element that makes it difficult for predicting and challenging to manage, while with the global warming faster that it was previously understood the new features of key climatic variables have brought to even more uncertainty concerning the water resources future (Ray & Brown, 2015).

Climate change is already altering the global water cycle, making river flows more unpredictable. This process is projected to accelerate for many decades, generating a greater degree of uncertainty than societies, water managers and users have traditionally had to cope with (Jiménez Cisneros et al., 2014). Altering fundamental flow regime, lowering water availability and reducing water quality, the climate change can intensify existing problems of water resources management and can profoundly impact on water ecological services (Le Quesne et al, 2010; Matthews & Mauroner, 2015). Observed changes in air temperature and precipitation are beginning to shift from their role as the intensifiers to a widespread driver of ecosystems fundamental change, with a potential for ecological and economic impacts comparable to the worst of previous human interventions. Under current climate projections, most freshwater ecosystems will face ecologically significant climate change impacts by the middle of this century; some ecosystems have already begun to feel these effects (Jiménez Cisneros et al., 2014; Yan & Pottinger, 2013).

Thus, water and climate are inseparable, and any changes in climate present new kinds of problems, especially for audiences who are needed in precise and accurate quantitative data about future water conditions decades from now. Our ability to provide these data is framed primarily by the climate science and climate models (Matthews & Mauroner, 2015).

Weaver et al. (2013) believe that currently there is a severe underutilization of climate models as tools for supporting decision-making, and this fact is slowing a progress in developing the comprehensive adaptation and mitigation responses. This underutilization stems partially from a widespread, but limiting, conception that usefulness of climate models begins and ends with regional-scale predictions of multidecadal climate change. That is why, the quoted authors conclude (*ibid,* p. 39): "…addressing these root causes will require expanding the conception of climate models not simply as prediction machines within 'predict-then-act' decision frameworks, but as scenario generators, sources of insight into complex system behavior, and aids to critical thinking within robust decision frameworks". We cannot fail to agree with this statement. Matthews (2015) consider a presumption that *climate models* could predict future patterns safely as one pillar basing strategies for addressing climate change. He believe, that although climate models show little consistency (and generate little confidence) in their projections, providing only certain (weak) tools for imprecise, uncertain application, they cannot be neglected in quantitative water management (see also Ray & Brown, 2015).

And, at last, in addressing the role of water for development, alongside with discussions about global goals and targets, it is important to consider the new Post-2015 development agenda (Bates-Eamer et al., 2012) in *local* contexts. There is an evident lack of *location-specific knowledge* on water issues as well as a lack of modeling tools to adequately reflect the risks posed by new environmental challenges. Significant concerns are raised by unprecedented and deeper uncertainties about future regional and local climate.

Among the most widely used watershed and river basin–scale models, the Soil and Water Assessment Tool *(SWAT)* can be called. Due to a comprehensive nature, strong model support and open access status, this model, representing multiple decades of its individual components perfecting (Gassman et al., 2007, 2014), has proved to be highly flexible in addressing a wide range of water resource problems, including those concerning the climate change. The widespread use of SWAT in comparison with several other leading hydrologic models was demonstrated by Refsgaard et al. (2010); a good review of SWAT extensive testing for hydrologic modeling on different spatial scales is provided by Zhan et al. (2008).

The goal of this study was to examine the suitability and reliability of the SWAT model for simulating the water yields in current and likely regional climate on those territories of the Republic of Moldova (Moldova) where water resources are presented mainly as small anthropogenically modified rivers.

2. Initial Material and Methods

2.1 Study area

As a study area there was mainly used the Codrii Natural Reserve (hereafter, the Reserve) – the first national reserve of Moldova that was founded in 1971 with the aim to conserve the most representative forests, specific for the Moldavian Central Upland, also known as Codrii (Fig. 1). The surrounding landscape has been formed by marine and continental deposits of Miocene, and now it has a complex ridge-hilly relief with the surface deeply dissected by river valleys, gullies, ravines, erosion, landslides and local karst processes. The most common geomorphologic units are upland areas (89.2%) followed by lowlands (10.8%). A general exposition, determined by the relief and water flow, is northeastern and southwestern with slopes varying from 0-2° (plateau, meadow) to 21°. The Reserve's area is covered mainly by secondary forests; here and there grasslands are met. The natural vegetation includes more than 1,000 species of plants, which here are preserved much better in comparison with other regions of Moldova. Small agricultural fields and vineyards are located at the foot of hills.

Fig. 1. Moldavian Central Upland (Codrii). *Shaded* – an upper watershed of the Cogilnic River basin *(green contour)* that was used for a pilot study

Although Moldova territory belongs to the basins of two main rivers (Dniester and Prut, which both are transboundary with Ukraine and Romania, respectively), their tributaries, as well as the Cogilnic River crossing the study area, are small rivers, very poor by water resources. Their riverbeds sometimes partially dry up (in very dry years – completely), especially in the upper riches. Due to absence of a continuous water stream, in wintertime they usually freeze. Within the study area and in the neighborhood there are also many creeks and springs with a small debit, and the shallow ponds (1-3 m at their dams). Because a main source of ponds supply is melt water and precipitation, in dry years they are significantly reduced in their volume. Ground waters are generally located at a depth of 5 m, on watersheds and plateaus – at 10-14 m, but in some cases – at depths 1.5-2.0 m and even on the surface, causing landslides and other exogenous processes.

The rivers, streams flow of which are studied in this work, like practically all other small rivers in Moldova, are extremely polluted and anthropogenically disturbed, being almost on the verge of extinction (Casac & Lalikin, 1995). This situation is caused by an illegal creation of numerous ponds in their watersheds (often without any project documentation), by water withdrawal for the personal needs of local people and tenant farmers, as well as by high-water dykes and uncontrolled landfills on river banks. As a result, these rivers' channels are changing, they are losing their sources and tributaries, and precipitation and snow-melt water either evaporate or infiltrate to different depths. Drying of small rivers affects seriously the general state of watershed ecosystems, thus changing a plant cover and evapotranspiration. The current ecological condition of Moldova's small rivers and their watersheds create undoubted prerequisites for significant uncertainties in their runoff modeling.

Climate of the study area is temperate continental with short mild winter and long hot summer. Here, the last two (1996-2015) decades' mean annual air temperature was 9.5°C, with the winter and summer averages respectively -1.3°C and 20.2°C. Mean temperatures of transition seasons were between 9.6° and 9.7°C. Absolute minimal temperatures were observed in January-February (on the average about -13°C), absolute maximum temperature – in July and August (above 39°C). Mean annual sum of precipitation in this period was 580 mm, varying from 400 mm to 760 mm. 70% of total precipitations fall during the warm season (April to October); only about 10% of precipitation falls as snow. The negative aspects of regional climate are, especially in a warm season, the water deficit and dry spells that sometimes can last from 10 days to 2.5 months.

Climate and ecological conditions favor the growth and development of rich and varied flora. The vegetation is represented by deciduous forests like those in Central Europe. The basic species are oak; the others are main or secondary mixtures, depending on the flora dominant position – ash, linden, maple, hornbeam, apple and pear trees, etc. The inter zone vegetation was formed in hollows and is represented by narrow strips and patches of poplar and mesophilic meadows. However, water scarcity limits the spread and normal growth of many plant species.

2.2 SWAT Modeling

In this work, the ArcSWAT interface (Winchell et al., 2013), which has evolved from the AVSWAT2000 and ArcView extensions developed for the SWAT earlier versions, was applied. It uses a hydrologic modeling approach that utilizes spatially distributed climate, topography, soils, land use and land management practices.

The driving force behind all modeling processes is the water balance impacting plant growth and movement of water-related components. Simulation of the watershed hydrology is separated into a land phase, which controls the amount of these components' loading to the main channel, and an in-stream or routing phase presenting the movement of water through a watershed channel network to the outlet (Arnold et al., 2012 b). For modeling purposes, the watershed is partitioned into subwatersheds, connected by a stream network, and then – into the hydrologic response units *(HRUs)*, identified as small entities with the same characteristics of hydrologic soil type, land use and slopes. This delineation allows SWAT to reflect spatial heterogeneity in the watershed; lumping of the similar soil and land use areas into a single unit through HRU delineation also minimizes the computational costs of simulations (Zhang et al., 2008). On the other hand, this approach requires detailed spatial and temporal input data describing all land use, land cover and soil characteristics, available from various information sources, as well as their distribution within the watershed (Arnold et al., 2012 a).

SWAT model has proven to be an effective tool for assessing water resource for a wide range of scales and environmental conditions across the globe (see, for example, Gassman et al., 2014), and as such it has gained international acceptance as a robust interdisciplinary watershed modeling tool. However, certain weaknesses encountered in some of the SWAT outputs show clearly that expanded testing of this model, initially developed and adapted to specific USA conditions, is needed, and the SWAT users are to bear in mind that modeling results should reasonably reflect the actual hydrologic processes (*ibid)*.

In this work, the SWAT performance capabilities are used for addressing two problems: (1) the assessment of uncertainties in a small river's watershed runoff simulation, considering such uncertainties as a function of anthropogenic loads on the watershed; (2) the assessment of likely changes in the volume of watersheds runoff based on new projections of changes in regional climate. The addressing of these tasks is demonstrated on two specific examples.

3. Results and Discussion

3.1 Anthropogenic Factor in Surface Runoff Uncertainty

3.1.1 Initial Material

The working hypothesis, adopted in this study, can be formulated as follows: the differences between the simulated runoff in the river bed and the actually observed runoff, which cannot be eliminated during the model calibration, are the result of unaccounted anthropogenic factors.

To test this hypothesis, the upper part of the Cogilnic River watershed *(UCRW)* was selected, from the river source in the Codrii to the hydrological post *Hincesti* where monitoring observations of the streamflow were carried out (Fig. 1). The drain area of UCRW is about 243 km^2, the length of the river main channel in the studied area – 45.6 km. A perennial streamflow is generated at the highest elevations in the *UCRW's* northern part. A mean channel slope is about 6.1 m/km, lowering from 393.7 m in the river source to 115.7 m in *Hincesti*, with a surface runoff generally toward the southeast.

Like other small rivers in this zone, the Cogilnic River drainage area is very poor by water sources, being significantly transformed anthropogenically. In particular, according to Casac & Lalikin (1995), the approximate reductions of its streamflow, caused only partially due to some anthropogenic factors, are: land treatment – up to 20%; artificial reservoirs – 10-15%; irrigation – 4-5%; urbanization – 10%. Unfortunately, over two decades after the quoted work the situation only worsened.

Following to the working hypothesis, the research approach involved the application of SWAT to simulate three-years (1 January 2010 to 31 December 2012) monthly and annual runoffs from the UCRW watershed and its comparison with the observed Cogilnic streamflow at Hincesti hydrological post in this period (Table 1). Usually, such time series of the streamflow and associated climate data provide an essential foundation for validation of the conceptual models designed to simulate watershed water yields.

Table 1. Monthly statistics of the Cogilnic River streamflow in 2010-2012 (m^3/s)

Year	Statistics	Months											
		1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*
2010	Mean	0.075	0.17	0.17	0.15	0.31	0.17	0.17	0.03	0.07	0.11	0.12	0.21
	Max	0.22	0.50	0.22	0.39	1.13	1.51	1.29	0.22	0.45	0.19	0.19	1.09
	Min	0.03	0.04	0.13	0.10	0.16	0.01	0.03	0.01	0.02	0.06	0.07	0.08
2011	Mean	0.20	0.21	0.19	0.31	0.18	0.28	0.15	0.08	0.06	0.13	0.11	0.14
	Max	0.52	0.48	0.23	1.17	0.24	2.54	0.32	0.10	0.07	0.21	0.12	0.18
	Min	0.13	0.15	0.16	0.16	0.13	0.10	0.10	0.06	0.05	0.09	0.09	0.11
2012	Mean	0.10	0.11	0.17	0.17	0.12	0.11	0.15	0.15	0.15	0.16	0.07	0.17
	Max	0.11	0.13	0.28	0.22	0.14	0.11	0.26	0.15	0.15	0.26	0.13	0.30
	Min	0.09	0.09	0.11	0.14	0.11	0.11	0.11	0.15	0.15	0.12	0.04	0.12

A watershed's climate provides moisture and energy inputs that control water balance and determine the relative importance of different components in a hydrological cycle (Winchell et al., 2013). The SWAT allows imputing climatic variables from daily observations or their simulating from averaged monthly values. Because of practically no free access to daily weather information in Moldova, the historical three-year (2010-2012) monthly observations of mean (Tmean), maximum (Tmax) and minimum (Tmean) air temperatures, and precipitation at the Codrii weather station (Table 2) were used to simulate the UCRW climatic conditions, considering them as uniform for the whole study area.

Table 2. Monthly weather statistics at Codrii weather station in 2010-2012

Year	Months												Annual
	1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*	
	Mean monthly maximum temperature, °C												
2010	-2.1	2.7	9.7	16.8	23.0	26.2	28.8	30.7	21.3	11.8	15.2	1.6	15.5
2011	2.2	0.8	9.8	15.4	22.9	25.7	28.5	27.7	25.2	14.9	7.2	6.2	15.5
2012	1.2	-3.4	9.5	19.8	25.1	30.0	33.3	30.0	26.1	18.0	9.7	0.3	16.6
Sd	2.83	3.34	2.84	1.89	2.24	1.88	2.09	1.66	2.63	1.75	2.80	2.93	0.9
	Mean monthly minimum temperature, °C												
2010	-8.0	-3.3	-1.5	4.1	10.4	14.6	16.0	16.4	9.4	3.0	6.2	-5.7	5.1
2011	-5.3	-6.0	-1.9	3.1	8.7	13.4	14.5	12.7	9.9	2.4	-1.6	-1.3	4.1
2012	-5.6	-12.7	-1.2	5.8	11.0	14.5	16.2	14.6	10.9	6.7	3.0	-6.7	4.7
Sd	2.48	3.19	1.81	1.50	1.29	1.05	1.03	0.97	0.92	1.42	2.72	3.24	0.58
	Precipitation, mm												
2010	78.5	63.9	23.8	30.6	68	86.7	104.4	70.6	68.5	58.2	36.5	69.8	760
2011	27.5	20.4	10.1	74.4	86.9	176.5	52.7	26.9	13.1	43.6	1.7	14.7	549
2012	20.3	55.6	21.2	42	44.8	13.9	97.5	35.3	34.6	38.8	29.2	129.4	563

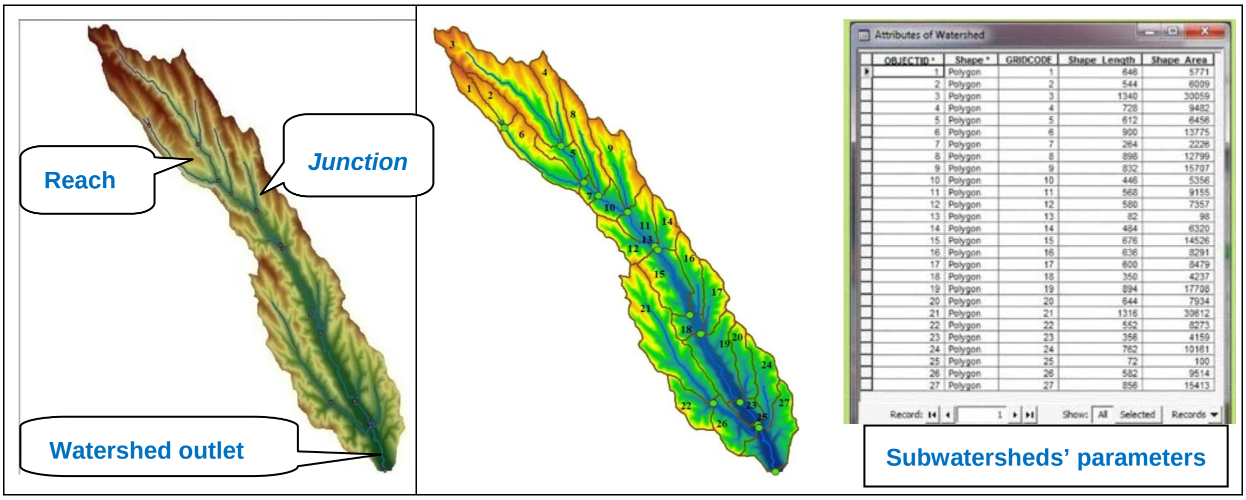
The standard deviations *(Sd)* of monthly temperatures, necessary as an additional input for modeling, were based on 20-yrs observation period (1993-2012). Other input weather parameters, required by SWAT (solar radiation, wind speed and relative humidity) were simulated by Weather Generator *(WGEN)* that is embedded in the model.

3.1.2 Watershed delineation and HRUs determination

The UCRW delineation for identifying the reaches and corresponding subwatersheds was carried out in the ArcSWAT environment, using the Digital Elevation Model *(DEM)* built on topographical data (scale 1:25 000), digitized at the Moldavian Academy of Sciences (Zhuk et al., 1995). Vectorization of the topographic maps resulted in a pixel size of 10x10 m that is suitable for a hydrological analysis.

Reaches were defined as parts of the river with drainage areas more than a threshold value – a critical source area, which defines a minimum upstream subwatershed required to form the origin of a stream (Winchell et al., 2013). Proceeding from the study area, the threshold value was selected equal to 500 ha. According to this criterion and the level of relief roughness, 27 subwatersheds were automatically defined on the reaches upstream of Hincesti hydrological post (Fig. 2). The lengths of reaches were between about 0.3 km and 10.2

km, with the mean value of 3.9 km. The location of selected hydrological post *Hincesti* coincides with the UCRW outlet, or a point where the streamflow exits this watershed and therefore reflects its entire drainage network. Such coincidence is useful to compare a modeled watershed runoff and measured streamflow.



OBJECTID *	Shape *	GRIDCODE	Shape_Length	Shape_Area
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2	Polygon	2	544	6009
3	Polygon	3	1340	30059
4	Polygon	4	728	9482
5	Polygon	5	612	6456
6	Polygon	6	900	13775
7	Polygon	7	264	2226
8	Polygon	8	898	12799
9	Polygon	9	832	15707
10	Polygon	10	446	5356
11	Polygon	11	568	9155
12	Polygon	12	580	7357
13	Polygon	13	82	98
14	Polygon	14	484	6320
15	Polygon	15	676	14526
16	Polygon	16	636	8291
17	Polygon	17	600	8479
18	Polygon	18	350	4237
19	Polygon	19	894	17708
20	Polygon	20	644	7934
21	Polygon	21	1316	30612
22	Polygon	22	552	8273
23	Polygon	23	356	4159
24	Polygon	24	762	10161
25	Polygon	25	72	100
26	Polygon	26	582	9514
27	Polygon	27	856	15413

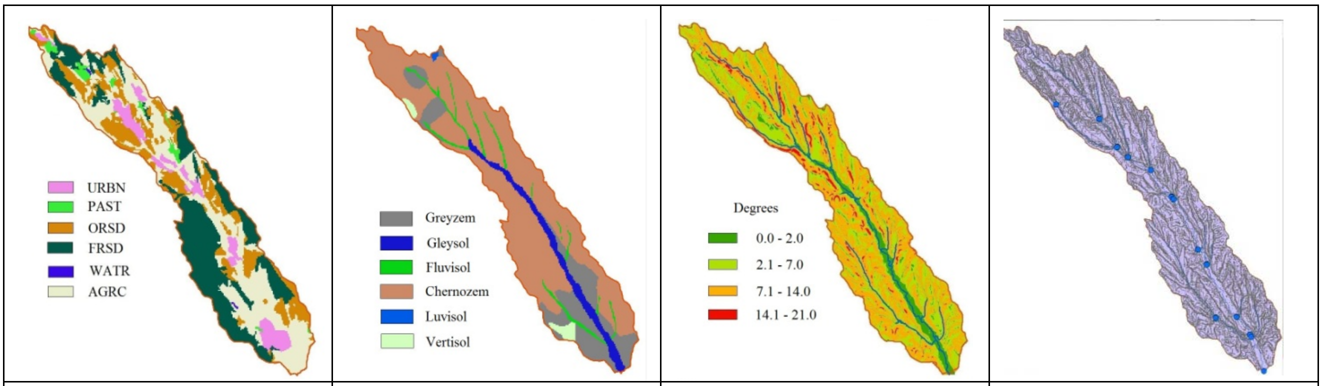
Fig. 2. The UCRW’s drainage network and subwatershed outlets defined as stream junction points overlapped with the DEM *(left),* its subwatersheds *(centre)* and their parameters *(right)*

Subdivision of the UCRW into HRUs enabled reflecting the differences in its hydrological conditions for different localities. HRUs were determined by the dominant land-use category, soil type and slope class within subwatersheds (Winchell et al., 2013). Due to relatively small areas of delineated subwatersheds, only a single HRU was identified for each, and thus 27 HRUs were received for the UCRW’s part above the hydrological post where a water yield was measured. Subwatershed/HRU characteristics were obtained from the GIS’s vector data layers (Fig. 3).

The land-use codes of CORINE (*Co-ORdinated INformation on the Environment)* land cover vector files *(http://www.eea.europa.eu/publications/COR0-landcover)* were used to create the UCRW watershed ***land-use*** maps. These maps were built based on the interpretation of satellite images and its following clarification on orthophoto images with a resolution of 1 m. Then these materials were generalized and translated in a raster format. In the Corine codes the land-use was distributed as follows: Residential *(URBN)* – 1,969 ha; Orchard *(ORSD)* – 5,217 ha; Pastures *(PAST)* – 510 ha; Complex cultivation patterns (AGRL) – 8,848 ha; Broad leaved forests *(FRSD)* – 7,719 ha; Water (WATR) – 34 ha. The available ***soil*** maps (scale 1:50 000), generalized and converted to a raster format, served as a basis for a vector version of the UCRW soil map. All soils were classified according to the World Reference Base for Soil Resources, deposited as the Food and Agriculture Organization (FAO) Corporate Document Repository at the FAO website (IUSS, 2014), and grouped into six classes and areas: Greyzem *(GR)* – 4,590 ha; Chernozem *(CH)* – 16,677 ha; Fluvisol *(FL)* – 900 ha; Gleysol

(GL) – 1,649 ha; Vertisol *(VR)* – 432 ha, and Luvisol *(LV)* – 50 ha. The average ***slope*** of UCRW is about 6.9 degrees. Four categories – less than 2^0, 2.0^0 to 7.0^0, 7.0^0 to 14.0^0 and 14.0^0 to 21^0 – were used to capture all slopes, from low to high, occupying 12, 40, 45, and 3% of this watershed area, respectively.

Reclassification of land use, soils and slopes maps into the SWAT layers enabled their overlay. This procedure resulted in a new layer called *FullHRU*, which was added to the SWAT geodatabase. Surface runoff and base flow were predicted separately for each HRU and routed to obtain a total water yield.



Land use & land cover | **Soil** | **Slope** | **Full HRU**

Fig. 3. Three thematic layers for identification of hydrological response units *(HRUs)* and the result of their overlay

3.1.3 SWAT validation

The annual results of three SWAT simulations are shown in Table 3. These standard outputs contain summary information on the model runs, including the UCRW-level statistics that help to determine whether the SWAT model is producing valid results.

Table 3. Results of the UCRW water yield simulation for 2010-2012

Year	SWAT Outputs, mm								
	PREC	*SURQ*	*LATQ*	*GWQ*	*LATE*	*SW*	*ET*	*PET*	***W. YIELD***
2010	759.6	82.2	51.9	56.1	86.5	32.3	297.1	852.6	**192.8**
2011	549.0	53.1	37.6	26.2	49.3	32.4	246.5	853.3	**118.5**
2012	563.4	46.5	64.0	71.3	132.0	35.0	287.6	847.8	**185.0**

Abbreviations: RREC – average amount of simulated precipitation; *SURQ* – amount of surface runoff contribution; *LATQ* – lateral subsurface flow contribution; *GWQ* – ground water contribution; *LATE* – water percolation past bottom of soil profile; *SW* – amount of water stored in soil profile; *ET* – actual evapotranspiration; *PET* – potential evapotranspiration; *WATER YIELD* – watershed runoff to streamflow.

A quick analysis of these results gives some formal reasons to consider them as quite correct. In particular, the water yield exceeds amount of water stored in soil profile about five times; the ratio *ET/PREC* changes from 0.39 to 0.51 that is somewhat smaller than its averaged value, for example, for US (~0.62), but US climate in whole is warmer than Central Moldova climate. However, the SWAT, as a comprehensive river basin model, contains a large number of input parameters that are used to describe spatially distributed water movement through a watershed system, and due to this complexity it requires an additional calibration.

Usually, the calibration procedure is targeted at better adjusting of the model to local conditions, thereby reducing its inherent uncertainty. The calibration of watershed models is complicated by above mentioned necessity to estimate a large number of input parameters in order their values, which generally represent only one possible combination, could produce a response similar to that observed (Van Liew et al., 2005). The overview of all key facets required for an ideal SWAT calibration and validation was made by Arnold et al. (2012b) who considered a river stream flow as a good example of these procedures. In practice, the main objective of hydrologic model calibrations is to receive the best agreement between observed and simulated values, and a final conclusion can be only achieved through direct comparison of the river’s watershed simulated water yield with the real runoff to its main stream.

To compare the Cogilnic River streamflow observed at Hinchesti hydrological post (Table 1) with the UCRW simulated runoff, the former was recalculated from m^3/sec into monthly and annual volumes. In turn, the simulated Water Yields, initially expressed in mm (Table 3), were converted to cubic meters through multiplying them by the UCRW area expressed in m^2. As can be seen from the comparison of simulations and observations (Table 4), the discrepancy between them is very significant to be neglected, thus necessitating the SWAT calibration. For example, if to express observed annual stream flows as a percentage of simulated water yields, they amount only 9.9, 18.5 and 9.6 percents for 2010, 2011 and 2012 yrs, respectively. These differences are even greater if to compare individual months.

The manual calibration is usually performed by changing the values of SWAT input parameters that aims to produce outputs within a certain range of measured data. Processes, which take place in the streamflow formation, are comprised of the water balance in the land phase of the hydrology, including evapotranspiration, lateral and return flow, surface runoff, channel transmission losses, deep aquifer recharge, etc. If data are available for each of these processes, they can be calibrated individually.

Table 4. The Cogilnic River observed streamflow *(S)* and simulated runoff *(R)* from the corresponding subwatershed (both in m^3) as their ratio *(R/S)*

Month	2010			2011			2012		
	S	***R***	***R/S***	***S***	***R***	***R/S***	***S***	***R***	***R/S***
1	202176	0	0.0	544320	0	0.0	256003	0	0.0
2	416189	2430	0.0	499392	2430	0.0	238205	1579364	6.6
3	468288	10895178	23.3	520992	5364976	10.3	443232	3591230	8.1
4	400896	1251342	3.1	796608	515115	0.6	435456	2322879	5.3
5	832896	403345	0.5	482976	177375	0.4	322272	840707.3	2.6
6	437357	123919	0.3	733536	48596	0.1	285120	918460.6	3.2
7	465350	12068767	25.9	389664	9077695	23.3	400896	9179747	22.9
8	70157	6633327	94.6	214618	4077188	19.0	401760	6239701	15.5
9	186624	4492682	24.1	145930	2665480	18.3	388800	6174096	15.9
10	291341	1739730	6.0	338688	894163	2.6	415584	2837995	6.8
11	310522	4072328	13.1	278554	2206249	7.9	189389	5095270	26.9
12	558490	5170593	9.3	368064	3766175	10.2	449280	6164377	13.7
Year	*4640285*	*46853641*	*10.1*	*5313341*	*28793012*	*5.4*	*4225997*	*43969480*	*10.4*

Calibration parameters concerning a streamflow are usually divided into those governing surface runoff and those governing subsurface runoff, or baseflow (Arnold et al., 2012b; Van Liew et al., 2005). The most popular parameter from the first group is *CN2* – an initial SCS runoff curve number for moisture condition II; the second group includes *SOL_AWC* – an available water capacity of the first soil layer (mm/mm) and *ESCO* – a soil evaporation compensation factor (Neitsch et al., 2011). *CN2* is an empirical parameter based on the area's hydrologic soil groups, land use and land cover types, and hydrological conditions. This parameter computes runoff depth from total rainfall depth and is widely used as an efficient method for determining the approximate amount of direct runoff from a rainfall event in a particular area, mainly for small catchments and hill slope plots. *SOL_AWC* is an available water capacity of a soil layer (mm water/mm soil). *ESCO* adjusts the depth distribution for evaporation from the soil to account for the effect of capillary action, crusting, and cracks; when the *ESCO* is reducing the model is able to extract more of the evaporated demands from the lower levels.

For each time step, SWAT calculates the amount of water that infiltrates into the soil and evaporates; the rest of water becomes *runoff* that occurs whenever the rate of water application to ground surface exceeds the rate of infiltration (Neitsch et al., 2011). From this viewpoint, parameters *SURQ*, *LATQ* and *GWQ* (Table 3) define runoff, or the water loading from HRUs to the main stream; the rest parameters define infiltration and evapotranspiration. Average watershed values are a weighted sum of all HRUs’ contribution to the streamflow and soil profile before any channel routing is simulated; the annual averages provide users with basic understanding of the watershed water balance.

The example of our surface runoff calibration through changing *CN2* is shown in Table 5. As it can be seen from the table, with 10, 20 and 30% reduction of *CN2*, the surface runoff *(SURQ)* is respectively reducing. However, *Water Yield (WY)* varies to a little degree because of a corresponding proportional increase in subsurface runoff (*LATQ & GWQ*). In other words, we observe a simple redistribution of water yield components, and even with 30% reduction of the runoff curve number the *WY* reduces within 5% limits.

Table 5. Changing the Water Yield *(WY)* from the UCRW with 10% sequential decrease of a runoff curve number *CN2*

CN2	2010				2011				2012			
	SURQ	*LATQ*	*GWQ*	***WY***	*SURQ*	*LATQ*	*GWQ*	***WY***	*SURQ*	*LATQ*	*GWQ*	***WY***
78.8	131.9	70.9	100.9	307.7	41,5	62.1	85.4	193.1	43.5	61.9	84.4	193.4
71.0	91.5	77.6	128.8	303.0	16.3	66.6	101.0	188.8	190.0	66.8	90.1	191.2
63.,1	69. 8	81.1	144.2	300.8	6.4	68.5	107.2	187.2	6.5	68.3	106.5	186.4
56.2	55.4	83.3	154.7	299.6	4.2	69.0	108.7	187.0	4.0	68.8	108.2	186.2

Abbreviations – see Table 3.

A similar pattern was observed when calibration parameters *SOL_AWC* and *ESCO* were changed, i.e. a discrepancy between simulations and observations was very significant to be eliminated by any calibration. These results support available experiences that SWAT capabilities are quite limited in relation to small rivers, especially those exposed to great anthropogenic changes, and the model calibration in these cases is unable to take into account all factors affecting their runoff, thereby causing the uncertainties and inevitable bias in evaluation.

On the other hand, these results demonstrate an evident potential to use the hydrological modeling, in particular the SWAT, to quantify a human burden on small rivers. Most available estimations, for example, the above cited work of Casac and Lalikin (1995), are mainly expert judgments that require a well-grounded corroboration. From this viewpoint, it seems that of this sort hydrological modeling is a tool that provides a reliable quantitative assessment of the level of anthropogenic load on river basins.

3.2 Hydrological modeling of water yields under climate change

3.2.1 Initial material and methods

This time, unlike to identification of the uncertainties in the hydrological modeling caused by anthropogenic factors, the study of uncertainties due to climate change was based on a somewhat greater area that included watersheds of three small rivers crossing the Codrii: *Bucovăţ, Coghilnic* and *Botna* (Fig. 5). Also, since the SWAT modeling of the watershed runoff has been described in previous sections, here only the principal intermediate steps are presented.

In particular, the delineation of study area has resulted in 34 subwatersheds (Fig. 4), with lengths of their reaches from about 0.3 km to 11.5 km (4.2 km on average). The subwatersheds' mean, maximum and minimum areas were equal 11.94, 28.07 and 1.07 sq. km, respectively; the analogous values of their altitudes above sea level were 191.6, 308.1 and 124.4 m. Accordingly, 34 HRUs were received for the entire watershed, based on the dominant land-use category, soil type and slope class within each subwatersheds, obtained as the GIS's vector layers of corresponding information.

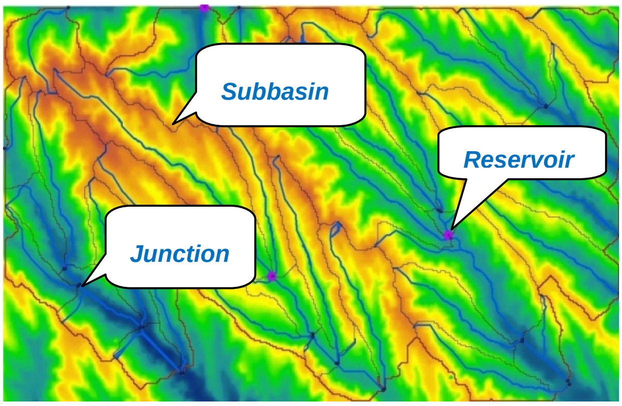


Fig. 4. Codrii watershed's drainage network, delineated in subwatersheds through reach junction points and overlapped with the DEM

The Codrii climatic conditions in 1970-2000, taken by the Intergovernmental Panel on Climate Change (IPCC) as baseline thirty years for estimation of likely climate change in the 21th century, are shown in Table 6. The corresponding monthly averages of mean maximum and mean minimum air temperatures and their standard deviations as well as monthly precipitation sums were registered at *Corneşti* weather station – the most representative one for this area. As before, these climatic variables were considered as uniform for the whole territory; other weather parameters, needed for runoff modeling, were simulated by the SWAT Weather Generator.

Table 6. Averages of monthly climatic variables at Corneşti weather station in 1970-2000

Climatic parameter	*Months*											
	1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*
Tmax, °C	0,7	2,4	8,0	15,4	21,7	24,7	26,7	26,5	21,0	14,8	7,2	1,9
SD	3,0	3,8	3,4	2,2	2,1	1,7	2,0	1,9	2,2	1,5	2,9	2,6
Tmin, °C	-5,1	-4,2	-0,3	5,4	10,7	13,9	15,9	15,4	10,9	6,0	0,8	-3,7
SD	3,2	3,2	2,2	1,6	1,3	1,1	1,4	1,3	1,3	1,2	2,9	2,7
Precipitation, mm	32	33	35	54	61	98	86	57	69	35	44	39

Scenarios of likely local climate change were based on the latest high resolution (12.5 km) data set that has been developed from a multi-model ensemble of regional climate simulations (Jacobs *et al.*, 2013). Such high resolution, provided by the EUROCORDEX initiative (*http://www.euro-cordex.net/*), never has been reached in previous regional climate model projections. Moreover, the EUROCORDEX climate change scenario simulations used a principally new approach to the assessment of future anthropogenic load on the global climatic system. The scenarios of greenhouse gas concentrations – the so-called *Representative Concentration Pathways* (*RCPs),* defined for the IPCC Fifth Assessment Report (Moss et al., 2010), assume different pathways to the achievement of target radiative forcings (and a corresponding global warming relative to pre-industrial conditions) in this century.

For the present work, the grid information on likely changes in key climatic variables for 2050 and 2100 time horizons in Europe was kindly provided by the Climate Service Centre, Germany (*http://www.climate-service-center.de/*). *RCP2.6, RCP4.5* and *RCP8.5* scenarios, used in this research, assume a low, moderate and strong radiative forcing (2.6, 4.5 and 8.5 W/m^2, respectively) and the corresponding levels of global warming.

The impact of climate change on the watersheds runoff was estimated as a difference between their values in the baseline and future climatic conditions.

3.2.2 Codrii runoff in current climate

The SWAT simulation of the Codrii drainage area's annual runoff in the current climate, shown in Fig. 5, provides a basic understanding of its spatial distribution here. These modelled values are a weighted sum of the HRUs' contributions to the streams flow and in the soil profile before any channel routing is simulated. As one can see, the maximal annual runoff (>350 mm) takes place in the northwest part, and the minimal (<320 mm) – in the southwest of the study area. However, for its most part the runoff amounts 330-350 mm per year.

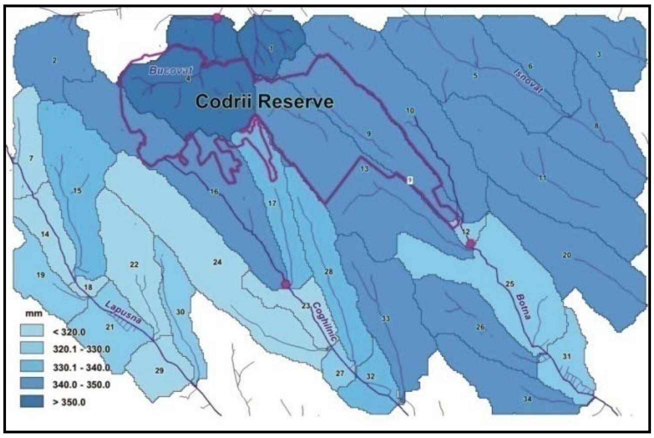


Fig. 5. Spatial distribution of the annual runoff from the Codrii watershed

Multiplication of a runoff per unit area *(water yield, mm)* by the watershed area gives its total runoff in cubic km (Table 7). Additionally, there were modeled the water yields from drainage areas of three small rivers crossing the Codrii and the volume of water potentially entering the ponds created in their floodplains. These artificial reservoirs accumulate water for the Reserve water supply, mainly for the suppression of forest fires here, as well as to meet other economic needs. The minimal runoff is observed in January–May period, the maximal – in the second part of the year. An annual total runoff in the Codrii area can be up to 0.135 km^3 (red circles in Fig. 5), the water flow in the selected reservoirs – from ~0.008 to above 0.13 km^3. However, given an undeniable bias in these values due to the above discussed anthropogenic load on small rivers, these estimates are to be considered only as a basis for the relative assessment of climate change impacts on the future runoff and rivers flow.

Table 7. Monthly water yields of three rivers drainage area and runoff into reservoirs in 1970-2000

Drainage area	Month												Water yield, mm	Runoff, cubic km
	1	2	3	4	5	6	7	8	9	10	11	12		
Bucovăţ	0.0	11.4	27.6	9.6	6.3	4.7	56.2	53.4	51.3	32.4	40.5	45.9	339.2	0.0075
Coghilnic	0.0	11.2	23.5	10.8	8.0	3.3	42.3	56.1	52.1	38.7	36.5	51.7	334.2	0.0094
Botna	0.0	12.3	25.7	10.2	7.3	3.6	48.0	53.6	50.9	35.1	37.3	48.8	332.8	0.0132
Codrii	***0.0***	***12.0***	***26.0***	***10.1***	***7.1***	***3.8***	***48.7***	***52.6***	***50.1***	***34.0***	***37.2***	***47.6***	***329.2***	***0.1346***

3.2.3 Codrii runoff under future climate

Results of the downscaling of the European climate change projections for the study area, carried out in Corobov et al. (2014), are shown in Table 8.

As seen from these figures, depending on a radiative forcing, the Codrii annual Tmax can increase by 0.2-1.9°C and Tmin – by 0.1-1.4°C by the 2050s; by the end of this century the increase can amount 0.3-5.2°C and 0.2-3.5°C, respectively. The expected change of precipitation is not so significant: from a decrease by ~5% to an increase by ~2%. Nevertheless, the combined effect of new temperature-humidity conditions should be taken into account. It must be also assumed, that an expected increase of air temperature, even with a slight change in total annual precipitations, will be accompanied by an increase in evapotranspiration and, accordingly, by a corresponding reduction of a surface runoff.

Table 8. Projections of likely climate change in Codri area in the 21th century

Season	Time horizons, yrs											
	2021-2050						2071-2100					
	Representative concentration pathways *(RCPs)*											
	RCP2.6		*RCP4.5*		*RCP8.5*		*RCP2.6*		*RCP4.5*		*RCP8.5*	
	Mean air temperature (℃)											
	Tmax	Tmin	Tmax	Tmin	Tmax	Tmin	Tmax	Tmin	Tmax	Tmin	Tmax	Tmin
Winter	0.5	0.5	2.1	2.1	2.2	2.1	0.9	0.9	3.1	3.1	5.5	5.2
Spring	-0.2	-0.1	1.8	0.9	2.2	1.1	0.4	0.2	3.4	1.6	5.2	2.5
Summer	0.2	0.1	2.0	1.4	1.7	1.2	-0.2	-0.1	3.3	2.3	5.5	3.9

Autumn	0.2	0.1	1.2	1.0	1.6	1.4	0.0	0.0	2.3	2.0	4.1	3.4
Year	*0.2*	*0.1*	*1.8*	*1.3*	*1.9*	*1.4*	*0.3*	*0.2*	*3.1*	*2.1*	*5.2*	*3.5*
	Precipitation, mm											
	Abs	%	Abs	%	Abs	%	Abs	**%**	Abs	%	Abs	%
Winter	3	3.3	17	18.9	12	13.3	3	3.3	13	17.4	23	25.6
Spring	21	15.6	8	5.9	10	7.4	-46	-34.1	13	16.0	17	12.6
Summer	-49	-21.5	-26	-11.4	-18	-7.9	-3	-1.3	-16	-7.0	-33	-14.5
Autumn	-5	4.0	-1	-0.8	-2	-1.6	11	8.8	11	8.8	5	4
Year	*-30*	*-5.2*	*-2*	*-0.3*	*2*	*0.3*	*-35*	*-2.1*	*21*	*3.6*	*12*	*2.1*

Note: *RCP2.6, RCP4.5, RCP8.5 – low, moderate* and *strong* radiative forcing *(W/m^2)*on the global climate system, respectively

The SWAT modeling of a surface runoff in the Codrii area, based on the projected values of air temperature and precipitation (the sums of the baseline ones and expected changes) has confirmed these assumptions (Table 9). A possible reduction of the water yield in stream flows, caused by expected changes in local climate could reach, depending on a time horizon and radiative forcing, from about 2% to 21%. On average, this reduction can be 6.5% in the 2021-2050s and 16% in the last thirty years of the current century.

Table 9. The modeling annual surface runoff (Abs, mm) and its relative increase (%) as to 1970-2000 in Codrii area

Baseline climate (1970-2000)	Time horizons, yrs											
	2021-2050						*2071-2100*					
	Representative concentration pathways *(RCPs)*											
	RCP2.6		*RCP4.5*		*RCP8.5*		*RCP2.6*		*RCP4.5*		*RCP8.5*	
	Abs.	%	Abs.	%	Abs.	%	Abs.	%	Abs.	%	Abs.	%
329 mm	*310*	***5.8***	*323*	***1.8***	*290*	***11.9***	*260*	***21.0***	*286*	***13.1***	*283*	***14.0***

4. Conclusion

The presented study provides certain evidences that SWAT is an effective tool for modeling a watershed runoff. At the same time, being useful for design purposes, it seems less powerful in modeling the flow of small anthropogenically altered streams. In these cases, the simulated runoff, which eventually enter to the river stream, does not reflect water losses resulted from agricultural, municipal, industrial and other human activities. The comparison of annual runoff simulations for a pilot watershed with the observed streamflow of its corresponding river has shown that the latter was only between 10 and 20 percents of the modeled value. These discrepancies must be considered as substantial uncertainties of the hydrological modeling.

The SWAT modeling of the future runoff from small rivers' watersheds, as a function of projected values of future local air temperature and precipitation, confirmed IPCC assumptions (Jiménez Cisneros et al., 2015) about expected decrease of water resources. A possible reduction of water yields in studied area (on average about 6.5% in the 2021-2050s and 16% – in the 2071-2100) must be considered as additional uncertainties that depend strongly on a time horizon and presumptive radiative forcing.

Thus, the correct use of up-to-date hydrological modeling tools allows accounting for runoff losses due to "nonnormalized" anthropogenic pressures on surface waters caused by their poor management, which combining with climate change effects can negatively affect the quantity and quality of water supply necessary for sustainable functioning of national economies and ecosystems services.

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