საქართველოს მეცნიერებათა ეროვნული აკადემიის მოამბე, ტ. 16, №3, 2022
BULLETIN OF THE GEORGIAN NATIONAL ACADEMY OF SCIENCES, vol. 16, no. 3, 2022

Geophysics

Analysis of Soil Moisture under Different Land Use Conditions in the Bolnisistskali River Basin

Peter Rončák*, Peter Šurda*, Justína Vitková*

**Institute of Hydrology SAS, Bratislava, Slovak Republic*

(Presented by Academy Member Tamaz Chelidze)

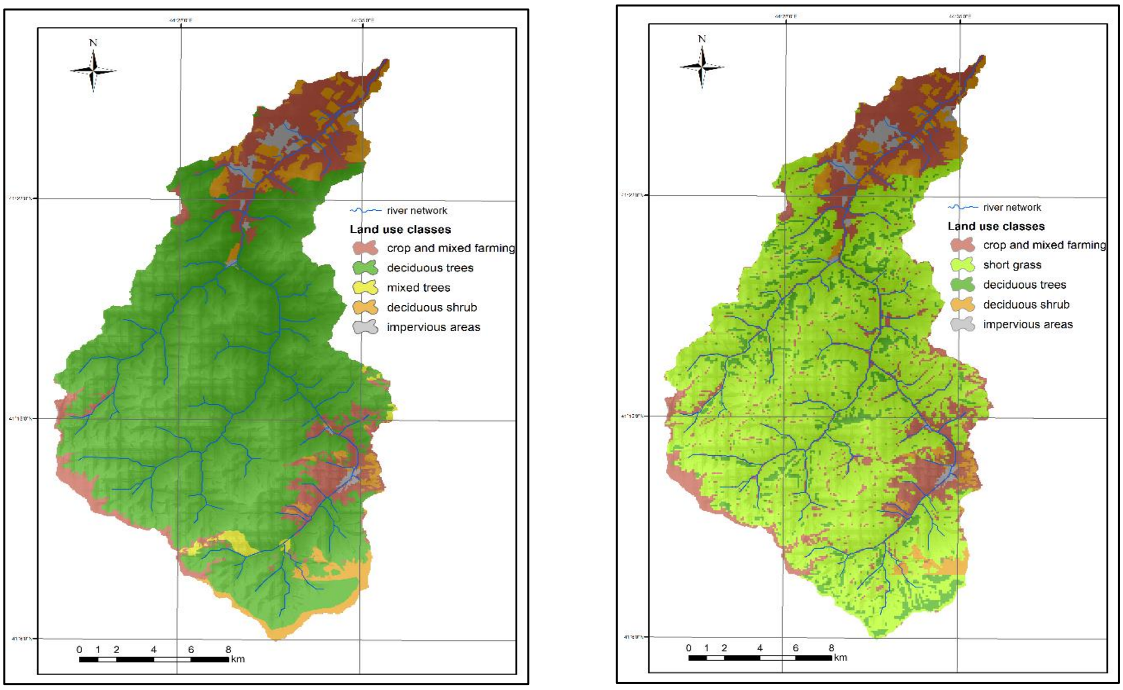
Soil moisture plays a significant role in both crop growth and vegetation restoration in the environment. Its spatial and temporal variability results from topography, soils, vegetation and land use. This contribution deals with an analysis of the soil moisture in the Bolnisistskali River basin with the current land use. The results of the analysis were compared with a scenario consisting of a change in land use. The scenario is geared toward land use for agricultural purposes and cattle breeding. The rainfall-runoff model with spatially distributed parameters was used for the research and comparison analyses. From the results of the modelling, it is obvious that using the scenario it is possible to achieve a better state of soil moisture in the basin. *© 2022 Bull. Georg. Natl. Acad. Sci.*

wetspa model, land-use change scenario, soil water content

Soil water content (i.e. soil moisture) is a key factor affecting vegetation structure in water-limited environments [1]; in turn, vegetation exerts vital controls on the entire water balance via complex and mutually interacting hydrological processes [2]. Land use can significantly affect soil properties, such as bulk density, saturated hydraulic conductivity, infiltration rate, and available soil water (moisture) content [3]. Because soil properties are the main factors controlling soil water variations [4], land use could influence soil water variations by changing soil properties. Land use is one of the main factors controlling soil water variability [5, 6].

Changes in land use may cause land degradation, defined as the temporary or permanent decline in the productive capacity of the land while the soil completely loses its productive capacity [7]. Agricultural activities on large blocks of land are considered one of the main anthropogenic factors negatively influencing soil erosion and the landscape’s ecological stability, which however could be eliminated by effective landscape management activities [8].

This article builds on research [9] in which the authors addressed the impact of land-use change on runoff processes, using the same inputs. In the present paper, we focused on the development of a land-use change scenario and soil moisture simulation for estimating potential changes under the changed land use conditions in the Bolnisistskali catchment. The soil moisture change in the land-use scenario was compared to the current state.



a) b)

Fig. 1. a) Map of the current land use; b) Map of the land-use change scenario.

Description of the Study Area

The Bolnisistskali River basin with the Samtsverisi final profile, an area of 360 sq. km, and an altitude ranging from 450 to 2540 m a.s.l. was selected as a study area for the rainfall-runoff modelling. The catchment is situated in south-eastern Georgia in Kvemo Kartli region. Deciduous forests predominate in land use (Fig. 1a). The cropland is situated in the northern part of the catchment. The soil types are mainly characterized by sandy-clay loam and loam soils [10].

By the end of the century on the eastern Georgia plains, in particular, in Kvemo Kartli, the annual precipitation amount will decrease by 50% or more and will be only 150–200 mm, and the precipitation daily maximum will decrease by about 20 mm and be only 10–15 mm, which naturally intensifies desertification processes of steppe and semi-desert landscapes. In the large parts of eastern Georgia, annual precipitation decreases, decadal trend composes 1–3%. The largest decrease in rainfall trend is observed in Kvemo Kartli. The same trends are reserved for precipitation in warm and cold periods of the year [11].

Methodology

An analysis of the land use in a territory involves the calculation of the individual areas of the land use. We are therefore talking about the percentage of each type of land use utilized in the catchment. As part of this work, we have been working with the current land use and a land-use change scenario. The land-use scenario was created based on the combination of the slope characteristics and land use classes (Fig. 1). Zones with slopes of less than 12% and covered with grass were changed to cropland. Areas with a declination (12-20%)

Table. 1. Comparison of the land use elements between the land-use change scenario and the current state

Land-use type	Current state [%]	Scenario [%]	Increase/ decrease [%]
Cropland	14	18	+ 4
Short grass	-	64	+ 64
Deciduous trees	73	6	- 67
Mixed trees	1	-	- 1
Deciduous shrub	10	10	0
Impervious areas	2	2	0

covered with cropland were changed to grasses. Areas with over 20% slopes, cropland, and grasses were changed to deciduous trees. The percentages of the individual land use elements and their increases or decreases between the current state and the land-use change scenario are shown in Table 1. The percentages of the various land-use types are expressed in the total area of the selected river basin. Based on the delimitation criteria, the forested areas (- 67%) in the scenario were mostly replaced by short grass (+ 64%).

To simulate the soil moisture from the basin, the physically-based WetSpa rainfall-runoff model was used. The model uses geospatially referenced data as the input for deriving the model parameters, which include most data types supported by ArcGIS, such as shapefiles, grids, and ASCII files. Digital maps of the topography, land use and soil types are the 3 base maps used in the model, while other digital data are optional, depending upon the data availability, the purpose, and the accuracy requirements of the project [12]. The following meteorological and hydrological data were used in the model: daily precipitation totals from spot measurements at 2 stations and the average daily values for the air temperature at 4 climatological stations. The flow data consisted of the average daily flows at the Bolnisistskali – Samtsevrisi profile. The input data (spatial and hydro-meteorological) was provided by the National Environmental Agency (NEA, Tbilisi). We used the data from the period between 1971 and 1985. The calibration period was from 1971 to 1985. Twelve parameters for which a range of admissible values was set were optimized. The Nash–Sutcliffe (NS) coefficient was chosen as the dominant criterion in this work. In this case, the NS coefficient value was 0.65, which represents a comparatively good degree of accuracy in the calibration of the global parameters. It is essential in rainfall-runoff modelling to take into account various sources of uncertainties that influence the quality of the simulated runoff from a catchment [13].

Statistical Analysis

Differences between the parameters estimated in different sites were evaluated using Welch's t-test. The unequal variances t-test is a two-sample location test which is used to test the hypothesis that two populations have equal means. It is named for its creator, Bernard Lewis Welch, and is an adaptation of the Student's t-test, and is more reliable when the two samples have unequal variances and/or unequal sample sizes. These tests are often referred to as unpaired t-tests, as they are typically applied when the statistical units underlying the two samples being compared are non-overlapping.

Welch's t-test defines the statistic t by the following equation:

$$t = \frac{\overline{X}_1 - \overline{X}_2}{\sqrt{\frac{s_1^2}{N_1} + \frac{s_2^2}{N_2}}}, \qquad (1)$$

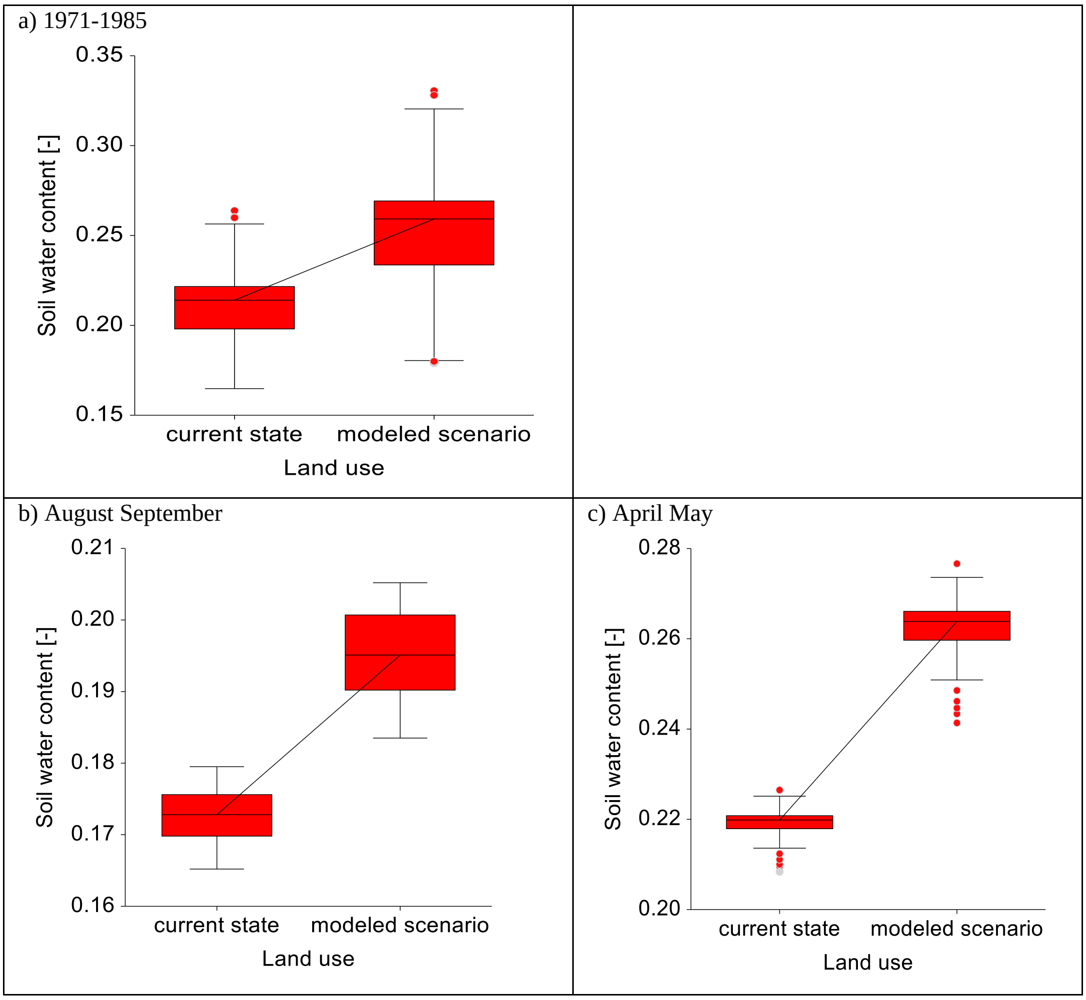
where $\overline{X}$, s, N and are the sample mean, sample variance and sample size, respectively.

Results

The mean values of soil water content at the study site for the period 1971–1985, modelled for two scenarios (current land use and alternative scenario)

Table 2. Statistical parameters of soil water content at the study site a) for the period 1971–1985, b) for the two driest months during the period 1971–1985, c) for the two wettest months during the period 1971–1985, estimated for 2 land-use scenarios. Arithmetic means with the same letter are not significantly different from each other (Welch's t-test).

Attribute	Time period	Land Use	Minimum	Maximum	Median	Mean	SD	Skewness	Kurtosis
SWC[-]	1971-1985	CS	0.165	0.264	0.214	0.210^a	0.018	-0.470	2.685
		MS	0.179	0.331	0.259	0.251^b	0.027	-0.682	2.765
	A-M (1971-1985)	CS	0.208	0.227	0.220	0.219^a	0.004	-1.072	4.294
		MS	0.241	0.277	0.264	0.262^b	0.007	-1.127	4.287
	A-S (1971-1985)	CS	0.165	0.180	0.173	0.173^a	0.004	-0.244	2.122
		MS	0.184	0.205	0.195	0.195^b	0.006	-0.135	1.854


a) 1971-1985

b) August September

c) April May

Fig. 2. Boxplots of soil water content at study site a) for the period 1971–1985, b) for the two driest months during the period 1971–1985, c) for the two wettest months during the period 1971–1985, estimated for 2 land-use scenarios. Boxplots display statistics (i.e., median, 25th and 75th percentile, and largest or smallest value extending from hinge up to 1.5-fold the interquartile range).

are presented in Table 2 as box plots in Fig. 2. The alternative land use scenario showed a positive effect on soil water content at the study site, as according to the modelling results, there was a statistically significant increase in the mean annual SWC within the MS scenario compared to the current state. Besides the average annual SWC value, it is important to monitor the value of SWC during the driest and also during wet seasons. The differences in modelled values of SWC between MS and CS scenarios were statistically significant also during the dry and wet seasons of the period 1971–1985 and we can state that the transition to an alternative land use scenario would have a positive effect on the form of increasing of SWC at the study site.

The dynamics of mean daily soil water content in the diagnosed horizon of the soil aeration zone have a cyclical character with a one-year repetition period at the study site. In most years of the analysed period, this cycle can be divided into saturation period and period of discharge. Soil water content is increasing since autumn with the peak in the early spring months (Fig. 3). The beginning of the growing season is manifested by a significant decrease in winter reserves and the availability of soil water is fully influenced by the actual precipitation. This situation may generate conditions for plant water stress.

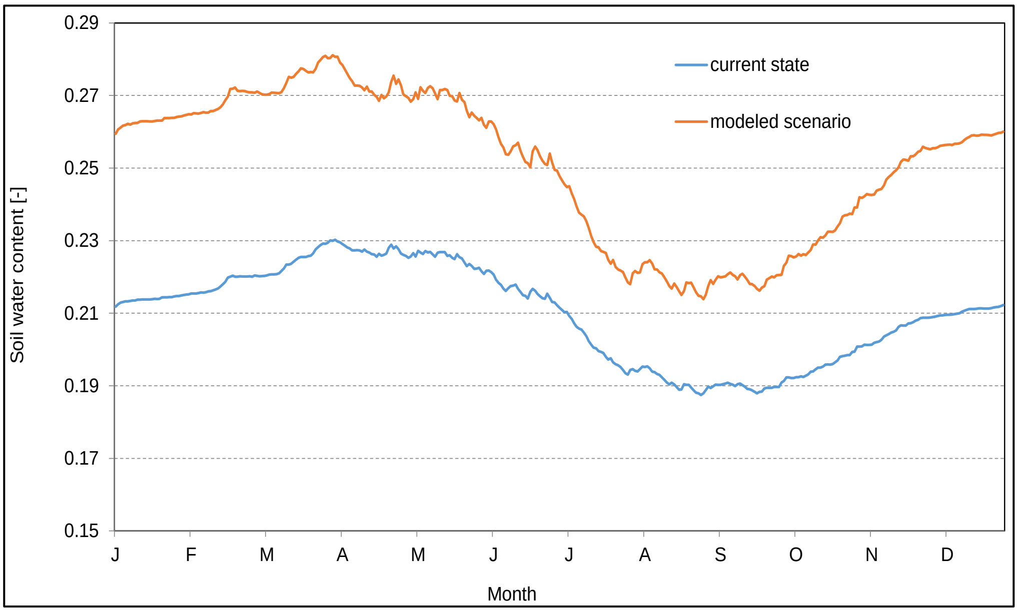


Fig. 3. The cyclical course of mean daily soil water content from the period 1971–1985 was estimated for 2 land-use scenarios.

Conclusion

The present paper describes the possible impact of land-use change on the component of water balance. Soil moisture is important in many hydrological processes. Therefore, it is important to know their behaviour in the changing conditions, especially how the land-use change affects soil moisture. The soil moisture changes were evaluated by comparing the simulated average soil moisture for the current state and the land-use change scenario. Land-use change scenario showed a positive effect on soil water content at the study site, as according to the modelling results, there was a statistically significant increase in the mean annual SWC within the MS scenario compared to the current state.

The created scenario was also used to analyse the ability of the Wetspa model to simulate changes in land use. The WetSpa model demonstrated sufficient ability to simulate soil moisture under changing land use conditions. For an interpretation of these findings, however, one should not forget the limits of rainfall-runoff modelling. Computer simulation models are inherently uncertain, and even more so when considering future projections.

This work was supported by Scientific Grant Agency No. VEGA 2/0155/21 and is also the result of the project Mob-Open-20-03.

გეოფიზიკა

ნიადაგის ტენიანობის ანალიზი მდინარე ბოლნისისწყლის აუზში მიწის სხვადასხვა გამოყენების პირობებში

პ. რონჩაკი*, პ. შურდა*, ი. ვიტკოვა*

**ჰიდროლოგიის ინსტიტუტი, ბრატისლავა, სლოვაკეთის რესპუბლიკა*

(წარმოდგენილია აკადემიის წევრის თ. ჭელიძის მიერ)

ნიადაგის ტენიანობა მნიშვნელოვან როლს ასრულებს როგორც მოსავლის ზრდაში, ასევე გარემოში მცენარეულობის აღდგენის საკითხში. მისი სივრცითი და დროითი ცვალებადობა გამოწვეულია ტოპოგრაფიით, ნიადაგებით, მცენარეულობით და მიწათსარგებლობით. ნაშრომი ეხება ბოლნისისწყლის აუზში ნიადაგის ტენიანობის ანალიზს მიწის ამჟამინდელი სარგებლობის გამოყენებით. ჩატარებული ანალიზის შედეგები შედარდა სცენარს, რომელიც შედგება მიწათსარგებლობის ცვლილებისგან. სცენარი ითვალისწინებს მიწათსარგებლობას სასოფლო-სამეურნეო მიზნებისთვის და მესაქონლეობისთვის. კვლევისა და შედარებითი ანალიზის ჩატარებისათვის გამოყენებულია წვიმა-ჩამონადენის მოდელი სივრცით განაწილებული პარამეტრებით. მოდელირების შედეგებიდან ჩანს, რომ სცენარის გამოყენებით შესაძლებელია აუზში ნიადაგის ტენიანობის უკეთესი მდგომარეობის მიღწევა.

REFERENCES

1. Rodriguez-Iturbe I., D'odorico P., Porporato A., Ridolfi, L. (1999) On the spatial and temporal links between vegetation, climate, and soil moisture. *Water Resources Research*, **35**(12): 3709-3722.
2. Porporato A., D'odorico P., Laio F., Ridolfi L., Rodriguez-Iturbe I. (2002) Ecohydrology of water-controlled ecosystems. *Advances in Water Resources*, **25**(8-12): 1335-1348.
3. Tellen V. A., & Yerima B. P. (2018) Effects of land-use change on soil physicochemical properties in selected areas in the North West region of Cameroon. *Environmental Systems Research*, 7(1): 1-29.
4. Tiwari S., Singh C., Boudh S., Rai P. K., Gupta V. K., Singh J. S. (2019) Land use change: a key ecological disturbance declines soil microbial biomass in dry tropical uplands. Journal of *Environmental Management,* 242: 1-10.
5. Qiu Y., Fu B., Wang J., Chen L. (2001) Soil moisture variation in relation to topography and land use in a hillslope catchment of the Loess Plateau, China. *Journal of Hydrology*, **240**(3-4): 243-263.
6. Gao X., Wu P., Zhao X., Wang, J., Shi, Y. (2014) Effects of land use on soil moisture variations in a semi-arid catchment: implications for land and agricultural water management. *Land Degradation & Development*, **25**(2): 163-172.
7. Hlavčová K., Danáčová M., Kohnová S., Szolgay J., Valent P., Výleta R. (2019) Estimating the effectiveness of crop management on reducing flood risk and sediment transport on hilly agricultural land–*A Myjava Case Study*, 172: 678-690. Slovakia. Catena.
8. Vyleta R., Valent P., Nemetova Z., Hlavcova K. (2019) An assessment of changes in ecological stability and landscape management practices over the last centuries: a Case Study from Vrbovce, Slovakia. In IOP Conference Series: *Materials Science and Engineering* **603,** 2: 022083.
9. Rončák P., Maliariková M., Nosko R., Kordzakhia G., Kordzakhia M. (2018) Utilization of a rainfall-runoff hydrological model in studies on the impact of land use changes: Case Study from Georgia. *Bull. Georg. Natl.* Acad. Sci, **12**(2):63-69.
10. Elizbarashvili E. S., Chavchanidze Z. B., Elizbarashvili M. E., Maglakelidze R. V., Sulkhanishvili N. G., Elizbarashvili S. E. (2006) Soil-climatic zoning of Georgia. *Eurasian Soil Science*, **39**(10): 1062-1065.
11. Elizbarashvili M., Elizbarashvili E., Tatishvili M., Elizbarashvili S., Meskhia R., Kutaladze N., Khardziani T. (2017) Georgian climate change under global warming conditions. *Annals of Agrarian Science,* **15**(1): 17-25.
12. Wang Z., Batellan O., De Smedt F. (1996) A distributed model for water and energy transfer between soil, plants and atmosphere (Wetspa), *Phys. Chem. Earth*, 21: 189-193.
13. Valent P., Danko M., Miklánek P. (2014) Sensitivity analysis of a rainfall-runoff model (Analýza citlivosti zrážkovo-odtokového modelu). *Acta Hydrologica Slovaca*, **15**, 2: 267 - 280 (in Slovak).

Received February, 2022