CZU 551.83+631.6.02 https://doi.org/10.54326/1857-0046.21.1.08

Corobov R.,[1] Syrodoev G.[2]

Rainfall erosivity and climate change: some estimations for the Baltata River basin

Abstract

The paper assesses the possible impact of changes in precipitation due to global warming on rainfall soil erosion in a small river basin. The Modified Fourier Index (MFI) was selected as an indicator of erosivity. Comparison of this index values in two climatic thirty-years (1991-2010 vs. 1961-1990) has showed that due to insignificant changes in the total amount of annual precipitation, a weak level of erosion hazard, caused by rainfalls in the previous period, has remained in the studied basin under conditions of climate change.

Keywords: *river basin, climate change, erosivity, the Modified Fourier Index*

Erozivitatea precipitațiilor și schimbările climatice: unele estimări pentru bazinul râului Baltata.

Rezumat

Lucrarea evaluează impactul posibil al schimbărilor de precipitații cauzate de încălzirea globală asupra eroziunii solului cauzate de acestea în bazinul unui râu mic. Indicele Modificat Fourier (MFI) a fost selectat ca indicator al eroziunii. Comparația valorilor acestui indice în doi treizeci de ani climatici (1961-1990 și 1961-2020) a arătat că, din cauza modificărilor nesemnificative în cantitatea totală de precipitații anuale, un nivel slab de pericol de eroziune cauzat de acestea în perioada anterioară a rămas în bazin sub evaluare și în condițiile schimbărilor climatice.

Cuvinte cheie: *basinul hidrografic, chimbarea climei, eroziunea, Indicele Modificat Fourier*

Эрозионная активность осадков и изменение климата: некоторые оценки для бассейна реки Балтата.

Резюме

В работе оценивается возможное воздействие изменения количества осадков, обусловленного глобальным потеплением, на вызываемую ими почвенную эрозию в бассейне малой реки. В качестве индикатора эрозионности выбран Модифицированный Индекс Фурье (MFI). Сравнение значений этого индекса в два климатических тридцатилетия (1961-1990 и 1961-2020) показало, что вследствие незначительности изменения общего количества годовых осадков, слабый уровень эрозионной опасности, вызываемой ими в предыдущий период, сохранился в оцениваемом бассейне и в условиях изменения климата.

Ключевые слова: *речной бассейн, изменение климата, эрозионность, Модифицированный Индекс Фурье*

1. Introduction

[1] Eco-Tiras International Association of River Keepers, Chisinau, The Republic of Moldova

[2] Institute of Ecology and Geography, Chisinau, The Republic of Moldova

Soil erosion is one of the most widely reported forms of land degradation in the world. A long list of references on this issue can be found, for example, in Briak et al. [1]. The second important adverse factor impacting the land and water resource management is sedimentation. The sediments, delivered to rivers and reservoirs, end up eventually in seas and oceans, causing their pollution. Because soil erosion is also a main component of non-point pollutions, the studies of these geomorphological processes are very important, creating a basic work to calculate the sediment yield and their migration. However, an activity on reducing the soil erosion and sedimentation intensity first of all requires to determine their drivers and sources, thereby identifying the areas where conservation works should be focused.

According to the based on numerous studies review, carried out by Merritt et al. [2], the process of erosion that results in the sediments development can be described in *three stages*: detachment, transport and deposition. In this triad, the stage of surface soil detachment is partially considered as a result of raindrop impacts caused by intense shear stresses, locally generated at the soil surface by raindrops. Rainfall erosivity is the term, used for indication of the degree of rainfall potential to cause soil loss [3], and by its essence describes the kinetic energy of raindrop's impact and the rate of associated runoff. Sometimes, this indicator is defined as rain aggressiveness, e.g. [4, 5].

Rainfall erosivity causes a loss of fertile soil, damage to agriculture and infrastructure, water pollution, etc. It is influenced by changes in rainfall patterns, including those caused by climate change effects, depending primarily on rain intensity and amount. As an erosive agent, rainfall erosivity is among dynamic factors causing a soil erosion and sediment production around the world [6-10]. Besides the use in soil erosion modeling and sediment estimation, the recent studies have also employed rainfall erosivity in the modeling of floods, hydrological hazards, landslides and aerosol pollution as well as in the assessment of ecosystem services and water management. As such, the rainfall erosivity has been studied for decades, at least since it was formally integrated into the widely used Universal Soil Loss Equation (USLE) model. In the RUSLE model (one of the USLE modification) the rainfall erosivity is included as the *R*-factor — a multi-annual average index measuring rainfall's kinetic energy and intensity in describing the effect of rainfall on sheet and rill erosions.

In the USLE model the rainfall erosivity is assessed by the total rainfall kinetic energy of a given event multiplied by the maximum 30-minute rainfall; then these values are summed for all storms over the assessment period (e.g., García-Barrón et al, [5]). Xie Y. and al. [11] estimated daily rainfall erosivity in China. However, in many cases and for different reasons (the scale of a study, environmental conditions, data availability, etc.) this approach is not considered as appropriate. Existing constraints have led to a search for alternative procedures to assess the rainfall erosivity from more easily determinable rainfall parameters. In particular, as alternative approach for calculating erosivity the different indexes are used.

So, to correlate rainfall with sediment loads in rivers of large catchments, Fournier [12] developed an index, known as *Fournier Index (FI)*:

$$FI = p_{max}^2/P(mm),$$

where p_{max} is a mean rainfall amount (mm) of the wettest month of a year, and P is the mean annual rainfall amount (mm).

As such, *FI* provides a measure of rainfall variability: its large values relate to high variability, while low values characterize sites with an evenly distributed rainfall. The original *FI* was initially devised specifically to provide a measure of erosivity that could be applied at a regional scale. However, since then it has been widely applied, most especially in analyses of erosion from river basins, correlating broadly with both the USLE erosivity index and with rates of erosion at a basin scale [13].

However, *FI* has shortcomings as an estimator of the rain erosivity because rainfall low amounts also have erosive power, and any increase in total rainfall amount should also yield in a corresponding erosivity increase. Therefore, Arnoldus [14] modified *FI* and proposed the Modified Fournier Index *(MFI)* that takes into account precipitation in all months of a year:

$$MFI = \Sigma p^2/P \ (mm),$$

where p is monthly rainfalls, and P — annual rainfalls; both in mm.

During the last decades there were developed equations to calculate rainfall erosivity based on daily, monthly, and annual rainfall amounts with aim to extent its datasets lengths [6]. However, mostly due to limited availability of long-term rainfall data series with high temporal resolution, only few studies have investigated trends in rainfall erosivity [3, 15], including that under climate change [16]. At the same time, changes in rainfall erosivity as one of important soil erosion parameters are of general interest for decision makers, land managers, and the general public. As an example, Bezak et al [6], with the aim to investigate temporal changes in rainfall erosivity, reconstructed its past value in Europe for the period 1961–2018.

This study aims to estimate the long-term rainfall erosivity and its trends in the Baltata River Basin.

2. Material and methods

The Baltata River is a right tributary of the Dniester River — one of main Moldavian rivers that flows into the Black Sea. Thus, all surface pollution and litter entering its mainstream are directly transported to the Black Sea. Also, the catchment of this small river presents the current situation in other analogous river basins of Moldova.

The Baltata basin area (Fig. 1) has 153.9 km^2; its length from northwest to southeast is 27.47 km, the width – 7.74 km. Mostly, it is located within the steppe zone; a smaller northwestern part — in the forest-steppe zone, with a predominantly flat relief. The absolute marks of heights vary from 16 m to 219 m, averaging 120 m. The slopes of the territory vary from sub-horizontal to steep (about 17º), on average being 4º28´. Slopes from 2º to 5º are most common, and horizontal surfaces are less than 0.1%. The basin soils are affected by erosion processes. About 60% of its carbonate and ordinary chernozems are subject to various types of erosion, requiring the anti-erosion measures, without which the current slightly eroded soils pass usually into the category of moderately eroded ones. The intensity of erosion manifestation is also largely determined by the basin relief, main indicators of which are usually degree of surface dissection, depth of local bases of erosion, length and shape of slopes.

As it was already mentioned above, in the study of rainfall erosivity effects two complementary models can be used: the intensity models that are based on sub-hourly rainfall records, and the volume models, based on monthly rainfall records. The volume models based on monthly rainfall records are extensively available in most countries. In particular, Gabriels [18] proposed a methodology for calculating rainfall indices, based on monthly data, for their possible use in describing and assessing the rainfall erosive potential in view of their validation through a comparison with field erosion losses in different countries and regions of Europe. In this study, as initial information there were also used monthly precipitation records at the Baltata weather station, located in this river basin, for the 1961-2020 period. This time interval covers two climatic thirty years: 1961-1990 and 1991-2020. These periods characterize respectively the basin area precipitation regime before and after the global warming evolvement. It was assumed that any change in precipitation should be accompanied by corresponding changes in the rainfall erosivity.

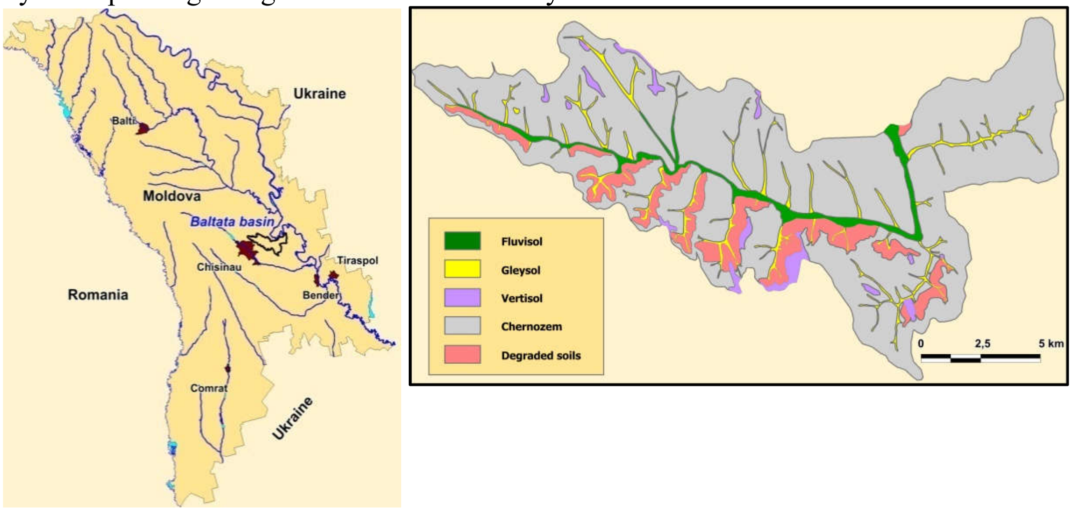

Fig. 1 Location of the Baltata River basin (*left*) and the map of its soil (*right*) [17].

The data procession included two tasks: the study of *time trends* in the *MFI* historical data and the MFI *descriptive analysis* aimed to describe and compare its basic features in compared periods. Also, according to the available data sets, two different procedures, proposed by Bezak et al. [6], were used to *MFI* calculation. In the first case the monthly rainfall amounts are averaged over all years, and then *MFIs* were calculated from these averaged rainfall data sets and reported as MFI_1. In the second case, this index was calculated from monthly rainfall amounts of each individual year and then averaged over all years. Those long-term average values are reported as MFI_2.

All statistical analysis was performed, using appropriate tools provided by the Microsoft Excell.

3. Results and discussion

3.1 Historical precipitations in the Baltata basin

According to the *MFI* equation, it is completely based on the precipitation amounts. Thus, we can presuppose that its change in time depends on precipitation changes, and the analysis of change in *MFI* due to global warming should be preceded by an analogous precipitation analysis (Table 1).

The analysis of Table 1 shows that climate change, observed over the past decades, had an extremely insignificant effect on the total annual precipitation in the basin under consideration: 501 mm in 1991-2020 vs. 526 mm in 1961-1990, or only about by 5%. However, the annual distribution of precipitation has changed significantly. While maintaining their somewhat weakened maximum in June-July, the minimal precipitation shifted from March to February and from October to December (Fig. 2). Also, the annual course of precipitation has somewhat smoothed out, which is expressed in a decreases in their monthly extremes and the range of annual precipitation amounts (from 401 to 377 mm).

Tab.1

Monthly precipitation in the Baltata River basin in two climatic periods, mm

Statistics	Months												Year
	1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*	
1961 - 1990													
Average	34	33	30	43	49	76	72	48	46	28	35	35	526
Max	157	68	74	116	119	166	158	130	153	81	91	80	732
Min	1	7	5	4	2	8	30	9	3	1	2	2	331
Range	156	61	69	112	117	158	128	121	150	80	89	78	401
1991 - 2020													
Average	29	24	30	33	50	68	63	48	45	40	37	34	501
Max	69	58	110	83	123	201	125	180	140	121	140	89	659
Min	5	2	3	3	8	12	3	2	2	1	0	1	282
Range	64	56	107	80	115	189	122	178	138	120	140	88	377

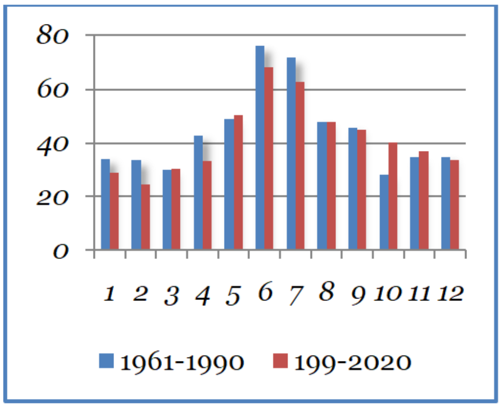

Fig. 2 Monthly precipitation (mm) in the Baltata basin in two climatic periods.

3.2 Descriptive statistics of the Modified Fournier Index

The values of *MFIs*, calculated using the two afore mentioned approaches, respectively were: MFI_1 = 67.6 and MFI_2 = 65.5. In view of insignificance of the difference between two estimates, all further results are based on the second approach, namely, the averaging of the indices calculated for each year.

The main statistics of rainfall erosivity in the Baltata basin in the period under study, expressed in *MFIs*, are shown in Table 2.

Table 2

Descriptive statistics of the Modified Fournier Index
in the Baltata basin in two climatic periods, mm

Period	Statistics					
	Average	Maximal	Minimal	Range	Sd	CV, %*
1961-1990	65.1	104.7	38.9	65.8	16.7	25.6
1991-2020	65.9	102.8	45.5	57.3	14.2	21.6
1991-2020	65.5	104.7	38.9	65.8	15.4	23.3

Note: * Coefficient of variation (CV) = Sd/Average

The analysis of Table 2 results in two principal conclusions:

- Over all observation period the rainfall erosivity, estimated in accordance with the generally accepted classification (see, for example, Arnoldus [14]), can be estimated as low (class 2; *MFI = 60-90)*
- Differences between average MFIs in two compared periods are very small, which should be expected, proceeding from very small changes in precipitation caused by climate change.

Some smoothing of the annual course of precipitation in 1991-2020 has caused a decrease in the range of *MFIs* annual differences, primarily due to an increase in their minimal values, as well as caused a decrease in their variability, expressed by standard deviation *(Sd)* and Coefficient of variation *(CV)*.

3.3. Time trends in rainfall erosivity

Because the rainfall erosivity is an environmental indicator directly related to erosion, the knowledge of its dynamic *over long periods* is particularly useful for the management of soil conservation, agricultural planning and the development of environmental policy on the whole. For example, Xie et al [11] studied a spatiotemporal variation in rainfall erosivity in China in 1956-2008. Diodato el al. [19] have analyzed a long times series of historical rainfall patterns across the Mediterranean in the last three centuries and investigated changes in the erosive forcing as related to climate changes. Their results showed that an erosive forcing, due to a higher frequency of intensive storms, is increasing in the recent warming period at low Mediterranean latitudes.

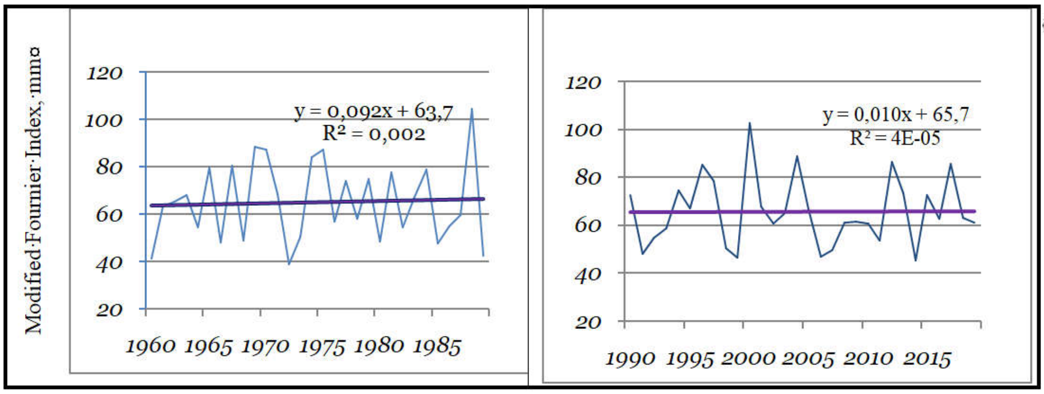

Fig. 3 Trends of Modified Fournier Index in the Baltata River basin in two periods.

In Fig. 3 there are shown trends of *MFI* in the Baltata basin in periods of stationary climate (1961-1990) and during its intensive manifestation (1991-2020). The obtained trends well confirm the results of descriptive analysis. In particular, there is no reason to speak about a significant increase or decrease in rainfall erosivity caused by climate change, which naturally follows from the discussed above statistically insignificant changes in total precipitation amounts.

Conclusion

The carried out research can in no way be considered as a certain indicator of the change in erosion rate in the basin under study. The *MFI* as an environmental indicator is based only on monthly rainfall records and does not include other aspects related to erosion such as slope length, soil types, wind activity (e.g. Tuo et al., [9]), land use, etc. Nevertheless, it can be useful in case of significant changes in the precipitation amount, when the contribution of rainfall erosivity to the development of erosion processes will become more significant.

Acknowledgment: This publication has been produced with the financial assistance of the European Union (BSB963 Project of the EU Black Sea Regional Operational Programme, 2014-2020). The contents of this publication are the sole responsibility of its authors and can in no way be taken to reflect the views of the European Union.

References

1. Briak H., Mrabet R., Moussadek R., Aboumaria K. Use of a calibrated SWATmodel to evaluate the effects of agricultural BMPs on sediments of the Kalaya river basin (North of Morocco). In: International Soil and Water Conservation Research, 2019, 7, p.176-183. https://doi.org/10.1016/j.iswcr.2019.02.002
2. Merritt W.S., Letcher R.A. Jakeman A.J. A review of erosion and sediment transport models. In: Environ. Model. Softw. 2003, nr.18, p. 761–799. https://doi:10.1016/S1364-8152(03)00078-1
3. Nearing M., Yin A.S., Borrelli P., Polyakov V.O. Rainfall erosivity: An historical review. In: CATENA 157, p. 357-362. https://doi.org/10.1016/j.catena.2017.06.004
5. Fernandez H., Martins F., Isidoro J.: Using the Modified Fournier Index to model rainfall aggressiveness with scarce rainfall data. In: Geophysical Research Abstracts, 2018, Vol. 20, p. 906.
6. García-Barrón L., Morales J., Sousa A. A new methodology for estimating rainfall aggressiveness risk based on daily rainfall records for multi-decennial periods. In: Science of The Total Environment, 2017, nr. 15, p. 564-571. https://doi.org/10.1016/j.scitotenv.2017.09.305
7. Bezak N., Ballabio C., Mikoš M., Petan S., Borrelli P., Panagos P. Reconstruction of past rainfall erosivity and trend detection based on the REDES database and reanalysis rainfall. In: Journal of Hydrology, 2020:590:125372 https://doi.org/10.1016/j.jhydrol.2020.125372
9. Borrelli P., Van Oost, K., Meusburger K., Alewell C., Lugato E., Panagos P. A step towards a holistic assessment of soil degradation in Europe: Coupling on-site erosion with sediment transfer and carbon fluxes. In: Environ. Res. 2018, 161, p. 291–298. https://doi.org/10.1016/j.envres.2017.11.009
10. Liu C., Walling D.E., He Y. Review: The International Sediment Initiative case studies of sediment problems in river basins and their management. In:. Int. J. Sediment Res., 2018. Nr. 33, p. 216–219. https://doi.org/10.1016/j.ijsrc.2017.05.005
11. Tuo D., Xu M., Zhao Y., Gao, L. Interactions between wind and water erosion change sediment yield and particle distribution under simulated conditions. In: J. Arid Land, 2015, nr. 7, p. 590–598. https://doi.org/10.1007/s40333-015-0128-7
12. Xin, Z., Yu, X., Li, Q., Lu, X.X.,: Spatiotemporal variation in rainfall erosivity on the Chinese Loess Plateau during the period 1956-2008. In: Reg. Environ. Chang., 2011, nr. 11, p. 149–159. https://doi.org/10.1007/s10113-010-0127-3

13. Xie Y., Yin S.-Q., Liu B.-Y., Nearing M.A., Zhao Y. Models for estimating daily rainfall erosivity in China. In: J. Hydrol. 2016, 535, p. 547–558. https://doi.org/10.1016/j.jhydrol.2016.02.020
15. Fournier F. Climat et érosion. PhD Thesis. Presse Universit. de France, Paris, 1960, 201 p.
16. CORINE: Copernicus Land Monitoring Service product portfolio overview. 2020. Available at: https://land.copernicus.eu/product-portfolio/overview.
17. Arnoldus H.M.J. An approximation of the rainfall factor in the Universal Soil Loss Equation. In: Assessment of Erosion, 1980. De Boodt M, Gabriels D (eds). John Wiley & Sons, Ltd, Chichester, p. 127–132.
18. Petek M., Mikoš M., Bezak N. Rainfall erosivity in Slovenia: Sensitivity estimation and trend detection. In: Environ. Res. 2018, 167, p. 528–535. https://doi.org/10.1016/j.envres.2018.08.020
19. Almagro A., Oliveira P.T.S., Nearing M.A., Hagemann S. Projected climate change impacts in rainfall erosivity over Brazil. In: Sci. Rep. 2017, 7. https://doi.org/10.1038/s41598-017-08298-y
20. Крупеников И.А., Родина А.К., Урсу А.Ф. Почвенная карта Молдавской ССР. Кишинев, 1986.
21. Gabriels D. Assessing the Modified Fournier Index and the Precipitation Concentration Index for Some European Countries. In: Soil Erosion in Europe (Boardman J. and Poesen J., eds.). 2006, John Wiley & Sons, Ltd., Chichester, p. 675-684.
22. Diodato N., Bellocchi G., Romano N., Chirico, G.B. How the aggressiveness of rainfalls in the Mediterranean lands is enhanced by climate change. In: Clim. Chang. 2011, 108, p. 591–599. https://doi.org/10.1007/s10584-011-0216-4

Primit la redacţie – 07/04/2021