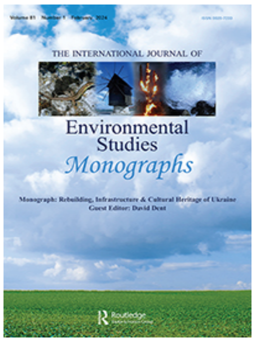


International Journal of Environmental Studies

ISSN: (Print) (Online) Journal homepage: www.tandfonline.com/journals/genv20

Loss of small rivers across the steppe: climate change or the hand of man? Case study of the Chaplynka river

Iryna Chushkina, Hennadii Hapich, Olena Matukhno, Artem Pavlychenko, Volodymyr Kovalenko & Yevheniia Sherstiuk

To cite this article: Iryna Chushkina, Hennadii Hapich, Olena Matukhno, Artem Pavlychenko, Volodymyr Kovalenko & Yevheniia Sherstiuk (2024) Loss of small rivers across the steppe: climate change or the hand of man? Case study of the Chaplynka river, International Journal of Environmental Studies, 81:1, 260-274, DOI: 10.1080/00207233.2024.2314853

To link to this article: https://doi.org/10.1080/00207233.2024.2314853

INTERNATIONAL JOURNAL OF ENVIRONMENTAL STUDIES
2024, VOL. 81, NO. 1, 260–274
https://doi.org/10.1080/00207233.2024.2314853

Loss of small rivers across the steppe: climate change or the hand of man? Case study of the Chaplynka river

Iryna Chushkina [a], Hennadii Hapich [b], Olena Matukhno [a], Artem Pavlychenko [a], Volodymyr Kovalenko [b] and Yevheniia Sherstiuk [a]

[a]Faculty of Water Management Engineering and Ecology, Dnipro University of Technology, Dnipro, Ukraine; [b]Institute of Nature Management, Dnipro State Agrarian and Economic University, Dnipro, Ukraine

ABSTRACT

Innumerable small steppe rivers have been degraded and lost through the construction of dikes and dams, as well as changing regional hydrology. A failed restoration project involving mechanical clearance of the channel of the small river Chaplynka is investigated. Field and laboratory studies included sampling and analysis of water and silt deposits. Muller's I_{geo} class, categorising the technogenic load on the water ecosystem, and a bottom accumulation coefficient illustrate the degradation of the catchment and the absence of hydraulic connection along the erstwhile river channel. The river flow has not returned. The most obvious shortcoming of the riverbed clearing operations was the dumping of the dredged material on the riverbank, from where it was washed back into the channel. Moreover, excavation of the channel drained shallow aquifers that are no longer replenished by depleted precipitation and infiltration.

KEYWORDS

Small river; catchment; restoration; bottom deposits

Introduction

Management of water resources is a key task in the conservation of water and wetland ecosystems and, also, socio-economic development [1,2]. The usual way to store useful volumes of water is to create ponds and reservoirs by building dikes and dams. There are more than 50 000 such ponds within Ukraine [3], mostly in the industrialised parts of the steppe zone [4]; their construction, more than 60–80 years ago to provide water for industry and irrigation [5], turned small rivers into fragmented, artificial wetlands with stagnant water [6,7].

Rivers have suffered long-term pollution and water abstraction [8]; at the same time, changes in land use and climate have decreased the natural discharge [9–11]. Historical breaking of the sod that protected the soil surface and loss of humus that maintained soil structure, cut infiltration and transmission of rain and snowmelt to the groundwater. Absence of winter snow cover also cuts the replenishment of groundwater and, so, there is less streamflow in summer [12]. In recent decades, loss of self-clarification, excess evaporation and cessation of flow have much changed the composition of natural waters

CONTACT Hennadii Hapich hapich.h.v@dsau.dp.ua Institute of Nature Management, Dnipro State Agrarian and Economic University, Serhiy Efremov Street, 25, Dnipro 49009, Ukraine

Published online 08 Feb 2024

in the small rivers of the Ukrainian steppe [13,14] – to the extent that the continued use of their water is hazardous [15]. More than 10 000 small rivers were irretrievably lost in the period up to 1991 [16]; *this number has since doubled.*

River restoration usually requires the removal of dikes and dams [17,18] and clearing the riverbed [19]. Assessment of the ecologically safe level of water use is a multi-criteria issue; improvement of an ecosystem requires solving several optimisation problems. Therefore, we analyse the interactions of human activity and natural factors in the degradation and disappearance of small river ecosystems in the steppe zone: the geography and hydrology of the catchment, changes in water quality, composition of bottom sediments which are reliable indicators of pollution and the ecological state of a river [20–24], and the effects of riverbed clearing.

Materials and methods

Study area

The Chaplynka River basin in the Dnipropetrovsk Region of Ukraine (Figure 1). The land slopes from northeast to the southwest. The river length is 62 km; the catchment area 565 km^2 – surface water occupies 1.1%, ploughland 75%. The density coefficient of the network (taking account of rivers less than 10 km long) is 0.14 km/km^2; total stream gradient is 64.4 m; its weighted average slope is 0.85 m/km; mean flow is 20 million m^3 per year but only 5.4–12.5 million m^3 in dry years. At present, there are 32 ponds and 3 small reservoirs in the catchment, with a total volume of 9.8 million m^3 and a surface area of 4.5 km^2.

Research methodology

Field routes were established along the main riverbed and within the catchment. Photographs were taken of the state of the river before and after riverbed clearing. Water and bottom sediments were sampled. Indicators of water quality were established and laboratory studies carried out to determine the chemical elements in bottom sediments. Processing of the results made use of QGIS, AutoCAD, and Microsoft Excel software. When determining the contamination of bottom sediments by heavy metals, G Muller's I_{geo} classes [25] were applied:

$$I_{geo} = log_2\left(\frac{C_n}{1.5 \cdot B_n}\right), \quad (1)$$

where Cn is measured concentration of element n in bottom sediments; B_n is geochemical background (maximum permissible) concentration of element n; 1.5 is a coefficient that considers natural fluctuations.

These geoaccumulation indices were used to assign bottom sediments to different quality classes. To estimate the ratio of pollutant concentrations in bottom sediments (C_{bs}) and in water (C_{water}), a bottom accumulation coefficient (BAC) was used:

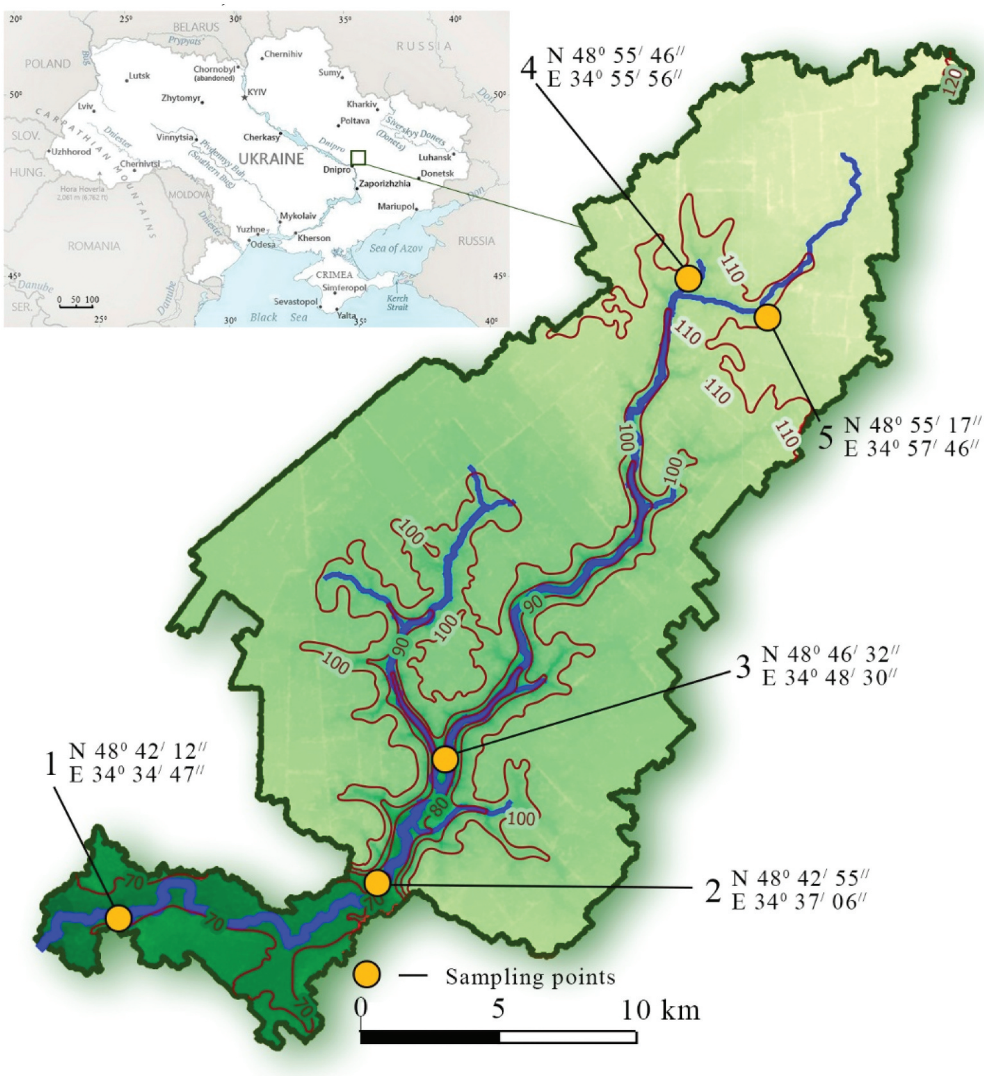


Figure 1. Catchment the Chaplynka River.

$$BAC = \frac{C_{bs}}{C_{water}} \quad (2)$$

Assessment of the degree of chemical pollution of surface water based on BAC characterises the chronic toxicity of a waterbody. Table 1 presents the evaluation criteria.

Salt composition of water

The following indicators were determined: water pH, dry residue, total hardness, sulphates, chlorides, calcium, magnesium, and phosphates [26]. Samples were collected

Table 1. Criteria to assess the technogenic load on a hydroecosystem.

Characterstics of the levels of bottom sediment pollution in terms of I_{geo} classes				
I_{geo}	I_{geo} class	Level of bottom sediment pollution with heavy metals	Technogenic load	Ecological status of the hydroecosystem (class of the bottom sediment state)
>0	0	Unpolluted	Slight (slightly hazardous)	Standard (satisfactory condition)
>0–1	1	Unpolluted to slightly polluted		
>1–2	2	Moderately polluted	Moderate (moderately hazardous)	Risk zone (unfavourable condition)
>2–3	3	Medium-polluted		
>3–4	4	Heavily polluted	Considerable (hazardous)	Crisis zone (very unfavourable condition)
>4–5	5	Heavily to extremely polluted		
>5	6	Extremely polluted	Extreme (extremely hazardous)	Disaster zone (catastrophic condition)
Criteria to evaluate environmental status of the hydroecosystem in terms of bottom accumulation coefficient (BAC)				
BAC		$<10^3$	Relatively satisfactory	
		10^3-10^4	Environmental emergency	
		$>10^4$	Environmental crisis	

along the entire river length in accordance with current standards [27–30]. Water mineralisation was determined using an AquaKut portable TDS-metre.

Composition and particle-size distribution of bottom sediments

The elemental composition of the bottom sediments was determined by X-ray fluorescence analysis of powdered samples using an Elvax (Elvatech, Ukraine) desktop spectrometer which provided high accuracy, speed, and low detection limits for a wide range of elements; the error is ≤0.05%. Particle-size distribution was determined by a combination of wet sieving and sedimentation, following Boichenko [31].

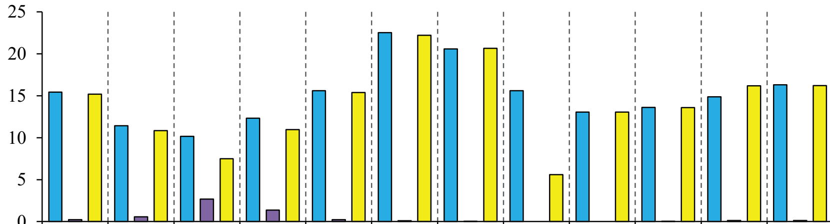
Results

Since the mid-20th century, reservoirs have been constructed that held about 10 million m^3 of water. Subsequently, the river flow ceased and the channel became overgrown. Climate warming and redistribution of precipitation in time and quantity are implicated but so is land use change. Even in the nineteenth century, Dokuchaev [32] and, later, Izmailsky [33] attributed the drying of the steppe not so much to lesser rainfall as to the breaking of the sod and the resulting loss of humus and soil structure which gravely reduced the soil's infiltration capacity and transmissivity. As a result, rainfall and snowmelt generate immediate, erosive runoff rather than recharging groundwater and baseflow. Soil conditions are now a great deal worse than in Dokuchaev's day, so are the droughts. Torrential summer rains are not retained in the soil, and winter snow cover has decreased, further decreasing replenishment of the groundwater that supports river base flow. Moreover, the ponds intended to retain water resources also increased the evaporative area, contributing further irreversible water loss.

With the falling water level, the river began to disappear. For the last decade, the main characteristics of annual flow distribution according to different years of

Table 2. Annual distribution of the Chaplynka River flow, %.

Annual water content (probability, P)	Months												
	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	year
25%	11.4	33.5	18.1	9.1	7.9	3.5	1.9	0.9	1.3	2.7	4.1	5.6	100
50%	9.8	7.3	47.7	19.3	6.3	3.3	1.6	1.0	0.7	1.5	3.2	4.6	100
75%	7.7	9.4	44.4	22.9	6.0	2.7	0.6	0.1	0	0.3	1.2	4.4	100
95%	4.2	10.6	49.8	25.6	4.3	1.8	0.4	0	0	0.2	0.7	2.4	100



	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
Precipitation	15.42	11.43	10.16	12.33	15.6	22.51	20.57	15.6	13.06	13.602	14.87	16.3
Streamflow	0.226	0.568	2.669	1.372	0.231	0.097	0.021	0	0	0.011	0.129	0.13
Evaporation/infiltration	15.19	10.85	7.497	10.96	15.37	22.21	20.65	5.597	13.06	13.591	16.19	16.2

Figure 2. Water balance of the river basin (probability, P = 95%), million m^3.

availability (Table 2) and water balance (Figure 2) confirm the influence of climatic factors on the river flow – which is actually available only in winter and spring.

Moreover, non-compliance with environmental protection and water legislation has degraded the ecosystem by exceeding the norms of reservoir storage, non-compliance with riparian water protection zones, intensive ploughing of the catchment, and both chemical and biological pollution of reservoirs. Combination of all these factors in the absence of flow and self-cleaning ability of the river led to rapid degradation of the ecosystem. In response, over the period 2017–2021, 'ecological sanitation' of the Chaplynka River basin was undertaken by removal of silt from the stream channel. According to the main data of engineering and hydrogeological prospecting works, the need to dredge silt to a depth of up to 2 m was established (Figure 3).

Excavators were used to remove silt from the channel and spread it on the river banks (Figure 4(a)). But, it is now apparent that the dredging operation only made matters worse. In many places, the channel is now significantly shallower or dried completely (Figure 4(b)) and, in many places, overgrown with tall vegetation.

Water quality

The water quality was determined in reaches of the river where reservoirs and ponds are located. The chemical composition of the water of this small river is determined by surface runoff contaminated by eroded soil and fertilisers leached from arable land, runoff from the streets of the towns and villages, and groundwater inflow. Since groundwater inflow is insignificant, the chemical composition of water can change dramatically from point to point. Table 3 presents a comparison of previous and recent data.

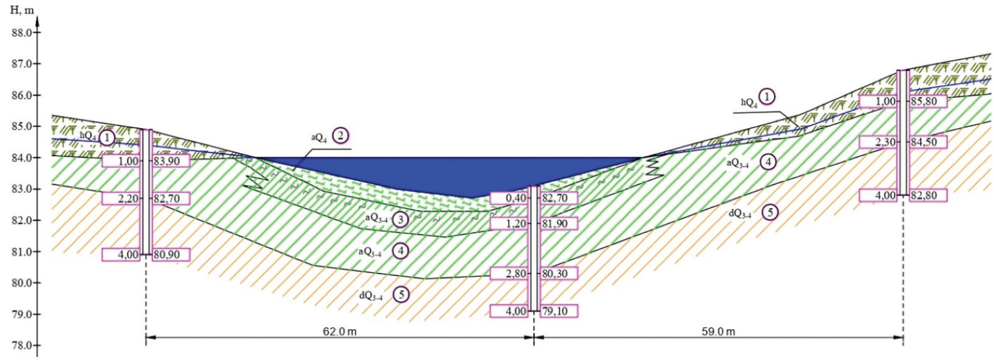


Figure 3. Engineering and geological section in terms of the research object. hQ_4 – modern organic and mineral formations; aQ_{3-4} – quaternary alluvial deposits; dQ_{3-4} – quaternary deluvial deposits; *1* – soil and vegetation layer (humic and silty clay loam); *2* – flow silt with much organic matter and residual algae; *3* – brownish, dense, wet, and silty clay loam; *4* – brownish, dense, wet, and very soft clay loam; *5* – light-grey, dense, wet, and plastic clay loam.

Water quality has deteriorated significantly over less than three decades: concentrations sometimes almost doubling, as in the case of dry residue at point 4 (village of Magdalinivka) and, at this point, all chemical parameters show an increase in concentration. Dry residue and sulphate levels exceed permissible limits for all sites in all years of research; magnesium and iron are also beyond the limits. Perhaps surprisingly, mineralisation generally decreases downstream. This may be explained by the lack of any hydraulic connection between individual reservoirs on the river; the natural watercourse has been transformed into a succession of artificial reservoirs now functioning as separate ecosystems.

Bottom sediments

Bottom sediments of watercourses and reservoirs accumulate various salts, compounds of heavy metals, and suspended substances of natural and man-made origin. Their qualitative composition yields a reliable assessment of the risk of exposure to heavy metals for aquatic organisms; the hydrochemical parameters of surface water are usually more variable in time.

Bottom samples were collected and analysed in September 2022 from five different river reaches. Their particle-size distribution is fairly consistent (Figure 5) with 10–25% clay, 40–50% silt and 30–40% sand. Their elemental composition (Table 4) is strikingly more variable.

The data reveal that *Ca, Fe, K*, and *Si* predominate; *Mg, Cd, W, Ge*, and *As* show the lowest concentrations. Figure 6 shows the spectral analysis of the content of chemical elements.

In general, the results of the spectral analysis and calculations of I_{geo} classes demonstrate intensive accumulation of heavy metals in the bottom sediments. To assess the ratio of pollutant concentrations in bottom sediments and in water, a bottom accumulation coefficient (BAC) was determined. Figure 7 represents the obtained parameters calculated according to formulas 1 and 2.

a) *b)*

Figure 4. State of the Chaplynka River before (*a*) during and (*b*) after riverbed clearing.

Assessment of the degree of pollution of river bottom sediments with heavy metals according to I_{geo} classes shows a significant technogenic load on the ecosystems. The analysed elements fall into I_{geo} classes 0 (unpolluted) to 6 (extremely polluted) but may be grouped conditionally into a first group (*Fe, Mn, S, Zn, V*, and *Pb*) that impose an insignificant to moderately dangerous technogenic load on the water ecosystem although, at the same time, the status of the ecosystem is defined as relatively satisfactory. The second group of elements (*Ni, Cr, Cu*, and *Co*) has a significant and extremely hazardous impact on the ecosystem and the status of the ecosystem corresponds to a crisis or, even, catastrophe.

Table 3. Salt composition indices of the Chaplynka River.

Components of chemical composition			Indices at the points of analysis (downstream from the headwaters to the mouth)							
			4		3		2		1	
Years of sampling		MAC*	2007	2022	1994	2022	2020	2022	1994	2020
Distance from the mouth	km	–	61.2		38.5		6.6		0	
Dry residue,	mg/dm^3	≤1000	3374	7182	2075	2019	3200	2007	1242	2640
Sulphates, SO_4	mg/dm^3	≤500	1537	4325	743	894.6	1291	861	373	1355
Chlorides, Cl	mg/dm^3	≤350	149	213	248	149.1	270	157	44.0	146
Calcium, Ca^{2+}	mg/dm^3	200.0	90.2	168	107	100.8	144	112	142	144
Magnesium, Mg^{2+}	mg/dm^3	50.0	229	834	114	239	199	219	66.0	70.4
Ammonium nitrogen, NH_4	mg/dm^3	2.0	<0.15	–	0.23	–	0.16	–	0.16	0.14
Nitrite nitrogen, NO_2	mg/dm^3	3.3	0.7	–	0.010	–	–	–	0.010	–
Phosphates, PO_4	mg/dm^3	0.7	–	5.2	0.40	–	<0.05	0.308	1.20	<0.05
Total iron, Fe	mg/dm^3	0.3	0.05	1.6	0.10	0.6	<0.05	0.108	0.30	<0.05
Copper, Cu,	mg/dm^3	1.0	<0.01	<0.01	–	–	–	–	–	–
Manganese, Mn	mg/dm^3	0.1	<0.01	<0.01	–	–	0.09	–	–	0.05
Total hardness	$mg\text{-}equiv/dm^3$	–	23.3	46.6	14.8	14.8	23.6	14.38	12.5	13.0
pH value	–	6.5–8.5	7.4	8.59	8.1	7.94	7.9	8.47	8.2	8.17
Chemical composition of water	–	–	Sulphate-hydrocarbonate-magnesium-sodium							

*Hygienic standards of water quality to meet potable, household, and other needs of the population (Order of the Ministry of Health Protection of Ukraine #721 of 02.05.2022). Access mode: https://zakon.rada.gov.ua/laws/show/z0524–22#Text

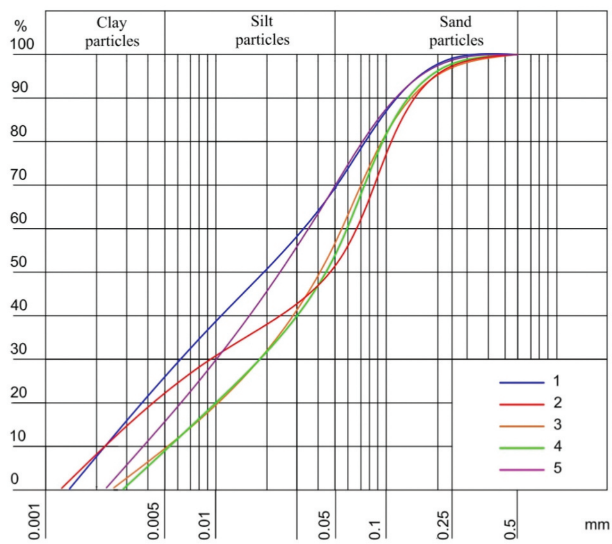


Figure 5. Particle-size distribution of bottom sediments (numbers 1–5 correspond to the sampling points).

The accumulation of heavy metals and predominance of high-order I_{geo} classes that indicate severe and extreme pollution in the headwaters is striking – the impact of economic activity and urban development in this part of the catchment. It emphasises the fact that there is no hydraulic connection between the successive reservoirs in the riverbed, already mentioned in respect of water quality.

Table 4. Total content of chemical elements in the bottom sediments.

Chemical element	Concentration at the points of analysis (downstream from the headwaters to the mouth), % 5	4	3	2	1
Si	6.443 ± 0.079%	5.701 ± 0.073%	6.790 ± 0.077%	32.225 ± 0.116%	23.704 ± 0.102%
Ca	27.143 ± 0.202%	36.622 ± 0.183%	30.390 ± 0.185%	2.667 ± 0.118%	13.567 ± 0.135%
Fe	23.875 ± 0.108%	18.042 ± 0.091%	20.491 ± 0.095%	7.160 ± 0.034%	10.081 ± 0.043%
K	5.271 ± 0.228%	3.735 ± 0.209%	4.178 ± 0.207%	5.809 ± 0.209%	5.063 ± 0.156%
Al	0.311 ± 0.148%	0.233 ± 0.138%	0.286 ± 0.136%	3.149 ± 0.080%	2.790 ± 0.086%
Cl	1.191 ± 0.047%	0.836 ± 0.042%	0.801 ± 0.042%	1.609 ± 0.032%	1.381 ± 0.031%
Ti	2.239 ± 0.072%	2.143 ± 0.076%	1.932 ± 0.068%	1.304 ± 0.033%	1.120 ± 0.032%
Mn	0.825 ± 0.021%	0.370 ± 0.017%	2.272 ± 0.031%	0.109 ± 0.006%	0.405 ± 0.009%
S	0.550 ± 0.008%	0.459 ± 0.008%	0.616 ± 0.008%	<0.005%	0.419 ± 0.006%
Zn	0.111 ± 0.005%	0.074 ± 0.005%	0.079 ± 0.005%	0.024 ± 0.001%	0.044 ± 0.002%
P	0.007 ± 0.015%	0.007 ± 0.016%	0.008 ± 0.015%	0.018 ± 0.008%	0.042 ± 0.010%
Ni	0.094 ± 0.010%	0.084 ± 0.009%	0.085 ± 0.009%	0.032 ± 0.003%	0.034 ± 0.003%
Cr	0.058 ± 0.024%	0.052 ± 0.025%	0.046 ± 0.022%	0.034 ± 0.009%	0.031 ± 0.010%
V	0.073 ± 0.042%	0.064 ± 0.044%	0.053 ± 0.039%	0.017 ± 0.018%	0.025 ± 0.018%
Cu	0.047 ± 0.006%	0.019 ± 0.005%	0.040 ± 0.005%	0.007 ± 0.002%	0.019 ± 0.002%
Pb	0.041 ± 0.005%	0.030 ± 0.005%	0.033 ± 0.005%	0.013 ± 0.002%	0.015 ± 0.002%
Ga	0.013 ± 0.004%	0.010 ± 0.004%	0.009 ± 0.004%	0.003 ± 0.001%	0.004 ± 0.001%
Co	0.010 ± 0.037%	<0.033%	0.013 ± 0.034%	<0.012%	0.003 ± 0.014%
Se	<0.005%	0.003 ± 0.004%	0.005 ± 0.004%	0.001 ± 0.001%	<0.001%
Mg	<0.736%	<0.720%	<0.680%	<0.252%	<0.279%
Cd	<0.055%	<0.054%	<0.051%	<0.017%	<0.017%
W	<0.011%	<0.010%	<0.010%	<0.003%	<0.004%
Ge	<0.004%	<0.004%	<0.004%	<0.001%	<0.001%
As	<0.005%	<0.004%	<0.004%	<0.001%	<0.001%

Attempting to combine different criteria of pollution results in an untidy picture. For instance, iron is assigned to the *ecological crisis* category at all studied sites according to its level of accumulation and gross content, although it is assessed as *unpolluted* according to the I_{geo} class of impact on the water ecosystem. An excess of manganese and copper is highlighted separately in sites 1 and 4. Other elements (calcium, sulphur and chlorine) correspond to the parameters of *relatively satisfactory situation* and, in some cases, *extreme environmental situation*. Taken as a whole, the data testify to a substantial technogenic load and ecological crisis in this small river ecosystem.

Discussion

The most obvious shortcoming of the riverbed clearing operations was the dumping of the dredged material on the riverbank, not stabilised by immediate sowing of perennial grasses. Most of this material was subsequently washed back into the channel by rain and meltwater. Complete removal or secure storage would have been better options; alternatively, where the material is of appropriate quality, it might have been spread on agricultural land [33] although this option requires more research [34].

Another factor is non-compliance of the technical standards for the depth of dredging. Dredging by excavators led to a significant deepening of the channel, in some areas by more than 2 m. Removal of fine-textured alluvium that previously plugged aquifers abutting the channel provoked a rapid discharge of these aquifers into the river but, subsequently, on account of the lack of recharge of the aquifers, river flows ceased.

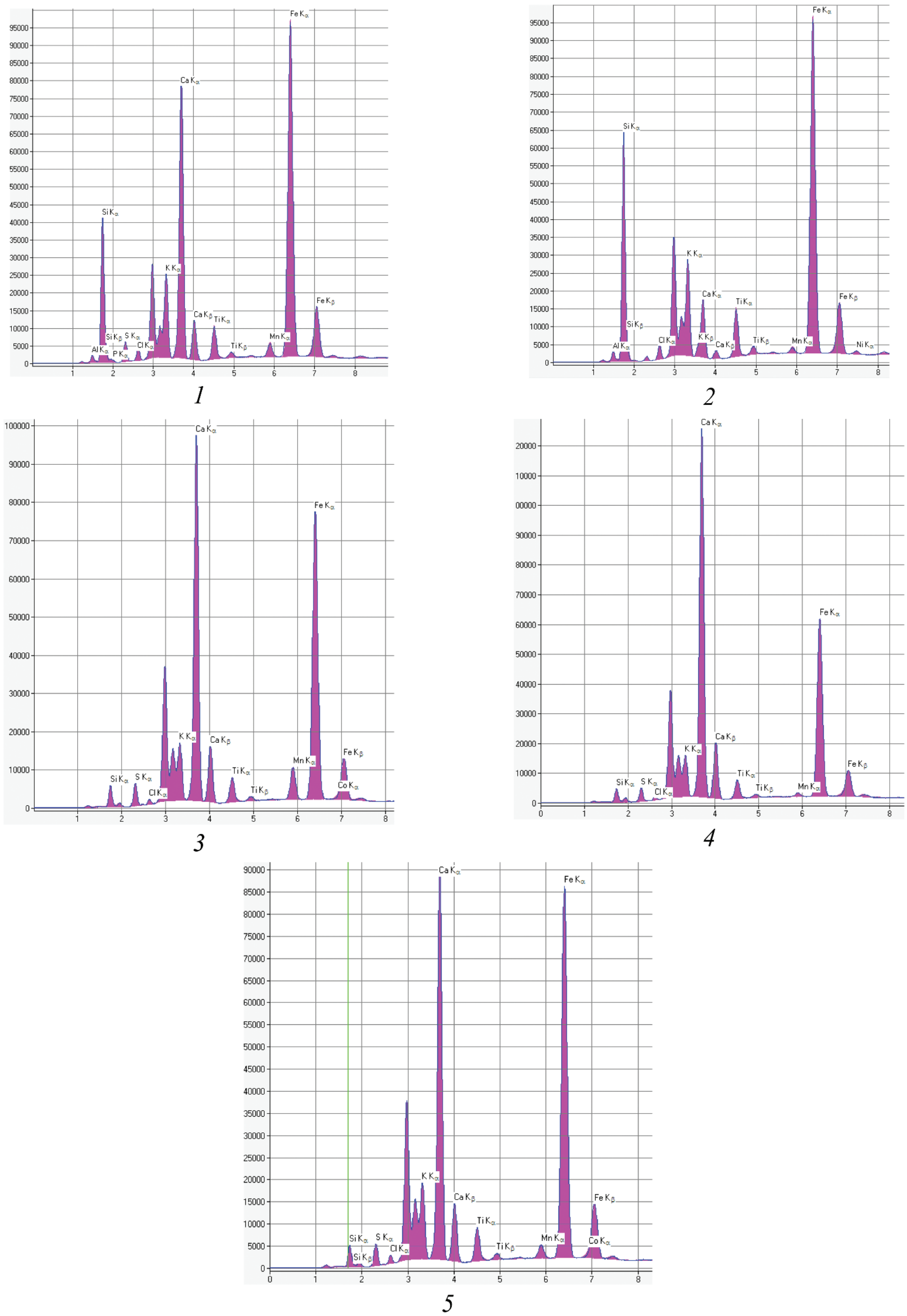


Figure 6. Content of chemical elements in bottom sediments as determined by energy dispersive spectrometry (the drawings are numbered according to sampling points).

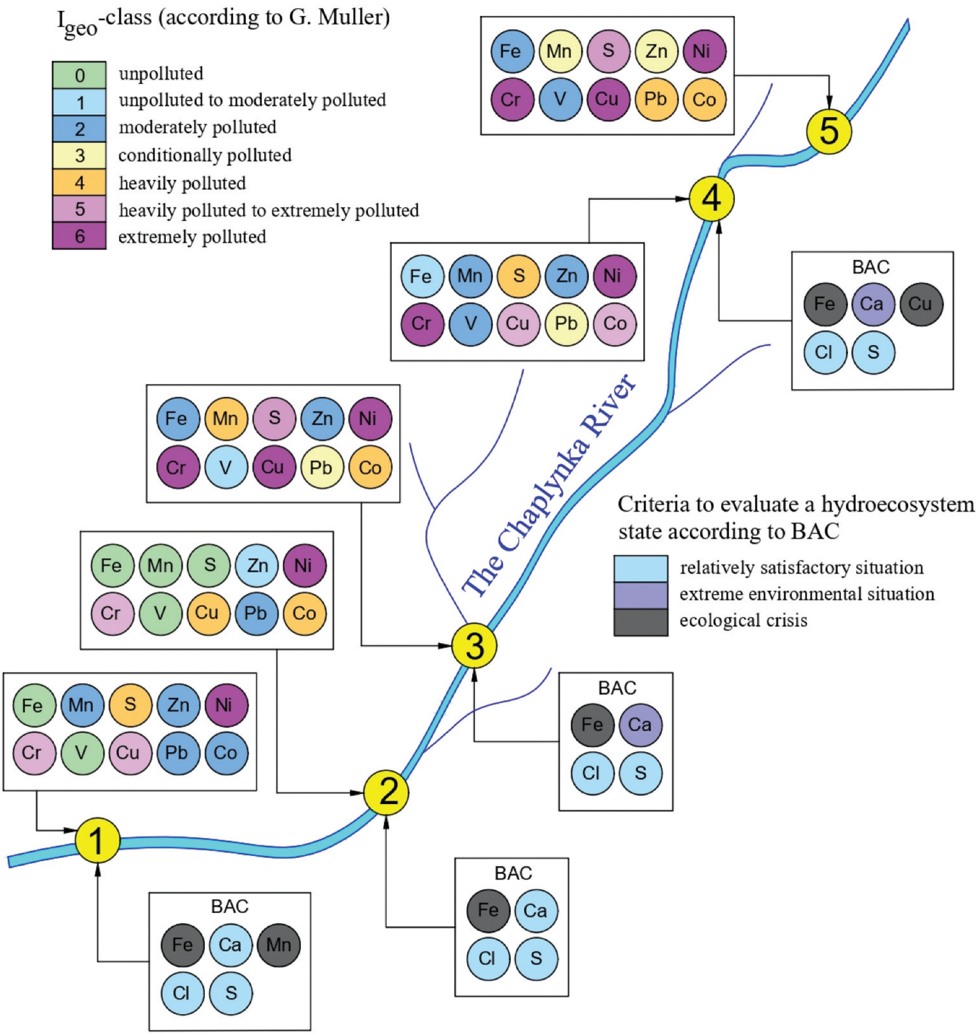


Figure 7. Bottom sediment contamination of the Chaplynka River in terms of I_{geo}-classes and assessment of the hydroecosystem status by the bottom accumulation coefficient (BAC).

The Chaplynka River and similar small rivers of the steppe zone of Ukraine lack a natural buffer zone that would allow their ecosystems to function [35]. In fact, the norms of the Water Code of Ukraine regulating the provision of water protection zones and riparian protection strips *are not met for any of the small rivers*. The banks are densely built-up, cultivation extends almost to the water's edge, and river flow is obstructed by many and various blind dams and crossings, mostly constructed illegally. So, strings of reservoirs have no hydraulic connection, and there is a rapid accumulation of silt in erstwhile channels and a lot of pollution.

The complete degradation and disappearance of the river and its ecosystem is evident, and the identified failings of the river-renewal project offer lessons for future restoration work in the steppe zone. Moreover, the standards of maximum permissible norms of various elements in bottom sediments require further consideration; currently, Ukraine has no regulatory standards. This is a substantial task for further research and development.

Conclusions

- Worldwide, small rivers are assailed by land use change and climate change. Across the steppes, they are degraded and disappearing because of regional changes of land use and precipitation, all leading to a decrease or complete disappearance of the infiltration process as the main factor of groundwater replenishment and, accordingly, further groundwater feed of the rivers. This is exacerbated by blockage of the rivers by dams and diversions; chemical and biological pollution; non-compliance with technical and technological regulatory water use norms; and violation of the water and nature protection legislation regarding riparian protection strips.
- In the case of the Chaplynka river, some after-effects of an unsuccessful riverbed clearing project are analysed. The river almost completely dried up. The most obvious and direct causes are excessive deepening of the channel, storage of the dredged material on the riverbank without appropriate reclamation and consolidation, and the absence of proper surface and groundwater inflow.
- In the absence of hydraulic connection along the erstwhile river channel, water quality deteriorated dramatically, for instance, a doubling of dry residue in the last 25 years and, generally, greater concentration of pollutants in the headwaters. The natural watercourse has been transformed into a string of artificial reservoirs, functioning as separate ecosystems.
- The defined I_{geo} criteria indicate a heavily polluted ecosystem with a significant technogenic load. *Ni, Cr, Cu*, and *Co* stand out among the elements having a negative impact. The assessment of the hydroecosystem state based on the bottom accumulation coefficient indicates the level of ecological crisis in terms of iron, manganese and copper, whereas calcium, sulphur and chlorides correspond to a relatively satisfactory situation. Accumulation of heavy metals in the headstream of the river and predominance of higher-order I_{geo} classes, corresponding to the level of severe and extreme pollution, emphasise the fact that there is no hydraulic connection between the string of reservoirs in the riverbed.
- The Chaplynka River exemplifies the deterioration of water quality, loss of water resources *in toto*, degradation of aquatic ecosystems across the steppe, and the need for further development of ways and means to evaluate complex technical and natural ecosystems of rivers and their catchments.

Disclosure statement

No potential conflict of interest was reported by the author(s).

ORCID

Iryna Chushkina http://orcid.org/0000-0003-1251-6664
Hennadii Hapich http://orcid.org/0000-0001-5617-3566
Olena Matukhno http://orcid.org/0000-0001-5536-6745

Artem Pavlychenko http://orcid.org/0000-0003-4652-9180
Volodymyr Kovalenko http://orcid.org/0000-0003-3865-597X
Yevheniia Sherstiuk http://orcid.org/0000-0002-1844-1985

Availability of data and materials

The datasets generated during and/or analysed during the current study are available from the authors on request.

Consent for publication

All authors agreed with the final version of the manuscript.

References

[1] Jasmyn, A., Lynch, J., Kalumanga, E. and Ospina, G.A., 2016, Socio-ecological aspects of sustaining Ramsar wetlands in three biodiverse developing countries. *Marine & Freshwater Research* **67**(6), 850–868. doi: 10.1071/MF15419.

[2] Everard, M., 2019, A socio-ecological framework supporting catchment-scale water resource stewardship. *Environmental Science & Policy* **91**, 50–59. doi: 10.1016/j.envsci.2018.10.017.

[3] Khilchevskyi, V., Grebin, V., Zabokrytska, M., Zhovnir, V., Bolbot, H. and Plichko, L., 2020, Hydrographic characteristic of ponds distribution in Ukraine – basin and regional features. *Journal of Water and Land Development* **46**, 140–145. doi: 10.24425/jwld.2020.134206.

[4] Andrieiev, V. and Hapich, H., 2020, Impact of ponds and reservoirs construction on the environmental safety of small river basins of the steppe zone of Ukraine (the case of Dnipropetrovsk region). *Land Reclamation & Water Management* **1**, 158–166. doi: 10.31073/mivg202001-228.

[5] Hapich, H., Orlinska, O., Pikarenia, D., Chushkina, I., Pavlychenko, A. and Roubík, H., 2023, Prospective methods for determining water losses from irrigation systems to ensure food and water security of Ukraine. *Naukovyi Visnyk Natsionalnoho Hirnychoho Universytetu* **2**, 154–160. doi: 10.33271/nvngu/2023-2/154.

[6] Hapich, H., Andrieiev, V., Kovalenko, V. and Makarova, T., 2022, The analysis of spatial distribution of artificial reservoirs as anthropogenic fragmentation elements of rivers in the Dnipropetrovsk Region, Ukraine. *Journal of Water and Land Development* **53**, 80–85. doi: 10.24425/jwld.2022.140783.

[7] Hapich, H., Pikarenia, D. and Orlinska, O., Kovalenko, V., Rudakov, L., Chushkina, I., Maksymova, N., Makarova, T. and Katsevych, V., 2022, Improving the system of technical diagnostics and environmentally safe operation of soil hydraulic structures on small rivers. *Eastern-European Journal of Enterprise Technologies* **2**(10), 18–29. doi: 10.15587/1729-4061.2022.255167.

[8] Andreev, V.H., Hapich, H.V. and Kovalenko, V.V., 2021, Impact of economic activity on geoecological transformation of the basin of the Zhovtenka River (Ukraine). *Journal of Geology, Geography and Geoecology* **30**(1), 3–12. doi: 10.15421/112101.

[9] Arnell, N.W., 1998, Climate change and water resources in Britain. *Climatic Change* **39**, 83–110. doi: 10.1023/A:1005339412565.

[10] Farjad, B., Gupta, A., Razavi, S., Faramarzi, M. and Marceau, D., 2017, An integrated modelling system to predict hydrological processes under climate and land-use/cover change scenarios. *Water* **9**(10), 767. doi: 10.3390/w9100767.

[11] Scibek, J., Allen, D.M., Cannon, A.J. and Whitfield, P.H., 2007, Groundwater–surface water

interaction under scenarios of climate change using a high-resolution transient groundwater model. *Journal of Hydrology* **333**(2–4), 165–181. doi: 10.1016/j.jhydrol.2006.08.005.

[12] Singha, K. and Navarre-Sitchler, A., 2022, The importance of groundwater in critical zone science. *Groundwater* **60**(1), 27–34. doi: 10.1111/gwat.13143.

[13] Andrieiev, V., Hapich, H., Kovalenko, V., Yurchenko, S. and Pavlychenko, A., 2022, Efficiency assessment of water resources management and use by simplified indicators. *Naukovyi Visnyk Natsionalnoho Hirnychoho Universytetu* **5**(5), 148–152. doi: 10.33271/nvngu/2022-5/148.

[14] Hapich, H., Andrieiev, V., Kovalenko, V., Hrytsan, Y. and Pavlychenko, A., 2022, Study of fragmentation impact of small riverbeds by artificial waters on the quality of water resources. *Naukovyi Visnyk Natsionalnoho Hirnychoho Universytetu* **3**(3), 185–189. doi: 10.33271/nvngu/2022-3/185.

[15] Rudakov, L., Hapich, H., Orlinska, O., Pikarenia, D.S., Kovalenko, V.V., Chushkina, I.V. and Zaporozhchenko, V.Y., 2020, Problems of technical exploitation and ecological safety of hydrotechnical facilities of irrigation systems. *Journal of Geology, Geography and Geoecology* **29**(4), 776–788. doi: 10.15421/112070.

[16] Yatsyk, A., Byshovets', L.V. and Bohatov, Y.O., 1991, Small rivers of Ukraine: Directory. [Kyiv: Urozhai, in Ukrainian].

[17] Tullos, D.D., Finn, D.S., Walter, C. and Pandit, M.K., 2014, Geomorphic and ecological disturbance and recovery from two small dams and their removal. *PLOS ONE* **9**(9), e108091. doi: 10.1371/journal.pone.0108091.

[18] The Guardian, 2023, *Dam fine work:Record number o barrier removals helps restore rivers across Europe* (25 Apl 2023). https://www.theguardian.com/environment/2023/apr/25/record-number-of-dam-barrier-removals-helps-restore-rivers-across-europe-aoe.

[19] Velychko, S.V. and Dupliak, O.V., 2022, Hydrological simulation and assessment of the optimal parameters of the water replenishment of the floodplain lake and old riverbed on the Uzh river. *IOP Conference Series: Earth and Environmental Sciences* **1049**, 012037. doi: 10.1088/1755-1315/1049/1/012037.

[20] Ciszewski, D., 1997, Source of pollution as a factor controlling distribution of heavy metals in bottom sediments of Chechło River (south Poland). *Environmental Geology* **29**, 50–57. doi: 10.1007/s002540050103.

[21] Nascimento, M.R.L. and Mozeto, A.A., 2008, Reference values for metals and metalloids concentrations in bottom sediments of Tietê River Basin, southeast of Brazil. *Soil and Sediment Contamination* **17**(3), 269–278. doi: 10.1080/15320380802006996.

[22] Jaskuła, J., Sojka, M., Fiedler, M. and Wróżyński, R., 2021, Analysis of spatial variability of river bottom sediment pollution with heavy metals and assessment of potential ecological hazard for the Warta River. *Minerals* **11**(3), 327. doi: 10.3390/min11030327.

[23] Senze, M., Kowalska-Góralska, M., Czyz, K., Wondołowska-Grabowska, A. and Łuczyńska, J., 2021, Aluminum in bottom sediments of the lower Silesian Rivers supplying dam reservoirs v. selected chemical parameters. *International Journal of Environmental Research and Public Health* **18**, 131–170. doi: 10.3390/ijerph182413170.

[24] Chushkina, I., Maksymova, N. and Semenyaka, I., 2022, Impact of dredging operations on the ecological state of a small river taking into account the composition of bottom sediments. *Problems of WaterSupply, Drainage and Hydraulics* **40**, 65–77. doi: 10.32347/2524-0021.2022.40.65-77.

[25] Muller, G., 1979, Heavy metals in Rhine sediments. Changes since. *Umschau* **79**, 778–783. (German).

[26] ISO 5667-2:2003, 2004, *Water quality. Sampling of samples*, Ukrainian standard, entered into force on July 1, 2004 (Ukrainian).

[27] ISO 6059, 2003, *Water quality. Determination of total calcium and magnesium*. Ukrainian standard, entered into force on July 1, 2004 (Ukrainian).

[28] Measurement technique 081/12-0109-03, 2004, *Surface, groundwater and return water. Method for determining the mass concentration of dry residue (solutes) by gravimetric method*. Ukrainian standard, entered into force on June 30, 2004 (Ukrainian).

[29] Measurement technique 081/12-0177-05, 2005, *Surface, groundwater and return waters. Method of performing measurements of mass concentration of sulfates by titrimetric method*. Ukrainian standard, entered into force on June 21, 2005 (Ukrainian).
[30] Boichenko, P.O., 1950, The granulometric composition of soils and grounds on different scales of hydraulic particle size. *Pochvovedenie*, 228–233. ISSN:0032-180X (Russian).
[31] Dokuchaev, V.V., 1892, *Our steppes before and now* (Moscow: Moscow University, in Russian; also published in St Petersburg: Dept Agriculture, Ministry of Crown Domains for the World's Columban Exposition at Chicago, 1893).
[32] Izmailsky, A.A., 1937, How our steppe dried. In: V.R. Williams (Ed.) *Selected works* (Moscow/Leningrad: State publisher of agricultural literature), pp. 80.
[33] Kazberuk, W., Szulc, W. and Rutkowska, B., 2021, Use bottom sediment to agriculture – effect on plant and heavy metal content in soil. *Agronomy* **11**(6), 1077. doi: 10.3390/agronomy11061077.
[34] Tomczyk-Wydrych, I. and Świercz, A., 2021, Methods of management of bottom sediments from selected water reservoirs – a literature review. *Geologos* **27**(2), 127–134. doi: 10.2478/logos-2021-0013.
[35] Gandziura, V.P., Afanasyev, S.O. and Biedunkova, O.O., 2023, The concept of Hydroecosystems' health (a review). *Hydrobiological Journal* **59**(2), 3–7. doi: 10.1615/hydrobj.v59.i2.10.