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Evaluation of dams constructed on the rivers of the North Development Region of the Republic of Moldova

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ABSTRACT: Main aim of the present research is mapping as well as general evaluation of the state of the dams built on the streams and rivers of the North Development region of the Republic of Moldova. Dams' mapping was performed form actual satellite images connected to Google Earth, using geoinformational techniques. In total 2,523 dams were identified and mapped. In comparison in official statistic the number is by 2.2 times higher. Dams' average length is about 134, ranging from 8 to 626 m. From the total number, 86% of dams' are estimated to be generally in satisfactory condition, the other 14% being partially demolished. In case of the dams' upstream part, only for 49% of them reservoirs and ponds are in good condition, those in eutrophic condition and semi-dry accumulations are of 13%, the upstream of other 30% is characterized by dry territory and 8% by wetland. Dams' density is considered very high in case of streams, the average being 0.57 dams/ river km or about 1 dam on every 1.77 km of river, and much lower on medium rivers, being only 0.15 dams/river km or one dam is constructed on almost every 7 km of river. Dams' density in the limits of river basins and districts, calculated as dam per km^2, is on average 0.25 dams/km^2. In general, the highest density is established for the southern part of NDR and the lowest – for its eastern part, values for the central part are similar to the average for the whole region, while those from the western part are slightly lower than the medium. Further studies, including those in the field, should be performed in order to improve actual dams' knowledge and finalize the development of the comprehensive database of dams. Also, dams' mapping and evaluation should be extended for the whole country which further would facilitate decision makers to identify and apply measures for river restoration.

KEYWORDS: dams, density, conditions, spatial database, Republic of Moldova

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1. INTRODUCTION

Dams and reservoirs are hydrotechnical constructions built to provide water to the different needs of human life and activity. From various purposes of these structures, main refer to water supply, flood control, fishery, irrigation, navigation, electricity production and recreation (ICOLD RD, 2024; Altinbilek & Cakmak 2001, Binnie, 2004 etc.). Social and economical benefits are large, quality of life and financial growth of the reservoirs surrounding regions being on the rise. In conditions of climate change and due to increasing dependence on water resources, dams and reservoirs will continue to play an important role in human development and maintenance of life. Even if the costs of their construction are high, dams and reservoirs will continue to appear in all regions of the world. Global trend shows that, for the last 70 years, from 5000 large dams, built by the 60' of the last century, at present this number has increased by 12.6 times (Adamo, 2020; ICOLD, 2024).

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Despite the fact of high importance of dams and reservoirs, the negative effect of dams and reservoirs is estimated to be a great global challenge. Construction of dams on river courses has modified their connectivity either directly through the impeding effect of the structure itself, or indirectly through alterations to the hydrological, thermal, sediment regimes, as well as had lead to changes of riparian and aquatic ecosystems. (Grill et al., 2019). The impact of dams is proportional with their scale, large dams having higher impact (Brown et al., 2024), however in some circumstance, cumulative impact of small dams (which are usually outnumbered and little considered) can be significant (Spinti et al., 2023). Many reviews, made during the last decades (Pirestani et al., 2011; Khir Alla & Liu, 2021; Ledec et al., 2003; Zahng et al., 2022; Dixon et al., 1987; Lin 2011; Zang 2022), have defined and described in details the negative impacts of dams on the environment, basing on which the following groups of destructive effects of dams were estimated: physical, chemical, biological (aquatic and terrestrial ecosystem), health and human well-being, economical, social, cultural, climate, induced seismicity, hydrological and morphological. Dams' effect was also analyzed for different phases: during dam construction, reservoir impoundment and reservoir operation (Khir Alla & Liu, 2021,). As a result of evaluation of the negative effect of dams and reservoirs, many researches propose key indicators of likely environmental impacts (Ledec et al., 2003,), certain mitigation measures as well as decision making and management recommendations for decreasing the impact (Liu, 2021; Dams and Development 2000).

In order to establish a framework for the protection of surface waters and groundwater, Water Framework Directive was adopted by European Parliament and the Council (EU Directive 2000/60/EC). The Directive treats with special attention water bodies classified as heavily modified. These are the result of physical alterations caused by human activity that substantially changed their character (Art. 2 EU Directive 2000/60/EC). Guidance document no. 4 *Identification and Designation of Heavily Modified and Artificial Water Bodies* was developed in order to delineate such type of water bodies (Guidance document n.o 4 for implementation of EU Directive 2000/60/EC). Interruption of longitudinal and lateral connectivity is hydromorphological condition taken into account when establishing if a water body is heavily modified or not. Dams as well as reservoirs represent one of the main reasons of attribution to water bodies the status of heavily modified.

In the Republic of Moldova, Water Framework Directive is partially transposed in the Water Law (Legea apleor 2011). River basin management plans for two districts: the Dniester as well as the Danube-Prut and Black Sea (H.G. 814/2017; H.G. 955/2018, Proiect Nistru II), are developed and implemented for 6 years cycles. In 2024 national legislation was progressively enriched with methodologies in order to better transpose Water Framework Directive. In this regard, methodologies on the identification and designation of surface water bodies as artificial or heavily modified, on the identification of hydromorphological changes, monitoring and assessment of water bodies, on analysis of pressures and assessment of anthropogenic risks within river basin districts (H.G. 648/2024; H.G. 675/2024; H.G. 709/2024) were developed and approved. All these methodologies contain reference to hydromorphological alteration induced by dams and reservoirs. However, even if methodology on analysis of pressures and assessment of anthropogenic risks is applied for the development of river basin management plans, heavily modified water bodies as well as hydromorphological changes of water bodies still need to be evaluated using approved approaches. Even so the national management plans (H.G. 814/2017; H.G. 955/2018, Proiect Nistru II) contains measures in order to identify and eliminate the dams causing interruption of river continuity, as well as to renaturate the river courses.

Despite progressive modern technological tools, development and maintenance of world dataset on dams and reservoirs remains a challenge (Wang J., et al., 2022). Total number of dams is still unknown, although the estimations show a number of 63,000 dams higher 5 m from 166 countries, from which only two-thirds are currently georeferenced (ICOLD, 2024). Datasets on reservoirs and dams form 2011 (Lehner et al., 2011) resulted in establishment of a total number of reservoirs of 16.7 mil. with total area of 305,723 km^2 and a total storage volume of 8,069 km^3. The largest world datasets are the World Register of Dams, updated mainly by the International Commission on Large Dams (ICOLD WRD, 2024), GlObal geOreferenced Database of Dams (Mulligan et al., 2020), Global River Obstruction Database (GROD) (Yang et al., 2022), Global River Width from Landsat database (Allen & Pavelsky, 2018), United Nations Food and Agricultural Organization (FAO) AQUASTAT (AQUASTAT, 2024) and the Global Reservoir and Dam database (Lehner et al., 2011), Georeferenced global Dams And Reservoirs dataset, GeoDAR (Wang et al., 2022), Global Dam tracker (Zhang et al., 2023). Some datasets contain rich and valuable information like reservoir purpose, storage capacity, dam height, etc.), however, essential information (like geographic coordinates) is missing or inaccessible to public. Other datasets present accurate dams location but included dams characteristics are few (Wang et al., 2022). Other datasets contain position and many dams characteristic but the total number of registered dams is still small. Nevertheless, dams and reservoirs databases continue to be improved and enriched with information.

In the Republic of Moldova, a certain database on dams can be found in the yearbooks of the Inspectorate of Environmental Protection (IPM, 2010-2019). Main parameters about dams are their and their hydrotechnical structures state, usually classified as satisfactory, damaged or absent. No data is given about dams physical parameters (lengths, height, width, etc.). Information is integrated in special tables linked to reservoirs and is updated every year. Small reservoirs and ponds, as usual, are not long lasting. Due to climate change, reduction of water resources, siltation processes, ponds became unusable in 10-15 years, transformation being to dry land or occasionally wetland. When it happens, renaturalization of rivers and streams by demolishing the dams is not often performed. Subsequently, when the reservoirs physically disappear, the dams continue to negatively influence the state of water bodies, and in some cases statistical data do not reflect them anymore in the yearbooks. A comprehensive and complete spatial database on reservoirs and dams is absent.

Present research represents a first attempt to develop such a database as well as to check the official statistic about these hydrotechnical structures. Main aim is mapping the dams built on the river streams. The objectives are identification of their spatial position using satellite images and mapping of dams situated on river with a length over 2.5 km, estimation of their general state, evaluation of upstream part state and calculation of dams' density.

2. STUDY AREA

Study area is considered the North Development Region (NDR) of the Republic of Moldova. NDR represents one of the most important regions of the country, its surface being about 10,014 km^2 or approx. 33% of the total area of the Republic of Moldova. NDR includes 11 districts (rayons): Briceni, Edineţ, Ocniţa, Donduşeni, Rîscani, Drochia, Soroca, Glodeni, Făleşti, Sîngerei, Floreşti and the municipality of Balti (Figure 1).

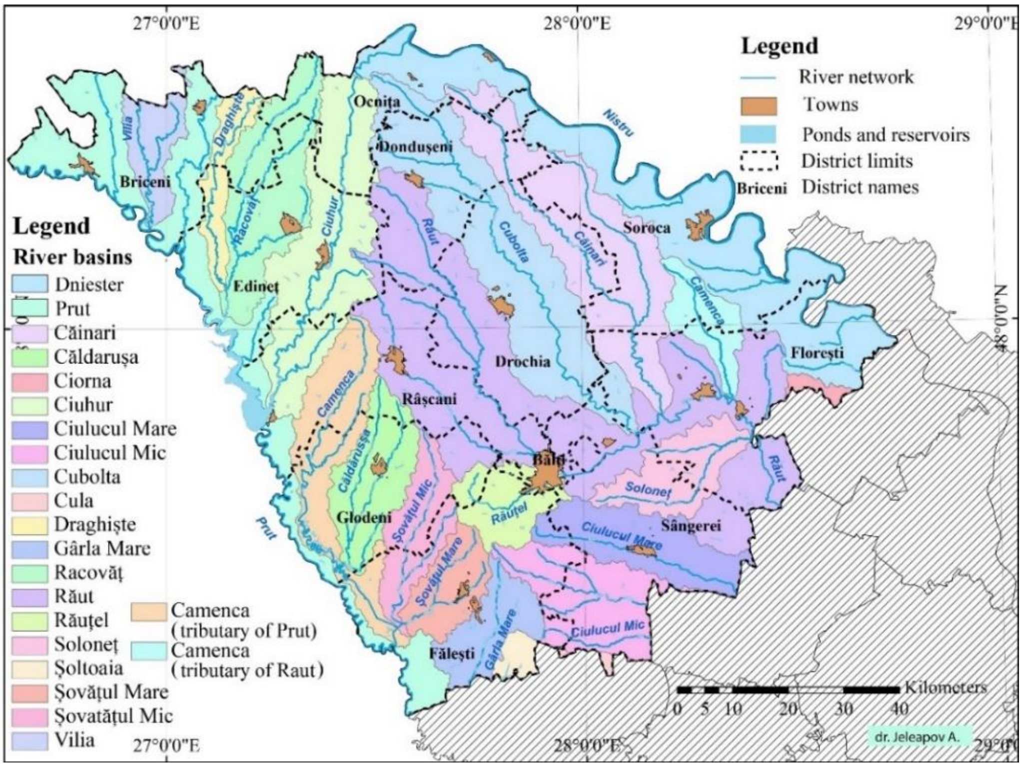


Figure 1. River network of the North Development Region of the Republic of Moldova.
Source: own work.

The total number of settlements is 572, including 20 towns. The population number is 980 ths. inhabitants of which 36.4% live in urban area and 63.6% - in the rural (Profilul socio-economic RDN, 2019).

The main rivers that pass through the NDR are the Prut and the Dniester, which are the eastern and western borders of the region. Within the limits of the study area, the length of the Dniester river is 194 km, the area of the basin – 6,087 km^2, and of the Prut river - 232 km, the area of the basin being 3,964 km^2. The main tributary of the Dniester river is the Răut, its length being 161 km, and the area of the basin - 5009 km^2 (in the limits of NDR). The most important tributaries of the Răut river are Cubolta, Căinari, Soloneț, Camenca, Răuțel etc. The main tributaries of the Prut river are Camenca, Ciuhur, Racovăţ, Vilia (Figure 1). The flow direction of the large rivers as well as the rivers of the Dniester basin is from northwest to southeast, the rivers of the Prut basin flow from northeast to southwest.

In NDR, reservoirs and ponds, created on rivers and stream by damming, have different needs: fishery, recreation, irrigation, etc. For the last 10 years, general tendency shows an increasing number of reservoirs and ponds in the NDR from about 2,460 in 2010 to 2,624 in 2019, and decreasing of their surface from 20,000 ha to 16,000 ha (Burduja & Bacal, 2021), which means that reservoirs became smaller in size and bigger in number. In 2019, water accumulations constructed on rivers and streams counted 1,157 or only 44% of their total number (Burduja & Bacal, 2021).

3. MATERIALS AND METHODS

Geospatial technologies represent a modern method of assessing the state of rivers. They allow the collection of information, the assessment of the spatial position and the initial analysis of the hydromorphological elements of the rivers and the factors that determine their deterioration. The speed of spatial analysis, remote management and enabling rapid decision-making are obvious advantages of geospatial technologies, GIS, satellite imagery. Modern and world-wide used software which contains actual satellite images is Google Earth pro (Google Earth 7.3.6., 2023). It was mainly used for mapping of dams, evaluation of their general state and identification of their upstream part status. According to data from version 7.3.6. satellite images correspond to 2020 year. Final maps and statistical calculations were performed in QGIS (Quantum GIS 3.30, 2023).

The spatial database on dams was performed for rivers of the network of NDR with a length over 2.5 km. Considered river network was extracted from National geospatial data fund, geoportal.md (NGDF, 2022). The rivers were classified in 4 categories: streams (length 2.5 km - 10 km), small rivers (length 10 km - 100 km), medium rivers (length > 100 km), large rivers: Prut and Dniester (for the study these were not considered). Classification is attributed to Water Law (Legea apelor nr. 272 din 23.12.2011). As a result of dams' state analysis, these were grouped in two: satisfactory with the mean that the dams is visually undamaged and partially demolished which, as usual, are destroyed in the middle part in order to release the natural flow (Figure 5). Along with evaluation of dams' conditions, the upstream part of the dams was also analyzed. As usual, it is considered to be a water accumulation. However, the study shows that the upstream part can be classified in: reservoirs (surface over 2 ha), ponds (surface less 2 ha), eutrophic water accumulation, semi-dry water accumulation, dry land, wetland. Finally, as a result of identification and mapping of dams, their lengths as well as their density were calculated.

4. RESULTS AND DISCUSSION

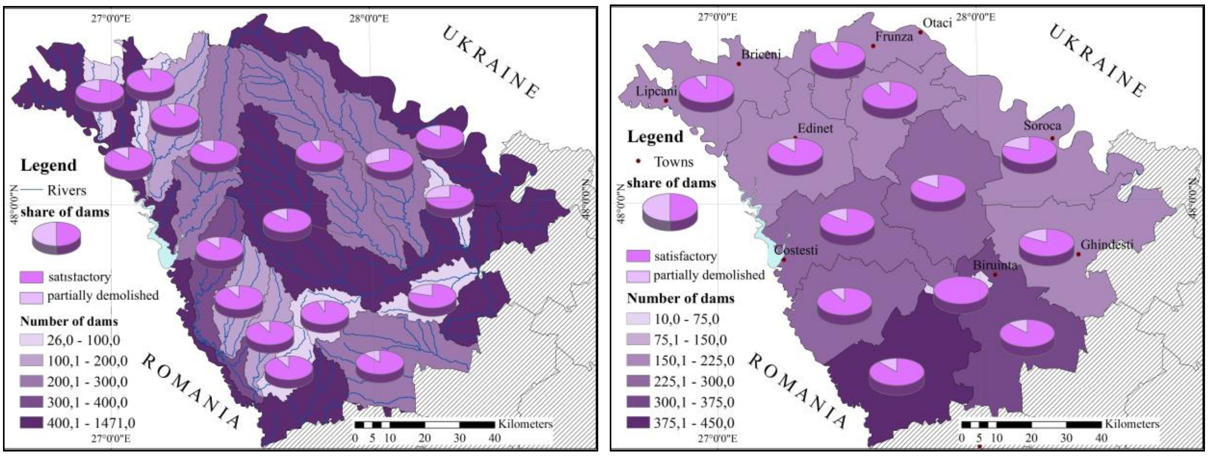
4.1. Mapping the dams position

The results of spatial identification and mapping of the dams situated on rivers and streams of the North Development Region of the Republic of Moldova are shown on figures and tables below. Total number of dams is 2,523, total length is 338 km (Figure 2, Figure 3 and Table 2).

In the limits of the Dniester river basin part, 1,471 dams were identified (1,002 – on streams, 423 – on small rivers, 46 – on medium rivers), from which 1,335 dams are situated on rivers of the Răut river basin (905 – on streams, 384 – on small rivers, 46 – on medium rivers) including 242 dams in the Cubolta river basin (140 – on streams, 83 – on small rivers, 19 – on Cubolta), 204 – in the Căinari (157 – on streams, 28 – on small rivers, 19 – on Căinari), 240 – in the Ciulucul Mic (165 – on streams, 58 – on small rivers, 8 – on Ciulucul Mic). A high number of dams is identified in the Răuțel and Soloneț river basins, despite the fact that these are quite small. Thus, in the Răuțel basin from 98 dams, 79 are situated on streams, 7 dams on small rivers and 12 dams are on the Răuțel. In the Soloneț basin from 97 dams, 58 are situated on streams, 18 dams on small rivers and 21 dams are on the Soloneț.

In the limits of the Prut river basin part, 1,052 dams were mapped, including 378 dams on rivers of the Camenca rivers (213 – on streams, 140 – on small rivers, 25 – on Camenca), 229 – on Ciuhur (175 – on streams, 39 – on small rivers, 15 – on Ciuhur), 155 - on Racovăț (76 – on streams, 59 – on small rivers, 20 – on Racovăț). The rivers and streams from the Camenca river basin are highlighted by the highest hydromorphological alteration. Here, in the Căldărușa basin the dams are built as follows 63 – on streams, 29 – on small rivers, 14 – on Căldărușa, in Șovățul Mare basin: 45 – on streams, 10 – on small rivers, 16 – on Șovățul Mare and in Șovățul Mic basin: 62 – on streams, 18 – on small rivers, 31 – on Șovățul Mic.

Figure 2. Spatial position of the dams situated on river streams of NDR.
Source: own work.



(a) **(b)**

Figure 3. Dams' number in the limits of river basins (**a**) and districts (**b**).
Source: own work.

The number of dams was calculated also for districts (Figure 3, Table 2). Thus, highest number of dams was estimated for Fălești – 379, Sîngerei – 326, and the lowest for Soroca – 169, Briceni – 168, Florești – 167, Dondușeni – 163. In the rest of the districts the number of dams ranges from 225 to 268. In the Balti municipality there are 10 dams.

Average length of the dams is 134 m. In the limits of the Dniester basin, this value ranges from 105 m in Răuțel basin to 164 m in the Camenca basin, in other basins it is about 123-136 m, average being 131 m (Table 1). In the Prut basin, dams' average length is higher. It ranges not much, from 126 m (Vilia basin) to 146 m (Draghiște basin), average value being around 140 m.

In order to estimate relationships between dams, rivers, basins, correlation were built between different parameters (Figure 4). Satisfactory correlations were identified between number of dams and river length. On average, number of dams' constructed on streams (average length - 4.45 km) is 2.5 dams, on small rivers (average length - 19.5 km) is 8 dams, on medium rivers (average length - 121 km) is 18 dams. The dams' number increases with river length, however, on the medium rivers its range is 19-25 (except Raut river with inly 8 dams on the course), while the highest number of dams is observed on the rivers between 20 and 80 km, the average being 13 dams, and the range from 3 to 31 (Figure 4).

Stronger correlation was evaluated between dams length and water accumulations area. General evaluations show that ponds are dammed by up to 110 m length dams, for reservoirs with surface up to 10 ha the dams' length is from 110 – 250 m, for those of 10-30 ha, the hydrotechnical structure is of 250-400m. The dams over 400 m embank reservoirs over 30 ha. Expected strong correlation was obtained for number of dams and river basins, larger the basin - higher the number of dams. Also, high correlation was estimated between number of dams in the limits of the districts and dam density in the same areas.

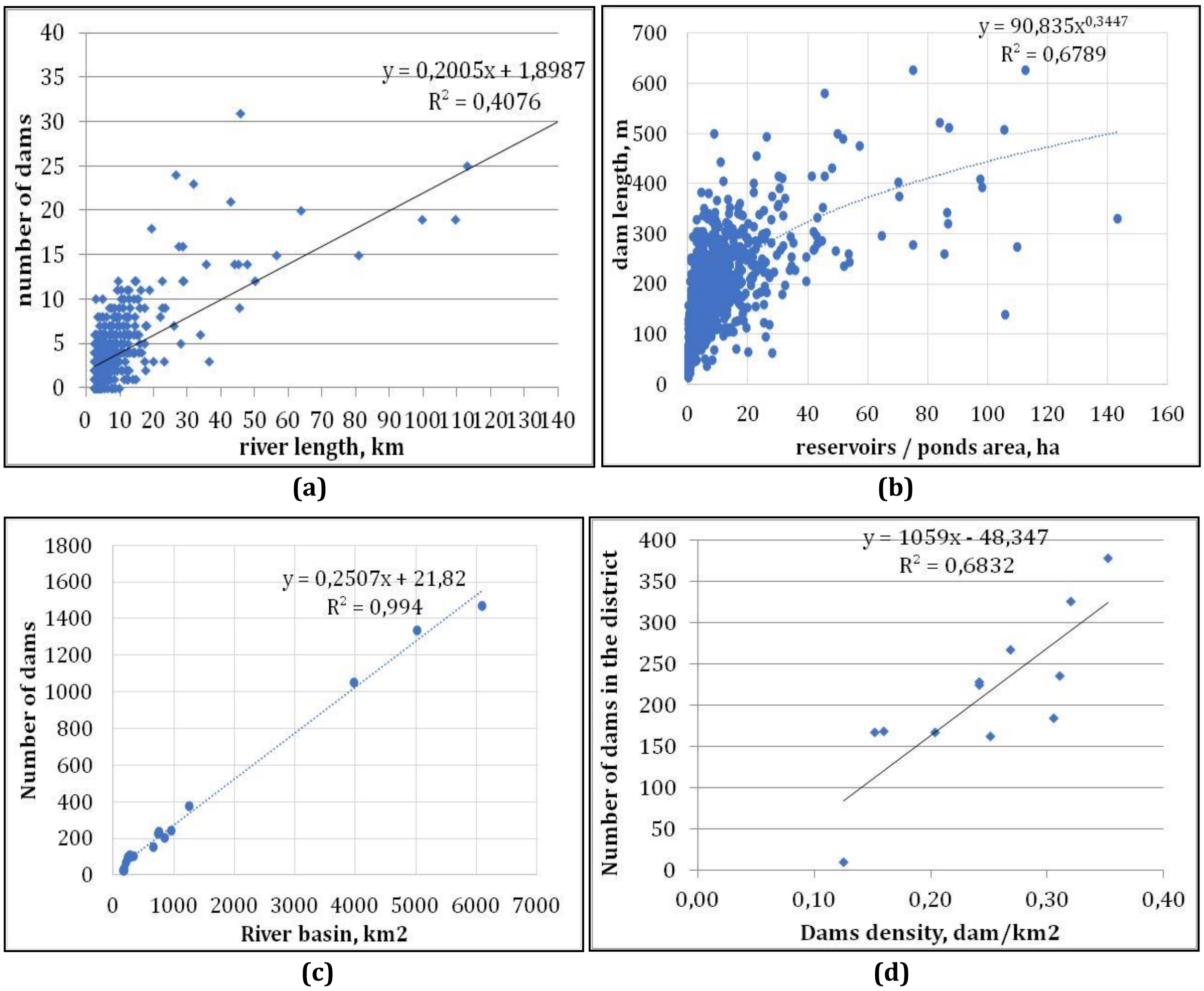


Figure 4. Correlation between: dams' number and river length (**a**); dams' length and reservoirs areas (**b**); dams' number and river basins (**c**); number of dams in the district and dams density in the district (**d**).
Source: own work.

4.2. The state of the dams

Dams' condition was grouped in satisfactory – when no damages are identified as a result of visual analysis, and partially demolished – when dams breach is observed and river flows through it (Figure 5).

(a) **(b)**

Figure 5. Dam in satisfactory condition (**a**); Partially demolished dam (**b**).
Source: Google Earth, 2023.

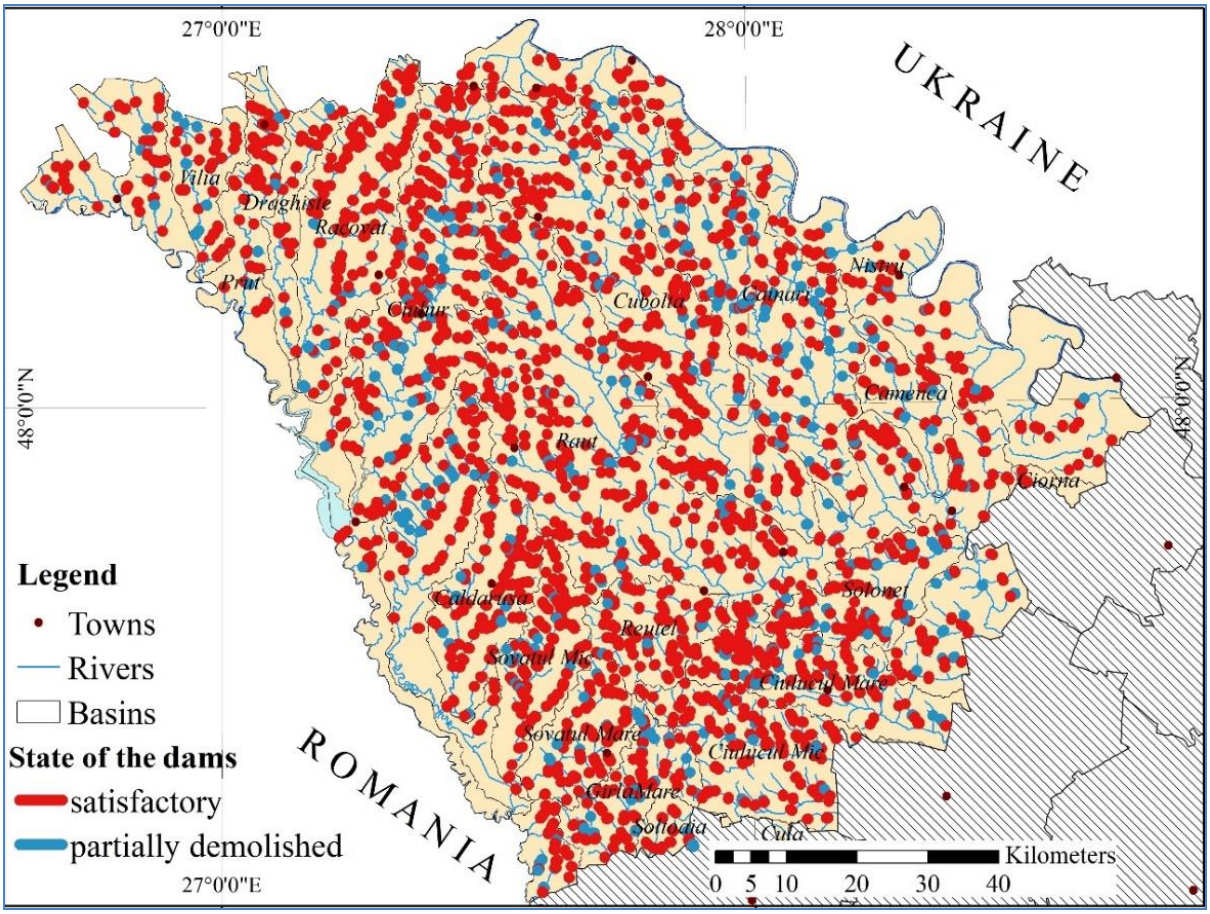
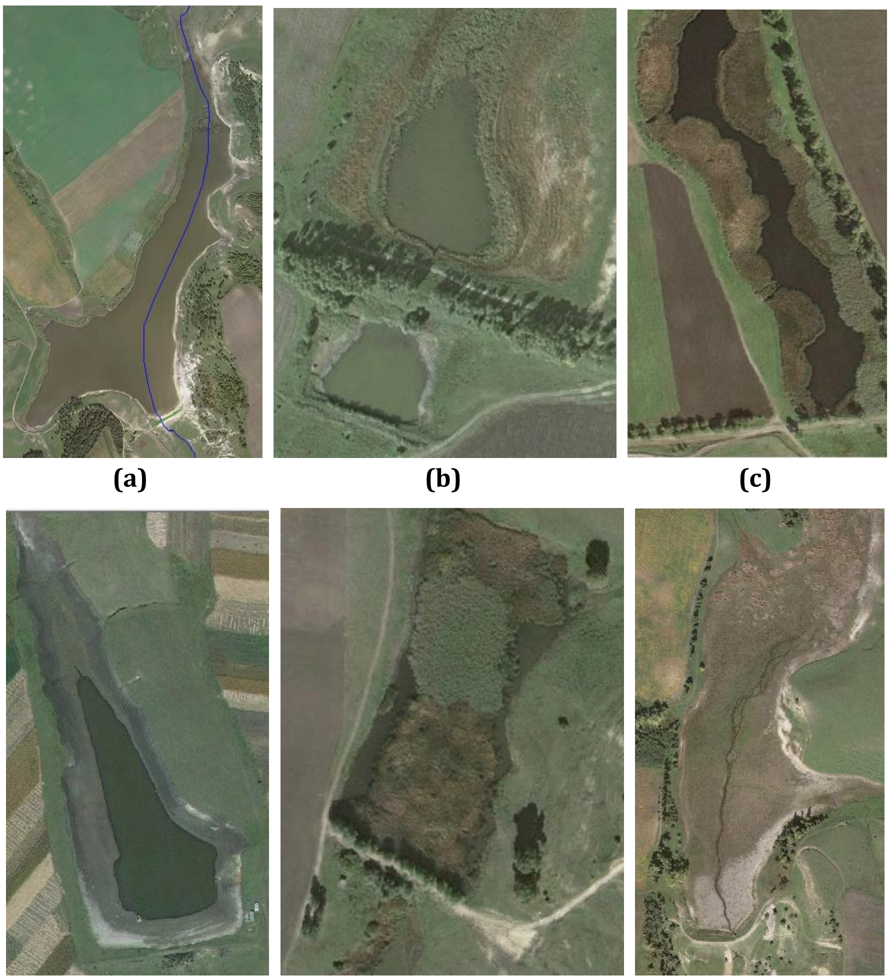


Figure 6. The state of the dams.
Source: own work.

In total from 2,523 dams, 361 dams or 14.3% have breach in the body, and 2,161 dams or 85.7 % are in satisfactory state (Table 1, Table 2, Figure 6). In the Dniester basin part from 1471 dams or 14.4 % are partially demolished. The share varies from 7% in the Răuţel river basin, 8.7 % in the Cubolta river up to 21.6% in the Soloneț basin, 26% in the Camenca (Răut), 29 % in the Căinari river basin. The number of partially demolished dams in the Răut basin part is 201 or 15%. Classifying by the river type, about 16% of dams situated on stream are partially demolished, 10% dams on small rivers and 35% on medium rivers are of mentioned type of condition. The highest number of partially demolished dams is in the Căinari river basin. Here, these dams share is 26% on streams, 39% on small rivers, 37% on the Căinari. High share is also specific for the Camenca basin (Răut), where 28% of partially demolished dams are situated on streams, 17 % - on small rivers, 33 % - on the Camenca. In the Soloneț basin, partially demolished dams are situated on steams – 29% and on small rivers – 11%, and the river itself – 9.5%. In the Cubolta river basin, mentioned type of dams is in a number of 37% on the river itself, and only a few of them being on rivers and streams – 5-7%.

In the Prut river basin, the share of partially demolished dams is the same as in the Dniester, about 14%. It varies from about 8% in the Draghiște and Racovăț river basins, up to 19% in the Vilia basin. In the rest of the basins, the range is from 11 to 15%. By river type, 16% of these dams are situated on streams, 12% - on small rivers and 4% on medium rivers. In the Camenca river basin, the share of partially demolished dams is lower, 21.6% - on streams, 3% - on small rivers. Higher share is in Ciuhur basin, being 14% on streams, 15% on small rivers, 33% on the Ciuhur itself. The highest share is in the Vilia basin, where 13% of partially demolished dams are situated on streams, 12.5 % - on small rivers, 50 % - on Vilia.

In the districts, the highest share of partially demolished dams is in Soroca and Florești – about 20%, and the lowest share is in Ocnița and Briceni – 8-9%. In the rest of the districts this value ranges between 10% (Dondușeni) and 17% (Drochia). These dams can be the first in the list of measures for river state rehabilitation.



(a) (b) (c)

(d) (e) (f)

Figure 7. Reservoir (**a**); Ponds (**b**); Eutrophic water accumulation (**c**); Semi-dry water accumulation (**d**); Wetland (**e**); Dry terrain (**f**).
Source: Google Earth, 2023.

4.3. The state of upstream part of the dams

Along with mapping of dams, their upstream part was analyzed. It was classified in 6 classes. First two classes consist of normal water accumulations grouped in reservoirs with surface over 2 ha and ponds with surface less 2 ha. The other two classes refer to water accumulations in degraded state: one class is accumulations covered by vegetation with a small share of open water – classified as eutrophic and the other one is semi-dry accumulations which water surface occupy visible less than half of the real area. The rest two classes are represented by dry terrain and wetland developed as a result of reservoirs and ponds eutrophication. Examples of classification of dams' upstream part are shown in Figure 7.

Overall, in case of only 49% situations, in the upstream part, waters are presented by: 30% - reservoirs, 19% - ponds. The other 14% situations are characterized by accumulations in degraded state: 9% - eutrophic, and 5% - semi-dry. 30% of cases are represented by dry terrain and 8% by developed wetlands (Table 1, Table 2, Figure 8 and Figure 9).

Table 1. The state of dams situated on the river of the North Development Region.

Name of basin	River basin in the NDR limit. km²	Number of dams	Average length of the dams, m	Dam density, dam/km of river	Dam density, dam/km²	State of dams		The state of the upstream part of the dams					
						Satisfactory	Partially demolished	Reservoirs	Ponds	Eutrophic accumulations	Semi-dry	Dry land	Wetland
The Dniester river basin													
Cubolta	939	242	134	0.45	0.26	221	21	89	45	19	5	70	14
Căinari	830	204	123	0.40	0.25	145	59	30	39	12	10	101	12
Camenca	174	27	164	0.27	0.16	20	7	10	3	2	0	11	1
Soloneț	268	97	136	0.64	0.36	76	21	21	12	12	3	41	8
Răuțel	222	98	105	0.79	0.44	91	7	23	38	4	5	22	6
Ciulucul Mic*	743	240	134	0.49	0.32	205	35	53	31	17	29	90	20
Răut*	5009	1335	132	0.52	0.27	1134	201	365	232	108	71	450	109
Dniester*	6087	1471	131	0.50	0.24	1259	212	399	264	123	79	490	116
The Prut river basin													
Vilia*	172	37	126	0.40	0.22	30	7	14	6	5	1	8	3
Draghiște*	156	26	146	0.30	0.17	24	2	7	9	3	0	5	2
Racovăț*	656	155	142	0.44	0.24	142	13	45	41	20	1	29	19
Ciuhur	724	229	135	0.55	0.32	193	35	91	45	22	7	51	13
Căldărușa	321	106	137	0.65	0.33	94	12	52	24	3	2	19	6
Șovățul Mic	259	111	140	0.85	0.43	99	12	39	28	10	6	24	4
Șovățul Mare	204	71	142	0.68	0.35	63	8	20	16	0	7	22	6
Camenca*	1239	378	136	0.58	0.31	327	51	142	78	23	15	91	29
Prut*	3964	1052	140	0.52	0.27	903	149	359	210	97	35	267	84

*Total, in the limits of NDR

In the Dniester basin part, the share of the mentioned classes is as follows: 27% - reservoirs, 18% - ponds, 8.4% - eutrophic, 5.4% - semi-dry accumulation, 33.3% - dry terrain and 8% - wetlands. The share of reservoirs and ponds in the basins ranges from 33.8% (14.7% reservoirs and 19.1% ponds) - in the Căinari basin, 34% (21.6% reservoirs and 12.4% ponds) - in the Soloneț basin to 62.2% (23.6% reservoirs and 38.8% ponds) - in the Răuțel basin. The share of eutrophic and semi-dry accumulations is not high. The first ranges from 4% in the Răuțel basin to 12 % in the Soloneț basin, the share in the other basins being 6-8%. The second type of degraded accumulations is lower in number. No semi-dry accumulations were identified in the Camenca basin, in the others it is 2-5%, only in the Ciulucul Mic being 12%.

Quite high share of dry lakes was identified in the basins of the Dniester river. Aprox. 1/3 of the dams' upstream part is dry in the Cubolta, Răut, 40% - in the Ciulucul Mic, Camenca, Soloneț, and even 50% in the Căinari river basin. The share of wetlands is much lower, being 4% in Camenca, 6% in the Căinari, Cubolta and Răuțel and 8% in the rest of the basins.

Table 2. The state of dams in the districts of the North Development Region.

Name of district	District area, km^2	Number of dams	Dams density, dam/km^2	Average length of the dams, m	State of dams		The state of the upstream part of the dams					
					Satisfactory	Partially demolished	Reservoirs	Ponds	Eutrophic accumulations	Semi-dry	Dry land	Wetland
Briceni	824	168	0.20	141	152	16	56	40	22	3	30	17
Edineţ	933	225	0.24	133	192	33	76	48	37	1	49	14
Ocniţa	603	184	0.31	129	170	14	81	40	7	7	33	16
Donduşeni	649	163	0.25	128	146	17	61	32	15	5	40	10
Rîscani	943	228	0.24	144	190	37	94	31	24	8	54	17
Drochia	999	268	0.27	125	222	46	65	38	22	12	112	19
Soroca	1058	169	0.16	126	133	36	27	41	15	7	71	8
Glodeni	760	236	0.31	126	209	27	92	51	17	6	46	24
Floreşti	1103	167	0.15	158	135	32	47	16	18	8	64	14
Făleşti	1076	379	0.35	136	325	54	87	77	20	29	139	27
Sîngerei	1019	326	0.32	133	277	49	69	58	21	27	118	33
Balti	80	10	0.13	215	10	0	3	2	2	1	1	1

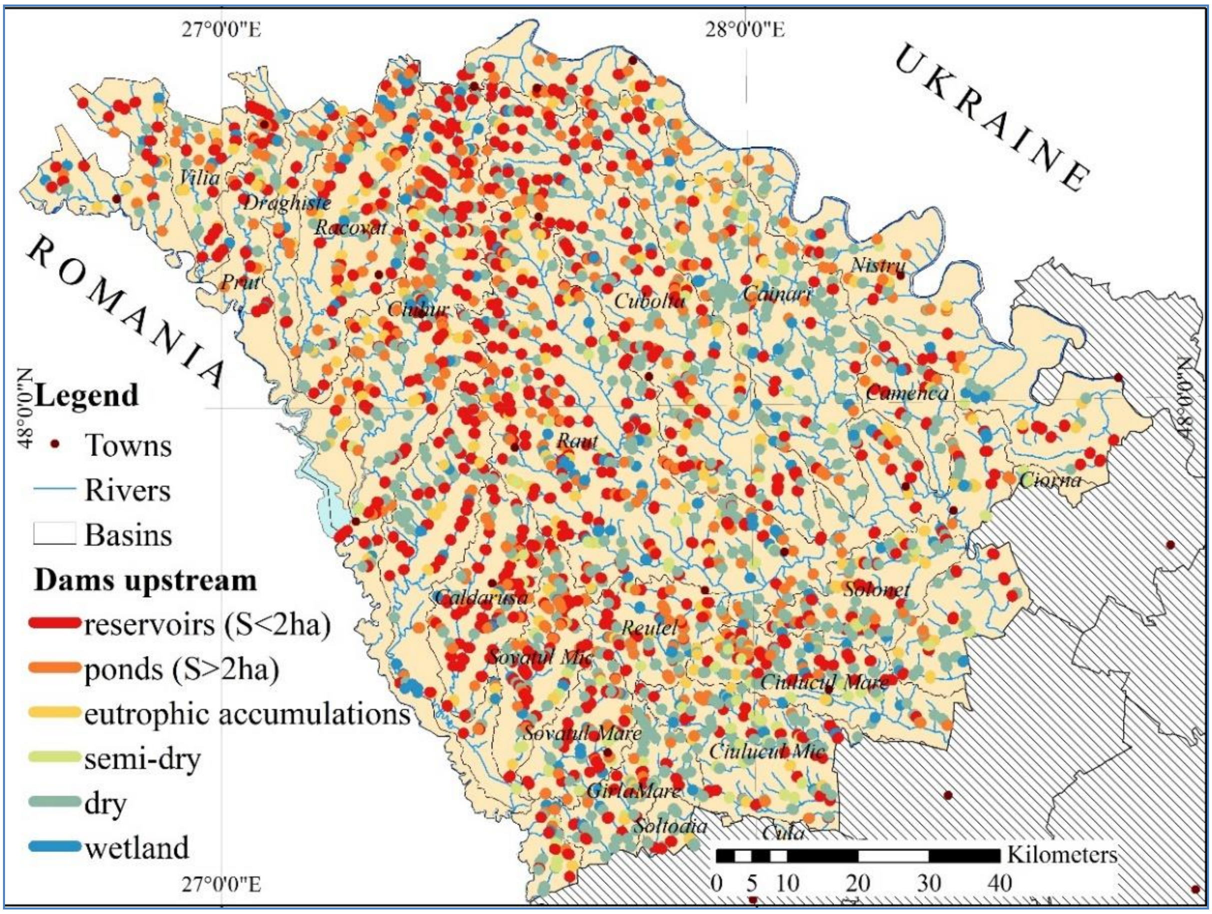


Figure 8. The state of the upstream part of the dams.
Source: own work.

In the Prut basin part, the share of the dams' upstream part is as follows: 34% - reservoirs, 20% - ponds, 9.2% – eutrophic, 3.3% - semi-dry, 25.4% - dry terrain and 8% - wetlands. The share of normal water accumulations is higher in comparison with the Dniester basin. Here, the range is 51% (28.2% reservoirs and 22.5% ponds) - in Șovățul Mic basin to 72% (49% reservoirs and 23% ponds) - in Căldărușa basin, in the other basins the share is 55%-60%. Eutrophic accumulations are higher in number in Vilia, Draghiște, Racovăț – about 11-14%, and lower in Căldărușa basin – 3%, null number is in Șovățul Mare basin. Semi-dry accumulations are absent in the Draghiște basin and just a few in the Căldărușa, Vilia, Ciuhur, Camenca, 2-4%, the highest number being in Șovățul Mare basin – 10%. In the basins of the Prut the share of dry terrains is lower than in those from the Dniester river. Approximately 1/3 of the dams' upstream part is dry in the Șovățul Mare basin, in the other basins their number in around 20%. Developed wetlands are in between 4% - Șovățul Mic basin and 12% - Racovăț basin, in the others the values are about 6-8%.

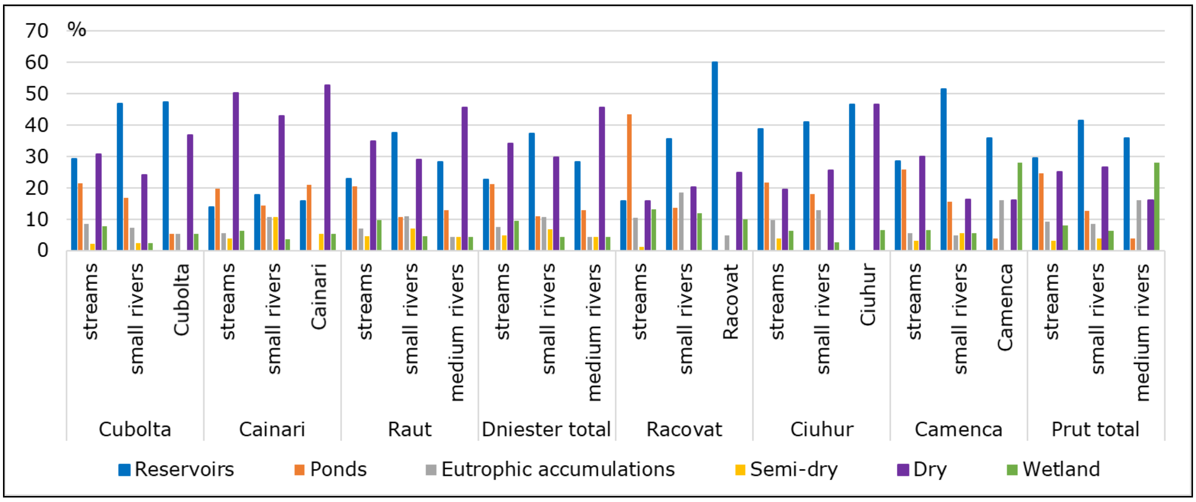
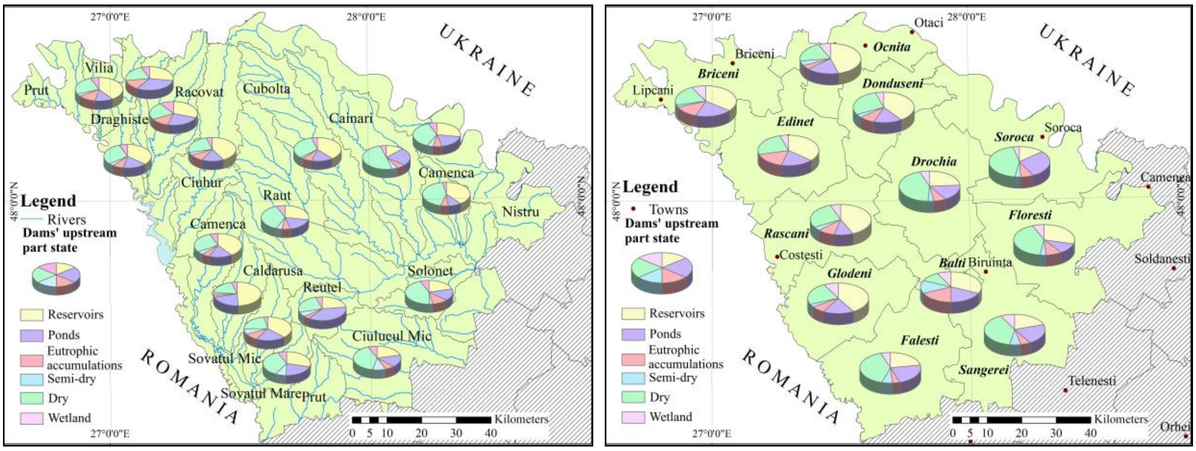


Figure 9. The state of the upstream part of the dams.
Source: own work.



(a) (b)

Figure 10. Dams upstream part state in the limits of river basins (**a**) and districts (**b**).
Source: own work.

The share of the dams' upstream part for considered types of rivers for the pilot basins is represented in Figure 9 and Figure 10. Main emphasized situations are reservoirs and ponds as well as dry land, less obvious are semi-dry and eutrophic accumulations and wetlands. Overall, in the Dniester basin, as well as in the Raut basin, on the streams highest share is specific for open water, reservoirs and ponds being of about the same number (aprox. 21% each) and dry land (35%). The share of wetlands is about 9.5%, twice higher than in case of other types of rivers. In case of small rivers, 1/3 of dams' upstream part is dry, while 48% is open water (from which 37% is reservoirs), and 10% eutrophic accumulations. On medium rivers, the share of reservoirs and ponds in sum is almost equal with the dry land, the other situation are of about 4% each. In comparison with basinal averages, in the Căinari basin, in case of all types of rivers, ½ of the dams' upstream part is represented by dry land, reservoirs and ponds are of the share, about 14-20%. Number of eutrophic and semi-dry accumulations is higher on small rivers, about 10%, in case of other rivers it is twice lower. In the Cubolta river, mainly open water is emphasized as a condition of dams' upstream state. Its number is over 50% in case of streams and Cubolta itself, and over 60% on small rivers. The share of dry land is also high of about 1/3.

In the Prut river basin, the obvious condition of the upstream part of the dams is mainly open water – reservoirs. The other conditions differ from type to type and from basin to basin. Overall, in the Prut basin as well as in the Camenca basin, on the streams, reservoirs, ponds and dry land are of about ¼ each. On small rivers, reservoirs occupy ½ of cases, ponds - 14% and dry land - ¼ or 1/5. On streams and small rivers, low share is specific for eutrophic and semi-dry accumulations and wetlands. In comparison with other river types, on the Camenca river – medium river, main conditions of the upstream part of the dams are reservoirs – 36%, wetlands – 28%, eutrophic accumulations – 16% and dry land – 16%. In the other basins, the dams upstream part conditions differ. More or less comparable are the situations in case of steams and small rivers of the Racovăț and Ciuhur basins. Thus, on streams, reservoirs and ponds summarize about 60%, however in case of Racovăț number of ponds is about 43% and reservoirs 16%, and in case of Ciuhur this number is reversed. Share of dry land is between 15% and 25%, eutrophic accumulations occupy a lower number, of about 10% - 18%. Wetlands are present mainly on the streams and small rivers of Racovăț, share being over 10% from the total number of the dams' upstream part conditions. In case of Ciuhur, half of situations is reservoirs and the other half is dry lands. The upstream part of the dams of the Racovăț river is mainly reservoirs – 60%, 25% is dry land and 10% is wetland.

At the district level, as in case of basins, main types of dams' upstream conditions are reservoirs, ponds and dry land. Conventionally, the districts can be divided in two groups, the one with almost equal share of open water and dry terrain, and the second with higher dominance of ponds and reservoirs. First group contains 5 districts: Drochia, Soroca, Florești, Fălești, Sîngerei, here the share of open water and dry land is about 40% each. In the other districts: Briceni, Edineţ, Ocniţa, Dondușeni, Rîscani, Drochia, Soroca, Glodeni, the share of ponds and reservoirs is about 50-60% while the value of dry land is around 20% or smaller by two or even three times than the previous one. The share of the other types of dams' upstream part is not high. Eutrophic accumulations are of about 10% (the lowest share of 4-6% is in Ocniţa, Făleşti, Sîngerei, and the highest share of 13-16% is in Briceni, Edineţ). Semi-dry accumulations are only a few, average being 4%, only 0.4% is specific for Edineț and about 7-8% for Făleşti, Sîngerei. Share of wetland is 8%, range being from 4.7% in Soroca and 10% in Briceni, Glodeni, Sîngerei.

4.3. The dams' density

The dams' density is a good indicator for understanding which type of rivers or basins and districts are the most affected by this phenomenon and its real extend. Evaluation of dams´ density was performed for considered river types, by estimation of number of dams constructed per kilometer of river. The map of dams' density for every river can be found in the Figure 11, while the average dams' density for the river basins is represented in Figure 12. Also, dams' density was evaluated as dam per km^2 of basins or districts. The maps with this indicator are shown in Figure 14.

In the Dniester basin, the highest density of dams was identified in the Soloneț and Răuţel basins. The dams on the streams have a density of 0.74 dams/river km (or a dam on every 1,36 km of river) in the Soloneț and of 0.95 dams/river km (or a dam on every 1.06 km of river) in the Răuţel basin. In these basins, the dams' density on small rivers is also higher than in others. On average, in the Soloneţ, it is 0.54 dams/river km and in the Răuțel – 0.47 dams/river km or a dam on every 2 km of river. The lowest values of dams' density are in the Camenca basin, on the streams this indicator is 0.38 dams/river km (or a dam on every 2,66 km of river), and on small rivers it is 0.18 dams/river km (or a dam on every 5.66 km of river). In the other basins, Cubolta, Căinari, Ciulucul Mic, Răut and Dniester overall, the values of dams' density are more or less the same. The dams on the streams have a density of 0.5 dams/river km (or a dam on every 2 km of river). Mentioned density on small rivers ranges from 0.27 dams/river km in Căinari basin to 0.51 dams/river km in Cubolta, in other basins being about 0.4 dams/river km. Average dams' density on medium rivers is 0.17 dams/river km in Cubolta basin and 0.19 dams/river km in Căinari or a dam on every 5 km of river. Average value in the Dniester basin is 0.12 dams/medium river km (or a dam on every 8 km of river), the lowest is on the Răut itself - 0.05 dams/ river km (or a dam on every 20 km of river).

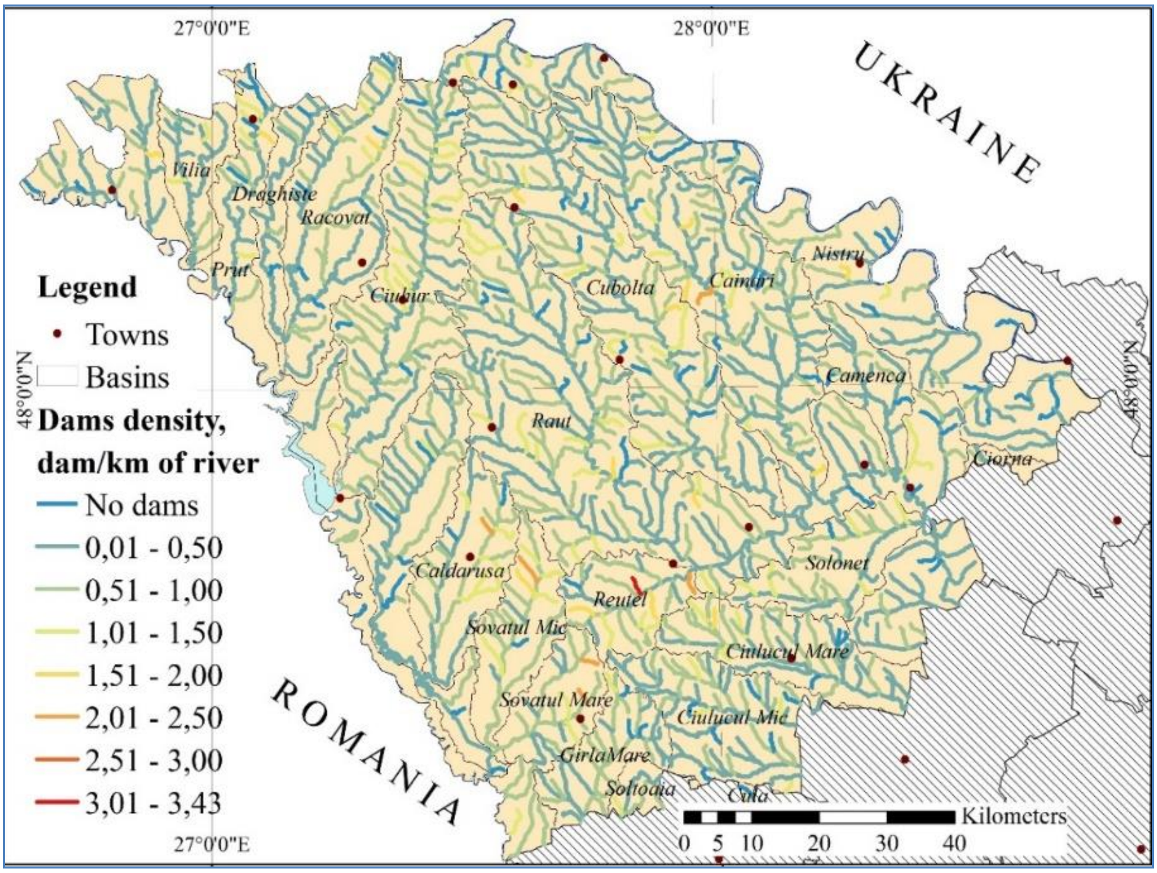


Figure 11. Density of the dams.
Source: own work.

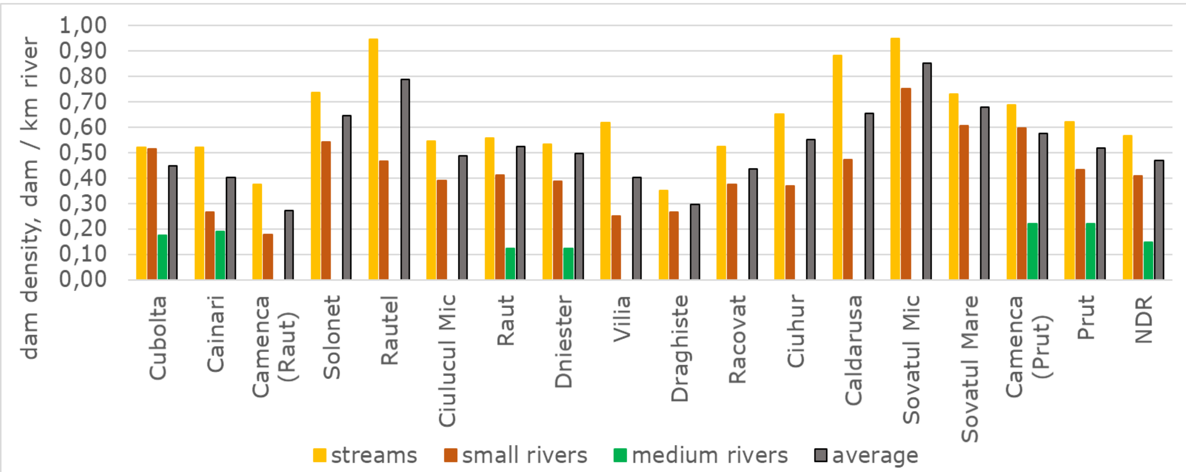
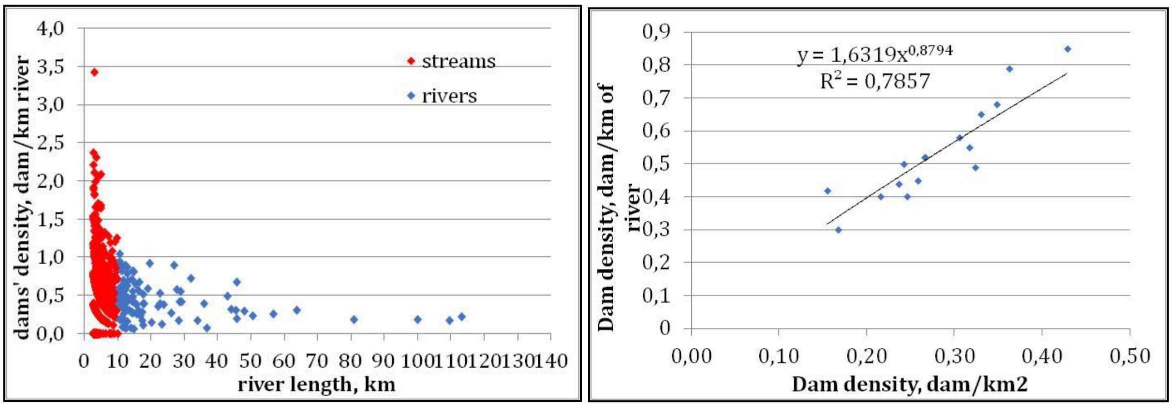


Figure 12. Average dams' density in different river basins.
Source: own work.

In the Prut basin, the dams' density on the streams and small rivers is higher than in the Dniester basin. The Camenca river with its tributaries is emphasized at the basin level. On its streams this indicator is from 0.73 dams/ river km in the Șovățul Mare (or a dam on every 1.37 km of river) to 0.95 dams/ river km in the Șovățul Mic (or a dam on every 1.05 km of river). On its small rivers, dams' density is from 0.47 dams/river km in the Căldărușa (or a dam on every 2.11 km of river) to 0.75 dams/ river km in the Șovățul Mic (or a dam on every 1.33 km of river). Dams' density on the Camenca itself is 0.22 dams/ river km or a dam on almost every 5 km of river. In the other basins, dams' density on streams is lower and is about 0.5 dams/ river km, ranging from 0.35 dams/ river km in the Draghiște to 0.65 dams/ river km in the Vilia, Ciuhur, Prut overall. Dams' density on small rivers is about 0.3 dams/ river km varying from 0.27 dams/ river km in the Vilia and Draghişte basin to 0.37 dams/ river km in the Racovăț and Ciuhur.

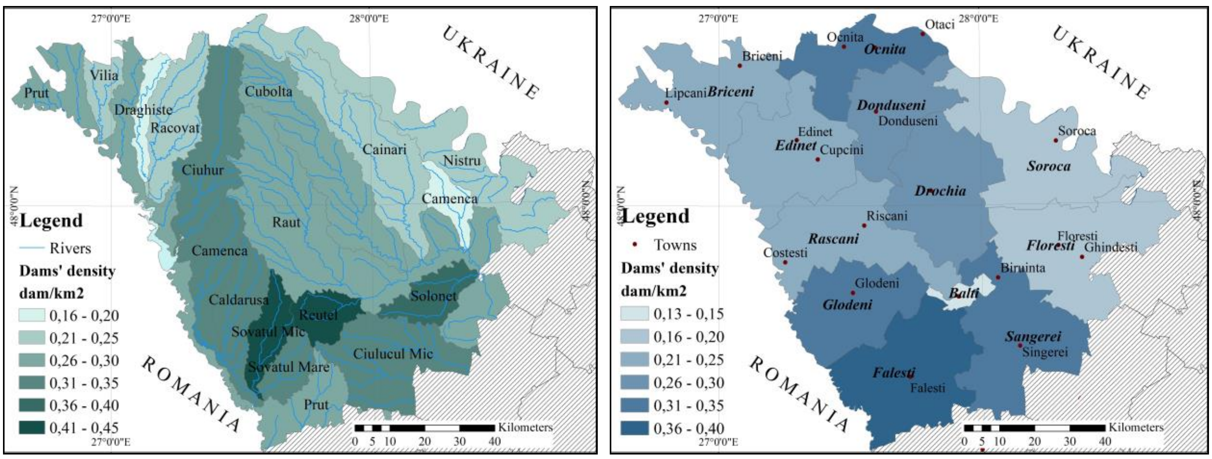
On average the density of dams is 0.47 dams/ river km, which means that on almost every 2 km of rivers a dam can be found. The value is almost the same in the Dniester and the Prut basins. However, analysis of this indicator with reference to river types shows that the highest density is specific for streams, here the average value is 0.57 dams/river km, which means that a dam is constructed on every 1.77 km of stream. In comparison, on small rivers this indicator is much lower, average is 0.41 dams/river km or one dam is found on every 2.45 km of river. The lowest dams' density is specific to medium rivers, being only 0.15 dams/river km or one dam is constructed on every 6.8 km of river. Thus, the streams are the most affected by dams' phenomenon (Figure 13).



(a) **(b)**

Figure 13. Relationship between dams' density and river length (**a**), dams' density related to river length and basin areas (**b**).
Source: own work

Dams' density in the limits of river basins and districts, calculated as dam per km², is on average 0.25 dams/km². The highest values are specific for basins Sovatul Mic, 0.43 dam/km², and Rautel, 0.44 dam/km². The parameter in the nearest basins is lower, of 0.36 dam/km² in the Solonet basin, of 0.31-0.33 dam/km² in the Ciuhur, Camenca, Caldarusa, Sovatul Mare and Ciulucul Mic basins. The lowest values are estimated for Camenca (Raut) and Draghiste – 0.16 dam/km², situate to the north and to the east of the region. The central part of the region is characterized by dams' density of 0.26 dam/km² (basins Raut, Cubolta). For the districts, the highest dams' density is established for Falesti – 0.35 dam/km², while in the Glodeni, Sangerei (situated in the south of NDR) as well as in the Ocnita (situated in the north of NDR) this indicator is 0.31 dam/km². In the east districts, the value is lower, of 0.15 dam/km² and in the west districts of about 0.2-0.24 dam/km². For the central districts of NDR, the density is average, 0.25-0.27 dam/km².



(a) **(b)**

Figure 14. Dams' density in the limits of river basins (**a**) and districts (**b**).
Source: own work.

In general, the highest density is established for the southern part of NDR and the lowest – for its eastern part, values for the central part are similar to the average for the whole region, while those from the western part are slightly lower than medium (Figure 14).

6. CONCLUSIONS

In the North Development Region of the Republic of Moldova, dams and reservoirs situated on rivers and stream is performed for fishery, recreation, irrigation. In official statistic, information about 1,157 reservoirs and their dams can be found (Burduja & Bacal, 2021), the real mapped number of dams being 2523 or at least 2.2 time higher. It should be mentioned that in many cases, if water accumulations do not represent any economic importance, they are abandoned without performing any river renaturalization activities, and are not considered anymore in official statistics. Thus, further studies, including those in the field, should be performed in order to develop a full database of dams, their state and measures as well as steps of rivers naturalization and unnecessary dams demolishing.

Average dams' length is about 134, ranging from 8 to 626 m. Ponds' dams are of by up to 110 m length, of the reservoirs with surface up to 10 ha these are from 110 to 250 m, for those of 10-30 ha, the hydrotechnical structure is of 250-400 m. The dams over 400 m embank reservoirs over 30 ha.

From total number of 2,523 dams mapped on the stream and rivers of the NDR, 86% are estimated to be generally in satisfactory condition, the other 14% being partially demolished. Analysis of the upper part of the dams' showed that only in case of 49% there are presented reservoirs and ponds in good condition, those in eutrophic condition and semi-dry accumulations are of 13%, the upstream of other 30% is characterized by dry territory and 8% by wetland.

Dams' density is considered very high in case of streams, the average being 0.57 dams/ river km or about 1 dam on every 1.77 km of river, and much lower on medium rivers, being only 0.15 dams/river km or one dam is constructed on almost every 7 km of river. Thus, real extent of the dams' impact comes to light only after a detailed mapping and analysis. Maximum human impact is attributed to streams, while medium rivers are less influenced by this phenomenon. From another point of view, water stacked in a huge number of ponds and reservoirs constructed on streams is mostly lost, and doesn't reach large rivers, thus overall water resources being significantly reduced.

Dams' density in the limits of river basins and districts, calculated as dam per km^2, is on average 0.25 dams/km^2. In general, the highest density is established for the southern part of NDR and the lowest – for its eastern part, values for the central part are similar to the average for the whole region, while those from the western part are slightly lower than the medium.

Present research is a first attempt to develop a dams' spatial database. Further studies, including those in the field, should be performed in order to improve actual studies and finalize the development of a comprehensive database of dams. Also, dams' mapping and evaluation should be extended for the whole country which further would facilitate decision makers to identify and apply measures for river restoration.

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