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ROLE OF THE RETENTION RESERVOIR IN SZABRUK FOR THE CHLORINE ION MIGRATION FROM ITS AGRICULTURAL CATCHMENT

ZNACZENIE ZBIORNIKA RETENCYJNEGO SZĄBRUK W MIGRACJI JONÓW CHLORU ZE ZLEWNI ROLNICZEJ

Abstract: The role of a retention reservoir in chlorine migration from an agricultural catchment area was analyzed during the hydrological years 2005/2007. The investigated retention reservoir is situated in a valley, in the lower course of the Szabruk stream flowing into Lake Wulpinskie located in north-eastern Poland, in the Olsztyn Lakeland mesoregion. The chlorine content of water evacuated from the catchment was determined in the range of 3.0 mg Cl · dm^{-3} to 43.0 mg Cl · dm^{-3}, and it was determined by the type and intensity of catchment use. The highest chlorine levels were noted in agricultural catchments connected to a drainage network (20.6 mg Cl · dm^{-3} on average), lower concentrations were found in farming areas drained via ditches (11.4 mg Cl · dm^{-3}), while the lowest Cl content of water was determined in outflows from afforested catchments (5.3 mg Cl · dm^{-3} on average). Chlorine concentrations were lower in the growing season in all studied catchment types. The chlorine load evacuated from the catchment was determined by the type of catchment use. The greatest chlorine loss per hectare of the catchment area was noted in the agricultural catchment connected to a drainage network (13.8 kg Cl · ha^{-1} · $year^{-1}$), a smaller Cl load was evacuated from the catchment drained via ditches (6.2 kg Cl · ha^{-1} · $year^{-1}$), while the smallest loss was observed in the afforested catchment (4.1 kg Cl · ha^{-1} · $year^{-1}$). Chlorine concentrations increased by 10 %, from 8.2 mg Cl · dm^{-3} to 9.0 mg Cl · dm^{-3} following the passage of the stream's waters through the retention reservoir. The above resulted from the inflow of drainage water with a high chlorine content as well as higher Cl concentrations due to evapotranspiration. The chlorine content of water remained unchanged after the Szabruk stream passed through the retention reservoir and the band ditch, indicating that chlorine is a good tracer of water movement through drainage facilities.

Keywords: retention reservoir, agricultural catchment area, chlorine

In nature, chlorine is found primarily in the reduced form of the chloride anion (Cl^-), and a naturally occurring form of potassium perchlorate ($KClO_4$) has been determined only in the Chile saltpetre. Chloride is abundant in living organisms and it is the main mineral anion in plants [1]. There are very few publications addressing the effect of

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chloride on water quality. Most studies investigating water pollution with mineral components in rural areas focus on nitrogen compounds and phosphates. The absence of reports discussing the role of chloride hinders the determination of the origin of polluting substances, it prevents making pollution forecasts and taking adequate recovery measures. The chloride content of water is an important indicator of water quality. Chloride ions differ significantly from nitrates, ammonium and phosphates. Chlorides do not undergo change in soil and water, they are not absorbed by soil material or bottom deposits, therefore they remain fully soluble in water and soil solutions. Chlorides are absorbed by plants and they are easily leached from the soil, including surface runoffs, which makes them a natural tracer of water and water-borne substances [2].

In rural areas, chlorides reach water bodies from various sources, mainly human settlement, farming production and precipitation. Introduced in the form of kitchen salt, chloride is an indispensable component of food products. The average daily consumption of chloride reaches 6–12 g, of which only up to 1 % is ingested with water [3]. Chlorides found in detergents are evacuated nearly in their entirety with household sewage water, while chlorides in unconsumed food and other types of household waste are deposited in dumps. Sodium chloride and calcium chloride are used in road thawing. Road-side snow contains up to 4000 mg Cl $\cdot$ m^{-3} on average [3]. Farming production is a major source of chloride that reaches water resources. Potassium fertilizers are administered mostly in the form of potassium chloride. Kitchen salt is added to animal feed with other mineral supplements, it is also available in the form of salt licks in pastures. Every year, an estimated 180 000 Mg Cl are evacuated to soil in Poland. Organic fertilizers are also an abundant source of chloride. The average chloride content of slurry is 1040 mg Cl $\cdot$ dm^{-3} [4, 5]. Unused components of mineral and organic fertilizers are leached out from the soil, transported to the water-bearing horizon or directly to surface water. For this reason, farming production is an important determinant of the quality of surface and groundwater in rural areas [6, 7]. Chloride levels throughout the entire country are also dependent on atmospheric precipitation. In Poland, wet precipitation supplies approximately 12 kg Cl $\cdot$ ha^{-1} with average concentration of 3.12 mg Cl $\cdot$ dm^{-3} [8–10].

This study analyses the effect of catchment use on the chlorine content of water outflows and the role of a retention reservoir in chlorine migration to surface waters.

Examination methodology

The role of a retention reservoir in chlorine migration from an agricultural catchment area was analyzed during the hydrological years 2005/2006 and 2006/2007. The investigated retention reservoir is situated in a valley, in the lower course of the Szabruk stream in north-eastern Poland, in the Masurian Lakeland macroregion and the Olsztyn Lakeland mesoregion. The catchment area of the Szabruk stream consists of an agricultural and an afforested part. The afforested part with an area of 4.4 km^2 occupies 33 % of the total catchment area of 13.2 km^2 (Fig. 1). Household sewage from two wastewater treatment plants located in the nearby residential areas was discharged to the stream until June 2005. Wastewater was not evacuated to the stream during the experimental period. A retention reservoir with a total area of 24.80 ha and the maximum depth of 1.51 m is situated in the lower part of the Szabruk stream valley. The reservoir was built 25 years ago, it is enclosed by a dike and is equipped with an outlet box. In the western part, the reservoir is enclosed by a band ditch which controls water flow by evacuating excess water from the Szabruk stream. Outflows from the reservoir pass through the terminal section of the Szabruk stream to Lake Wulpinskie. The study covered the Szabruk stream, the inflows and outflows of the retention reservoir (Fig. 1) and two drained catchment areas.

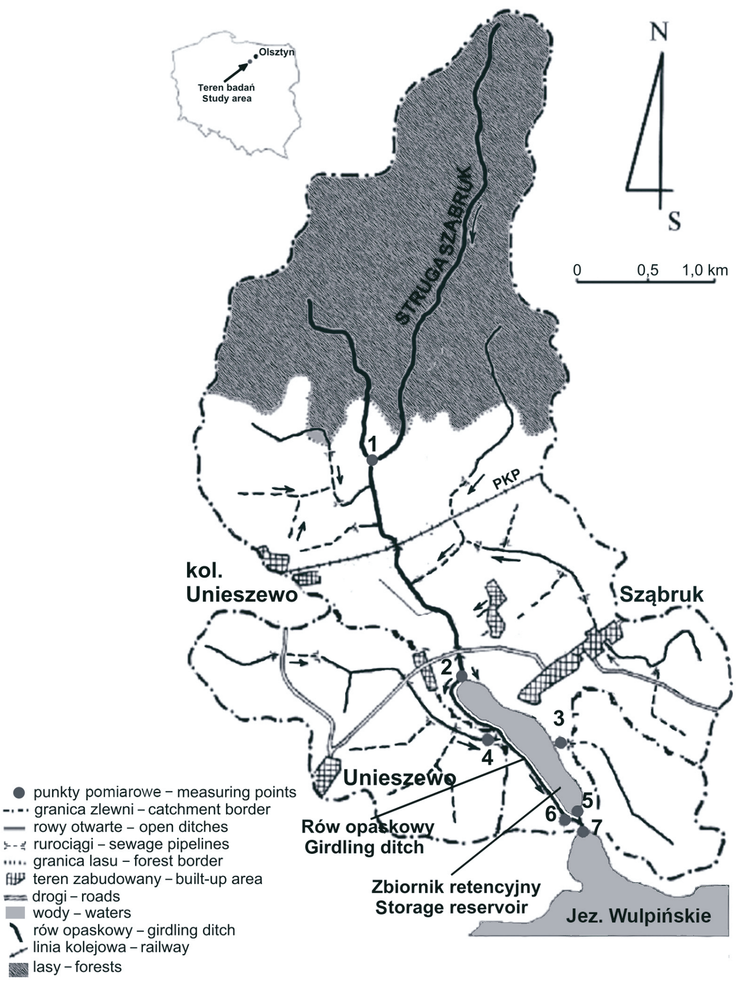

Fig. 1. Map showing the Szabruk creek catchment; 1 – Szabruk creek downstream of forest catchment, 2 – Szabruk creek upstream of storage reservoir, 3 – inflow from drained catchment to storage reservoir, 4 – inflow from drained catchment to girdling ditch, 5 – outflow from storage reservoir, 6 – outflow from girdling ditch, 7 – inflow to Wulpinskie Lake

The experiment involved hydrological measurements and laboratory analyses. The flows of the Szabruk stream were measured below the afforested catchment, at the reservoir inflow (outflow from the agricultural catchment, inflow to the retention reservoir and to the band ditch), at the drainage outflow to the band ditch, at the drainage outflow to the retention reservoir, at the outflow from the reservoir, at the outflow from the band ditch and at the inflow to Lake Wulpinskie. Flow measurements were performed weekly with the use of a VALEPORT electromagnetic flow-meter. The volumetric method was applied at low flow levels (below 2 $dm^3 \cdot s^{-1}$). Water samples for physical and chemical analyses were collected every two months at flow measurement points, and Cl^- levels were determined by the argentometric method in line with the generally observed standards [11].

The chlorine load evacuated from the catchment, supplied to and discharged from the reservoir was calculated by summing up the product of monthly flows and the corresponding chlorine concentrations. The growing season was the period from April to October.

Results and discussion

The results of the study, carried out from 2005 to 2007, showed significant variations in chlorine concentrations in different sections of the Szabruk stream, the inflows and outflows from the retention reservoir, the band ditch and the inflows to Lake Wulpinskie, subject to the type of catchment area (Table 1). High fluctuations in chlorine levels were determined in various periods of the study in the range of 3.0 mg $Cl \cdot dm^{-3}$ to 43.0 mg $Cl \cdot dm^{-3}$. Chlorine concentrations were always lower in the growing season than in the winter. The maximum Cl concentrations determined *per annum* were twice higher than the lowest chlorine levels noted in each catchment. The lowest chlorine content was reported in the Szabruk stream, in the outflow from the afforested catchment, in the range of 3–7 mg $Cl \cdot dm^{-3}$, with an average of 5.3 mg $Cl \cdot dm^{-3}$. Chlorine concentrations were lower in the summer (3–5 mg $Cl \cdot dm^{-3}$) and higher in the winter (5–7 mg $Cl \cdot dm^{-3}$). The above findings are similar to the average chlorine concentration determined in European rivers in 1959 at 6.9 mg $Cl \cdot dm^{-3}$ [12] which was adapted as the background concentration for fresh water resources [2]. Higher chlorine levels were observed in runoffs from farming areas at 11.4 mg $Cl \cdot dm^{-3}$ on average, leading to an increase in average Cl concentrations to 8.2 mg $Cl \cdot dm^{-3}$ in the stream's outflow from the combined afforested and agricultural catchment.

Significant seasonal variations in the chlorine content of water were found. Average concentrations in the summer were 20 % lower than in the winter and reached 7.2 mg $Cl \cdot dm^{-3}$. Higher Cl levels in the runoffs from agricultural catchments could be due to the use of mineral and organic fertilizers. Chlorides not absorbed by plants move deeper into the soil profile and reach surface waters. High Cl concentrations in the range of 12 to 43 mg $Cl \cdot dm^{-3}$, with an average of 20.6 mg $Cl \cdot dm^{-3}$, were reported in drained catchments which directly supply the retention reservoir and the band ditch. The highest chlorine levels were determined in the drainage ditch feeding into the band ditch around farm buildings where Cl concentrations were five times higher than in the outflows from the afforested catchment and twice higher than in the drained farming area. The above indicates that fertilizer storage, human settlement and animal production significantly contribute to chlorine pollution of water. An insignificant increase in Cl levels was noted after the passage of water through the retention reservoir, from 8.2 mg Cl · dm^{-3} at the inflow to 9.0 mg Cl · dm^{-3} at the outflow. The above increase resulted from the influx of drainage water with higher Cl concentrations as well as deposition due to atmospheric precipitation. Evapotranspiration could also be a potential cause of raised chlorine levels [2].

Table 1

Means of concentrations of chlorine in chosen points of catchment

Measuring points	Cl [mg · dm^{-3}]					
	Hydrological year 2005/2006 and 2006/2007		Outside vegetation period		Vegetation period	
	Mean	Ranges	Mean	Ranges	Mean	Ranges
Szabruk creek downstream of forest catchment	5.3	3.0–7.0	5.8	5.0–7.0	4.6	3.0–5.0
Szabruk creek upstream of storage reservoir	8.2	5.0–11.0	9.0	7.0–11.0	7.2	5.0–8.0
Inflow from drained catchment to storage reservoir	16.7	12.0–26.0	17.7	14.0–26.0	15.3	12.0–19.0
Inflow from drained catchment to girdling ditch	24.5	13.0–43.0	25.8	17.0–43.0	22.3	13.0–38.0
Outflow from storage reservoir	9.0	7.0–11.0	9.2	7.0–11.0	8.8	7.0–11.0
Outflow from girdling ditch	13.7	9.0–20.0	13.5	11.0–20.0	11.6	9.0–15.0
Inflow to Wulpinskie Lake	11.0	8.0–16.0	11.8	10.0–16.0	10.0	8.0–11.0

A comparison of water samples collected from the Szabruk stream after passage through the retention reservoir and through the band ditch indicates that chlorine concentrations were lower in the water evacuated from the reservoir than in the water flowing through the band ditch. The above was due to a high share of drainage water marked by the highest Cl concentrations in the catchment (24.6 mg Cl · dm^{-3}). Following the mixing of the outflows from the retention reservoir and the band ditch, the average chlorine content of water at the inflow to Lake Wulpinskie was 11.0 mg Cl · dm^{-3}.

Average chlorine concentrations and flow data gathered at various measuring sites were used to develop an annual chlorine balance in different parts of the Szabruk stream's catchment area (Table 2). The results of the study indicate that along a section stretching from the stream's source to a point situated above the retention reservoir, Szabruk's waters carried 5018 kg Cl · $year^{-1}$. The outflows from the afforested catchment carried 1823 kg Cl · $year^{-1}$, of which 56 % was evacuated in the growing season. The above findings supported the conclusion that the Szabruk stream collected 3195 kg Cl · $year^{-1}$ during its passage through the agricultural catchment. Annual chlorine outflows per hectare of the catchment area increased after the stream's waters had passed from the afforested catchment to farmed areas. Chlorine outflows from afforested catchments reached 4.1 kg Cl · year^{-1} and from agricultural catchments – 6.2 kg Cl · year^{-1}. The mixing of waters from farming and afforested areas resulted in average chlorine runoffs of 5.2 kg Cl · year^{-1}, including 52 % in the growing season. Outflows from drained catchments reached 13.8 kg Cl · year^{-1}, of which 62 % was evacuated during the summer drainage outflow. The total chlorine loss from the Szabruk stream catchment to Lake Wulpinskie was 6612 kg Cl · year^{-1}, with an average of 5.0 kg Cl · year^{-1}. A greater chlorine load (53 % of total load) was evacuated from the catchment in the growing season due to more intense outflows from the drainage network.

Table 2

Load of chlorine forms in chosen points of catchment

Measuring points	Total load [Cl kg · year^{-1}]			Unit load [Cl kg · ha^{-1} · year^{-1}]
	Hydrological year 2005/2006 and 2006/2007	Outside vegetation period	Vegetation period	Hydrological year 2005/2006 and 2006/2007
Szabruk creek downstream of forest catchment	1823	789	1024	4.1
Szabruk creek upstream of storage reservoir	5018	2402	2616	5.2
Inflow from Szabruk creek to storage reservoir	3381	1599	1782	—
Inflow from Szabruk creek to girdling ditch	1637	803	834	—
Inflow from drained catchment to storage reservoir (agricultural catchment)	404	170	234	11.2
Inflow from drained catchment to girdling ditch (agricultural catchment)	1173	451	722	16.4
Outflow from storage reservoir	3601	1606	1995	—
Outflow from girdling Ditch	3011	1539	1472	—
Inflow to Wulpinskie Lake	6612	3145	3527	5.0

The Szabruk stream was divided above the retention reservoir, as the result of which a part of its waters was fed directly to the reservoir, while the remaining flow was evacuated via the band ditch. According to the annual balance, the retention reservoir discharged 184 kg Cl · year^{-1} less chlorine than the inflow. Cl outflows in the band ditch were 201 kg Cl · year^{-1} higher than total inflows. The above results support the conclusion that approximately 5 % of water with dissolved chlorine percolated from the retention reservoir to the band ditch.

The calculated chlorine balance showed that its amount did not change after the passage with the flowing water along the retention reservoir. It results from little plant demand for the component as well 0.2–0.5 % dry mass [13] as the fact that it is not cumulated by vegetation. The vegetation did not accumulate chlorine in spite of a significant share of macrophytes and helophytes in the water area as well as a relatively high biomass production. Chlorine, in general, does not form undissolved salts. Thus, it is hardly deposited in bottom sediments. In the sediments of the studied reservoir, where 2500 Mg of sediment is accumulated, the chlorine deposition is 70 kg [14] estimated as 1 % of exported that from its catchment by 25 years.

Conclusions

1. The chlorine content of water evacuated from the catchment was determined in the range of 3.0 mg Cl $\cdot$ dm^{-3} to 43.0 mg Cl $\cdot$ dm^{-3}, and it was determined by the type and intensity of catchment use. The highest chlorine levels were noted in agricultural catchments connected to a drainage network (20.6 mg Cl $\cdot$ dm^{-3} on average), lower concentrations were found in farming areas drained via ditches (11.4 mg Cl $\cdot$ dm^{-3}), while the lowest Cl content of water was determined in outflows from afforested catchments (5.3 mg Cl $\cdot$ dm^{-3} on average). Chlorine concentrations were lower in the growing season in all studied catchment types.

2. The chlorine load evacuated from the catchment was determined by the type of catchment use. The greatest chlorine loss per hectare of the catchment area was noted in the agricultural catchment connected to a drainage network (13.8 kg Cl $\cdot$ ha^{-1} $\cdot$ year^{-1}), a smaller Cl load was evacuated from the catchment drained via ditches (6.2 kg Cl $\cdot$ ha^{-1} $\cdot$ year^{-1}), while the smallest loss was observed in the afforested catchment (4.1 kg Cl $\cdot$ ha^{-1} $\cdot$ year^{-1}).

3. Chlorine concentrations increased by 10 %, from 8.2 mg Cl $\cdot$ dm^{-3} to 9.0 mg Cl $\cdot$ dm^{-3} following the passage of the stream's waters through the retention reservoir. The above resulted from the inflow of drainage water with a high chlorine content as well as higher Cl concentrations due to evapotranspiration.

4. The amount of chlorine contained in the water of the Szabruk stream did not change after passing the reservoir and sourrounding ditch what is the evidence of the balance between the amounts of the ion uptaken by plants and deposited in bottom sediments and the amounts released from decayed material and sediments.

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ZNACZENIE ZBIORNIKA RETENCYJNEGO SZĄBRUK W MIGRACJI JONÓW CHLORU ZE ZLEWNI ROLNICZEJ

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Abstrakt: Badania nad znaczeniem zbiornika retencyjnego w określeniu migracji chloru ze zlewni rolniczej prowadzono w latach hydrologicznych 2005/2007. Do badań szczegółowych wytypowano zbiornik retencyjny położony w dolinie końcowego biegu strugi Sząbruk wpadającej do Jeziora Wulpińskiego, położonej w północno-wschodniej Polsce w mezoregionie Pojezierza Olsztyńskiego. W wyniku przeprowadzonych badań stwierdzono, stężenie chloru w wodzie odpływającej ze zlewni mieściło się w granicach od 3,0 mg $Cl \cdot dm^{-3}$ do 43,0 mg $Cl \cdot dm^{-3}$ i zależało od sposobu i intensywności jej użytkowania. Najwyższe stężenie chloru stwierdzono w wodzie zlewni rolniczych odwadnianych siecią drenarską (średnio 20,6 mg $Cl \cdot dm^{-3}$), niższe z użytków rolnych odwadnianych rowami (11,4 mg $Cl \cdot dm^{-3}$), a najniższe natomiast w przypadku odpływu ze zlewni leśnej (średnio 5,3 mg $Cl \cdot dm^{-3}$). We wszystkich zlewniach cząstkowych mniejsze stężenia chloru stwierdzono w okresie wegetacyjnym niż poza nim. Ładunek chloru odprowadzany z obszaru zlewni był uzależniony od sposobu jej zagospodarowania. Największy odpływ chloru z jednostki powierzchni stwierdzono w zlewni rolniczej zdrenowanej (13,8 kg $Cl \cdot ha^{-1} \cdot rok^{-1}$), mniejszy ze zlewni odwadnianej rowami (6,2 kg $Cl \cdot ha^{-1} \cdot rok^{-1}$) i najmniejszy ze zlewni leśnej (4,1 kg $Cl \cdot ha^{-1} \cdot rok^{-1}$). W wyniku przepływu wody przez zbiornik retencyjny następowało podwyższenie w niej stężenia chloru o 10 %, z 8,2 mg $Cl \cdot dm^{-3}$ do 9,0 mg $Cl \cdot dm^{-3}$, co było efektem zasilania wodami drenarskimi o wyższych stężeniach chloru i zatężenia roztworu w wyniku ewapotranspiracji.

Słowa kluczowe: zbiornik retencyjny, zlewnia rolnicza, chlor