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ROLE OF RETENTION RESERVOIR IN SODIUM MIGRATION FROM AGRICULTURAL AND AFFORESTED CATCHMENT AREAS

ROLA ZBIORNIKA RETENCYJNEGO W MIGRACJI SODU ZE ZLEWNI ROLNICZO-LEŚNYCH

Abstract: The analisis of the role of retention reservoir in sodium migration from agricultural and afforested catchment areas and wastewater treatment plants was presented. The study was conducted on a stream with a pond at its outlet. For technical purposes, water was partially directed via a band ditch. The investigated site is situated in north-eastern Poland, in the Olsztyn Lakeland mesoregion. Detailed investigations of surface waters were carried out over a period of 3 years.

The highest sodium concentrations were noted in treated effluents (84.19 and 96.64 mg Na · dm^{-3} on average), lower levels were found in the outflows from agricultural catchments (7.54 to mg Na · dm^{-3} to 11.55 mg Na · dm^{-3}), while the lowest – in the outflows from afforested catchments (3.77 to 4.52 mg Na · dm^{-3}). In the outflow from the retention reservoir, sodium concentrations reached 7.87 mg Na · dm^{-3}, and in the outflow from the band ditch – 8.90 mg Na · dm^{-3}. Total sodium concentrations in water flowing from the catchments to Lake Wulpinskie was 8.09 mg Na · dm^{-3}. A total of 4706 kg sodium was discharged into the lake each year, which means that flow per ha of the catchment area was 3.4 kg Na. The retention reservoir significantly reduced the total sodium load flowing from the catchments into the lake. The main role of the reservoir was to equalize sodium concentrations. The sodium load was reduced by approximately 50 %.

Keywords: load reduction, sodium, stream, pond

Sodium is one of the most abundant elements on earth and it comprises 2.63 % of the earth's crust. Sodium is found in water in the form of various compounds, mostly chlorides (NaCl), and less frequently, sulfates (Na_2SO_4), carbonates ($NaHCO_3$ and Na_2CO_3) and nitrates ($NaNO_3$). The above compounds are highly water-soluble. The sodium content of natural water ranges from several grams to 30 g · m^{-3}. Underground

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water may contain up to 100 g · m^{-3} sodium, while sea and ocean water – up to 10 kg · m^{-3}. In sea water, sodium ions account for around 48 % of total cation mass [1, 2].

The presence of sodium bicarbonate is responsible for the sodium alkalinity of water. Water containing high levels of this compound is not fit for use in the pharmaceutical industry, the brewing industry or in the production of plant tannins. Sodium compounds found in fresh water are insignificant from the technical and industrial perspective, and they do not pose a health hazard. In certain circumstances, sodium salts occurring in the form of sodium nitrate(III) and (V) may be a measure of water pollution if supplied from municipal effluents or fertilized soil.

In naturally occurring water, sodium originates from the hydrolytic decomposition of minerals (plagioclase, nephelite, albite and others), magmatic rock weathering and leaching of sedimentary rocks containing sodium salts. Pollution is an additional source of sodium in surface waters. Sodium is used in households in the form of kitchen salt and it has numerous applications in various industries, including paper, glass, chemical, food processing industries, as well as medicine. The largest quantities of sodium are evacuated with industrial effluents from soda and salt plants, mineral salt processing plants and dye factories. Sodium chloride is used in de-icing roads in the winter. Every day, man excretes 5 g of sodium which reaches surface water deposits via municipal effluents. Sodium is difficult to remove because it does not form insoluble compounds with substances used in the treatment of water, while it participates in sorptive processes. Therefore, in most part, sodium is discharged with treated effluent water.

The chemical composition of substances dissolved in the waters of agricultural and afforested areas is determined by geochemical conditions in the catchment, biological processes and human activity. In afforested areas where the above pollution sources are negligent, the composition of water-borne compounds is determined by geochemical conditions and phytocenosis. In agricultural areas, geochemical conditions are difficult to separate from farming and household sources of pollution. The volume of sodium outflows from the catchment is determined mainly by land relief, vegetation cover, soil cohesion, farming intensity and treated effluents. Water flow through a preliminary reservoir on a stream reduces point-source pollution (effluents from sewage treatment plants) as well as surface washings from agricultural and afforested areas [3, 4].

The objective of this study was to determine the sodium load discharged with water from the agricultural and afforested catchment, and to investigate the role of retention reservoir in reducing sodium concentrations and loads in surface waters contaminated with treated effluents.

Materials and methods

The study was carried out in the Olsztyn Lakeland, and it covered three hydrological years. The investigated site was the Szabruk stream with a catchment area of 13.2 km^2, occupied by forests (33 %) and farmland (67 %). The catchment features two residential estates (population of 607), each with a wastewater treatment plant (no. 1 and no. 2), as well as scattered buildings with approximately 40 residents with no wastewater treatment option.

For the needs of the study, water evacuated via the Szabruk stream from afforested areas, water evacuated via drains from agricultural areas and wastewater were sampled for analyses. Water flow measurements were performed with the use of an electromagnetic flow meter. Samples were collected at 13 test sites (Table 1, Fig. 1).

Table 1

Water sampling sites

Site no.	Location (Fig. 1)
1 and 2	Inflow from the afforested catchment
3	Stream above the inflow from the wastewater treatment plant in Unieszewo
4	Inflow from the wastewater treatment plant in Unieszewo
5	Inflow from the agricultural catchment with housing
6	Szabruk stream above the inflow from the wastewater treatment plant in Szabruk
7	Inflow from the wastewater treatment plant in Szabruk
8	Stream below the wastewater treatment plant in Szabruk during the effluent discharge period
9	Drain flow from the agricultural catchment to the band ditch
10	Band ditch at stream inlet below the pond
11	Drain flow from the agricultural catchment to the pond
12	Inflow from the pond to the stream
13	Outflow to the lake

Water flow at test sites on the Szabruk stream was characterized by high variability. In general, water flow was intensified in the spring thaw period. The pond can act as a flow regulator because its structure minimizes rapid flow fluctuations. It is also capable of accepting large quantities of water and evacuating it to the stream with a delay.

Water runoffs at each flow measurement site differed throughout the period of the study (Fig. 2).

In the group of agricultural catchments, the most intensive flow per ha of catchment area was noted in the smallest catchment (82.4 ha, test site no. 11) feeding into the pond at 3.1 $dm^{-3} \cdot s^{-1} \cdot km^{-2}$. Size is not the only characteristic feature of this catchment. It features a deep and drained hollow from which water is evacuated via a drain pipeline directly to the pond.

Runoff per area unit was most variable in drained agricultural catchments (no. 9 and 11), while the highest average runoff was observed in the afforested catchment (no. 1) at 3.9 $dm^{-3} \cdot s^{-1} \cdot km^{-2}$, ie slightly below the characteristic values for the Masurian Lakeland [5].

The outflows from the wastewater treatment plant in Unieszewo supplied 7.8 m^3 of pre-treated effluents daily at a rate of 0.09 $dm^{-3} \cdot s^{-1}$. The inflow of treated sewage did not significantly affect the flow rate. The treatment plant in Szabruk discharged an average of 25 m^3 of treated sewage per session at a rate of 0.29 $dm^{-3} \cdot s^{-1}$. There were two discharge sessions per day, each lasting 30 minutes. Treated wastewater was evacuated to an indirect ditch which significantly delayed the time of reaching the

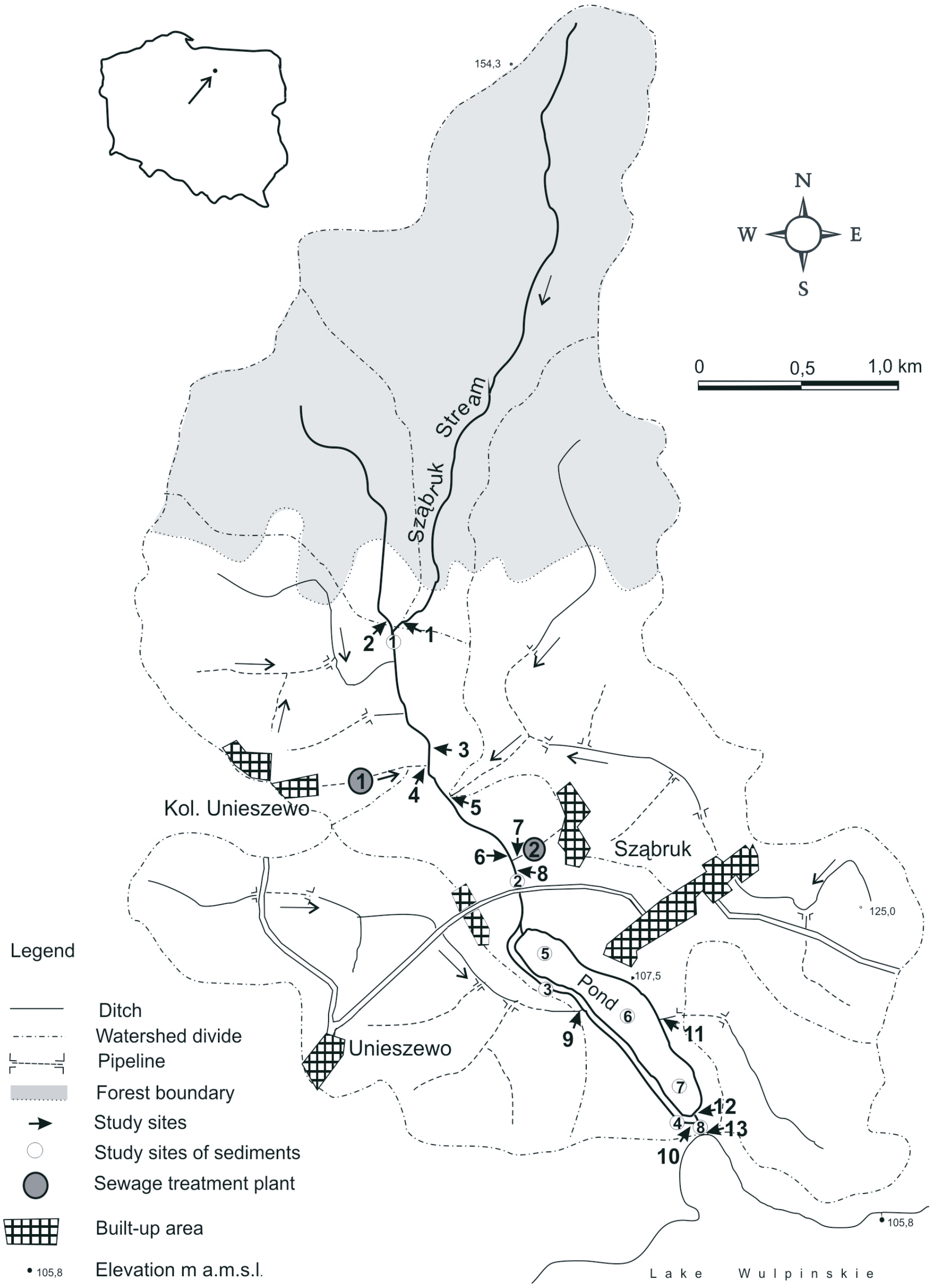

Fig. 1. Location of test sites in the catchment of the Szabruk stream

Szabruk stream. As a result, the waste was diluted and it did not visibly increase the flow in the stream, thus supporting the self-purification process. The total volume of treated wastewater fed by both treatment plants into the Szabruk stream was estimated at 58 $m^3 \cdot day^{-1}$, ie 0.38 $dm^{-3} \cdot s^{-1}$, and it did not have a significant impact on the volume of water flowing in the stream. The main inflow of treated wastewater to the stream was observed in the area of test site no. 8. In view of the flow rate determined at the above site at 26.85 $dm^{-3} \cdot s^{-1}$, the duration of the discharge session and the volume of discharged waste, the treated wastewater had a 2.5 % share of instantaneous flow and accounted for 33 % during discharge.

Water samples were collected once a month. Flow measurements were performed during sample collection. Sodium (Na^+) concentrations were determined by atomic emission spectrophotometry in water samples, and by colorimetry in vegetation and deposit samples. Analyses were conducted in accordance with the universally accepted methodology [6].

Results

The process of sodium flow through water bodies under natural conditions is highly complex, it varies over time and, therefore, it is difficult to observe.

Table 2

Sodium concentrations in the investigated catchments

Type of water	Site no.	Na^+ concentrations [$mg \cdot dm^{-3}$]			Na^+ load [$mg \cdot s^{-1}$]
		Average	Range	±SD	
Inflow from the afforested catchment	1	3.77	2.50–4.80	0.50	36.7
Inflow from the afforested catchment	2	4.52	2.00–5.60	0.71	20.4
Stream above the inflow from the wastewater treatment plant in Unieszewo	3	4.22	2.10–5.60	0.83	69.1
Inflow from the wastewater treatment plant in Unieszewo	4	84.19	23.30–158.0	37	7.6
Inflow from the agricultural catchment with housing	5	8.23	4.40–53.20	9.7	54.3
Stream above the inflow from the wastewater treatment plant in Szabruk	6	7.14	4.40–23.50	3.38	191.8
Inflow from the wastewater treatment plant in Szabruk	7	96.63	12.60–172.7	40	29.0
Stream below the wastewater treatment plant in Szabruk during the sewage discharge period	8	39.19	4.80–99.00	27	1052.3
Stream below the wastewater treatment plant in Szabruk (daily average)	8’	8.48	5.22–27.92	8.9	227.7
Drain flow from the agricultural catchment to the band ditch	9	11.55	4.00–24.8	6.0	66.7
Band ditch at stream inlet below the pond	10	8.90	2.90–12.90	1.94	136.6
Drain flow from the agricultural catchment to the pond	11	7.54	1.80–15.80	3.0	26.8
Inflow from the pond to the stream	12	7.87	4.80–12.40	1.81	24.4
Outflow to the lake	13	8.09	2.50–12.00	1.75	148.9

±SD – standard deviation.

The dynamics of those processes is determined by fluctuations in the factors determining the volume of external load as well as changes taking place inside the water bodies. The concentrations of sodium evacuated to surface waters in afforested and agricultural areas, and sodium levels in pre-treated sewage discharged from two residential sewage treatment plants were determined (Table 2).

Sodium concentrations in the inflows feeding into the Szabruk stream varied subject to weather conditions and, above all, the supply source. Inflows from afforested catchments were characterized by very low sodium levels. Despite the lowest average sodium concentrations (3.77 and 4.52 $Na^+ \cdot dm^{-3}$), inflows from afforested catchments were also marked by the lowest fluctuations in sodium levels throughout the year (Fig. 2).

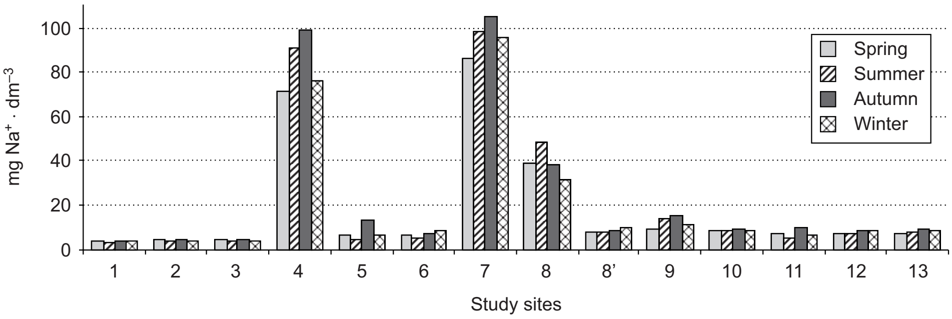

Fig. 2. Seasonal variability in sodium concentrations at each test site in mg $\cdot$ dm^{-3}. Test sites are described in Table 1

Inflows from agricultural catchments supplied the highest sodium load in the autumn, ranging from 10.52 $Na^+ \cdot dm^{-3}$ (directly to the pond) to 15.10 $Na^+ \cdot dm^{-3}$ (to the band ditch). Outflows from agricultural catchments feeding into the stream and into the pond carried nearly twice more sodium, and inflows to the band ditch – more than twice the sodium load supplied by afforested catchments in every season of the year. Sodium levels in surface waters in the investigated catchment were lower than in areas marked by intensive farming production [7, 8].

The effluents discharged by two residential treatment plants showed high sodium concentrations. At both treatment plants, the lowest sodium ion levels were noted in the spring: 70.87 $Na^+ \cdot dm^{-3}$ in the Unieszewo plant and 86.31 $Na^+ \cdot dm^{-3}$ in the Szabruk plant. Similarly to agricultural catchments, the highest sodium concentrations were observed in the autumn at 99.09 and 105.04 mg $Na^+ \cdot dm^{-3}$, respectively (Fig. 2). Sodium concentrations were lower in the effluents from the treatment plant in Unieszewo than in the sewage discharged from the Szabruk facility due to the applied sewage treatment process. The Unieszewo plant relies on three filter beds and two reservoirs. Sewage from the treatment plant continuously feeds into the stream by overflow and via an underground pipeline. Wastewater treated at the Szabruk plant is aerated by Kessener brushes. The plant operates periodically with two pauses during which wastewater is clarified and discharged to the stream. Both treatment plants process domestic sewage.

Inflows from the treatment plants were significantly diluted in the stream. Effluents from the treatment plant in Unieszewo and inflows from the agricultural catchment with residential housing decreased water quality and increased sodium levels by 32 %. Effluents from the Szabruk plant raised sodium concentrations 4.5-fold during the sewage discharge session and by 19 % on a daily basis on average. Treated sewage from Szabruk dramatically decreased water quality, in particular as regards biogenic element supplies, leading to oxygen deficit [9–11].

A rapid increase in sodium concentrations was observed in the Szabruk stream mostly during sewage discharge sessions from the Szabruk treatment plant. The sodium content of the pond was reduced by more than 7 % on average per year. Sodium concentrations in the ditch band increased by nearly 5 % over the same period, mainly due to inflows from the agricultural catchment which supplied an average of 11.55 $Na^{+} \cdot dm^{-3}$.

An analysis of the investigated parameters at each test site showed that despite an increase in catchment area and the inflow of pollutants, sodium concentrations at stream outlet to the lake were lower than at the point of wastewater inflow from the Szabruk treatment plant (Table 2). The load discharged from the treatment plant and evacuated from the catchments was reduced in the preliminary reservoir. It can be concluded that during passage through the pond with an area of 24.8 ha, the sodium load of water polluted with pre-treated sewage became accumulated in bottom deposits and littoral vegetation [12].

In the overall sodium balance (water flow times Na concentrations), treated effluents had a 15 % share, afforested catchments – a 24 % share, while agricultural catchments – the highest 61 % share of sodium load fed into the stream. In the course of three experimental years, the catchment fed an average of 6355 kg sodium into the pond per year. Sodium outflow from the pond accounted for 12 % of its inflow, therefore, vast quantities of this element were retained in the water body. The sodium load passing through the pond was reduced by 88 %. Such a significant reduction of sodium load probably resulted from intense percolation of water from the pond to the band ditch due to an altitude difference of around 140 cm between the pond outflow and the terminal part of the band ditch. For this reason, the sodium load balance was determined collectively for the pond and the band ditch. In the overall balance, the total reduction in sodium concentrations passing through the pond and the band ditch reached 54 %, despite the inflow from agricultural catchments.

Sodium levels in the biomass of littoral vegetation were generally in a range of 0.03–0.49 % DMA (dry matter accumulation, air-dry basis). Significant variations were reported between different vegetation sampling sites, and a 16-fold difference between the lowest and the highest sodium concentrations was noted. Vegetation samples collected in the direct proximity of the inflow were marked by the highest sodium levels, and the sodium content of water decreased with distance from the main supply source. A repeated increase in sodium concentrations in littoral plants was observed in the terminal part of the pond due to inflows from the agricultural catchment. Pond vegetation accumulated 318 Na on average, ie 31 kg Na per ha.

The thickness of bottom deposits in the stream did not exceed 10 cm, and in the pond deposits were formed in the course of 25 years and their thickness was determined by pond depth. The thickest deposits of up to 20 cm were observed in the deepest point of the pond. Their thickness gradually decreased towards shallower parts of the pond, and layers of 0–5 cm occupied the largest pond area of 11.9 ha. For this reason, this layer contained the highest sodium load. An increased sodium content of bottom deposits was observed below points of intensified sodium supply, ie the treatment plant in Szabruk, at 475 mg $\cdot$ kg^{-1} DMA, and the inflow from the agricultural catchment to the band ditch where the highest sodium content was noted at 653 mg $\cdot$ kg^{-1} DMA (Table 3). The investigated water body accumulated 2515 tons of bottom deposits with 1097 kg Na, ie 101 Mg of deposits with 44.3 kg Na per one hectare of pond area.

Table 3

Sodium concentrations in bottom deposits [mg $\cdot$ kg^{-1} DMA]

No.	Sampling site	Na^+ in layers of 0–10 cm	Na^+ in layers of 10–20 cm
1	At point of stream connection below the forest	134	—
2	Below the wastewater treatment plant in Szabruk	475	—
3	Band ditch	230	—
4	Terminal part of the band ditch	653	—
5	Pond-beginning	341	223
6	Pond-middle	549	549
7	Pond-end	564	564
8	At point of connection with pond outflow	490	—

— deposit thickness did not exceed 10 cm.

Conclusions

1. Effluents discharged by small rural treatment plants supply higher sodium concentrations than agricultural and afforested areas, but agricultural catchments are responsible for the highest sodium load introduced to water bodies.
2. Water flow through the retention reservoir reduces the concentrations and load of sodium which becomes accumulated in littoral vegetation and bottom deposits.
3. Pond vegetation accumulated 31 kg Na/ha. Reed canary grass (*Phalaris arundinacea* L.) was the predominant species of littoral vegetation in the studied pond.
4. Bottom deposits with a thickness of 5 to 20 cm, 7.7 cm on average, were formed in the course of the pond's life of 25 years. On average, 101 Mg of deposits containing 44.3 kg Na were accumulated per ha of pond area.
5. The construction of a pond on the watercourse fed with pre-treated effluents improved water quality. Sodium concentrations were reduced by 7 % on annual average. The reduction of sodium load passing through the pond and the band ditch reached 54 %.

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ROLA ZBIORNIKA RETENCYJNEGO W MIGRACJI SODU ZE ZLEWNI ROLNICZO-LEŚNYCH

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Abstrakt: Praca zawiera wyniki badań dotyczące znaczenia zbiornika retencyjnego w migracji sodu dopływającego ze zlewni leśnych, rolniczych oraz oczyszczalni ścieków. Obiektem badań był ciek, na ujściu którego zbudowano staw. Ze względów technicznych część wód kierowano rowem opaskowym. Obiekt badań położony jest w północno-wschodniej Polsce, w mezoregionie Pojezierza Olsztyńskiego. Badania szczegółowe wód powierzchniowych prowadzono 3 lata.

W wyniku przeprowadzonych badań stwierdzono, iż największe stężenie sodu występuje w odpływach z oczyszczalni ścieków średnio 84,19 i 96,64 mg Na · dm^{-3}, na odpływie ze zlewni rolniczych średnio od 7,54 mg Na · dm^{-3} do 11,55 mg Na · dm^{-3}, najmniejsze zaś ze zlewni leśnych 3,77 i 4,52 mg Na · dm^{-3}. Na odpływie ze zbiornika retencyjnego stężenie sodu wynosiło 7,87 mg Na · dm^{-3}, natomiast z rowu opaskowego 8,90 mg Na · dm^{-3}. Całkowite stężenie sodu w wodzie odpływającej ze zlewni do Jeziora Wulpińskiego wynosiło 8,09 mg Na · dm^{-3}. Do jeziora spływało rocznie 4706 kg sodu, co dało spływ jednostkowy 3,4 kg Na z 1 ha zlewni. Zbiornik retencyjny w znacznym stopniu zmniejszał ilość sodu odpływającego ze zlewni do jeziora. Główna jego rola polegała na uśrednianiu stężeń. Redukcja ładunku sodu wynosiła ok. 50 %

Słowa kluczowe: redukcja ładunku, sód, ciek, staw