The effect of Uchinsk reservoir coastal landscape components on the migration of pollutant elements

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Abstract. Landscape components were studied on the territory of the Volga water management system by the method of landscape-geochemical profiling. The content of chemical elements in the landscape components was determined, sources of pollution were identified, and the pathways of migration of elements were studied. The studies of the ecological state of the coastal zone of the Uchinsk reservoir were carried out in summer of 2020. Plant communities were studied, and soil sections were described. It was established that forest biogeocenoses of the water protection zone of the reservoir do not have noticeable anthropogenic disturbances, there are windblow areas, lesions by the bark beetle-typographer characteristic of Moscow region. Due to the grass and shrub cover in forest biocenoses, subsurface runoff predominates, forest soils serve as an effective barrier that retards the migration of heavy metals. When analyzing the distribution of chemical elements in the soil profile and bottom sediments, their different origin was revealed; for example, phosphorus and potassium enter with waters of the Volga spring, heavy metals enter with the soil runoff, while the accumulation of manganese increases with an increase in soil acidity.

1. Introduction

The Uchinsk reservoir of the Moscow Canal is a source of water supply for Moscow, and the quality of water supplied depends on the state of its water area and adjacent catchment areas [1, 2, 3]. Various pollutants can enter with surface runoff from the areas adjacent to the reservoir and as a result of migration of pollutants entering the catchment area with the transfer of air masses. Pollutants can enter from the Volga spring, the runoff of small rivers flowing into the reservoir [4, 5].

The water protection zone of the Uchinsk reservoir belongs to specially protected areas; there are no industrial and agricultural activities in this area; the only local source of anthropogenic impact is low-rise residential buildings in the water protection zone and the recreational use of the territory adjacent to the reservoir. Thus, pollutants can enter with waters of the Volga source, surface runoff, primarily coming with the transfer of air masses from distant sources, and as a result of the recreational use of the territory adjacent to the reservoir.

In order to reveal the possible influence of biogeocenoses of the water protection zones on the migration path and the distribution of chemical elements, topoeological studies were carried out in the water protection zone. Three typical biocenoses of the water protection zone were identified: meadows, mixed birch-aspen forests, and spruce forests; within typical plots, topoeological profiles were established for geobotanical descriptions description of soil sections and subsequent chemical
an analysis of soil samples. To assess the migration paths of chemical elements, samples of bottom sediments were taken in the water area adjacent to the topocological profiles, and the chemical analysis of moss - Schreber's pleurosis, which is used as an indicator of pollution input with the transfer of air masses, was carried out.

An important role in reducing soil and environmental pollution belongs to geochemical barriers (3, 4), where there is a sharp change in the intensity of migration of chemical elements and their accumulation. Various geochemical barriers with a thickness of several millimeters and centimeters are formed in soils, although the thickness of the soil is calculated in centimeters and meters. The acidic or slightly acidic conditions of the soil environment in the humus horizon are replaced by neutral or alkaline conditions in the illuvial horizon. An increase in the pH values is associated with acidic leaching of cations from the upper horizon and their partial accumulation in the lower one. This means that the presence of an acidic environment in the upper soil layer causes the appearance of an alkaline one in the lower one. Cations concentrated in the lower soil layers take part in the formation of the alkaline medium. For example, as a result of biogenic accumulation, the upper soil horizons of the landscapes of forest catenas are enriched in organic matter, nitrogen, calcium, phosphorus, sulfur, and often zinc, copper, nickel, cobalt, and tin. Silicon accumulates in the eluvial horizon and iron and aluminum are removed in the form of chelates. At the border of horizons A2 and B, there are several barriers: alkaline, sorption and even oxygen, where iron, aluminum, manganese, copper, vanadium, nickel, zinc, cobalt are deposited. Iron and manganese accumulate in the B1 and B2 horizons of sod-podzolic soils.

In the subordinate landscapes of hydromorphic catenas, plants receive nutrients from the atmosphere and with the solid and liquid runoff from the eluvial landscapes located above. In acidic taiga landscapes, leaching and removal of mobile elements from soils occur; they partially accumulate on gley and sorption geochemical barriers of subordinate landscapes (floodplains, terraces, depressions, marginal zones of bogs). The components of their landscapes are enriched with calcium, phosphorus, potassium, iron, manganese, cobalt, boron, etc., which contributes to the quality of products. Mobile calcium compounds cause an alkaline (pH up to 8 in the upper soil horizon) reaction of the medium and saturation of the absorbed complex with calcium and magnesium. A characteristic element of these landscapes is iron, which plants accumulate and it actively migrates in waters and soils, concentrating in their upper horizons on the oxygen barrier. Oxidizing and alkaline conditions promote the precipitation of iron, and acidic and reducing conditions contribute to the dissolution of its compounds. In comparison with sandy and sandy loam soils, loamy soil-forming rocks sorb chemical elements from waters more efficiently.

Changes in the redox conditions also contribute to the formation of geochemical barriers. In water bodies, flooded soils and bottom sediments that accumulate elements serve as geochemical adsorption barriers. Under the influence of flooding, significant changes in the chemical and physicochemical properties of soils occur. The reaction of water and salt extracts of soddy-podzolic soils flooded by the reservoir shifts towards more the neutral one in comparison with similar soils of the reservoir bank. There is a decrease in hydrolytic acidity in flooded soils, an increase in the amount of absorbed bases and saturation in horizon A to 62 - 82%. A decrease in the content (up to 0.40 - 0.32 mg per 100 g of soil) of exchangeable aluminum compared to that (2.47 mg per 100 g of soil) in coastal soils was revealed. An increase was found during flooding of mobile forms of phosphorus, potassium, ammonium nitrogen with a decrease in the humus reserves in the upper soil horizons due to its biogeochemical consumption under the anaerobic conditions. In the gley medium, the transition of ferric iron to the bivalent one is activated. There is a tendency to increase the amount (up to 209 mg FeO per 100 g of soil) of ferrous iron in the upper soil horizons.

2. Materials and methods

Studies of the biocenoses were carried out by the method of landscape-geochemical profiling, when the profiles were laid in the direction of the flow of substances – from the autonomous positions to the subordinate ones and were accompanied by sampling of landscape components [1, 4].
topoecological profiles were laid from the water edge to 100 m. The choice of location of the profile was determined by the most typical vegetation. Test plots were located at a distance of 0–5, 15–25, 75–100 m from the water's edge. Geobotanical descriptions and descriptions of soil sections were made at the sites; average samples were taken along the soil horizons for the subsequent chemical analysis. For a comparative analysis of the chemical composition and identification of the migration paths of chemical elements, samples of bottom sediments were taken in the water area of the reservoir opposite the topoecological profiles; samples of Schreber's pleurosis moss were taken as an indicator capable of accumulating heavy metals entering with air masses [1]. The chemical analysis of samples was carried out in the laboratory of the Faculty of Geography, Moscow State University using generally accepted methods. To take samples of bottom sediments in the water area, the SOI (State Oceanographic Institute) tube was used.

3. Results and Discussion

When examining the coastal territory of the Uchinsk reservoir, three profiles were laid. The herbage of the first profile is dominated by awnless rump (aristata caudam), wheatgrass with an admixture of meadow geranium (meadow geranium wheatgrass admixtis), meadow cornflower (cornflower locis palustribus). St. John's wort (hypericum perforatum). The second profile was laid in a mixed birch-aspen-spruce forest with an insignificant admixture of pine and pedunculate oak on the sod-podzolic medium loamy soil. The first layer of the stand is represented by birch and aspen, having a height of 15-20 meters and a trunk diameter of 15-35 cm. The second layer consists of birch and aspen, with a slight admixture of spruce; the height of the trees is 3-12 meters and the trunk diameter is 5-10 cm. The undergrowth is also represented by birch and aspen with an admixture of spruce with a height of 0.5-2.5 m.

In the herbage, awnless rump prevails, there are several species of sedges, willowweed and dioecious nettle. The third profile was laid in the sorrel spruce forest. It was revealed that willow stands with a width of 3–5 m predominate directly at the water's edge on the third profile, and reed thickets prevail in shallow water. Spruce forests develop along the willows with a gradual increase in relief, represented by several associations with a predominance of sorrel spruce forest with local areas of raspberry spruce. The soils along the entire length of the profile are podzolic, medium and heavily loamy. The first layer of the stand consists of Norway spruce with a height of 30–35 m and a trunk diameter of 40–100 cm. The second layer of the stand also consists of spruce. The height of the three-layer trees is 15–25 m, the trunk diameter is 15–30 cm. The undergrowth is poorly developed and represented mainly by mountain ash, 0.50–2.50 m high. Warty euonymus and forest honeysuckle are occasionally found. The male thyroid has a height of 40–50 cm. Of rare plants, there is spring combo, confined to the edges and windows in the stand.

There are also Kashubian buttercup, yellow zelenchuk, hoof and other species. Mainly aspen and spruce are renewed. The soil surface is covered with dry leaves and needles. There is no wetting of the soil surface. Mosses (Schreber's pleurosis) are found only at the base of tree trunks and on dead wood. On the test plots, soil sections were made, which revealed the presence of soddy-podzolic soils on the profile with meadow vegetation and the profile laid in a mixed birch-aspen forest; typical podzolic soils were determined on the third profile laid in a spruce forest. A chemical analysis of soil samples was carried out along the horizons for all three profiles from the water's edge to a distance of 75-100 meters. Data on the chemical composition of soil samples, bottom sediments and moss (Schreber's pleurosis) taken on the third profile are presented in Table 1.

Table 1 demonstrates the dependence of distribution of chemical elements on the type of biogeocenosis characteristic of each of the profiles and the distance from the water's edge within the profile. The acidity index pH in soil samples depends on the type of biogeocenosis and a soil horizon, which is due to the patterns of migration of elements and biogeochemical processes in the soil. The type of a plant community and species composition have the greatest influence on the pH value. The most acidic soils (pH = 5.4–5.84) are characteristic of the sorrel spruce forest, close to neutral soils are present on the profile with meadow vegetation.
Table 1. Chemical composition of soil samples, bottom sediments, moss by topoecological profiles

| Distance to the water's edge, m | Soil horizon | pH   | Element content, mg / kg air dry mass |
|---------------------------------|--------------|------|---------------------------------------|
|                                 |              |      | P<sub>2</sub>O<sub>5</sub> | K<sub>2</sub>O | Cd | Pb | Zn | Mn |
| topoecological profile 1        | A1           | 7,2+0,1 | 102±0,05 | 107±0,05 | 0,29+0,2 | 38,7+0,2 | 6,5+0,2 | 6,6+0,2 |
| 0–5                             | A1           | 7,3+0,05 | 18,1+0,05 | 60±0,05 | 0,23+0,2 | 48,7+0,2 | 18,1+0,2 | 311+0,2 |
| 15–25                           | A2           | 7,1+0,1 | 15+0,05  | 45±0,05 | 0,25+0,2 | 13,3+0,2 | 14+0,2  | – |
| 15–25                           | B1           | 7,0+0,1 | 15+0,05  | 47±0,05 | 0,29+0,2 | 19,6+0,2 | 17+0,2  | – |
| 75–100                          | A1           | 7,3+0,1 | 19+0,05  | 62±0,05 | 0,24+0,2 | 36,6+0,2 | 19,7+0,2 | 357+0,2 |
| topoecological profile 2        | A1           | 6,4+0,1 | 103±0,05 | 101±0,05 | 0,26+0,2 | 17,8+0,2 | 7,8+0,2 | 350+0,2 |
| 0–5                             | A1           | 6,1+0,1 | 12±0,05  | 64±0,05 | 0,24+0,2 | 19,2+0,2 | 12,7+0,2 | 347+0,2 |
| 15–25                           | A1           | 6,2+0,1 | 17±0,05  | 60±0,05 | 0,25+0,2 | 19,9+0,2 | 14,6+0,2 | 638+0,2 |
| topoecological profile 3        | A1           | 5,5+0,1 | 99±0,05  | 108±0,05 | 0,22+0,2 | 38,7+0,2 | 18,1+0,2 | 381+0,2 |
| 0–5                             | A1           | 5,5+0,1 | 17±0,05  | 58±0,05 | 0,25+0,2 | 48,7+0,2 | 15,3+0,2 | 300+0,2 |
| 15–25                           | A1           | 5,4+0,1 | 15±0,05  | 57±0,05 | 0,25+0,2 | 20,1+0,2 | 21,3+0,2 | 350+0,2 |
| Bottom sediments                | A1           | 5,5+0,1 | 15±0,05  | 57±0,05 | 0,25+0,2 | 20,1+0,2 | 21,3+0,2 | 350+0,2 |
| Schreber's pleurosis            | A1           | 5,5+0,1 | 15±0,05  | 57±0,05 | 0,25+0,2 | 20,1+0,2 | 21,3+0,2 | 350+0,2 |
| 15–25                           | -            | -      | -       | -      | 0,08±0,02 | 2,9+0,2  | 3,5+0,2 | 32+0,2 |

Note: dash means no data.

In the mixed birch-aspen forest (the second profile), the soils are slightly acidic (pH = 6.1–6.4). On the meadow profile, the reaction is neutral (7.0–7.3), which is typical of soddy podzolic soil. For all three topoecological profiles, regardless of the soil process and soil acidity, the maximum content of P2O<sub>5</sub>, K2O is observed in the soil at the water's edge in the zone of development of coastal aquatic vegetation, characterized by periodic flooding with fluctuations in the reservoir level and constant high moisture content. The content of phosphates in bottom sediments is 15–20% less than in the soil at the water's edge, while in soils that are not constantly affected by reservoir water, at a distance of 15 or more meters from the water's edge, the content of phosphorus compounds is 5-7 times lower.

Similar data are also typical for potassium compounds - maximum concentrations are observed in the zone of constant flooding of the reservoir with water; along the profile, the content of potassium salts decreases by 40-50% and remains constant throughout the profiles, the content of salts potassium in bottom sediments is 4-5 times less than in soils at the water's edge. The nature of distribution of phosphorus and potassium salts along all three profiles, characterized by different types of vegetation and different soil processes, is practically the same, which allows us to assume the supply of these elements from the sources located upstream of the reservoir. At the water's edge, in the zone of willow and coastal vegetation, there is a geochemical barrier that assimilates these elements [6,7], partially phosphorus and potassium compounds are assimilated by aquatic and coastal aquatic vegetation; when they die off, they accumulate in bottom sediments.

Comparison of the content of heavy metals in soils of topoecological profiles and their content in Schreber's pleurosis shows that the content of cadmium is 2 or more times higher than its content in
the soil samples, the content of zinc is 2–4 times higher. Since Schreber's pleurosum receives mineral nutrition mainly with precipitation, it can be assumed that the main source of zinc and cadmium is air masses [8, 9].

The content of cadmium remains constant in the soil samples for all profiles, while its content in bottom sediments is three times lower than in the soil samples; this indicates the weak binding of cadmium by soils of all types, its constant migration into water of the reservoir; there is no accumulation of cadmium in bottom sediments. A similar behavior is typical of zinc. Lead and manganese in Schreber's pleurosis are found in concentrations less than or equal to those found in the soil profile in all types of biocenoses, while the distribution of lead and manganese in the soil in all topoecological profiles is almost uniform and does not depend on the types of soil and biocenosis, which suggests that their source is local soils, while these chemical elements are tightly bound by geochemical barriers and do not migrate with the soil runoff.

Vegetation plays an important role in the retention of elements and suspended matter in spring waters and runoffs. The relationship between plants and soils determines the biological cycle. It includes two opposite processes: production and destruction. The production process is the basis for the plant communities and an important driving force in the development of biogeocenoses. This process is important for the circulation of chemical elements in the biosphere, the dynamics of CO2 and for managing the production process in agrocenoses (130-162 days). Agricultural landscapes are characterized by annual alienation with a harvest of a certain amount of elements of mineral nutrition of plants. Alienation of substances in meadow landscapes occurs as a result of hay-making, cattle grazing and varies significantly depending on the height of the grass stand. Plants react differently to soil fertility and supply of nutrients. The reserves of ash elements in the aboveground biomass of cultivated plants are 1.1–5.0 times less than in meadows, which is due to a decrease in the mass of roots of cultivated plants compared to that of meadows.

The analysis of the ash from the cuttings of plants indicates a change during the growing season in the content of elements in the range from 26, 23 (anthropogenic landscapes) to 243.47 (meadow) kg / ha. The maximum concentrations of silicon (up to 77.00 kg / ha), sulfur (up to 10.90 kg / ha), manganese (up to 0.53), sodium (up to 4.16) were found in the grass stands of meadow landscapes, and calcium (up to 63.62 kg / ha), magnesium (up to 10.10), iron (up to 1.01) – in the anthropogenic landscapes. It is necessary to pay attention to the autumn accumulation of silicon and other elements in plants of natural meadow and cultivated landscapes with a simultaneous decrease in the concentration of potassium due to its outflow into the roots. The maximum of phosphorus and potassium was revealed in the mowing of fescue with timothy grass. Clover accumulates a lot (up to 60 kg / ha) potassium in autumn. Magnesium is consumed by plants throughout the growing season until the aging phase. It should be noted that plants serve as biogeochemical barriers in the retention of elements and suspensions from spring waters and effluents. The maximum of elements was revealed in autumn.

4. Conclusion
Different origins of chemical elements entering the soil, vegetation, water, bottom sediments of the reservoir were revealed. The biogenic elements, phosphorus and potassium enter with the water of the Volga spring, local runoff of small rivers and are actively bound by soils in the zone of coastal and aquatic vegetation. To a lesser extent, the accumulation of phosphorus and potassium compounds is expressed in bottom sediments formed during the dying off of aquatic vegetation and phytoplankton. With fluctuations in the hydrological regime of the reservoir, there is a likelihood of leaching out of the elements accumulated during the dying off of aquatic vegetation and in soils in the immediate vicinity of the water's edge. The regular removal of coastal and aquatic vegetation can reduce the accumulation of nutrients. The study of distribution of heavy metals over the soil profiles with different types of vegetation did not reveal obvious differences in their content depending on the types of soil, soil acidity and various plant communities. Metals such as manganese and lead are almost evenly distributed over all the profiles; a comparison of their content in the soil and Schreber's
pleurosis did not reveal their possible input from external sources. On the contrary, the content of zinc and cadmium in Schreber's pleurosis is 2-4 times higher than in the soils of all three profiles, with their minimum content in bottom sediments. This suggests a constant supply of zinc and cadmium with the transfer of air masses and the absence of both geochemical barriers capable of binding these elements in soils, and the absence of their binding by aquatic vegetation and phytoplankton. In the absence of damage to the vegetation cover, there is no surface runoff, and all heavy metals enter the soil profile and either bind by the soil profile like lead and manganese, or migrate into the reservoir with the subsurface runoff. A possible advantage of forest biocenoses is the ability to reduce wind speed in the surface layer and a large absorption surface, which makes it possible to recommend using forests as biochemical barriers.

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