Method for Reducing Total Iron Concentration in Rivers of Leningrad Region Using Bank Protection by Gabion with a Special Filler

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Abstract. The authors of the article studied the rivers and lakes of the Leningrad region of the North-West region of the Russian Federation for the total iron content and analyzed the results obtained. This chemical indicator is being investigated due to the fact that it can have an adverse effect on the environment and human health. The main goal of the work was to analyze the most polluted water bodies of the Leningrad region in terms of excess of the maximum permissible concentration (MPC) for total iron and to develop a way to reduce its concentration. A colorimetric analysis method was used to obtain the data. Exceeding the maximum permissible concentration for total iron was found in more than 80% of samples. A detailed analysis of the three most polluted water bodies was carried out. The results obtained showed that the water bodies of the Leningrad region are heavily contaminated with common iron. In this regard, it is required to develop special measures to reduce its concentration. The authors suggest the use of gabion structure with a special filler for bank stabilization and reduction of the concentration of total iron to the most polluted rivers of the Leningrad region.

1. Introduction
Pollutants entering surface waters pose a constant threat to the environmental situation and require constant monitoring. With the help of hydrochemistry, which studies the processes of formation of natural waters and their chemical composition in continuous change in time and space and in connection with physical and biological processes occurring in the environment as a result of the action of natural factors and human activities. Therefore, the analysis of water by hydrochemical indicators is an important component of environmental research [1, 2].

Most of the water bodies of the Leningrad Region have a high iron content associated with the swamp feeding of rivers and lakes. Thus, it is necessary to carry out constant monitoring to control the quality of water [3].

Iron is one of the most abundant elements in the earth's crust, which makes it permanently present in natural waters. The most common natural minerals of iron are magnetite (magnetic iron ore Fe₃O₄, hematite (red iron ore) Fe₂O₃, pyrite (iron pyrite) FeS₂). The term “total iron” is used to denote the total concentration of all dissolved forms of iron in water.

As a result of hydrolysis, Fe (III) ions at pH> 3 are converted into hydrated insoluble iron oxides, which make up a significant fraction of the total iron content in waters. The presence of humic and fulvic acids in the waters, due to the formation of rather strong complexes, prevents the hydrolysis of Fe (III) to one degree or another and contributes to its maintenance in a dissolved state. For this
reason, the content of dissolved iron in humified waters is, as a rule, higher than in waters where there are few humic substances.

For Fe (II), the ionic form is more characteristic, however Fe (II) can exist only at low values of the redox potential (with oxygen deficiency) and low pH values. The reduction of Fe (III) to Fe (II) is facilitated by the presence of humic, tannin and fulvic acids.

The main natural source of iron input into surface waters is the processes of chemical weathering of rocks, accompanied by their dissolution. A significant part of iron also comes from underground runoff.

The composition and forms of occurrence of iron compounds in waters are significantly influenced by such factors as pH and Eh, the presence of natural complexing agents.

The concentration of total iron in most cases ranges from 0.01 to 1.0 mg / dm$^3$ in river and lake waters. The total iron content in surface waters is standardized. The maximum permissible concentration of dissolved iron in the water of water bodies for fishery purposes is 0.1 mg / dm$^3$. In water bodies for drinking and cultural purposes, the gross iron content is normalized, for them the MPC is 0.3 mg / dm$^3$. The required daily rate of iron concentration for humans is in the range of 10–20 mg / dm$^3$ [4].

2. Methods

Water sampling includes several stages:

1. Before direct sampling, the used container is washed 3 times with water from the investigated water body.

2. On the surface of a water body from the shore or from a boat, immerse a container under water, collecting a sample (using the glass holder or the container itself).

3. When sampling from a depth, a special sampling equipment is used - a bathometer. From a boat or other watercraft (floating structure), the bottle is lowered (in the open state) to the required depth, after which the bottle is closed and lifted onto the watercraft, where the sample is placed in a container.

The volume of the sample taken depends on the parameters determined in the future and their quantity, but not less than 0.5 liters.

4. Preparation for storage includes:
   - filtration (centrifugation);
   - conservation;
   - cooling (freezing).

To determine the iron content, a colorimetric method of analysis is used, which is based on the selective absorption of electromagnetic radiation from different parts of the spectrum by a homogeneous system [5]. The main characteristic of electromagnetic radiation is the wavelength $\lambda$. Electromagnetic radiation of various wavelengths constitutes the electromagnetic spectrum.

The method was called colorimetry, since the analysis was originally based on assessing the color intensity of a solution of various concentrations of a given substance. The colored solution absorbs continuous radiation of the nonchromatic visible region of the spectrum; therefore, colorimetry based on the study of the color intensity of the solution is a special case of spectrophotometric analysis.

The spectrophotometer is designed to measure the transmittance and optical density of solid and liquid samples of various origins.

The method for the determination of iron is based on the interaction in a strongly acidic medium of oxidized iron (III) and thiocyanate ions with the formation of a red-colored complex compound of rhodane iron according to the chemical equation (1):

$$Fe^{3+} + 3CN^- = Fe(CN)_3$$

The color intensity is proportional to the iron concentration. The sensitivity of the method is 0.05 mg / dm$^3$ Fe. The range of measured concentrations is 0.05–4.0 mg / dm$^3$. 
To determine the concentration of the analyte in the samples taken, standard solutions are prepared with an accurately known concentration. On the basis of these solutions, a calibration graph of the ratio of optical density to concentration is constructed (Fig. 1).

![Calibration graph of the dependence of iron concentration on optical density.](image)

Figure 1. Calibration graph of the dependence of iron concentration on optical density.

The optical density is measured on a LEKISS1207 device, a blue-green light filter (wavelength: 490 nm) is used in cuvettes with an optical layer thickness of 3 cm, in relation to distilled water. The optical density of the blank sample Dx is determined each time before a series of experiments.

Due to the simplicity of the experiment, rapidity, and sensitivity, the colorimetric method is widely used in the practice of chemical laboratories.

Initially, the analysis was based on assessing the color intensity of a solution of various concentrations of a given substance. The colored solution absorbs continuous radiation of the nonchromatic visible region of the spectrum; therefore, colorimetry based on the study of the color intensity of the solution is a special case of spectrophotometric analysis.

This dependence can be expressed through the Bouguer-Lambert-Beer law: solutions of the same colored substance with the same concentration of this substance and the thickness of the solution layer always absorb an equal amount of light energy, that is the light absorption of such solutions is the same.

The Bouguer-Lambert-Beer law can be expressed by the mathematical equation (2):

$$I_i = I_0 \times 10^{-Ecl}$$  \hspace{1cm} (2)

where $I_i$ is the intensity of the light flux passing through the solution;
$I_0$ is the intensity of the incoming light beam;
$E$ is the light absorption coefficient;
$c$ is the molar concentration of the colored substance;
$l$ is the thickness of the substance layer through which the light passes.

In fig. 2 shows a scheme of the Bouguer-Lambert-Beer law:
Any spectrophotometric determination consists mainly of two stages:
1. Carrying out a photometric reaction.
2. Measurement of the absorption of the prepared solution.

3. Results and discussion
The analysis of the results of the investigated concentrations of iron in water bodies, taking into account the excess of the MPC for water bodies for fishery purposes, was carried out.

Table 1 shows the results of the analysis of water bodies of the Leningrad region for total iron.

| Sample No. | Sampling location                          | Concentration range, mg / dm³ | The multiplicity of exceeding the MPC |
|------------|--------------------------------------------|------------------------------|--------------------------------------|
| 0, 1/1, 1  | lake Bludechko                            | <0,02                        | 0                                    |
| 3/1, 4     | Lake Serebryanoe                          | <0,02                        | 0                                    |
| 5, 5/1, 6, 6/1 6/1' | Lake Pridorozhnoe                  | <0,02-0,02                   | 0                                    |
| 7, 9       | Lake Gladyshevskoe                        | 0,25-0,34                    | 2,5-3,4                              |
| 10         | Roshinka river                            | 0,83                         | 8,3                                  |
| 11, 11', 12, 12' ,13, 13/1, 13 c,14, 14/1 | Black river (DOL "Okean")  | 0,55-1,56                    | 5-15                                 |
| 17, 17', 18,19 | Privetnaya river                  | 0,89-1,24                    | 9-12                                 |
| 20         | Gulf of Finland, "Vostok-6"              | 1,39                         | 14                                   |
| 24, 25,26  | Smolyachkov stream                        | 1,9-2,14                     | 19-21                                |
| 29, 30, 33', 33/1, 35, 37, 38, 38', 39 | Lake Upper Suzdalskoe, Lake Srednee Suzdalskoe, Lake Lower Suzdalskoe | <0,02-0,17                  | 0-2                                  |
| 42         | Kamenka river (source at the bridge)      | 0,19                         | 2                                    |
| 44, 45, 45/1 | Starozhilovka river                | 0,89-3,68                    | 9-37                                 |
| 46         | Sestrorets reservoir                      | 1,55                         | 15,5                                 |
| 47, 47/1, 61, 62, 63, 64/1, 66 , 67 | Malaya Sestra river                | <0,02-3,39                   | 0-34                                 |
| 70, 70/1   | Rzhavaya ditch                            | 3,13-6,31                    | 31-63                                |
| 91, 92, 93, 94, 94', 95 | lake Shchuchye              | 0,31-0,53                    | 3-5                                  |

The table shows that the cleanest water bodies are Golubye Lakes (Blyudechko, Serebryanoye and Pridorozhnaya lakes), and the most polluted are water bodies near the Sestrorets city spill (Malaya Sestra river, Rzhavaya Kanava stream, Gulf of Finland) (Fig. 3).
Figure 3. Schematic map of water bodies near the Sestroretsk spill (Malaya Sestra river, Rzhavaya ditch stream, Gulf of Finland).

In fig. 4 shows a diagram of iron concentrations exceeding the MPC at various sampling points in the Sestroretsk spill.
Figure 4. Total iron concentrations exceeding the MPC at various sampling points in water bodies of the Sestroretsk spill.

Points with an excess of maximum permissible concentration by 63 times were found in this water body. The maximum excess of MPC was noted at point 70/1. The reasons for exceeding the maximum permissible concentration at point 70/1 are swamp feeding and the nearby combined heat and power plant (CHP).

Figures 5 and 6 show schematic maps with sampling points of such water bodies as the river. Black and Smolyachkov brook in the Kurortny district of St. Petersburg. At some points, a significant excess of the MPC for total iron was noted, which requires special attention, since both water bodies are located near children's health camps (DOL), parks of sanatoriums and rest homes (Chernaya river: DOL «Okean», DOL «Mayak», DOL «Druzhnykh», DOL «Molodezhnoe»; Smolyachkov stream: DOL «Iskatel'», park of the sanatorium «Chernaya Rechka», park of the rest house «Teatral'nyj»).

Figure 5. Schematic map of the Chernaya river (Kurortny district of St. Petersburg, settlement Serovo, settlement Molodezhnoe).
Figure 6. Schematic map of Smolyachkov stream (Kurortny district of St. Petersburg, settlement Smolyachkovo).

A diagram of iron concentrations in the Chernaya river and Smolyachkov stream was constructed by combining the results of analyzes for two water bodies (Fig. 7).

Figure 7. Total iron concentrations exceeding the MPC in the Chernaya River and Smolyachkov stream.

From the diagram shown in Figure 7, it follows that the maximum concentration of iron is observed in sample 13/1 pr.br., which exceeds the established MPC by 15 times. And the minimum concentration is observed in sample 11', which is 5 times higher than the established MPC.

Figure 8 shows the number of samples divided by the multiplicity of excess of the MPC for total iron.
**Figure 8.** The number of samples, divided by the multiplicity of excess of the MPC for total iron.

Figure 4 shows that the number of samples in which the total iron concentration does not exceed the MPC is very small, and an excess of 1-5 and 10-32 times is observed in 20 and 19 samples, respectively.

Thus, the above data indicate a strong iron contamination of the total water bodies of the Leningrad region, which requires the development of special measures to improve their ecological state [6-8].

Considering that rivers are the most polluted, we propose an environmental protection measure that will perform two functions:
1. Strengthen river beds (bank protection).
2. Reduce the concentration of total iron and other heavy metal ions in rivers.

This event consists in strengthening the river channels with gabion structures of a special composition.

Figure 9 (zone "A") shows a typical gabion bank protection structure [9].

**Figure 9.** a) Bank protection using gabion structures; b) Scheme of hexagonal mesh cells: 1 - edge wire; 2 - main wire; B - cell size; B1 - the size of the cell diagonal.
Gabion is a prefabricated double-twisted metal mesh container. The cell parameters of a twisted wire mesh with hexagonal cells for gabion structures are in the range: 60 - 100 mm (B) and 80 - 120 mm (B1) (Fig. 9, zone "B") [9].

Gabions are filled with various stone fillers during construction and installation work [10]. Stone materials such as pebbles, stone, near, cobblestone can be used as filler.

Gabions are used for: strengthening slopes and slopes, retaining walls, bank protection; protection against soil erosion and soil stabilization; reinforcement; protection from rockfalls, avalanches, mudflows; protection of underwater pipelines, etc.

Gabions can be of various shapes and compositions of fillers, depending on the specific task of application. Therefore, the lower part of the section (Fig. 9, zone "A"), which is in direct contact with water, is proposed to be filled with a coarse material that has a sorption capacity for heavy metal ions, including iron ions [11-13]. Such materials can be investigated at the Department of Engineering Chemistry and Natural Science of Emperor Alexander I St. Petersburg State Transport University (PGUPS) [14-20]: crushed construction waste in the form of heavy concrete, foam concrete and silicate bricks, phosphogypsum, cement clinker, granulated blast furnace slag, phosphogypsum, shungite-containing crushed stone, etc. [21-22].

The following basic requirements must be met for the selected material:
- the size of the filler (must be larger than the mesh size of the gabion mesh (Fig. 10));
- sufficient strength and mechanical characteristics (to maintain the standard service life of the gabion structure);
- environmental safety (the composition of the material should not harm the water body (flora and fauna), not wash out hazardous chemicals into the water).

4. Conclusion
The following conclusions were made based on the results obtained.

1. 65 water samples were taken for hydrochemical analysis. An excess of the maximum permissible concentration for total iron (0.1 mg/dm³) was found in 53 samples.
2. The cleanest water bodies are the Blue Lakes (Lakes Blyudechko, Serebryanoe and Pridorozhnoe), and the most polluted is the Sestroretsk spill.
3. The maximum excess of the MPC was noted in the Sestroretsk spill at a point located near the heat and power plant.
4. An excess of MPC by 10-32 times is observed in 19 samples, which indicates a strong total iron contamination of water bodies in the Leningrad region.
5. It is proposed to use a gabion structure with a special filler for bank protection and reduction of the total iron concentration as an environmental protection measure for the most polluted rivers of the Leningrad region.

5. References
[1] Korableva A I, Fedotov D O 2016 Gidrohimicheskij analiz i srovnitel'naya ocenka koncentracij zheleza obshchego v otdel'nyh vodnyh ob"ektah Leningradskoj oblasti i Sankt-Peterburga XXI Mezhdunarodnyj i Mezhregional'nyj Bios-forum i XXI Molodezhnaya Bios-olimpiada Sbornik materialov pp 153-157
[2] Stroganova M S, Kushnerov A I, Fedotov D O 2016 Kompleksnaya ocenka sostoyaniya vodnyh ob"ektov po integral'nym pokazatelyam i indeksam Sbornik nauchnyh trudov molodyh uchenyh, studentov i prepodavatelei VII molodezhnogo ekologicheskogo kongressa «Severnaya pal'mira» pp 183-187
[3] Doklad «Ob ekologicheskoj situatsii v Leningradskoj oblasti v 2017 godu» podgotovlen v sootvetstvii s Federal'nym zakonom ot 10 yanvarya 2002 goda № 7-FZ «Ob ohrane okruzhayushchej sredy» i vo ispolnenie punkta 18 perechnya poruchenij Prezidenta Rossijskoj Federacii ot 6 dekabrya 2010 goda № Pr-3534 123
Baidarashvili M, Sakharova A, Petriaev A 2017 The Modern Structure for Storm Sewage Purification of Roads Procedia Engineering 189 pp 576–581 DOI: 10.1016/j.proeng.2017.05.091

Sakharova A, Baidarashvili M, Petriaev A 2017 Transportation Structures and Constructions with Geocoprotective Properties Procedia Engineering 189 pp 569–575 DOI: 10.1016/j.proeng.2017.05.090

Sakharova A S, Petriaev A V, Kozlov I S 2019 New Construction Solutions for Geoenvironment Protection of Transport Infrastructure IOP Conference Series: Earth and Environmental Science 272(2) 022220 DOI: 10.1088/1755-1315/272/2/022220

Shershneva M, Sakharova A, Kozlov I 2020 Geocoprotective screens for road construction and operation in cold regions Lecture Notes in Civil Engineering 50 pp 347-356

Shershneva M, Sakharova A, Anpilov D, Eremeev E 2020 Efficiency evaluation of the use of mineral technogenic substances in geocoprotective technologies of transport construction Lecture Notes in Civil Engineering 50 pp 357-367

Shershneva M, Kozlov I, Pankrateva G, Drobyshov I 2020 Geocoprotective building structures for transport construction using mineral technogenic silicates and their properties Lecture Notes in Civil Engineering 50 pp 319-327

Shershneva M, Puzanov Y, Sakharova A 2020 Geocoprotective technologies from heavy metal ions pollution for transport construction in permafrost regions Lecture Notes in Civil Engineering 50 pp 329-338

Rusanova E, Abu-Khasan M, Sakharova A 2019 The control waste of communal services IOP Conference Series: 2019 Earth and Environmental Science 272(2) 022109 DOI: 10.1088/1755-1315/272/2/022109

Abu-Khasan M, Solovyyova V, Solovyov D 2018 High-strength Concrete with new organic mineral complex admixture 2018-MATEC Web of Conferences 193 03019 DOI: 10.1051/matecconf/201819303019

Rusanova E, Abu-Khasan M, Egorov V 2020 The complex evaluation of geo eco-protective technologies taking into account the influence of negative temperatures IOP conference series: materials science and engineering p 022042 DOI: 10.1088/1757-899X/753/2/022042

Baydarashvili M, Sakharova A, Shrednik N 2020 Conservation of mineral resources in transport and civil construction Lecture Notes in Civil Engineering 50 pp 479–486 DOI: 10.1007/978-981-15-0454-9_50

Kazanskaya L, Privalov N, Privalova S 2019 Fine ground granulated blast furnace slag for saving quantity of binder E3S Web of Conferences 110 01055 DOI: 10.1051/e3sconf/201911001055

Abu-Khasan M, Egorov V 2020 The Influence of Different Types of Reinforcement on the Deformation Characteristics of Clay Soil in the Conditions of Seasonal Freezing and Thawing IOP conference series: materials science and engineering p 022041 DOI: 10.1088/1757-899X/753/4/042083

Egorov V, Kravchenko A, Abu-Khasan M 2020 The Application of Evolutional Algorithm Optimization of Sprengel Systems of Transport Buildings and Structures for Northern Districts. IOP conference series: materials science and engineering p 022020 DOI: 10.1088/1757-899X/753/2/022020

Egorov V, Abu-Khasan M, Shikova V 2020 The systems of reservation of bearing structures coatings of transport buildings and constructions for northern areas IOP conference series: materials science and engineering 022021 DOI: 10.1088/1757-899X/753/2/022021

Abu-Khasan M, Egorov V 2020 The Influence of Different Types of Reinforcement on the Deformation Characteristics of Clay Soil in the Conditions of Seasonal Freezing and Thawing IOP conference series: materials science and engineering 022021 DOI: 10.1088/1757-899X/753/4/042083
[20] Chernykh A K, Gorshkova E E, Dergachev A I, Abu-Khasan M S Use of Integrated Accounting Methods for Calculation of the Profile Volume of Embankments IOP Conference Series: Earth and Environmental Science DOI:10.1088/1755-1315/459/6/062008

[21] Vilkov V B, Dergachev A I, Chernykh A K, Abu-Khasan M S 2020 On the Concept of Solving a Fuzzy Cooperative Game with Side Payments 2020 International Multi-Conference on Industrial Engineering and Modern Technologies (FarEastCon) 9271558 DOI: 10.1109/FarEastCon50210.2020.9271558

[22] Dergachev A, Dergachev S, Perepechenov A, Abu-Khasan M 2019 Fundamentals of Algorithmization of Functional and Computational Problems 2019 International Multi-Conference on Industrial Engineering and Modern Technologies (FarEastCon) 8933942 DOI: 10.1109/FarEastCon.2019.8933942