Geomorphometric approach in geoecological assessment of groundwater in the territory of the Arkhangelsk region

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Abstract. It is shown that the Terrain Ruggedness Index, calculated on the digital elevation model, predetermines the chemical composition of groundwater. The high ruggedness of the relief, the small stratum of the overlying bedrocks of Quaternary deposits, the absence of water barriers contribute to the desalination of groundwater due to the penetration of ultra-fresh atmospheric precipitation. The low ruggedness of the relief also causes a low intensity of water exchange and, as a consequence, a higher mineralization of groundwater.

1. Introduction
The composition of ground waters reflects the history of the geological structure of the Earth, conditions of their relations with rock formations, organic substances, microorganisms and gases as well as a character and intensity of anthropogenic impact on the ground [1]. The relief has a great influence on a water exchange and the formation of surface runoff. In the publication [5] it is noted that high ruggedness of the relief contributes to the formation of numerous water spring systems. The geomorphological features of the catchment areas determine the length of filtration paths and the time of water exchange from recharge areas to discharge areas.

The geomorphometric approach makes it possible to take an objective remote geoecological assessment of the territory for determining a possible pollution of ground waters and changes of their natural chemical composition.

2. Materials and methods
Using the digital elevation model (DEM) of the Arkhangelsk region [6], built on the basis of the global digital elevation model ASTER GDEM v2, there was calculated a geomorphometric parameter – Terrain Ruggedness Index (TRI). This parameter “calculates the sum change in elevation between a grid cell and its eight neighbour cell and provides a rapid, objective measure of terrain heterogeneity” [11]. Cluster analysis of TRI and identified three clusters – minimal (1), average (2) and maximal (3) values was conducted.

Also DEM was subjected to a hydrological correction using the method of authors Wang and Liu [12], got a sink mask, calculated the density of closed sinks per unit area, made a cluster analysis with dividing the density into three clusters – minimal (1), average (2) and maximal (3) values. All operations were done in SAGA GIS software.
3. Results and discussion

The natural connection between a relief of a territory and a correlation of piezometric levels of ground waters and their composition was found by Silin-Bekchurin [10]. On the areas of elevations and watersheds the water head reduction in the water bearing stratum goes in the descending direction; here one can find fresh, calcium hydrocarbonate ground waters.

When the relief is concave, the hydrodynamic pressure in the formations increases from the upper horizons to the lower ones. In artesian basins of the platform type, in elevated areas of the relief, groundwater resources are replenished, and the lower areas are drainage (outflow) zones. On the valleys ascending water have a higher level of mineralization, sulphate hydrocarbonate and magnesium-calcium composition. In the large centers of an ascending water discharge there often form hydrochemical anomalies, i.e. under the river valleys one can see the formation “domes” of salt waters and salt brines of chloride sodium composition [1].

The Terrain Ruggedness Index indirectly determines the chemical composition of ground waters. The higher the inhomogeneity (ruggedness) of the relief and thinner the layer of quaternary deposits covering parent rocks, the bigger amount of fresh precipitation water will reach water bearing layers and by dilution and desalination of rocks gives a certain chemical composition of ground waters. At the same time relatively low relief ruggedness causes a low level of water exchange intensity and as a result almost 2 times higher mineralization of ground waters [4].

On the territory of the Arkhangelsk region the higher ruggedness is typical for elevations – the Belomor-Kuloy plateau (BKP), the Konosha-Nyandoma elevation, the Ustysansko plateau and the Dvina-Pinega intersream area. In territory BKP and its immediate surroundings are five major areas of groundwater of different qualities (Fig. 1): fresh standard (1), fresh substandard (2), brackish (3), salt (4) and mixed waters (5) [7].

![TRI, clusters](image)

**Figure 1.** Areas of groundwater of different qualities (area numbers are indicated in the text) and cluster values of Terrain Ruggedness Index (1 – minimal, 2 – average and 3 – maximal values).
The current activation of faults, the karst porosity of the area favour the formation of an effective zone of interrelation of ground waters and surface in the groundwater formation areas of fresh standard, fresh substandard (due to the high content of strontium in them) and brackish water. A thin layer (up to the full absence) of covering quaternary deposits opens water-bearing complexes of Carbone, upper and lower Permian, making them accessible for ultra fresh atmospheric precipitation. Due to the high ruggedness and conductivity of rocks the penetrating atmospheric precipitation dilutes insertions of gypsum and anhydrite in carbonate rocks that favours the change of hydrocarbonate magnesium-calcium chemical composition of ground waters to a sulphate calcium one [9].

The Vendian water bearing complexes (salt groundwater formation area), as well as mixed waters of quaternary deposits of river valleys are covered on the surface by a thick layer of quaternary formations and have a water barrier such as Mikulino clays. So, despite the high values of the Terrain Ruggedness Index they turn out to be protected from the diluting and desalting activity of atmospheric precipitation [9].

In the source [2] one can find a map of groundwater protection from pollution. It is pointed out that according to the degree of natural protection water bearing complexes on the most part of the territory (50%) are non-protected or nominally protected from the pollution. When making a proper assessment of ground water protection the following aspects were taken into account: thickness, lithological composition, filtration properties of rocks overlying the water bearing layer. The correlation of levels of the studied and the upper water bearing stratum, presence or absence of lithological, tectonic and geochemical barriers were also taken into account.

A map of the degree of ground water protection with cluster values of closed sink density (fig. 2) that are determined with the use of DEM was compared. A closed sink is a storage, i.e. in such areas there can happen an accumulation of precipitation waters including polluters and then their penetration into the lower water bearing layers.

![Figure 2. Degree of ground water protection from pollution according to [2] and cluster values of closed sink density: 1-3 – protection of water bearing complexes: 1 – well protected, 2 – nominally protected, 3 – non-protected; 4-6 – cluster values of basin density: 4 – minimal, 5 – medium, 6 – maximal.](image-url)
It is shown on the figure 2 that the territories with non-protected water bearing complexes spatially coincide with maximal values of closed sink density. This fact arises a great ecological concern, because the main sources of anthropogenic impact to the environment of the Arkhangelsk region are also located on these territories [8].

4. Conclusions
The geomorphometric approach (calculation of geomorphometric parameters with the use of DEM) can be an objective tool for the geocological assessment of ground water quality. The Terrain Ruggedness Index predetermines the chemical composition of ground waters. The high ruggedness of the relief, low thickness of quaternary deposits covering parent rocks, absence of water confining stratum favour the freshening of ground waters due to the penetration of ultrafresh atmospheric precipitation. The low ruggedness of the relief contributes to a low intensity of water exchange and as a result higher mineralization of ground waters. Geomorphometric parameters of the relief should be taken into account when planning and carrying out anthropogenic activities to avoid a development of unnecessary effects.

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References
[1] Galperin A M, Zaitsev V S, Haritonenko G N and Norvatov Ju A 2009 Geology: Part III – Hydrogeology: textbook for higher education instituteis [Moscow: Moscow State University] P 400
[2] Gubaidullin M G 2002 Geocological conditions of the mineral resource exploration in the northern European part of Russia [Arkhangelsk: Pomorsky University] P 310
[3] Dzhamalov R G, Zlobina V L, Mironenko M V and Ryzhenko B N 1996 Precipitation acidification influence on the chemical balance. Thermodynamic modelling Vodnye resursy 5 pp 556–64
[4] Zverev V P 2011 Underground hydrosphere Problems of fundamental hydrogeology (Moscow: Moscow State University) P 260
[5] Zlobina V L, Medovar Ju A and Jushmanov I O 2017 Groundwater characteristic and composition transformation caused by environmental changes (Moscow: Moscow State University) P 191
[6] Kutinov Ju G, Mineev A L, Poljakova E V and Chistova Z B 2019 Choice of the reference digital elevation model (DEM) of even territories of northern Eurasia and its preparation for geological division (on the example of the Arkhangelsk region) (Penza: Sotsiosfera) P 176
[7] Malov A I 2003 Groundwaters of the south-eastern part of the White sea area: formation, role in geological processes (Ekaterinburg: UrD of RAS) P 234
[8] Poljakova E V 2019 The use of geomorphometric parameters of the relief in the implementation of anthropogenic activities in the Arkhangelsk region Eurasian Union of Scientists 3-2 (60) pp 33–37 DOI: 10.31618/ESU.2413-9335.2019.2.60.33-37
[9] Poljakova E V, Kutinov Ju G, Mineev A L and Chistova Z B 2019 Underwater condition assessment on the South-Eastern part of the White sea area with the use of the digital elevation model (Sergeevskie chteniya) 21 pp 358–363
[10] Silin-Bekchurin A I 1958 Groundwater dynamics (Moscow: Moscow State University) P 258
[11] Reily Shawn J, DeGloria Stephen D and Elliot Robert A 1999 Terrain Ruggedness Index That Quantifies Topographic Heterogeneity Intermountain Journal of Science 5 (1-4) pp 23–27
[12] Wang L and Liu H 2006 An efficient method for identifying and filling surface depressions in digital elevation models for hydrologic analysis and modelling International Journal of Geographical Information Science 20 (2) pp 193–213 https://doi.org/10.1080/13658810500433453