Contemporary approaches to studying and mapping of active water exchange zone of ground water

C Ye Moraru

Institute of Geology and Seismology of Academy of Science, Kishinev, Moldova

E-mail: cmoraru@yahoo.com

Abstract. The article deals with a zone of ground water active exchange. New principles of the zone study and mapping under the platform hydrogeological condition are discussed. The assessment and distribution techniques are suggested for the active water exchange zone under the condition of hydrogeological parameterization uncertainty. The efficiency and significance of the suggested techniques are proved using the example of ground water in the southwest of Black Sea artesian basin.

1. Introduction

Vertical hydrodynamic zonality is referred to the basic regularities of ground water distribution in the upper (water-saturated) part of lithosphere. The first who wrote about this regularity was V.I. Vernadsky (1933). B.L. Lichkov was the first who described hydrogeodynamic zonality (1933). The three hydrogeodynamic zones were distinguished by F.A. Makarenko (1939).

N.K. Ignatovich [2] proved the concept of three hydrogeological zones in practice: active water exchange, impeded circulation (migration), and non-moving water. According to Ignatovich (1944), active water exchange zone is an upper part of hydrogeological section including ground water and upper level of artesian water involved in water exchange with atmosphere and river inflow.

Almost simultaneously with Ignatovich's research [2], the works by K.V. Filatov (1947), Z.A. Makeev (1948), and M.A. Gatal'skiy (1954) were published. The works by Zavarzin L.G. (1969), Yezhov Yu.A., Vdovin Yu.P. (1970), Zaitsev I.K. (1979), Valukonis G.Yu., Khod'kova A.Ye. (1968,1973) analysed the theoretical and practical issues of hydrogeodynamic zonality up to 1973. Ye.V. Pinneker (1983) also paid much attention to this question.

In 1978 S.L. Shvartsev [7] was the first who generalized the data on hydrochemistry of hypergenesis zone. It was stated that there are few works in the sphere of hydrogeochemistry, whereas those about intensive (active) exchange water zone are virtually absent. Shvartsev's ideas were developed and specified by many researchers. Among them one can mention an extensive work by Ye.M. Dutova on hydrogeochemistry of hypergenesis zone in the Altay-Sayan folded belt [1].

The foreign concept of low temperature groundwater geochemistry [8-14] is similar to that of active water exchange zone.

The most practically applicable and well-grounded classification is Ignatovich's one [2] (or Ignatovich – Lichkov – Makarenko's). The contemporary ideas of active water exchange zone are not clear enough (Kurennoy V.V., 2010). Vsevolozhsky V.A. (2007) noted that delineation methods for this zone were far from being perfect. The number of works on active water exchange is few, though ground water of this zone is of great significance (Shvartsev S.L [7]).

The author of the article suggests a set of techniques to delineate and map the active water exchange zone of platform ground water.

2. Materials and methods

The research is based on long-term results of complex hydrogeological investigation in the southwest of the Black Sea artesian basin including the territory of Moldova, south of Ukraine, and Subcarpathia part of Rumania. To collect the data, the field expedition was organized to sample ground water and rocks, to measure hydrogeological, hydrogeochemical parameters, and in some cases – to obtain ecological, meteorological, engineering and other information.

The analysis includes laboratory and field (express) identification of chemical elements and physic-chemical parameters. In the laboratory the macro- and microelements (atomic spectroscopy laboratory of Chemistry Institute of Moldova Academy of Science), helium (device INGEM-1, operator is the author of the article) are determined. The data on tritium content in natural water and water temperature of deep wells are taken from the archive of the Hydrogeology Laboratory of Geology and Seismology Institute (Moldova Academy of Science).

The number of author’s chemical analyses (element determination) is about 2500 for ground water, more than 3000 helium samples are determined in water and natural gases. Besides, geologic-hydrogeological data are collected and generalized for more than 1000 wells (stratigraphy, water level, flow rate etc.).

Data processing is performed using the modern quantitative methods of geologic information processing, techniques of physical-chemical modeling and mapping. The following software Microsoft 2013, SPSS10-14, AquaChem 4.0, Surfer 7.0-8.0-9.0-11.0, ModFlow (PMWin 4.1, Visual ModFlow), RockWorks 14.0, CorelDraw 12.0 and GWW, as well as GIS software are used.

3. Results and discussion

At the moment there is no common method of hydrogeodynamic zone delineation, zone of active water exchange, in particular. The following set of techniques is suggested to be applied collectively [5].

A) Hydrogeochemical method. Mineralization value is chosen as a form of generalized factor of ground water hydrogeochemical condition. At present, there are a number of ground water classifications in terms of mineralization value. It has been suggested to use Vernadsky’s classification (1933 – 1936) with changes by V.A. Priklonsky (1933, 1949), according to which water is divided into 4 groups: fresh – with mineralization value of up to 1.0 g/L; brackish - 1.0 – 10.0 g/L (1.0 - 3.0 g/L and 3.0 - 10.0 g/L according to Priklonsky); saline - 10.0 – 50.0 g/L; brine - > 50.0 g/L. The active water exchange zone contains mostly fresh water with mineralization up to 1.0 g/L. The data on ground water composition (water type, element composition etc.) are also used in this method.

B) Geothermal method. Ground water is involved in formation of physical-chemical equilibrium systems with the environment, the basis of which is presented in pairs: “water–rock”, “water–gas”, “water–dissolved substance” and “water–living world” (Vernadsky V.I., 1933; Samarina V.S., 1977). Water as a chemical substance increases or decreases functionally its participation in the chemical reactions depending on its temperature (or system) in the equilibrium systems.

Water-bearing rock solution or formation of new minerals occurs mostly in “water - rock” system. The data analysis on solid solubility in water at different temperatures shows that solubility in water occurs in low quality at the ambient temperature of about 20^{o}C, but at temperature of more than 20^{o}C the amount of dissolved substances sharply increases [3]. The analysis of natural gas solubility values (N, H_2, O_2, CH_4, H_2, CO_2, and C_2H_6) in water at the temperature range from 0^{o}C to 100^{o}C reveals that the maximum decline in natural gas solubility in water is observed at the temperature range from 0.0 to 20^{o}C [6]. Hence, the marginal temperature for basic equilibrium systems is 20^{o}C. This temperature value is suggested to be used for low boundary delineation of the active water exchange zone.

B) Tritium in ground water. Tritium distribution in ground water is known to be a direct indicator of its relationship with precipitation and surface water (Zelenin I.V.,1974; Dubinchuk V.T.,1979;

Morkovkina I.K., Romanov V.V., 1975). Tritium falls out with rain water, flows into surface and ground waters. There are different patterns of tritium migration in ground water (Zelenin I.V., 1974). We take a simple and effective assumption: presence of tritium in ground water reveals its connection with the Earth surface and vice versa – its absence is an indicator of the absence of such a connection. The low boundary of active water exchange zone can be determined by zero (tritium absence) or close to zero tritium content.

C) Helium in ground water. Helium distribution in ground water is regulated by the following factors: tectonic fault location, background concentration of the element within the aquifer, crystalline foundation location and downward infiltration vertically to rainfalls in ground water. The latter is closely related to the development of active water exchange zone. Helium concentration deviation from the background concentration towards its decrease clearly shows mixing of aquifer water with water of overlying aquifers or meteoric water that, as a rule, contains low helium concentration or no helium at all. Helium field contrast ratio best demonstrates the given phenomenon [4]. Helium field contrast can express the spatial location of active water exchange zone.

D) Hydrogeological stratigraphy. In the platform condition, aquifers, as a rule, correspond to the definite stratigraphic units. Structurally, aquifers are separated by impermeable (or relatively impermeable) strata. At low bedding angle of aquifer (or closer to horizontal location) similar hydrogeochemical properties are typical for large territories. Memphian layers, Mississippian depression (the USA) can serve as examples [10].

Stretching and location of active water exchange zone is structurally connected with and confined to the definite aquifers or their parts. Therefore, hydrogeological stratigraphy characterizes indirectly the spatial location of the active water exchange zone.

Ground water that is involved into the first from the surface aquifers and has complex hydrogeodynamic pattern is, by its definition, a part of active water exchange zone.

The suggested set of techniques for assessment and location of active water exchange zone is used for ground water of the southwest Black Sea artesian basin. Tectonically, in terms of folded basement age, the whole study area is divided into the area of Precambrian folded basement (margin of the East-European Platform) and the area of Hercynian folded basement (Scythian Plate). Hydrogeologically, the study area is southwest part of the Black Sea artesian basin of the first order.

As a result of the suggested technique, the geometrical parameters of the active water exchange zone in the southwest of the Black Sea artesian basin (by the example of Moldova territory) are characterized by the following features: a) the thickness of active water exchange zone ranges unevenly within 10.0 – 550.0 m from the Earth surface. The active water exchange zone includes: in the north – Quaternary, Neogene, and Cretaceous-Silurian aquifers; in the center – Quaternary and Neogene aquifers; in the south – Quaternary and Neogene aquifers (to lower Sarmatia); b) the thickness of active water exchange zone increases towards southwest and southern directions and is regulated by geologic structure and hydrogeological conditions of interstratal aquifers; c) according to the plan, active water exchange zone location coincides with the location of ground water recharge area; d) areas where active water exchange zone is located are characterized by maximum density of water supply wells; e) as for a percentage of the total aquifer area location, the active water exchange zone location has the following values: Cretaceous aquifer – 55%, lower Sarmatia – 64%, middle Sarmatia – 71%, upper Sarmatia - Pontian – 91% and Quaternary aquifers – 100%.

4. Conclusion

For platform areas, in the condition of hydrogeological parameterization uncertainty a set of techniques is suggested to delineate the boundaries of active water exchange zone vertically and according to the plan. It consists of the sequence of the following methods: (a) hydrogeological stratification, (b) hydrogeochemical method, (c) geothermal method, (d) tritium in ground water, and (e) helium technique.

Active water exchange zone of ground water in the southwest of the Black Sea artesian basin is delineated both vertically and in plan using a set of suggested techniques. It comprises ground and intermediate waters of Quaternary, Pontian, Meotian, upper-, middle-, lower- Sarmatia, Cretaceous, and Silurian periods.

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