System-integrated GIS-based approach to estimating hydrogeological conditions of oil-and-gas fields in Eastern Siberia

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Abstract. The article describes the basic methodological elements of system-integrated approach to estimating water abundance in the upper hydrodynamic zone of Eastern Siberia territory to optimize water exploration. The technique is based on materials available at the pre-survey stages of exploration. When processing the information, the integrated geoinformation analysis has been used.

1. Introduction
At present in the territory of Eastern Siberia hydrocarbon fields with low reservoir pressure and temperature (6-20°C) are being developed and planned to be developed, which, in turn, implies significant expenditures with less economic benefits than, for instance, in Western Siberia. Hence, the issues of investment optimization at different types of exploration is more topical than ever before.

One of the most urgent problems faced by production engineers in the oil and gas fields is groundwater prospecting for multi-purpose water supply and optimization of water well location.

The maximum geological and economic effect is possible to achieve by means of developing the estimating system of the most perspective water sites that would be applied at the early stages of exploration. To solve the geological problem, such an estimating system should include minimal amount of field information due to maximum use of prior information or information provided by: archives and literature sources as well as the Earth remote sensing data. In this case, the estimate of water abundance perspectives of study areas should be scientifically based on the used data.

At present at the early stages of exploration the pre-survey information analysis is performed, however, cartography developed at this stage is not used for complete forecast information to full extent. At the contemporary stage of studying perspective oil fields in Eastern Siberia, the information obtained at the pre-survey stage cannot be directly used for exploration due to the lack of information on study areas. Thus, identification of high water abundance zones for subsequent drilling with the help of direct hydrogeological parameters is virtually impossible.

The purpose of the given article is to determine a number of indirect parameters that are possible to estimate at the initial exploration stage and to develop integrated index of water abundance, which is a basis for exploration optimization involving groundwater reserve estimates, that is collectively defined as a system-integrated approach.
2. Objects and methods
The integrated approach based on integrated-model analysis has been used before for estimating sustainability of underground hydrosphere in the urban territories, solution of optimization problems of geological exploration of Lenskoye gold fields (Auzina, 1997). The current article considers modern GIS-based technique.

Development of the described technique was performed within the exploration project at oil and gas condensate fields (OGCF) of Chonsk group (Eastern Siberia) located in the extremely complex geological-structural and permafrost-hydrogeological conditions. The geological structure of the study area is defined by Archean, Proterozoic, Paleozoic formations, Mesozoic and Cenozoic deposits, as well as trias intrusions.

Most fields are confined by Nepsko-Botuobin anteclise, within which, as a result of several stages of tectogenesis, multi-block structure has been conditioned by fractures of different ages of north-eastern, north-western and submeridional directions. Sufficient deformations are conditioned by intrusion of trappean rock into Early-Triassic period of magmatism. The most significant result of neotectonic uplift was development of contemporary relief and identification of zones with different water exchange regimes in the cross section: free, confined by the bottom of Middle and Upper Cambrian deposits, and impeded, beginning from the aquifer of Lower and Middle Cambrian rocks.

Spatial distribution of permafrost rocks is of rather a complex pattern and not confined by definite relief features.

Such a diversity of natural conditions determined the extreme complexity in pre-survey estimate of hydrogeological features of study areas and the necessity to develop integrated index including a number of parameters influencing water abundance of prospective hydrogeological bodies in the upper hydrodynamic zone and identified at the initial survey stages.

The technique was implemented using geoinformation approach, some elements of which have been used for exploration of ore fields (Parshin, Spiridonov, 2014) and geocological monitoring (Filimonova et al, 2015, Pokrovsky et al, 2014, Pokrovsky et al, 2015). In this case the technique was applied to explored and operated groundwater deposits, and then it was used for new oil and gas fields.

At the initial stage of pre-survey operation, marking and vectoring of archive cartography is performed for study area and the adjacent sites including topographic and geological mapping, accessible satellite information, and results of aerogeophysical survey. This information allows the initial digital base and database (DB) development added by the results of the field hydrometric and filtration operations including hydrogeological, geocryological maps, patterns of head distribution, groundwater level, filtration parameters of water-bearing material and some other information. One of the most important parameters from the list above is a consistent digital elevation model (DEM) that allows calculating a number of morpho-structural parameters.

Based on the initial information, the additional layers of morpho-structural parameters are calculated:
- fracture index defined by relationship of river bed length not confined by Quaternary deposits and crossing the square of statistical subsquare to its size, which depends on research details (Auzina, 2014), (Fig. 1a);
- proximity of target point to water stream crossing of the 3-d and 4-th orders;
- height and distance to the nearest drain;
- height and distance to the main drain;
- terrain ruggedness index (Riley et al, 1999), (Fig. 1b);
- downward gradient, exposure;
- elevation of target point.
Figure 1. Mapping of designed indexes "Terrain ruggedness index" according to Riley et al. 1999 (above) and "Specific fracture index" (below). Mapping is normalized and scaled in such a way that black colour means minimum index (values close to 0), white – maximum index (values close to 1).
All mentioned indexes are determined by map layers, digital layers of drainage system and DEM, i.e. they are available at the pre-survey exploration stage.

Thus, the database was generated consisting of more than 50 predictors. They were independent vector layers in the general geoinformation project “Hydropoisk”. As is known, a large number of GIS-project layers is not convenient for visual analysis, therefore, it is appropriate to generalize it to a less number of informative integrated indexes by means of GIS mapping (Budyak, Parshin, 2013; Filimonova et al, 2015).

Reduction in information size without loss of information was performed by means of development of integrated index of water abundance (IIWA). To identify the key factors concerned with water abundance, the factor analysis was used for geodata of the analogous site by means of robust principal components method. As a result, among the whole set of primary and designed indexes a number of parameters were distinguished that reflected water abundance of the perspective sites and, at the same time, did not involve any difficulty to obtain them at the early exploration stage. Despite the significant difference in geological-hydrogeological and permafrost conditions of the license areas, the list of universal and efficient parameters included fracture index, proximity to water stream crossing of the 3-d and 4-th orders, height above the main and nearest drain, distance to the nearest drain, terrain ruggedness index, seldom - downward gradient, elevation of target point, distance to fault zones of definite types.

The values of indexes were brought to uniform dimension by means of normalizing, scaling, and/or classification by Delphi method, after that corresponding raster layers were developed with unified grid step. The potential hydrogeological significance of every parameter and, consequently, the raster values were ranged within the interval from 0 to 1, where the least values reflected unproductive sites from the point of view of water exploration. Integrated index of water abundance means a sum of all significant parameters. It was plotted in conditional units from minimum to maximum values, where the latter denoted the most perspective sites. All calculations can be performed both in rasters (as in the above example) and in tables of database. The suggested technique is based on open GIS technology, mostly DBMS PostgreSQL/PostGIS and QuantumGIS system, therefore, it is in full conformity with the latest government decision on refusal from public procurement of propriety foreign software programs.

3. Results and Discussion

Integrated index designed on the basis of OGCF developed for production to a different extent or being currently developed has been applied to the sites of the early exploration stage. The example below shows (Figure 2) maximum values denoting the most perspective sites which are in red colour.
4. Conclusion
In some sites, the drilling results have shown that, on the whole, the suggested mapping reliably determines the expected hydrogeological conditions. Depending on the task and a set of available geodata, the integrated index can be calculated with different detail level.

The technique was tested in one of the license sites of Chonsk group deposits. The initial results of implementation of suggested approach has proved its high efficiency: more reliable forecasting allowed solving geological problem, having reduced the number of exploration wells by 30%, in this case the possibility of well inclusion into perspective ones increased 60-80%. At the moment, testing of its efficiency is underway at other license sites.

The suggested approach is universal to a great extent. Depending on the set target and exploration scale, one can only change a number of parameters, but the basic indexes of geodata processing technique remain the same.

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