Landscape transformation in the areas of geothermal systems operation

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Abstract. The article presents an analysis of the main areas of change of the landscape components in the areas of geothermal systems operation, the most significant processes of transformation of the natural-territorial complex were determined.

Key words: landscape, geothermal systems, landscape components, exploitation, impact.

1. Introduction

The current level of scientific and technological development is largely determined by the natural resource potential of the Earth. Over the past decades, the reserves of the main types of resources, including energy, mineral and biological resources, have significantly decreased. On the other hand, the exponential growth of the speed of the technospheric development of civilization requires a constant increase of the natural resources involved in the production. This led to the depletion of the latter. This trend defines the need to find, study and promptly involve alternative sources of resources into operation. Alternative sources of resources include geothermal resources characterized by high energy technology and ecological potential [1]. At the same time, the operation of geothermal fields has a negative impact on natural landscapes as one of the types of anthropogenic activity [2].

The main areas of exploitation of geothermal systems include the use of heat resource, energy resource, mineral resource and balneresource potential [3, 4]. The implementation of each geotechnological scheme of exploitation of geothermal resources entails a geo-ecological transformation of the landscape and its components.

The landscape is a synergistic system and provides a person with the maximum range of material and energy resources for development. This is grounds to consider the landscape as an object of geoeological research. Despite the broad interpretation of the concept of landscape, the scientific literature distinguishes the general scientific (F N Milkov), regional (individual) (L S Berg, L G Ramensky, A A Grigoriev, S V Kolesnik, A G Isachenko, N A Solntsev et al) and typological (A N Ponomareva, M A Pervukhina, B B Polynova, L S Berga, A I Perelman, N A Gvozdetsky) interpretation of this concept [5]. The authors of the article adhere to a regional interpretation where the landscape is considered to be an individual (specific) territorial unit, a complicated geographic complex with the presence of components interacting with each other through the cycles of matter, energy and information. Certainly, the regional interpretation of the landscape combines both individual and typological approaches, but the basis of the regional view of the landscape is based on different-quality, different-order geocomplexes and recognition of the primacy of specific regional geocomplexes.
When extracting all kinds of resource potential of a geothermal field it is unavoidable negative environmental impact on the landscape as a whole and on its individual components. The components of the landscape include lithogenic basis, water and air masses, biota and soil cover. Each of the components is a “representative” of individual private geospheres within the geographic envelope. In any component of the landscape there is the substance of the rest of its components, which gives the landscape emergent properties. The latter directly affects the speed of propagation of the negative impact on the landscape, the depth of structural changes during its operation. Thus, the transformation of the lithogenic basis, including as a result of construction work, laying of engineering communications changes not only the orographic and geomorphological characteristics of the landscape, but also leads to a change in the groundwater pattern, their properties, affects the change in the characteristics of surface discharge, changes in the nature of the landscape vegetation, etc. Of course, the directions of landscape transformation while extracting the natural-resource potential of a geothermal system are very heterogeneous in their nature. The degree of change in each case depends on both the technologies used and the local conditions in which the project is carried out.

Consider changes in each of the components of the landscape during the operation of the geothermal system.

2. Lithogenic basis
   It is an inert component of the landscape and serves as its foundation. The lithogenic basis serves as the territorial basis of any natural complex, as well as the depositing medium where the main reserves of the mineral matter of the landscape are concentrated. The use of various types of geotechnological schemes for operating a geothermal field first of all transforms the lithogenic basis of the landscape. Elementary landforms with petrographic features of surface and near-surface rocks are most often affected. At the stages of geological exploration and development of the field, it is the lithogenic base that is subjected to maximum modification. It should be noted that landscapes in areas of geothermal fields belong to the mountain class, which determines a narrow range of landscape stability to any of gravitational unbalance.

   The main types of environmental impacts on the lithogenic basis of the landscape as a result of a geothermal field operation include geological and overburden operations during geological exploration, relief changes (appearance of ravines and the spread of erosion) as a result of creating infrastructure engineering structures and communications, lowering the hydrostatic level of aquifers during drilling and putting them into operation, the development of dangerous geological processes and phenomena (landslides, rocks avalanches), change of the area’s field resistance. Secondary effect of the lithogenic basis change is changing of other landscape functions. First of all, it is necessary to note the violation of moisture circulation and water balance. In addition, groundwater recession can lead to a mix of hydrothermae from the high-temperature basin with a flow of corrosive termae. These processes can be accompanied by the disappearance of sources and fumarols or lead to a change in their surface manifestation [6].

3. Water and air masses
   They transfer chemical compounds and bind the solid base matter to the biotic component of the landscape. These components perform a mobile function in the landscape. Fundamentally, the water and air mass is a kind of blood of any natural-territorial complex. Therefore, their change is most often considered through the prism of chemical and physical pollution.

   As a result of the development and operation of a hydrothermal field, carbon dioxide, hydrogen sulfide, methane, small admixtures of nitrogen, ammonia, radon, boron, and ammonium fall into the air component of the landscape. Carbon dioxide and methane have the highest greenhouse potential among the above gases. The carbon dioxide content in gas emissions from geothermal fields reaches
Studies in recent years confirm that the exploitation of geothermal fields does not create an additional influx of carbon dioxide compared with natural emissions of geothermal fields [7]. Hydrogen sulfide with a strong odor and toxicity has an emission range from geothermal installations of 0.03–6.4 g/kWh at low concentrations and hydrogen sulfide content can reach 90% among the emissions of non-condensed [8]. Belonging to a heavy gas group hydrogen sulfide tends to be concentrated in low relief forms. Consequently, the scale of pollution is correlated with the topography and characteristics of the landscape, as well as with the features of surface discharge and wind direction.

As for the water component of the landscape, its changes are noted here as a result of chemical and physical pollution by geothermal solutions [9, 10, 11]. The main pollutants in the liquid fraction of the geothermal heat carrier are boron, ammonia, arsenic, mercury and other heavy metals, such as lead, cadmium, zinc. The predominant dissolved materials are sodium chloride, bicarbonates, sulphates, oxides of silicon, calcium and potassium [12]. Some geothermal fluids with an excessive salt concentration can negatively affect not only changes in the chemical composition of water, but also accumulate in the soil and biota. The change in the physical characteristics of the water masses of the landscape is mainly due to the discharge of waste geothermal solutions and condensate into water bodies. An increase in the temperature of water bodies in which there are places of food supply and spawning grounds of ichthyofauna representatives can lead to a change in the ecosystem, including the eutrophication of water bodies. When operating geothermal systems, it is necessary to apply technical solutions to reduce the negative impact and increase the rationality and complexity of the use of geothermal resources [14, 15, 16, 17].

4. **The soil**
It has a bio-bone nature and is the most easily destructible component of the landscape. On the other hand, it is the soil cover that is responsible for the sustainable functioning of the biota, and therefore for the resistance of the landscape itself. Referring to the mountain class, landscapes in areas of geothermal systems have thin and intermittent soil cover. Therefore, even a small degree of anthropogenic impact leads to degradation of the soil component of the landscape. More often, in areas where geothermal systems are used, active processes of soil erosion, mechanical destruction of soil cover, changes in the thermal regime of soils, and salt and gas in the soil are observed. It is especially important to change the soil for tundra landscapes of high mountains, where the duration of the cold season led to the formation of biologically scarce natural-territorial complexes. Therefore, the preservation of soil differences within such landscapes is a priority task for the preservation of the entire geocomplex.

5. **Biota**
It is an active component of the landscape and is directly related to the range of landscape resistance to external influences. Thus, in the areas of geothermal fields the transformation of vegetation as the main part of the biocenosis and primary biomass producer leads to serious violations of the geochemical functions of the landscape. The violation of the vegetation cover in the areas of geothermal fields is associated with the processes of erosion, the removal of mineral substances beyond the boundaries of the landscape, changes in habitats and feeding base of animals. In addition, well drilling, laying of engineering infrastructure lead to succession change of plant associations.

6. **Conclusions**
It is obvious that in the areas of exploitation of geothermal resources there is an active transformation of the landscape in general and of its individual components in particular. Such components of the
landscape as a lithogenic base, biota and soil are subjected to a special transformation during the exploration and construction of the infrastructure of a geothermal field. Since geothermal areas are located within the boundaries of the mountain-class landscape, changing components such as soil and biota is the most dangerous from the point of view of maintaining the stability of the geosystem as a whole.

It should be noted that many areas of geothermal fields are located within the boundaries of unique and picturesque landscapes with high recreational potential. Therefore, the preservation of landscape complexes in the areas of geothermal resources operation is one of the main environmental objectives.

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