Trends of disturbance of Volga-Ural steppe landscapes in oil-and-gas production and approaches to land use optimisation solutions

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Abstract. We study the factors and tendencies for a technogenic disturbance of Volga-Ural steppe region landscapes exposed to the influence of oil-and-gas production. The study area is 1500 km², including landscapes of more than 25 oil-and-gas fields with a various time of development and different alternatives and scales of technogenic impact. Survey of landscapes is as a part of the regional geo-ecological analysis, which incorporates the analysis of a group of natural factors that specify the attributes of the steppe zone, and classification and identification of the most large-scale and widespread environmental problems. We present the recommended algorithm for making a regional geo-ecological analysis which incorporates the ways, methods, and approaches to achieving ecological-subsoil-user balance in oil-and-gas production areas. We show that such environmental problems as haphazard expansion of disturbed lands, fragmentation of landscapes, change in conditions of water reservoirs, intensification of exogenic processes, creation of temperature anomaly areas, reduction of the number of mammals are most likely to occur within oil-and-gas fields. So-called Technogenic geosystems of oil-and-gas fields form in the landscapes. Knowledge about the specific aspects and regularities in the functioning of these geosystems should be used to create prognostic scenarios of disturbed lands development and target-focused optimisation measures.

1. Introduction
Despite an increasingly growing role of renewable energy resources in the world economy, the production of hydrocarbons remains to be the most essential industrial sector. There are problems in reaching the necessary capacity of the known renewable energy resources; hence, either nuclear power generation industry, which introduction is somewhat problematic, or the existing non-renewable energy sources, i.e., coal, oil, and gas, may provide the required amounts of energy [1]. Production of oil-and-gas has currently been a type of using mineral resources, which is underway in 54 countries and, together with agriculture, is one of the main factors that aggravate environmental problems in steppe regions [2, 3]. USA, Saudi Arabia, and Russia are the top three worldwide leaders in crude oil production. Natural landscapes within oil-and-gas fields are transformed into natural and technogenic ones, with profound and often irreversible changes. When oil-and-gas production companies are seeking an increase in financial benefits and maximisation of profit, often up to the damage of environmental favourable conditions, it inevitably leads to worsening ecological and social and economic components of the population life quality at all levels of territorial hierarchy. However,
despite all these environmental hazards, oil-and-gas are the most important resources and their production is necessary and economically justified.

The ways to solve the problem of optimisation of natural resources use and prevention/mitigation of environmental consequences in the lands of oil-and-gas fields may be related to the introduction of so-called ecological-subsoil-user balance. This balance should imply oil-and-gas production activities, maintaining an equilibrated ratio between unavoidable technogenic load at the sections of oil-and-gas fields as well as preservation and rehabilitation of structural and functional properties of natural landscapes. The exploitation of oil-and-gas fields in conditions of such a balance will create the prerequisites to form up a system of economically effective oil-and-gas production with minimum geo-ecological alterations. The ways to achieve an ecological-subsoil-user balance at the landscapes of oil-and-gas production primarily imply the identification of the main factors and tendencies for technogenic disturbance of landscapes, considering the specific natural features of the study area.

2. Objects, data and methods
Volga-Ural steppe region, chosen as a study area, is a part of Volga-Ural oil-and-gas province, where 22% of the Russian oil and 2% of gas are produced. The amounts of the produced crude oil and a great number (more than 400) of fields operated in the Volga-Ural steppe region imply an enormous technogenic impact and substantial structural disturbance of landscapes as well as scientific representativeness of the landscapes (figure 1).

Figure 1. The study area: 1 - Volga-Ural steppe region, 2 – outlines of oil-and-gas fields (based on open-source data of the Federal Agency for Mineral Resources “Rosnedra”). Source of original map: ESRI.
Administratively, Volga-Ural steppe region incorporates northeastern part of Volgograd, the eastern part of Saratov, the southern part of Samara and Orenburg Oblasts. Oil-and-gas exploration and development in the region began in the 1930s; natural and technogenic landscapes within oil-and-gas fields have formed in a complex manner, and this process has long taken place during a problematic phase of developing USSR environmental policy when there was no need for evaluating consequences for the environment. Together with the use of mineral resources, agricultural production plays a key role in the economy of the Volga-Ural region. It may be characterised as a total agricultural transformation of steppe landscapes: approximately 88% of territories are covered with agricultural lands. Today’s steppe landscapes are almost everywhere represented as agricultural areas seeded with adapted species of biota. Introduction of technology-related elements of oil-and-gas fields into agro-steppe systems can disrupt the existing balance and have a substantial negative effect on steppe biodiversity.

Main factors and tendencies for the technogenic transformation of landscapes in conditions of oil-and-gas production were identified as a part of the regional geo-ecological analysis of the territory. The geo-ecological analysis serves as a basis for solving problems of optimising and balancing management of natural resources in terms of territorial governance, preventing the processes of desertification and degradation of steppe landscapes as well as preserving the unique steppe biodiversity.

Regional geo-ecological analysis of steppe landscapes, where oil-and-gas are produced, included:

- development of a theoretical and methodological framework for an interdisciplinary study of consequences of oil-and-gas resources use;
- analysis of a group of natural factors that specify typical features of the steppe zone and the emergence of certain geo-ecological problems;
- classification and identification of the most large-scale and wide-spread geo-ecological problems, which specify changes in natural processes, disturbance in the existing structure of landscapes, and creation of critical environmental conditions.

The total area of the study key plots within Volga-Ural steppe region was approximately 1500 km² and included landscapes of more than 25 oil-and-gas fields with various time for mineral resources development as well as different alternatives and scales of man-induced impact. Surveys were performed based on field trips, involving remote sensing data.

3. Results and discussion

We have identified specific aspects and regularities of technogenic disturbance of Volga-Ural steppe region landscapes in oil-and-gas fields. The processes of transforming steppe landscapes are subject to certain regularities associated with both particular properties of oil-and-gas production processes and nature-climatic territory characteristics related to the geographical zonal position. Such attribute of steppe plain-like territories as an extremely minor sharpness of natural geographical barriers capable for restricting territorial expansion of oil-and-gas fields (low forest land percentage, low ruggedness of terrain, lack of deep rivers, sparse network of water objects) has a substantial influence on intensity and immensity of disturbance processes. These natural conditions facilitate a constant increase in disturbed land areas, which continues until completion of the field operation and causes fragmentation of the landscapes. Linear disturbances of landscape have a substantial role in developing fragmentation. They occur as a result of constructing a traffic system within fields. The traffic system density may increase by 44% throughout the operation of one field. Disturbed lands often expand due to adjacent segments, which initially were not intended to be utilised but suffering from a haphazard expansion of human-impacted areas. More than a third of roads within fields are unofficial access routes created by drivers of departmental heavy truck transport for convenient transportation. Severe damages to vegetation and soil covers during the operation of oil-and-gas fields have such hidden effects as disrupting carbon cycle balance [4].
In addition to the haphazard expansion of disturbed land areas and fragmentation of landscapes, there are some other types of disturbance of environmental components in the zones affected by oil-and-gas fields.

Change in conditions of water bodies. There are studies, which prove that disturbance of runoff and, hence, hydrological regime of small rivers, occurs due to the influence of oil-and-gas production [5, 6]. Disturbance in the processes of forming slope runoff is mainly related to dikes of well clusters, constructing linear facilities, creating quarries on the ground. Since the landscape structure of water catchment areas changes, runoff is intercepted by quarries, and terrains are submerged due to technogenic impact, annual runoff of small rivers may be reduced by 25-30% [6]. A majority of surface runoff shallows of small rivers watershed basins in the study area pass through agglomerations of oil-field facilities that may cause changes in both the volume of water body feeding and transportation of chemical and mechanical pollutants from oil-and-gas field sites to a water reservoir. In conditions of the steppe zone with its varying and insufficient water content, such situations may have extremely negative consequences for the entire ecosystem.

Intensification of exogenic processes. Grass vegetation in steppe regions is among the few natural factors, preventing erosion from development. Surface soil layers well covered with grass [7] resist active development of water and wind erosion processes, whereas, among all characteristics of relief, the surface slope has a maximum effect on the emergence of erosion [8]. Usually, lands with more than 3% slope bear erosion risk. Analysis of the studied area terrain slope has demonstrated that significant part of oil-and-gas fields (11%) is located in the areas with more than 3% terrain slope that substantially increases the risk of erosion processes, occurring due to disturbance of vegetation cover strengthening properties [9].

Creation of thermal anomaly areas. Gas flares (associated gas flaring units) constitute the main sources of thermal impact on landscapes during operation of oil-and-gas fields. Ground surveys have shown a significant increase in temperature of landscape surface and ground level air near flares, especially, ground horizontal flares. Based on thematic processing of thermal channels of Landsat-8 satellite images, changes in temperature of landscape surface were analysed within the range of flares. We have found that when flare is operated, the temperature of the near-surface layer may increase by more than 8 degrees in a 30-350-m radius from the point of heat distribution. Hence, when one flare operates, the landscape surface and ground level air temperature increases on average within the area of 0.085 sq km, and when associated gas flaring occurs using 100 flares, the temperature may change within the area of more than 8 sq km.

Reduction of the number of mammals. We have performed a comparative analysis of the number of some typical steppe mammals in the areas with a high level of technology-related disturbance and the regions not exposed to a substantial influence of oil-and-gas production. We studied four mammal species: marmot, common red fox, brown hare, and Siberian roe deer. We have revealed that for these three species, namely, marmot, Siberian roe deer, and brown hare, a well-developed oil-and-gas infrastructure constitutes a limiting factor, owing to which an average number of these animals here is always lower compared to wealthier regions [10].

The enumerated consequences in one or another combination occur when there are other types of impacts on landscapes. However, the presented complex of consequences characterises the newly emerged situation within the fields’ landscapes, resulting in the creation of techno-geosystems of oil-and-gas fields with their system-based properties, principles of formation and development. The performed researches and suggested results are an integral part of the regional geo-ecological analysis of steppe oil-and-gas production landscapes. Thus, regional geo-ecological analysis of steppe landscapes in conditions of oil-and-gas production should be aimed to analyse space and time dynamics as well as regularities in operation of techno-geosystems of oil-and-gas fields, including examination of multiple interrelations between them, and development of scientifically justified activities to eliminate environmental problems provided that necessary social and economic functions of landscapes are maintained. The recommended algorithm for making an analysis incorporates the ways, methods, and approaches to achieving ecological-subsoil-user balance in oil-and-gas production areas (figure 2).
Figure 2. Algorithm for making a geo-ecological analysis of technogenic geosystem of oil-and-gas field
4. Conclusion
The revealed regularities of technogenic disturbance of steppe landscapes caused by oil-and-gas production and the concept of technogenic geosystems of oil-and-gas fields may be used for creating prognostic scenarios of geo-ecological situation development. These scenarios suggest target-focused optimisation measures and restrictions at the stage of designing and exploring new oil-and-gas fields as well as assessing environmental risks upon justification of measures to be taken for environmental rehabilitation of disturbed lands.

The presented algorithm for geo-ecological analysis shall be the basis to forecast the life cycle of oil-and-gas field technogenic geosystem, development of target-focused optimisation measures, including those designed during an international exchange of experience in conserving landscapes of oil-and-gas production. A decrease in a negative impact of oil-and-gas production on environment and population is possible through reordering the existing priorities, i.e. the gradual replacement of commercial policy of mineral resources management with ecological-economics policy, what now happens.

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