ISSN 1028-334X, Doklady Earth Sciences, 2017, Vol. 474, Part 2, pp. 709–712. © Pleiades Publishing, Ltd., 2017.
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GEOGRAPHY

Steppe Landscapes of the Ural–Volga Region in Response to Oil and Gas Production: Evaluation and Minimization of Direct Geoecological Aftereffects

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Received January 25, 2017

Abstract—This paper reports on the geoecological state of landscapes of oil and gas fields in the Ural–Volga steppe zone. Large-scale direct disturbances and impacts with dramatic aftereffects have been revealed on the basis of field research using the geographic information system (GIS) and data from remote sensing of the Earth. It has been shown that the current land-use pattern in oil and gas production areas is in need of professional control to protect and recover the landscapes in the steppe zone.

DOI: 10.1134/S1028334X17060228

In spite of the increasing contribution of renewable energy sources in the world economy, hydrocarbon production is the most significant industry and one of the main factors aggravating ecological problems in areas with a developed network of oil and gas enterprises. The Russian Federation continues to develop production fields and explore new oil and gas fields. There is no reason to believe that this situation will change significantly in the very near future, because oil and gas production plays a key role in the national economy [1]. Optimization of natural resource management within technogenic landscapes of oil and gas fields is particularly topical for fragile natural ecosystems. These systems include arid and semiarid areas characterized by increasing land degradation on all continents [2–6].

Our work considers some geoecological aftereffects of operation of the oil and gas fields, which are situated in the Russian part of the South Ural–Volga steppe zone. This region includes the fields of Volgograd, Samara, Saratov, and Orenburg oblasts (see figure). Our previous works have shown that, in addition to agricultural reclamation, oil and gas production is the most significant factor in technogenic transformation of the Ural–Volga steppes [7, 8]. The landscapes of most of the steppe zone of Russia have been altered by agricultural activities, in one way or another. However, oil and gas facilities implemented on these complexes considerably disrupt the land-use system and have a negative impact on the water and biological resources of the regions.

Our research included a simulation technique of a random distribution of points. Therefore, within the boundaries of the Ural–Volga steppe, key sites were selected—9 polygons, each one around 100 km^2 (10 by 10 km) in area (see figure). To select the key sites, a map of the oil and gas field contours of Russia was used. This map was freely available on the website of the Federal Agency on Subsoil Use, Rosnedra.

Our multiyear study of nature complexes within the oil-and-gas fields revealed that the most significant direct aftereffects are disturbance of the topsoil and vegetation cover. Common disturbances resulting in long-term dramatic aftereffects are also provoked by facilities located near water courses and erosion-initiating activity.

To exclude zones with a disturbed ecological balance [5], low-flow areas and domination of low layered (grassland) vegetation have to be taken into account in economic planning in semiarid landscapes.

The characteristics stated create specific requirements to protect the steppe landscapes. Special attention should be paid to protection of the water courses against chemical and mechanical pollution and maximum conservation of the vegetation cover, which is the main source of oxygen, atmospheric carbon absorption, and the habitat of steppe fauna. In addition, semiarid lands are characterized by a greater hazard of erosion, only well-vegetated upper horizons of soils can resist active development of water and wind erosion [4, 10]. Vegetation is one of the few natural factors that restrains advancing erosion, while the surface slope has the greatest impact on the formation of

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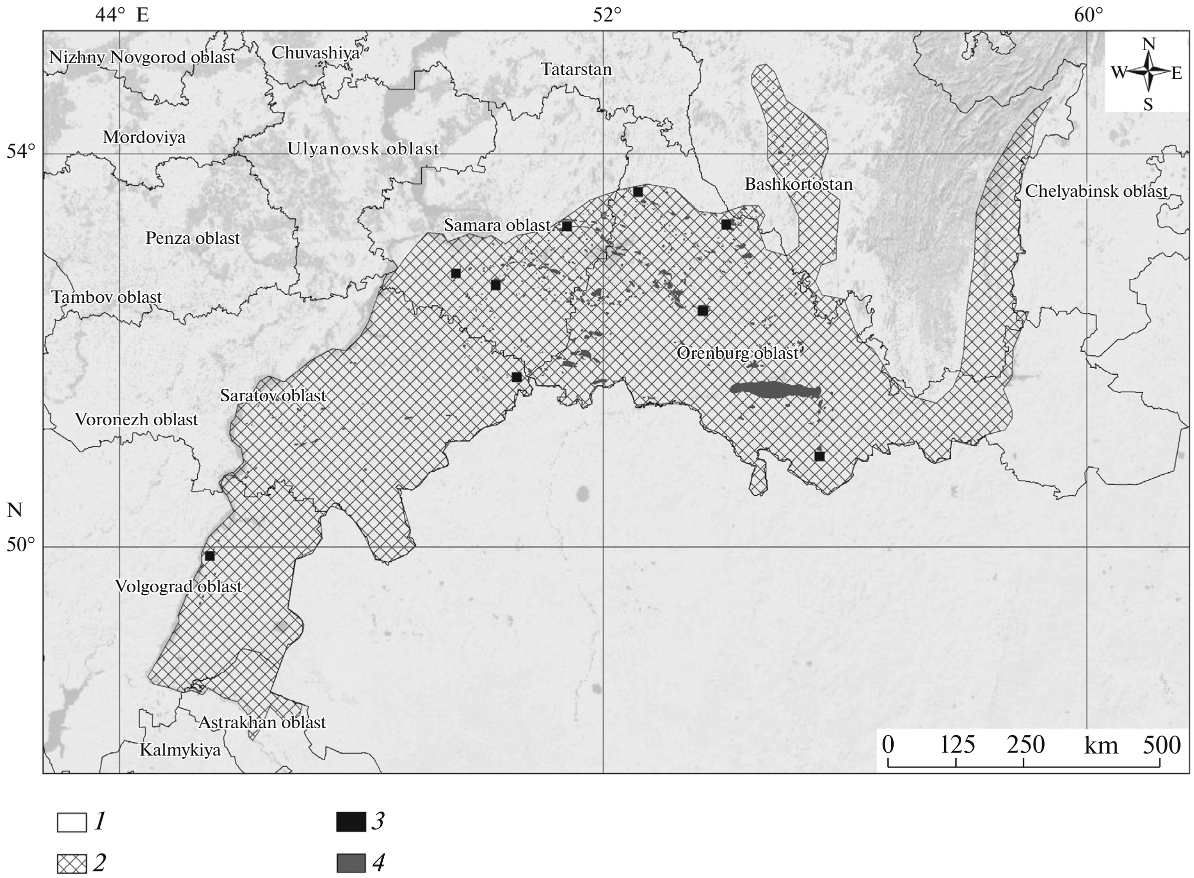

Fig. 1. Objects of research: (*1*) boundaries of constituent entities of the Russian Federation, (*2*) Ural–Volga steppe zone, (*3*) key sites under study, (*4*) areas of oil and gas fields (on the basis of data of the Federal Agency on Subsoil Use, Rosnedra). The source of the basic map is the Environmental Systems Research Institute (ESRI).

erosion compared to other relief features [10, 11]. Generally, the lands with a slope of >3° are considered lands threatened by erosion; however, for example, G.L. Shchepachenko suggests sloping lands with a slope of >1° should be included in the category of land threatened by erosion [10]. Again, local accumulation of pollutants in soils and their infiltration into ground waters are possible with a complete lack of the surface slope.

Digitization of the oil and gas facility areas and the road network was performed for the key sites on the basis of field research and interpretation of aerial and satellite images with a high spatial resolution (ArcGIS 10.2). The total length and average width of the special-purpose roads connecting facilities and the all-purpose roads as well as the average area of the field facility areas were calculated (see table).

At all key sites, the watercourses were recognized and digitized to reveal the number of production areas located nearby. A 500-m buffer zone was designated for each watercourse, and the number of facilities located within the zone was calculated. This optimal width of the water protection zone was chosen on the basis of our own observations, data of other researchers [11], and public health regulations related to the water supply network [12]. According to these rules, in flatlands, this distance is considered relatively safe in preventing a waterbody from pollution.

Then we analyzed the number of the polygons that are situated on lands with a slope of > 3° using the digital relief models of the Shuttle Radar Topographic Mission (SRTM3). The data of SRTM3 were reprocessed in a metric system of coordinates, then the areas with a desirable slope were distinguished by means of ArcGIS Spatial Analyst tools (see table).

The results of our research (see table) showed that the area of territories destroyed by the field infrastructure can reach up to 5% of the total area of a key site. The total area of damage depends not only on the number of facilities, but also on the sizes of their placement areas. In the course of field research, it was revealed that damaged lands are often expanded because of adjacent territories use of which had not been planned. These lands suffer due to unstructured expansion of technogenic areas. For example, assuming that the lands that are occupied by the roads of the

Characteristics of direct effects of infrastructure facilities of oil and gas fields on key sites

Key site number and start year of subsoil development	Number of oil and gas production areas with facilities on key site	Density of road network on key site, km/ha	Oil and gas field road percentage of total density of roads, %	Percentage of lands disturbed by oil and gas field infrastructure, (production areas and roads) of key site total area, %	Percentage of production areas with facilities located within 500 m of watercourses of the total number of production areas, %	Percentage of production areas with facilities located on lands with a slope > 3° of the total number of production areas, %
1. 1989	13	0.031	22.31	0.88	0	0
2. 1949	158	0.034	58.94	3.67	37	0
3. 1977	34	0.014	50.44	1.38	14	10
4. 1990	12	0.02	27.87	0.93	0	0
5. 1945	49	0.036	56.98	3.35	21	5
6. 1947	98	0.032	58.41	5.18	57	13
7. 1961	168	0.034	49.20	4.39	38	1
8. 1974	120	0.027	35.69	3.04	13	12
9. 1997	9	0.021	12.38	1.16	4	4

oil and gas fields make up 12–59% of the key site road network, about one-fourth of these roads, at a rough estimate, are unofficial access routes. These roads are used by drivers of the departmental heavy truck transport for efficiency of movement. Without the possibility to act without oversight, disturbance of the topsoil and vegetation cover could be significantly lower. It is important to note that, in the development of oil and gas fields, continued expansion of new, operative areas to arrange additional facilities takes place. A continuous increase in the share of disturbed land until a field is completely depleted is a distinctive characteristic of the production of nonrenewable energy sources.

The data show that a considerable part of the facilities (in some cases more than 50%) are situated within the 500-m zone from watercourses and in production areas with a slope of >3° (see table).

In analyzing the modern structure of the landscapes that host oil and gas production and taking into account the scale of the process, it could be assumed that there are no well-defined ecological standards or construction and operation requirements in the Ural–Volga Region. However, this is not the case. For example, the scope of documentation on design/operation of wells has to include a section on the environment impact assessment. When choosing the location of facilities, remoteness from a watercourse and the surface slope have to be taken into account among other significant factors [12]. In practice, in many cases, these sections do not have crucial importance in agreeing projects and accepting decisions. The current environmental standards and requirements are often ignored in favor of increase, simplification, and cheapening of raw material extraction. Correlation of recommendations and the actual environmental situation on the fields shows that the sections on environment impact assessment often perform a decorative function. The problems of low-priority ecological components in the design and operation of facilities pose a large-scale character and reach the national level. For example, in the report submitted by the State Duma Committee on natural resources, environment management, and ecology, I.I. Nikitchuk concluded that "in every case, owners of enterprises who are going to produce and process raw material have received, one way or another, the environment seals of approval issued by the environmental and supervisory authorities, health and well-being support services, the General Expertise, etc." [14].

In addition, a serious drawback in methodological approaches to environmental assessment is their unification. The factors of differentiation of landscapes—-geographical zoning and the specific characteristics of natural complexes associated with that—-are generally ignored. For example, the water protection zone for watercourses is established depending on their length [14, p. 65). However, in some cases, even water bodies in which the water meets fishery management requirements are in danger of pollution and/or eutrophication, because they are at a distance of less than 100 m from the field facilities. It is our opinion that amid the growing global freshwater deficiency, it is necessary to correct the value of water bodies for the low-flow areas. Each waterbody has to be considered in terms of minimization of harmful effects, in this case the remoteness of waterbodies from potentially hazardous facilities has to be no less than 500 m.

CONCLUSIONS

Inefficient development and use of the project documentation sections and high loyalty of the supervisory authorities to the companies and subsoil users in operation of facilities are the principal causes of environment degradation of the steppe landscapes. Nothing but the environment impact assessment, which is independent of the subsoil users, and professional increase in supervision over the current land-use patterns will provide conservation and restoration of the steppe landscapes. Failure to follow the above requirements will result in unavoidable technogenic degradation of these areas. The aftereffects of degradation have already resulted in the formation of environmentally neglected zones and disasters.

ACKNOWLEDGMENTS

This work was carried out within the scope of the research scientific work of the Steppe Institute, Ural Branch, Russian Academy of Sciences, project no. GR AAAA-A-17–1170/26/0022–5.

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Translated by V. Krutikova