Geo-ecological features of the transformation of the natural environment (a case study of oil and gas field development in the Chechen Republic)

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Abstract. The article analyses the transformation of the natural environment of the Chechen Republic resulting from the development of oil and gas fields. The Chechen Republic has physical and geographical features that are reflected in the complex differentiation of its mountainous landscapes, associated with the location of the territory at the junction of various tectonic formations and faults. The authors mapped the main areas of oil and gas fields, varying in terms of the development of the oil and gas complex and its impact on landscapes. The results of field studies with a sampling of soil, water, plant ash and bottom sediments assess the ecological-geochemical situation that has developed in the republic, and Grozny in particular, over recent decades.

1. Introduction

Oil and gas are nowadays the main fuel and energy and raw material resources with a huge impact on economic and social development [1]. However, we should note that the oil and gas industry belongs to the list of the dirtiest technologies, ranking third among 130 industries of modern production in terms of environmental impact hazard [2]. Oil and gas facilities at all stages of construction and operation have a negative impact on the components of the natural environment. Moreover, the development of the oil and gas industry at the present stage features an increasing technogenic impact. The processes of creation and operation of oil and gas industry facilities lead to the transformation of natural complexes and the formation of a new landscape-technogenic structure with its ersatz of natural elements [3].

The development of oil and gas fields in the Chechen Republic followed low-tech waste management schemes. The long-term impact of the oil and gas complex resulted in profound changes to the landscape structure of the region. At the same time, there was contamination of soils, grounds, surface and underground waters in places of intensive development of oil and gas fields (Fig. 1) [3–6]. Moreover, the development of oil and gas fields contributed to ground deformation, shifting formations, increased landslides, and earthquakes (6). Therefore, timely measures to eliminate the consequences of pollution require geo-ecological analysis of the territory of the republic and operational methods of mapping the spatial boundaries of pollution to develop a set of science-based measures to optimize the natural environment.
Figure 1. A generalised scheme of the impact of oil and gas facilities on the natural environment (compiled by the author based on: Solntseva, 1998 [2]; Haustov, Redina, 2006 [7]; Yakovlev, 1979 [8])

2. Materials and methods
The work is based on field and expedition studies (2001-2004; 2007-2008 and 2014-2019) conducted in the territory of the Chechen Republic to assess the impact of the oil and gas complex on the natural environment. In addition, it included the interpretation of NOAA, Landsat-5,7 and Ikonos satellite images.

The geochemical pollution of the Grozny area was assessed by sampling soils, surface water, bottom sediments and plant ash. The researchers took 16 soil samples each from eight 300x300 metre sites set up in different parts of the city limits.

In addition, three geochemical profiles across the floodplain of the Sunzha River were sampled for water, soil and vegetation. The study collected a total of 145 soil samples within Grozny: 36 vegetation samples and 6 water samples from the Sunzha River, and analysed them for the content of heavy metals and some organic compounds.

The main assessment methods involved the field method, the area method and the profiling method.

3. Results and discussion
3.1. Physical and geographical features of oil and gas field development
Many oil and gas bearing areas of the world demonstrate a close spatial relationship between oil and gas content and the activity of crustal blocks at their boundaries, especially disjunctive nodes. Block structure is observed not only in the structure of oil and gas bearing basins or oil and gas accumulation zones, but also in the structure of the fields themselves. The majority of the large and giant oil and gas fields have been identified as young, having formed mostly during the Neogene and Quaternary periods [9].

Oil and gas fields in the Chechen Republic are located close to active tectonic fault zones. They belong to the foremost ranges of the Tersk-Sunzhenskaya Upland and the Chechen piedmont sloping
plain. The anticlinal folds of the Front Range have widely developed longitudinal strike-slip and thrust faults formed under compression conditions. Their activity led to the formation of complex plicata structures, broken up into separate blocks. This, in turn, determined the complex structure of oil and gas deposits confined to the Miocene sediments of the Tersky and Sunzhensky ridges [10]. The confinement of oil and gas fields to transition zones of large physiographic countries and regions has determined the heterogeneity of development conditions and landscape dynamics in the Chechen Republic at various stages of development.

Given the physical and geographic differentiation of the territory of the Chechen Republic, as well as the geological and tectonic features and conditions of oil and gas occurrence, we identified three main areas of impact on landscapes: 1 - Priterechny - terraces of the Terek River. Terek River terraces with dry steppe and azonal floodplain vegetation (including ravine forests); 2 - Submontane ridges and intermountain hollows (Tersk-Sunzhenskaya Upland and Chechenskaya Plain) composed of Neogene sedimentary rocks and Quaternary sediments with steppe and forest-steppe vegetation; 3 - Chernogorsky - low mountain ranges composed of Paleogene and Neogene sediments with broad-leaved forest and post-forest meadow vegetation (Fig. 2). Anthropogenic activities, primarily related to oil and gas development, have been leading factors in the formation and dynamics of these landscapes over the past 100 years.

The development of oil and gas fields has had a very strong impact on the urban landscapes of Grozny, where long-term oil and gas operations have caused severe pollution of the geological environment. Large accumulations of technogenic lenses of hydrocarbons in the geological environment of Grozny have become a constant source of groundwater pollution, with oil product content ranging from 1.1 to 4 mg/l, and phenols up to 4.1 mg/l [3]. Liquid hydrocarbons accumulated underground, together with groundwater, transport pollution from the place of its formation over long distances, with the oil products accumulated underground partially seeping into surface water.

The environmental consequences of anthropogenic impacts associated with the development of oil and gas fields are very diverse in form and severity. They cover the entire fishing territory and extend beyond it. There is a restructuring of landscapes: complex complex anomalies are formed - natural-technogenic systems that differ significantly in their properties from the properties of the original landscapes [11, 12].
Figure 2. The main areas of the Chechen Republic affected by oil and gas development
3.2. Ecological-geochemical assessment of the territory of the Chechen Republic

The ecological and geochemical assessment of the territory, based on the results of field studies and processing of materials of modern multizone survey from LANDSAT-7, showed that the ecological situation is rather tense only in the central parts of the Republic, with the oil and gas facilities, as well as in old oil fields, where during the war numerous oil leaks from flowing wells and accidents at oil pipelines took place [3]. However, we should note that we surveyed particular areas of settlements: Grozny, Gudermes, Argun, Urus-Martan, Belgatoi, Dzhalka, Mesker-Yurt, Mekenskaya, Chervlennaya, Sernovodsk and others. Analyses are performed for the most toxic elements. The calculation of the total pollution index for soils used elements of hazard class I, II whose concentration coefficient exceeded 2 or more times.

The results of the eco-geochemical assessment of soil sampling in the settlements of the republic revealed an excessive content of hydrocarbons, Pb, Zn, Cu, Cd, Sr and other pollutants. Table 1 shows the results of the soil sampling.

| Settlement      | Value of the total pollution indicator (Zc) in conventional units | Geochemical associations of the leading pollutants. (Numbers indicate the value of the concentration factor) |
|-----------------|---------------------------------------------------------------|--------------------------------------------------------------------------------------------------|
| Grozny          | 26.4                                                          | Pb_{13}, Zn_{11}, Cd_{3,5}, Hg_{2}, Sb_{5,4}                                                    |
| Gudermes        | 19.1                                                          | Pb_{11}, Zn_{7}, As_{3,6}                                                                        |
| Urus-Martan     | 12.1                                                          | Pb_{1,1}, Zn_{3,1}, Sr_{2}                                                                       |
| Argun           | 9.7                                                           | Pb_{12}, Zn_{3,1}, Cu_{3}                                                                        |
| Makenskaya      | 9.4                                                           | Pb_{11,2}, Zn_{4}, Cd_{2,1}                                                                        |
| Chervlennaya    | 8.1                                                           | Pb_{2,1}, Zn_{3,2}, Sr_{2,2}                                                                      |
| Dzhalka         | 8.4                                                           | Pb_{2,6}, Zn_{1,6}, Sr_{2,1}, Mo_{5,2}                                                           |
| Mesker-Yurt     | 7.1                                                           | Pb_{3,2}, Zn_{2}, Sr_{1,9}                                                                       |
| Belgatoi        | 8.3                                                           | Pb_{3,2}, Zn_{2,7}, Sr_{2,1}                                                                      |
| Sernovodsk      | 7.2                                                           | Pb_{2,3}, Zn_{2,1}, As_{2}                                                                       |

The results of analytical processing of soil samples in Grozny showed that the main polluting elements in urban landscapes include: Pb, Zn, Sb, Cd, Cu, Hg, as well as benz(a)pyrene and oil products. Combustion products contain Hg, Cd, Rn, dioxides, benz(a)pyrene, etc. [3]. The values of the total soil contamination index (Zs) of heavy metals for urban areas, on average, exceed the highly hazardous level (20-30 conventional units), and in some points - the extremely hazardous level (128 conventional units).

4. Conclusions

Oil and gas fields in the Chechen Republic belong to transitional zones of physiographic countries and regions, with the local morphostructural features playing an important role in the stability of occurrence and the way of oil and gas field development.

Low environmental friendliness of technological processes used in the development of oil and gas fields is the main reason for the formation of an extensive area of pollution, which has a negative impact on the components of the natural environment of the Chechen Republic.

The detailed eco-geochemical assessment of Grozny's urban landscapes, identifying heavy metals and organic compounds of anthropogenic origin, has shown that the sources of pollution are confined to the sites of oil and gas field development.

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