Methodology for integral assessment of environment state dynamics and its components in coastal-marine region of Western Yamal

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Abstract. Recently, various monitoring programs have been operating on the territory of the permafrost zone, this is associated with both the development of the permafrost zone for various practical purposes, and with the growing interest of the scientific community in global environmental change trends (including the climatic changes). Under the influence of an anthropogenic factor or natural processes independent of humans, negative changes can occur in the territories occupied by permafrost, accompanied by environmental crises, natural or man-made disasters. To prevent such changes or take timely measures to protect and eliminate the consequences, it is necessary to understand the essence of the processes occurring in the permafrost zone, as well as develop plans for the balanced development of territories. The work is aimed at studying major natural phenomenon, i.e. the formation of specific geoecological conditions in the transition region from land to sea under climate change. The article discusses the proposed basic principles of the integral (point-rating) assessment of the dynamics of geoecological state of natural environment of the coastal-marine region of Western Yamal under climate change. The information basis of the proposed methodology for the integral assessment of the dynamics of the state of natural environment is the analysis of changes in the parameters/factors of natural and man-made environment, reflecting the composition, structure, and state of its individual components, and determining its geoecological state with climate change.

1. Introduction
Related to observed climate dynamics, the study of geoecological processes becomes especially relevant when drawing up long-term plans for the development of climate-dependent sectors of economic activity.

The climatic condition changes:
• affects the social and economic activity of the regions, living conditions of people and human’s health;
• leads to changes in the natural environment and is reflected in the species composition of flora and fauna, river runoff and level, weather conditions, seasonal rhythm;
• leads to the degradation of permafrost, spread of areas of natural focal diseases, etc., creates a fire hazardous situation and provokes environmental disasters.

Climate change is causing reversals, both negative and positive.
Assessment of changes in geoecological conditions in the Arctic, with climate warming and industrial development, has become a priority problem in recent decades. Changes in climatic conditions affecting the permafrost, sea hydrology, as well as the potential increase in negative anthropogenic pressure associated with the growth of oil and gas production in the Arctic and the development of related infrastructure, sharply increase the level of geoecological risks. Climate and environmental change is changing the conditions for land use.

2. Results
The work is aimed at studying major natural phenomenon, i.e. the development of specific geoecological conditions in the transition region from land to sea under climate change. The data of the adapted monitoring geoecological observations are the basis for the analysis of the processes of changes in the natural environment, as well as for the verification of mathematical models.

A set of studies, including climatic, marine hydrological observations, the study of morphology and landscape structure, dynamics of permafrost and unfavorable cryogenic processes, was carried out on the western coast of Yamal in the area of the Marre-Sale geostationary. The territory was chosen as a model because all the features of the natural environment are present and manifested here. In the Marre-Sale region, the main morphological levels are represented, i.e. the third sea terrace, low and high river floodplains, modern low accumulative formations (marine laids). The territory belongs to the typical tundra with a full set of characteristic plant communities. Continuous permafrost is ubiquitous. The peculiarities of land use are the combination of the traditional way of life of indigenous peoples and industrial oil and gas development on one territory.

The proposed basic principles of the integral (point-rating system) assessment of the dynamics of geoecological state of natural environment of the coastal-marine region of Western Yamal under climate change are as follows:

1) sustainability is assessed using indicators characterizing the variability (dynamism) of the geosystem: the more dynamism, the less sustainability, and vice versa;
2) the values of these indicators should be the result of the implementation of the largest possible number of intrasystem connections: the more connections, the more representative the indicator.

In the integral assessment of indicator dynamics (the environmental factors affecting the geoecological situation) for a given territory with low anthropogenic impact (social and economic and economic function is insignificant) a classification and cartographic approach was applied (the classification of climate change indicators by environmental impact).

The information basis of the proposed methodology for the integrated assessment of the dynamics of state of natural environment is the analysis of changes in the parameters/factors of natural and man-made environment, reflecting the composition, structure, state of its individual components, and determining its geoecological state, with climate change.

The dynamics of geoecological conditions of the coastal-marine region of western Yamal under climate change was quantitatively assessed using the ecological-geoinformation approach, landscape-indicator method, GIS technologies, Earth remote sensing data and those created on their basis; small-scale assessment maps, including forecast estimates based on climate and oceanographic databases, long-term field measurements and mathematical modeling.

The methodology for the integral assessment of geoecological state dynamics of natural environment of coastal-marine region of Western Yamal includes the following provisions:

- determination of a set of indicators/factors of the natural environment that affect geoecological situation;
- identification of reversible indicators of environmental change;
- ranking the levels of geoecological disturbance (destabilization);
- identification of a set of assessment criteria for geoecological stress of environment;
- technology of substantiation of scale of point-rating assessment of the dynamics of geoecological conditions, based on the selected assessment criteria, in relation to the indicators of the stability of the geosystem, taking into account the reversible indicators.
• integral (point-rating system) assessment of the dynamics of geoecological conditions of coastal-marine region of Western Yamal in relation to the indicators of the stability of geosystem, using GIS technologies and based on the developed methodology.

  Geoecological changes occur in all components of the geoecological environment; however, this paper considers those that can be assessed based on the data obtained.

  **The set of criteria for the dynamics of the state** of the geoecological environment was developed on the basis of a four-rank assessment structure, and correlated with the indicators of geosystem stability. To assess the dynamics of geoecological conditions of the coastal-marine region of Western Yamal, a point-based approach was chosen, where each indicator (environmental factor affecting geoecological situation) was assigned a point from 1 to 10. The points are calculated as a percentage relative to the geosystem stability indicators.

  **Ranking the levels of geoecological disturbance (destabilization).** According to the Law 7-FZ “On Environmental Protection” the following categories of geoecological situations are distinguished taking into account the degree of severity:

  I) favorable or normal, and

  II) intense of varying degrees of severity: 1 - relatively satisfactory; 2 - conflict; 3 - tense; 4 - critical (acute); 5 - crisis (or zone of emergency ecological situation); 6 - catastrophic (or zone of ecological disaster). For the study area the degree of ecological problem is defined as conflict (II.2) and tense (II.3), that is, an area characterized by the presence of irreversible processes that negatively affect the state of ecosystems [1].

  The assessment of the degree of ecosystem degradation was carried out according to criteria that determine negative changes in the structure and functioning of ecosystems and take into account their spatial differentiation by the degree of disturbance, as well as the dynamics of degradation processes [2, 3].

  **Algorithm for identifying a set of evaluation criteria for changing the dynamics of geoecological conditions in the coastal-marine region of Western Yamal:**

  • **Atmospherical temperature:** change by 1.5°C [4-6].

  • **Pressure** relative to the change in days with normal pressure (1012.10-1012.50 hPa) and the change in the number of cyclones and anticyclones.

  • **Summer period duration:** if it exceeds 60 days, considering that an increase and decrease in the duration of the summer period by 2 months will lead to catastrophic consequences.

  • **Degree Days Temperature (DDT) and DDT^{1/2}:** change relative to the number of days with positive temperatures (100% maximum).

  • **Wind speed:** based on the increase in the number of storm winds (assuming 100% is all storms).

  • **Wave height:** according to the increase in storm waves (100% is all storms).

  • **Height and density of snow cover (in%):** relative to the initial one, taking into account that a 100% increase in height/density of snow cover will lead to maximum waterlogging of the territory and, at the same time, an increase in the stability of the geosystem [7-9].

  • **Permafrost temperature:** (transition through 0°C). An increase in soil temperature contributes to the transition of soils from a solid-frozen state to a plastic-frozen and thawed one.

  • **Retreat of the sea coast** is taken as 100%. To take into account the coastal retreat: a) the information material was analyzed and the ArcGIS software package was selected; b) changes in the coastline were determined, both from ground-based observations for the period 1978-2020, and from space images.

  • **Accumulation rate** (accumulative surface) is the reciprocal value of coastal degradation [10].

  • **Depth of seasonal thaw depth (STD):** thawing to the depth of the permafrost degradation zone (2 m) is taken as the maximum; and the change in the STD depth over the study period.

  • **Cryogenic processes.** To take into account cryogenic processes the following was accomplished: a) the information material was analyzed and the ArcGIS software package was selected;
b) the main cryogenic processes influencing the erosion processes used in the GIS model were determined; c) there were categorized cryogenic processes (areal swelling, frost cracking, cryogenic cracking, wind erosion, solifluction and cryogenic landslides) and determined their intensity in the study area. The GIS model takes into account the parameters that greatly affect the development of the intensity of cryogenic processes: coastal retreat, digital elevation model (DEM) of the study area, landscape structure, orographic features (absolute height, slope steepness, etc.), precipitation and vegetation, STD, DDT.

- **Vegetation** change (in % for the model site): based on the DEM and overlapping landscape maps of 1978 and 2019, taking into account the change in species composition [11].
- **Anthropogenic impact**: it is extremely small in the study area, but it has almost irreversible effect leading to persistent negative changes in the state of natural ecosystems, i.e. a decrease in the species diversity, the disappearance of certain species of plants and animals, and even the destruction of natural geosystems, i.e. violation of natural balance, degradation of flora and fauna, loss of the gene pool.

**The scale of point-rating system of the dynamics of geocological conditions in the coastal-marine region of Western Yamal.** Each indicator/factor is rated on a 10-point scale. Points are calculated on the basis of the selected evaluation criteria as a percentage relative to the indicators of the stability of the geosystem, taking into account the reversible indicators: 5 points (0%) correspond to geocological stability (no changes, normal rate); points from 4 (25%) to 1 (100%) correspond to the stability increase of the geosystem; points from 6 (25%) to 9 (100%) correspond to decrease in geosystem stability; 10 (100%) points show complete destruction of the geosystem (disaster) (Table 1) [12].

**Table 1.** Integral (point-rating system) assessment of the dynamics of geocological conditions of coastal-marine region of Western Yamal in relation to the stability indicators of the geosystem (fragment)

| Rate of change                          | Years                        | Measurement start value | Measurement end value | Change | Unit | Points |
|-----------------------------------------|------------------------------|-------------------------|-----------------------|--------|------|--------|
| **Climate**                             |                              |                         |                       |        |      |        |
| Atmospheric temperature Average annual  | 1914-2019                    | -8.30                   | -7.2                  | 1.10   | °C   | 7      |
| *Sea hydrology*                         |                              |                         |                       |        |      |        |
| Seawater temperature Average annual    | 1998-2019                    | -1                      | 3                     | 4.00   | °C   | 10     |
|                                          | Average annual offshore      | 1920-2005               | -1.7                  | -0.4   | °C   | 8      |
| **Permafrost soil and landscape structure** | 1979-2019                    | -6.2                    | -4.5                  | 1.70   | °C   | 9      |
| Permafrost temperature conditions Annual T |                              |                         |                       |        |      |        |
| Vegetation cover Occurrence, projective cover | 1978-2019                    | 1                       | 2                     | 1.00   | %    | 5      |
| Anthropogenic impact Disturbed/undisturbed | 1978-2019                    | 15                      | 9                     | -6.00  | cm   | 4      |
| **Average**                             |                              |                         |                       |        |      |        |

3. **Conclusion**
Geoecological conditions can still be considered quite stable (7 points, > 50%) with the exception of cases of industrial development, where the anthropogenic load may exceed the adaptive capabilities of natural environment.

To take into account possible consequences when the geocological conditions of the coastal-marine territory change, geographic forecasting is of particular importance, i.e. the scientific study of specific opportunities for the development of geographic phenomena.
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