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Environmental Monitoring of Total Hydrocarbon Contents in Fjords of Svalbard, Grönfjord

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Abstract

Hydrocarbon levels in Grönfjord (the Greenland Sea, Svalbard) were assessed in this study. The field works were held in the marine expeditions of the North-Western Branch of Research and Production Association "Typhoon" (NW FSBI RPA "Typhoon") onboard RV "Barentsburg" in summer periods 2012-2022. Simultaneous measurements of hydrological and hydrochemical characteristics of the water column were done. The results showed pronounced interannual variations of total hydrocarbon contents. It is supposed that local natural sources contribute to some elevated total hydrocarbon content levels both in the water column and in the bottom sediments of the fjord. Some local elevated petroleum hydrocarbons concentrations, detected in the surface water layer and locally in sediments, imply existing industrial activity affecting the waters of the Grönfjord.

Keywords

Spitsbergen, Hydrocarbons, Sediments, Environmental Monitoring, Sampling Surveys, Contaminants

1. Introduction

The article presents long-term studies of the content of petroleum hydrocarbons and the total hydrocarbon content (THC) in the waters of Grönfjord where the assessment of seasonal fluctuations in concentrations is very complicated due to

the length of openwater period. For the purpose of environmental monitoring and assessment of the levels of pollution, it is very important that the specialized hydrochemical data banks should be created and updated. It has been repeatedly demonstrated that in environmental damage assessments, it is very useful to have information about sources of hydrocarbons present in the affected area before accidents or any human activities [1] [2]. Together with volumes of water, rivers carry mineral and organic suspensions, dissolved mineral substances. All this geoflow, regulated primarily by the magnitude and regime of water runoff, has a powerful direct and indirect impact on the natural situation of the coastal, hydrophysical processes and ecological conditions of the Arctic seas [3]. Identification of environmental factors of a cyclic nature makes it possible to conduct a comparative analysis of transformations and substantiate the effect of a polluting factor. The main objective of the study is to receive new information on the concentration of contaminants of anthropogenic origin such as oil hydrocarbons (in measures of total hydrocarbon contents (THC). The results of the study are supposed to present a comprehensive assessment of degree of anthropogenic impact, accounting for oil pollution and can possibly help to identify the processes between ongoing changes and influencing factors.

2. Materials

Materials of the research are based on data collected on the Svalbard archipelago located in the high Arctic (76˚N-80˚N) within the northernmost reach of the West Spitsbergen Current (WSC), in this specific setting close to the Polar Front, where even small variations in the system of flows are expected to give large and distinct signals in paleoceanographic parameters [4].

A brief discussion of the study's limitations

The fjords of Southwest Spitsbergen (European Arctic) are a climatically sensitive area, where warm Atlantic water-masses meet cold Arctic Water. There are sufficient long-term series of reliable observations of physical characteristics of seawaters and only some fragmentary data on the hydrochemical parameters of the aquatic environment, particularly, in regards to the content of oil hydrocarbons in seawater/bottom sediments. For the purpose of environmental monitoring it is very important that the specialized hydrochemical data banks should be created and updated. Still there are some limiting factors such as the induced focus on summer sampling periods, which causes omissions of episodic pollution events. Still, the results of the survey showed that Grönfjord is a fairly representative study area. When examining the state of knowledge, it is clear that the main problem now is the unevenness of the study of issues related to the geology, petrology, and tectonics of the pre-Devonian and Devonian complexes of this region.

2.1. Work Area

Isfjord, cutting into Western Svalbard near Barentsburg with coal mining areas

located nearby is an important navigable area. Grönfjord is the southwestern creek of the Isfjord. It is located between 77˚07'N and 77˚58'N latitude and 13˚56'E and 14˚20'E longitude in the western part of the archipelago and extends meridionally to the South-South-East. The North European Basin (NEB), including the Norwegian and Green-land Seas, plays a key role in water exchange between the Arctic Basin (AB) and the North Atlantic (NA) is a significant energy-active zone due to its geographical position [3] [5]. This is due to the fact that Grönfjord extends deep into the glacier-covered land and at the same time it has free exchange with the atmosphere and hydrosphere of the Arctic Ocean.

The West Spitsbergen Current (WSC) forms powerful cyclonic eddies in the central part of the Greenland Sea (maximum depth—about 4800 - 5527 m). The formation of the hydrological regime of the fjords of the West Spitsbergen Island is under the influence of several factors: the inflow of warm saline Atlantic waters, the inflow of relatively desalinated cold Arctic waters, river runoff and the processes of ice formation and ice melting [6] [7]. The main body (from the horizon of 40 m to the bottom) of Grönfjord is occupied by slightly warmer intermediate waters of 34.0‰ - 34.7‰. Owing to reasonably high accumulation rates, these settings are especially suitable for providing high resolution sedimentary records of regional hydrological and environmental changes.

The study area covers Grönfjord—a part of the bigger Isfjord, Spitsbergen archipelago, Greenland Sea) (**Figure 1**).

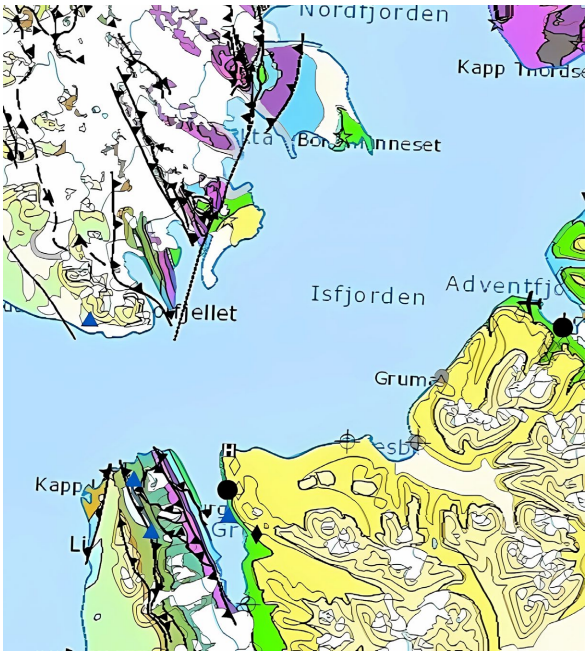

Figure 1. Observation area, Grönfjord (https://svalbardkartet.npolar.no/).

There is also a considerable number of watercourses in the area, which contribute to the accelerated rate of sedimentation in the basin [8]. Sedimentation then also undergoes spatial and temporal changes associated with the dynamics of the

aquatic environment. More fine-grained material is carried out seaward, the bulk of the terrigenous material comes in the form of a solid runoff of rivers due to the transfer from land, providing the supply of pollutants, including oil products. Bottom sediments, having a high sorption capacity, accumulate petroleum hydrocarbons, which in cold arctic conditions can be stored for a long time due to extremely slow bio-degradation processes. In these specific settings close to the Polar Front, even small variations in the system of flows are expected to give large and distinct signals in paleoceanographic parameters [4].

2.2. Methods

All chemical analysis of sediments were carried out by NW FSBI RPA "Typhoon" in accredited methodology for PAH/THC analyses. THC has been analysed by gas chromatography with flame ionization detector. The onboard works were conducted as a part of the ongoing state monitoring programme. Background observations were carried out in order to study interannual variability at stations, located in the areas with lower levels of pollution, or in the clean waters. In general, samples of local monitoring were taken at stations adjacent to the territory of Barentsburg in East Grönfjord. The location of the stations was chosen according to geomorphological characteristics of the bottom and the configuration features of Grönfjord coastline. Sea water samples were taken onboard with the use of Niskin bathometer with a volume of 5 - 10 *l* for two horizons (surface and bottom). Bottom sediment samples were taken by a Van Veen grab, an instrument to sample (disturbed) sediment up to a depth of 15 cm in the seafloor. Sampling, preservation and chemical analysis was carried out in accordance with GOST 17.1.3.07-82 [9]. All samples were collected in accordance with guidance documents [10] [11].

3. Data

In this study in order to determine the levels of pollutants, including petroleum hydrocarbons, NW FSBI RPA "Typhoon" took water samples in surface and in near-bottom layers in the eastern part of Grönfjord in the area adjacent to the territory of Barentsburg where the sea depth reaches 110 m with an average depth of 49 m and in the western part in the adjacent waters at depths ranging from 7 to 11 m. The article is based on data collected in field surveys in the period 2012-2023 presenting concentrations of total hydrocarbon content (THC) (μg/dm^3) in the area. A series of samplings was done in surface and in near-bottom sea waters. The sampling surveys were performed in the period of transition from summer warming phase with the maximum influence river runoff to autumn cooling phase with a reduced river runoff. In total 362 water samples were collected in surface and in bottom layers of the water column and analyzed for petroleum hydrocarbons.

The results of THC study (μg/dm^3) in surface waters showed average concentrations ranging from 5 to 22 μg/dm^3 with a local maximum of 86 μg/dm^3 (station

14) at the mouth of Grönfjord. An increase in the content of hydrocarbons in surface layer is determined in the range of 33 - 70 μg/dm³ (at stations 28, 26) in the coastal areas of Grönfjord.

4. Results

4.1. Results of THC Study in Surface Waters

For the study area, the average and elevated THC were annually determined. THC plots (Figure 2) depict sampling results for the surface horizon. Approximately similar values of average and maximum concentrations were observed in the surface and bottom layers at the stations furthest from the shore. An increase in the concentration of petroleum hydrocarbons in the surface layer occurred in the coastal areas of the fjord in 2013, 2014-2015, and 2016 (Figure 2).

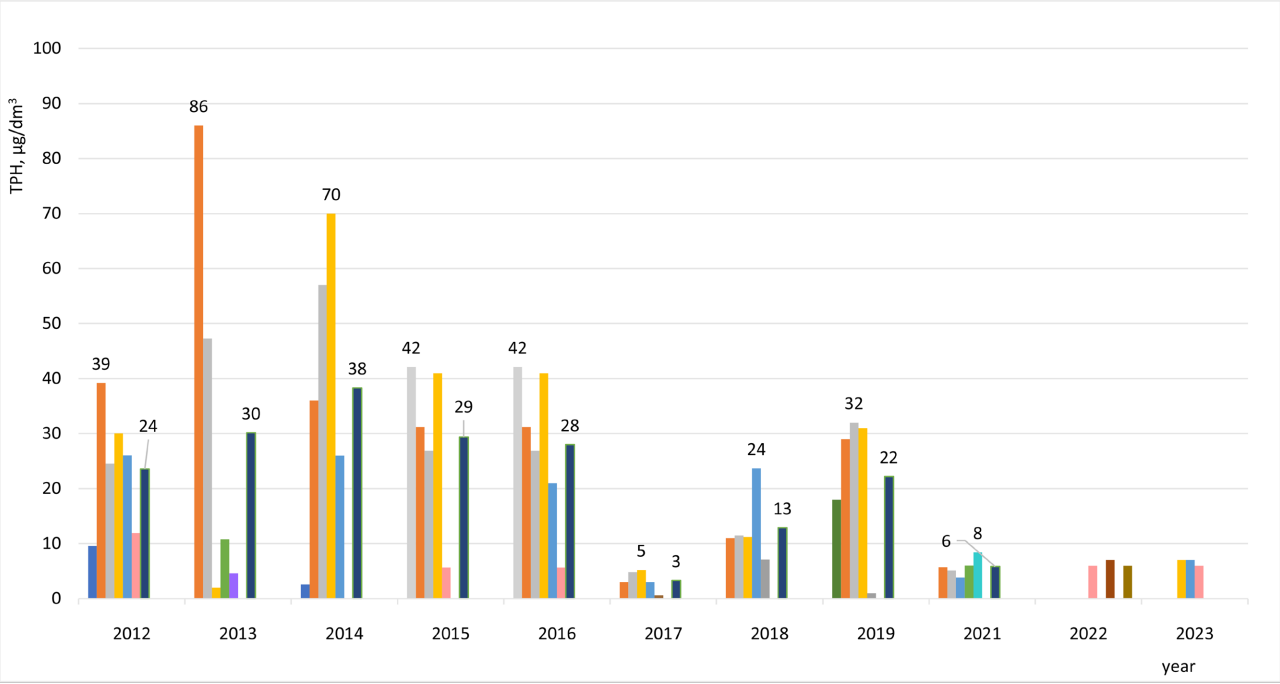

Figure 2. Long-term changes in maximum and average THC concentrations in near-bottom layer, μg/dm³ in Grönfjord (2012-2023).

The maximum values of the total content of petroleum hydrocarbons for the period from 2012 to 2023 in surface waters in different areas of the fjord varied from 18 (in the open part of the bay) to 85 (in the area where the stream flows into the fjord, near the village of Barentsburg). For different areas of the sea, the average concentrations of petroleum hydrocarbons in the studied area of the Spitsbergen archipelago decreased sequentially from the station located in the area of the stream (23 - 21 μg/dm³) to the station located north of the village of Barentsburg (9 - 6 μg/dm³) and then to the open sea.

In recent years elevated values declined and reached 3 μg/dm³ (in 2021). Earlier, in 2016 average concentrations were approximately at the levels of 2015 and lower than those of 2014, 2015 (averaged to 29 - 38 μg/dm³) reaching up to 42 μg/dm³

at the western margin of Grönfjord.

In surface waters hydrocarbon content varies on a broad range: from 5 to 22 μg/dm^3 with a local maximum up to 86 μg/dm^3.

In 2012 THC ranges at lower levels than concentrations in 2013 (from 9 to 39 μg/dm^3 at average of 19 μg/dm^3). In the waters of the eastern part of Grönfjord THC varies from 2 to 86 μg/dm^3 (starting from the outer area towards the area of the confluence of the stream flowing through Barentsburg).

In 2014, 2015 THC varied mainly within 2 - 70 μg/dm^3 (beginning from the northern part of Grönfjord to the area of confluence of the stream flowing through Barentsburg), at average 26 μg/dm^3. In 2016 THC concentrations ranged from 5 to 42 μg/dm^3, in 2017 THC varies at levels from 0.6 to 5 μg/dm^3. In 2018 concentrations range from 7 to 23 μg/dm^3 raising in direction from the adjacent water area of Billefjorden to the north of Barentsburg. In 2019 THC varied from 1 to 32 μg/dm^3 northward of Barentsburg at average value of 15 μg/dm^3. In 2021 THC concentrations ranged from 3 to 5 μg/dm^3 at average about 4 μg/dm^3. For different areas of the sea, the average THC in the study area decreased starting from station 14 (22 μg/dm^3) to the water area north from Barentsburg (station 27 (9) and further to the of Grönfjord outlet (station 33 (5) (Western part < Central part). In 2019 the highest values of THC (70 - 86) were observed. Maximum values of THC varied from 2012 to 2023 in different areas of Grönfjord in the range: 11 - 86 μg/dm^3 (from the open part to the area at the mouth of Grönfjord near Barentsburg (station 14). The range of values in surface layer is somewhat broader than in near-bottom layer, the results of which are discussed below.

4.2. Results of THC Study in Near-Bottom Waters

In 2016 the results of the study of THC (μg/dm^3) in near-bottom waters are detected at maxima of 35 μg/dm^3 in the main parts of the gulf; in 2018 concentrations - 38 μg/dm^3 (in the area north of Barentsburg); in 2019 - 42 μg/dm^3 in the area at the mouth of the stream flowing through Barentsburg (in total - 10 μg/dm^3). In 2017 in the gulf outlet concentrations turned out to be lower than in previous years, their content in 2016 averaged to 21 μg/dm^3. The average THC concentrations decreased for different areas in sequence: from the station 14, located in the area at the mouth (22 μg/dm^3)—to the station 27 in the direction to the north of Barentsburg (9 μg/dm^3) and to the open part of the gulf (5 μg/dm^3). The results revealed pronounced interannual variations of THC concentrations near the bottom in the study period. Basically, in near-bottom layer, the THC content at almost all the stations is lower than that in surface layer, with some exceptions for 2 stations - 27 and 12 μg/dm^3.

In 2019 among all controlled areas of the gulf, the highest value of the average concentration of petroleum hydrocarbons reached 42 μg/dm^3 in near-bottom layer. Herein, THC content in near-bottom horizon is 1.5 - 3.6 times higher than in surface layer. Such features in the distribution of hydrocarbons can be explained by water dynamics in near-bottom layer [12] contributing to resuspension

of sediments and formation of elevated amount of suspended matter and higher concentrations of hydrocarbons. Besides, at some stations elevated levels of hydrocarbon concentrations can be associated with HC fluid flows from the sedimentary layer suggesting migration of hydrocarbons from deeper sediment layers. Rapid sea-level drops, tectonic uplift, and re-activitation of faults may be responsible for the leakage of hydrocarbons [13]. The results showed that THC had substantial reduction the last years (2021, 2022) supposing a reduction in revenue from natural sources and transport of contamination in near-bottom layer. Results of long-term marine environmental monitoring in the Grønfjord area indicate its waters moderately polluted, elevated values localized primarily in the area of port and energy facilities. According to the Water Pollution Index (WPI), most observations classify the waters as quality class II (clean) [5] [14]. However, in the coastal zone (**Figure 3**), isolated exceedances of maximum permissible concentrations (MPCs) for total petroleum hydrocarbons and phenol are occasionally recorded, while in the deepwater zone, such instances are rare. As defined, WPI assesses the degree of pollution in water bodies based on the concentrations of various physical, chemical, and biological parameters with a goal to integrate water quality data into a single numerical result to simplify interpretation (shunwaste.comresearchgate.netjournals.plos.org). The WPI takes into account the observed concentration and the maximum permissible concentration for each parameter. An assessment of marine water quality in accordance with fisheries regulations allowed to classify the waters of the surveyed Grønfjord waters near Barentsburg in summer 2021 as "dirty", class *IV*. Noted that since 2017, there has been a trend toward increasing pollution of Grenfjord's marine waters [15].

Figure 3. The shore of the Grönfjord, Svalbard, 2022 (https://commons.wikimedia.org/wiki/File:Дальний_берег_залива_Грён-фьорд.jpg).

Bottom sediments of Grønfjord Bay consist of silts, silty sands, and sands mixed with pebbles and gravel. The highest concentrations of nutrients were found in

the silty sand of the coastal section of the bay, which is exposed to wastewater from the adjacent territory. Bottom sediments are characterized by elevated concentrations of petroleum products; the elevated values of which occur in areas of technological activity. However, intervention levels according to international criteria ("Neue Niederlandische Liste. Altlasten Spektrum 3/95") were not achieved, indicating a moderate impact on the fjord ecosystem during the analyzed period [5] [14] [16] [17].

However, according to the previous results local natural sources may be a cause of elevated concentrations of hydrocarbons in bottom water and in bottom sediments.

5. Conclusions

This study assessed THC in Grönfjord—in a navigable area, which is due to escalating economic activities exposed to a risk of oil spill. In the study region with the concentration of various marine users in a small coastal area in order to avoid the land use conflicts and preserve the unique ecosystem sustainable management regulations are highly recommended.

The results depicted the distribution of the elevated hydrocarbon levels. Since 2017, there has been an increasing tendency in the degree of pollution for surface waters. The maximum concentrations for near-bottom waters are depicted at a depth of 85.5 m at the station in the southern part of Grönfjord (42 μg/dm^3). Generally, elevated THC concentrations at horizons of 20.5 - 110.0 m are typical during the period of ice melting or a sign of supplies of petroleum hydrocarbons in navigable areas. The results highlight the necessity to continue monitoring the volatility of the parameters in continuous observation of the state of the Grönfjord waters. Though no exclusively anthropogenic impact on the water body was depicted in this study some local concentration maxima for THC in the surface horizon may be an evidence of a marked anthropogenic impact on the water area along the coastline indicating that many processes in the North European Basin require further continuous research. In days to come summer hydrochemical studies will make it possible to measure the presence of WSC in the waters of Grönfjord and track the pollutant inflows into the Arctic Ocean. At present, the region of the Greenland Sea is an object of intensive field research and this paper aims to continue the previous studies.

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Datasets and Software Availability Statement

Datasets and software for this research are included in this paper (in the part Methods, and also in **Figure 2**). Software description for this research is also available on access the official website of Northwestern branch of Scientific and

Production Association "Typhoon" in the section "Areas of work" and at https://www.rpatyphoon.ru/about/structure/units/szf.php, description of hydrochemical parameters is available in some annual reports edited by Korshenko (2019, 2021).

Data Availability

Data available on request the North-Western Branch of Scientific and Production Association "Typhoon", e-mail: typhoon.ecol@mail.ru.

Conflicts of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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