IDRiM (2023)13(2) **ISSN: 2185-8322**
DOI10.5595/001c. 91476

Journal of Integrated Disaster Risk Management

Original paper

Accidents with Oil Spills Triggered by Natural Hazards

Elena G. Petrova[1*]

Received: 12/05/2023/ Accepted: 08/08/2023/ Published online: 28/12/2023

Abstract In addition to direct social and economic damage, natural hazards also have a devastating impact on technological facilities, which may trigger accidents at these infrastructures. Especially dangerous consequences for the population and the environment are caused by such natural hazard triggered technological accidents (Natechs), which may result in the release of various hazardous chemical substances including mineral oil. This paper analyzes Natech accidents involving spills of oil and oil products. The materials of the author's database of technological and natural hazard triggered technological accidents occurred in Russia since 1991 are used as initial information for the analyses. The types of natural hazards and adverse natural phenomena that caused accidents with oil spills on the territory of Russia in 1991-2021 are identified. Natechs make up about 6% of all accidents with oil spills. The main triggers of these accidents are hydrological and meteorological hazards such as strong winds, storms, floods, melt waters, rainfalls, lightning, snow loads, and heat wave, as well as landslides and other ground movements. Earthquakes caused the largest damage, but they are less frequent events in Russia. More often, mineral oil leaks occur as a result of ship accidentsor the destruction of oil storage facilities and pipelines. The regions of the greatest risk of accident occurrences with oil spills in Russia are identified.

Keywords: Natural hazard impact,technologicalfacility, Natech, oil spill, oil tanker, oil storage, pipeline, database

[1]Faculty of Geography, Lomonosov Moscow State University, Russia
* Corresponding author email: epgeo@mail.ru

1. INTRODUCTION

In addition to direct material damage, natural hazards can affect technological facilities, triggering various accidents. Such types of accidents in technological systems and infrastructure, which are triggered by the impact of any natural hazard, are considered as natural hazard triggered technological accidents (so called Natech accidents or Natechs). Especially dangerous consequences for the population and the environment have accidents resulting in releases of various pollutants (Showalter and Myers 1992; Cruz et al. 2006; Cruz and Okada 2008; Petrova and Krausmann 2011). Pollution with oil and oil products is very harmful for the natural environment. Oil spills degrade the quality of surface and ground waters, reduce usable water and land resources, destroy soil and vegetation cover, affect aquatic and terrestrial ecosystems, cause biodiversity decline and many other adverse environmental changes. The consequences of oil pollution are difficult to eliminate.

The Russian Federation is one of those few countries in the world that have a long tradition of mineral oil production and processing. As the volume of production, transportation, storage, processing, and consumption of mineral oil resources increases, the scale of spills and pollution of the natural environment by crude oil and oil products may increase. As world practice shows, no mineral oil production, transportation and further use of mineral oil and oil products can be absolutely environmentally friendly and safe: a certain amount of hydrocarbons is inevitably lost and enters the environment. According to expert evaluations, irrecoverable losses of mineral oil in pollutions and wastes are estimated in Russia from 3 to 7% of the total volume of oil produced, transported and stored. On average, losses of mineral oil are estimated at 17 to 20 million tons per year (Vorobyov et al. 2005). According to Russian Federal Service for Supervision of Natural Resources (Rosprirodnadzor), in 2018, more than 3000 cases of oil spills were registered, which caused soil contamination on a total area of 214.5 hectares; in 2019, there were 819 cases with soil contamination on an area of 93.6 hectares (TASS 2020).

Technogenic pollution of the natural environment becomes especially large in cases of major industrial and transport accidents (Krausmann et al. 2011). Unlike “regular” or background emissions and leaks of pollutants, which inevitably occur in more or less small quantities even during the normal operation of various technological facilities (such as refineries, chemical and metallurgical plants, thermal power plants, automobile and other modes of transport, pipelines), emergency emissions and spills of crude oil and oil products can be much more significant in their scales. In such accidents, a large amount of pollutant enters the environment at a time.

More often, accidental oil spills occur due to violations of the tightness of gathering pipelines (Vorobyov et al. 2005). Pipelines of this type transport the crude oil from wells to a treatment plant or processing facility. Their diameter usually does not exceed 200 mm, but the operating pressure can be more than 32 MPa. The total length of gathering pipelines in Russia exceeds 300000 km, and about half of them have long ago completed their expected period of service, which islimited to 10 to 25 years by the state standards. The estimated service life of 25 years is determined for structures operated in highly aggressive environments. Accidents at

gatheringpipelines occur mainly due to internal corrosion of metal caused by pipe wear (corrosion accounts for up to 90% of accidents). In addition, according to Federal Service for Ecological, Technological and Nuclear Supervision (Rostekhnadzor), there are more than 75000 km of transportation pipelines in Russia, which transport crude oil and oil products throughout the country and abroad; most of them have been in operation for more than 30 years. The active development of the Russian pipeline networks took place in the 1960s - 1980s what was connected with the relocation of the mineral oil production to the Western Siberia. By the early 2000s, the ageingof fixed assets of the main oil pipeline transport exceeded 70% (Vorobyov et al. 2005). This may be fraught with a further increase in the accident rate at the pipeline system. Currently, the pipeline network of Russia is being actively upgraded.

Besides operational causes of mineral oil spills, natural hazards of various origins, which affect oil transmissionpipelines, oil storage facilities, oil tanker ships, and other technological systems and infrastructures of the oil complex, act as additional triggers of accidents around the world. For example, the catastrophic oil spills due to natural factors were caused by Hurricane Katrina (Steinberg et al. 2008), which occurred in late August 2005 and was one of the most destructive hurricane in US history. The overall estimate of the total volume of spilled oil is between 8 and 9 million gallons (Brunsma et al. 2010), which had enormous economic, social and environmental problems.

An example of catastrophic accidental pollution of the natural environment by mineral oil product due to natural triggers in the Russian Federation was the emergency event that occurred on May 29, 2020 in Norilsk, which caused big ecological losses and a great public outcry. Norilsk city is located in the East Siberia, in the north of the Krasnoyarsk Territory 300 km north of the Arctic Circle; it is the northernmost city in the world with a population of more than 150000 people. As a result of an accident at a heat and power plant (owned by JSC “Norilsk-Taimyr Energy Company”, a structure of Norilsk Nickel), more than 21000 tons of diesel fuel spilled out of the reservoir; out of this amount, 6000 tons fell into the ground and 15000 tons flowed down into the nearest water bodies, which are the Bezymyanny stream, the Daldykan and Ambarnaya rivers, and the large lake Pyasino. The total area of the pollution was estimated to be 180000 m^2. Ecologists described this accident as the largest environmental disaster in the Arctic and the world's largest diesel fuel leak in recent decades. The Ministry of Emergency Situations of the Russian Federation classified this event as an emergency situation of a federal scale. According to Rostekhnadzor (State of… 2020), the main causes of the fuel spill were shortcomings in the design and construction of the heat and power plant, as well as poor control of its operation. The immediate cause of the accident was a natural trigger: it was the depressurization of the fuel tank due to the subsidence of the underlying concrete platform in conditions of thawing of permafrost soil due to abnormally high air temperatures. Rosprirodnadzor estimated the environmental damage from the accident at almost 148 billion rubles (about US$2 billion) (RIA Novosti 2021).

This paper analyzes Natech accidents with spills of crude oil and oil products in the Russian Federation. The purpose of the study is to identify the main types of hazardous natural

processes and phenomena that may cause accidents with oil leaks, and to reveal industrial facilities that are most exposed to these hazardous natural impacts. The lessons from the case study can be learned for other countries having the same environmental problems of oil pollution and for other regions with similar climate conditions and similar set of natural hazards. The author'sexperience in compiling and analyzing the database of accidents may be useful for other studies.

2. MATERIALS AND METHODS

As source materials for analysis, this study uses the information collected by the author in an electronic database of technological and Natech events, which occurred in the Russian Federation from 1991 to 2021. Unfortunately, it is not possible to use information on earlier events (before 1991), since these data are very scattered. The database was created using Microsoft Access. The relational structure of the database and the procedure of its development and operation are described in more detail in Petrova (2009) (in Russian) and Petrova (2020) (in English). Currently, the database contains more than 26.5 thousand pieces of information and is constantly updating with new data from open sources.

The information accumulated in the database is structured according to the following key parameters: 1) the date of accident; 2) its location (including the distance to the nearest settlement and large city, regional centre or the capital of the constituent entity of the Russian Federation); 3) the type of accident (according to the classification by the Ministry of Emergency Situations and the author's assessment, which is done taking into account the influencing factors); 4) a brief description of the accident, including possible causes and triggers of the accident, its consequences and implemented measures; 5) the scale of the emergency (local, regional, interregional, federal, cross-border); 6) the number of injured people and victims; 7) economic and environmental damage; 8) information source. When compiling the database, only open sources of information are used. The main sources of data are the daily operational reports by the Ministry of Emergency Situations of the Russian Federation (EMERCOM), which are published on the official website of the Ministry (https://en.mchs.gov.ru/for-mass-media/operativnaya-informaciya). These reports are accessible not only in Russian, but also in English. If the required information is missing or insufficient, the brief description of the EMERCOM is supplemented in the database by electronic media reports from the Internet sitesof the Russian news agencies.

It is clear, that not all accidents occurring in the Russian Federation can be included into the operational reports by the Ministry of Emergency Situations. It is also impossible to include all the accidents into the author's database, because they are too numerous. As a rule, only those accidents that reach the rank of emergency situation according to the national regulation are recorded. An emergency situation is considered as a situation that has developed in a certain area as a result of an accident, a dangerous natural phenomenon, a catastrophe, the spread of a

disease, a natural or other disaster that may or did entail human casualties, damage to human health or the environment, significant material loss and disruption of the living conditions of people (Federal Law 1994). On January 1, 2022, a federal law came into force in Russia establishing new criteria for information by the EMERCOM on natural and technological emergency situations. Each type of emergency situation has specific criteria to be reported. The criteria for information about accidents with oil spills / releases are as follow: 1) spill / release of oil / oil products on the terrestrial part of the country area in the amount of five tons or more; 2) pollution of a water body (including internal sea waters, territorial sea, contiguous and exclusive economic zone of the Russian Federation, as well as surface and underground water bodies) with oil / oil products in the amount of one ton or more; 3) pollution of a source of drinking water supply within the boundaries of the sanitary protection zones (EMERCOM 2021). The same criteria are used for including information into the author's database. Accidents that meet criteria by the EMERCOM can produce emergency situations in surrounding areas.

The format of an electronic database by Microsoft Access allows an automated searching for information needed among the data array depending on the objectives of a study. Appropriate search queries according to the given parameters and keywords, as well asdata sorting are used for these purposes. The searching results are displayed in the form of a table that can be subjected to further computer processing and statistical analysis. In this study, a search for the information about accidents with spills and releases of mineral oil and oil products was carried out throughout the author's database. Among all the technological accidents with oil spills, accidents caused by the impact of unfavorable and hazardous natural processes and phenomena of various origins were singled out.

The sorting of data, geographic and statistical analysis of the searching results allowed finding out the main causes and triggers of accidents, their temporal and spatial distribution within the country territory. The main types of natural hazards, which affect technological systems and infrastructure facilities dealing with mineral oil production, transportation and storage, as well as types of oil complex facilities most exposed to natural impacts and regions most at risk of accident occurrences, were identified.

3. RESULTS AND DISCUSSION

As a result of search queries in the author'sdatabase, 584 accidents with crude oil and oil product spills leading to emergency situations for the population and the environment were identified in the Russian Federation from 1991 to 2021. All the accidents met the defined criteria by the EMERCOM described above in Section 2. This means that their consequences have exceeded a certain critical threshold of significance to be reported. The further research investigated these 584 emergencies; their causes and triggers, types of affected and damaged facilities, geographic location, and consequences of accidents were examined.

The main causes and triggers of accidents, leading to the oil spills and environmental oil pollution, are as follows:

- low quality of installed equipment, manufacturing defects, or corrosion of metals;
- errors in design, construction and installation, repair works and operation of equipment;
- high level of ageing of the main production assets of the mineral oil complex;
- unauthorized actions, including illegal tapping into pipelines;
- impacts of hazardous natural processes (Natech accidents).

Based on the results of the analysis of the author's database information, the main sources of accidental oil spills causing pollution of the natural environment in Russia were identified. These accidents were classified by the type of affected facilities. The revealed types of accidents included:

- accidents at gathering and transportation pipelines;
- accidents of oil tankers;
- accidents on drilling platforms;
- accidents at oil storage facilities;
- railway accidents with overturning and destruction of oil tanks;
- road accidents with destruction of tank trucks or collisions of vehicles with pipelines;
- accidents of various vehicles (including sea and river ships, cars, *etc.*) with leakage of liquid fuel.

Among all the causes and triggers of above accidents with oil and oil product spills, the share of natural hazards is relatively small: natural factors account to only about 6% of accidents. Studies by other researchers who analyzed the main European and US databases of industrial accidents showed similar contribution of natural factors to their occurrences: Natechs accounted for 2 to 5% of all industrial accidents (Cozzani et al. 2010; Krausmann et al. 2011; Sengul et al. 2012; Luo et al. 2020). This could be an underestimation as all the databases record accidents with severe consequences. Nevertheless these Natech accidents may cause great damage, especially in the case of a natural disaster of a large scale, such as those triggered by an earthquake, a hurricane or a flood.

The proportion of Natech accidents with oil spills at different types of technological facilities, which were registered in the database during the period under consideration (from 1991 to 2021), is shown in the Figure 1. The majority of these Natechs are accidents with damages to oil storage facilities or oil tank farms by various natural hazards or natural phenomena (about

47% of all the accidents recorded), followed by oil tanker or other ship accidents (34%) and pipeline ruptures (19%).

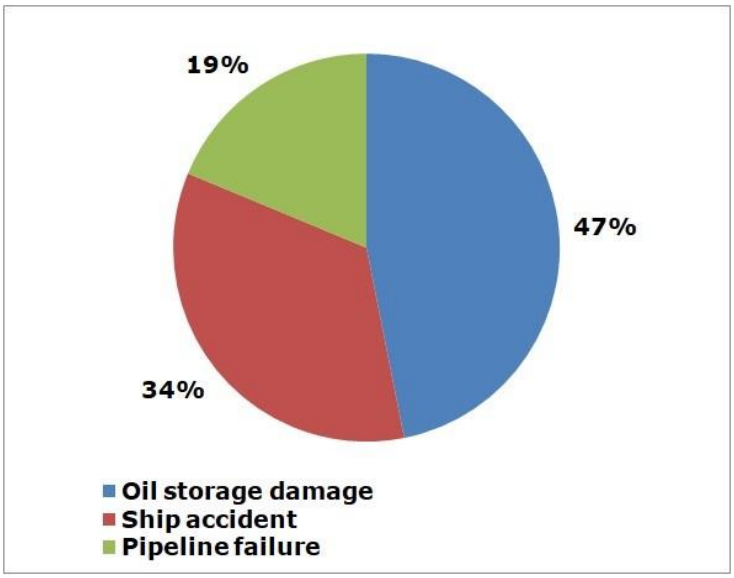

Figure 1. The proportion of Natech accidents with oil spills at different types of technological facilities

The following natural factors, which have triggered Natech accidents with oil spills on the territory of the Russian Federation during the period of study (1991-2021), were registered in the database:

- storms, typhoons, strong winds, fogs and other hazardous meteorological phenomena that causes accidents of oil tankers and other ships;
- heavy rains leading to washing out of oil from the territories of tank farms or to overflow of tanks by rainwater ;
- melt water, ice drifts and floods destroying oil tanks and washing out oil to rivers, lakes and other natural water reservoirs;
- snow loads on pipelines leading to their ruptures;
- landslides, soil displacements, and other slope processes leading to damages of oil tanks and pipelines;
- direct lightning strikes on the oil storage facilities with leakage and ignition of oil products;
- thawing permafrost with damage to the infrastructure of the oil complex;
- earthquakes with numerous damages to the infrastructure facilities of the oil complex;
- thermal impact on oil storage facilities during high heat leading to hydrocarbon leaks.

The proportion of natural factors triggering Natech accidents with oil spills and releases is shown in the Figure 2. Most of these Natechs are caused by natural hazards of hydrologicaland meteorological genesis, such as strong winds, storms, fogs, heavy rains, snow loads, floods, lightning strikes, and heat waves. Among other natural hazards earthquakes, landslides, and soil displacements due to various factors including thawing of permafrost are most important. For the purpose of comparison, 79 records for Natech accidents triggered by earthquakes, 272 caused by floods and 721 triggered by lightning were collected from the analysed databases by Krausmann et al. (2011) for industrial accidents in fixed chemical installations (such as oil refineries, high-capacity storage tank farms) and in pipelines.

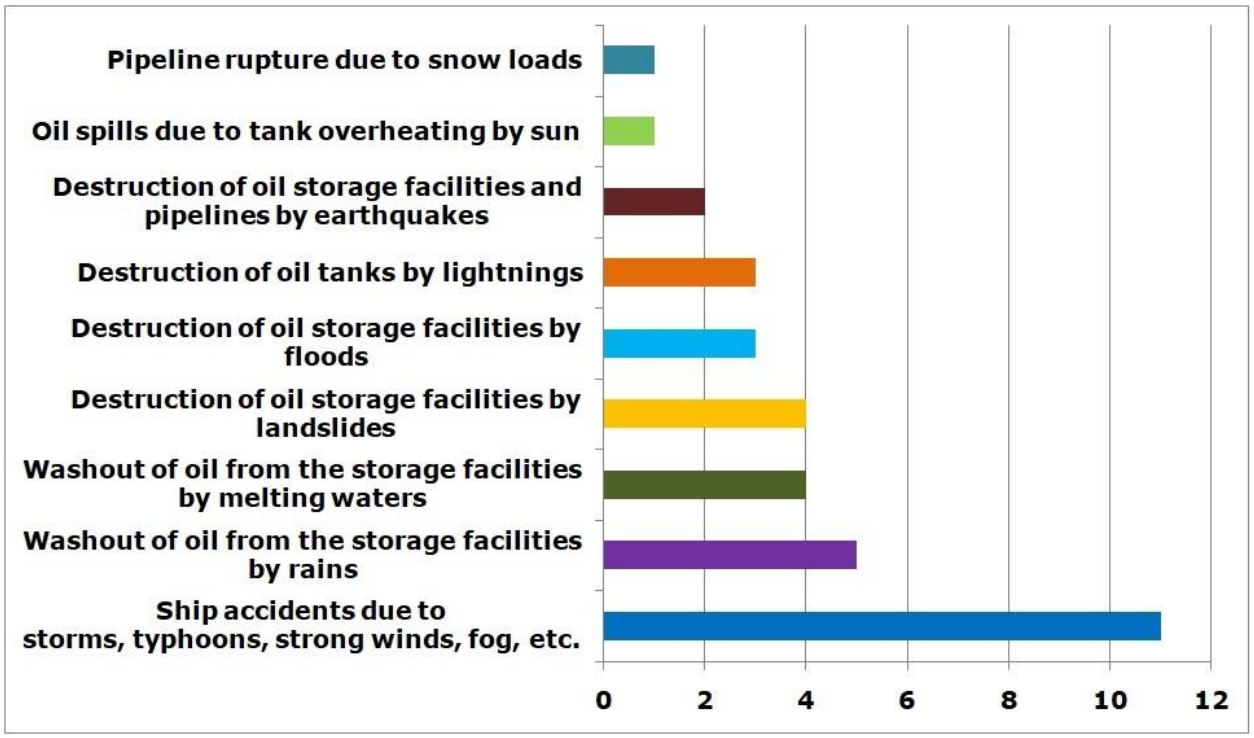

Figure 2. Natural factors of accidents with oil spills registered in the author's database in 1991-2021

Especially numerous among recorded events with oil spills were shipwrecks and oil tanker accidents due to various natural causes of meteorological origin such as storms, typhoons, strong winds, and fogs. On November 28, 2015, the “Nadezhda” tanker was blown by strong wind aground off the coast of Sakhalin Island near the port of Nevelsk, with eight crew members and 786 tons of oil products on board. The hull of the tanker was damaged; as a result, oil products got into the water of the Tatar Strait. The spill of oil products caused the pollution of more than 20,000 square meters of the water area and about seven kilometers of the coastline leading to the mass death of birds. On November 11, 2007, due to a storm in the Sea of Azov and the Black Sea, four ships sank, six ran aground, and two tankers were damaged. About 2,000 tons of fuel oil spilled into the sea from the broken “Volgoneft-139” tanker. In the Kerch Strait, a 50-fold excess of the maximum permissible concentration of oil products in water was noted causing a mass death of birds and fish. The environmental damage was estimated by Rosprirodnadzor at 6.5 billion rubles (US$260 million), which will be required for the

remediation measures (RIA Novosti 2021). The economic damage amounted to 30 billion rubles (US$1.2 billion).

The next numerous types of accidents are various accidents with washout of oil products from the territories of oil tank farms as a result of heavy rains, melt waters and floods. One of the most disastrous events of this type was registered in May 2001, when a catastrophic flood destroyed the oil storage depot in the city Lensk located in Eastern Siberia, Republic of Sakha (Yakutia). More than 12 thousand tons of oil products flowed from the area of the storage facility into the waters of the River Lena (Vorobyev et al. 2005).

Direct lightning strikes on oil storage tanks leading to a violation of their tightness with leaks and ignition of hydrocarbons also have serious consequences; fortunately they do not happen as often as other hydro-meteorological events. Only three cases of such type were recorded in the database between 1991 and 2021. The most serious consequences were caused by an accident occurred on August 22, 2009, when, as a result of a lightning strike, tank No. 7 of 8 tanks with commercial oil ignited in the tank farm of the Konda linear pumping booster station (120 km northwest of Urai station, Kondinsky district, Khanty-Mansiysk Autonomous District, in Western Siberia). The destruction of tank No. 7 led to oil spills and ignition of three more tanks. During the destruction of burning tanks, eight firefighters were injured, three of them died. In total, 403 people and 95 fire engines were involved in extinguishing the fire.

Various slope processes leading to deformation of oil storage tanks or destruction of pipelines are among significant natural factors too. One of such accidents occurred on April 19, 2007 as a result of ground movement in the area of the settlement Malaya Tyumerlya (80 km west of the city of Cheboksary, the capital of the Chuvash Republic); it caused a rupture of the Almetyevsk- Nizhny Novgorod pipeline (pipe diameter 500 mm). About 10 cubic meters of fuel spilled out as a result of this accident.

The only one case of pipeline damage due to snow load was registered on March 25, 2006 in the city of Kurilsk on Iturup Island (Sakhalin Region). As a result, 195 tons of diesel fuel leaked. The cause of the accident was a pipeline rupture under the weight of wet snow.

The climate changes observed on the territory of Russia in recent decades lead to the thawing of permafrost soils, which becomes a big problem for the stability and integrity of the oil complex equipment in the Arctic region. Meteorological and geographic analysis shows the highest rate of increasing of the average annual air temperature on the coast of the Arctic Ocean, especially in the Asian part of the Russian Federation. The temperature growth accounts to 0.9ºC in 10 years (Roshydromet 2017). In winter, the maximum warming occurs in the northwest of the European part of Russia. The disastrous consequences of the accident at heat and power plant in Norilsk on May 29, 2020 due to thawing permafrost were described above in Section 1. As permafrost thaws in Arctic, the number of such events may increase. This requires special attention to the state and condition of the infrastructure of the oil complex in the Arctic region.

Earthquakes affecting various facilities of the oil industry and oil transportation have the largest environmental impacts; however they are relatively rare events in the Russian Federation. The greatest earthquake disaster registered in the data base occurred in May 1995 in Neftegorsk, Sakhalin Region (Petrova 2011). The Neftegorsk earthquake caused about 200 oil pipeline ruptures with tens of thousands of tons of oil spilled in the northern part of Sakhalin Island (Vorobyev et al., 2005).

Natech accidents of different types with oil and oil product spills were registered in the database in 14 regions (constituent entities) of the Russian Federation (the total number of constituent entities comprises to 89). These regions and the types of accidents occurring in each of them are listed in Table 1. The most events were registered in the Sakhalin Region (10 accidents) and the Krasnodar Territory (5 accidents), as well as in the Leningrad and Orenburg regions, and Khanty-Mansiysk Autonomous District (2 accidents each); in all other regions, one event was recorded in each. This is due both to natural conditions of these regions including their sets of natural hazards, and the location of the oil complex facilities subject to adverse and dangerous natural impacts and vulnerable to these impacts.

Table 1. Types of Natech accidents with oil and oil product spills and regions of their occurrences

Type of accident	**Constituent entities of the Russian Federation**
Ship accidents due to storms, typhoons, strong winds, and fogs	Kamchatka and Krasnodar territories; Leningrad and Sakhalin regions
Accidents at oil storage facilities due to: - melt water and floods	Krasnoyarsk Territory; Republic of Sakha (Yakutia); Leningrad and Orenburgregions; Khanty-Mansiysk Autonomous District
- heavy rains	Krasnodar Territory; KomiRepublic
- lightning strike	Orenburg Region; Republic of Kalmykia;Khanty-Mansiysk Autonomous District
- earthquake	Sakhalin Region
- landslides	Altai Territory
- heating by sun	Sankt-Petersburg
Accidents on pipelinesdue to: - landslide, ground movement	Chuvash Republic; Samara Region
- snow load	Sakhalin Region

Since the majority of Natech accidents with oil and oil product spills were triggered by natural hazards of a meteorological and hydrological nature, their number and severity of their consequences in general may increase in the future due to climate changes expected. These forecasted climate changes include an increase in the number of severe rain floods, high water, and storm winds, as well as an increase in the number of days with an anomalously high amount of winter precipitation (Kattsov 2017). Challenges to the oil sector due to a changing climate

and more frequent extreme weather events were investigated by other researchers for other regions of the world. Cruz and Krausmann (2013), for example, conclude that climate change and extreme weather events represent a real physical threat to the oil and gas sector, particularly in low-lying coastal areas and areas exposed to extreme weather events. These issues should be investigated in more detail in the future research especially addressing Natech accidents.

4. CONCLUSIONS

Accidents with oil spills make up the most part of the total accidents involving releases and spills of various chemical substances dangerous for the population and the environment. The main causes of oil spills in the Russian Federation in the critical events are depressurization and emergency destruction of oil tanks, pipelines, and other equipment due to the high degree of their ageing, as well as errors in design, construction, installation, and operation. The main sources of accidental oil spills are accidents of oil tankers and drilling platforms, pipelines, oil storages, railway, and road accidents. Since the consequences of oil pollution are very difficult to eliminate, the main efforts should be directed to their prevention.

Natural hazard impacts pose an additional threat to the equipment of the oil complex triggering accidents at various facilities (about 6% of accidents). In general, this is consistent with the results obtained by other researchers cited above in the analysis of various databases for countries in Europe and the United States. Among all types of natural hazards, hydrological and meteorological hazards such as strong winds, storms, floods, melt waters, rainfalls and snowfalls, lightning strikes, and heat waves, as well as landslides trigger the majority of accidents. Earthquakes cause the largest social, economic and ecological damage, but they are relatively rare events in Russia. Lessons learned from this study show that although Natechs represent a relatively small proportion of the total number of oil spill accidents, they should be carefully examined because they cause catastrophic damage in the case of large-scale events.

Regions (constituent entities) of the Russian Federation, in which different types of accidents with oil and oil product spills were registered during the period of the study (1991-2021), were identified. Natech accidents were recorded in 14 constituent entities.Most accidents were registered in the Sakhalin Region and Krasnodar Territory where oil complex facilities are most exposed to various hydrometeorological hazards. In addition, Sakhalin is located in a seismic zone. Future analysis of the database will focus on local differences in natural conditions, the range of natural hazards and the vulnerability of the oil complex to their impacts in local context.

The most part of Natech accidents with oil spills were recorded on oil tankers, oil storage facilities, and pipelines. The high degrees of ageing of the fixed assets of the oil industry and transport facilities are fraught with a further increase in the accident rate. The modernisation of the oil complex equipment taking into account the increase in their resistance to external influences is needed to prevent accidents.

The climate changes expected on the territory of Russia in the near future may lead to an increase in the number and severity of consequences of accidents triggered by hydrological and meteorological hazards due to the increasing in their frequency and severity expected in most of the country area, as well as due to thawing permafrost ground in the Arctic. These issues should be also addressed in the future research especially in relation to potential risk of Natech accidents.

ACKNOWLEDGMENTS

The study was supported by Lomonosov Moscow State University (grant 1.7 “Danger and risk of natural processes and phenomena” AAAA-A21-121051300175-4).

REFERENCES

Brunsma, D. L., Overfelt, D., & Steven Picou, J. (2010). *The Sociology of Katrina: Perspectives on a modern catastrophe* (2nd ed.). Rowman & Littlefield Publishers, Inc.

Cozzani, V., Campedel, M., Renni, E., & Krausmann, E. (2010). Industrial accidents triggered by flood events: Analysis of past accidents. *Journal of Hazardous Materials*, 175, 501–509.

Cruz, A. M., & Krausmann, E. (2013). Vulnerability of the oil and gas sector to climate change and extreme weather events. *Climatic Change*, 121, 41–53. https://doi.org/10.1007/s10584-013-0891-4

Cruz, A. M., & Okada, N. (2008). Consideration of natural hazards in the design and risk management of industrial facilities. *Natural Hazards*, 44(2), 213–227.

Cruz, A. M., Steinberg, L. J., & Vetere-Arellano, A. L. (2006). Emerging issues for natech disaster risk management in Europe. *Journal of Risk Research,* 9(5), 483–501.

EMERCOM (2021). Order of the Ministry of Emergency Situations of the Russian Federation dated July 5, 2021 No. 429 “On the establishment of criteria for information on natural and technological emergency situations”. (In Russian)

Federal Law (1994). Federal Law of the Russian Federation "On the protection of the population and territories from natural and technogenic emergencies", December 21, 1994 N 68-FZ. (In Russian)

Kattsov, V. M. (Ed.) (2017). *Report on climate risks in the Russian Federation*. A. I. Voeikov Main Geophysical Observatory (FGBU "GGO"), St. Petersburg. (In Russian)

Krausmann, E., Renni, E., Campedel, M., & Cozzani, V. (2011). Industrial accidents triggered by earthquakes, floods and lightning: Lessons learned from a database analysis. *Natural Hazards*, 59(1), 285–300.

Luo, X.,, Cruz, A. M., & Tzioutzios, D. (2020). Extracting natech reports from large databases: Development of a semi-intelligent natech identification framework. *International Journal of Disaster Risk Science*, 11(6), 735-750.

Petrova, E. (2009). Natural-technological emergencies in Russia: experience in compiling and analyzing a database. In A. L. Shnyparkov (ed.), *Snow avalanches, debris flows and risk*

assessment (pp.152–162). Publishing house «Universitetskayakniga», Moscow, (In Russian)

Petrova, E. (2011). Natural factors of technological accidents: the case of Russia. *Natural Hazards and Earth System Sciences*, 11, 2227-2011. https://doi.org/10.5194/nhess-11-2227-2011

Petrova, E. (2020). Natural hazard impacts on transport infrastructure in Russia. *Natural Hazards and Earth System Science*, 20, 1969–1983. https://doi.org/10.5194/nhess-20-1969-2020

Petrova, E. G., & Krausmann, E. (2011). Postface "From natural hazards to technological disasters". *Nat. Hazards Earth Syst. Sci.*, 11, 3063–3065. https://doi.org/10.5194/nhess-11-3063-2011

RIA Novosti (2021). Major spills of oil and oil products in Russia in 1994-2021. *RIA Novosti news feed*. https://ria.ru/20210811/razliv-1745316414.html (In Russian)

Roshydromet (2017). Report on climate features in the Russian Federation for 2016. https://www.meteorf.gov.ru/upload/pdf_download/%D0%94%D0%BE%D0%BA%D0%BB%D0%B0%D0%B42016.pdf (In Russian)

Sengul, H., Santella, N., Steinberg, L. J., & Cruz, A. M. (2012). Analysis of hazardous material releases due to natural hazards in the United States. *Disasters*, 36(4), 723–743.

Showalter, P. S., & Myers, M. F. (1992). *Natural disasters as the cause of technological emergencies: A review of the decade, 1980–1989*. Boulder, CO: Univercity of Colorada.

State of emergency in Norilsk (2020). How an "ordinary" accident became an environmental disaster. *Portal for subsoil users: 06/09/2020*. https://dprom.online/oilngas/chp-v-norilske-kak-ryadovaya-avariya-stala-ekologicheskoj-katastrofoj/ (In Russian)

Steinberg, L. J., Sengul, H., & Cruz, A. M. (2008). Natech risk and management: an assessment of the state of the art. *Nat Hazards*, 46, 143–152. https://doi.org/10.1007/s11069-007-9205-3

TASS (2020). Chronology of the largest oil and oil product spills in Russia. News feed TASS. 06/03/2020. https://tass.ru/info/8641491 (In Russian)

Vorobyov, Yu. L., Akimov, V. A., & Sokolov, Yu. I. (2005). *Prevention and liquidation of emergency spills of oil and oil products*. In-octavo, Moscow. 368 p. (In Russian)