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MAPPING FREQUENCY OF OIL SPILLS IN THE CASPIAN SEA USING SENTINEL-2 OPTICAL IMAGES

Abstract. The main goal of this work is to evaluate the capabilities of optical images in the problem of detecting oil spills, testing them in the task of mapping zones with a high frequency of oil spills during one year. Using SAR imagery, sometimes it is difficult to separate anthropogenic oil spills and false targets, usually called “look-alikes”. Using optical images for oil spill detection, we rely on the spectral characteristics of objects, and although the reflectivity varies depending on the thickness and composition of the slick, in most cases, oil spills can be distinguished from “look-alikes”. The region near Absheron peninsula was selected as a study area. Optical images of the Sentinel-2 (A, B) satellites were used to detect oil spills and calculate the zones of their most frequent occurrence. Object based approach was chosen for segmentation and classification images. The map of hot spots with high frequencies of oil spills during 2019 year was presented in this article. Conclusions about the advisability of using optical images along with radar data for monitoring oil spills were made.

Key words: oil spills detection, Caspian Sea, Sentinel-2, optical imagery.

Introduction. The environmental situation in the Caspian Sea, which is literally saturated with products of the oil industry, is one of the acute issues for the littoral states. The Caspian Sea is subject to increasing anthropogenic impact, there is an increase in water pollution by oil products, heavy metals, and chemical products. At a rapid pace, there is a decrease in marine bioresources. The main sources of sea pollution are: river runoff; industrial and municipal effluents; oil production at sea and onshore; transportation of oil products by sea or through pipelines; flooding/drainage of the coastal zone as a result of the rise/fall of the Caspian level [1].

Oil spills at sea can be of natural origin (natural oil emissions due to fractures of geological structures, griffins, mud volcanoes), but in most cases they are of anthropogenic nature: they arise as a result of ships and tankers discharging ballast and bilge water, due to the removal of oil stains or pollution with river flows, industrial effluents, in the event of accidents of ships and tankers, in the breakdown of offshore oil pipelines, in the discharge of drill cuttings and in accidents due to exploratory drilling and industrial production [2,3]. This is especially felt in offshore zones where oil and gas fields are being developed, oil is extracted and transported. Oil pollution in coastal zones has a detrimental effect on flora and fauna, leads to pollution of coastlines, which entails large material losses associated with the cleaning of these territories. The marine ecosystem of the Caspian Sea, a closed reservoir, which self-cleaning ability is very small, is especially sensitive. Almost every year, there are reports of the death of sturgeon, seals, birds, in the carcasses of which oil products are found [4].

International experience shows that space monitoring methods are the most effective way to detect and evaluate the development dynamics of most natural and a number of man-made emergencies, in particular oil spills. Modern systems of remote sensing make it possible to obtain overview and detailed information about emergencies of various sizes in large areas. At the same time, space monitoring methods are much more economical than traditional ground-based data collection methods. It is practically impossible to control oil spills in the Caspian Sea scattered over a gigantic area (over 377,155 thousand square kilometers) by traditional land-based methods, and the use of aerial observations is expensive and can only be carried out in limited local areas. Therefore, remote sensing is the most effective method for timely detection of oil spills in the Caspian Sea with its large territory.

There are two types of sensors used in remote sensing - active (radar) and passive (optical).

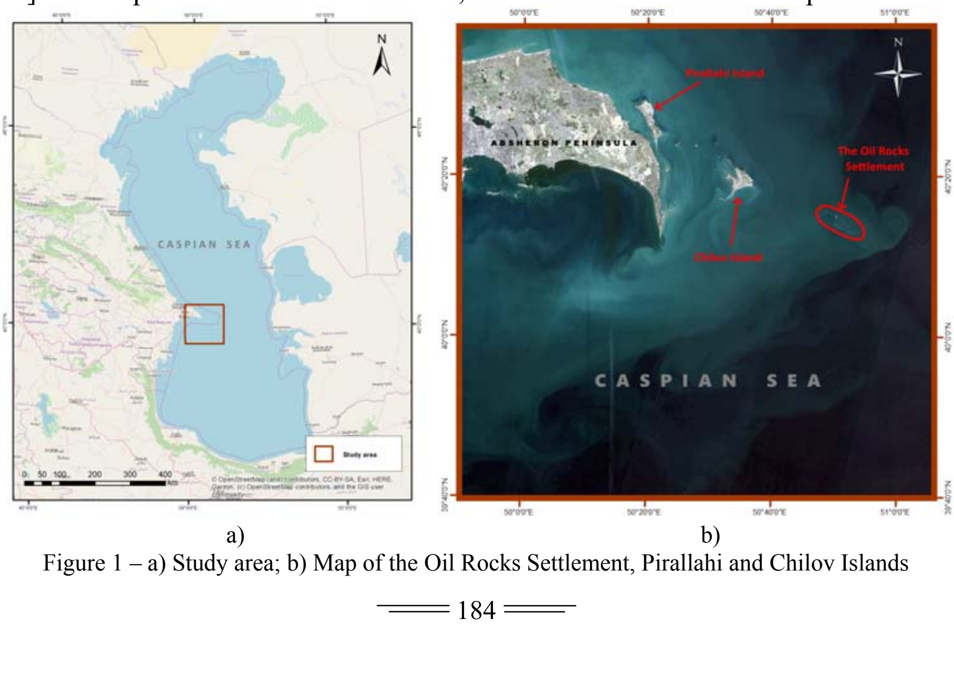
Both types of sensors have their advantages and disadvantages. Optical sensors can detect oil spills only in the daytime when there is no cloud, fog or smoke above the area of interest, that is, when nothing obscures the object from the sensor. Radar images can detect oil spills despite the cloudiness and time of day. Also, a large coverage area of radar images is an advantage. Nevertheless, there are weather conditions under which radar images are "powerless" for this task, namely, rain, and wind force above the sea surface beyond the interval of 2.5-12.5 m/s [5-8]. Due to many of the advantages listed above, radar is now the most common means of oil spill remote sensing.

However, using SAR imagery, sometimes it is difficult to separate anthropogenic oil spills and false targets, usually called “look-alikes”, which include low wind areas, areas, sheltered by land, rain cells, organic films, grease ice, wind fronts, up-welling zones, oceanic fronts, algae blooms, current shear zones, etc. One group of researchers showed that even with extensive processing of SAR (synthetic aperture radar) imagery, 20% of the images reported as “oil spills” were still “look-alikes” [9]. This means that using only radar images to monitor oil spills, about a fifth of all detected objects will be false targets, and when calculating their total area or analyzing maps built on such data, the error will be large.

Using optical images for oil spill detection, we rely on the spectral characteristics of objects, and although the reflectivity varies depending on the thickness and composition of the slick, in most cases, oil spills can be distinguished from “look-alikes”. Of course, limitations of optical imagery are a serious obstacle to monitoring efficiency. But in cases when mapping accuracy is more important, optical images are needed.

So, purpose of this work was to test opportunities of optical imagery in oil spill detection task by trying mapping hot spots with high frequency of oil spills during year.

Study area. The region near Absheron peninsula was chosen for a reason. Oil spills detected more often in this region than in other regions of the Caspian Sea. Accurate oil spill frequency map of this region, built by using optical sensors, will be useful for future oil spill monitoring. There are 3 oil fields in this region: Oil Rocks Settlement, Chilov and Pirallahi Islands. Oil Rocks Settlement is located 35 km from the coast of the Caspian Sea. Its development began in 1949. Oil Rocks is an industrial settlement in Baku, Azerbaijan. A full town on the sea, it was the first oil platform in Azerbaijan, and the first operating offshore oil platform in the world, incorporating numerous drilling platforms [10]. Pirallahi Island is located 1.6 km from the coast of the Caspian Sea. Chilov Island is located 16 km from the coast of the Caspian Sea [11]. The map of the Oil Rocks Settlement, Chilov and Pirallahi Islands is presented in figure 1(b).



a) b)

Figure 1 – a) Study area; b) Map of the Oil Rocks Settlement, Pirallahi and Chilov Islands

Methods and data processing. Optical images of the Sentinel-2 (A, B) satellites were used to detect oil spills and calculate the zones of their most frequent occurrence during 2019. Sentinel-2 is an Earth observation mission from the Copernicus Programme that systematically acquires optical imagery at high spatial resolution (10 m to 60 m) over land and coastal waters. The mission is a constellation with two twin satellites, Sentinel-2A and Sentinel-2B [11].

Eighteen L1C images with less than 20% cloud cover were downloaded from the USGS Earthexplorer website. Downloaded images were pre-processed to obtain L2A imagery from L1C. Sen2Cor Processor was used for that purpose. Sen2Cor is a processor for Sentinel-2 Level 2A product generation and formatting that performs the atmospheric, terrain and cirrus correction of Top-Of-Atmosphere Level 1C input data. Sen2Cor creates Bottom-Of-Atmosphere, optionally terrain and cirrus corrected reflectance images. In addition, Sen2Cor generates Aerosol Optical Thickness, Water Vapor, Scene Classification Maps and Quality Indicators for cloud and snow probabilities. Its output product format is equivalent to the Level 1C User Product: JPEG 2000 images, three different resolutions, 60, 20 and 10 m [12, 13].

Object based segmentation and classification was used for oil spill detection. In contrast to pixel-based classification that classify pixels one-by-one, object-based approach first groups image pixels into spectrally homogenous image objects using an image segmentation and then classifies the individual objects [14, 15]. Then detected oil spills objects were checked through visual interpretation. After all, GIS overlay analysis was performed for computation of oil spill frequency, and determination of spatiotemporal distribution. The workflow for the detection of oil spill frequency presented in figure 2.

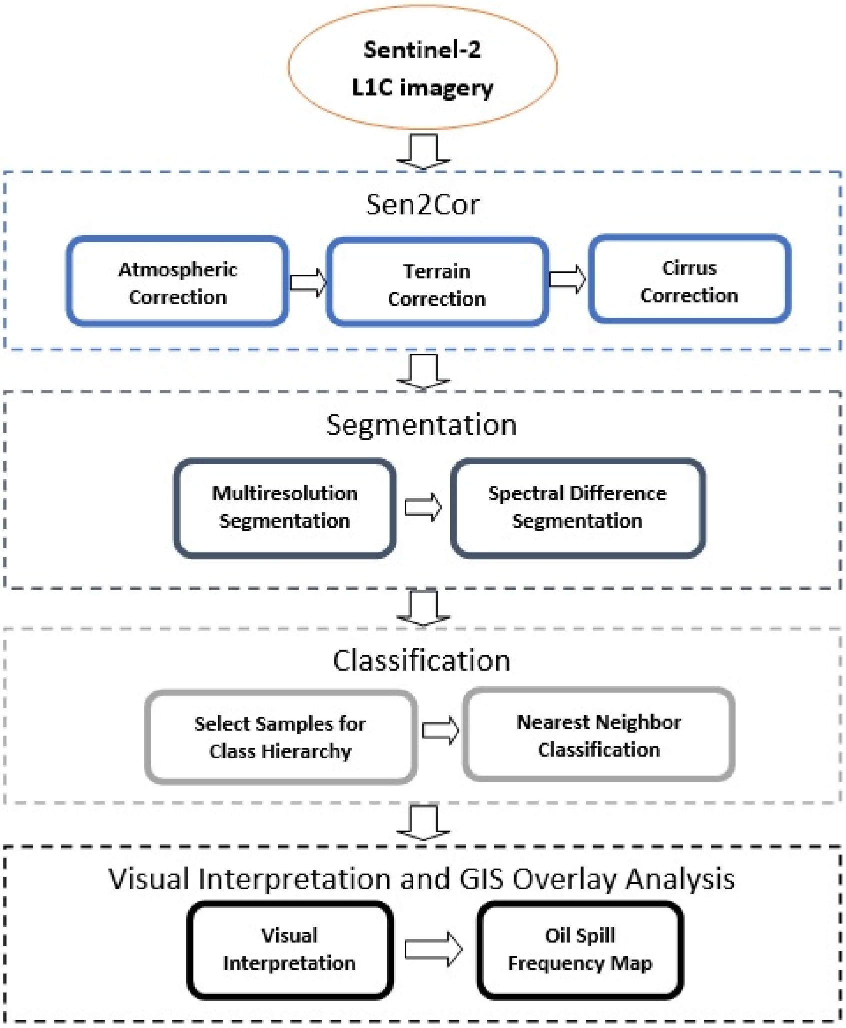


Figure 2 – Workflow for the detection of oil spill frequency

Results and discussion. Oil spills in the study area for the most cases are easily detected visually in the visible range of the electromagnetic spectrum, they usually have a silver-blueish color (figure 3 a, b), which indicates the thinness of the slicks [16].

a) b)

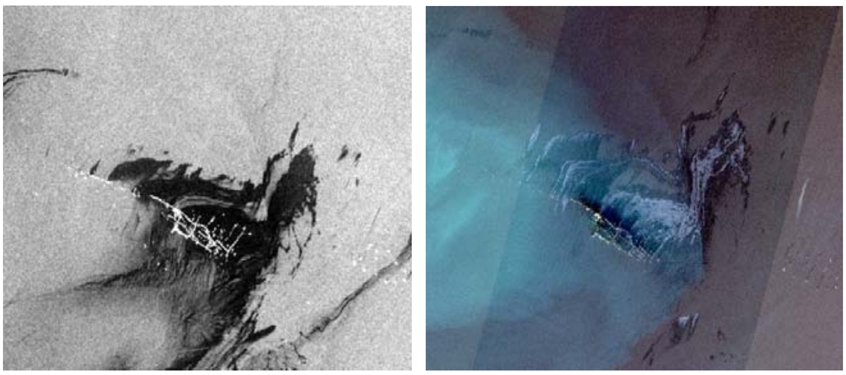
Figure 3 – Well visible oil spills (a-The Oil Rocks Settlement, b – Pirallahi Island)

But it should be noted that in some cases in the zones of accumulation of biogenic material such as surface seaweeds or sunken kelp beds oil detection was difficult. One of that cases presented in figure 4. Under many conditions, oil is not visible on the surface of the water [17]. Oil spills on shorelines is difficult to identify positively because seaweeds look similar to oil and oil cannot be detected on darker shorelines [18].

Figure 4 – One of difficult cases

In addition, there remain limitations such as cloudiness in the images. Indeed, many pictures for 2019 were cloudy over 20%. This is completely unsuitable for operational monitoring.

Therefore, it is better to take an integrated approach, namely the use of both radar and optical images. This approach also partially solves the issue of validation in those days when the sensing days coincides of both radar and optical sensors. This allows us to compare the obtained oil spill detection results. Example of that comparing presented in figure 5 (a, b), where we see the correspondence.



a) b)

Figure 5 – a) Radar image on 26th of April; b) Optical image on same date

The detection of oil spill from Sentinel-2 images and multi-temporal GIS overlay analysis resulted in the map of hot spots with high frequencies of oil spills during 2019 year, presented in figure 6. On the map we see that the main hotspot of oil spills is the Oil Rocks Settlement, what was to be expected. The medium class of oil leak sources were observed around the Oil Rocks Settlements and Chilov Islands and the small and occasional leak sources were observed around Pirallahi Island.

This map will allow to increase the accuracy and reliability of detected oil spills in future monitoring. For example, the oil spill areas with no overlaps and far away from the oil spill hot spots will not be mapped because of the lower reliability of occurrence.

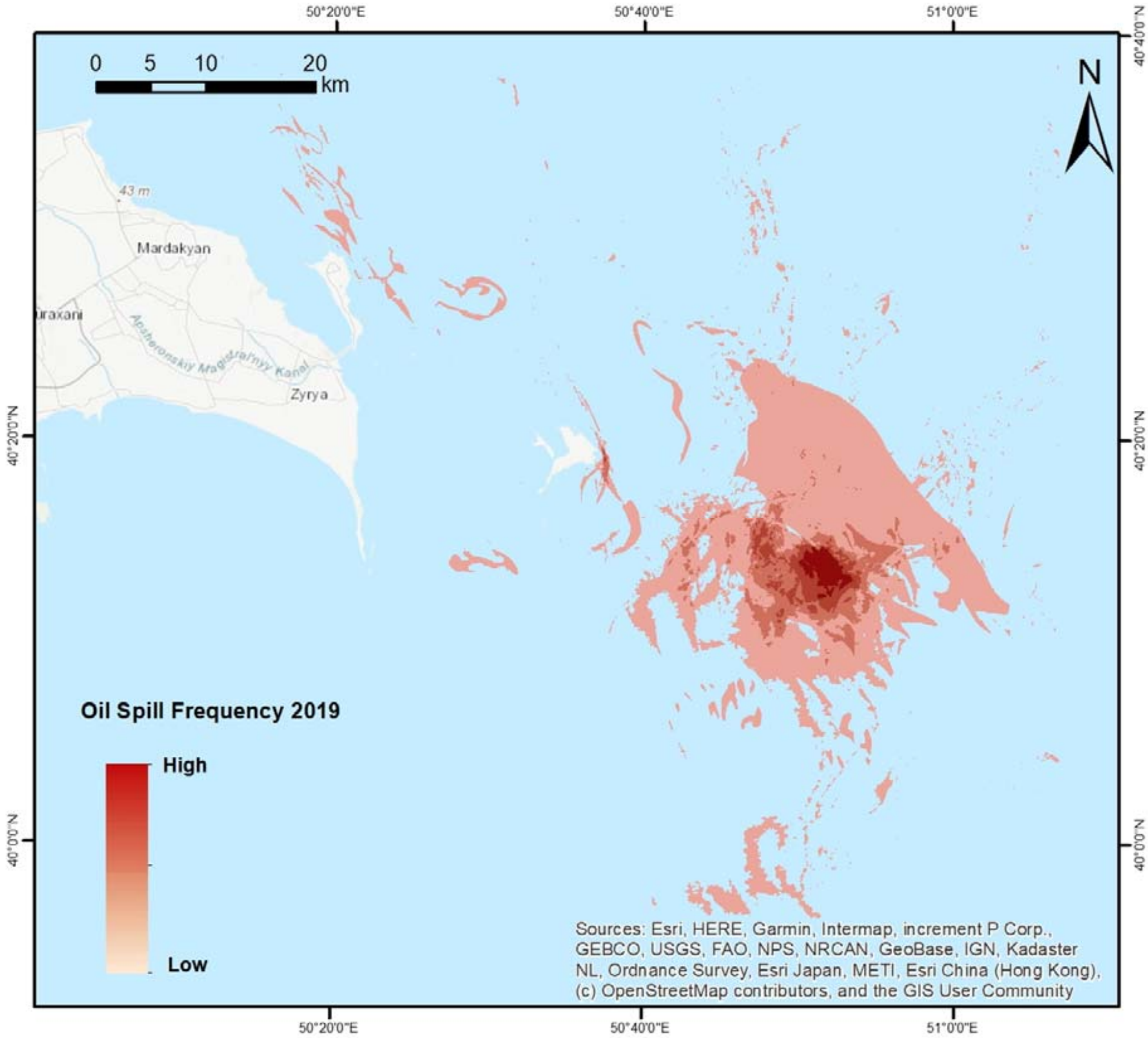


Figure 6 – Map of oil spill frequency in 2019

Conclusion. Research in this direction will be continued with the use of more remote sensing data, their statistical analysis, with the aim of increasing the likelihood of detecting oil pollution and its practical application. Preliminary results are considered successful and consistent, with a high degree of applicability to other Sentinel-2 satellite imagery. Further testing and proper tuning of the proposed object-oriented methodology should be carried out using SAR images.

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SENTINEL-2 ОПТИКАЛЫҚ СУРЕТТЕРІН ПАЙДАЛАНА ОТЫРЫП, КАСПИЙ ТЕҢІЗІНДЕГІ МҰНАЙДЫҢ ТӨГІЛУ ЖИІЛІГІН КАРТАҒА ТҮСІРУ

Аннотация. Мұнай өнеркәсібінің өнімдерімен ластанған Каспий теңізіндегі экологиялық жағдай – жағалау маңындағы мемлекеттер үшін маңызды проблемалардың бірі. Каспий теңізі күннен күнге антропогендік әрекетке ұшырауда. Жыл сайын судың мұнай өнімдерімен ластануы артып келеді. Теңіз биоресурстарының қысқаруы тез қарқын алуда. Халықаралық тәжірибе көрсеткендей, ғарыштық мониторинг әдістері көптеген табиғи және техногендік төтенше жағдайлардың, атап айтқанда, мұнайдың төгілуінің даму динамикасын анықтау мен бағалаудың неғұрлым тиімді тәсілі болып табылады. Қазіргі заманғы қашықтықтан зондылау жүйелері үлкен аумақтардағы әртүрлі көлемдегі төтенше жағдайлар туралы шолу және толық ақпарат алуға мүмкіндік береді. Сонымен қатар, ғарыштық мониторинг әдістері деректерді жинаудың дәстүрлі жерүсті әдістерінен әлдеқайда үнемді. Қашықтықтан зондылауда сенсорлардың екі түрі қолданылады - активті (радарлық) және пассивті (оптикалық). Сенсорлардың екі түрінің де өз артықшылықтары мен кемшіліктері бар. Көптеген артықшылықтардың арқасында радарлық суреттер қазіргі уақытта мұнайдың төгілуін қашықтықтан зондылаудың ең көп таралған құралы болып табылады. Алайда, радарлық суреттерді пайдалана отырып, кейде антропогендік мұнай төгілуін және оларға ұқсас жалған объектілерді бөліп алу қиын болады және әдетте оларға "look-alikes" деп аталатын, желсіз аймақтарды, табиғи текті органикалық пленкаларды, балдырлардың гүлденуін және т. б. қамтиды. Бұл жұмыстың негізгі мақсаты – бір жыл ішінде мұнай төгілуінің жоғары жиіліктері пайда болатын аймақтарды картаға түсіру және мұнай төгілуін анықтау мақсатында оптикалық суреттердің мүмкіндіктерін бағалау. Апшерон түбегінің маңындағы Каспий теңізі ауданы зерттеу ауданы ретінде таңдалды. Мұнайдың төгілулері Каспий теңізінің басқа аймақтарына қарағанда осы өңірде жиі анықталады, сондықтан оптикалық сенсорларды пайдалана отырып салынған осы өңірдегі «Мұнайдың жиі төгілу аймақтары картасы» болашақта мұнай төгілуінің мониторингі үшін пайдалы болады. Sentinel-2 (A, B) жерсеріктерінің оптикалық бейнелері мұнайдың төгілуін анықтау және олардың жиі пайда болу аймақтарын есептеу үшін пайдаланылды. Жүктелген суреттер L1C-ден L2A суретін жасайтын Sen2Cor утилитасы арқылы алдын ала өңделді. Пикселдерді бір-бірден жіктейтін пикселдер негізіндегі жіктемеге қарағанда, объектілі-бағытталған тәсіл алдымен бейненің пикселдерін бейненің сегменттеуін пайдалана отырып, спектрлік біртекті объектілерге топтастырады, содан кейін жекелеген объектілерді жіктейді. Мұнай төгілуі ретінде жіктелген объектілер көзбен шолу арқылы тексерілді. 2019 жыл ішінде мұнай төгілуінің жоғары жиіліктері бар аймақтардың картасы ұсынылды. Салынған карта бойынша 2019 жылы мұнай төгілуінің ең жиі көздері анықталды, атап айтқанда "Мұнай тастары", "Чилов" және "Пираллахи" кен орындары. Сондай-ақ, мақалада кейбір төгілулерді көрнекі түсіндіру кезінде туындаған қиындықтардың мысалдары келтірілген. Нәтижесінде, «мұнайдың төгілуін мониторингілеу үшін радиолокациялық деректермен қатар оптикалық бейнелерді пайдалану да орынды», - деген қорытынды жасалды.

Түйін сөздер: мұнай төгілуін анықтау, Каспий теңізі, Sentinel-2, оптикалық суреттер.

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КАРТИРОВАНИЕ ЧАСТОТЫ РАЗЛИВОВ НЕФТИ В КАСПИЙСКОМ МОРЕ С ИСПОЛЬЗОВАНИЕМ ОПТИЧЕСКИХ ИЗОБРАЖЕНИЙ SENTINEL-2

Аннотация. Экологическая ситуация на Каспийском море, которое буквально насыщено продуктами нефтяной промышленности, является одной из острых проблем для прибрежных государств. Каспийское море подвержено возрастающему антропогенному воздействию. С каждым годом увеличивается загрязнение воды нефтепродуктами. В быстром темпе происходит сокращение морских биоресурсов. Международный опыт показывает, что методы космического мониторинга являются наиболее эффективным способом выявления и оценки динамики развития большинства природных и техногенных чрезвычайных ситуаций, в частности разливов нефти. Современные системы дистанционного зондирования позволяют получать обзорную и подробную информацию о чрезвычайных ситуациях различных размеров на больших территориях. В то же время методы космического мониторинга намного экономичнее традиционных наземных методов сбора данных. В дистанционном зондировании используются два типа сенсоров - активный (радарный) и пассивный (оптический). Оба типа сенсоров имеют свои преимущества и недостатки. Благодаря многим преимуществам, радарные снимки в настоящее время являются наиболее распространенным средством дистанционного зондирования разливов нефти. Однако, используя радарные снимки, иногда бывает трудно отделить антропогенные разливы нефти и ложные объекты, похожие на них, и обычно называемые «look-alikes», которые включают безветренные области, органические пленки естественного происхождения, цветение водорослей и т. д. Используя же оптические изображения для обнаружения разливов нефти, мы полагаемся на спектральные характеристики объектов, и хотя отражательная способность варьируется в зависимости от толщины и состава пятна, в большинстве случаев разливы нефти можно отличить от похожих ложных объектов. Основная цель данной работы - оценить возможности оптических снимков в задаче обнаружения разливов нефти, опробовав их в задаче картирования зон с высокой частотой появления разливов нефти в течение одного года. Район Каспийского моря возле Апшеронского полуострова был выбран в качестве района исследований. Разливы нефти обнаруживаются в этом регионе чаще, чем в других регионах Каспийского моря, поэтому карта зон с частыми разливами нефти в этом регионе, построенная с использованием оптических сенсоров, будет полезна для будущего мониторинга разливов нефти. Оптические изображения спутников Sentinel-2 (A, B) использовались для обнаружения разливов нефти и расчета зон их наиболее частого появления. Скачанные снимки были предварительно обработаны с помощью утилиты Sen2Cor, генерирующей изображения L2A из L1C. Объектно-ориентированный подход был выбран для сегментации и классификации изображений. В отличие от классификации на основе пикселей, которая классифицирует пиксели по одному, объектно-ориентированный подход сначала группирует пиксели изображения в спектрально однородные объекты изображения с использованием сегментации изображения, а затем классифицирует отдельные объекты. Объекты, классифицированные как разливы нефти, проверялись путем визуальной интерпретации. Был проведен анализ наложения и представлена карта зон с высокими частотами появления разливов нефти в течение 2019 года. По построенной карте, были определены наиболее частые источники разливов нефти за 2019 год, а именно месторождения «Нефтяные камни», «Чилов» и «Пираллахи». Также в статье приведены примеры сложностей, возникших при визуальной интерпретации некоторых разливов, и сделаны выводы о целесообразности использования оптических изображений наряду с радиолокационными данными для мониторинга разливов нефти.

Ключевые слова: обнаружение разливов нефти, Каспийское море, Sentinel-2, оптические снимки.

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