THE USE OF REMOTE SENSING DATA FOR INVESTIGATION OF ENVIRONMENTAL CONSEQUENCES OF RUSSIA-UKRAINE WAR

SHEVCHUK A. SERHII [1], VYSHNEVSKYI I. VIKTOR [2], BILOUS P. OLENA [3,4*]

[1]Central Geophysical Observatory, Nauky Ave., 39, 2, Kyiv, 02000, Ukraine, e-mail: sergey_shevchuk_(at)ukr.net
[2]National Aviation University, Liubomyra Huzara Ave., 1, Kyiv, 03058, Ukraine; e-mail: vishnev.v(at)gmail.com, http://orcid.org/0000-0002-2900-1598
[3]Institute of Hydrobiology and Aquatic Ecosystem Management (IHG), University of Natural Resources and Life Sciences, Gregor-Mendel-Straße 33/DG, 1180 Vienna, Austria; e-mail: olena.bilous(at)boku.ac.at
[4]Institute of Hydrobiology of NAS of Ukraine, Heroiv Stalingrada Ave., 12, 04210, Kyiv, Ukraine; e-mail: bilous_olena(at)ukr.net, http://orcid.org/0000-0001-5229-3667
**Corresponding author email: bilous_olena(at)ukr.net*

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ABSTRACT

The usage of remote sensing data for tracking or monitoring war conflicts is a reality nowadays. The Russian invasion in Ukraine seriously impacted on the environment of the attacked country in all areas: air, soil, water, flora and fauna. The war has created a massive increase in air pollution in some regions of Ukraine, and might have effect in neighbouring countries. The Russian attack has caused many fires at places such as oil depots, industrial complexes, equipment and ammunition stockpiles, the forests, and residential areas. In addition to this, many bridges, hydraulic and other structures located over and near the water bodies were destroyed. These events were analysed in this paper by using publicly available remote sensing data: NOAA-2, Suomi NPP, Aqua and Terra satellites, Sentinel and Landsat satellites, as well as from other sources open to public. We assume that the use of remote sensing data is an excellent tool to monitor effects of military conflicts on environment. The conducted research with proposed method can serve as a good scientific practice that should be implemented for monitoring of the harm to nature caused by wars.

Keywords: Russian invasion, fires, pollution, remote sensing data, war conflicts

INTRODUCTION

Direct combats and military engagements have continuously plagued a human civilization leading to deaths of millions of people (Sarkees *et al*., 2003). Beyond deaths, wars have been also documented as having a significant impact upon ecosystems (Dudley *et al*., 2002; Lawrence *et al*., 2015; Garzón &Valánszki, 2020). The degree to which the warfare can affect the nature is one of the stages for assessment of the scale of military influence.

Definitely, the scale of military impact on environment, ecosystem structure and function, are strongly connected with the scope of the warfare. The large-scale invasion, started by Russia on February 24, 2022 is the first large-scale armed conflict over the past 80 years happened nowadays that could be compared with the World War II. Analysing Europe, after

this cruel war with millions of victims and enormous harm to environments, only isolated armed conflicts have sporadically appeared. The wars that could be mentioned on some comparable scale occurred in Balkans (1991–2001), Iraq (2003), Georgia (2008), Syria (2014), and Ukraine (2014) with the Russian occupation of the part of its territory. But none of the named military conflicts had the same damage as the Second World War. Perhaps this could serve an explanation why there is no significant amount of papers describing the impact of the named wars on the environment.

The impact of the World War II military engagements on the environment was comprehensively investigated (Glandz, 2005; Gleick, 2010; Vyshnevskyi, 2011; Hart, 2015). Some dramatic scenarios appeared in 1940 in the Netherlands when the army was forced to flood the Gelderze Valley to create a water barrier for German troops (Gleick, 2010). Similar measure was also used on August 18, 1941 when Soviet military forces to stop enemy decided to blown up a recently built dam in Dnipro hydroelectric power plant (HPP) in Zaporizhya city in Ukraine. This explosion of dam has created high wave that killed many German soldiers, however also Soviet soldiers (Vyshnevskyi, 2011). Another example is the destruction of the dam on the Eder (Germany) and Liri rivers (Italy) by British troops, which also led to significant flooding (Gleick, 2010).

In the south-eastern Europe, the most recent war was in Balkans and affected republics which previously composed Yugoslavia (Slovenia, Croatia, Bosnia and Herzegovina, Montenegro, Serbia, and North Macedonia). The most significant impact on the environment was accompanied by pollution by petroleum products and other chemical compounds which have being discharged into the Danube River (Fenrick, 2001; Mannion, 2003). The same effect on environment but on the broader scale Europe observes nowadays in the continent.

During Russian war against Ukraine the massive effect on the infrastructure occurred at oil storage sites which were attacked by targeted missiles and bomb strikes. In addition, there have been many forest fires due to indiscriminate Russian shelling. The destruction of bridges, hydraulic and sewage treatment plants has also affected Ukrainian water bodies. The waters of the Black and Azov Seas, where several ships have been sunk, were also polluted. Huge areas of land are now covered with fragments of bombs and shells, as well as remnants of discarded equipment, tanks, and military vehicles. As a result of this war, all spheres of the environment have been negatively affected and with no doubt should be assessed and monitored.

In recent decades, to assess the large-scale environmental data, scientific research is increasingly started to make use of remote sensing data. This is especially true in times of war or invasion, when the possibilities of using other methods are limited. The results of relevant research (Kwarteng, 2009; Al-doski *et al.*, 2013; Witmer, 2015; Szpakowski & Jensen, 2019; Fakhri *et al.*, 2020; Gkanatsios, 2021; Garzón &Valánszki, 2020) are built on multispectral images obtained by Landsat satellites. The hostilities are often accompanied by fires, which have long been studied using remote sensing data (Hurteau *et al.*, 2014; Rocca *et al.*, 2014; Szpakowski & Jensen, 2019). An example of such a study in the work (Babushka et al., 2021), dedicated to fires in the Chernobyl Exclusion Zone. Here, Sentinel 2 satellite data were used to determine the area of burned forests, on which the basis of the Normalized Burn Ratio was calculated. As noted in the paper by (Szpakowski & Jensen, 2019) over the past two decades, MODIS Terra and Aqua have become the primary sensors for active fire detection and monitoring due to their high temporal resolution of special channels. Thus, it is difficult to overestimate the benefits of remote sensing data exploring the damage that people do with environment.

The large-scale consequences on environment caused by Russian war is hard to estimate using only common techniques and methods (Harada *et al.*, 2022). With this work we

hypothesize that the negative effects of wars on a large-scale is possible to asses properly using remote sensing data. Therefore, the main purpose of this research is to demonstrate the capabilities of remote sensing data for analysis of impact of the Russia-Ukraine war on the environment.

MATERIALS AND METHODS

The study area and the course of the invasion

The territory of Ukraine as a whole is located in the south-eastern part of Europe. The majority of the country, with the exception of the Ukrainian Carpathians in the west and Crimean Mountains in the south, could be best described as flat terrain or plain. The largest cities of the country are Kyiv (about 3 million citizens), Kharkiv (1.4 million), Dnipro and Odesa (about 1 million each) (Fig.1).

Fig. 1: Location of Ukraine and its neighbouring countries

Russia's war against Ukraine began in February 2014 which mainly concerned itself at that time to Crimea and the Donbas-Luhansk regions. The situation started to become more critical in the autumn of 2021, when Russia began to concentrate its military forces closer to the border with Ukraine including some being concentrated on the southern border of its neighbouring country Belarus.

A large-scale invasion of Russian troops into Ukraine took place on the morning of February 24, 2022. It began with the massive bombardment of missiles, which struck many infrastructure facilities including not only military sites but also many residential areas. Simultaneously, the invasion of Ukraine began on many fronts: north, east and south. The southern occupation of Ukrainian territory came namely from Crimea which has turned out to be the most successful conquest path for the Russian forces. During the first days of the

war, they managed to reach the Dnipro River and capture the Kakhovska HPP, as well as the main control building for the North Crimean Canal and some week after Kherson city in the south. In the north, the Russian forces near Kyiv has been blocked and in the end of March 2022, this part of the country was liberated. However, important infrastructure, including oil depots were left under strikes. The same applies in many other regions of the hostilities.

Remote sensing data and image analysis

The main source of data for writing this article was the data obtained not only through official sources but also from remote sensing, which are in the public domain. First of all, the results of the Earth survey by NOAA-2, Suomi NPP, Aqua and Terra satellites together with information contained on the site Fire Information for Resource Management System (FIRMS, 2022).

The resolution of NOAA-2 and Suomi NPP satellite equipment is 375 m. In turn, the resolution of the Aqua and Terra satellite equipment depends on its spectral imaging channel of between 250–1000 m. The thermal channels of these satellites, which reflect the places of combustion, have the worst resolution. Each such event in the FIRMS program is accompanied by data showing coordinates, date and time, as well as the registration of the event by satellite.

Another source of data on combustion burning sites is the EOSDIS Worldview (EOSDIS Worldview, 2022) which shows the results of surveying the Earth's surface by above mentioned Aqua and Terra satellites. Their results are presented in what are called “layers of Fires and Thermal Anomalies”. The benefit of using information from this site is that they not only display any fires but also show the cloud cover at that time.

This work also uses images of Sentinel satellites contained on the site (Copernicus Open Access Hub, 2022). The main feature of Sentinel 1 satellite is the installation of radar equipment that is capable of performing surveys during any weather condition. Its spatial resolution is 10 m. The spatial resolution of Sentinel 2 satellites, of which there are actually two in the orbit, in the visible range of the spectrum is 10–20 m, infrared – 60 m.

This paper also uses data from Landsat 8 and Landsat 9 satellites contained on the site (USGS, 2022). The resolution of the channels of the visible range of Landsat 8 and Landsat 9 satellites is 30 m, thermal ones – 100 m. The Landsat 8 scene size is 185-km-cross-track-by-180-km-along-track.

The correspondent satellite images were used for the search of places of burning, the spread of smoke, water pollution, etc.

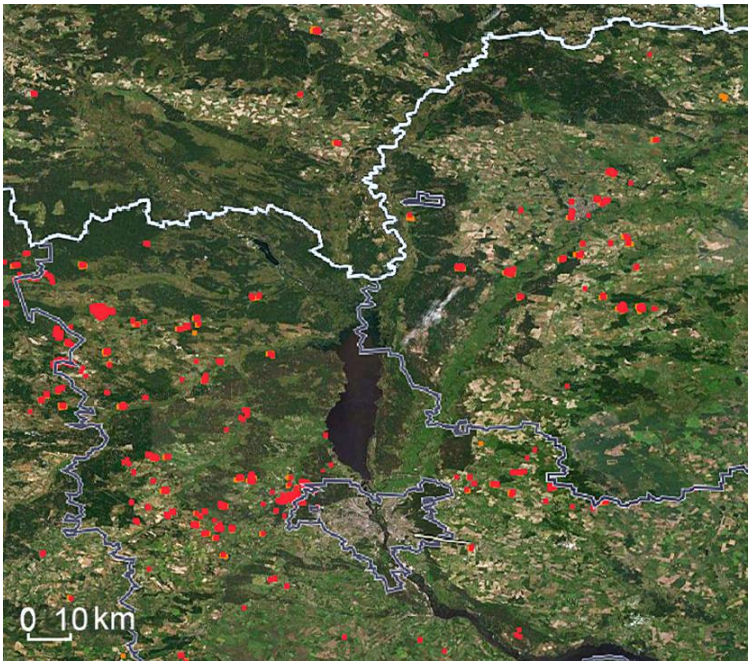
Satellite images were processed using ArcMap 10 program. Spectral channels of satellite images were selected for the best image visualization and search for fires sites. In particular, the validity of satellite data use and their processing for scientific field research was confirmed in the study (Vyshnevskyi & Shevchuk, 2018).

RESULTS

The hugest war on the European continent form the last 80 years started with massive but pointed bombing over the whole Ukrainian territory. The bombings on the first day of the war did not provoke massive fires burning in Ukraine and was not recorded by remote sensing data. To some extent, it can be explained by weather conditions that is typical for Ukrainian territory during the end of the winter. The first fires that were observed with the help of satellites for these areas were recorded on February 25, 2022. Images from Aqua and Terra satellites revealed fires in Ivankiv (70 km northwest of Kyiv) and on the outskirts of Chernihiv (130 km northeast of Kyiv). The next day, as hostilities continued towards Kyiv,

numerous outbreaks of fire started to appear in the cities of Irpin and Hostomel being some 20 to 25 km northwest of Kyiv. The largest number of fires were recorded during the month of March namely March 23, 2022 when the Russian forces were being driven back from northern Ukraine (Fig. 2).

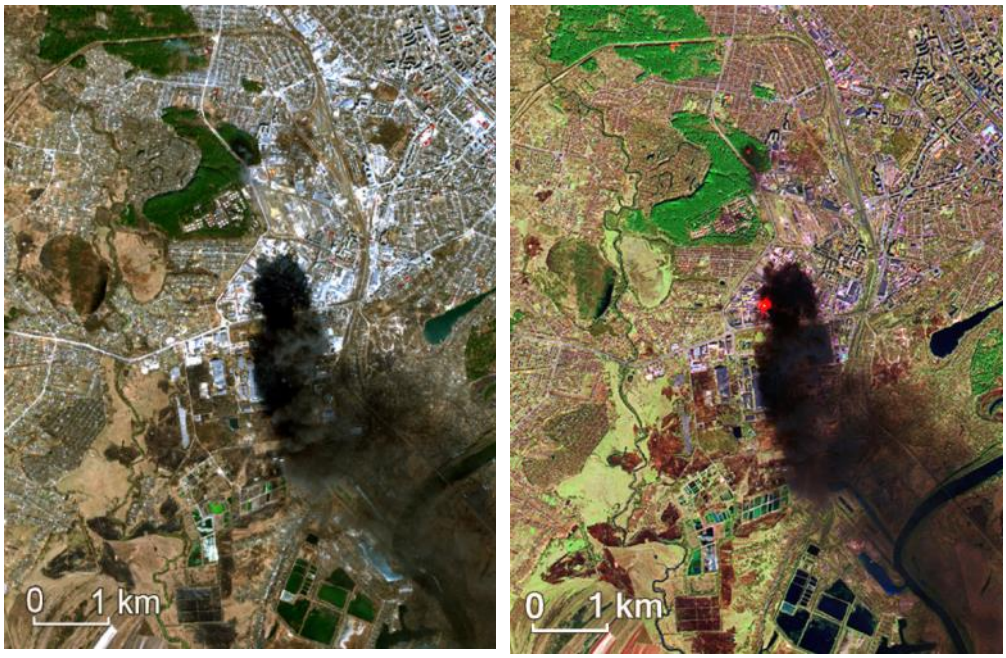
Fig. 2: Outbreaks of fire and smoke in the region north of Kyiv on March 23, 2022, according to Aqua and Terra satellites



Since the beginning of the Russian invasion, oil installations have become the target of many missile and bomb strikes. In particular, the oil depots were targeted in Vasylkiv (30 km southwest of Kyiv on February 27, 2022), Chernihiv (March 3, 2022), Zhytomyr and Chernyakhiv, March 7, 2022), Lutsk (March 11 and March 27, 2022), Chernihiv (March 23, 2022), Kalynivka (30 km southwest of Kyiv, March 24, 2022), Lviv and Dubno (March 26, 2022), Dnipro (March 30, 2022), Odesa (April 3, 2022), Synelnykove (40 km southeast of Dnipro, April 6, 2022), Lysychansk (16 April, 2022), in Novomoskovsk (18 June, 2022). In addition, some oil refineries were targeted: Kremenchuk (April 2, May 12, June 18), Odesa (April 3, 2022), in Lysychansk (many times). In fact, strikes against oil installations have been carried out by the Russian invading forces throughout the entire territory of Ukraine.

In many cases, the fires at the oil depots have been tracked by Sentinel 2. Processing satellite data has provided good fire visualization. It is being performed by a combination of channels (B2, B3 and B4), as well as nearby infrared channels (B11 and B12). The combination of channels B3, B8 and B11, in particular are giving good results. Using channels of the infrared part of the spectrum increased location accuracy of the fires – at least within the spatial resolution of the channels of the satellite equipment (Fig. 3).

Fig. 3: Image of the fire at the oil depot in the south-western part of Chernihiv according to Sentinel 2B satellite from March 23, 2022: *a* – by combinations of channels of the visible spectrum, *b* – using the infrared channel B11.



a *b*

On the night of April 2, 2022, Russian forces launched several strikes on the Kremenchuk refining plant located in the centre of Ukraine. The Terra satellite recorded 4 fires here (Fig. 4). This plant has been attacked several more times since and due to massive infrastructure damage, this plant has stopped working.

Numerous fires were observed at places of fierce fighting. The cities of Irpin, Bucha, Hostomel and Horenka village, located northwest of Kyiv, for example, showed a high number of fires. Sentinel 2 satellite data made it possible to visualize these events in accurate detail. In particular shown below is the image from Sentinel 2B satellite during March 23, 2022 where numerous epicentres of fire were visible, as well as the spread of the smoke (Fig. 5). In this figure, the fires on the left part correspond to the city of Irpin, to the right – the Horenka village. An actual visit of these locations proved that Horenka village was destroyed even larger than the city of Irpin.

Fig. 4: Sites of the fires at the oil refinery in Kremenchuk on April 04, 2022 according to FIRS

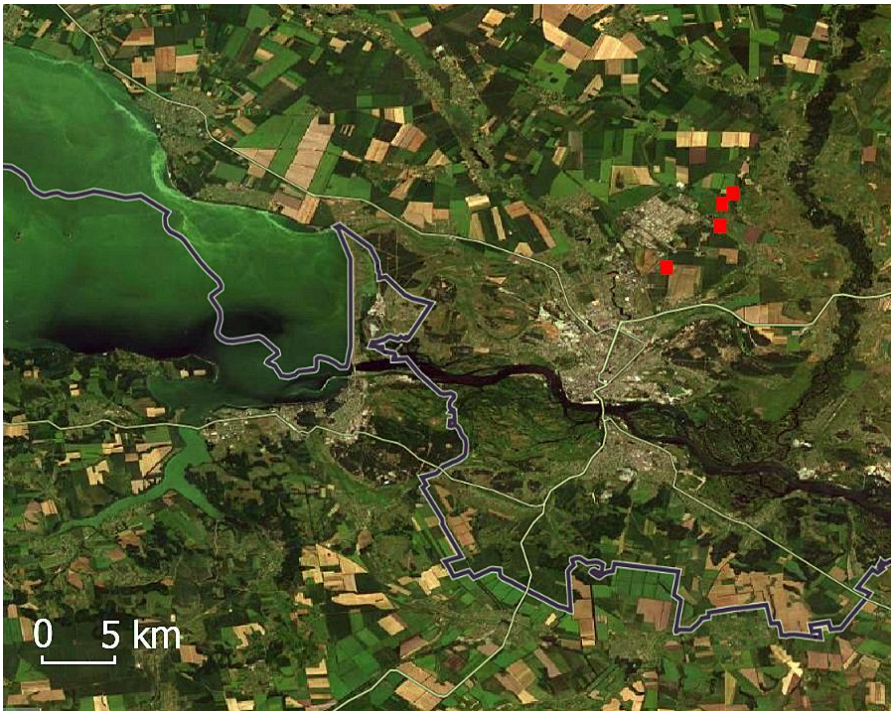
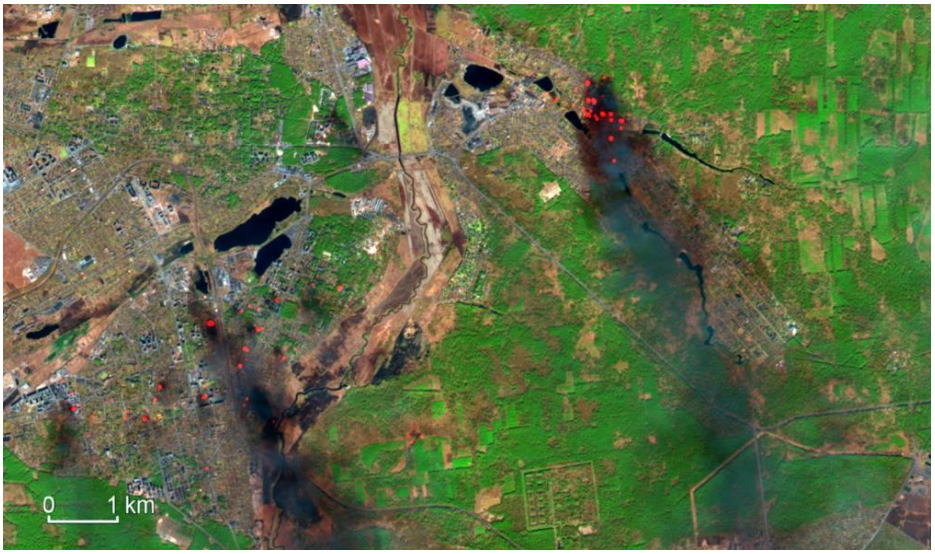


Fig. 5: Numerous places on fire together with smoke in Irpin city and Horenka village on March 23, 2022 according to Sentinel 2B satellite



The city of Mariupol has become the place of some of the fiercest fighting, so far, during the invasion. Numerous fires were recorded here throughout March 2022. Fires also broke out at the Azovstal steel plant which is located in the eastern part of the city (Fig. 6).

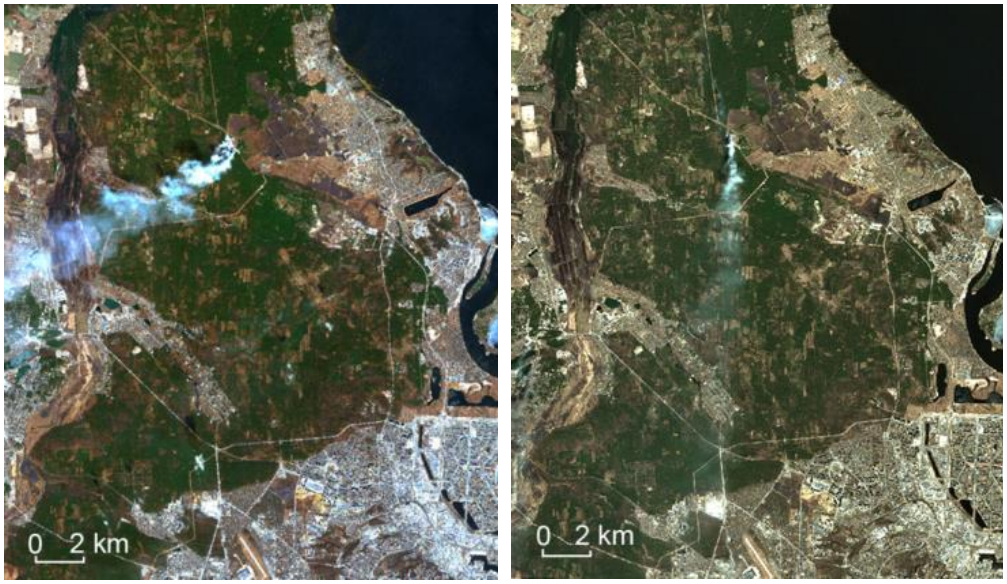
Fig. 6: Places of fires and there spread of smoke shown in Mariupol on March 24, 2022 according to FIRS

During the war there continued to be many more fires, which massively increased the air pollution. On March 18, 2022, a fire broke out at a landfill site on the eastern outskirts of the village Novi Petrivtsi which is located north of Kyiv. Smoke was recorded emitting from here until March 23. This fire was recorded on Sentinel 2 satellite images from 18.03.2022 till the 21.03.2022 (4 images in total). Initially, the smoke from this fire spread in a westerly direction, and later, due to a change in the wind – to the south. As a result, the smell of smoke was recorded on the right-bank part of Kyiv for several days (Fig. 7).

As a result of hostilities, there have been many cases of forest fires. First, they were observed in the north of Kyivska and Chernihivska oblasts which are rich in forests. These fires partially affected the area that was also contaminated by the Chernobyl Nuclear Power Plant accident. Fires in this part of Ukraine lasted from February 25 to March 29, 2022. A sharp decrease in the number of fires occurred from March 30, which, on the one hand, was due to rain, and on the other – the retreat of Russian military forces.

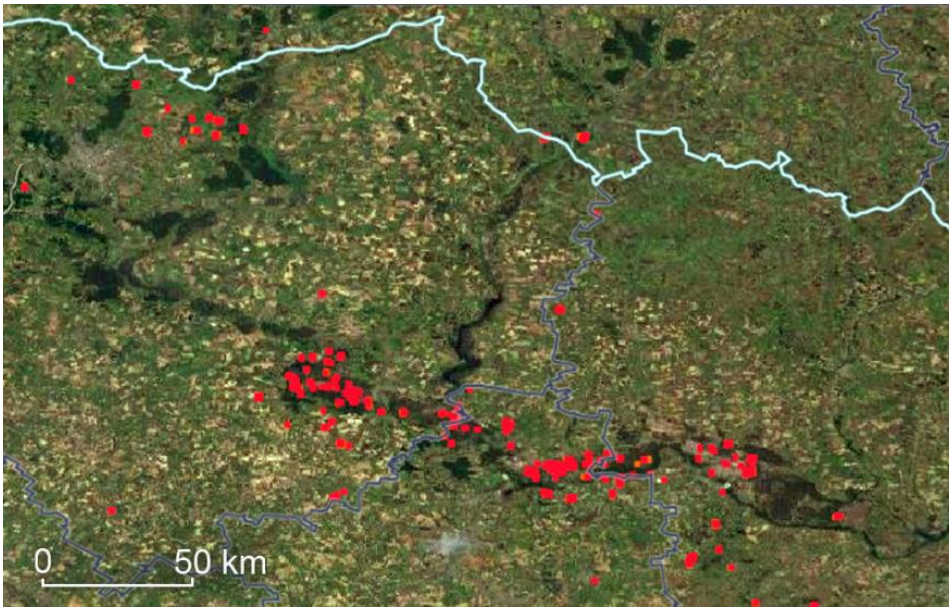
In early May 2022, the main fighting moved to Kharkivska, Donetska and Luhanska oblasts, where the number of fires increased sharply. Most of them have occurred near the Siverskyi Donets River, where a large forest is concentrated. The largest number of fires here was recorded on the days of the 05–08.05.2022, 12–13.05.2022 and 20.05.2022. This part of Ukraine has had the highest number of fires since the start of the invasion (Fig. 8).

Fig. 7: The spread of smoke from the burning in a landfill site on the western outskirts of the village Novi Petrivtsi according to Sentinel 2 satellite: *a* – on March 18, 2022, *b* – on March 21, 2022



a *b*

Fig. 8: Numerous forests burning sites near the Siverskyi Donets River on May 05, 2022 according to FIRS



In April–May 2022 fires also occurred in the south of the country, in particular the Kinburn Peninsula between the Dnipro estuary and the Black Sea. Many of the forest areas burned are located within the Black Sea Biosphere Reserve. The same has applied to pine forests located within the Oleshkivski Sands National Nature Park, which is located slightly to the east. The locations of these fires are clearly visible according to FIRS, as well as in the image from Sentinel 2A satellite from 09.05.2022 (Fig. 9).

Fig. 9: Numerous forest fires on the Kinburn Peninsula and within Oleshkivski Sands National Nature Park according to Sentinel 2A satellite from May 09, 2022

Fig. 9 shows that the plume of smoke from forest fires had reached a length of more than 100 km. At the time of these fires, most of this area was occupied by the Russian forces who made no attempt to douse the blazes.

Numerous fires during the invasion have also occurred in the Dnipro River Delta, namely within the Lower Dnipro National Nature Park. In this case, large areas of the reed beds were burned.

The Russian military engagements have also affected the aquatic environment, primarily in the rivers and the hydraulic facilities created on them. In particular, many bridges north of Kyiv were destroyed in order to slow down the enemy's offensive. Only on the Irpin River, which flows on its western outskirts, 5 bridges were destroyed. The effect of destruction to the retaining structure at the mouth of this river has been even greater. After this destruction, water from the Kyivske reservoir flooded the Irpin River floodplain. The width of this flooding was considerable and exceeded 1 km (Fig. 10).

Many negative consequences of the war stem from water pollution. The search for information on such cases was performed on the basis of media, as well as remote sensing data. One such case occurred, near Vasylivka town, Zaporizka oblast. Due to the destruction of the sewage treatment plant adjacent to the town on March 14, 2022 by the Russian invasion forces caused parts of the Kakhovske Reservoir to be polluted. It is possible to trace this pollution on the image of Landsat 8 satellite from March 28, 2022. This image was processed by selecting several spectral channels, which allowed to best visualize the spread of the contaminated water (Fig. 11).

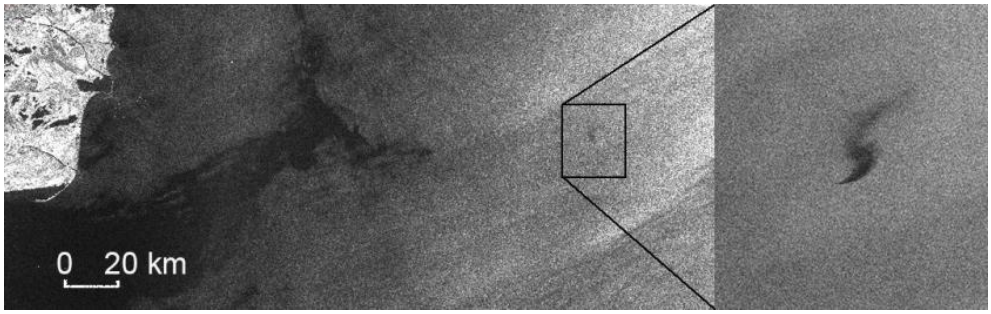
Fig. 10: Satellite images of Sentinel 2 from March 11, 2022 (a) and March 18, 2022 (b) showing the spread of flooding on the Irpin River floodplain

a *b*

Fig. 11: Water pollution in the Kakhovske reservoir near Vasylivka town according to Landsat 8 satellite on March 28, 2022

Since the start of the invasion the Black and Azov Seas were polluted as well. On April 14, 2022, the Russian cruiser "Moscow" was sunk. The place of its sinking was initially roughly established from information sources. This was followed by an analysis of the available satellite images on the day and a few days after the sinking of the cruiser. As the relevant part of the Black Sea was covered with clouds at that time, radar images of Sentinel 1A satellite from 19.04.22 and 24.04.2022 were used. Careful analysis of these images made it possible to identify the location of the oil slick with the following coordinates: 44°55'N and 31°29'E. This place is located about halfway between the mouth of the Danube River and the Crimea (Fig. 12).

Fig. 12: Oil slick in the Black Sea at the place of the sinking of the cruiser "Moscow" according to the satellite image Sentinel 1A from April 24, 2022

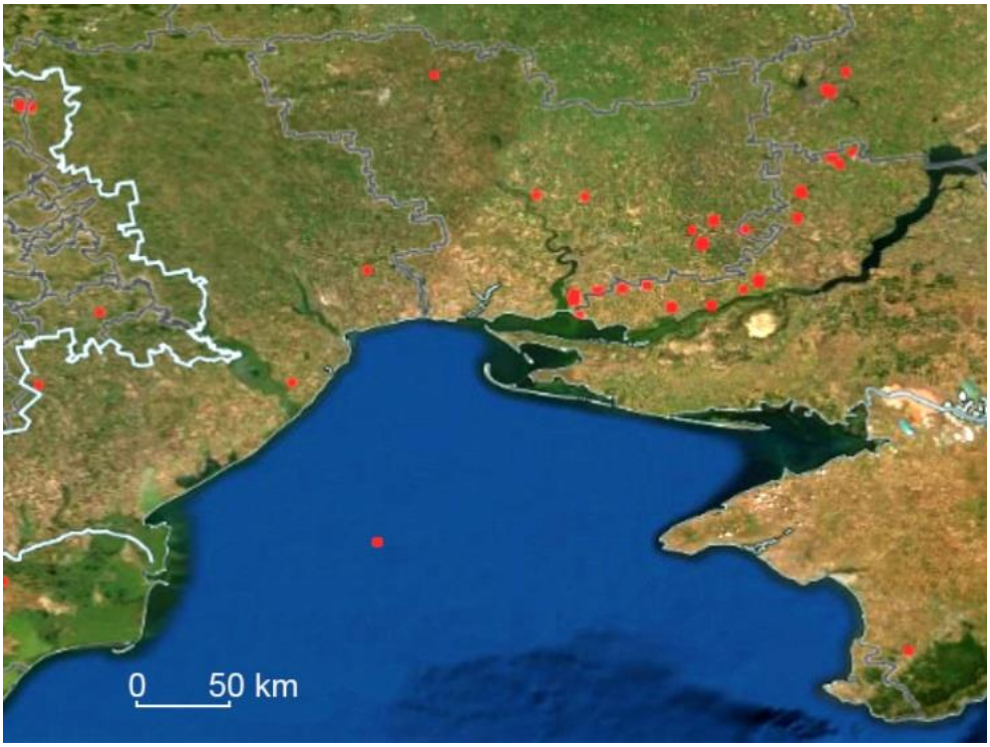


During the Russian military engagements, several more ships have been sunk, both in the Black Sea and in the Sea of Azov. On March 24, 2022 a rocket strike sank the ship "Saratov" in the port of Berdyansk located on the northern shore of the Sea of Azov. The first images of a fire on this ship were recorded by Suomi NPP satellite at the beginning of the following day.

On June 20, 2022 the place of fire appeared on the Black Sea. At that day it was announced a missile strike of Ukrainian forces on drilling platforms of gas production used Russian forces for military cases. The fire in this place continued for some months and during that time Russia couldn't or didn't want to extinguish the fire. As a result of this fire was polluted not only the air but also a sea (Fig. 13).

It is clear that the military attack has affected the economic sphere, in particular with regard to the state of the agricultural land. These were bombed, damaged by military traffic and becoming contaminated. Some of these areas were not sown in the spring of 2022. In Khersonska oblast, where irrigation is widespread, it has stopped in a large area. This is eloquently shown by images of Sentinel and Landsat satellites.

Fig. 13: The fire in the place of drilling platforms in the Black Sea from June 20, 2022 according to FIRS



DISCUSSION

An environment always suffers silently from human warfare, but the impact on nature is profound. Actually, due to the military events natural system is destroyed at every level (Dudley *et al*., 2002; Lawrence *et al.*, 2015; Garzón &Valánszki, 2020). Wars annihilate habitats of almost all living organisms of injured area, kill wildlife and lead to changes in biodiversity (Swintek, 2006; Reuveny *et al*., 2010). The long-term effects will be visible not only on wild animal and plant life, but also on crops at arable lands (Al-doski *et al*., 2013). On a large scale, military conflicts generate pollution of water and air (Al-doski *et al*., 2013), and even intensify climate change (Omar *et al*. 2009; Mach *et al*., 2019).

Described large-scale effects remains for dozens of years. The severe damage caused by the World War I, can still be seen today in some areas. For instance, 250,000 acres of farmland in Somme (France) were severely destroyed as a result of trench warfare and were deemed unfit for agriculture. The negative effect of Vietnam War is terrifying by result of Agent Orange usage. This deadly combination of chemicals killed grass, foliage, woody species, and left the soil too infertile to support life (Davis, 1998).

The dramatic effect of a war is known from invasion of Kuwait in 1990–1991 when a large-scale pollution was caused mainly by destruction of oil wells. At that period about two million tons of oil were released and polluted the Persian Gulf (Mannion, 2003). The

production of soot and gases, such as carbon dioxide and sulphur dioxide, caused pollution episodes were registered within and beyond the region.

The war in Ukraine, the country that have well-developed industry with 15 nuclear reactors at four power plants, chemical plants and their storage facilities, oil depots, coal mines and gas lines, could bring severe negative impact on environment for future. In case of ruin or damage named industrial facilities, the enormous number of dangerous particles could be released. This would lead to dramatic changes in all spheres of the environment: earth's surface, arable lands, air, water, along with flora and fauna. The effect will be noticeable not only within territory of the country, but thousands of kilometres far from the place of disaster. The scale of military engagements and strikes obtained due to remote sensing data analyses leads to understanding of the damage caused to nature. To a certain extent, a conducted research is similar to the approach presented in the work (Garzon &Valanszki, 2020).

During our research we had some difficulties with data analysis of the photos. The satellite images are of medium resolution and it also sometimes does not allow us to investigate certain desirable areas. Images obtained from Sentinel 2 satellite with a resolution of 10 m, still make it almost impossible to detect the many individual changes on the Earth's surface and almost impossible to count. It should be added that the possibility of using these Sentinel satellites has only been available relatively recently, namely since their launch in 2014–2015. Until now, only satellite data of a much lower resolution was available in the public domain.

Even high-resolution military satellites did not appear until 1999–2000 which is, almost when the Aqua and Terra satellites also appeared. This means that monitoring the course and consequences of this war and any other conflict has only become possible since the Iraq war in 2003. Prior to that, satellite data could only be used to observe certain components of the environment covering a large area. The oil pollution produced during the Gulf War in 1990–1991 was studied using Landsat 4 and Landsat 5 satellites with a resolution of 30 m (Kwarteng, 2009). As for the data presented in the paper (Omar *et al*., 2009), then their analysis was formed using old and tried traditional methods which made it extremely hard to detect the total damage to almost two hundred oil wells and the same conditions applied in those days to monitoring the groundwater pollution.

Nowadays there are significant opportunities to use remote sensing data in order to detect fire and smoke. In this case, a favourable factor is that the corresponding data collection is performed several times a day. Therefore, significant fires in oil depots and forests, which lasted over several days, were able to be recorded by NOAA-2, Suomi NPP, Aqua and Terra satellites. Additional data from Sentinel 2 satellites are also useful in these studies. However, a combination of several spectral channels, including infrared channels are also required in these cases. This allows not only a good visualization of combustion sites but also can be used to clarify their coordinates.

The consequences of the Russian military engagements regarding the aquatic environment are numerous. Many water bodies have become polluted, some of which have been changed significantly. When the destruction of the hydraulic structure at the mouth of the Irpin River caused significant flooding of the floodplain, we can assume that this was accompanied by water pollution. During the early days of the invasion many bridges and pontoon crossings were destroyed, parts of which fell into rivers as well as abandoned and destroyed military equipment. It is well beyond doubt that the groundwater has also been polluted.

According to remote sensing data, there have been numerous forest fires in places of hostilities. The day after the start of the war, the number of forest fires in the north of Kyivska and Chernihivska oblasts increased sharply. The relocation of fighting to the eastern part of Ukraine in early May 2022 has also caused numerous forest fires along the Siverskyi Donets River.

Remote sensing data has also made it possible to detect numerous cases of smoke in the atmosphere. In some cases, the length of the smoke plumes from the forest fires exceed 100 km. Added to this is that some fires occurred in the area that was contaminated by the Chornobyl Nuclear Power Plant disaster. The additional impact was of dust from military vehicle. As a result, the level of gamma radiation near Chornobyl nuclear power plant became higher than before (Harada *et al*., 2022).

It is obvious that the Russian invasion has also negatively affected the animal world. The war has led to the death and injury of many animals as well as disrupting their habitat. It is important that the active phase of the military attack fell during the spring period which is the time that many animals commence their yearly reproduction cycle. It can be argued that in these conditions, the greatest damage was caused to the highly organized animal groups, including mammals and birds. This fact is proved by press-release report of the Turkish Marine Research Foundation about numerous cases of dolphins' death at the shoreline of the Black sea (TUDAV, 2022). It can be assumed and, in many cases, proven that many animals were and are being deliberately killed for food needs by the Russian forces.

A variety of negative consequences of the environmental pollution of this war was also described in recently published article (Harada *et al*., 2022). The smoke resulting from explosions contain toxic gases and particulate matters that spread and migrate contaminating water and soil. Thus, groundwater, agriculture and animal products become source of poisoning in humans. The explosives usually contain ammonium nitrate which will eventually leach into water. Ammonium can lead to toxicity in fish and eutrophication. Detonation of explosives will lead to the release of CO2, N2, NH3, N2O, NO and other gases.

All described results of the military events during this cruel war is possible to monitor and analyse using remote sensing data. We consider that the proposed approach serves a good tool in the analysis of military consequences on environment.

CONCLUSION

Available information sources and data from remote sensing have made it possible to establish numerous facts about the impact of the Russian war has on the environment in all areas: the earth, air, water, flora and fauna.

From the start of the military engagements there have numerous fires broke out in the forests of northern and eastern Ukraine. Many of the fire events were in nature reserves and national parks. Added to which numerous fires have also been started at oil depots and other facilities, having significant effect on air pollution. The satellite images revealed the smoke from some fires has spread for more than 100 km.

Analysis of data from the remote sensing is also made it possible to identify the cases of the negative impact on the aquatic environment. We can assume significant hydrological changes of some water bodies as destruction of the hydraulic structure of rivers and floodplain floods. Using remote sensing data, also allowed us to monitor spots of pollution in rivers and in the Black Sea.

With conducted research, we proved advantages of remote sensing data approach for estimation of large-scale consequences of war on environment.

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CONFLICT OF INTEREST

The authors declare that they have no competing interests.

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