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Applications of earth remote sensing for natural resource monitoring in Ukraine

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ABSTRACT: In this paper, the Ukrainian experience of using satellite data for natural resources monitoring, management and preservation from the academic and purely practical perspective was studied using an integrative literature review with elements of scoping review according to PRISMA guidelines. The results of the review indicate that the most widely used Earth Remote Sensing (ERS) methods include the application of the information from Landsat and Sentinel satellites, mainly because of their advantages in terms of the cost, period able to be studied, appropriate resolution, and adequate number of spectral channels to enable a large array of possible studies. Ukrainian scientists use satellite images to monitor changes and condition of the landscape and waters to obtain information about the amount of damaged landscape, the condition of the agricultural lands, and the condition of the different types of land for prediction of the deteriorative processes and potential sources of dangerous situations, as well as study origin, history, characteristics of the water resources and provide more precise picture using machine processing software (mostly Google Earth Engine and ArcGIS) with build-in machine algorithms to extracted Normalized Difference Vegetation Index, Modified Normalized Difference Water Index, and Normalized Difference Built-Up Index. The most widely used ERS methods include the application of the information from Landsat and Sentinel satellites, mainly because of their advantages in terms of the cost (free access to their databases), period able to be studied (from 1972 to present), appropriate resolution (10m/pixel to 120 m/pixel), and adequate number of spectral channels to enable a large array of possible studies.
Keywords: environmental monitoring; geoinformation systems; natural resource conservation; spatial analysis.

Aplicação do sensoriamento remoto da terra para monitoramento de recursos naturais na Ucrânia

RESUMO: Neste artigo, a experiência ucraniana de utilização de dados de satélite para monitoramento, gestão e preservação de recursos naturais a partir de uma perspectiva acadêmica e puramente prática foi estudada usando a revisão integrativa da literatura com elementos de revisão de escopo de acordo com as diretrizes PRISMA. Os resultados da revisão indicam que os métodos ERS mais utilizados incluem a aplicação da informação dos satélites Landsat e Sentinel, principalmente pelas suas vantagens em termos de custo, intervalo de tempo a ser estudado, resolução apropriada e número adequado de canais espectrais para permitir uma grande variedade de estudos. Os cientistas ucranianos utilizam imagens de satélite para monitorizar as mudanças e as condições da paisagem e das águas, a fim de obter informações sobre a quantidade de paisagem danificada devido a atividades mineiras ilegais (especialmente no que diz respeito à mineração de âmbar), condição das terras agrícolas, por exemplo, como produtividade das culturas no aspecto espacial e temporal, condição dos diferentes tipos de terras para previsão dos processos deteriorativos e fontes potenciais de situações perigosas; bem como estudos da origem, história, características do recursos hídricos. Em gerla, os estudos usam de processamento de máquina (principalmente Google Earth Engine e ArcGIS) com algoritmos de máquina integrados para extrair o Índice de Vegetação por Diferença Normalizada, o Índice de Água por Diferença Normalizada Modificado e o Índice de Construção por Diferença Normalizada. Os métodos ERS mais utilizados incluem a aplicação das informações dos satélites Landsat e Sentinel, principalmente devido às suas vantagens em termos de custo (acesso gratuito às suas bases de dados), intervalo de tempo passível de estudo (de 1972 até ao presente), resolução adequada (10m/pixel a 120 M/pixel) e número adequado de canais espectrais para permitir uma grande variedade de estudos possíveis.
Palavras-chave: monitoramento ambiental; sistemas de geoinformação; conservação de recursos naturais; análise espacial.

1. INTRODUCTION

The term Earth remote sensing (ERS) was introduced in 1960 by geographer Evelyn Pruitt (USA), and today, it is globally and widely used. ERS methods began to develop especially intensely in the 1970s in connection with the development of space technologies, which led to the possibility of installing ERS equipment on space carriers.

According to the definition of the Scientific and Technical Subcommittee of the UN Committee on Outer Space, ERS is the observation and measurement of energy and polarization characteristics of the own and reflected radiation of elements of the Earth's landscape, ocean and atmosphere in various ranges of electromagnetic waves, which contributes to the description of the location, nature and temporal variability of natural parameters and phenomena, natural resources of the Earth, the environment, as well as anthropogenic objects and formations without direct contact with the object.

The main strategic goal of ERS is to improve the interaction between mankind and the natural environment and optimize economic activity to minimize damage to nature, specifically natural resources (HRUZEVSKYI, 2023). The main tasks of ERS are i) providing up-to-date information about changes in the ecosystems; ii) observing the chemical, biological, and physical processes;

iii) We monitor anthropogenic pollution of the atmosphere, hydrosphere, and soils and determine its consequences.

Application of ERS for natural resources monitoring, management, and preservation includes the following types:

- monitoring of landscape;
- monitoring of water objects and their use;
- monitoring of soils and subsoils;
- monitoring of specially protected natural territories;
- monitoring of mountain ecosystems and desertification;
- monitoring of forest;
- monitoring of wildlife; and
- monitoring of vegetation.

Four main components can be distinguished in the aerospace ERS system: the imaging equipment carrier, the imaging equipment, onboard means of receiving, processing and transmitting information to Earth by radio channel, and land-based complexes of information reception, its thematic processing, archiving and transmission to consumers.

According to the type of carrier used for ERS systems, they are divided into two main groups:

• aviation – airplanes, helicopters, gliders, hang gliders, unmanned aerial vehicles, aerostats (airships and balloons);

• space – artificial satellites of the Earth and other planets, orbital stations, interplanetary vehicles (BORTSOVA et al., 2023).

The real era of space exploration and ERS utilization for natural resources monitoring, management, and preservation began with the launch of the American Landsat-1 space exploration satellite on July 23, 1972. Today, more than two dozen countries are engaged in remote sensing of the Earth's surface from space using satellites` information.

More than 30 Earth observation satellite missions with low and medium spatial resolution operate in near-Earth space, providing space-based imaging in various spectral ranges for global and regional research (KRYVOSHEIN, 2023). Almost all of this data is freely distributed for scientific research. A significant number, but not all, of these observation satellite missions are used for ERS and related tasks (MARAIEVA, 2022).

The Landsat program is the longest-running project to obtain satellite photographs of the Earth. The first satellites under this space program were launched in 1972; the most recent, Landsat 9, was successfully launched on September 27, 2021 (WULDER et al., 2019; WULDER et al., 2022). The data on ERS received by Landsat spacecraft shows that their application is in more than 100 countries. Of these, 17 countries, including the USA, have receiving stations. The information received from Landsat system satellites is widely used to solve many economic, scientific, political, and military problems. In particular, ERS data are widely used in the following areas: geography, oceanography (Kubraykov et al., 2021), hydrology (Tasumi, 2019), geology (Pour et al., 2019), study of natural resources of individual regions, countries and the earth as a whole (Black, 2019), mapping of the earth's surface (Potapov et al., 2020), ecological and environmental control (GAO et al., 2021).

Copernicus is a European professional program run by the European Union, with the European Space Agency (ESA) coordinating the space component of the program. ESA is currently developing seven missions using Sentinel satellites. Missions aim to provide images for land, ocean, and atmospheric observations. Each mission is based on two Sentinel satellites. The first satellite, Sentinel-1A, was launched on April 3, 2014. Sentinel-1 provides all-weather day and night observations of land and oceans (e.g., management of disasters and monitoring of geohazards) (FERNANDEZ et al., 2022). Sentinel-2 provides high-resolution optical imagery for land monitoring (e.g., vegetation, soil, inland waterways and coastal areas) (PHIRI et al., 2020). Sentinel-3 provides ocean and global Earth monitoring (i.e., environmental and climate) (STRUGAREK et al., 2019). Sentinel-4 provides data for atmospheric monitoring, as does Sentinel-5. The newest one, Sentinel-6, provides data for study regarding oceanography and climate (DONLON et al., 2021).

In the context of natural resources monitoring, ERS data using Sentinel satellites have been practically implemented by the European Union in the creation of specialized European authorities for:

- land monitoring service to obtain geographic information on soil and vegetation to further use it for spatial planning, forestry, water resources management, agriculture, etc. (ANDRIMONT et al., 2021);

- marine monitoring service to obtain information on the state of the oceans and seas, currents, winds and ice movement on the seas and oceans to further use it for ship routing services, search and rescue operations, ensuring safety at sea, as well as for sustainable management of marine resources (LE TRAON et al., 2019);

The atmospheric monitoring service provides information on the composition of the atmosphere and its daily changes, maps of the occurrence and distribution of greenhouse gases, chemically active gases, ozone and aerosols, etc. (PEUCH et al., 2022).

Terra satellite, with a mission to observe the Earth system, was launched in December 1999 by NASA. The Terra satellite contains five probes to observe the Earth's atmosphere, ocean, land, snow and ice, and energy status:

ASTER to create maps of the Earth's surface temperature, emissivity, reflectivity and height;

CERES to measure the total volume of the Earth's radiation and provide data to determine the role of clouds in the radiation flow from the surface to the top of the atmosphere;

MISR to measure the solar radiation reflected by the Earth (both the surface and the atmosphere);

MODIS to monitor the global dynamics of the planet Earth (i.e., changes in cloudiness, radiation balance and processes occurring in the oceans, on land and in the lower layers of the atmosphere);

MOPITT will monitor the nature of atmospheric pollution.

Moreover, Terra-MODIS data can be retrieved free of charge from the global catalog located on one of NASA's official websites. In Ukraine, Terra-MODIS reception is performed in Dunaivtsi city (Khmelnytskyi region). Data from Terra-ASTER can also be retrieved for free through the Internet.

Planet Labs, a startup created by former NASA employees, aims to provide services to see the exact appearance of any part of the Earth almost online based on a subscription. Planet Labs designs manufactures and launches miniature remote sensing satellites called Doves, which have a life span of three years. Since 2014, the company has launched more than 233 mini-satellites to monitor weather, prevent natural disasters, and predict crop yields.

RapidEye, a group of five mini-satellites owned by BlackBridge AG (formerly RapidEye AG), was launched on August 29, 2008. The satellites can provide daily coverage of an area of approximately 4 million km^2 and provide data primarily for agriculture and forestry monitoring, oil and gas complex and energy monitoring, thematic and special mapping, ecology and environmental protection, and emergency management.

Satellite images contain a wide array of information that can be further analyzed using several special software tools called geographic information systems (GIS). Today, a large amount of software is created both commercially and open-source. For example, one of the most popular, freely available, functional cross-platform GIS is Quantum GIS, created in 2002 and regularly upgraded by active volunteers.

CIS systems` information is a precious source for further special analysis, including interpretation, evaluation, and model of GIS data. Generally, spatial analysis of GIS data is used to measure distances and shapes, build routes and track transportation, and establish relationships between objects, events, and territories by correlating their location with a point on a geographic map. Regarding the precise tasks of natural resource management and conservation, spatial analysis is currently applied in agriculture, forestry, marine sciences, oil and gas production, mining, economics, and other fields. In the agricultural field, special analysis enables studying the density of plant cover, the degree of soil moisture, soil temperature, the condition of crops, etc. In landscape management, the spatial analysis of GIS data enables, for example, deforestation detection and prediction of the occurrence of fires based on critically high-temperature indicators.

The precise fields of natural resource management and resource preservation that the use of ERS information can enhance are land supervision, forestry, water resources control, monitoring of coastal zones and oceans, climatology, control of the global atmosphere, meteorology, geodesy, cartography, urban planning, search for minerals and energy sources, and emergency monitoring.

Surface monitoring is one of the most important and typical applications of remote sensing using satellite images to determine the physical condition of the Earth's surface (e.g., forests, pastures, road surfaces, etc., including the results of human activity, such as the landscape in industrial and residential areas, the state of agricultural territories, etc.). Surface monitoring and detection of changes in the condition of the Earth's surface is necessary for updating maps and rationalizing the use of natural resources to develop and implement the environmental protection policy and perform complex calculations (e.g., determining the risks of erosion).

For agricultural purposes, satellites enable obtaining images of individual fields, regions and districts with a certain cyclicity that allow scientists and practitioners to receive valuable information about the status of the plots, including the identification of crop type, identification crop location, degree of land depletion, the determination of the sown areas of crops and the state of the harvest, etc., ultimately providing the possibility of accurate management and monitoring at various levels, optimization of farming and spatially oriented management of technical operations, implement a plan of reclamation measures, for local optimization of the use of agricultural chemicals (MAZUR et al. 2023).

Satellites can significantly contribute to the process and efficiency of natural resource monitoring, management, and preservation, and in some cases, they are completely free. Therefore, this research aims to study the Ukrainian experience of using satellite data for natural resource monitoring, management and preservation from an academic perspective.

2. MATERIALS AND METHODS

We used the integrative literature review with elements of the scoping review method to study the Ukrainian experience of using satellite data for natural resources monitoring, management and preservation from the academic perspective. This integrative literature review, which included elements of a scoping review, was performed using PRISMA guidelines.

To study the existing literature sources, we used the Google Scholar database.

To create a pool of articles of interest, we used several keywords related to Earth remote sensing using satellites, such as Remote Sensing, Remote Probing, Photogrammetry, Natural Resources, Soil Monitoring, Water Monitoring, Landscape Monitoring, Marine Monitoring, Atmospheric Monitoring, Ecological Monitoring and Ecological Control, Environmental Monitoring and Environmental Control, Satellite, Landsat, Sentinel, and Terra.

To select the relevant articles, we used the following inclusion criteria: 1) articles cover the practical implementation of ERS for natural resource monitoring; 2) articles cover original research; 3) articles cover reviews (to extract additional original research); 4) articles are published in journals; 5) articles are published in Ukrainian and English; 6) Ukrainian authors publish articles; 7) articles provide full text; 8) articles are published from the beginning of 2019 to present.

To exclude the irrelevant articles, we used the following exclusion criteria: 1) articles cover the aspects of ERS use for natural resource monitoring other than practical implementation; 2) articles do not provide full text; 3) articles published in another language (not Ukrainian and English); articles published before the beginning of 2019.

First, the articles were reviewed and verified using their titles and abstracts to create a primary pool of relevant articles (740). After that, all the primary articles included were reviewed and verified using their full text to create a secondary pool of relevant articles for the close study (216 articles). The next step involved the organization and classification of the relevant articles based on the subtopics within the main aim of this study, namely "study of Ukrainian experience of use of the satellite data for natural resources monitoring" (47 articles). Next, we developed and applied evaluation questions to extract the tertiary pool of the most relevant articles from the practice perspective (28 articles).

Finally, to the organized and classified articles, we applied qualitative analysis based on understanding, interpretation, synthesis, and deduction techniques to draw a picture of the Ukrainian experience of using Earth remote sensing (i.e., satellite technologies) for practical aspects of natural resources monitoring, management, and conservation from the academic perspective.

3. RESULTS

In the qualitative analysis, we revealed that only some articles covered the entire list of evaluation questions. Rather, two groups in the article focused more on the natural resources (and merely touched image processing) and more on image processing (and merely touched natural resources). Therefore, we included both groups to draw the fullest picture. Table 1 summarizes the most relevant articles (25) on the practical implementation of ERS use for natural resources monitoring, management and preservation.

Table 1. Summary of the most relevant articles covering the use of satellites for natural resources monitoring in Ukraine.
Tabela 1. Resumo dos artigos mais relevantes que cobrem o uso de satélites para monitoramento de recursos naturais na Ucrânia.

First author	Satellite application details		
	Satellite	Designation	Region
ZAIACHKIVSKA et al. (2024)	Planet Labs	Monitor of landscape (amber mines)	Rivne region
KACHANOVSKYI(2020)	Landsat-8	Monitor of landscape (amber mines)	Polissia
BASHTOVYI et al. (2019)	Landsat-7, SPOT, Quickbird	Monitor of landscape (protected areas)	Sumy region
DOMARATSKYI et al. (2023)	Sentinel-2	Monitor of landscape (agriculture)	Mykolaiv region
PASHCHENKO et al. (2023)	Sentinel-2	Monitor of landscape (agriculture)	Not specified
ZIBTSEV et al. (2019)	Landsat 5, 7, 8	Monitor of landscape (forest)	Rivne region
HLOTOV et al. (2022)	Landsat 7, 8	Monitor of landscape (soil)	Lviv region
SHEVCHUK (2019a)	Sentinel-2	Monitor of landscape (mines)	Rivne region
SHEVCHUK (2019b)	Landsat, Sentinel-2, Terra, Aqua	Monitor of landscape (water reservoirs)	Cherkassy region
REN (2023a)	Landsat 8 and Terra Modis	Environmental monitoring	Lviv region
TROFYMCHUK et al. (2023)	Sentinel-2A, Sentinel-1A, SkySat, WorldView 01-03, Capella, CSM, RCM1, ICEYE	Environmental monitoring (fires)	Kherson and Mykolaiv region
LYALKO et al. (2023)	Sentinel-2	Monitor of landscape (peatlands)	Polissia and Kyiv region
APOSTOLOV (2020)	Landsat, Terra Modis	Monitor of landscape (soil)	Southern regions
REN (2023b)	Landsat, Sentinel, Terra Modis	Monitor of landscape	Whole Ukraine
LANDIN et al. (2020)	Sentinel-2	Monitor of landscape (forest)	Zhytomyr region
BANDURKA et al. (2022)	Terra MODIS and NOAA AVHHR	Monitor of landscape (forest)	Kyiv region
LISHCHENKO et al. (2022)	Landsat 4-8, SRTM, Sentinel 2	Monitor of landscape (peatlands)	Chernihiv region
HARBAR et al. (2024)	Sentinel-2	Monitor of landscape (soil)	Zhytomyr region
MYRONIUK (2019a)	Landsat-8	Monitor of landscape (forest)	Sumy region
LAKYDA et al. (2020)	Sentinel-2	Monitor of landscape (forest)	Eastern regions
MYRONIUK (2019b)	Landsat-8, SPOT 7, PlanetScope	Monitor of landscape (forest)	Kyiv region
FESYUK et al. (2023)	Sentinel-2	Monitor of landscape (forest)	Volyn region
ALEKSIYCHUK (2023)	Sentinel-2 and Landsat-8	Monitoring of water (water reservoirs)	Volyn region
DREBOT et al. (2020)	Landsat 1, 4-7, 8	Monitoring of water (water reservoirs)	Khmelnytskyi region
ANDRIEIEV et al. (2020)	Landsat-8	Monitoring of water (river)	Dnipro river

Table 1 data shows that the satellite images were mostly used for monitoring the surfaces (e.g., landscape, water, etc.) that provided different information for various practical purposes, but, in essence, the satellite images were for the primary evaluation of the surfaces.

More detailed objects of the studies and image information are below.

Zaiachkivska et al. (2024) used information from Planet Labs PBC in four-spectral satellite images created between 2016 and 2023 with a resolution of 3 m/pixel. Kachanovskyi et al. (2020) used multispectral space images obtained from the Landsat-8 satellite system between 2013 and 2017 to evaluate the percentage of disturbed lands caused by amber mining activity and determine the period of the heaviest disturbance.

Bashtovyi et al. (2019) used a combination of images from three satellites to develop a method of phytogeomonitoring in protected areas that combines the collection, preservation, processing, access, display and distribution of spatial data, enabling integral storage, regulation, analysis and monitoring of the protected areas' condition.

Shevchuk et al. (2019a) (Rivne region) used Sentinel-2's multispectral survey data to study the possibility of monitoring the condition of open mining operations on a specific site. Domaratskyi et al. (2023) used satellite images obtained from Sentinel-2 created during the period between 2019 and 2021 with a resolution of 10 m/pixel for the determination of spatial-temporal dependence of sunflower productivity on the plasticity of hybrids and the introduction of restorative chemicals. The images were further processed using spatial analysis and calculations to calculate the vegetation index. Pashchenko et al. (2023) applied the data from Sentinel-2, fractal analysis, to develop methods of monitoring agricultural lands and crops.

Fesyuk et al. (2023) used the data from Sentinel-2 to develop a methodology for assessing the forest cover, verifying and evaluating the current state of the forest cover, simultaneously determining the trends of its change and main measures to improve the protection and rational use of forest resources. Zibtsev et al. (2019) analyzed multispectral satellite images obtained from Landsat 5, 7, and 8 with a resolution of 30 m from 2006 to 2016 to record the quantity and location of the previous fires in the forests. Bandurka et al. (2022) used data from Terra MODIS and NOAA AVHHR to develop a method for identifying fire-hazardous areas. Myroniuk (2019a) focused on using RES for species composition in forests and, in his other work (Myroniuk, 2019b), on forest inventory accounting. Lakyda et al. (2020) used satellite images to evaluate the productivity of forests. Lamdin et al. (2020) used the ERS methods to evaluate the areas of pathological drying in the forests due to pests and forest diseases.

Hlotov et al. (2022) used images of Landsat 7 for the study of the 2000 year and Landsat 8 for the study of the 2019 year for monitoring the changes in land cover for the prediction of erosive processes, displacing processes, karst processes, etc. Apostolov et al. (2020) used satellite images to determine the territory's moisture availability and desertification processes. For this purpose, the authors used images of Landsat-5 in 2007 and Landsat-8 in 2017, Terra-MODIS in 2007 and Landsat-8 in 2017 and Terra-MODIS in 2007 and 2015. HARBAR et al. (2024) utilized another ERS method (Sentinel-2) for the study of the structure and spatio-temporal dynamics of the land cover on the territory of the ridge, as well as the dependence between the structure of the land cover and the characteristics of ridge biodiversity.

Shevchuk et al. (2019b) (Cherkasy region) for studying water objects in Ukraine, using several satellites, including Landsat, Sentinel-2, Terra and Aqua. Combining several satellites allowed the authors to study water resources' origin, sizes, and conditions more precisely and achieve higher accuracy. Aleksiychuk (2023) used images of Sentinel-2 and Landsat-8 made in 2022 to determine the level of lake eutrophication for its rational use and conservation, improvement of water quality and conditions for the existence of hydrobionts. Drebot et al. (2020) used a whole range of satellite images starting from 1975 (Landsat-1), going to 1989 and 2001 (Landsat 4-7), and ending with 2018 (Landsat-8) to estimate changes in water resources, precisely the reduction of the water body areas. Andrieiev et al. (2020) used the ERS methods to build hydrological cartographic models of the river.

Ren (2023a) (Lviv region) focused on monitoring the quality of the natural environment and compared images obtained from Landsat 8 in 2015 and 2021.

In another study, Ren (2023b) (whole Ukraine) focused on monitoring the changes in land cover throughout Ukraine from 2000 to 2015. Ren used Google Earth Engine for study purposes, which contains open-access images from the Landsat satellite, Terra-MODIS, and Sentinel 1, 2, and 3 satellites.

Lyalko et al. (2023) used data from Sentinel-2 obtained in 2019 and 2021 to analyze the characteristics of peatlands for the future potential utilization of peat as an alternative energy source. Lishchenko et al. (2022) utilized data from a combination of three satellites for the same purpose. Since only some authors indicated the methods they used to process the images, we enhanced the previous list of articles with relevant ones focused on image processing. The second group of articles (16) is given in Table 2.

In addition, we can draw patterns in preferences for using specific satellite missions. Figure 1 represents the percentage of the use of the specific satellite system for scientific studies in Ukraine.

The data of Figure 1 show that the most widely used satellite mission in Ukraine is a Landsat mission, closely followed by the Copernicus mission with its Sentinel satellites. Additionally, for academic purposes in Ukraine, rare use found the following satellites: Planet Labs, SPOT, Quickbird, SkySat, WorldView 01-03, Capella, CSM, RCM1, ICEYE, NOAA AVHHR, and SRTM.

In addition, we noticed that many studies used combinations of images obtained from different satellites (Figure 2).

In 54% of the studies, utilizing a single satellite was enough, while in 46%, the scientists used a combination of 2-4 satellites to obtain the fullest picture possible. In rare cases, 6 and 10 satellites were used to conduct the research.

Table 2. Summary of the technique for remote sensing image processing.
Tabela 1. Resumo da técnica de processamento de imagens de sensoriamento remoto.

First author	Satellite application details		
	Processing software	Processing methods	Purpose
KAVATS (2019)	EOS Processing	Principal Component Analysis and Scale Invariant Feature Transform	Change detection on different time images
DAVYBIDA (2021)	Google Earth Engine	Not specified	Calculation of NDVI, MNDWI, NDBI
BANDURKA et al. (2022)	Erdas Imaging	Specially developed algorithms	Detection of forest fire pixels
SAKHNO et al. (2024)	Google Earth Engine	Digitals and QGIS algorithms	Coordinate determination
ANDRIEIEV et al. (2020)	ArcGIS 10.5 from ESRI	Spatial Analysis algorithms	Calculation of NDVI
HARBAR et al. (2024)	Google Earth Engine, Q-gis, Crosclassification	Primary processing and classification	Spatio-temporal analysis
BASHTOVYI et al. (2019)	EARTH OBSERVING SYSTEM	Built-in algorithms	Calculation of NDVI
MYRONIUK (2019)	Google Earth Engine	k-nearest neighbors method, Euclidean distance	Calculation of NDVI and detection of tree types
LAKYDA et al. (2020)	SNAP	Sen2Cor, Sen2Three, Biophysical Processor	Calculation of NDVI, TVI, LAI, FAPAR, FCOVER, CAB, and CW
BILOUSOV et al. (2022)	No special software	Discrete two-dimensional Fourier transform, filtration, inverse two-dimensional discrete Fourier transform	Filtration of simple-periodic instrument malfunctions
FESYUK et al. (2023)	Google Earth Engine	EOS Forest Monitoring, Global Forest Change, Global Forest Watch	Calculation of forest area
DOMARATSKYI et al. (2023)	ArcGis 10.6	Not specified	Image processing, cartogram construction, and spatiotemporal analysis
PASHCHENKO et al. (2023)	ArcGIS Online	Not specified	Calculation of NDVI and field of fractal dimensions
HLOTOV et al. (2022)	Not specified	Classification based on the maximum likelihood method and filtration	Calculation of areas
SHEVCHUK (2019a)	ESA/SNAP and Quantum GIS	Processing, geocoding	Calculation of areas
LISHCHENKO et al. (2022)	SNUP, QGIS, and Scilab	Not specified	Calculation of fire risks

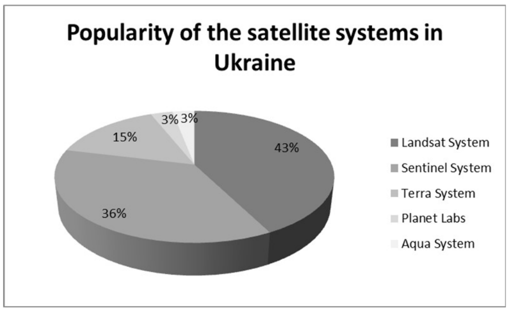

Figure 1. Percentage of using the specific satellite system for scientific studies in Ukraine.
Figura 1. Percentagem de utilização do sistema de satélite específico para estudos científicos na Ucrânia.

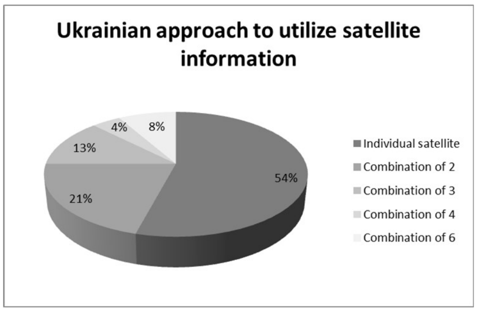

Figure 2. Percentage of using the specific number of satellite systems for scientific studies in Ukraine.
Figura 2. Percentagem de utilização do número específico de sistemas de satélite para estudos científicos na Ucrânia.

4. DISCUSSION

Ukraine has a long history of applying ERS technologies to monitor and preserve its natural resources.

In 1987, a Scientific Council was created on the problem of studying natural resources by remote methods based on the Department of Earth Sciences of the Academy of Sciences of the Ukrainian SSR. One of the recommendations of the Scientific Scientific Council was the expediency of establishing an organization in the Academy of Sciences focused on fundamental and applied scientific research of the Earth using remote aerospace methods – "Scientific Center for Aerospace Research of the Earth of the Institute of Geological Sciences of the National Academy of Sciences of Ukraine". The main task assigned to the Scientific Center is to conduct fundamental and applied scientific research on the Earth using remote aerospace methods to obtain new scientific knowledge and practical implementation of this knowledge in the interests of innovative development of Ukraine and meeting economic and social needs (LYALKO et al., 2022).

ERS research conducted at the Scientific Center related to various aspects of geoecology summarized in five main directions: 1) geological environment issues; 2) fire danger and atmospheric issues; 3) hydrosphere issues; 4) landscape and climate issues; and 5) urban area issues. To conduct high-quality and up-to-date research, the Scientific Center receives information from five satellites: Sentinel-1, Sentinel-2, Landsat-8, Landsat-9 and Terra/AQUA. Moreover, all the achievements were implemented to manage and conserve natural resources or are waiting for implementation (POPOV, 2024).

Global open data satellites for land monitoring and conservation are primarily multispectral and radar missions and global digital terrain models (DEMs). Our literature review revealed that the satellite mission most commonly used for studies on natural resources in Ukraine is the Landsat mission. The Landsat mission is the longest-running project, with the first satellite launched in 1972 and the most recently launched in 2021. Therefore, the Landsat mission provides the broadest period for studying the various changes occurring on the land, in the water, and in the atmosphere. Thus, Drebot et al. (2020) used numerous Landsat satellites to draw a picture of the reduction of the water body areas in one of the Ukrainian regions from 1975 to 2018, a period of 43 years. In addition, Landsat images are publicly available on the NASA website for free, providing a resolution range from 15m to 120m and an expanded set of spectral channels. Landsat, e.g., Landsat-8, has 11 spectral channels, one of them being sensitive to dark blue and violet colors and able to provide unique, in comparison with other satellites, data (e.g., shallow water), another one being a unique thermal channel, and survey frequency of 16 days.

In contrast, Sentinel-2 is a more versatile system with a higher resolution of 10 m/pixel, an average survey frequency of 5 days, and a wide coverage area that enables capturing images of a large area with high detail.

The main advantage of Landsats and Sentinels from the academic perspective is the absence of charges for their use, in contrast to commercial Planet Labs, for example, that provide much higher resolution (3.7 m/pixel) and much higher detalization but for higher charges.

Once obtained, satellite images must be processed. Remote sensing images are processed in preparatory and thematic phases, using specialized software or manually (rarely). Manual processing is performed manually by a human who deciphers what he/she sees in the image. Machine processing is performed using software packages to group objects according to some decoding features, with the ultimate purpose of classifying.

Our review revealed that Ukrainian researchers tend to use machine processing to process satellite images and extract valuable information.

In five researches, such as Davybida (2021), Sakhno et al. (2024), Harbar et al. (2024), Myroniuk (2019), and Fesyuk et al. (2023), Google Earth Engine was utilized to process satellite images for the following purposes: calculation of NDVI, MNDWI, and NDBI indices, determination of coordinates, spatiotemporal analysis, and calculation of areas.

Google Earth Engine is a cloud platform for geospatial processing and analysis of environmental monitoring data. A special advantage of this software is the possibility for modal decoding of the received images in existing systems, such as Digitals and QGIS. For processing purposes, the Google Earth Engine contains a catalog of many publicly available sets of geospatial data: 1) space and aerial photographs taken in various ranges of the electromagnetic spectrum; 2) weather forecast models and climate parameters; 3) earth cover maps; 4) topographic and socio-economic data sets; 5) various parameters of the environment (for example, soil moisture or outgoing thermal radiation of the Earth). For example, Davybida (2021) used GEE to calculate the normalized differential indices NDVI, MNDWI, and NDBI using the Earth Engine API/JavaScript for the Ukrainian regions.

In three types of research, such as Andrieiev et al. (2020), Domaratskyi et al. (2023), Pashchenko et al. (2023), and ArcGIS software was used. Other examples used for research purposes include EOS Processing, Erdas Imaging, EARTH OBSERVING SYSTEM, SNAP, Quantum GIS, SNUP, QGIS, and Scilab.

The preparatory processing methods include the following: contrast enhancement, resizing, orthocorrection, radiometric correction, morphological processing, removing background, noise or other unwanted objects in the image, image enhancement, using filters, segmentation, etc. Thematic processing includes methods designed to solve specific tasks related to finite elements, such as object detection and recognition, object classification in an image, etc.

Our review revealed that the images may require processing from the very first steps of obtaining, e.g., for image correction. At the preparatory processing stage, the input image's quality is improved. Geometric, radiometric, and atmospheric correction methods, noise removal, and spatial resolution enhancement are used. For example, they are correcting using spatial filtering methods by applying transformation in a sliding window. During this transformation, the brightness values of each pixel in the image are recalculated. This is done by moving a window across the image and calculating a new value for the center pixel of the window based on the values of the pixels surrounding it.

Accurate deciphering of space imagery may also require calibration data, which is used to correct measurements and convert signals from satellite sensors into physical units.

Image segmentation is a key processing stage where objects are obtained for further analysis. Using special segmentation methods, the image is divided into areas (segments) where pixels have similar values. Different types of properties are calculated for the image segments: 1) geometric properties: size, area, border length, compactness, rectangularity, length, width, ratio of border length to object area; 2) spatial properties: relative location of image objects: presence of a common border, length of a common border4 3) spectral properties of objects: vegetation index NDVI, water surface identification index NDWI, normalized shadow identification index NSVDI, brightness, saturation and color of the object in the HSV color model; 4) statistical properties of objects: average value of object pixels, root mean square deviation of object pixels; 5) textural properties of objects: the brightness of the contours at the border of the segment, the Roberts gradient filter was used for its calculation.

At the image classification stage, a decision is made about which pre-announced classes the segment belongs to. For this purpose, different classification methods and models can be chosen. For example, Harbar et al. (2024) used a two-step classification of the satellite images: an automatic k-means clustering algorithm and Q-gis. The Crosclassification algorithm implemented in the Semi-Automatic Classification Plugin (SCP) was used to detect temporal changes in land cover.

Our research revealed that only a few Ukrainian researchers developed their methodology to use the ERS for natural resource monitoring, management and preservation.

Thus, Kavats (2019), for processing satellite images, developed an automated information technology for deciphering anthropogenic changes on different time images based on EOS Processing software. Generally, EOS Processing software is designed to perform operations of the preliminary and thematic processing of the satellite images obtained from Sentinels, Landsats, WorldViews, RapidEye, SPOTs, Pleiades, KOMPSAT-3, TripleSat, and several others. The developed technology includes performing pre-processing of images (increasing informativeness, correction), performing Principal Component Analysis, and specifying georeference before searching for changes in multi-temporal high-spatial-resolution images based on the Scale Invariant Feature Transform method (locating and storing the key points on the image, feature matching and indexing, selecting key points based on their stability, comparing the images and recognizing the objects, using the Euclidean metric, and storing the data).

Bandurka et al. (2022) used specially developed algorithms to detect potential fire-related pixels on the images for satellite image processing. The algorithms examine each pixel of the satellite image and assign one of the following classes to each pixel: no data, cloud, water, potential fire, or uncertainty. Pixels with missing factual data are classified as "missing data" and excluded from further analysis. (NULL) and excluded from further consideration. The pixels of clouds and water objects are determined using the masking technique of clouds and water objects and are assigned to the cloud and water classes, respectively. This algorithm eliminates potential "non-fire" pixels; the remaining pixels are further tested to determine whether they belong to an active fire. The next stage of this algorithm is evaluating the radiometric signal of a potential "fire" pixel. Therefore, the algorithms aim to identify pixels where one or more fires are actively burning simultaneously as the satellite passes over the Earth.

Our review revealed that the most widely used characteristics for natural resource monitoring, management, and preservation were the Normalized Difference Vegetation Index (NDVI), Modified Normalized Difference Water Index (MNDWI), and Normalized Difference Built-Up Index (NDBI).

Ukrainian researchers use NDVI to monitor drought and predict agricultural production, fire risks, and desertification. This index is considered the best for monitoring vegetation, as it allows for the variability of lighting conditions, surface inclination, exposure and other external factors. NDVI generally indicates plants' health based on their ability to reflect light of certain frequencies.

MNDWI is used to identify water objects accurately, reducing the influence of built-up areas, which are often correlated with open water surfaces classified based on other spectral indices. MNDWI is used for analyzing the dynamics of water bodies, determining water table areas, monitoring flooding and inundation by groundwater, and forecasting droughts, assessing the risk of forest fires since its values are sensitive to the moisture content in vegetation and soils.

NDBI is used to make built-up areas more contrasting and is based on a ratio that mitigates the influence of atmospheric phenomena and different levels of illumination of the area. This index is widely used for mapping land cover types, monitoring urbanization, transformation of natural landscapes, etc.

5. CONCLUSIONS

Through its long application history, ERS has been used in many fields, one important being natural resource monitoring, management, and preservation. In Ukraine, the exploration of the ERS started in 1987 with the establishment of the Scientific Council, followed by the Scientific Center for Aerospace Research of the Earth of the Institute of Geological Sciences of the National Academy of Sciences of Ukraine.

In this paper, we attempted to study and summarize the achievements of scientific authorities and academic representatives to explore the current situation of using satellite information to solve purely practical tasks of natural resource monitoring, management, and preservation.

The most widely used ERS methods include the application of the information from Landsat and Sentinel satellites, mainly because of their advantages in terms of the cost (free access to their databases), period able to be studied (from 1972 to present), appropriate resolution (10m/pixel to 120 m/pixel), and adequate number of spectral channels to enable a large array of possible studies. Concerning the Ukrainian experience of the practical implementation of natural resource-related tasks, Ukrainian scientists use satellite images to monitor changes and condition of the landscape and waters to obtain information about the amount of damaged landscape due to illegal mining activities (especially regarding amber mining), condition of the agricultural lands, for example, crop productivity in spatial and time aspect, condition of the different types of land for prediction of the deteriorative processes and potential sources of dangerous situations, as well as study origin, history, characteristics of the water resources and provide more precise picture mostly using Normalized Difference Vegetation Index, Modified Normalized Difference Water Index, and Normalized Difference Built-Up Index. For satellite image processing, Ukrainian scientists prefer machine processing software, such as Google Earth Engine and ArcGIS packages with built-in algorithms for image processing. However, other software is also being implemented.

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