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THE CURRENT STATE OF SPACE IMAGERY USED FOR MONITORING LOCAL-LEVEL OBSERVATIONS

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Abstract:

This study examines the current state and practical application of space imagery and Earth remote sensing data for local-level environmental monitoring. The research focuses on the characteristics of optical-electronic and radar imagery, spectral ranges, spatial resolution, coordinate systems, georeferencing, and the use of raster and vector data in monitoring natural objects and specially protected natural areas. The methodological approach is based on comparative and descriptive analysis of remote sensing materials, spatial coordinate systems, image-processing methods, and multi-temporal satellite imagery. The results demonstrate that the reliability of local-level monitoring depends on the spatial and radiometric resolution of satellite images, accurate georeferencing, appropriate selection of spectral ranges, and correct interpretation of natural objects. The analysis also shows that multi-temporal comparison of raster and vector data makes it possible to identify changes in ecosystem boundaries and environmental conditions. However, the effectiveness of remote sensing is strongly influenced by image quality, technical resources, and the professional competence of specialists. The study concludes that the integration of satellite imagery, GIS technologies, and a unified spatial framework can substantially improve the accuracy and efficiency of local environmental monitoring.

Keywords: *Remote sensing of the Earth,* space imagery, spectral range, optical and radar sensors, GAT, decoding, environmental monitoring.

INTRODUCTION

Earth remote sensing has become one of the most important sources of spatial information for environmental monitoring, natural-resource management, land-cover assessment, and the observation of protected territories. The continuous development of satellite technologies has significantly increased the availability of optical, multispectral, thermal, and radar imagery with different spatial, spectral, temporal, and radiometric characteristics. These developments enable researchers to observe environmental processes over large territories and repeatedly examine the same geographical areas without relying exclusively on conventional field surveys. Remote sensing has therefore become an essential component of modern geographic information systems and environmental monitoring.

The practical importance of satellite imagery is particularly evident in monitoring environmental processes that vary considerably in their spatial extent and rate of development. Rapid events such as wildfires, floods, and other natural disturbances require timely observation, whereas vegetation degradation, changes in water bodies, habitat transformation, land-cover change, and ecosystem succession may develop over longer periods. Multi-temporal satellite observations make it possible to compare environmental conditions at different dates and identify spatial changes that may be difficult to detect systematically through ground-based observations alone.

Remote sensing is especially valuable for monitoring specially protected natural areas, where regular field observations may be limited by large territories, difficult terrain, accessibility constraints, financial resources, or the need to minimize human disturbance. Satellite data can support the assessment of habitat extent and condition, vegetation dynamics, ecosystem boundaries, anthropogenic pressure, and environmental threats. Nevertheless, the availability of satellite imagery does not automatically guarantee reliable environmental information. Its effectiveness depends on the characteristics of the sensor, the properties of the monitored object, the quality of the source imagery, and the methods used for processing and interpretation.

One of the central methodological issues is the selection of imagery with appropriate spatial and spectral characteristics. Contemporary remote sensing systems provide spatial resolutions ranging from sub-meter observations to hundreds of meters per pixel. High-resolution imagery can reveal relatively small landscape objects and detailed boundaries, whereas medium- and lower-resolution imagery may be more appropriate for observing regional environmental processes and long-term changes. Different portions of the electromagnetic spectrum also provide different types of information about natural objects. Visible, near-infrared, mid-infrared, thermal infrared, and radar observations vary in their sensitivity to vegetation, water, soil, geological materials, temperature, surface structure, and atmospheric conditions. Consequently, satellite imagery should be selected according to the characteristics of the object and the specific monitoring objective.

The interpretation of remote sensing data is further complicated by the spatial and spectral variability of natural objects. Vegetation, water bodies, soils, rocks, snow, and clouds have different spectral characteristics, and their appearance may change according to season, moisture conditions, vegetation state, illumination, and other environmental factors. Therefore, reliable interpretation requires knowledge of both the physical characteristics of the observed landscape and the technical properties of the imagery.

Geometric accuracy is another fundamental requirement for local-level monitoring. Environmental change detection frequently involves comparing spatial information obtained during different observation periods. If multi-temporal images are not accurately georeferenced within a consistent coordinate framework, positional discrepancies may be incorrectly interpreted as changes in landscape or ecosystem boundaries. This problem becomes particularly important when archival cartographic materials and contemporary satellite images originate from different coordinate systems. A unified spatial framework is therefore necessary for integrating raster imagery, vector boundaries, archival maps, and newly acquired spatial information.

The integration of raster and vector data within geographic information systems provides an effective methodological basis for multi-temporal environmental analysis. Boundaries derived from an earlier observation period can be compared with satellite imagery obtained during a subsequent period. When differences remain within the positional accuracy of the original data, the object may be considered spatially unchanged. When discrepancies exceed the acceptable tolerance, they may indicate actual environmental changes requiring further assessment. However, distinguishing real environmental transformation from differences caused by spatial resolution, geometric error, seasonal conditions, or image-processing procedures remains a significant methodological challenge.

Although modern satellite data are increasingly accessible, obtaining reliable information from space imagery is not an entirely automatic process. Image preprocessing, geometric and radiometric correction, classification, interpretation, coordinate transformation, spatial comparison, and accuracy assessment can all influence the reliability of the final results. Professional competence also remains important because effective interpretation requires knowledge of natural processes, remote sensing principles, geoinformation technologies, and the limitations of particular datasets.

Despite substantial technological progress, there remains a practical need to integrate these technical and methodological components into a coherent framework for local-level environmental monitoring. Spatial and spectral resolution, coordinate systems, georeferencing accuracy, image quality, temporal comparability, and raster-vector integration should be considered together rather than independently. Failure to account for any of these factors may reduce the reliability of detected environmental changes.

Accordingly, this study examines the current state and practical applicability of space imagery for local-level observations, with particular attention to environmental monitoring and specially protected natural areas. The research considers optical-electronic and radar imagery, spectral ranges, spatial and radiometric resolution, coordinate systems, georeferencing, raster and vector data integration, and multi-temporal change detection. The main aim is to identify the technical and methodological conditions that determine the reliability of satellite-based local monitoring and to demonstrate the importance of integrating remote sensing data and GIS technologies within a unified spatial framework.

METHODS

This study employed descriptive, comparative, and geospatial analytical approaches to evaluate the characteristics and applicability of space imagery for local-level environmental monitoring. The analysis considered optical-electronic and radar remote sensing data with different spectral, spatial, and radiometric characteristics. Particular attention was given to visible, near-infrared, mid-infrared, thermal infrared, and radio spectral ranges and their suitability for identifying and monitoring natural objects [1].

The methodological framework also included a comparative assessment of geographic and rectangular geodetic coordinate systems, particularly SK-42 and WGS-84, because geometric correspondence between multi-temporal images is essential for reliable change detection. Raster and vector spatial data were considered within a unified GIS framework to ensure spatial and geometric consistency [2].

Multi-temporal change detection was examined through the sequential comparison of spatial data obtained during different observation periods. Vector boundaries from an earlier observation period were superimposed on raster imagery from a subsequent period. Where boundary differences remained within the spatial accuracy of the original data, the contour was considered unchanged; where the discrepancy exceeded the acceptable tolerance, a new boundary was identified. This approach enables the differentiation of actual environmental change from discrepancies caused by spatial positioning or image resolution. Similar principles of multi-temporal remote sensing and change detection are widely applied in environmental and protected-area monitoring [3].

The collection of space images is currently very extensive and includes materials obtained by various imaging systems - scanners (multispectral, panchromatic), radars (at different wavelengths, with different signal polarizations) and photography (black and white, color, spectrozonal and multizonal in different parts of the electromagnetic spectrum) (Table 1), with different spatial (from 0.4 m to several kilometers) and radiometric resolution (8,11,12,16 bits/pixel).

Table 1. Sections of the spectrum of electromagnetic vibrations that are transferred to the cell

Spectrum plot	Wavelength range	Recordable radiation
Visible	0.40– 0.69 μm	Reflected solar radiation
Near infrared	0.70–1.3 μm	
Mid-infrared	1.4–3.0 μm	
Infrared heat	3.0–1000 μm	Thermal radiation of the Earth's surface
Radio range	1 mm–tens of meters	Earth's surface radiation or artificial radiation (radar)

Currently, there are more than 50 optical-electronic and radar spacecraft. two dozen countries, V-shaped satellites of the latest generation. Compared with archival materials, the parameters of the research data have changed significantly. First, advances in the field of fiber-optic communication have made it possible to significantly improve the spatial accuracy of optical-electronic research systems, which has led to the widespread use of meter and submeter accuracy in the visible and near-infrared regions [4].

A coordinate system is a method of determining the location of points in space. The main feature of all coordinate systems is the location of any coordinates. The points are necessarily defined by their coordinates. The use of images for monitoring, that is, for comparing and detecting changes, necessarily implies their geometric correspondence, that is, their reference to a spatial coordinate system [5]. At the local or regional level, monitoring is carried out on large and medium scales of topographic maps, that is, not less than 1:500,000. In this case, one of three spatial coordinate systems can be chosen: geographic (latitude-longitude) or two rectangular (SK-42 and WGS-84), the most widely used at the moment (Table 2).

Table 2. The most common geodetic coordinate systems

Geodetic coordinate system	Projection	Ellipsoid
SK-42 (Pulkovo)	Gauss-Kruger	Krasovsky
WGS-84	UTM (Transverse Cylindrical Mercator)	WGS-84

When working with data in raster format, we can use both geographic and geodetic systems, but if we plan to create maps in vector format, it is better to choose rectangular geodetic systems.

Geodetic coordinate systems record the location of points or objects in the metric system, most often in meters. Each coordinate system has two parameters (complex mathematical expressions): one of them is used to convert the Earth from its "incorrect" shape to a strict mathematical form - an ellipsoid, and the second - a projection - determines the rules for projecting the ellipsoid onto a plane (map). Until recently, most developed countries with large territories had their own coordinate systems [6]. The emergence of space imaging systems and satellite-based coordinate determination systems (GPS) made it necessary to have a common, universal coordinate system (World Global System). Digital space images provided by foreign distribution companies are already supplied with a transfer to the WGS-84 coordinate system, while domestic topographic maps were compiled in the SK-42 state coordinate system. In both systems, the calculation of coordinates is carried out from the equator (in SK-42 this is the x coordinate axis, and in WGS-84 it is the z axis) and from the meridian axis of the zone (in SK-42 y and in WGS-84 x, respectively). For the convenience of calculating coordinates in coordinate systems, the surface of the ellipsoid is divided into 60 6-degree zones, the calculation of which begins in our system from the Greenwich meridian, and in WGS-84 from 180° east longitude. In the territory of our country, the difference in the values of point coordinates in these two systems can reach up to 2 km along the z axis in the WGS-84 system (x in the SK-42 system), and up to several hundred meters along the other axis [7].

An important step in creating a system for monitoring protected areas is the development of a single spatial framework designed to integrate archival data, modern sources, and incoming new information, ensuring their spatial, geometric, and semantic consistency. Such spatial information should serve as the basis for mapping.

A basemap is a thematic data layer designed to serve as a geographic foundation and to georeference other spatial data. The geometric accuracy of a basemap determines the accuracy of all new data layers created from it [8].

The content of the map should consist of objects that meet two main requirements: they must have clear contours and be physiognomic, that is, they must be depicted on aerial images of different sizes. Depending on the geographical features of the area, different objects meet these requirements. For almost any area, such objects are hydrographic features: rivers, lakes, and coastlines. These can be the main structural elements of the base map, providing the geographic location of the data. For example, this can be a network of channels that are limited by relatively high dams and therefore not very winding. On the contrary, in most high-mountainous areas, small streams often change direction, are saturated with suspended matter, and are poorly distinguished from rocks and debris on aerial images. Here, the base map can show ridges, cliffs, and characteristic bends at the upper border of coniferous forests. In cases where the river network is poorly developed, for densely forested areas, such objects may be the contours of treeless areas, and vice versa, in the forest-steppe zone - forest areas combined with elements of roads and settlements [9].

Digital aerospace imagery can be provided in a variety of raster image formats, such as TIFF (Tagged Image Format), HDF (Hierarchical Data Format), and formats used in specialized image processing packages. It should be noted that these and some other formats store images without loss, but there are also formats for compressed imaging that lose some information when converted (JPEG, GIF, PNG, etc.).

Computer processing of remote sensing data includes geometric and brightness transformation and classification [10].

One of the methodological approaches that allows for sequential comparison of maps from different periods. It involves superimposing a vector image from one observation period on a photograph (raster image) from the next observation period [11]. If the boundaries of the units in the two images match or differ by no more than the number of pixels corresponding to the accuracy of the original data, the position of the vector boundary is not changed. If the discrepancy exceeds the tolerance, a new boundary is drawn [12]. A similar procedure is carried out for other observation periods. Thus, the unchanged contours will be the same throughout the entire series of transition maps from different periods, and the misalignment of the boundaries will reliably indicate the real presence of changes [13].

RESULTS AND DISCUSSION

The results demonstrate that the effectiveness of local-level remote sensing monitoring is determined by the combined influence of spatial resolution, spectral characteristics, geometric accuracy, and temporal comparability of satellite imagery. Higher spatial resolution improves the identification of relatively small landscape features, whereas medium- and lower-resolution imagery remains valuable for observing broader environmental processes and long-term changes. This confirms previous findings that different monitoring objectives require different combinations of satellite sensors and spatial resolutions.

The comparison of coordinate systems further demonstrates that accurate georeferencing is a fundamental prerequisite for multi-temporal environmental analysis. Even when images accurately represent the same territory, inconsistencies between coordinate systems may produce apparent spatial displacement that can be incorrectly interpreted as environmental change. Consequently, the integration of archival and contemporary imagery requires a unified spatial framework and consistent geometric correction [14].

The findings also indicate that remote sensing should not be regarded as an entirely automatic source of environmental information. Reliable interpretation depends on the spectral properties and spatial characteristics of the objects under investigation, the quality of source imagery, appropriate GIS processing, and the professional competence of the researcher. This is consistent with the broader literature showing that remote sensing substantially strengthens protected-area and ecosystem monitoring but that methodological standardization and integration of multiple data sources remain important challenges [15].

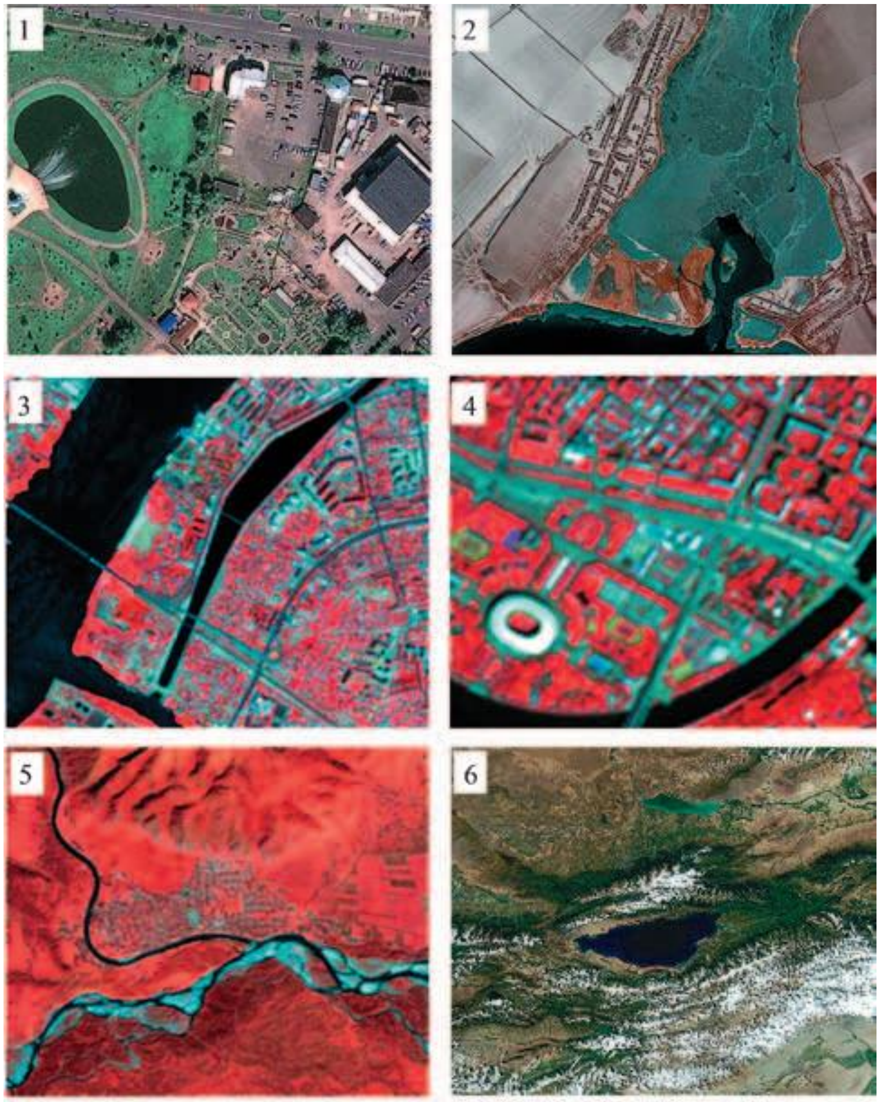

Figure 1. Appearance of images with different spatial dimensions:
1 – about 2 m, GeoEye (Google Earth); 2 – 5 m, SPOT-5; 3 – 10 m, ALOS;
4 – 15 m, ASTER; 5 – 30 m, Landsat; 6 – 500 m, MODIS

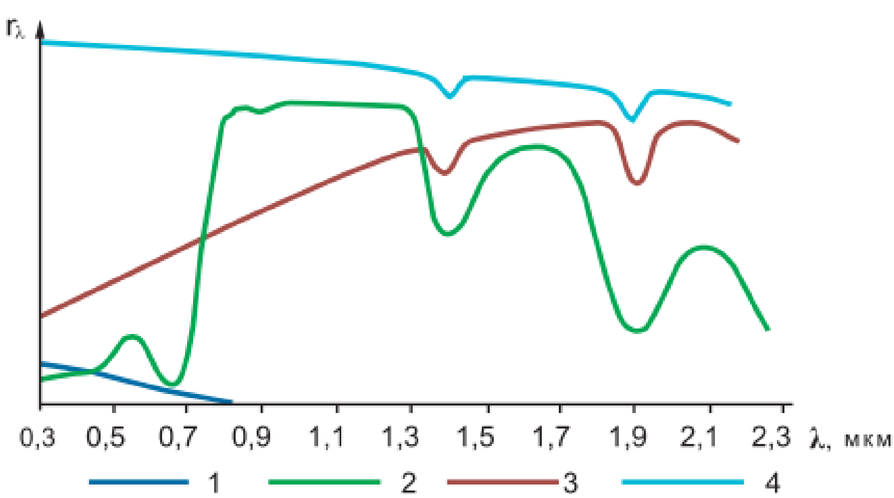

Figure 2. Spectral radiation curves of the main classes of natural objects:1 – water bodies; 2 – plants; 3 – soil and rocks; 4 – snow, clouds.

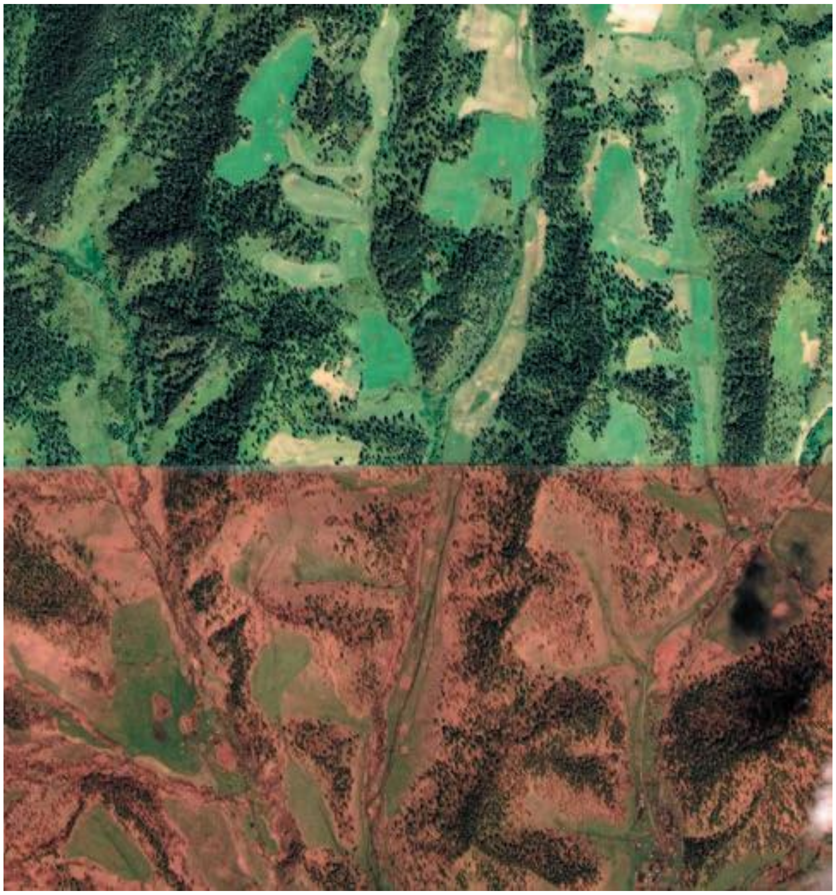

Figure 3. Illustration of plants in different seasonal states: The bottom part of the image is in spring, May 8, 2020, and the top part is in summer, August 29, 2015. (Google Earth).

CONCLUSION

Recently, space imagery has become a key tool in environmental monitoring, especially in protected areas. The range of tasks that can be solved using remote sensing data is so wide that classification systems have been developed.

The widespread use of space imagery often gives the false impression that it is easy to obtain reliable information using it. In fact, obtaining reliable information about the state of natural objects and their changes over time is a complex and laborious task.

The reliability of the data obtained from the images largely depends on several factors, the most important of which are the characteristics of the objects being studied and the qualifications of the person conducting the research. The reliability of the identification of natural objects in the image is very important, given their spectral characteristics, definition of boundaries, degree of variability, and the presence of stable relationships with other objects. The qualifications of the contractor require that, in addition to basic training in natural sciences, they know the theoretical foundations of remote sensing, have experience in interpretation, and master geoinformation technologies. Important factors in the reliability of the results are also the quality (characteristics) of the images and the technical support of the work (computers and programs), which is strictly dependent on funding.

Overall, the study demonstrates that space imagery provides an effective technological basis for local-level environmental monitoring when satellite data are combined with appropriate coordinate systems, GIS technologies, multi-temporal analysis, and reliable interpretation methods. The accuracy of monitoring depends not only on the technical characteristics of satellite imagery but also on geometric consistency, image quality, object characteristics, software and hardware resources, and specialist competence. The establishment of a unified spatial framework integrating archival and contemporary remote sensing data can therefore improve the reliability of change detection and environmental assessment. Future studies should focus on the practical validation of these approaches using multi-source satellite datasets and quantitative accuracy assessment for specific ecosystems and protected areas.

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