The importance of remote sensing in geography education

DENISA SIMERSKÁ

Masaryk University, Faculty of Education, Department of Geography, Brno, Czechia; e-mail: 442002@mail.muni.cz

ABSTRACT This study highlights the importance of integrating remote sensing methods and materials into the school environment, particularly at the primary and secondary school levels. The integration of environmental and digital learning into educational programmes and strategies is an area that requires ongoing commitment and prominence. One approach to achieving this goal is to harness the potential of remote sensing in the classroom. Remote sensing is a multidisciplinary field linking geography, biology, physics, mathematics, and computer science. As a combination of the study of natural sciences and new technologies, and despite being a rapidly growing field driving high demand for skilled workers, this young discipline has yet to establish an adequate position in schools. Remote sensing methods and materials, can demonstrate, in practically real-time, environmental problems such as deforestation, fires, desertification, water pollution, rising water temperatures, glacial melting, drought, and many other phenomena. This overview study presents new perspectives alongside a list of arguments to support the importance of using remote sensing methods and materials in schools.

KEY WORDS geography education – remote sensing – earth observation systems – satellite images

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1. Introduction

Geography education is currently undergoing transformation, but it is not the only domain experiencing change. Most subjects taught in schools are experiencing some kind of transformation steered by the need to adapt to the demands the twenty-first century. Forecasts of the development of contemporary society recommend greater efforts to incorporate modern digital technologies into teaching (Fryč et al. 2020). In addition to this greater integration of digital technologies, a second requirement under the Strategy of the Czech Republic's Education Policy 2030+ (hereinafter the "2030+ Strategy") is to raise awareness in students of sustainable development and environmental problems. According to the OECD (Organisation for Economic Co-operation and Development) studies, most existing jobs will be transformed in the near future; new positions will be created, and some existing positions will vanish (Fryč et al. 2020). The subjects taught in schools should reflect this reality and attempt to introduce more student-friendly learning which is linked to modern technologies. Geography has the potential to meet these new requirements through areas such as geoinformation technologies, geographic information systems (GIS), remote sensing methods and computer-aided design modelling.

Remote sensing of the Earth can be defined as a method which helps us evaluate information about our planet through satellite or aerial images and measurements of electromagnetic radiation in one or more regions of the electromagnetic spectrum reflected, absorbed or emitted by the Earth's surface (Campbell, Wynne 2011). Although the scope of remote sensing of the Earth has a range of significance, they have a common definition in the remote collection of information: "Remote sensing of the Earth is an art or science that allows us to communicate specific information about an object on the Earth's surface without getting into physical contact." (Fischer, Hemphill, Kover 1976) In science and other research fields, remote sensing is now a relatively common method of obtaining relevant data on the Earth's environments, atmosphere, oceans and other surfaces without the need for physical contact with the object under study (Esbri 2021).

Whether using drones or satellites, remote sensing enables the collection of information about the Earth and opens up new possibilities for teaching geography in a digital environment (Albertz 2007) and obtaining comprehensive understanding of the landscapes explored. The greater demand for the collection and evaluation of remote sensing data in education has been driven mainly by rapid advances in technology (Núñez et al. 2020; Amici, Tesar 2020). The use of data obtained from drones, ground-based aircraft and satellites has become prevalent in institutions at the scientific, technological, government and commercial levels and now also extends into everyday life. Incorporating remote sensing methods and data into school curricula therefore opens up an opportunity to introduce primary and secondary school students to many new capabilities (Hejcmanová et al. 2015).

Through the Framework Educational Programme of Grammar School Education (RVP G), Czech grammar schools have been introduced to remote sensing, although without any significant allocation in terms of time, and the technical and theoretical aspects are generally taught without any link to practical scenarios or interpretation of images. This separates the notions of teaching remote sensing as a core unit and teaching certain subjects with the inclusion of remote sensing materials. remote sensing images, for example, are powerful tools for visualizing and interpreting subject matter beyond the traditional study of geography since the wavelengths of electromagnetic radiation at the Earth's surface can be monitored extensively and enable the exploration of topics such as air pollution, deforestation, floods, wildfires and many other relevant issues.

Overall, it can be said that remote sensing is not given sufficient importance in primary and secondary school education. Despite remote sensing offering many significant opportunities for education, major barriers limit its uptake. Supported by the scientific literature in this field, the main aim of this article is to summarize the benefits of using remote sensing materials in education and to encourage teachers to employ them in lessons. The article approaches this discussion as a narrative review study, first examining the options for introducing remote sensing images into the materials for school curricula, then describing the barriers to teaching and using these materials in the classroom. A significant part of the current study provides justification for incorporating remote sensing into schooling at the level before university. The study's findings are then summarized.

2. Opportunities and obstacles in employing remote sensing materials and methods in geography education

The use of remote sensing has been specified in Czechia's RVP G for some time (Ministry of Education, MŠMT 2021, p. 35). This curriculum document was released for the 2009/2010 school year and published in the RVP G for secondary vocational schools which specialize in geodesy and real estate cadastre. These subjects make significant use of remote sensing methods, and hence, represent a relatively new teaching area.

Recent modifications to the RVP G resulted from the 2030+ Strategy, which aims to make education more relevant to the needs of the dynamic and rapidly changing world of the twenty-first century. These changes have also introduced digital competence as a new core skill which should now be taught in most school subjects. The changes in the RVP G were designed to ensure that this skill was not left solely to be learned by studying computer science, which has also seen significant changes in its subject matter. Digital competence consists in the ability to navigate the digital environment, use digital technologies, possess insight into the effects of these technologies in our surroundings, and respond to technology consciously and with understanding (MŠMT 2021).

Incorporating remote sensing images into geoinformation technologies, for example, should follow these standards and develop digital skills in the context of geography education. By designing suitable learning tasks which use GIT tools, it is possible in the Czech educational context to achieve the objectives outlined in the RVP G. It suggests that using geoinformation technologies can foster digital literacy not just through geography education but also information and communication technology (Mísařová et al. 2021).

The integration of remote sensing studies into geography education is still in early stages, especially at the primary school level. Despite encouragement in both the 2030+ Strategy and the RVP G, working with remote sensing in this context has obstacles such as scarcity of educational resources, materials available only in English, the inherent complexity of the subject matter, and inadequate technical infrastructure. These challenges can complicate or even prevent the effective integration of remote sensing materials into geography teaching.

Most of the studies which have explored the incorporation of remote sensing materials into school curricula have found that teachers consider the adoption of these new teaching methods a significant challenge. Interviews and questionnaires conducted with teachers reveal that inadequate software and hardware and a lack of expertise in this area pose major problems. (Voss et al. 2007; Hodam, Rienow, Jürges 2019; Dannwolf et al. 2020).

Currently, additional software is not required to view aerial or satellite images, as there are freely available online mapping applications specifically dedicated to visualizing remote sensing data. These applications allow users to apply filters to areas covered by an image, set dates and select specific spectral band combinations. Spectral bands refer to ranges of wavelengths in the spectrum of electromagnetic radiation detected by remote sensing devices. A web browser is the only technology required to read, analyse and interpret these image types. If the image processing phase is performed as a more computationally intensive operation involving several steps, for example image download, correction and visualization, then dedicated software is required. The market offers several open-source programs and commercial software which can be requested by educational institutions. Examples of this type of software are ArcGis Pro (ArcGIS for Schools Bundle licence), SNAP and QGIS.

For schools to adequately benefit from using remote sensing data, they must possess the appropriate technical infrastructure. The most commonly mentioned barrier to implementing remote sensing-based teaching methods is inadequate technical infrastructure (Bachmann, 1995; Horning, Smith, Alfutis 2000;

Somantri, 2016). Lack of internet connectivity is also ranked as another significant obstacle (Hodam, Rienow, Jürges 2020; Rodriguez-Segura, Kim 2021). It is important to note that this obstacle is gradually disappearing; the equipment in Czech schools is not at the same level as in neighbouring Germany, for example, but the number of computers is steadily rising. In an analysis for the Czech Statistical Office, Wichterová (2019) described the development of information technology in the Czech school education system. The author reported that the number of desktop computers and laptops in Czechia is rising, but a significant problem exists equipment age, most computers (74%) having been purchased three to nine years ago. Aging computers may hinder work with high quality or large area raster data, which place much greater demands on the image rendering hardware and calculations performed by these devices.

Finally, teachers themselves may also represent a barrier by being unfamiliar with the use of remote sensing methods. Although this discipline has existed in the natural sciences for several decades, it is relatively new in the field of education. Teachers who have recently graduated or are new to the field may be familiar with remote sensing as a subject, but they may lack comprehensive theoretical or practical knowledge, a drawback often attributed to the limited time dedicated by universities to teaching remote sensing (Schulmann 2020; Hodam, Rienow, Jürges 2020). Teachers must also be given adequate conditions to teach remote sensing in schools, both through training courses and appropriate materials for use with students in the classroom.

2.1. Interpretation of remote sensing images

Many authors have stated that reading and being able to navigate within an remote sensing image assists in examining a particular site or problematic topic directly "with one's own eyes". Map visualizations never depict reality accurately since they incorporate many generalizations, but an image is a snapshot which reflects the most accurate possible state of the landscape. In primary and secondary school education, topics which overlap are often discussed outside the context of geography lessons. Examples include water pollution, destruction of rainforests, bark beetle calamities, desertification, wildfires, melting glaciers, and sea and ocean level fluctuations. Images are better able to illustrate the scales of these issues. For example, in the context of forest research, images provide information at true scale and significance. Images can be set in false colour to highlight a problem or factor within the landscape and for overall greater clarity. Interpreting images and the objects contained within them should therefore be an integral part of learning.

Interpreting an remote sensing image is a challenging task despite colours in the images matching those that people are generally accustomed to seeing. A key difference is that a two-dimensional image viewed from a directly overhead perspective is not natural, and a sense of depth is lost. The combination of an unfamiliar perspective, different scale and lack of discernible detail in an image can cause even the most recognisable object in our surroundings to become completely unfamiliar (Rajput et al. 2020). Moreover, if false colours are applied in an image, reading becomes more difficult, as colours in the spectrum visible to the human eye can often be the most important clues in identifying important details. People are generally accustomed to interpreting images rendered in RGB, in which a forest appears green and water blue, for instance. In a new composition with other colours, interpreting the image thus becomes more challenging. The absence of a legend also complicates reading a map. Legends can also be used in visualizations that rely on the calculation of spectral indices, and it is therefore essential to teach users how to interpret false colours to uncover new, hidden information from those layers.

3. Rationale for the use pf remote sensing images in the classroom

Remote sensing images of the Earth are rich sources of information, but they are not put to full use in schools. A common reason for this is inadequate hardware or software in school computers. A more fundamental reason, however, is teachers not having sufficient awareness of the subject. Teachers must be informed about the possibilities of using not only remote sensing images but also remote sensing methods; teachers require the encouragement and motivation to engage with remote sensing methods and materials and increase the frequency of their routine use in classes for regional geography, physical geography and socio-economic geography. This chapter outlines the benefits of using remote sensing methods and materials in schools.

3.1. Multidisciplinarity

Remote sensing is interdisciplinary in character and thus enables students to apply knowledge from several fields in any work with images (Voss et al. 2007; Somantri 2016; Hadjimitsis, Kyriakidis, Akylas 2020). The multidisciplinarity of remote sensing studies integrates the subjects of geography, biology, physics, mathematics and computer science. Linking the topics covered by multiple subjects is also essential to the study of remote sensing imagery. The initial stages of working with images involves explaining remote sensing principles, which overlap significantly with physics and require an understanding of the electromagnetic spectrum, wavelengths and radiation reflected, absorbed and emitted by

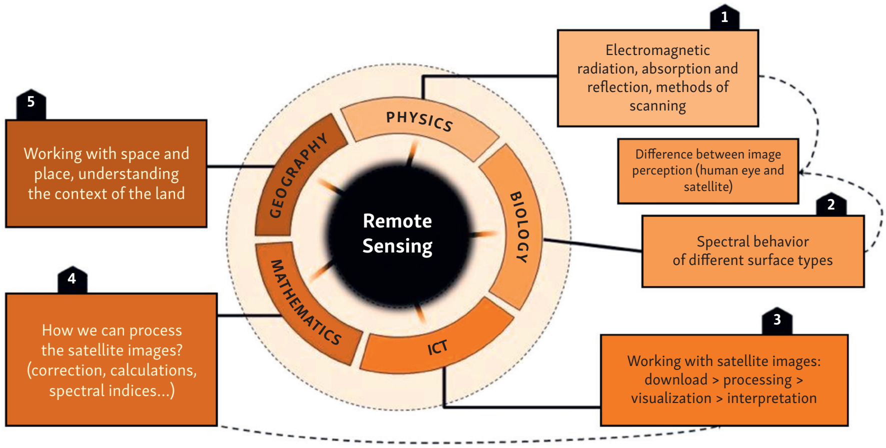

Fig. 1 – Links and relationships between subjects taught for working with remote sensing images

objects (Fig. 1). When knowledge is applied from biology, a pertinent question is the manner in which the images captured by satellites visualize the Earth (Dziob et al. 2020). To answer this, the differences between the perception of images by the human eye and brain and by artificial sensors must be sufficiently described. Every object or place on Earth reflects and absorbs solar radiation differently according to the spectral characteristics of its surfaces. To view or edit images, information technologies are required to work with and calculate spectral indices. These indices indicate a certain part of the electromagnetic spectrum in which, for example, a satellite, captures an image, and are designed to detect specific aspects of the landscape, for example vegetation health (Rajput et al. 2020).

Phenomena explained in a broader context include those described in the field of geography, and knowledge of these is necessary for interpreting and analysing images. Given the options offered by contemporary geoportals which use this type of data, it is possible to omit the image pre-processing and processing stages in addition to the computation and manipulation of spectral bands. Many portals already offer these indices alongside true and false colour compositions, therefore no deeper knowledge of data processing is required.

3.2. Realistic and real-time images as complements to school atlases

Images and the skills to interpret them should be given the same importance as the use of school atlases. Atlases illustrate the knowledge communicated during a teacher's frontal instruction or evaluation ("re-testing"), when a student applies acquired knowledge to a geographical context (Hátle, Kučerová 2013). Although remote sensing images are not widely used by teachers and students, their role in the classroom is not dissimilar to a school atlas. The potential of satellite or aerial imagery in education is enormous, much greater than simple regional maps (Naumann et al. 2009). A distinct advantage is the aforementioned accessibility and timelines of such data. Another important feature of these types of images is minimal geometric, topographic or thematic generalization of cartographic content. Cartographic generalization consists in the selection, geometric simplification and generalization of objects, phenomena and their interrelationships for graphical representation on a map. The purpose and scale of the map and the subject of cartographic representation influence this process (Plánka 2014).

Images from satellites, aircraft, and drones also often show objects or phenomena that are not recorded on topographic maps (or thematic maps, depending on their type) and can therefore serve as supplements. Examples include photovoltaic devices, small forests or ecotones (areas of steep transition between ecological communities or ecosystems). Depending on the reader's experience and the image's spatial resolution, these areas in the landscape can be identified clearly on images. However, topographic maps represent only information about present landscapes undisturbed by any dynamic landscape features or environmental processes. The ability to interpret these small elements in the landscape depends significantly on the map's spatial resolution. Spatial resolution is a measure of the smallest object that can be resolved by a sensor. Freely available images from satellites have smaller spatial resolutions than those obtained with aircraft and drones.

The involvement of GIS technologies and software in geography studies in secondary schools should be a top priority, but it is also important to develop a realistic idea of teaching with remote sensing images (Kholoshyn et al. 2019). Nerad (2018) writes about the potential of geoinformation technologies in teaching geography in primary schools and the necessity to address users' skills in interpreting remote sensing images. If users are able to interpret these image types, the potential of these images can be fully developed, and users can gain comprehensive understanding of the phenomena encountered in the Earth's landscapes.

This development of a realistic idea of the shape of our world is one of the main differences between the use of remote sensing images and maps. Distribution availability indicates the frequency of dissemination of images on the Internet and ease of their use, depending on the temporal resolution of the satellite which captured the images. This temporal availability is significantly greater than for traditional maps. Horák (2014) described this advantage in terms of real-time depiction and time stamps, although today the availability of these data sources is also a consideration. Availability and distribution are discussed in detail below in relation to today's possibilities and needs. The author also listed areal extent (scene size), repeatability, geometric accuracy, and standardization of images and information from distinct parts of the electromagnetic spectrum (spectral resolution) as factors.

3.3. Developing literacy in the natural sciences

Besides helping to develop literacy in the natural sciences, working with satellite images also cultivates digital thinking. Working with these image types is complex and requires knowledge in several scientific fields. Education in remote sensing can develop literacy in the natural sciences, especially in conjunction with education on environmental topics (Muller et al. 2013). Environmental topics are frequently under discussion around the world today, and schools are no exception. Issues concerning the environment, for example deforestation (Fig. 2), forest fires, melting glaciers, temperature changes, extreme weather, river pollution and many others, are frequently mentioned in the media. People are continually informed about these problems and the changes occurring on the Earth, changes for which humans are often responsible. However, according to Dziob et al. (2020), major problems exist in students perceiving the study of natural sciences as useless and in poor employment prospects and insufficient remuneration for natural science graduates. However, now especially, technology is increasingly entering general consciousness and may provide an opportunity for greater awareness of the possibilities of remote sensing through its multidisciplinary character.

Satellite imagery is useful in depicting natural conditions and can also be used to visualize socio-economic phenomena and structures (Pei et al. 2021). Topics such as urbanization, land use, development and land grabbing, transportation,

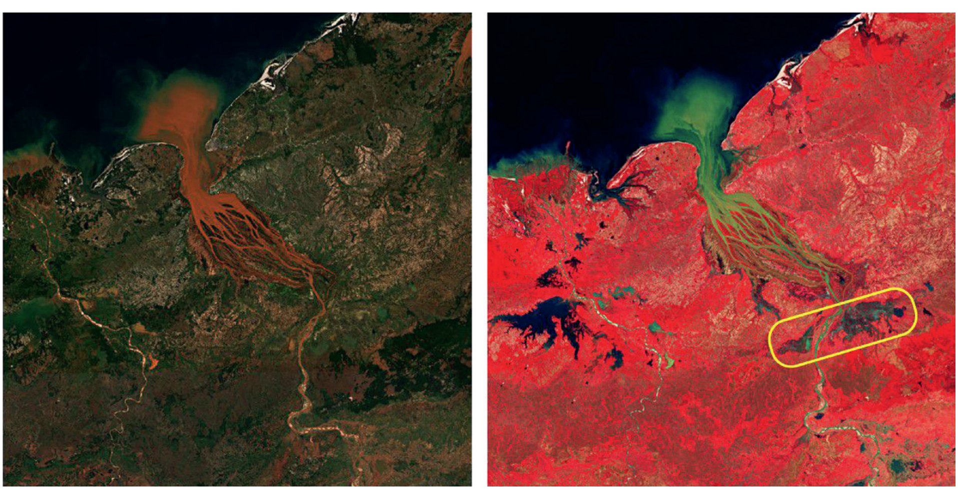

Fig. 2 – Effect of deforestation on sedimentation in the Batsiboka River in Madagascar captured by Sentinel-2. The 2022 image is shown in the visible spectrum (left) and as a composite in the infrared band (right). The highlight shows an area of deforestation which is not apparent in the RGB image. Data source: Sentinel Hub (2022).

and many others can be discussed using satellite imagery. According to Brucker (2006), satellite imagery is the key to understanding the Earth as a closed ecological system that is impacted by human influences and global changes. Both the natural and human realms are essential to understanding the global functioning of the world. Satellite images show the environmental, economic and social consequences of human activity.

Amici and Tesar (2020) selected wildfires as a topic to demonstrate the use of remote sensing imagery with school students. Wildfire is a natural phenomenon affected by changes in temperature and weather, but its occurrence is also influenced by human activity. Conducted in Italy, the study also placed the problem of burning biomass into context as a major risk today in relation to climate change and effects in the environment. The severity of the fires in Australia in 2019–2020, which could not be controlled and spread rapidly, were possibly a consequence of anthropogenic climate change. The occurrence and frequency of fires in turn affect other environmental conditions and thus potentially increase the probability of more fires. The topic could either simply be discussed, or students could be shown images of this phenomenon in process. Real-time images of Italy were shown to students to demonstrate the extent and impact of wildfires. Markuse (2020) stated that satellite imagery allows students to see a location or problem directly for themselves and gain knowledge by observing effects that would otherwise only be talked about in the classroom. To see the extent of a wildfire, a satellite image captured in the visible spectrum is usually insufficient since the visibility in that image will be impaired by smoke. To look through and beneath the smoke produced by fires, different bands of the spectrum must be captured. Spectral indices such as NDVI (normalized difference vegetation index) or NBR (normalized burn ratio) can be used to provide clearer images of the extent and effects of wildfires.

3.4. Employment and labour market requirements

As mentioned above, the necessity of studies in remote sensing today is significant. remote sensing is a rapidly growing technology with an increasing need for highly skilled personnel (Voss et al. 2007). Dziob et al. (2020) discussed the current need for remote sensing in disciplines such as geography, engineering, civil engineering, geology, forestry, environmental sciences, ecology, physical sciences, meteorology, computer science and programming. remote sensing images are also valuable sources of information during crisis management. If the current state of a landscape requires mapping, images which can be quickly produced and distributed allow better estimates of the extent of a disaster. Emergency services can consequently be dispatched promptly to an affected area, and the necessary medical or humanitarian aid can be better coordinated (Pavelka 2008).

Because little scope currently exists for students to learn about remote sensing at primary and secondary school, it is possibly a factor in why supply and demand of workers skilled in this field do not match. Orthophotos, however, are commonly used in the information systems of many governmental and public institutions, but as the ease of producing higher quality spatial resolutions increases, the limits of use of these image data are being pushed (Jančík 2009).

3.5. Availability and time series

As at other times in the past, the future is a key factor in assessing phenomena on the Earth. It is important to remember that many images do not necessarily indicate only what is happening now or what happened in the past. Through remote sensing methods and satellite technology, it is possible to model dynamic developments in the landscape, forecast conditions which have not yet occurred and reveal patterns. Examples include evaporation of bodies of water, mapping changes in coastlines around countries threatened by glacial melting and rising sea levels (Tralli et al. 2009), or even prediction of volcanic eruptions (Lundgren, Rossen 2003).

Several satellite missions regularly release freely available images that are distributed more quickly than thematic maps, thus offering a quantitative advantage. The interval between the production of new images corresponds to the temporal resolution of the satellites. Extensive time series such as these allow the evolution of a particular phenomenon to be followed for up to several decades. In addition to downloading images for work with specialized software, many other viewing services can now also be used. User-friendly programs include LandViewer and SentinelHub, which, in addition to visualizing the Earth in the visible spectrum, allow the bands of a particular sensor to be switched to alter the colour composition. It is also possible to view spectral indices which have already been calculated. Most internet users, however, will use Google's geoportal to view aerial maps produced in the visible spectrum.

Students today are generally familiar with the use of aerial or satellite images because they are freely available on the Internet (Kholoshyn et al. 2019). Common mapping portals include Google Maps, Seznam's Mapy.cz, and OpenStreetMap (Brucker 2006). These types of viewing service usually do not have any high-end hardware requirements. Remote sensing images, however, entail a different process of downloading, processing and interpreting, and several open-source software programs exist for these purposes.

Students today are increasingly using new and emerging geographic technologies and software such as Google Earth, GPS devices or other applications which use navigation systems (Naumann et al. 2009). The explosion of information and trend of massive availability on the Internet today has allowed students to easily access such software to quickly view and navigate remote sensing data. Teachers can thus also easily access this software, and it is especially relevant to those who may have studied pedagogy in the 1990s or earlier. Teachers who are not digital natives may not have had any opportunities subsequent to their original studies to take courses in remote sensing and may find the subject challenging, both theoretically and practically (Somantri 2016).

3.6. Problem solving

Using remote sensing data, natural (Fig. 3) and anthropogenic processes (Fig. 4) can be visualized. From these visualizations, scientists can evaluate the dynamics of specific processes, provide information about the location of objects on the Earth's surface, monitor the state of geographical objects and related processes, and formulate hypotheses or identify patterns (Kholoshyn et al. 2019). To understand certain environmental changes, for example involving a drying lake, a sequential series of satellite images is required to illustrate the dynamics in the environment that led to those changes. It is unlikely that thematic or topographic maps alone will be used to examine the dynamics of contemporary environmental problems, as these materials are not able to fully capture or reflect the real conditions behind any changes. The production and subsequent distribution of these map types are also relatively slow. Remote sensing images, however, can provide extended, sequential series of images which form time-lapse illustrations of environmental processes: in the example shown here, the process is of an inland sea drying and its bed vanishing over the span of several years.

4. Conclusion

Current trends in education are supportive of sectors which link to digital skills. Much of the working population requires computers in their employment, and humanity is fast entering an age that was previously considered science-fiction. The shape of work is evolving, as is supply and demand in the labour market, and this evolution should therefore also be reflected in education. Remote sensing of the earth represents a largely untapped source of information, and hence, one of the main areas of interest for geography educators to address and promote in school education (Brucker 2006; Siegmund, Menz 2005).

Satellite and aerial imaging are no longer technological novelties but ubiquitous materials for visualizing space. Remote sensing as a method of data collection and analysis is slowly being introduced into the curriculum at selected schools and

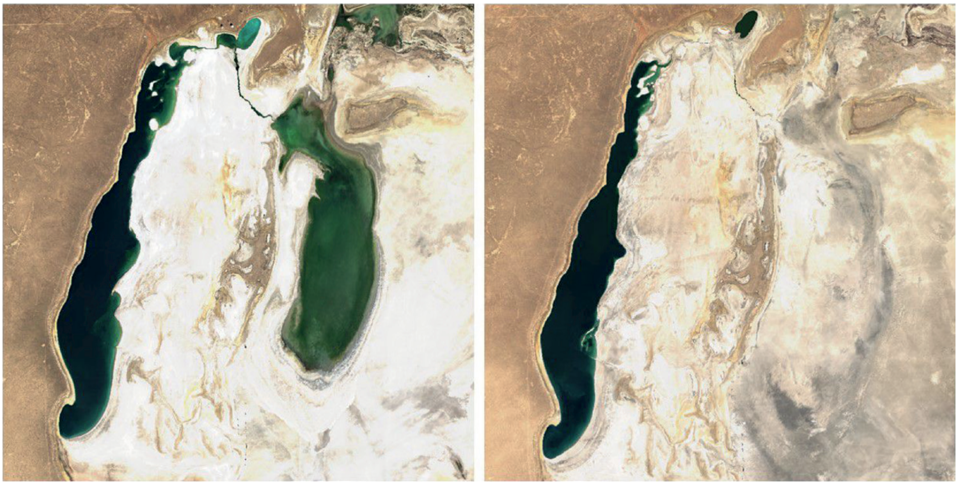

Fig. 3 – Disappearance of the Aral Sea captured by Sentinel-2. The images show the years 2018 (left) and 2022 (right). Data source: Sentinel Hub (2022).

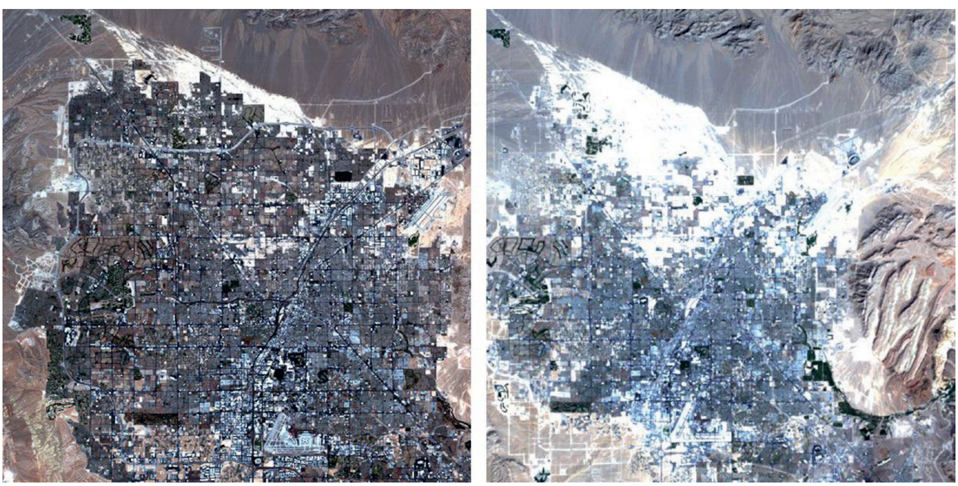

Fig. 4 – Expansion of the city of Las Vegas captured by Sentinel-2. The images show the years 2020 (left) and 2022 (right). Data source: Sentinel Hub (2022).

discussed as a separate discipline for subject matter such as weather, flora and fauna, and regional geography. However, remote sensing should not be viewed as a subtopic of geography. It is important to separately outline the importance of the discipline, its function and applications. Remote sensing should not culminate only in brief digressions simply because its use is not covered in detail in school curricula. Rather, it should be a tool that is suitable for explaining phenomena, processes and cross-cutting themes in science. Remote sensing methods and images can be effective tools in explaining subject matter that is traditionally taught in science subjects.

The huge volumes of freely available remote sensing images allow them to complement the use of school atlases. Content in these image types is generalized minimally compared to the content in atlases or other cartographic products (topographic and thematic maps) used in schools. In their most commonly available form, the colours in remote sensing images correspond to the real world. If additional bands beyond the spectrum visible to the human eye are recorded, or if spectral indices are used, a large number of invisible phenomena and processes can be directly viewed, either in RGB or in the field itself. One possible area of development is producing a view of the Earth's surface in false colour but not representing a false reality, i.e., altered colour compositions can often show a deeper reality not perceived by the limits of human eyesight.

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ORCID

DENISA SIMERSKÁ
https://orcid.org/0009-0005-8105-0134