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8. REVIEW AND DEVELOPMENT OF DATA SOURCES USED IN GEOGRAPHIC INFORMATION SYSTEMS

8.1. Introduction

Spatial information systems are well established and of great importance in today's world. Many institutions, using location information in the broad sense of the term, have implemented them long time ago into their activities, and it is difficult to imagine a return to using only classic maps, now called analog maps.

Spatial information systems are an effective tool for urban planning and development. It seems that the creation of smart city is not possible without the use of GIS, or at least this task is clearly facilitated by these systems. As will be presented later, among the components that make up a spatial information system is spatial data, to which this chapter of the monograph is devoted.

Generally, the term spatial information system should be understood as an information system which has several basic tasks, first of all, it allows the input of spatial data into databases, their collection in these databases, and then, during the actual exploitation, it enables the processing of these data and their visualization, as well as it allows to visualize the results of conducted analyses. If the scope of the system refers to the Earth's surface, then the name Geographical Information System (GIS) is often used, and if the scale of the study is large, the term Terrain Information System is also used. This division emerged in the second half of the 1980s, and the scale of 1:5000 was taken as the limit, up to which the term GIS is used, and above which the system is referred to as TIS. The versatility of GIS means that it is also used in other applications where position determination is important, and these include the use of the system to determine a position in space, concerning the surfaces of planets, or even during DNA gene sequence analysis[2].

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[2] Davis D.: GIS dla każdego. ESRI Polska, Warszawa 2004; Gottlib D., Iwaniak A., Olszewski R.: GIS. Obszary zastosowań, PWN, Warszawa.

The scale of popularity of spatial information systems has been determined by the wide range of their applications, ranging from spatial planning of various types of facilities, such as public facilities such as health centers, hospitals, stores, and educational institutions, to determining the location of roads, the location of transmitters, to monitoring the spread of weather phenomena, social-economic, etc. This is due to the basic capabilities of these systems, which have developed over the years, and this process continues to allow for further expansion of GIS into new industries, allowing for more efficient decision-making based on analysis and simulation. The combination of spatial information with the characteristics of objects, taking into account the relationships between objects, and the possibility of efficient data updating are undoubtedly advantages of GIS.

According to numerous literature sources, the basic and necessary components of spatial information systems include algorithms, procedures, and methods for processing and sharing information, which together constitute software, databases in which spatial data are collected and stored, hardware, and people associated with data processing, software development and the target users of the system themselves[3].

The term GIS was introduced in the 1960s and was derived from the name of an information system that was developed for Canada. In the late 1980s, the acronym GIS also came to denote a scientific discipline, Geographic Information Science, which deals with geographic information and GIS methods and techniques. Later it was assigned the names geomatics and geoinformatics.

The Canada Geographic Information System (CGIS) is considered the first system of its kind, and it was developed for the Government of Canada in the early 1960s. It began a long but dynamic development of this type of system that continues today. In the early days, achievements primarily in the field of cartography were used, but the development itself was determined by hardware capabilities and therefore strongly depended on the achievements of computer science. The pace of development was also determined by other factors related to computer science, such as the development of software or database systems, but also by other achievements, including the development of data sources used in the systems.

Due to the interpenetration of the fields of application of GIS and cartography, people began to look for mutual relations between them[4]. Depending on the views, GIS began to be treated as a subset of the technical and analytical tools of cartography, which was

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[3] Bielecka E.: Systemy informacji geograficznej. Teoria i zastosowania, Wydawnictwo Polsko-Japońskej Wyższej Szkoły Technik Komputerowych, 2006; Gaździcki J.: Systemy informacji przestrzennej, PPWK, Warszawa, 1990; Kwiecień J.: Systemy informacji geograficznej, Wydawnictwo Uczelniane Akademii Techniczno-Rolniczej w Bydgoszczy, Bydgoszcz 2004.

[4] Myrda G.: GIS czyli mapa w komputerze, Wydawnictwo Helion 1997; Richling A.: Systemy informacji geograficznej i ich znaczenie dla przyszłości geografii, P. Geograficzny, 1992, Vol. 64.

characteristic of cartographers, while proponents of GIS began to see spatial information systems as the successor of cartography, and cartography itself as a set of tools for the presentation of spatial data and the results of the analysis carried out on their basis. In fact, it is difficult to find a basis to fully justify any of the cited statements, GIS has not yet eliminated cartography but is a valuable tool that would not achieve the current level of applications and development if it did not also benefit from other fields, not only computer science but even remote sensing, photogrammetry and geodesy[5]. GIS systems undoubtedly grew out of the achievements of cartography and have their roots there, as it is the cartographic methodology that provides these systems with their concepts of modeling geographical space. They make it possible to organize information, they also lead to the creation of a model of geographical space, and many of them were created long before the advent of GIS or even computer science. Also, the idea of gathering and presenting information in layers has its roots in the times when GIS systems did not exist yet, namely this concept goes back to the 19th century when there was the development of overlay methods of developing classical maps. The early 20th century maps developed for New York City with economic and demographic themes is one such example[6].

Within the framework of this study, special attention was paid to the review of data sources used in geographic information systems and their development at the turn of the last decades. The main emphasis was placed on satellite techniques, which have clearly accelerated the acquisition of spatial data and thus triggered the development of GIS. However, a discussion of the characteristics of data sources and their development in the case of spatial data not related to the Earth's surface is completely omitted.

8.2. Geographic data characteristics

Spatial data relating to the Earth's surface is called geographic data as well as geodata. Their task is to describe objects by identifying their location, often supplemented by additional descriptive data. Thus, geographic data primarily include information about the location of objects in the adopted reference system, their geometric properties, spatial relationships with other objects, and several other descriptive features that define the desired properties[7].

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[5] Saliszczew K.: Kartografia ogólna, WNPW, Warszawa 1998; Sandecki J. (ed.): Teledetekcja, pozyskiwanie danych, Wydawnictwo Naukowo-Techniczne, Warszawa 2006.

[6] Baranowski M.: Rozwój kartografii komputerowej i systemów informacji geograficznej w Polsce na tle tendencji światowych, Polski Przegląd Kartograficzny, 1991, Vol. 23, No. 1–2; Kraak M., Ormeling F.: Kartografia – wizualizacja danych przestrzennych, PWN, Warszawa 1998.

[7] Werner P.: Wprowadzenie do systemów geoinformacyjnych, Warszawa 2004; Widacki W.: Wprowadzenie do systemów informacji geograficznej, IGUJ, Kraków 1997.

Due to the different purposes of spatial information systems, databases store information about objects, which can be both natural and artificial creations, but also social, economic, natural, and many other phenomena. Objects are described by specifying their attributes, which are divided into spatial and non-spatial. Spatial attributes in turn are divided into geometric and topological, while non-spatial attributes are divided into qualitative and quantitative[8]. This is depicted in Figure 8.1.

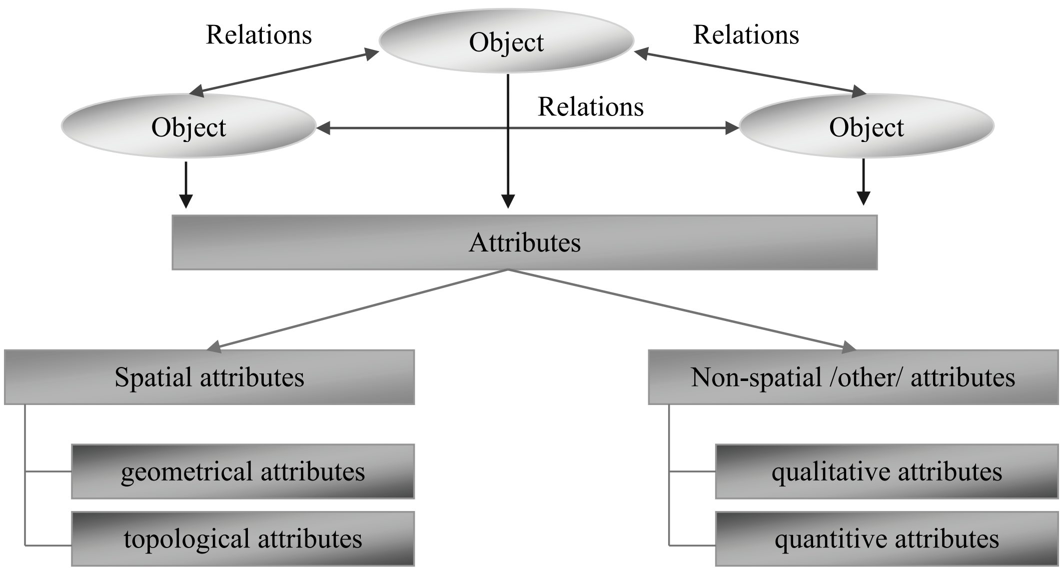

Fig. 8.1. Objects and their mutual relationships and classification of attributes describing objects
Rys. 8.1. Obiekty i ich wzajemne relacje oraz klasyfikacja atrybutów opisujących obiekty
Source: own elaboration based on literature data.

Geographic information systems distinguish the following relationships that occur between objects:

- bordering, e.g. two objects - land parcels with each other,
- affiliation, e.g. a freeway section between two exits belongs to the whole freeway,
- belonging, e.g. to any poviat, town, village, to a voivodeship.

In order to use geographic data, the transformation to a computer representation of the real world requires the development of a simplified version of it that can be understood by software, called a model[9]. As with any modeling, simplifications are necessary with this transformation, and it is necessary to create a data structure that allows for subsequent software processing. In the case of geographic data, each object must be given its location and, depending on the scale of the development, often also a specific shape. Topological relationships may also be specified. The way of visualization of

[8] Bielecka E.: Systemy informacji geograficznej. Teoria i zastosowania, Wydawnictwo Polsko-Japońskej Wyższej Szkoły Technik Komputerowych, 2006.
[9] Urbański J.: Zrozumieć GIS, Analiza informacji przestrzennej, Wyd. Naukowe PWN, Warszawa 1997.

objects on the screen or printout coming from the applied software is dictated by the standard adopted or developed, especially for these purposes. In this way, two models are distinguished:

- landscape models of geographic data, which are used to determine the location and topology, as well as other characteristics of objects,
- cartographic models of geographic data, which are used to determine how particular types of objects are represented on screen and/or print.

Based on the types of data used in spatial information systems, there are three main geographic data landscape models:

- vector models,
- raster models
- Triangulated Irregular Network (TIN) models.

The vector model is perfect for representing discrete data, the raster model – is for continuous data, while the TIN model - is for data containing information about the third dimension, i.e. height and it is used to represent terrain relief.

Depending on the type of geographic data - whether it is vector or raster, which results, among other things, from the way it is acquired, the way it is recorded and the subsequent possibilities of its processing differ. Data can be combined by presenting them in different layers, it is also possible to create complex objects, which are represented by more than one simple object. Complex objects are often created using vector data, in which each object is represented by a point, line, or surface10.

Points allow objects to be represented by a coordinate pair, which are usually longitude and latitude. They have a simple visualization, consistent with the cartographic model used. They are perfect for presenting objects whose size is not important in further analyses.

The second way of representing objects is a line, used for determining the location of objects characterized by one dimension – length. It is commonly used to determine the location of rivers, roads, railroads, power lines, district, provincial, national, and other borders. Lines are recorded by a sequence of coordinates of consecutive points, marking the entire course.

Objects that require two-dimensional representation are represented by polygons, whose area is determined by a series of coordinates of points. Examples of objects requiring such representation are seas, lakes, parcels, administrative units, etc.

The decision to use a particular style of representation is influenced not only by the type and characteristics of the object but also to a very large extent by the scale of the

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[10] Czyżkowski B.: Praktyczny przewodnik po ArcView 3.3., PWN, Warszawa 2006.

study. Small scale studies will be characterized by lower accuracy, which may result, for example, in the recording of surface objects in simplification by linear or even point objects.

The use of a vector model among all landscape data models allows to obtain high accuracy of objects location determination. Moreover, it also allows for recreating in computer representation the relations between objects, i.e. their topological relationships. Hence the division into simple vector model and topological vector model.

For geographic data recorded in raster form, different analysis and processing methods are used. The raster model is created by dividing the space into equal areas of square or rectangular shape. This operation is called tessellation and it results in a set (matrix) of elements, which are individual pixels. The position of individual pixels is given by their row and column numbers in the matrix. This is a very simple data record and therefore has found use often first in many GIS programs. Further operations based on the raster model take place differently from the vector model, but some similarities can be seen. Although the raster model is perfect for the representation of continuous data, it is possible to record the point, line, and polygon objects with its use, but this record will be more approximate, the bigger dimensions of a single element are, i.e. the bigger dimensions of the pixel are. Each pixel is accompanied by a single value, which can be any attribute. To increase the amount of data, it is necessary to use multiple layers, and data acquired from sensors mounted, for example, on artificial satellites of the Earth, recording electromagnetic radiation in different ranges is an example of such an approach. More information on this will be given later in the chapter.

Typical examples of data represented in raster models are terrain elevation, air temperature, air pressure, and even social phenomena. The concepts of spatial, spectral, and temporal resolution are directly applicable to raster data.

Related to spatial resolution is the size of a single pixel. As will be shown in the following sections, this is directly related to the way the data is acquired and the type of equipment used. The ability to distinguish objects in aerial photographs or satellite images depends mainly on this parameter.

The spectral resolution is a term related to the ability of the equipment used to acquire images in different ranges of electromagnetic radiation. Images are often captured in different ranges of radiation, not only in the visible light range.

Time resolution, on the other hand, allows determining the time after which a photo/image of the same area of terrain can be obtained. This is quite a characteristic parameter for any artificial satellite that is used to acquire geographic data. As it will be presented in section 3, this time varies considerably and can range from even tens of hours to tens of days and is due, among other things, to the altitude of the orbit.

Despite the ease of implementing the raster model and acquiring data for it, it has many drawbacks, including the large size of the databases. At the turn of the years and with the progress taking place in information technology, thus also in GIS systems, various forms of data storage optimization were applied, developing and using different methods of their compression. Looking from today's point of view, one can see numerous formats for saving images, although many of them are not used nowadays or have even been forgotten. All compression algorithms can be divided into lossy and lossless. Lossy compression typically allows for smaller data file sizes, but at the cost of content distortion due to the algorithms. The use of lossless compression prevents data degradation, but the effectiveness of such algorithms is usually lower from the standpoint of comparing data size before and after compression.

The last of the landscape models of geographic data presented was the TIN model, perfectly applicable to the presentation of three-dimensional data. It is the model of choice for creating numerical terrain models, allowing the height of the terrain position at any point to be determined. Unlike the raster model, the TIN model is usually irregular in structure, tessellation leads to triangles with varying side lengths. Each vertex of this triangle has known coordinates, allowing the computation to be performed anywhere in space. Simplifying considerations considerably, we can say that the TIN model is based on the topological vector model, additionally enriched with the height dimension. Analyses conducted with its use depend to a large extent on the density of vertices of the created grid, taking into account the discontinuities of the terrain by an appropriate selection of the location of grid points and on the interpolation algorithm used.

8.3. Geographic data sources

Geographic data can be extracted from a variety of sources including:

- satellite imagery,
- aerial photographs,
- geodetic measurements,
- measurements using satellite navigation systems[11].

Choosing a source from the above also involves choosing between raster data and vector data. The listed sources can be thought of as primary data sources, usually found in digital form, allowing for almost direct use in GIS programs. An airborne laser scanner

[11] Januszewski J.: Systemy satelitarne GPS, Galileo i inne, PWN, Warszawa 2006; Narkiewicz J.: GPS i inne satelitarne systemy nawigacyjne, Wyd. WKŁ, Warszawa 2007; Narkiewicz J.: Podstawy układów nawigacyjnych, Wyd. WKŁ, Warszawa 1999.

can also be used to feed systems that also need elevation data, such as TIN systems. It allows measuring the height of points located on the surface of the Earth with specified longitude and latitude coordinates. The measurement points are located close to each other and form a dense network, which makes the accuracy of height determination vary from 0.15 to 0.25 m[12].

Geographic data can also be secondary. These include traditional, classical maps and various databases. Scanning maps or photographs or creating terrain models based on topographic maps and levels visible on them, is not one of the most accurate ways of data acquisition, however, it is used. Secondary data are usually in analog form, which involves additional steps[13].

The division between primary and secondary data becomes blurred in some situations, as often data extracted from primary sources also need to undergo some preparation before being used in GIS systems. This processing, however, is more straightforward in nature, and the data extracted in this way is specifically intended for use in GIS. Secondary data, on the other hand, are obtained from other systems or have already been used in other studies. In this paper, attention will be focused on satellite imagery, undoubtedly a source of primary data.

Each of the sources is characterized by advantages and disadvantages, which in particular situations may determine the usefulness of the data thus obtained for the assumed purpose of the system work. Similarly, any data processing aimed at introducing them into spatial information systems is a source of potential errors. Both satellite images and aerial photographs are sources of raster data, while field measurements, whether geodetic or using satellite navigation systems, as well as airborne laser scanning, are sources of vector data. However, GIS software nowadays allows combining different types of data with each other as well as converting them[14].

Considering the type of landscape geographic data model, the data sources in the vector model can be both satellite images and aerial photographs, but in this case, the data obtained from measurements should be mentioned first. For the raster model the use of aerial photos and satellite images is the most natural way of data acquisition and in contrast to the vector model, does not require processing into vector form, so-called

[12] Bielecka E.: Systemy informacji geograficznej. Teoria i zastosowania, Wydawnictwo Polsko-Japońskej Wyższej Szkoły Technik Komputerowych, 2006; Longley P.A., Goodchild M.F., Maguire D.J., Rhind D.W: GIS. Teoria i praktyka, Wydawnictwo Naukowe PWN, Warszawa 2008.

[13] Pietrzak M., Siwek J.: Wykorzystanie map historycznych, przetworzonych przy użyciu GIS do oceny zmian użytkowania ziemi na Pogórzu Wiśnickim. Przemiany środowiska na Pogórzu Karpackim, T. 1, IGiGP UJ, Kraków 2001, pp. 21–29.

[14] Litwin L., Myrda G.: Systemy informacji geograficznej - zarządzanie danymi przestrzennymi w GIS, Wydawnictwo Helion, 2005; Longley P.A., Goodchild M.F., Maguire D.J., Rhind D.W: GIS. Teoria i praktyka, Wydawnictwo Naukowe PWN, Warszawa 2008; Szczepanek R.: Systemy informacji przestrzennej z quantum GIS. Część I, Politechnika Krakowska, Kraków 2013.

vectorization. In the last of the presented models – the TIN model, the source can be again vectorized images and photos, but again the main role is played by measurement data, which can be complemented by height or topographic maps.

Satellite images, as well as aerial photos, are models of a part of Earth's surface, which are obtained in a specific range of the electromagnetic spectrum, not necessarily in the visible range. These models can be recorded in analog or digital form, but currently, digital technology is dominating.

Depending on the scale of satellite images and aerial photographs, objects located on the surface of the Earth may be recorded in varying detail. As the scale of an image or photograph decreases, the number of registered elements decreases, i.e. its detail decreases, however, it is usually accompanied by an increase in the spatial scope of the study. The number of registered details is influenced mainly by the type of sensor placed on the satellite or mounted on the plane, which will also depend on the quality of the obtained image in different weather conditions. In the case of aerial imagery, the quality of the acquired data is also affected by the flight altitude, the stability of the flight path, and many other factors that are not present in satellite imagery[15].

Despite various limitations, satellite images and aerial photographs have for years been considered the two richest sources of information used in spatial information systems. Remote sensing and photogrammetry, among others, are used to process and interpret the data, allowing to recognize objects recorded in these images and enrich spatial data with descriptive data (remote sensing, i.e. measurement of properties of objects without physical contact with them) and correct determination of sizes, reconstruction of shapes and mutual position (photogrammetry). This is the way to obtain a distortion-free orthophoto map[16].

To recognize objects on aerial photographs or satellite images, that is, acquired through various sensors, recording electromagnetic radiation both reflected or emitted by objects located on the Earth's surface, in different ranges of electromagnetic radiation, remote sensing methods, and so-called recognition features are used. These are characteristic features of objects, enabling their recognition and even determining additional parameters. Depending on the conditions, it is possible not only to determine the size, and color, but even the height of some objects. For example, this is possible for tall objects photographed at a particular time of day based on the length of their shadow. Due to such possibilities of object recognition, the so-called object recognition features are divided into direct and indirect ones:

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[15] Ciołkosz A., Misztalski J., Olędzki J.: Interpretacja zdjęć lotniczych, Wyd. Naukowe PWN, Warszawa, 1999.
[16] Makowski A. (red.): Systemy informacji topograficznej kraju, Wyd. PW, Warszawa 2005; Mularz S.: Podstawy teledetekcji, Wydawnictwo PK, Kraków 2004.

- direct features include the most basic properties of objects, i.e., size, shape, tone or color of the photographic image, texture, etc;
- indirect features of objects include features that indirectly indicate the presence of an object and its characteristic properties. In addition to the shadow size already given, topographic distribution is also included in this group.

The cost of data acquisition is a very important aspect of data source selection . At the turn of the years of GIS development, the costs of computer equipment, software, data acquisition, and user training varied significantly. The data themselves were difficult to access, often requiring huge resources necessary to acquire them, which was also associated with large time outlays e.g. for taking measurements. In the case of using secondary data, both time and financial outlays are transferred to activities such as digitization or vectorization, but also data correction.

Satellite images and aerial photographs, as the sources of raster data, have a common feature, which is obtaining information based on registered electromagnetic radiation employing passive or active devices. The first of them allows recording solar radiation or radiation emitted by objects on the Earth, whereas active devices have sources of radiation, which is reflected by objects on the Earth's surface.

8.4. Satellite images

Since the first artificial satellites were launched, they started to be seen as a very good source of geographical data. They provided data, especially for military needs, however, they also opened the way for obtaining data for civilian needs. Nowadays, information for practically the entire Earth's surface can be drawn from this source. Numerous literature sources tell us that the first satellite used for mapping was the Landsat satellite, and this was back in the early 1970s.

The ability to acquire useful images from satellites is primarily due to the altitude of the orbit. Because there are two main types of satellites, which include heliosynchronous and geostationary satellites, their imaging capabilities differ. A large proportion of satellites that move in heliosynchronous orbits, or orbits that are synchronous to the Sun, are circumpolar satellites, which in effect cause them to move relative to the Earth's surface at the same speed as the Earth rotates around its axis. Heliosynchronous satellites allow to obtain information about different fragments of the Earth, moreover, they enable imaging of the same fragment of the surface at the same regular time, which facilitates analysis of occurring changes in the observed area. Acquisition of data from this source is characterized by the possibility of regular updating, but each time it requires the processing of data to the proper form, which is not always possible in an automatic or semi-automatic way.

Satellite images have a very different spatial resolution, according to different sources ranging from about 0.5 [m] to even 1 [km]. The size of acquired images expressed in pixels varies from a few hundred to a few thousand pixels in both directions, which, taking into account the spatial resolution, allows to determine the size of the imaged area in each image from about 9 x 9 [km] to 200 x 200 [km].

Besides spatial resolution, spectral and temporal resolutions are very important. Depending on the sensor installed on the satellite, the radiation can be recorded in one range of radiation (single-band systems) or many ranges simultaneously (multi-band). The simplest detector will be a sensor registering a range of visible radiation, but usually, devices registering more ranges are used.

Some of the best-known artificial satellites for acquiring this type of image are Landsat satellites, which in 2022 will record 50 years of operation.

Landsat is the name of a program to remotely acquire images of the Earth based on successive generations of satellites launched into space beginning in 1972. Some of these satellites are still operational (Landsat 7, Landsat 8, and Landsat 9), as shown in Table 8.1. One of the satellites, Landsat 6, was not put into service because it did not reach its planned orbit.

Table 8.1

Landsat satellites of the Earth remote image acquisition program

Satellite name	**Launch date**	**End date**	**Operat-ing time**	**Ranges and resolutions**	**Notes**
Landsat 1	July 1972	January 1978	66 months	Three-band RBV: 80 [m] Four-band digital MSS: 60 [m] /MS/	Original name: Earth Resources Technology Satellite 1. Altitude 900 [km], time resolution – 18 days
Landsat 2	January 1975	February 1982	85 month	RBV: 80 [m] Four-band digital MSS: 60 [m] /MS/	Altitude 900 [km], time resolution – 18 days

Satellite name	**Launch date**	**End date**	**Operat-ing time**	**Ranges and resolutions**	**Notes**
Landsat 3	March 1978	March 1983 / September 1983	60 months	RBV: 38 [m] /PAN/ Four-band digital MSS: 80 [m] /MS/	Altitude 900 [km], time resolution - 18 days. The 5th channel of the MSS failed shortly after launch
Landsat 4	July 1982	December 1993 (end of science data collection) / June 2001 (withdrawn from service)	136 months	Four-band digital MSS: 80 [m] /MS/ TM: 30 [m] /MS/ TM: 100 [m] /IR/	Seven-band TM, altitude 705 [km], time resolution – 16 days. Last remaining science data downlink capability failed in 1993
Landsat 5	March 1984	June 2013	351 months	Four-band digital MSS: 80 [m] /MS/ TM: 30 [m] /MS/ TM: 100 [m] /IR/	Seven-band TM, altitude 705 [km], time resolution – 16 days. MSS turned off in August 1995, TM in November 2011. In January 2013 satellite moved in to a lower orbit
Landsat 6	October 1993	October 1993	-	MSS: 80 [m] /MS/ ETM: 15 [m] /PAN/ ETM: 30 [m] /MS/ ETM: 120 [m] /IR/	Failed to reach orbit
Landsat 7	April 1999	-		ETM+: 15 [m] /PAN/ ETM+: 30 [m] /MS-RED, GREEN, BLUE/ ETM+: 30 [m] /NIR, SWIR-1, SWIR-2/ ETM+: 60 [m] /TIR/	Eight-bands ETM+ 8-bit data, altitude 705 [km], time resolution – 16 days. Single scene width about 165 [km]

Satellite name	Launch date	End date	Operat-ing time	Ranges and resolutions	Notes
Landsat 8	February 2013	-		OLI: 15 [m] /PAN/ OLI: 30 [m] /MS/ OLI: 30 [m] /NIR, SWIR-1, SWIR-2/ TIRS: 100 [m] /TIR-1, TIR-2/	Original name: Landsat Data Continuity Mission, eleven spectral bands,12-bits data, altitude 705 [km], time resolution – 16 days
Landsat 9	September 2021	-		OLI-2 / TIRS-2 Four-bands visible spectral one band near-infrared spectral three-bands shortwave-infrared spectral 30 [m] one band panchromatic 15 [m] two-bands thermal infrared 100 [m]	Data is publicly available from USGS, Landsat 9 replaces Landsat 7 taking its place in orbit – joins Landsat 8 in orbit – 8 days out of phase with Landsat 8, eleven spectral bands, 14-bit data

Source: own elaboration based on literature and internet sources, e.g. [18, 19, 28, 29, wikipedia].

The lifetime of each satellite varies, with the first three generations ranging between 5 and 7 years. The 4th and 5th generations achieved longer operating times and were just over 11 years and 29 years respectively. The lifetime of the active satellites of the Landsat series is over 23 and 9 years respectively. The newest one is working since September 2021. The achieved lifetimes are very long, which is positive from the economic point of view of the project and allows to launch the next generations less frequently.

Successive generations of satellites differ in the parameters of their sensors. So far, Landsat satellites use the following multispectral cameras and scanners: RBV – Return Beam Vidicon; MSS - Multispectral Scanner; TM – Thematic Mapper; ETM – Enhanced Thematic Mapper; ETM+ – Enhanced Thematic Mapper Plus. The equipment specifications of the first three generations of satellites were very similar to each other. The Landsat 4 generation, of which Landsat 5 was almost a copy, had an upgraded MSS scanner design and was additionally equipped with a Thematic Mapper TM. Landsat 6 was to use for the first time an Enhanced Thematic Mapper in addition to the MSS scanner, capable of capturing 15 [m] resolution images in panchromatic mode. Due to the failure of its launch, the next generation, which started work 5 and a half years later, used the Enhanced Thematic Mapper Plus solution, which also allowed to record images with a resolution of 15 [m] in panchromatic mode, but differed in additional capabilities of calibration (full aperture calibration). The next big changes are in Generation 8, which features the Operational Land Imager (OLI) and the Thermal InfraRed Sensor (TIRS).

Based on data presented by NASA, Landsat 8 and 9 satellites are capable of recording data in 11 bands ranging from visible light, near-infrared, shortwave infrared, and thermal infrared wavelengths. Three bands are visible light – natural color in the ranges of red, green, and blue, which allows observations of shallow water and coral, tracking smoke/dust. Each of the following bands has its purpose, with bands 10 and 11 allowing the recording of surface temperature. The next generation of Landsat satellites is currently under development and is expected to offer more than twice the number of bands as Landsat 8 and 9, with up to 25 bands planned. The estimated launch date for the next satellite is 2029/2030 according to official information released by NASA.

A good overview of the development of the Landsat satellites, their timing, and launch dates is given in Figure 8.2.

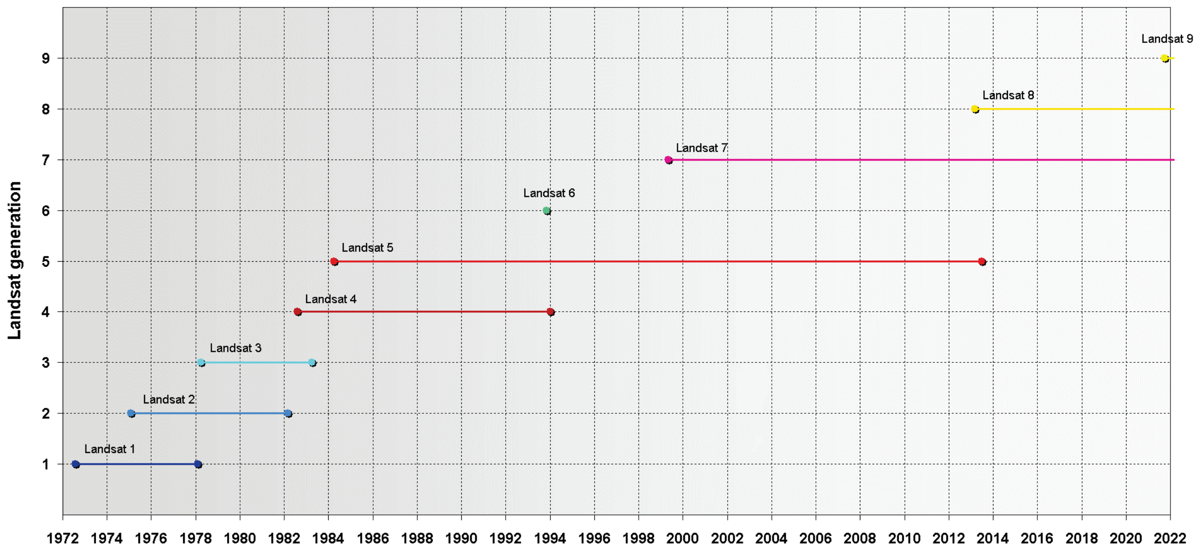

Fig. 8.2. Timeline of successive generations of Landsat satellites
Rys. 8.2. Linia czasu pracy kolejnych generacji satelitów Landsat
Source: own elaboration based on literature data

Among all the satellites of the Landsat series, the Landsat 5th generation features the most data expressed in terms of the number of images taken. This number is estimated to be over 3.7 million. Landsat 8 and Landsat 9, on the other hand, are characterized by the highest number of images taken per year (>700 scenes per day), but in terms of their operating time, they currently rank second and third, respectively. Landsat 7 has taken about 3 million images, and Landsat 8 has about 2 million images.

For full imaging of the country's surface by Landsat satellites about 32 images are needed, but several of these images will cover a very small area of Poland. It should be also remembered that areas presented on neighboring satellite images partly overlap.

Geographic information systems also use data obtained from other satellites. Among more known satellites there are SPOT, Quickbird, IKONOS, Radarsat, IRS, Meteosat, and ORBImage. Some of the mentioned satellites have several variations – generations, differing similarly to the next generations of Landsat satellites in the instrumentation used, which in turn influences the spatial and spectral resolutions. Examples of these satellites are shown in Table 8.2.

Table 8.2

Satellites used to acquire images of Earth

Satellite name	Start operation – end operation	Ranges and resolutions	Notes
ERS-1	July 1991 – marzec 2002	25 [m]	Altitude 785 [km]. The first satellite of the European Space Agency (ESA). Imaged belt with a width of 100 [km]
ERS-2	April 1995	25 [m]	Compared to ERS-1 it had the ability to measure ozone in the atmosphere
Radarsat-1	November 1995	25x28; 30x28; 25x28; 50x50; 100x100 [m]	Ability to work at different resolutions and view terrain from different angles
Radarsat-2	December 2007	From 3 to 100 [m]	Imaged areas from 20 to 500 [km] wide
IRS-1 CD	December 1995 (IRS-1 C), September 1997 (IRS-1 D)	PAN 5,8x5,8 [m] LISS-3 23,2x23,5 [m] MIR 70x70 [m] WIFS 188x188 [m]	Two satellites differing in orbit (circular or elliptical). Time resolution of 24 days (IRS-1 C) / 25 days (IRS-1 D)
IKONOS	September 1999	PAN 0,82x0,82 [m]; MSS 4x4 [m]	Orbit 822 km above the pole, image covering an area 11x11 [km], time resolution 3 to 5 days
SPOT-4	March 1998	10 [m] /PAN/ 20 [m] /MSS/	Altitude 832 [km], image covering an area of 60x60 [km]
SPOT-5	May 2002	PAN 2.5x2.5 [m] MSS 10x10 [m] Short-wave Near Infrared 20x20 [m]	Orbit 832 km above the pole, image covering an area 60x60 [km]. Time resolution of 26 days

Satellite name	Start operation – end operation	Ranges and resolutions	Notes
SPOT-6	September 2013	1,5 [m] /PAN/ 6 [m] /MSS/	Orbit 695 km above the pole, image covering an area 60x60 [km]. Time resolution of 1–3 days
ORBImage OrbView 3	1999	PAN 1x1 [m]; MSS 4x4 [m]	
ORBImage OrbView 4	2000	PAN 1x1 [m]; MSS 4x4 [m] Hyperspectral 8x8 [m]	
Quickbird	November 2000	0.82x0.82 [m]; 3.28x3.28 [m];	Has not reached orbit, the first of three planned for launch by 2008
Quickbird-2	October 2001-December 2014	0,61x0,61 [m] /PAN/ 2,44x2,44 [m] /MSS – BLUE, RED, GREEN, NIR/	Altitude 450 [km]. Two sensors: panchromatic and four-channel multispectral. Imaged area 16.8x16.8 [km], time resolution 1–3.5 days, orbit 450 (original) / 482 (post orbit modification) [km], 11-bit data
Envisat	March 2002	25 [m]	Successor of ERS-1 and ERS-2. Altitude 790 [km]. Belt width 56-100 [km]
Alos	January 2006 – May 2011	Up to 10 [m] (Fine mode) Approx. 100 [m] (ScanSAR mode) 30 [m] (Fine Polarimetric mode)	Altitude 697 [km], imaged area 70x70 [km] (Fine mode), 250x250 [km] (ScanSAR mode), 30x70 [km] (Fine Polarimetric mode)
Worldview-1	September 2007	0,5 [m]	Altitude 496 [km], 11-bit data, image covering an area of 17.6x17.6 [km]
Worldview-2	October 2009	0,46/0,50 [m] /PAN/ 1,84 [m] /MSS/	Altitude 770 [km], image covering area 16.4x16.4 [km], time resolution 1.1 to 3.7 days
GeoEye	September 2008	PAN 0,41x0,41 [m]; MSS 1,65x1,65 [m]	Considered a complement to the IKONOS satellites. Imaged area 15.2x15.2 [km], time resolution 3 days
Meteosat-1 Meteosat-2 Meteosat-3 Meteosat-4 Meteosat-5 Meteosat-6 Meteosat-7	November 1977 June 1981 June 1988 March 1989 March 1991 November 1993 September 1997	VISIR 2,5x2,5 [km] TIR 5x5 [km]	First generation of the Meteosat satellites, operations completed

Satellite name	Start operation – end operation	Ranges and resolutions	Notes
Meteosat-8 Meteosat-9 Meteosat-10 Meteosat-11	August 2002 December 2005 July 2012 July 2015	11 of the channels at a spatial resolution of 3x3 [km] HRV 1x1 [km]	Second generation of the Meteosat satellites, currently in use: Meteosat-9 – Meteosat-11

Source: own elaboration based on [17].

As can be seen, the spatial resolution for satellite images varies significantly. The temporal resolution also varies over a wide range, ranging from a few minutes (for Meteosat), to tens of days, such as for some IRS, Landsat, SPIN, etc. satellites.

8.5. Summary

The overview of geographic data sources used in GIS presented in this chapter of the monograph was intended to show the variety of ways of data acquisition. It was preceded by the characteristics of geographic data and all basic information allowing us to understand the whole issue. The characteristics of the data discussed are very much determined by the way they are acquired and the form in which they feed the databases. A different set of data can be obtained using data acquired during field measurements, another using aerial photographs and satellite images. The main selection factor here is the form of the data – whether it is a vector or raster data and how much additional information, so-called metadata, accompanies it.

The analysis of the development of data sources focuses mainly on satellite images, presenting the characteristics of the most famous satellites used for data acquisition, both public and privately launched. Much space is devoted to presenting the achievements of the Landsat program, which for the last 50 years has set some standards.

Aerial imagery shares many of its characteristics with satellite imagery. For many years the analog technique was used and in some cases still is, requiring post-processing of images to digital form, thus requiring digitalization. The use of digital cameras makes it possible to eliminate this step and is a natural step in the evolution of this data source. In the case of aerial imaging, it is faster and cheaper to put into use the latest developments, use newer sensors, etc., which in the case of satellite imaging requires launching another satellite of a newer generation.

[17] Peruń G.: Systemy informacji przestrzennej. Materiały dydaktyczne do wykładu, Politechnika Śląska, Katowice 2011; Peruń G.: Systemy informacji przestrzennej. Materiały dydaktyczne do zajęć, Politechnika Śląska, Katowice 2011; QuickBird Data Sheet, DigitalGlobe 2014.

Another difference between taking aerial photographs and creating satellite images is the altitude at which such images are acquired. Unlike satellite images, the height at which aerial images are acquired is usually between 3 and 9 [km], which results in a much smaller area presented in the image. Aerial images can also be taken in different radiation ranges, depending on the needs of their later use.

Although both satellite images and aerial photographs are raster data sources, it is possible to process them into vector form. It is also possible to create three-dimensional models, which results from the possibility of creating stereoscopic images from pairs of overlapping images. Geographic data acquired from artificial satellites are characterized by the possibility of studying areas of large areas, but still on small scale. It is also possible to image areas that are inaccessible for various reasons, which is not always possible to do using aerial imagery. These, however, are characterized by higher resolution, so they can provide data for GIS systems operating on a larger scale.