



KAPITAŁ LUDZKI
NARODOWA STRATEGIA SPÓJNOŚCI



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MATERIAŁY DYDAKTYCZNE DO PRZEDMIOTU REMOTE SENSING AND PHOTO- INTERPRETATION

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1. Introduction

The aim of the tutorial is to give the readers the background of remote sensing and photo-interpretation. According to the statutes of International Society for Photogrammetry and Remote Sensing (ISPRS), (August, 2012) the following definition can be presented [6]:

“Photogrammetry and Remote Sensing is the art, science, and technology of obtaining reliable information from noncontact imaging and other sensor systems about the Earth and its environment, and other physical objects and processes through recording, measuring, analyzing and representation.”

Remote sensing can be understood as technology for object recognition, which answers the question: “what are there on a given place?”. The aim of photogrammetry is answering the question: “where is the recognized object, what is the size of the object?”. The question of the location is connected with the coordinate system and spatial data base. Therefore, ISPRS also defines Spatial Information Science as a science related to Geographical Information System (GIS), [6]:

“Spatial Information Science is the art, science, and technology of obtaining reliable spatial, spectral and temporal relationships between physical objects, and of processes for integration with other data for analysis, portrayal and representation, independently of scale.”

GIS, as spatial data base, collects spatial objects. There are two models: vector and raster. In the vector model real world can be presented using points, lines and polygons and it is defined by coordinates (X,Y), (Tab.1., Tab.3. and Tab.5.). Attributes, containing information about the object can be linked to the object (Tab.2., Tab.4. and Tab.6.). Each object has unique identification (ID) in data base. Many IDs can be used in GIS data base, but only one is called general / main key. IDs are used for “linking objects laying on the map to the attribute tables” (Fig.1.).

Tab.1. Point definition in vector model (graphic part)

ID	X	Y
1	X1	Y1

Tab.2. Point definition in vector model (descriptive part)

ID	Attribute 1	Attribute 2	Attribute 3	Attribute 4
1	A1	A2	A3	A4



Tab.3. Line definition in vector model (graphic part)

ID	X	Y
2	Xp	Yp
	X1	Y1
	X2	Y2
	Xk	Yk

Tab.4. Line definition in vector model (descriptive part)

ID	Attribute 1	Attribute 2	Attribute 3	Attribute 4
2	B1	B2	B3	B4

Tab.5. Polygon definition in vector model (graphic part)

ID	X	Y
3	Xp	Yp
	X1	Y1
	X2	Y3
	Xp	Yp

Tab.6. Polygon definition in vector model (descriptive part)

ID	Attribute 1	Attribute 2	Attribute 3	Attribute 4
3	C1	C2	C3	C4

In the raster model, attributes are gathered in so called pixels, ordered as a matrix (Tab.7.). Points, lines and polygons are presented by pixels in the raster model. The location of the objects in the raster model is defined by the position in the matrix using pixel coordinate system (c- column, r – row) or any map coordinate system (X, Y). Attributes are directly saved in the matrix. It is also possible to save IDs in the matrix and link them to the table of attributes similar to the vector model. Some examples of a map in the raster model is shown in the Tab.7. We have one point (ID=1), one line



(ID=2) and one polygon (ID=3). Other pixels have no data (void). ID's numbers are saved directly on the computer disk, pixel by pixel, precisely bit by bit, not as a matrix, because it is more effective way for gathering the huge amount of the data. Therefore, we need the so called metadata containing information of the amount of bits by pixel and the numbers of columns, at least. The value saved in pixel is also called Digital Number (DN). Raster data can be presented visually using colours representing each DN. In our example ID=1 was shown in black, ID=2 in grey and ID=3 in light grey colour (Fig.2.).

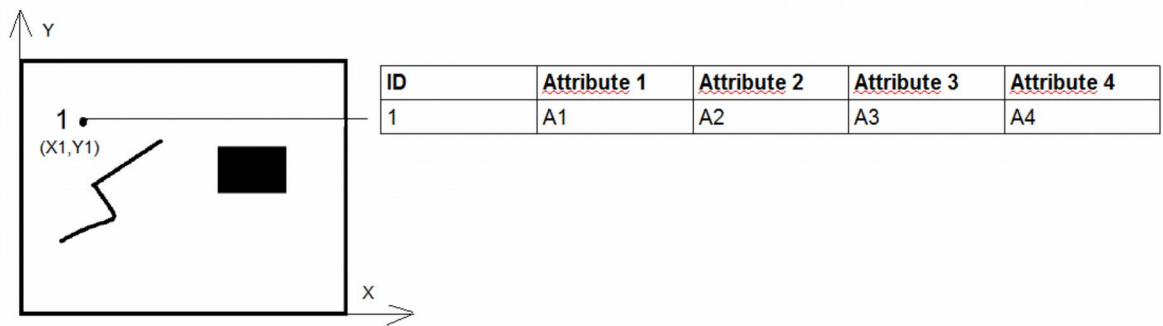


Fig.1. Data in vector model (left: map – graphic part, right: table of attributes – descriptive part); each object has its own ID, which allows for linking between the object on the map and the corresponding record in the attribute's table

Tab.7. Data in raster model

1	void	void	void	void
void	void	2	void	void
void	2	void	void	void
2	void	void	3	3
2	void	void	3	3

Photogrammetry and remote sensing deliver data to GIS (Fig.3.). The main aim of photogrammetry is to process images (airborne and satellite) to the given coordinate system. Finally, the image as a “photographic” map, called orthofotomap, is available. Google maps in satellite view is an example of “photographic” map. We see many details on this kind of the map but many important information are missing for example names of the cities, streets etc. but also we can probably recognize a forest but what type of forest it is not evident. Object recognition is exactly the subject of remote sensing. The



image can be interpreted manually by a photo interpreter basing on his knowledge, experience and ability of the object recognition. The procedure is time consuming and expensive, possible to apply in small areas, in operational conditions, for example in the army. Automatic approach is an alternative of drawing each object separately. Land use / land cover (LULC) map is an example of photointerpretation product, no matter if it is produced manually or in an automatic way. Orthophotomaps, LULC maps are necessary in further GIS applications. GIS is used as decision support for searching the new locations, transportation paths or modeling of different phenomena on the Earth (Fig.3.). Some project concerns LULC maps production share the maps for free. CORINE and URBAN ATLAS data base can be mentioned as an example (Fig.4.).

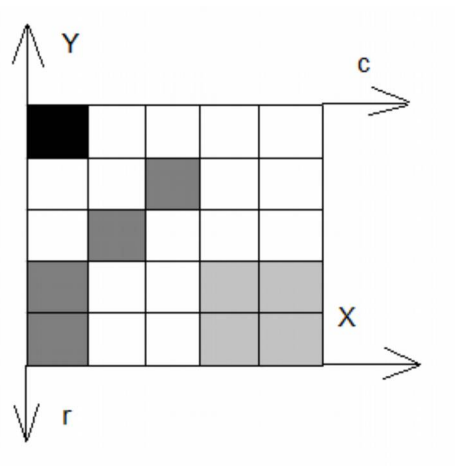


Fig.2. Data in the raster model; location of the objects is defined by placement in the matrix according pixel coordinate system (c, r) or national maps coordinate system or any map coordinate system; attributes are saved directly in pixels and can be presented visually by colours.

“The Urban Atlas is providing pan-European comparable land use and land cover data for Large Urban Zones with more than 100.000 inhabitants, as defined by the Urban Audit. The GIS data can be downloaded together with a map for each urban area covered and a report with the metadata.” [10].

For Kielce region the following files are available:

- pl012c.pdf – meta data, containing maps
- pl012l_kielce.pdf- meta data, containing maps
- pl012l_kielce.doc– meta data, processing description
- pl012l_kielce.shp – graphic part
- pl012l_kielce.dbf - attributes



- pl012l_kielce.shx
- pl012l_kielce.prj – project with coordinate system definition

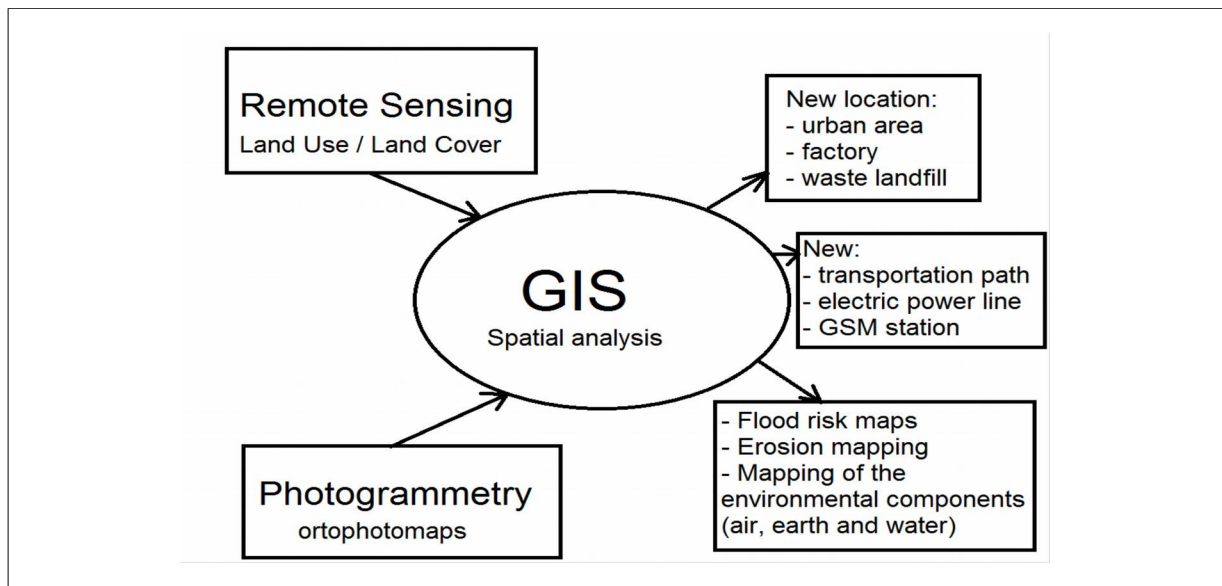


Fig.3. Remote sensing and photogrammetry as input data to GIS

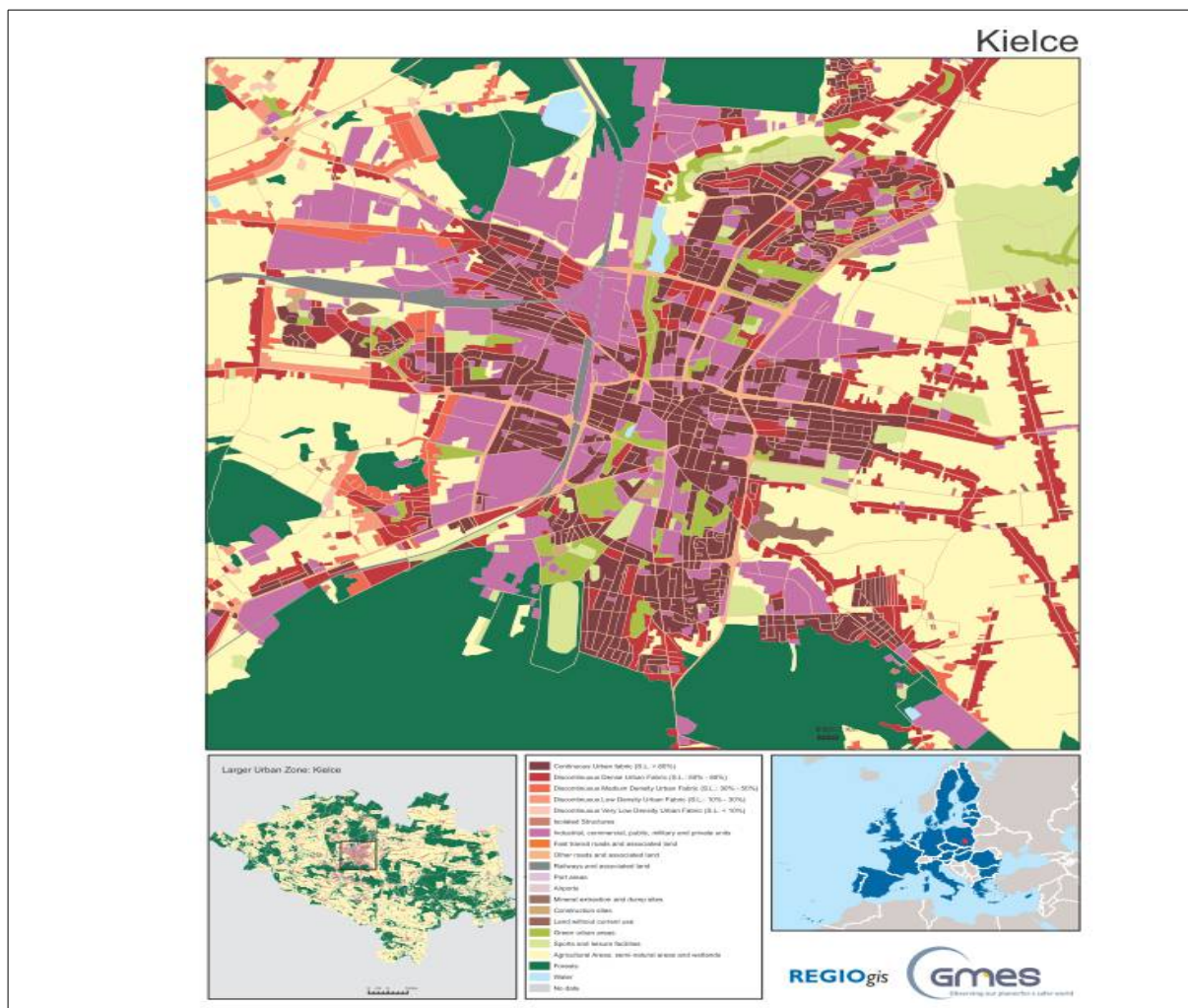


Fig.4. Urban Atlas – LULC map for Kielce area (pl012c.pdf)

2. Electromagnetic radiation (EM)

Electromagnetic radiation (EM) is a background of remote sensing. EM is the energy emitted in form of waves (light) or particles (photons) [8]. The source of the EM radiation is oscillation of electrons, particles, antenna etc. The oscillating element is bigger the wavelength is bigger. In our day-to-day life we meet EM very often (Fig.5.).

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1.1.1 Program Operacyjny Kapitał Ludzki Priorytet IV Działanie 4.1, Poddziałanie 4.1.1
na podstawie umowy z Ministerstwem Nauki i Szkolnictwa Wzwyższego UDA – POKL.04.01.01-00-381/10-00

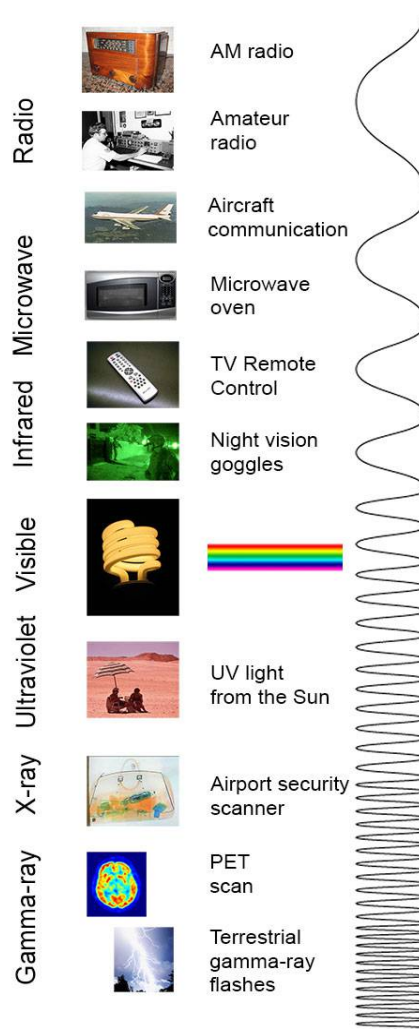


Fig.5. Electromagnetic spectrum [8]

Not all EM spectrum is applied in remote sensing for mapping objects and phenomenon on the Earth. Short-waves are absorbed in the atmosphere, thanks to it life is possible on the Earth because this radiation is dangerous for human beings. Long-waves are fully transmitted by the atmosphere but on the other hand, they deliver data with small resolution. So, some part of EM radiation, wavelength



from 0,3 μm to 100 cm are in remote sensing applied (Tab.8). EM radiation can be described by wavelength (λ) but also by frequency (ν). The speed of the light links these values: $c = \lambda * \nu$. So if radiation has long wavelength it also has small frequency, and the opposite (Fig.6).

Generally, in earth sciences a remote sensing is classified as: passive and active. The Sun is source of EM radiation in passive methods (Fig.7.). EM radiation emitted by the Sun is coming through the atmosphere to the Earth; then it can be absorbed, transmitted or reflected from the surface and is coming back through the atmosphere to the satellite (aircraft). The registered radiation is initially processed there and sent to the earth station where it is saved and distributed to users.

Tab.8. EM range used in remote sensing

EM range	wavelength
UV (ultraviolet)	0.3 – 0.4 μm
VNIR (Visible Near Infrared)	0.4 – 1.4 μm
SWIR (Short-Wave Infra Red)	1.4 – 2.5 μm
TIR (Thermal Infrared)	2.5 – 14 μm
MW (Microwave)	0.75 -100 cm

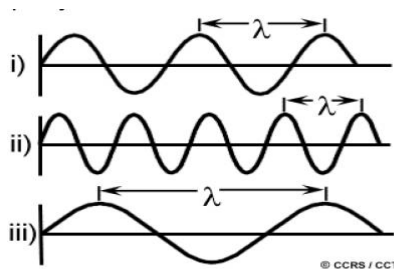


Fig.6. Different wavelength [4]

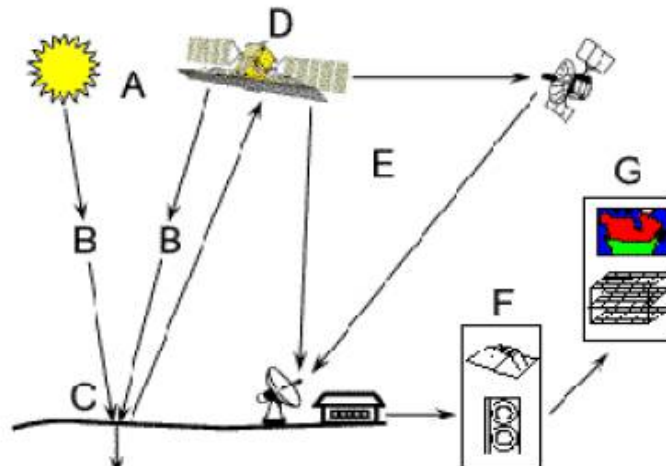


Fig.7. Path of EM radiation from Sun to the users [4]

3. EM interaction in the atmosphere and with objects on the Earth

EM radiation is passing through the atmosphere coming from the Sun to the Earth, and back to the sensor on the satellite. In the atmosphere, EM can be scattered (when the radiation changes the original direction) and absorbed (when the radiation loses energy), which depends on the size of particles in the atmosphere (Fig.8.). The clear explanation of the interaction of EM in the atmosphere can be found in tutorial of National Resources of Canada (NRCAN) [4]

There are Rayleigh, Mie and non selective scattering. Rayleigh scattering appears if the particles are very small, smaller than wavelength. This scattering increases with the decreasing of wavelength (therefore the sky is blue). Mie scattering are on the particles comparable with the size of wavelength and rather for longer wavelengths. Non selective scattering occurs when the particles much larger than the wavelength are present in the atmosphere and is equal for all wavelengths.

Absorption is the other phenomenon in the atmosphere. Ozon, carbon dioxide and water vapor absorb EM radiation. Ozon absorbs short radiation (UV) and allows us to live on the Earth, so it can be treated as positive. On the other hand carbon dioxide absorbs far infrared radiation and causes so called green house effect. On the other hand water vapor absorbs longways infrared and shortwave microwave radiation (between 22 μ m and 1m).

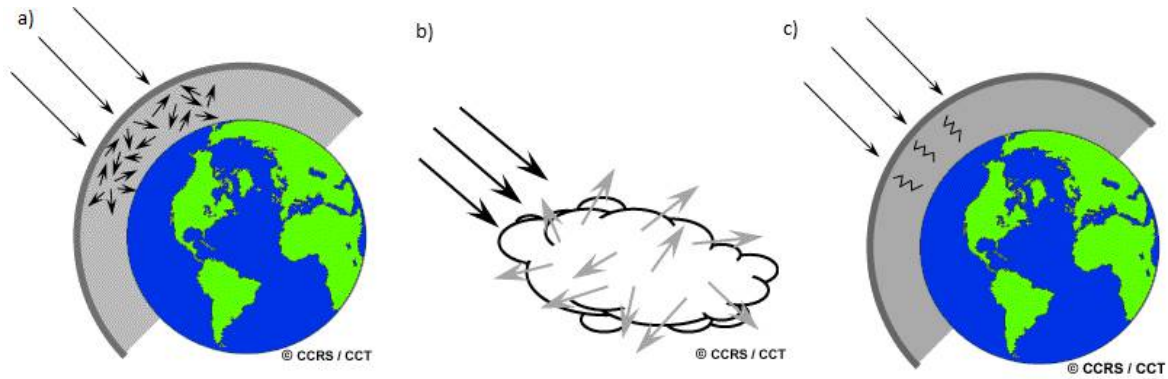


Fig.8. Scattering Rayleigh and Mie (a), nonselective scattering b) and absorption (c) in the atmosphere [4]

The phenomenon of absorption depends on the wavelength. In some EM ranges, radiation is transmitted, in some of them - is not. Therefore, the so called atmospheric windows are defined (Fig.9.).

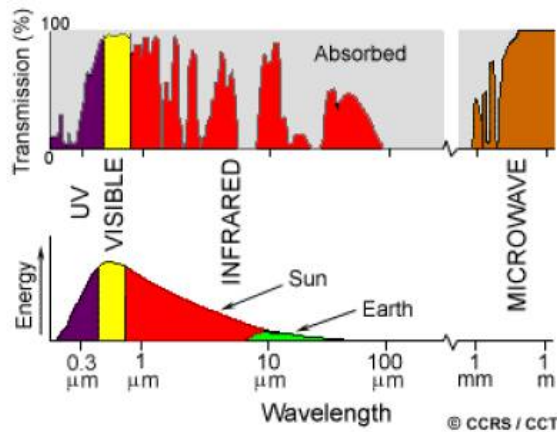


Fig.9. Atmospheric windows – relationships between transmission and wavelength, relationships between EM energy emitted by the Sun and the Earth in wavelength [4]



For short wavelengths the transmission of the atmosphere is small, even zero. Some part of UV is transmitted by the atmosphere and reaches the Earth. In remote sensing, it is applied to the water monitoring. All visible (VIS) EM range is transmitted almost in 100%. For longer wavelengths the transmission is selective, some parts of IR radiation is transmitted, some of them not. The atmosphere blocks the Sun radiation completely by water vapor (which was mentioned above). And again, for longer wavelengths, the atmosphere transmission increases to 100%. The atmospheric windows are crucial for remote sensing application because they determine the available spectral ranges. EM radiation can be recorded with visible range (like we normally see), so we can have normal colour image, where all colours are more or less natural. On the other hand, we can register EM spectrum in ranges we could not see, in remote sensing mainly in infra red and microwave ranges. EM radiation is registered similar to human eyes: separately in some spectral ranges corresponding to 3 basic colours: blue (B), green (G) and red (R). Besides, channels in infrared (NIR, SWIR and TIR) are also registered. Registration in many channels is called multispectral.

EM radiation interacts with the atmosphere but it also interacts with the Earth when radiation falls on the surface (Fig.10.).

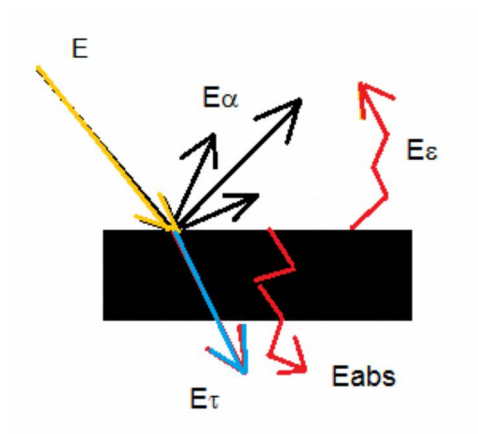


Fig.10. Interaction of EM with the Earth

Falling EM (E) radiation can be reflected ($E\alpha$), transmitted ($E\tau$) and absorbed (E_{abs}). The energy absorbed by an object can be emitted. If we assume there is no additional delivery of the energy, the energy emitted is equal to absorbed. The interaction between EM radiation and the object fulfills energy balance:

$$E = E\alpha + E\tau + E_{abs} = E\alpha + E\tau + E\epsilon \quad (1)$$



$$(1) \quad E = E\alpha + E\tau + E\epsilon = E\alpha + E\tau + E\epsilon$$

The energy in formula (1) depends on latitude, season and time of registration. Therefore, some unification was applied. We define coefficients of reflection (α), transmission (τ) and emission (ϵ) as follows:

$$\alpha = E\alpha/E \quad (2)$$

$$\tau = E\tau/E \quad (3)$$

$$\epsilon = E\epsilon/E \quad (4)$$

Therefore, energy balance can be written:

$$\alpha + \tau + \epsilon = 1 \quad (5)$$

For the object located on the land, transmission coefficient (τ) is usually equal zero.

4. Remote sensing images

The most popular remote sensing image recorded by satellites is LANDSAT [7]. Some of the archive images are possible to be downloaded for free (Fig.11., Fig.12.). In the first step we have to find a path and a row of our point of interest. Next, we decide from what version of Landsat data we are looking for. It depends on the time of registration: 2000's, 1990's or 1970's. One example of free downloaded Landsat image is shown on Fig.13.

One Landsat image covers a large part of the Earth: ca. 185 x 185 km. Please notice the path: 188, row: 25 covers south and central Poland. The data of registration is present in the name of compressed file (07.05.2000). Landsat data are composed of 9 files. The number of channel (1, 2 etc.) is placed at the end of the file name as: 10, 20 etc. Generally, there are 6 multispectral channels: 1 (B), 2 (G), 3 (R), 4 (IR), 5 (IR) and 7 (IR), one panchromatic (PAN) on (8) and 2 TIR – channel 6 (61 and 62). Spatial resolution of the multispectral channels are 30 m, PAN – 15 m and TIR – 60 m. Normal colour image can be prepared from channels 1, 2 and 3. Channel PAN contains registration of EM radiation in all VIS range without any separations by channels.



Fig.11. Landsat.org web site; Landsat Ortho are available for free [7]

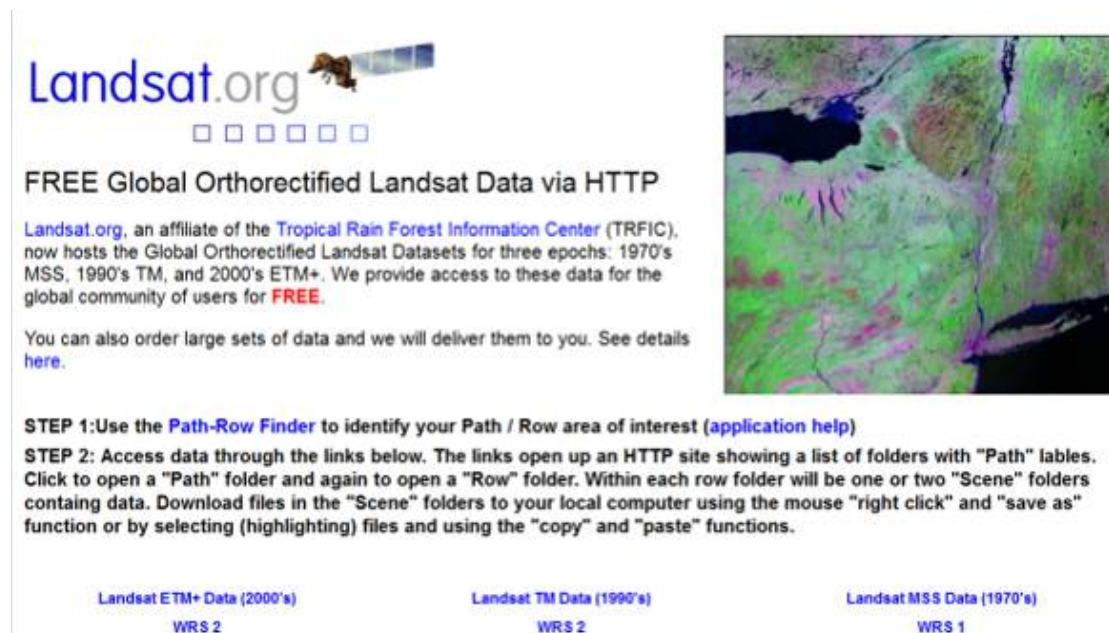


Fig.12. Free Global Orthorectified Landsat Data via HTTP [7]



Landsat Data is available for FREE

- Path: 188, Row: 25
- elp188r025_7t20000507.tar.gz
- GEOTIF

	Band	Wavelength (µm)	Resolution (m)
Blue	1	0.45 - 0.52	30
Green	2	0.52 - 0.60	30
Red	3	0.63 - 0.69	30
Near IR	4	0.76 - 0.90	30
SWIR	5	1.55 - 1.75	30
Thermal IR	6	10.40 - 12.50	120 (TM) 60 (ETM+)
SWIR	7	2.08 - 2.35	30

	Panchromatic	0.5 - 0.9	15
Nazwa	Rozmiar	Typ	Data modyfikacji
p188r025_7k20000507_z34_nn61.tif	17 823 KB	IrfanView TIF File	2002-09-15 09:19
p188r025_7k20000507_z34_nn62.tif	17 823 KB	IrfanView TIF File	2002-09-15 09:19
p188r025_7p20000507_z34_nn80.tif	284 740 KB	IrfanView TIF File	2002-09-15 09:15
p188r025_7t20000507_z34_nn10.tif	71 217 KB	IrfanView TIF File	2002-09-15 09:09
p188r025_7t20000507_z34_nn20.tif	71 217 KB	IrfanView TIF File	2002-09-15 09:09
p188r025_7t20000507_z34_nn30.tif	71 217 KB	IrfanView TIF File	2002-09-15 09:09
p188r025_7t20000507_z34_nn40.tif	71 217 KB	IrfanView TIF File	2002-09-15 09:09
p188r025_7t20000507_z34_nn50.tif	71 217 KB	IrfanView TIF File	2002-09-15 09:09
p188r025_7t20000507_z34_nn70.tif	71 217 KB	IrfanView TIF File	2002-09-15 09:09

Fig.13. An example of Landsat data

5. Software

There are many software for remote sensing. One of them is open-source: ILWIS. Name ILWIS comes from Integrated Land and Water Information System. The software is worked out by International Institute for Aerospace Survey and Earth Sciences (ITC) [5].

ILWIS is generally Geographical Information System (GIS) software but it is also possible to process remote sensing images. All processing presented in the manual are performed using this software.

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6. Digital image

Landsat image has to be imported to ILWIS, then it can be displayed (Fig.14.). Visualization is possible in different ways (colours).

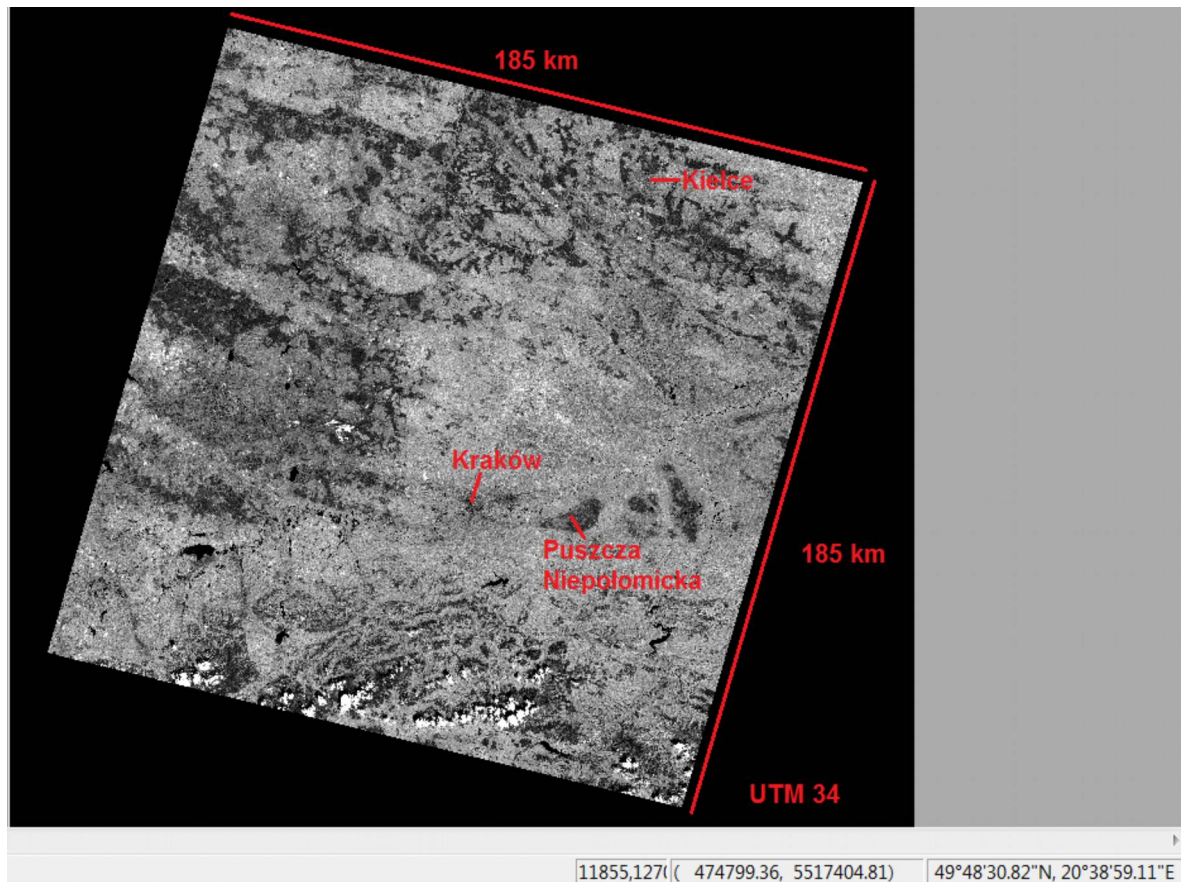


Fig.14. Panchromatic image: PAN 188/25

There are a few features describing remote sensing images:

- spatial resolution - pixel size in the ground (Fig.15.)
- spectral resolution – wavelength recorder for one channel, the number of channels (Fig.16.)
- radiometric resolution – how many bits are recorded for one pixel (Fig.17.)



- temporal resolution – how often it is possible to register the same area

Pixel Size = 10 m Image Width = 160 pixels, Height = 160 pixels	Pixel Size = 20 m Image Width = 80 pixels, Height = 80 pixels
Pixel Size = 40 m Image Width = 40 pixels, Height = 40 pixels	Pixel Size = 80 m Image Width = 20 pixels, Height = 20 pixels

Fig.15. Some example of different spatial resolution [2]

Spatial resolution is defined by pixel size on the ground. The image of the same area with higher resolution is composed of more pixels in width and in height. For example if pixel size is 10 m, image matrix is 160x160 pixels. If the image covers the same area but with pixel 80 m, image matrix is 20x20 pixels. The image of smaller pixel is of course sharper in comparison with the image of the bigger pixel size.

Spectral resolution answers the questions: how many channels cover some spectral range? For example panchromatic channel is composed of one channel and covers 0,3 μ m (Fig.16.) . Spectral resolution of multispectral channel (colour film) is 3 channels, cover 0,1 μ m each.



Radiometric resolution define how many bits are recorded in one pixel. Usually radiometric resolution is 8 bits, which gives 2^8 levels, 255 levels. Decreasing the radiometric resolution causes decrease of the ability of the object recognition (Fig.17.).

- Spectral range (μm):
- UV (0,3-0,4)
- VIS (0,4-0,7)
- VNIR (0,4-1,4)
- IR
- SWIR (1,4-2,5)
- TIR (2,5-14)
- MV (0,75-100cm)

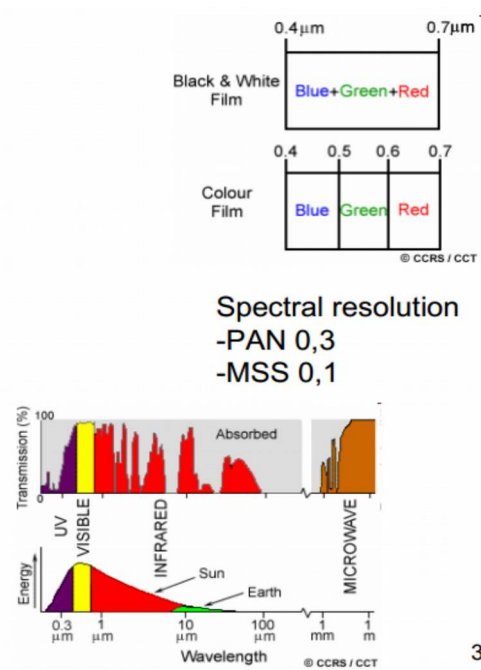


Fig.16. Spectral resolution, panchromatic image is composed of 1 channel that covers wider spectral range in comparison to the multispectral RGB [modified 2]

Image processing of remote sensing images can be divided into 3 steps:

- pre-processing
- image enhancement
- data extraction

In pre-processing phase RS image is prepared for further analysis. Some errors are usually removed. The aim of the image enhancement is such processing of the source image to obtain the best visualization. Image enhancement consists mainly of contrast stretching and colour composition analysis. Data extraction is the main core of the image processing. There are different approaches to data extraction depending on the type of processing RS images.

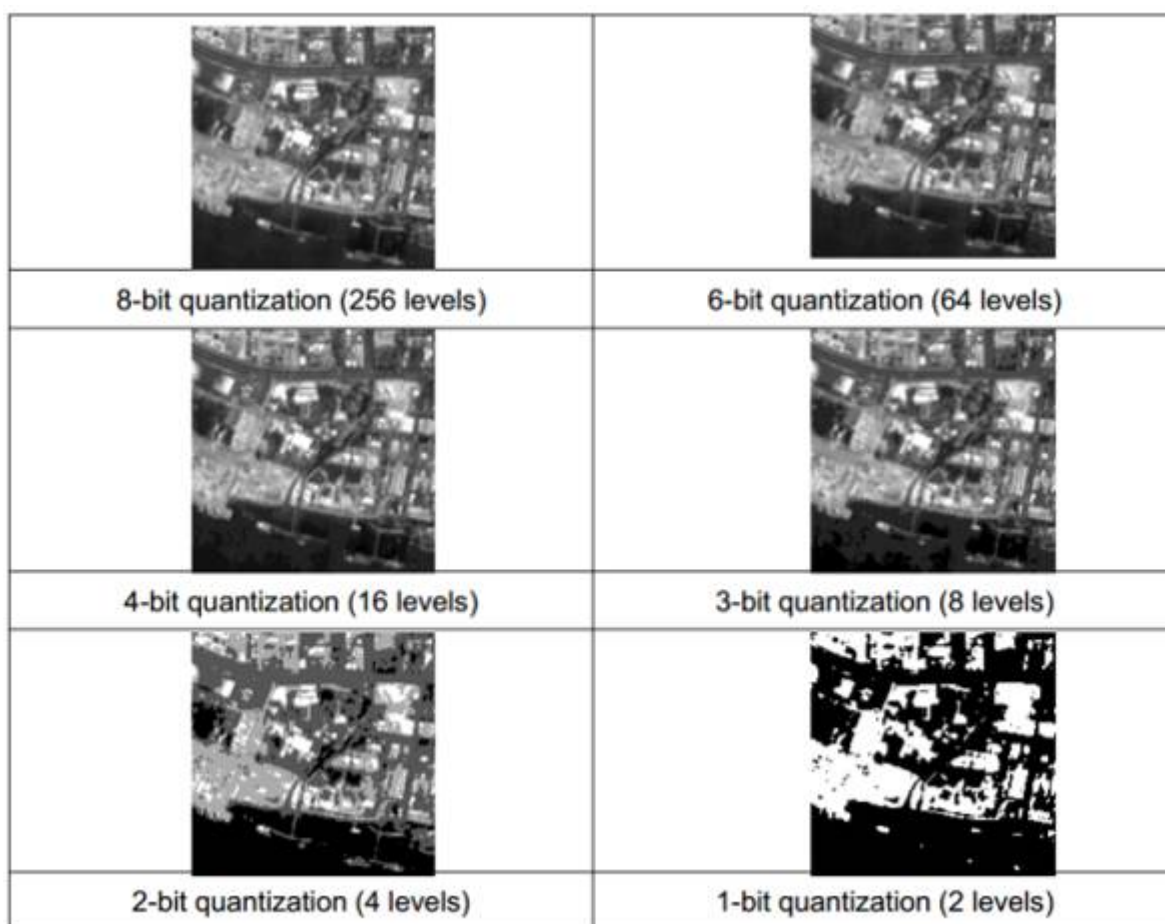


Fig.17. Radiometric resolution, the more bits per pixel, the higher radiometric resolution and more details are visible [2]

6.1 Image stretching

Digital image is composed of pixels (see matrix in Fig.2.). Numbers (DN) of the image can be statistically analyzed and histogram can be prepared (Fig.18.). Usually, RS image is recorded on 1 byte, which means 256 different DN (radiometric resolution of the image is in this case 8 bits, 1 byte).



Not always, rather very rarely are all values present in the image. 256 DN are potentially available but really small range is occupied (50-105 in Fig.18.). The histogram is defined as graphical representation of relationship between DN and the number of pixels, other words on the histogram we can see how many pixels have single value i.e. 50, 51, 52 ,....., 104, 105. Besides histogram, some statistics can be calculated: mean, median and standard deviation. Additionally, histogram distribution can be analyzed, visually or concerning DN after cutting 1% of the data (61:117 in Fig.18.). Ninety percent of DN are concentrated between: 66:93. Besides, cumulative histogram is presented on the histogram (red line in Fig.18.) showing how many pixels are in the image below the given DN. The histogram can be presented in graphical or numerical way. Visualization of the image basis of the taken colors, palette. It means 256 different colors are assigned to the DN. Colour “black” is assigned to the lowest DN and “white” to the highest and 256 colors in between are linearly assigned. If minimum value is 0 and maximal value is 255 but actually the information is between 50-105, colors assigned below 50 and above 105 are “lost”, because there is no data to be displayed in these colors. From practical point of view the image will have less contrast. Therefore, the first image enhancement method is contrast enhancement. The principles of contrast enhancement are shown in Fig.20.. Values from 58 to 158 are assigned to the range 0-255. It is also possible to apply a different function for contrast enhancement. After stretching, the values below minimum value (58) are assigned 0 and the values above maximum value (158) are assigned 255. Values between 58 and 158 are transformed according to a given function (simplest – linear) form 0 to 255. The histogram of the image PAN after linear stretching is shown in Fig.21. and the image visualization after stretching in Fig.22.

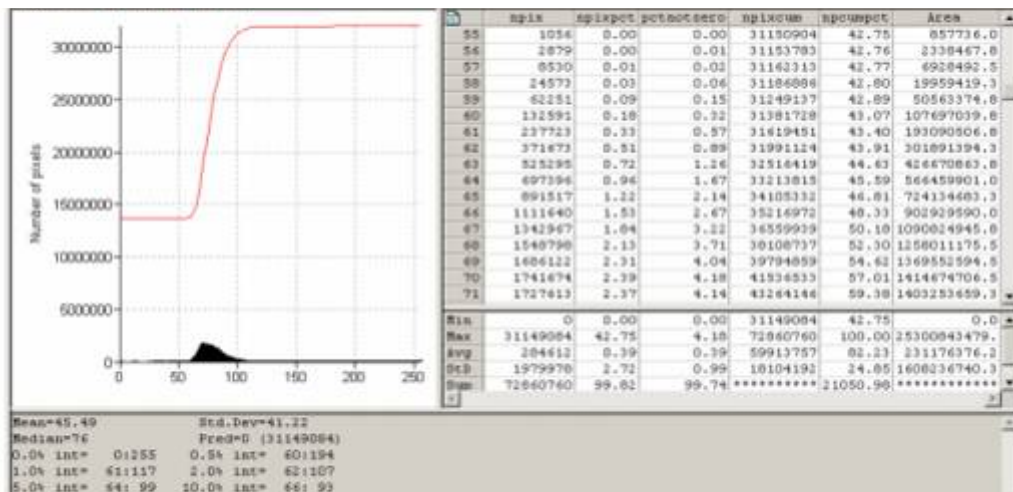


Fig.18. Histogram of Landsat image (PAN)

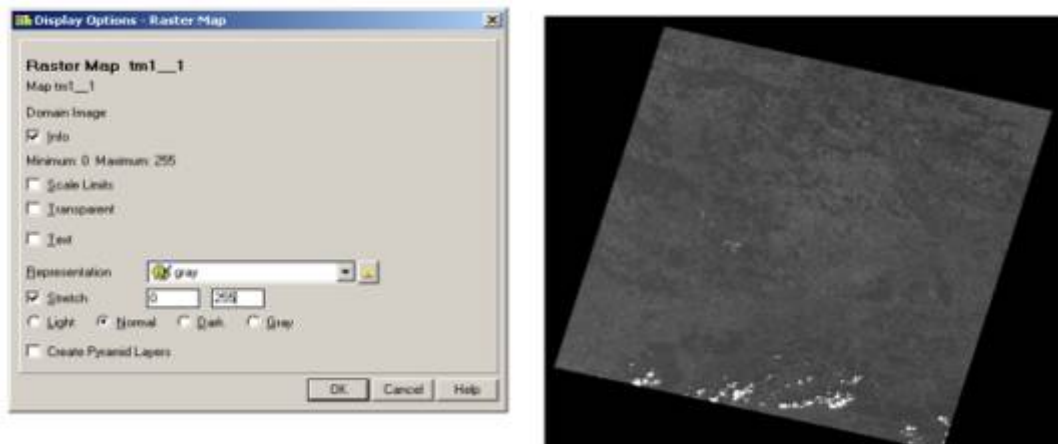


Fig.19. Landsat image displayed with all radiometric range (0-255)

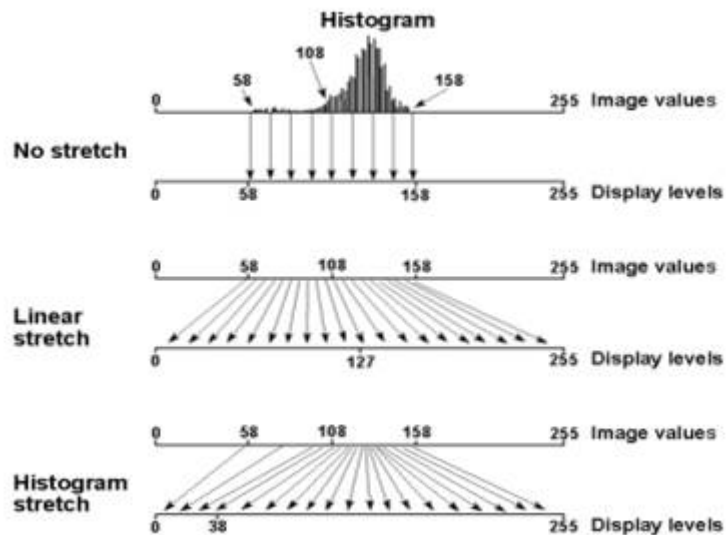


Fig.20. Principles of contrast enhancement [5]

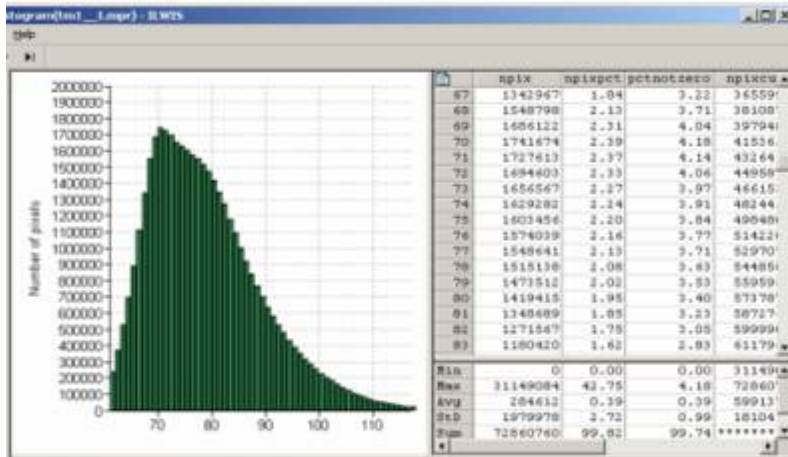


Fig.21. Histogram after stretching (see spectral range 0-120 instead of 0-255)

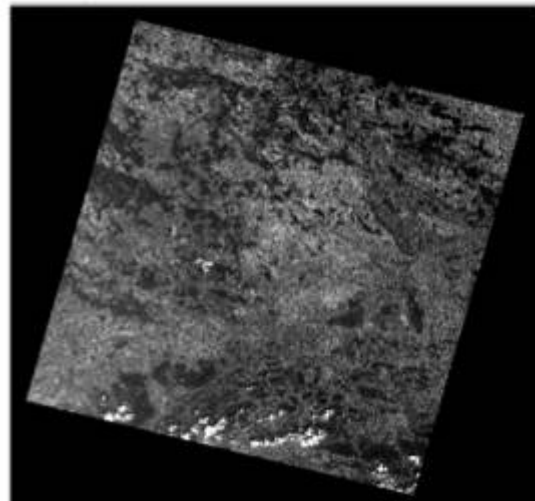
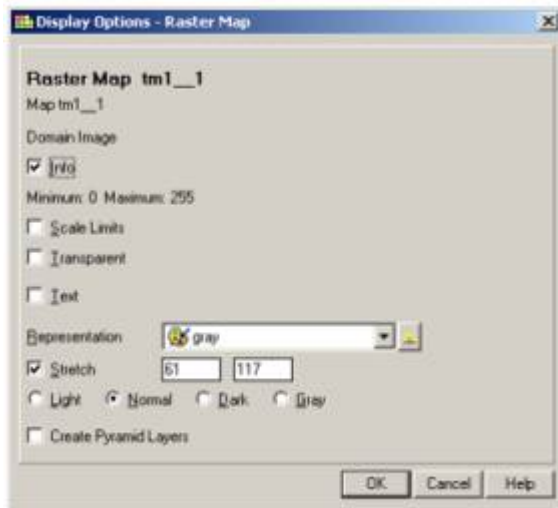


Fig.22. Landsat image displayed after stretching



6.2 Color composition

Multispectral images can be presented in visual form using basic colors: R, G, B. Assuming B as first multispectral Landsat channel and respectively G as second one and R as the third one, we have a composition in natural colors. Generally, we have only three basic colors: RGB or ordering according wavelength from short to long wavelength: BRG (Fig.23.). In figure we can see real world in natural colors. Vegetation is green, water – blue, grass and deciduous forest is light green and conifer forest is dark green. You can also observe white clouds, like “sheeps” in the south. We can also involve other channels, not only visual one. Some example, False Color Composite (FCC) is presented in (Fig.24.). There is one assumption during color composite preparation, namely, we can use only three colors as a basic one. So we have blue, green and red colors. In FCC we would like to involve infrared channel (Landsat channel 4), so we have to assume some color for that. In the composition red color is assumed for channel 4, green for red channel and blue for green channel, blue channel is not used in this case. In FCC vegetation is red, water – black, grass and deciduous forest is light red and conifer forest is dark red.

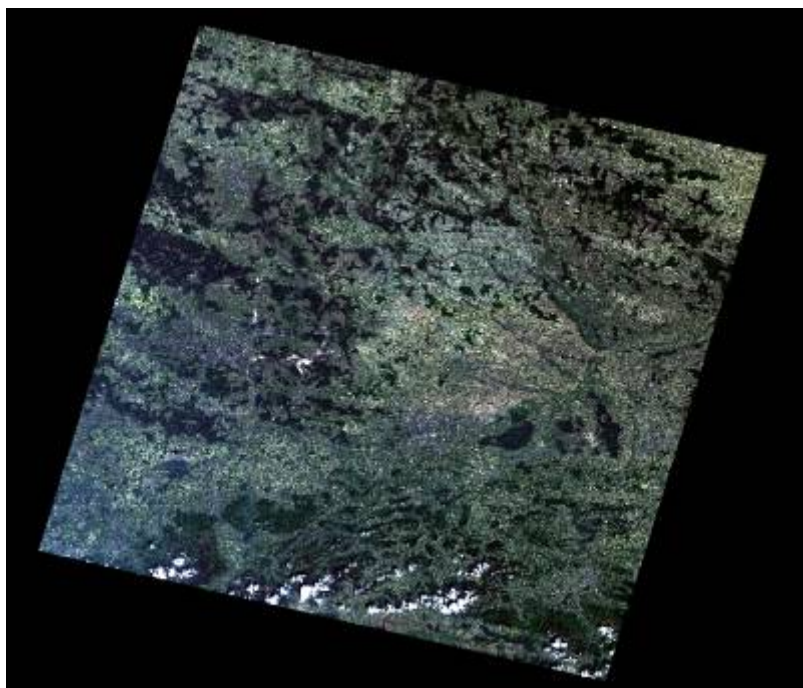


Fig.23. Composition in natural colors RGB (vegetation is green, water is blue, soil is brown etc.)



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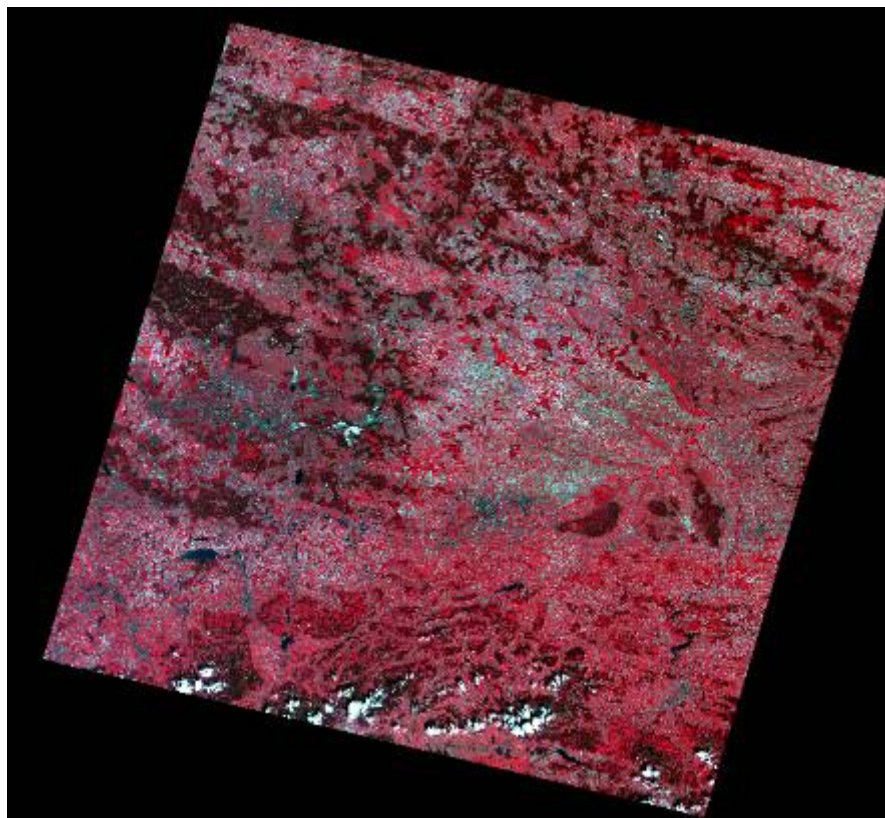


Fig.24. Composition in False Color Composite (FCC); (vegetation is red, water is black, soil is cyan etc.)

In the composition, the color depends on the reflection in the given channel. In real world, vegetation is green, water blue, so this cover types are presented in these colors. Reflection of vegetation is not the highest in green channel because its reflection in infrared is much higher in comparison with the visible range. Therefore, the FCC is mainly red. Other characteristic cover is water – black in FCC, because the reflection of water decreases with the wavelength, which will be explained in next chapters.

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Projekt „Politechnika Świętokrzyska – uczelnia na miarę XXI w.”

1.1.1 Program Operacyjny Kapitał Ludzki Priorytet IV Działanie 4.1, Poddziałanie 4.1.1
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6.3 Spectral curves

Spectral curve is defined as the relationships between reflection coefficient and wavelength (Fig.25.). The blue object reflects EM in blue and does not reflect in other spectral ranges, similar to green object. All other colors can be created of the three basic colors (RGB), for example cyan is created of blue and green and yellow of green and red. Black and white colors are created basing on the same rule, black means no reflection in any bands, white the opposite – maximum reflection in all channels.

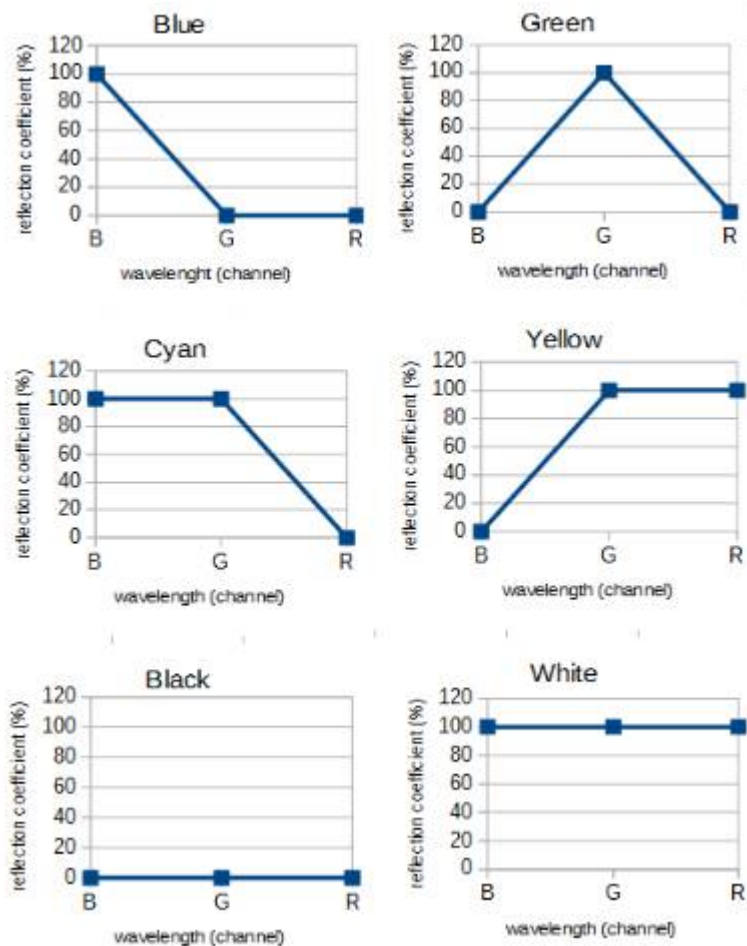


Fig.25. Spectral curves for basic colors

In remote sensing not only visible spectral range but also other wavelengths are used. Some example of reflection of real objects are in (Fig.26.). Reflection coefficient is almost zero for water. Granite and sandstone reflect high, reflection coefficient increases with wavelength. Spectral curve of vegetation is more complicated. In visible spectral range (left side of the chart) vegetation reflection coefficient is higher than water (we can see the peak in green) but less than granite and sandstone. For longer wavelengths, the reflection of vegetation varies depending mainly on water absorption. But in near infrared a significant peak is observed. It means that in NIR vegetation reflects very much EM radiation, which is the reason of red color of vegetation in FCC. Reflection in NIR is significantly higher in IR in comparison with VIS and vegetation is green if we see it in VIS but in fact it is infrared if we can see it.

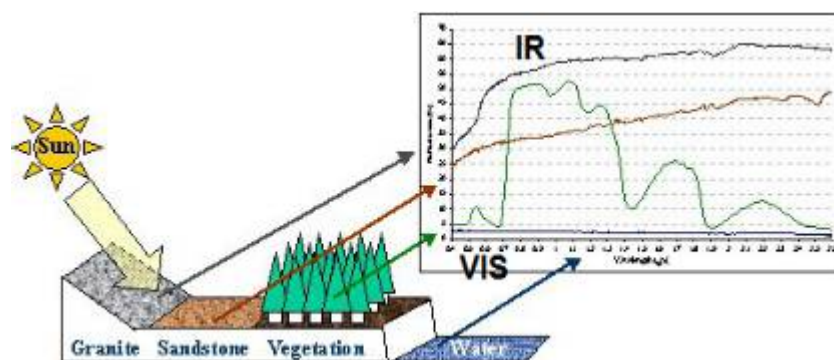


Fig.26. Spectral curves of real objects (granite, sandstone, vegetation and water), [3]

6.4 Photo-interpretation

Looking at the image at the beginning we start to “read” it. We say this is water and that is forest. What is the base of our object recognition? First of all, we see the image generally. Is it gray or color, contrast or non contrast (Fig.19., Fig.22., Fig.23., Fig.24.)? The following image characteristics are defined:

- brightness
- contrast
- resolution
- stereoscopic effect



Brightness is subjective reaction to the light, subjective perception. Image generally can be dark or bright, with less or strong contrast. Image resolution was explained above. Some technology delivers two stereoscopic images, which increases the image interpretation ability.

Object recognition features are also defined:

- tone, color
- shape
- size
- structure, pattern
- texture
- shadow
- association

Object tone, color depend on the reflection coefficient of the object. Generally water is dark or black on each image – water reflects less energy, irrespective of spectral range (water, Vistula river in Fig.27.). Anthropogenic objects like airport, transportation or agriculture fields have regular shape in comparison with the natural object, for example Wolski forest and natural water.

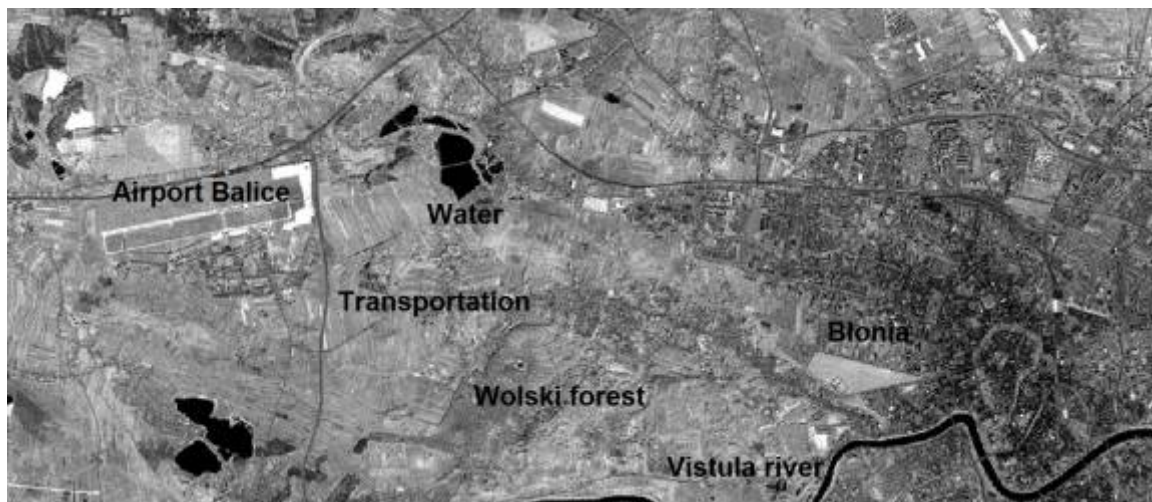


Fig.27. PAN zoom of image in (Fig.19.) covering Cracow



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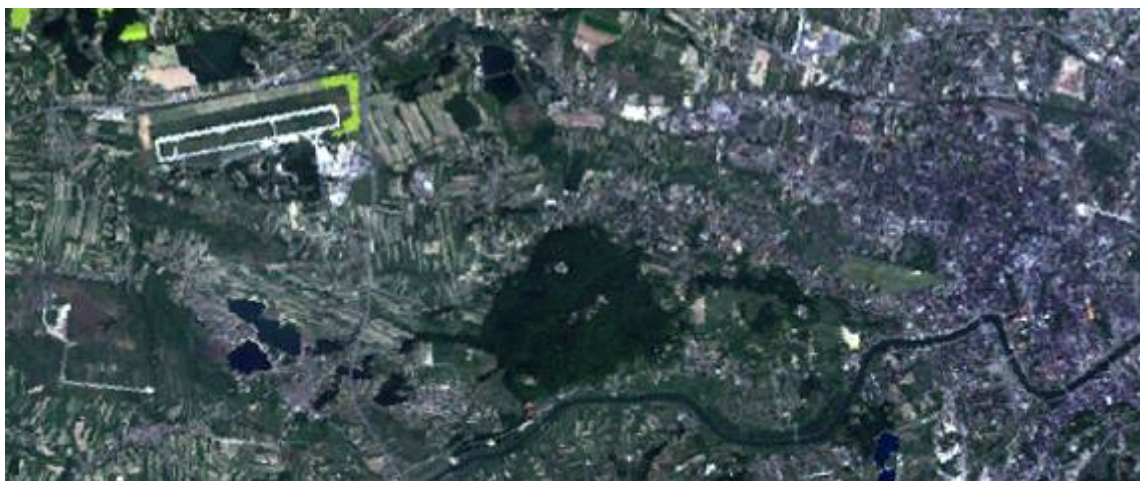


Fig.28. RGB zoom of image in (Fig.23.) covering Cracow



Fig.29. FCC zoom of image in (Fig.24.) covering Cracow

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Fig.30. PAN zoom of image in (Fig.19.) covering Kielce

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Fig.31. RGB zoom of image in (Fig.23.) covering Kielce

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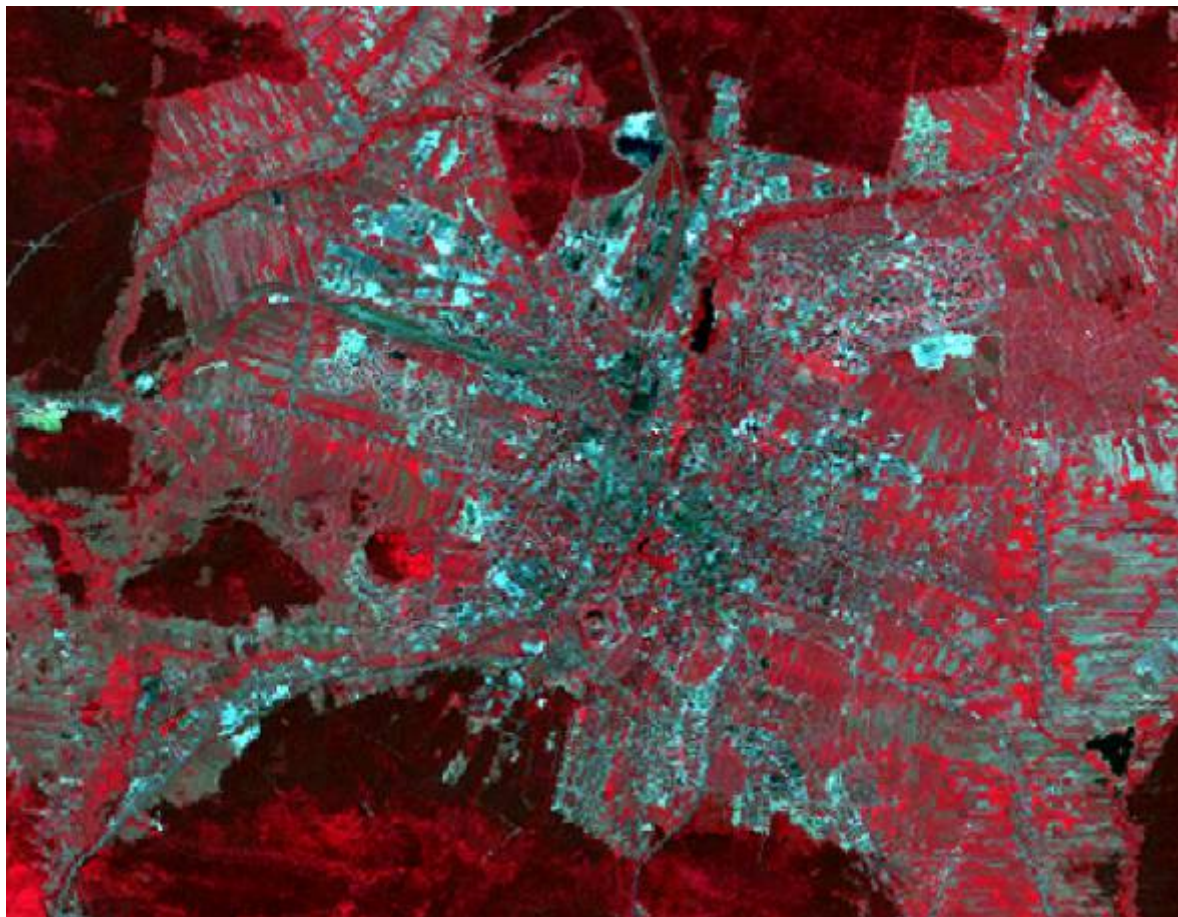


Fig.32. FCC zoom of image in (Fig.24.) covering Kielce

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7. Automatic image recognition

7.1 Theoretical background of image classification

General steps of conventional image classification can be pointed out according to [1]:

- class of LULC definition (for example: water, urban, agriculture, grassland and forest,
- image enhancement: filtering, stretching, color composite generation,
- sample set collection,
- supervised classification,
- post – processing, classification map improvement (for example filtering to remove “isolated” pixels),
- accuracy assessment.

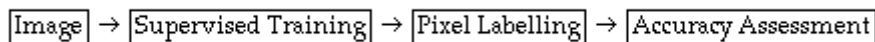


Fig.33. Scheme of supervised image classification [1]

Background of the automatic image recognition is the reflection of the objects. Reflection in relationship of the wavelength is specific for each LULC category (Fig.26.). Reflection in red channel (R) and (IR) for one pixel defines a point in the space: R, IR. Taking into account the sample sets of specific LULC objects defined by points, some natural groups can be noticed and a line between the sets can be delineated (Fig.34.). After training, sample set collection of each pixel is assigned to one class of LULC (pixel labelling). The question is how to assign pixel to the class?

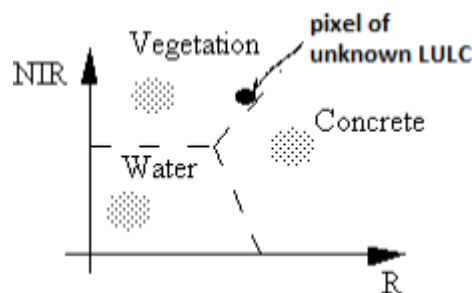


Fig.34. LULC classes delineation [modified 1]



The rules are based on the distance calculation between unknown point and the classes. Pixel is assigned to the class whose distance is the shortest. There are different ways to the distance calculation. As a rule, normal Euclidean distance is used but there are also other distance calculation possibilities.

Let us assume we have nc centers of classes [1]:

$$C = \{C_1, C_2, \dots, C_{nc}\} \quad (6)$$

C_i is the vector for i class, so we have nc classes, and nc vectors. Each C_i vector is defined in nb space, where nb is the number of bands. We can have coordinates of vector C_i defined by reflectance or simply by DN which are proportional to the reflectance.

$C_i, i = 1, 2, \dots, nc$ is the grey-level vector for class i .

$$C_i = \begin{cases} (DN_{i1}, DN_{i2}, \dots, DN_{inb})^T & \text{in digital number form.} \\ (r_{i1}, r_{i2}, \dots, r_{inb})^T & \text{in spectral reflectance form.} \end{cases} \quad (7)$$

Let us assume the vector for labelled pixel $g = (g_1, g_2, \dots, g_{nb})^T$, where g_i is DN in an individual channel. The pixel is assigned to class C_i if the distance between vector g and C_i is minimum in comparison to the distances between vector g and other classes. Distance (d_m) is defined generally as Mahalanobis distance, taking into account correlation between variables: x and y [9]:

$$d_m(\mathbf{x}, \mathbf{y}) := \sqrt{(\mathbf{x} - \mathbf{y})C^{-1}(\mathbf{x} - \mathbf{y})^T} \quad (8)$$

If there is no correlation between variables and variance of variables are the same, Mahalanobis distance is simplified to the Euclidean distance [9]:

$$\begin{aligned} d_m(\mathbf{x}, \boldsymbol{\mu}) &= \sqrt{(x_1 - \mu_1)^2 + \dots + (x_n - \mu_n)^2} \\ &= \sqrt{(\mathbf{x} - \boldsymbol{\mu})\mathbb{I}^{-1}(\mathbf{x} - \boldsymbol{\mu})^T} \end{aligned} \quad (9)$$

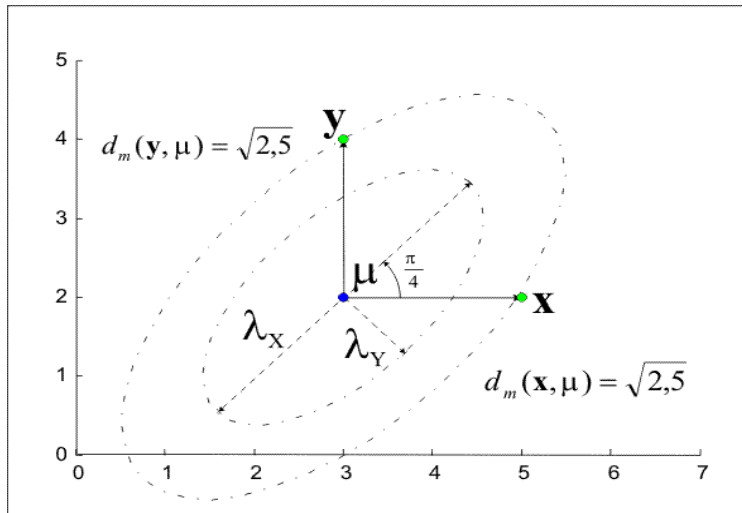


Fig.35. Mahalanobis distance [9]

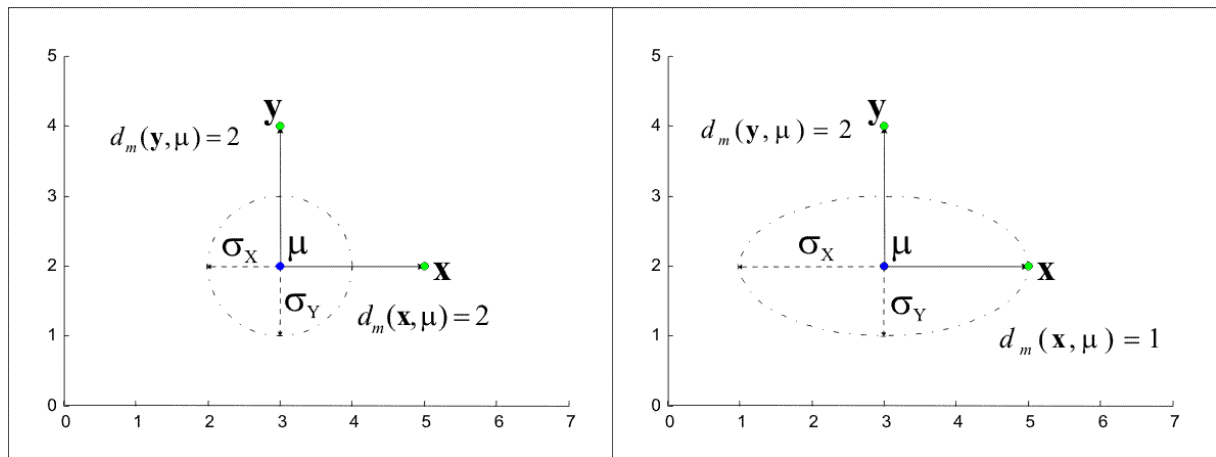


Fig.36. Mahalanobis distance, no correlation between variables (left - the same variance of variable x and y), (right – different variance of variable: x and y), [9]



If there is no correlation between variables and variance of variable x and y are different, the Mahalanobis distance is as follows [9]:

$$\begin{aligned} d_m(\mathbf{x}, \boldsymbol{\mu}) &= \sqrt{\frac{(x_1 - \mu_1)^2}{\sigma_1^2} + \dots + \frac{(x_n - \mu_n)^2}{\sigma_n^2}} \\ &= \sqrt{(\mathbf{x} - \boldsymbol{\mu})D^{-1}(\mathbf{x} - \boldsymbol{\mu})^T} \end{aligned} \quad (11)$$

where D is diagonal matrix: $\text{diag}(\sigma_1^2, \sigma_2^2, \dots, \sigma_n^2)$

According to remote sensing application of vectors defined above, Euclidean distance is the following [1]:

$$d_e(C_i, g) = \begin{cases} \sqrt{\sum_{j=1}^{nb} (C_{ij} - g)^2} & \text{Numerical form.} \\ [(C_i - g)^T (C_i - g)]^{1/2} & \text{matrix form.} \end{cases} \quad (12)$$

And Mahalanobis distance [1]:

$$d_m(C_i, g) = [(g - C_i)^T V^{-1}(g - C_i)]^{1/2} \quad (13)$$

where V^{-1} is the inverse of the covariance matrix of the data.

For supervised image classification we can apply the algorithms using different ways of distance calculation which was presented above. Another approach bases on the comparison of probability of the pixel belonging to the particular classes. Usually, we assume normal distribution of DN in sample set and the probability rule bases on Gaussian distribution function. After some modifications the decision rule can be formulated as follows [1]:

$$g(x) = -\log |V_i| - (x - \mu_i)^T V_i^{-1} (x - \mu_i) \quad (14)$$

where $g(x)$ – discriminant function,
 μ_i – vector of mean values for class i in all channels
 V – variance covariance matrix between classes.

The function $g(x)$ corresponds to the probability of pixel belonging to a particular class. So pixel is labelled to the class whose value of the function $g(x)$ is the highest.

Last step of image classification concerns accuracy assessment. Usually, after classification accuracy assessment is performed basing on the ground truth data in some sample test fields. Ground truth data are compared with the classification results and so called cross matrix or confusion matrix is prepared.

Tab.9. Confusion matrix [1]

		Reference			Row Total	Commission Error	
		F	W	U			
Classification	F	28	14	15	57	51%	F - Forest W - Water U - Urban
	W	1	15	5	21	29%	
	U	1	1	20	22	9%	
Column Total		30	30	40	100		
Omission Error		7%	50%	50%			

The correctly classified objects are placed on a diagonal and the overall accuracy is calculated [1]:

$$\omega = \frac{\sum_{i=1}^{nc} e_{ii}}{NT} \quad (14)$$

$$NT = \sum_{i=1}^{nc} \sum_{j=1}^{nc} e_{ij} = \text{the total number of samples.}$$

“From the example of confusion matrix, we can obtain $\omega = (28 + 15 + 20)/100 = 63\%$. “ [1].
From the table (Tab.9.) errors of omission and commission are presented.

7.2 Supervised classification – an example

Multispectral channels can be analyzed visually by looking at the pictures (Fig.27. - Fig.32.). Objects are recognized by fotointpreter and drawn on the screen. This approach is time consuming and expensive. MSS images can also be analyzed automatically. The procedure is composed of few steps. First, we decide which composition is the most useful for a given task. The most popular is FCC (Fig.29., Fig.32.). Then we learn the reading of the image, so we train ourselves to recognize the objects, we have to recognize interesting objects. Assume, we plan to prepare a land use/ land cover (LULC) map. We decide on the LULC categories, at least, for example: water (1), urban (2), agriculture (3), grassland (4) and forest (5). Usually we also assume specific codes in brackets. Next step is digitizing the sample set, we teach the software “to understand” the image, we “show”: this is water, this is urban etc. The sample set is shown in (Fig.37.). In this case the sample is composed of the pixels inside the rectangular. We draw a box as big as possible, but taking into account that we are interested in pure pixels, the box should be rather inside the object to avoid putting the pixels not belonging to the given category. Therefore the boxes are different in size.

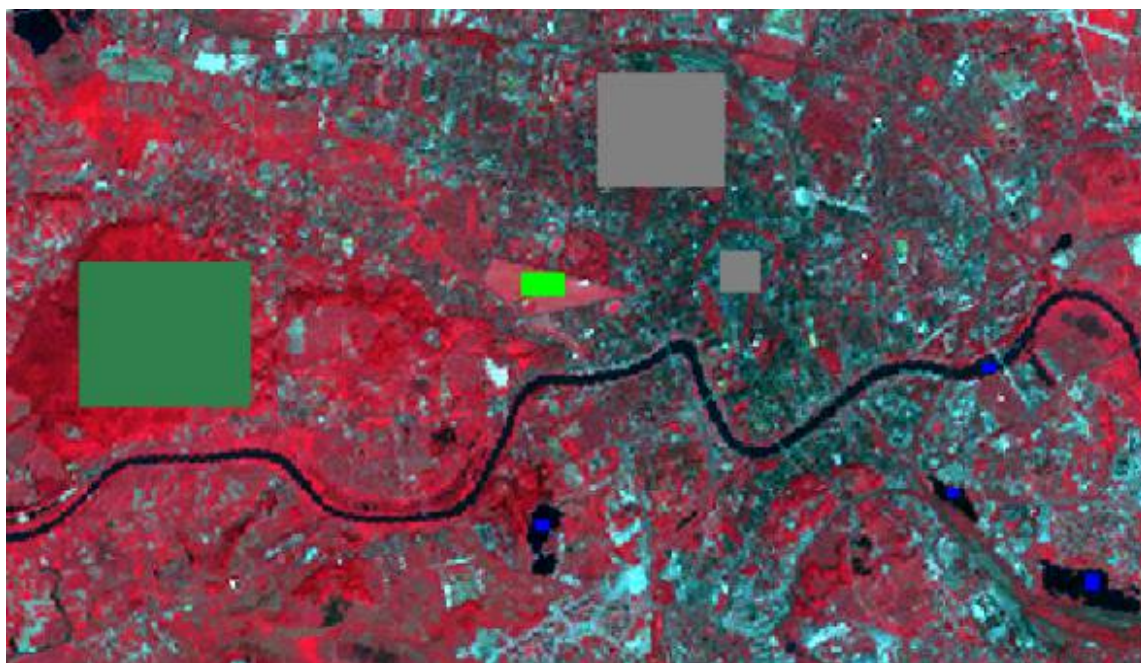




Fig.37. Sample set (blue – water, gray – urban, green – grassland, dark green – forest)

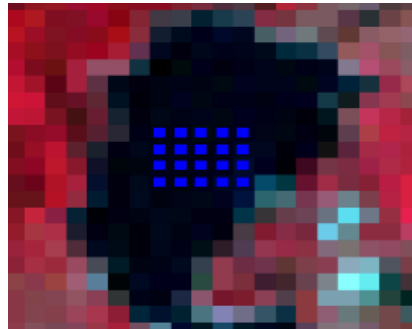


Fig.38. An example of one sample box of water, please note that all pixels are pure in the box

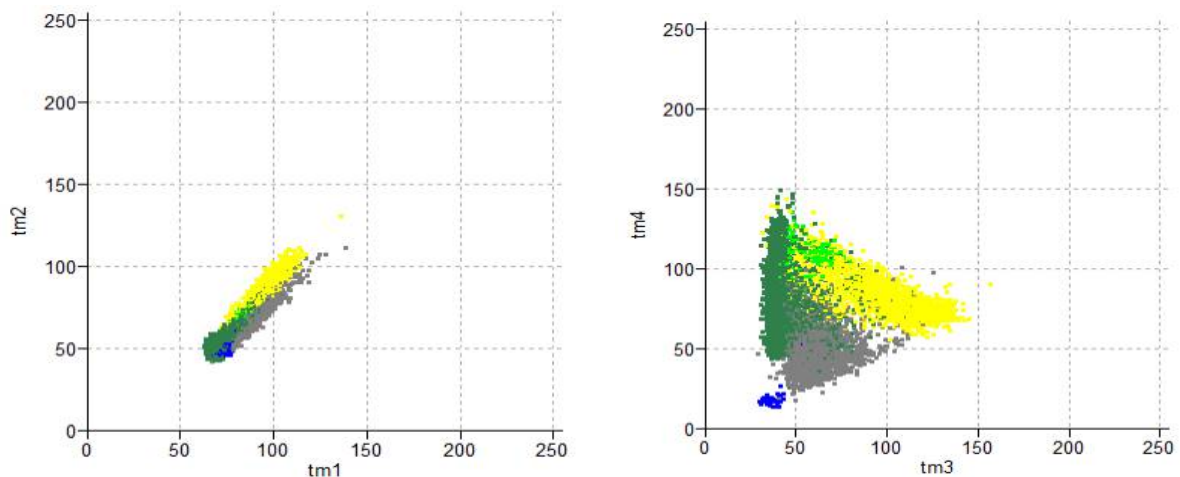


Fig.39. Scatter plot of all classes in channels: blue (tm1) and green (tm2), left; in channels: red (tm3) and infrared (tm4), right

The objects are similar in some channels and more different in others. Taking the DN of the pixels belonging to each class in the two chosen channel, the so-called scatter plot is possible to be prepared (Fig.39). Axis represents the DN, in (Fig.39. left) x - channel blue, y – channel green. The separation of the classes in channels blue and green is poor, sets are overlaying each other. Against: there are bigger differences between channels: red and infrared (Fig.39. right), where significant improvement

of the class separation is observed. The Fig.40. is a practical realization of the spectral curves in (Fig.26.).

It is possible to generate LULC basing on the automatic image classification. Some examples of applying one of the classification by algorithm of maximum likelihood is presented in (Fig.40.). Water is presented in blue color, urban in gray, grassland in light green, forest in dark green and agriculture in yellow. Accuracy assessment is the last step of automatic image classification. An example of accuracy analysis can be found in the confusion matrix (Fig.41.). Overall accuracy is 89,55%, producer accuracy: 74,42% and user accuracy: 72,16%.

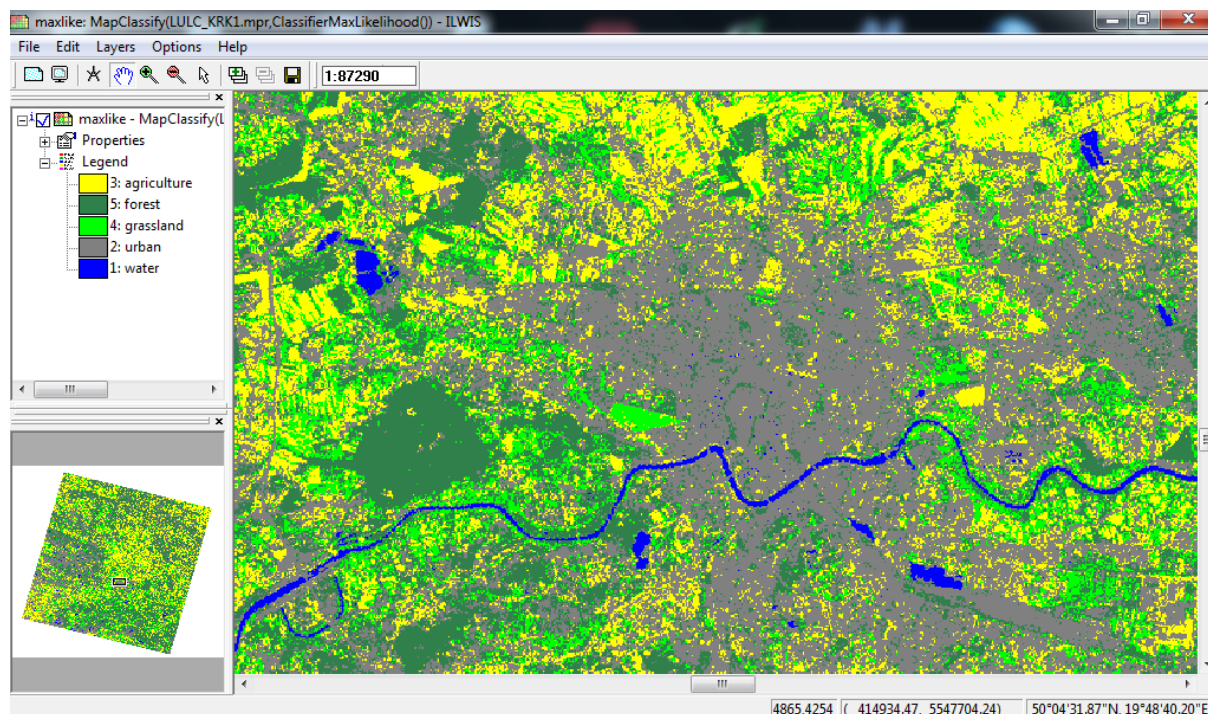


Fig.40. LULC map from maximum likelihood classification



Average Accuracy	=	74.42	%
Average Reliability	=	72.16	%
Overall Accuracy	=	89.55	%

	agricult	forest	grassland	urban	water	UNCLASSIFIED	ACCURACY
agricult	169	0	0	0	0	0	1.00
forest	2	518	1	46	0	0	0.91
grassland	0	49	1	0	0	0	0.02
urban	51	17	8	285	0	0	0.79
water	0	1	0	0	527	0	1.00
RELIABILITY	0.76	0.89	0.10	0.86	1.00		

Fig.41. Confusion matrix

8. Literature

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