Geoinformation Issues
Vol. 2, No 1 (2), 49-57/2010

Analysis of extent and effects caused by the flood wave in May and June 2010 in the Vistula and Odra River Valleys

Konrad Turlej
Institute of Geodesy and Cartography, 27 Modzelewskiego St., PL02-679 Warsaw, Poland
Tel.: +48 022 329-19-91 E-mail: konrad.turlej@igik.edu.pl

Maciej Bartold
Institute of Geodesy and Cartography, 27 Modzelewskiego St., PL02-679 Warsaw, Poland
Tel.: +48 022 329-19-78 E-mail: maciej.bartold@igik.edu.pl

Stanisław Lewiński
Institute of Geodesy and Cartography, 27 Modzelewskiego St., PL02-679 Warsaw, Poland
Tel.: +48 022 329-19-76 E-mail: stanislaw.lewinski@igik.edu.pl

Abstract. In May and June 2010 a flood occurred in Poland, which was the result of intensive rainfalls in the upper sections of the Vistula and Odra Rivers. Medium-resolution TERRA-MODIS satellite images were used for analysis of the extent of the flood wave. Images taken on 6 June for the Vistula River Valley and on 9 June for the Odra River Valley were selected from a generally accessible database. The size of flooded areas was delineated using an object-oriented classification methods in the eCognition software environment. Statistical analysis of classification results was performed at the municipality level, by comparing the classification with Corine Land Cover 2006 database. During the discussed flood, areas in 184 municipalities along the Vistula River and in 120 municipalities along the Odra River were flooded. The most extensive flooding occurred in Slonsk Municipality in the Odra River Valley, where 4055 hectares were flooded. In total, the Vistula waters flooded 4.01% of the area of municipalities located within the Vistula River Valley, and 3.29% of the area of Odra municipalities were flooded by the Odra River waters.

Keywords: flood monitoring, MODIS

Received: 1 October 2010 /Accepted: 9 December 2010

1. Introduction

An increasing frequency of weather anomalies has been observed recently, being the results of climate processes related to global warming. These changes result from the geo-system, which embraces complicated interrelations of processes which take place in the lithosphere, the hydrosphere, the atmosphere and the biosphere (Committee of Geological Sciences, 2009).

One of the factors which result in the global warming is the increased concentration of greenhouse gases, mainly represented by CO_2, in the atmosphere. The phenomenon of the, so called, ozone hole, resulting in excessive ultraviolet radiation reaching the Earth's surface, is of equal importance. At the same time, processes that occur on Earth may result in weather anomalies, due to their intensity, duration and spatial range. They are directly related to land cover changes and they concern the growing deforestation and desertification.

Depending on the intensity, duration and the spatial range, weather anomalies may cause natural calamities threatening human life and resulting in large economic losses. In Poland one may primarily observe an increasing number of rapid and long lasting rainfalls. They result in a real increase in flood hazards, in particular in the southern parts of the country and in big river valleys.

In Poland, about 7% of the country's land area is hazarded by floods every year (Bielecka and Ciołkosz, 2000). Four floods with catastrophic results occurred in Poland in the 20th century. They happened in 1934, 1960, 1970 and 1997. The last of these was the biggest flood in the Polish history. As a result, 52 people died and thousands of inhabitants were forced to evacuate; the flood also resulted in high material losses (Bielecka and Ciołkosz, 2000). A large flood occurred again in Poland in May and June 2010. Intensive rainfalls in southern and central parts of Poland, which occurred after long dry periods with high temperatures, caused rapid increase of water levels in the Vistula and Odra River Valleys. As in 1997, the flood waves broke through the floodbanks in many places, which resulted in flooding of built-up, agricultural and industrial areas.

Several analyses of flood situations have been performed at the Institute of Geodesy and Cartography (IGiK), using modern methods of remote sensing and geographic information systems. The first work covering these issues was the analysis of the flood situation in the south-western Poland in 1977 (Ciołkosz, 1977). The flood waters in the Bobr, Kwisa and Szprotawa River Basins were mapped using aerial photographs. Then, analyses concerning the development of the spring flood in the Bug and Narew River Valleys in 1979 were performed and the obtained results were sent to responsible state authorities. LANDSAT MSS satellite images of 79 m spatial resolution were used for this purpose for the first time in Poland. Results of visual interpretation were combined with accessible hydrological data. The discussed work proved the high usefulness of remote sensing information for operational purposes and for documenting flood situation (Ciołkosz, 1983).

During the flood in the Odra River Valley in 1997, IGiK participated in the analysis of the development and results of the natural calamity. Several articles presenting catastrophic results of the flood, which also promoted utilisation of remote sensing methods and geographic information systems, were published (Bielecka and Ciołkosz, 1998a; 1998b; 1999; 2000). ERS-2 satellite microwave images, of 20 m spatial resolution, as well as satellite LANDSAT TM, SPOT and IRS images of 20-30 m resolution, were used.

The presented work discusses the results of analysis of medium-resolution satellite images, which illustrate the flood situation in the Vistula and Odra River Valleys in June 2010.

2. Flood in the Vistula and Odra River Valleys in May and June 2010

The Vistula and Odra Rivers catastrophic flooding, which occurred in Poland in 2010 were caused by rainfalls of high intensity, in particular, over the upper sections of the rivers. In many places within the Upper Vistula River Basin, the average precipitation measured between 15 and 22 May exceeded 200 mm. The maximum precipitation was measured close to Swinna on the Skawa River and amounted to 400 mm (Fig. 1).

At the same time, heavy rainfalls resulted in spates of flood waters in many upper tributaries of the rivers, which directly contributed to the creation of a culmination wave (Naprawa, 2010). The situation was similar for the Odra River. Heavy rainfalls occurred again in June. The average amount of rain measured between 3 and 6 June in the Upper Vistula River Basin ranged between 10 and more than 100 mm, and the maximum rainfall reached between 20 and more than 140 mm (Fig. 2). The creation and passing of the second culmination wave was the result of disadvantageous meteorological and hydrological conditions on the Vistula and Odra Rivers.

3. Satellite data and investigation sites

Due to the meteorological situation, the Earth's surface is mainly covered by cloud layers during the flood. As a result, it is difficult, or even impossible to acquire satellite images of flooded areas, taken in optical bands. This also concerns aerial photographs, unless the cloud base is sufficiently high to take such photographs.

Exceptionally good meteorological conditions for aerial photography occurred during the flood on Bug and Narew Rivers in 1979. However, during other floods, which were analysed at IGiK, the cloud cover caused serious difficulties in selecting appropriate images. A similar situation occurred during the flood in May and June 2010.

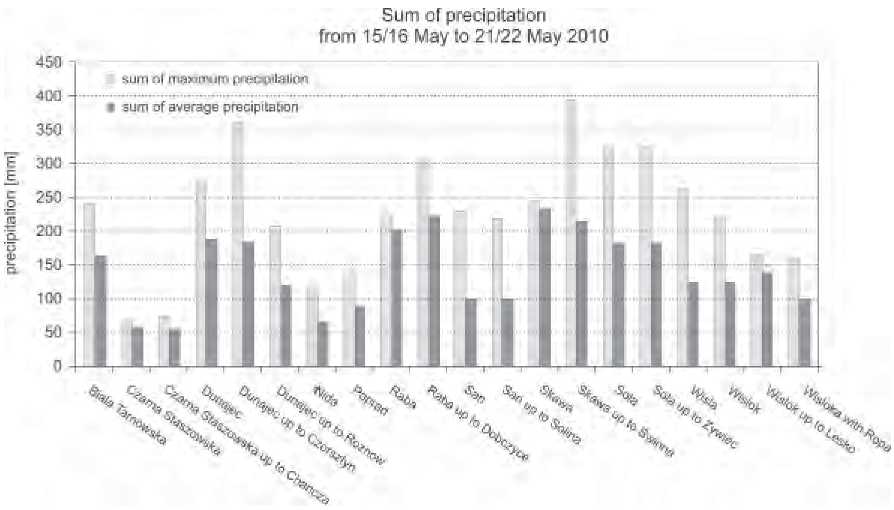

Fig. 1. Totals for the maximum and average rainfalls in May 2010, within the river basins operated by the RegionalAuthority for Water Management in Krakow (Proceedings from the IMGW Conference "The Flood 2010")

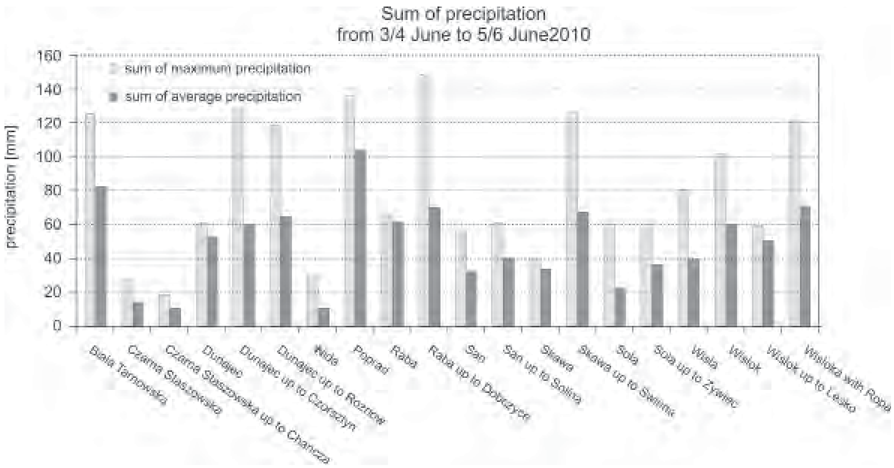

Fig. 2. Totals for the maximum and average rainfalls in June 2010, within the river basins operated by the Regional Authority for Water Management in Krakow (Proceedings from the IMGW Conference "The Flood 2010")

Due to the intensive cloud cover, the number of satellite images, which could have been used for mapping flooded areas, was limited. Within those two months, for only a few days was the cloud cover over Poland so much reduced that it was possible to fully visualise the Vistula and Odra Rivers.

After reviewing generally available MODIS images, registered daily by the TERRA and AQUA satellites, an image from 9 June of the Odra River and an image from 6 June of the Vistula River, were selected. The image from 6 June is presented in Figure 3. It was downloaded from the WIST server (NASA Warehouse Inventory Search Tool).

In the case of the MODIS images, the Earth's surface is registered in 36 spectral bands, covering the spectral range between 0.405 and 14.385 μm. The spatial resolution is not uniform for all bands and it is equal to 250 m for the 1st and 2nd bands, 500 m for bands 3÷7, and 1000 m for remaining spectral bands. Only two spectral bands of the resolution 250 m, the red and infrared range, were utilised for mapping flooded areas.

Analyses of flood extent in the Vistula and Odra River Valleys were performed nearly for the entire length of the rivers. Due to the low resolution of

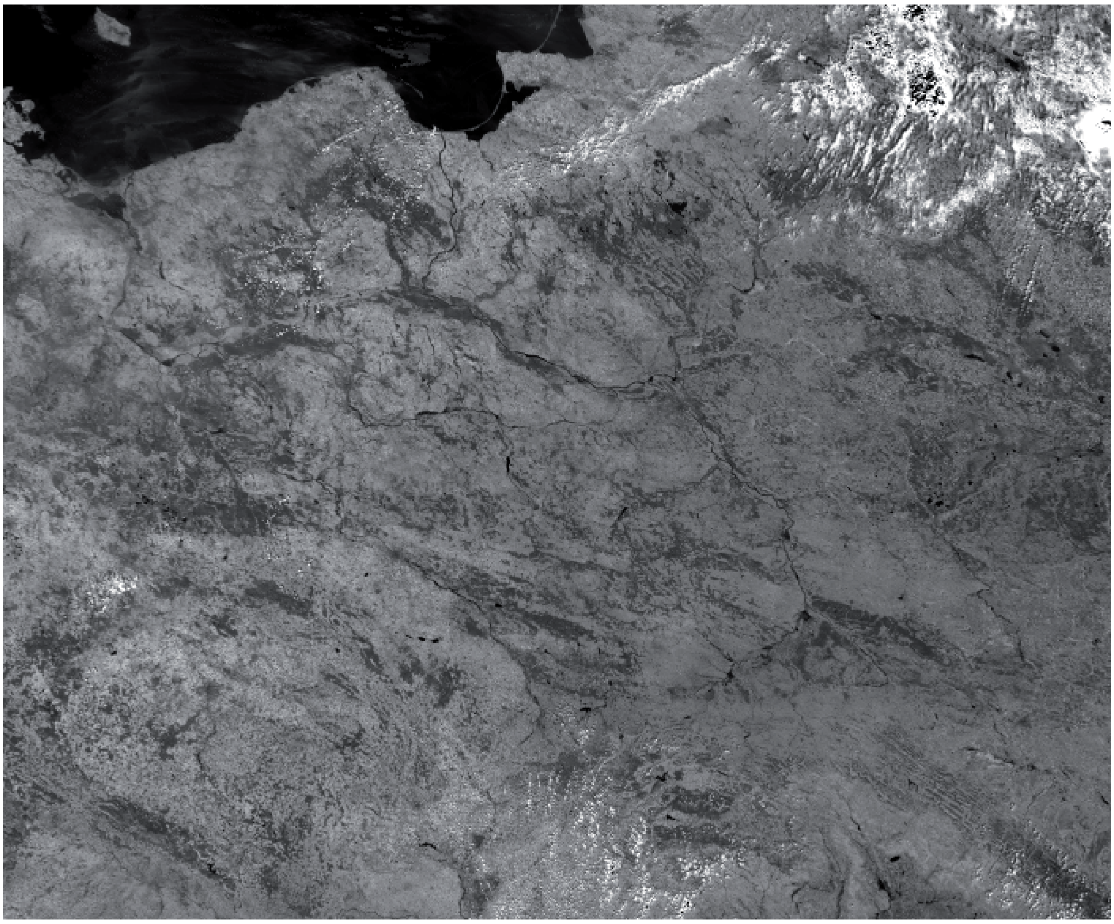

Fig. 3. Fragment of the TERRA-MODIS image of 6 June 2010, being the basis for the flood classification in the Vistula River Valley

the images, only upper sections of the rivers were not investigated; large flood pools were not created along those river sections. The width of river beds was too small to be correctly recognised on the satellite images. Small parts of the Warta River Valley (in the Odra River Basin) and the San River Valley (in the Vistula River Basin were also considered.

Moreover, in order to verify results, microwave images were utilised for selected parts of the rivers; they allowed for observing the Earth's surface despite the existing cloud cover. Within the ESA 7847 Project „Application of microwave images for the area flooded in May and June 2010 in Poland", ERS-2 images were acquired. The scenes covered the section of the Vistula River between Szczucin and Sandomierz, the Zegrze Lake and the vicinities of the Wloclawek Reservoir.

4. Satellite data classification and production of results using GIS tools

Processing and analysis was performed in many stages. A diagram of the processing steps is illustrated in Figure 4. After acquisition of appropriate images, land cover data and information of administrative borders, classification of satellite photographs, presenting the areas of the natural calamity, was performed. Then classification results were verified and GIS analysis was performed. The final results of the performed work was a map presenting the flood extent, as well as statistical data, which describes the flood.

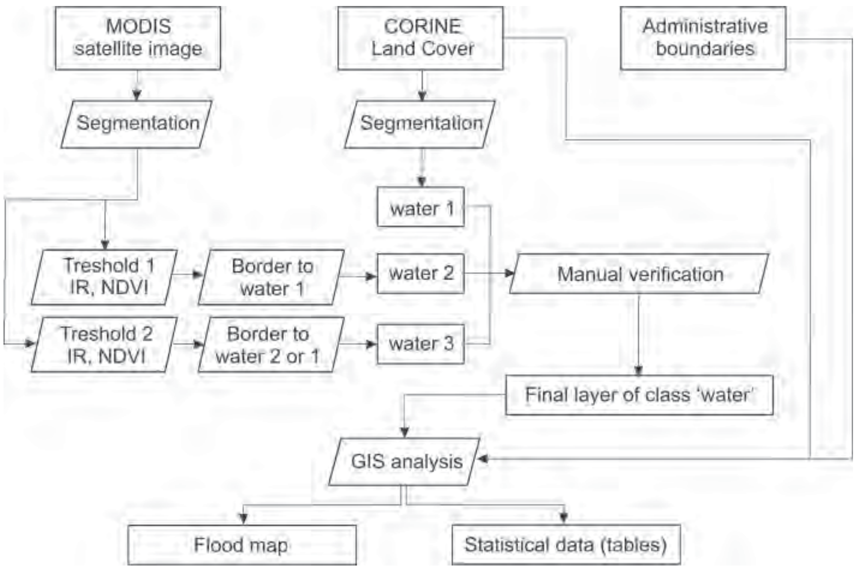

Fig. 4. Diagram of operations

4.1. Satellite image classification

The extent of the flood wave was delineated on satellite images using the object classification and the eCognition software tools. The experience of the Institute of Geodesy and Cartography, related to classification of satellite images of various resolution, was utilised for development of the processing algorithm (Lewiński and Bochenek, 2009; Lewiński et al., 2010).

The classification scheme of the MODIS images is presented in Figure 4. Recognition of the "water" class may be divided into two basic stages. The normal reach of water in the river valleys was recognised in stage 1 ("water 1" class). It was performed using information on river beds, available as a vector layer in the CORINE Land Cover 2006 database. Segmentation of the images was based on this vector layer, and thereafter objects falling within the CORINE 2006 class "rivers" were classified as water. Then, during the second stage of the classification, the extent of the actual flood was recognised ("water 2" and "water 3" classes). Only the Red and Infra-Red spectral bands of the MODIS images were used, which both have a spatial resolution of 250 m. A second segmentation was performed based on the image itself. Thereafter threshold values in the IR band and the NDVI vegetation index were used as classifiers. Also, objects had to border with "water 1" class recognised at the first stage of classification. The threshold values were modified twice, in order to improve the recognition of all flood pools. The final "water" class was created after manual verification. Then statistical analysis was performed.

4.2. Statistical analysis

Statistical analysis was performed using the ArcGIS software package. In order to acquire quantitative information concerning the structure of flooded areas, the created information layer presenting flood pools along the Vistula and Odra Rivers was intersected by the CORINE Land Cover 2006 layer and the layer of administrative borders (Fig. 4). The analysis was performed at the municipality level. The size of flooded areas was calculated for each municipality, according to the aggregated legend of land cover.

A flood extent map was also created (Fig. 5). The classification of flood extent was imposed on the aggregated CORINE Land Cover 2006 layer. It was presented using a transparency, which allows for observing the size of pools and comparing them with the normal river conditions. The background layer also includes rivers of the first hydrographic division.

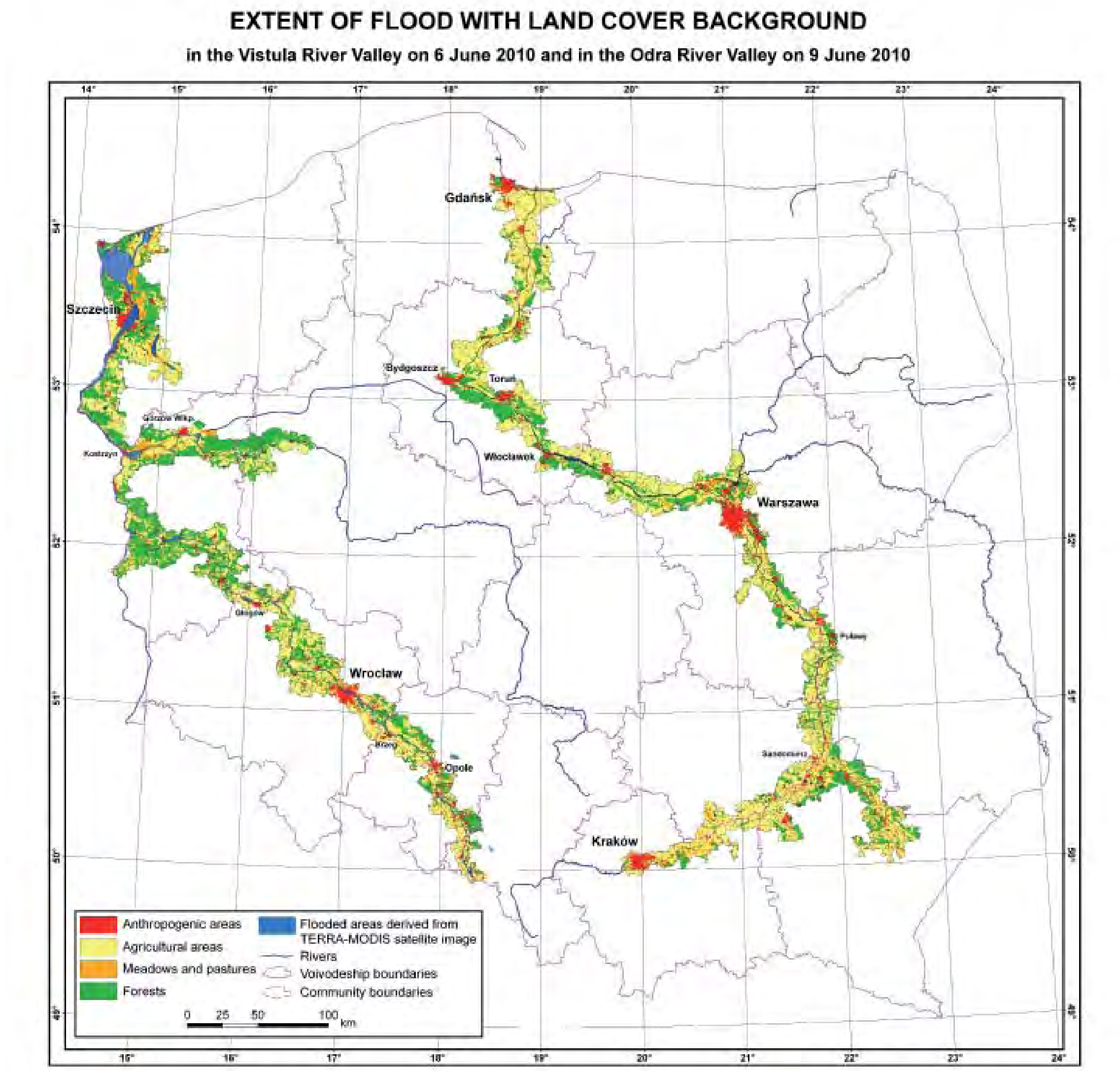

Fig. 5. The flood range map in the Vistula River Valley on 6 June and in the Odra River Valley on 9 June 2010

5. Results

The area of the June flood, recorded on the MODIS images, covered 304 municipalities. The existence of flood waters was observed in 184 municipalities along the Vistula River and in 120 municipalities along the Odra River. Table 1 presents a quantitative list of flood affected municipalities, according to the size of flooded areas.

Along the Vistula River, flood pools of the size of 700-1000 hectares prevailed. Pools of the size of 700-800 ha occurred in 27 municipalities, and 800 to 900 ha in 32 municipalities; however, in the majority of municipalities the flood covered areas were between 900 and 1000 hectares (57). Flood pools bigger than 1000 ha occurred in 15 municipalities; they are presented in Table 2. The biggest flooded area occurred in the Gorzyce Municipality – 3381.8 ha, which corresponds to 51.4% of the entire municipality.

In 69 municipalities located in the Odra River Valley, flood pools of the size of 600-900 ha prevailed, including 25 municipalities, where flooded areas have the size between 700 and 800 ha. Pools bigger than 1000 ha occurred in 12 municipalities (Table 3). The most extensive flooding occurred in the Slonsk Municipality, where 4055.1 ha were flooded – 25.4% of the entire municipality.

Table1. The number of municipalities flooded in the Vistula River Valley on 6 June and in the Odra River Valley on 9 June 2010, by the size of flooded areas

Flooded area [ha]	Number of communities	
	Vistula Valley	Odra Valley
>1000	15	12
900-1000	57	14
800-900	32	19
700-800	27	25
600-700	15	19
500-600	8	8
400-500	9	8
300-400	9	5
200-300	2	3
100-200	2	4
0-100	8	3
Sum	184	120

Table 2. Municipalities, where flood pools greater than 1000 hectares occurred in the Vistula River Valley on 6 June 2010

Communities	Flooded area	
	[ha]	[% of communities]
Gorzyce	3381.8	51.4
Szczurowa	2763.2	20.7
Szczucin	2664.1	22.2
Wilkow	2543.8	32.0
M. Tarnobrzeg	2359.5	27.8
Annopol - rural area	1622.4	11.3
Gabin - rural area	1594.6	13.4
Wietrzychowice	1501.8	31.0
Mielec	1368.7	18.0
Lubnice	1354.2	16.0
M. Gdansk	1336.1	5.1
Tryncza	1123.5	15.9
Magnuszew	1074.1	7.6
Nowy Korczyn	1072.1	9.0
Sandomierz	1007.6	32.5

Table 3. Municipalities, where flood pools greater than 1000 hectares occurred in the Odra River Valley on 9 June 2010

Communities	Flooded area	
	[ha]	[% of communities]
Slonsk	4055.1	25.4
Dabie	1896.1	11.2
Krosno Odrzanskie – rural area	1736.6	8.5
M. Szczecin	1720.4	5.7
M. Swinoujscie	1221.8	6.1
Deszczno	1216.4	6.5
Cybinka - rural area	1197.4	4.4
Mieszkowice - rural area	1161.7	5.0
Boleszkowice	1046.3	8.0
Niechlow	1022.8	6.7
Cedynia - rural area	1020.3	5.7
Skarbimierz	1010.9	9.2

A summary of damages is presented in Table 4. In total, on 6 June 2010, the Vistula waters flooded about 70 661 hectares, corresponding to 4.01% of the entire area of the analysed Vistula municipalities.

Table 4. Areas flooded by the Vistula River on 6 June and by the Odra River on 9 June in aggregated CORINE Land Cover 2006 classes

Land cover class	Flooded area [ha]	
	Vistula Valley	Odra Valley
Build-up areas	2 264.53	2 849.31
Industrial, commercial and transport units	1 426.54	2 464.45
Agricultural areas	36 118.91	15 324.84
Orchards	1 207.45	28.81
Grasslands and pastures	20 255.11	25 505.18
Deciduous forests	7 436.06	4 945.74
Coniferous forest	605.11	1 127.51
Mixed forests	276.71	801.08
Other classes	1 070.67	970.72
Sum	70 661.10	54 017.63

Geoinformation Issues
Vol. 2, No 1 (2), 49-57/2010

More than 2264 hectares of built-up areas, 36 118 hectares of arable lands, 20 255 ha of meadows and pastures and about 8317 ha of forests were flooded. On 9 June 2010, 54 017 ha were flooded, which corresponds to 3.29% of the entire size of the municipalities, in which flooding occurred. 2849 ha of built-up areas, 15 324 ha of arable lands, 25 505 ha of meadows andpastures and 6874 ha of forests were flooded.

6. Final remarks

Analysis of flood water extent in the Vistula and Odra River Valleys performed in June 2010, confirms the usefulness of the MODIS satellite images for delineation of flooded areas. They could be utilised despite their relatively low spatial resolution, which equals to only 250 m. However, the operational usefulness of these images is limited. It is difficult to acquire images necessary to monitor the flood development, since the usefulness of images depends on meteorological conditions. Even in the case of frequent revisits of satellites over the same area, the number of useful images may be insufficient. The TERRA and AQUA satellite system registers the image of the given area twice a day, but only two images acquired in May and June could be utilised. First of all, microwave images should be applied for operational work; such images are not influenced by cloud cover, which allows for observing the Earth's surface.

Acknowledgements

Work related to mapping flooded areas within the Vistula and Odra River Valleys during the flood in May and June 2010 were performed within the frame of the ESA 7847 Project „Application of microwave images for the area flooded in May and June 2010 in Poland". This paper concerns the analysis of flood conditions with the use of satellite images of medium spatial resolution.

References

Bielecka E., Ciołkosz A., (1998a): *Flood in Odra valley in 1997 as interpreted on the basis of satellite images*, Proceedings of the Institute of Geodesy and Cartography, Warsaw, Poland, T. 45, z. 97, pp. 81–95.

Bielecka E., Ciołkosz A., (1998b): *The role of remote sensing and GIS in determining extent and effects of flood in July 1997 in Odra valley* (in Polish), Proceedings of the conference „GIS in Practice" 28–29 October1998, Poznań, pp. 20–28.

Bielecka E., Ciołkosz A., (1999): *Mapping of floods in the Odra River Valley*, Polski Przegląd Kartograficzny, T. 31, No 2, pp. 115–116.

Bielecka E., Ciołkosz A., (2000): *Flood susceptibility of the Odra Valley; its relation to land use changes*, Archiwum Fotogrametrii, Kartografii i Teledetekcji, Vol. 10, pp. 26–1–26–8.

Ciołkosz A., Gronet R., (1983): *The extension of flood in the Bug and Narew rivers valley in spring of 1979 registered on Landsat satellite's photographs*, Fotointerpretacja w Geografii, Vol. 6 (16), pp. 9–21.

Ciołkosz A., (1977): *Determination of extension of flood in Southwestern Poland based on aerial photographs* (in Polish), Przegląd Geodezyjny, No 12, pp. 432–433.

Committee of Geological Sciences, (2009): *Attitude of the Committee of Geological Sciences of the Polish Academy of Sciences to the question of impending of global warming*, http://www.planetaziemia.pan.pl/GRAF_aktual-2009/11_Stanowisko_KNG.pdf.

Naprawa S., (2010): *Some problems related to 2010 flood at the lower section of upper Vistula river (138-287 km)* (in Polish), Proceedings IMGW of the Conference "Flood 2010", Warsaw (CD).

Lewiński St., Bochenek Z., (2009): *Rule-based classification of SPOT imagery using object-oriented approach for detailed land cover mapping*, Proccedings of the 28th EARSeL Symposium „Remote sensing for a changing Europe", Istanbul, Turkey, 2–5 June 2008 (CD).

Lewiński St., Bochenek Z., Turlej K., (2010): *Object-oriented method for classification of VHR satellite images using rule-based approach*, Geoinformation Issues, IGiK, Warsaw, Vol. 2, No 1, pp. 19–26.

Analiza zasięgu i skutków wywołanych przez falę wezbraniową w maju i czerwcu 2010 roku na Wiśle i Odrze

Konrad Turlej
Instytut Geodezji I Kartografii, ul. Modzelewskiego 27, 02-679 Warszawa
Tel.: +48 022 329-19-91 E-mail: konrad.turlej@igik.edu.pl

Maciej Bartold
Instytut Geodezji I Kartografii, ul. Modzelewskiego 27, 02-679 Warszawa
Tel.: +48 022 329-19-78 E-mail: maciej.bartold@igik.edu.pl

Stanisław Lewiński
Instytut Geodezji I Kartografii, ul. Modzelewskiego 27, 02-679 Warszawa
Tel.: +48 022 329-19-76 E-mail: stanislaw.lewinski@igik.edu.pl

Streszczenie. W maju i w czerwcu 2010 roku Polskę nawiedziły powodzie, powstałe w wyniku intensywnych opadów deszczu w górnych odcinkach rzek Wisły i Odry. Do analizy zasięgu fali wezbraniowej wykorzystano średnio-rozdzielcze obrazy satelitarne TERRA-MODIS. Z ogólnodostępnej bazy obrazów wybrano zdjęcia z 6 czerwca dla doliny Wisły i 9 czerwca dla doliny Odry. Zasięg obszarów zalanych wyznaczono przy użyciu metod klasyfikacji obiektowej w środowisku oprogramowania eCognition. Analiza statystyczna wyników klasyfikacji została wykonana na poziomie gmin przez porównanie klasyfikacji z bazą danych Corine Land Cover 2006. Podczas powodzi zalane zostały tereny w 184 gminach wzdłuż Wisły i w 120 gminach wzdłuż Odry. Największy obszar objęty powodzią wystąpił w gminie Słońsk, w dolinie Odry gdzie zalany został obszar 4055 ha. Łącznie wody Wisły zalały 4,01% powierzchni gmin wiślańskich, natomiast wody Odry – 3,29% powierzchni gmin odrzańskich.

Słowa kluczowe: monitoring powodzi, MODIS