MULTI-SOURCED, REMOTE SENSING DATA IN LEVEES MONITORING: CASE STUDY OF SAFEDAM PROJECT

K. Bakuła [1], D. Zelaya Wziątek [1,2], B. Weintrit [1,3], M. Jędryka [3], T. Ryfa [2], M. Pilarska [1], Z. Kurczyński[1]

[1] Dep. of Photogrammetry, Remote Sensing and Spatial Information Systems, Faculty of Geodesy and Cartography, Warsaw University of Technology, Poland
[2] Institute of Meteorology and Water Management - National Research Institute, Dam Monitoring Centre, Warsaw, Poland
[3]Astri Polska Sp. z o.o., Warsaw, Poland

Inter Commission III/IV

KEY WORDS: Flood protection, Crisis management, Levee monitoring, Remote sensing, Airborne Laser Scanning, Radar data

ABSTRACT:

In the following study, the authors present the development of a created levee monitoring system - a supplement to the existing programs of flood protection providing flood hazard and risk maps in Poland. The system integrates multi-source information about levees, acquiring and analysing various types of remote sensing data, such as the photogrammetric and LiDAR data obtained from Unmanned Aerial Vehicles, optical and radar satellite data. These datasets are used in order to assess the levee failure risk resulting from their condition starting from a general inspection using satellite data and concluding with UAV data usage in a detailed semi-automatic inventory. Finally, the weakest parts of a levee can be defined to create reliable flood hazard maps in case of levee failure, thus facilitating the constant monitoring of the water level between water gauges. The presented system is an example of a multi-source data integration, which by the complementation of each system, provides a powerful tool for levee monitoring and evaluation. In this paper, the authors present a scope of the preventative configuration of the SAFEDAM system and the possible products of remote sensing data processing as the result of a hierarchical methodology of remote sensing data usage, thus leading to a multi-criteria analysis defining the danger associated with the risk of levee failure.

1. INTRODUCTION

Floods are the most frequently occurring cataclysm in Europe and worldwide. For decades, human efforts towards flood prevention have been focused on levee construction and monitoring. These constitute particularly valuable products, which contribute to increasing the awareness about possible negative flood consequences, and in the meantime, allowing for a more accurate crisis and planning management in the form of flood risk and hazard maps. The current development of the remote sensing technology allows for fast and precise environment monitoring by analysing ongoing changes. For years, airborne optical sensors have provided a vast range of photogrammetric data for the interpretation of photo and remote measurements. Another modern technologies widely used nowadays for the purpose of environment monitoring are Airborne Laser Scanning (ALS) and satellite imaging systems, the usage of which expands every year thanks to the continuous improvement in the systems' resolution. Noteworthy to mention is also the development in the field of satellite radar systems, which in addition to the aforementioned technologies, provide accurate data regardless of weather conditions, both during the day and at night. Satellite images that are regularly acquired are willingly used in order to monitor the phenomena that concern wide areas, e.g. earthquakes, wide area forest fires (Kussul et al., 2011; Tralli et al., 2005).

Considering all the aspects mentioned above, the authors have prepared a levee monitoring system that integrates all the technologies mentioned above with the existing databases of the embankment parameters and the hydrological data in Poland. By analysing multi-source data, the system evaluates the risk of levee failure and provides valuable information supporting crisis management.

2. SAFEDAM PROJECT

The main goal of the project 'Advanced technologies in the prevention of flood hazard' named SAFEDAM is monitoring the levees in order to prevent hazards. In Poland, there are over 4000 km of levees, the technical condition of which has to be evaluated within a five-year cycle. The constant monitoring of levees' susceptibility to failure is a fundamental process for disaster prevention, especially in light of the intensification of the flood frequency occurrence. The aim of the SAFEDAM project is the creation of a levee monitoring system using Unmanned Aerial Vehicles - UAV (equipped with a light LiDAR unit - laser scanner and multispectral cameras - blue, green, red and near-infrared spectrum), optical and radar satellite imagery and archival aerial imagery. Multi-sourced and multi-temporal data make it possible to evaluate the levees' condition supplementing direct surveying measurements. A comprehensive IT system facilitates the collection, automatic data analysis and visualisation for hydrological services and crisis management professionals. Its implementation ensures the effective management of flood risk. SAFEDAM complements the already implemented projects of flood protection in Poland, such as an IT System of the Country's Protection - ISOK (Kurczyński and Bakuła, 2013) and a System of Hydrological Structures Control Records - SEKOP. It also goes beyond the recommendations of the Floods Directive (Directive 2007/60/EC).

The presented SAFEDAM system consists of two configurations: interventional and preventative. This article is focused on the preventative, an early warning part of the system being a module responsible for preparing data for the evaluation of the levee condition. In the system, multi-sourced levee information is used by implementing and analysing various types of remote sensing data, providing an assessment of the levee failure risk resulting from their condition.

The preventative module of the SAFEDAM system enables the collection, processing, management and distribution of the processed data. Its functionalities are predominantly based on the created aerial and satellite orthophotomaps, as well as on the digital terrain models obtained from various platforms. The implemented algorithms are based on the expert classification using radiometric vegetation indices. Furthermore, the system allows the user the possibility of supervision and manual correction, by providing tools for creating layers for supporting photointerpretation.

3. STUDY AREA

In order to verify the system's reliability and proper application of its functions, monitoring tests have been conducted on site. For the interest site selection, the following criteria have been applied: (1) levee with high frequency of natural failure occurrence; (2) sides with the highest amount of potential levee failure threats; (3) hydrological structures with a well-documented current and historical geotechnical state; (4) sites with limited access.

Based on the levee data analyses obtained from the Dam Monitoring Center (OTKZ), Institute of Meteorology and Water Management - National Research Institute (IMGW-PIB), five study areas have been selected (Figure 1). All levees are located near Vistula - the largest river in Poland, whose most recent breach occurred during the extended floods in Europe in year 2010, causing deaths and damage to properties.

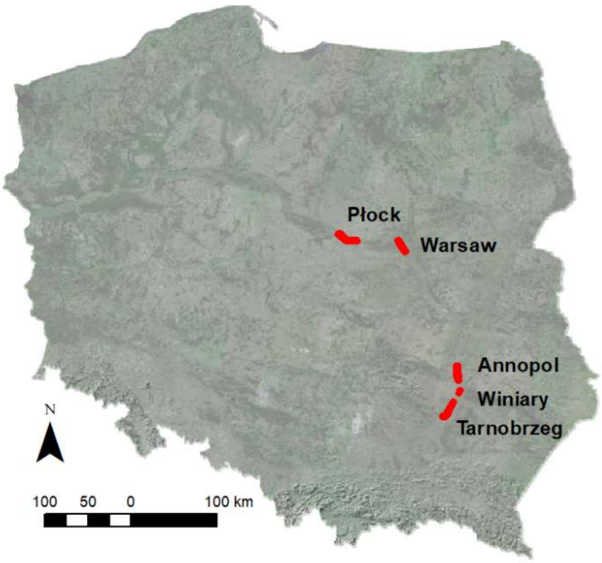

Figure 1. Study areas in the SAFEDAM Project.

Study area No. 1: located near the town of Płock, central Poland. Length: 8.7 km. After the embankment failure, the modernisation consisted of its reconstruction including a sheet pile wall in the levee body and gabion as an additional protection on the river slope. Study area No. 2: located near the city of Warsaw, central-east Poland. Length: 30 km. The breach occurred in the form of a landslide, as a result of a loss in levee stability. The embankment modernisation consisted of ground material exchange, soil compaction and additional slope protection by iron nets. Study area No.3: located near the town of Annopol, south-east Poland. Length: 6.2 km. After the failure, the levee was rebuilt (using soil compaction). A sheet pile was applied to a length of 105 m. The embankment was additionally secured with a bentonite blanket and iron net. Study area No. 4: located near the town of Sandomierz (Winiary village), south-east Poland. Length: 3.7 km. After the embankment failure, it was sealed using the iron sheet pile GU-7-600. Study area No. 5: located near the town of Tarnobrzeg, south-east Poland. Length: 7.5 km. The modernisation consisted of the embankment being sealed by a bentonite blanket and a sheet pile installation in the levee base.

4. PREVENTION SYSTEM DESCRIPTION

In the system few kinds of remote sensing data are used. Their use cannot be simultaneous. The system adopted the principle of using data from the general to the specific range. In the hierarchical dependence (Figure 2), satellite data as a data with lowest resolution are used to monitor the water range every few days and together with data from the geodetic repositories updated every 2-3 years, allow to indicate areas for more accurate measurements. The data items gathered from the UAV platform and direct surveying measurements constitute the most accurate sets of data that determine the state of the embankments. In the following subchapters, the division into these two source groups is discussed in more detail.

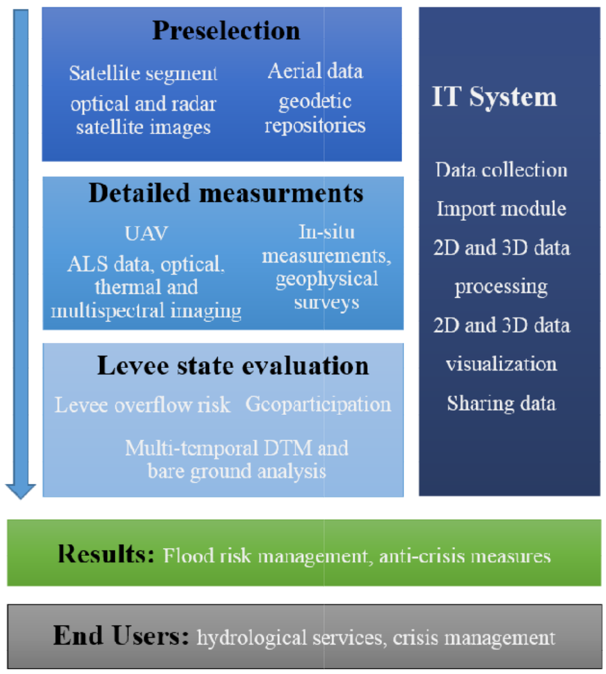

Figure 2. Diagram of the actions in the preventative configuration of the SAFEDAM project.

4.1 Satellite data - overall monitoring

In order to identify embankments, ongoing erosion processes, and small scale crest height changes, the most precise data available should be analysed. However, due to the preparation of a country-wide system, the collection and analysis of a large amount of data with a high spatial resolution reaching 10 cm is time consuming and economically inefficient.

To avoid unnecessary data processing and ensure immediate reaction, the system provides the possibility of pre-selecting areas for a further and more detailed analysis based on satellite data and data from the national geodetic and cartographic repository enriched by aerial images with a 25 cm spatial resolution for rural areas and 10 cm for urban areas. Additionally, the geodetic and cartographic repository in Poland provides a Digital Terrain Model (DTM) with a 15 cm accuracy and it is treated as a reference DTM for the further multi-temporal analysis.

The methodology of satellite data use in relation to the optical data in the SAFEDAM system has been described in Weintrit et al. (2017). The investigation into the project possibilities of radar data use has been described in the studies of Pluto-Kossakowska et al. (2017). Both sources investigated the possibilities of current water level identification (Figure 3) (considering satellite revisit), which is essential particularly in areas located between water gauges or in the case of gauge failure.

The temporal resolution of satellite optical systems for areas characterised by medium latitudes, such as Poland, is daily (e.g. Plèiades constellation) or up to several days (e.g. LANDSAT, Sentinel-2). It depends on the construction of the satellite system and the possibilities of its programming. For preventative monitoring, it is a sufficient revisit time, but the possibilities of the usage of satellite optical systems are limited due to weather and lighting conditions, such as cloud coverage. Optical imagery can be used only in periods of cloudless weather or with very little local cloudiness. The identification of levee damage can be conducted only as a quasi-continuous monitoring.

Due to restrictions, radar satellite data is more widely used. A special tool for the automatic gathering and processing of Sentinel-1 radar data was developed. It is providing a fully automatic analysis about water ranges. The Sentinel database is regularly queried using the shared api SCI HUB. With the regular inspection of the database by the application, all products will be downloaded on a regular basis. The process is a Windows service that runs one or two times a day. The subsequent process steps are recorded in logs: start of the process, area of interest (AOI) number, date of the last downloaded equal to the latest archive in the database for the AOI checked, number of archives to download, whether the file has already been downloaded for another AOI, information about adding to the database or assigning to the AOI an existing archive. In order to correctly save metadata from different sensors, including Sentinel data, metadata mappings from the source files were converted into tables in the SAFEDAM database.

In this configuration, high resolution satellite (VHRS) scenes ordered on demand and mainly aerial images from repositories and elevation data are also used to preselect areas, which require more detailed measurements. For this purpose, some supporting tools were prepared: vegetation indicators (Normalised Differential Vegetation Index - NDVI and Green-Red Vegetation Index - GRVI), raster algebra for analysing the DTM and an algorithm enabling automatic water detection. Indicated levees can be examined using more detailed remote sensing technology in higher resolution or in direct surveying measurements.

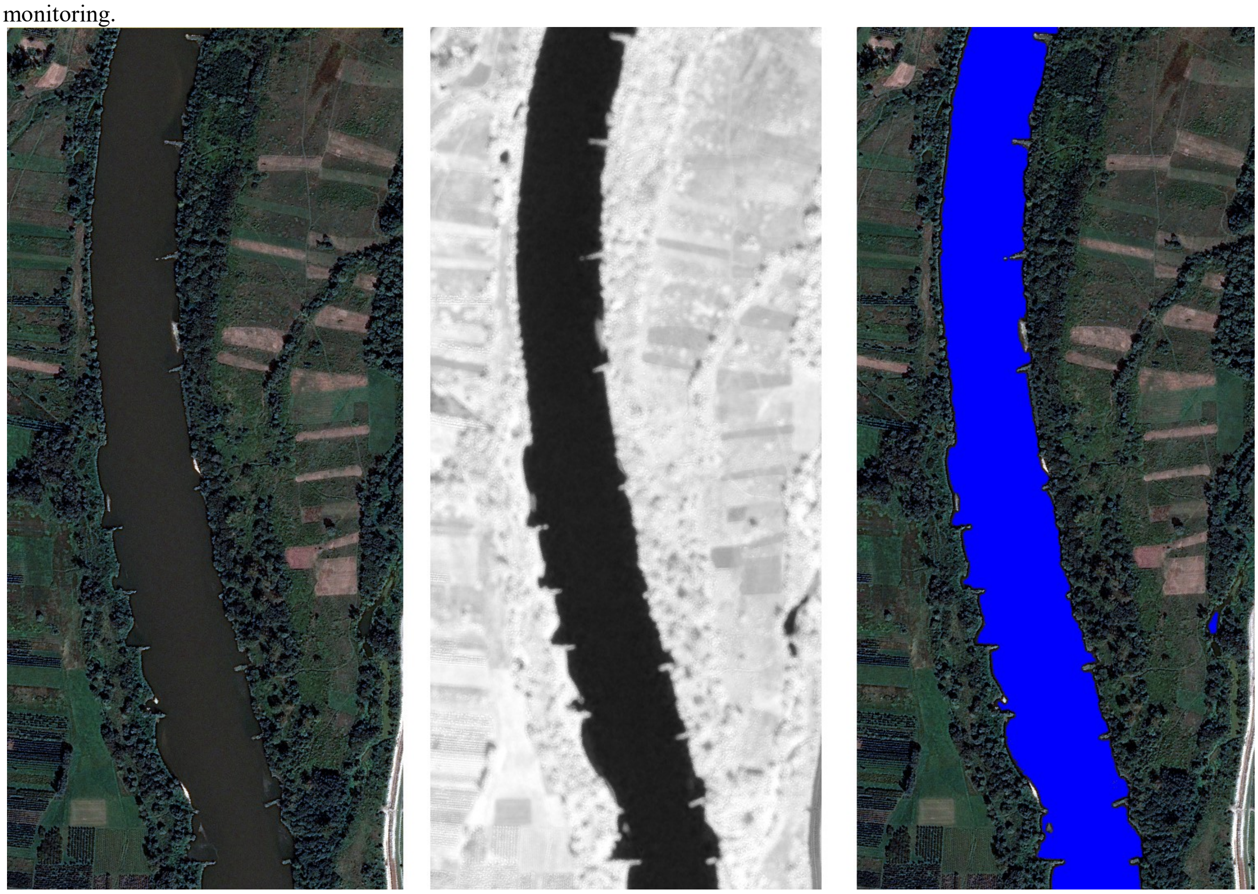

Figure 3. Automatic water bodies detection based on the Pleiades VHRS optical imagery (RGB composition, NIR channel and resulted water body overlaing ortohophotomap

4.2 UAV monitoring

Beside the satellite data, the levees are monitored using UAV platforms. These platforms can be equipped not only with cameras (RGB, near-infrared, thermal infrared), but also with light laser scanners collecting 3D point clouds. Equipping the UAV platforms with light laser scanners is still a novelty in the field of remote sensing, however there are already some articles about their application and accuracy (Petrie, 2013; Pilarska et al., 2016; Bakuła et al., 2016, 2017). Mounting more than one sensor on the UAV platforms makes it possible to acquire various data simultaneously, which enriches the analysis.

In the SAFEDAM project, the UAV application is a second phase of the levee monitoring, which can be conducted systematically in order to acquire up-to-date data, and obligatory when danger occurs. Therefore, the main advantage of the low-altitude UAV platforms over the airborne data in the levee monitoring is the possibility of fast data acquisition, high resolution of the final products and precise investigation of the area of interest. Additionally, the UAVs have a strong potential in monitoring linear objects, such as levees (Bakuła et al., 2016).

Within the SAFEDAM project, two types of platforms are considered: interventional and preventative. The aim of the interventional platform is to monitor the levees' condition when a hazard occurs. This platform needs to be light and easily operable, therefore it is equipped only with cameras. The second, preventative UAV platform, which is developed within the SAFEDAM project, is the fixed-wing NEO3 (Figure 4). This platform is equipped with a Riegl miniVUX laser scanner and two Sony a6000 cameras. One camera acquires the RGB images while the second one registers in the near infrared wavelength. This platform can provide the LiDAR data with a mean point density value of up to 8 points per square meter and register the data from a height between 100 and 150 m above the ground.

The LiDAR data, which are provided by the UAV platforms are used for the generation of the DTMs and the analysis of height differences. The RGB and NIR images are used for the emerging new bare ground detection. The classification of the bare ground is conducted based on the selected indices: NDVI or GRVI. Both differences in height and in bare ground range, which occur on the levee, are important in the levee monitoring because they might constitute a hazard sign.

Figure 4. The fixed wing NEO3 equipped with marked sensors: RGB and NIR cameras, and light laser scanner

4.3 Description of the preventative mode of the SAFEDAM system

The system is divided into two different configuration modes and it is operated by two different types of end-users. For the hydrological services, the prevention mode is dedicated, while the interventional mode is assigned to the crisis management services (Weintrit et al., 2018). Exceeding the appropriate value of the hazard condition assessment gives the user a statement about the threat. The IT system must have clearly defined functionality in each of the previously defined modes of operation. Some of them will be repeated, these are the so-called basic functionalities of the system, such as displaying spatial data layers, searching for data, or measurements. The main tools developed under the preventative mode are: a tool for the import and comparative analysis of satellite data and data from an unmanned measuring platform, a threat monitoring tool, a module for the determination of flood risk and flood risk analysis. The system's functions facilitate the monitoring of flood embankments for the purpose of flood risk and threat assessment, as presented in Table 1.

Type	desktop application
Access	login, appropriate permissions
Available data	access to the full SAFEDAM database (including ISOK, SEKOP, BDOT, PSHM) and continuous update
Basic functions	zooming, centering, displaying coordinates of the mouse cursor, dynamic scale of the map, searching for data in the database, the ability to turn off the visibility of layers, setting the transparency of layers, measurements of area, length and height, the ability to draw on the map, screen shot from 2D and 3D to graphic form, export of shapefiles with markings from the action, export of shapefiles with evaluation of leeves, sharing links to WMS layers visible in the system
Dedicated functions	the ability to create dynamic cross-sections
	displaying messages from geoparticipation application in the real time
	analysis and updating of the assessment of the condition of flood embankments
	presentation and updating of the water level from water gauges from the PSHM base
	display of warnings from the PSHM base
Result	updated flood risk and threat assessment

Table 1. Functions of the SAFEDAM system in the preventative mode.

4.4 State of risk - definition

In order to identify the appropriate moment to switch between the prevention and intervention monitoring modes, the state of danger needs to be defined. For that reason, a multi-criteria analysis of the parameters indicating the potential threat directly and indirectly has been applied. Multi-criteria analyses are based on three main sets of data: (1) water level data transmitted directly from the gauge monitoring network; (2) levee safety evaluation based on multi-source data; (3) alerts sent by civilians through the geoparticipation portal (Table 2).

Data set	Parameter		Data source
Levee condition	Level technical state evaluation based on geotechnical and geometrical parameters		SEKOP database
	Multi-temporal DTM change analysis	Multi-temporal bare ground raster analysis	Monitoring and analysis of remote data supported by DTM changes and new bare ground
	Levee overflow risk		ISOK database
Civilians alerts			Geoparticipation portal
Current water level			Gauge monitoring network

Table 2. Multi-criteria analysis scheme of the state of risk - definition

The levee safety evaluation is a result of the levee geotechnical, geometric and spatial parameter analysis. The elaborated multi-sourced levee safety evaluation methodology resulted from the weighted values of three data sets: (1) Level technical state evaluation based on the geotechnical and geometrical parameters; (2) Interpretation of remote data supported Multi-temporal DTM changes and bare earth raster analysis; (3) Levee overflow risk (Table 2). Levee technical state data originate from SEKOP and are based on the evaluation studies conducted by the OTKZ, however, the geometrical levee parameters, such as crown height, slope and crown width will be further updated and detailed based on the direct monitoring with use on the prevention platform. Data updates will differentiate the original, previously generalised levee technical state evaluation. The multi-temporal analysis of the geometry changes as well as the bare earth raster analysis will be conducted after every system update with new data: LiDAR scanning (for topography changes) and photogrammetric (for bare ground range changes). Another parameter affecting the levee safety is the information about the locations of the embankment overflow simulated as part of the ISOK project, calculated for a probability of one-hundred-year and five-hundred-year flood. According to the initial assumptions of the project, the user's alerts sent by the geoparticipation portal have been included as a component of the levee failure risk analysis. It was assumed that the activity on the geoparticipation portal will increase in line with the rising threat. However, due to the difficulties associated with information credibility authentication, alerts should be verified on a regular basis by the local system administrator. Water level data are an integral part of the SAFEDAM system. The transmission of the gauge provided data is conveyed directly by the Central Hydrology Database Systems (PSHM) administered by IMGW-PIB. The data is updated automatically every 24 hours while in prevention mode but in the case of the intervention mode, the data update rate increases to up to one hour. The PSHM provides information about the current water level and characteristic levels, which overpass results in the hydrological warning or alarm condition.

In order to automate the process of threat spatial distribution determination, a weighing system involving multi-criteria analysis parameters has been applied. The numerical values of all the parameters have been assigned according to their influence on the final result. As a result of the simulations carried out, it was found that the decisive factors influencing the determination of the threat state are the water levels. The second factor according to its significance is the state of the levees. The value of the civilians' alerts has been difficult to validate due to the pure geoparticipation portal distribution and lack of critical events during the project's second phase.

As a result of the conducted analysis, a new raster including the graphic representation of the embankment safety state is generated. The created algorithm allows for an evaluation of the four states, namely lack of threat, state of warning, state of alarm and critical state, to be conducted. In the final raster, the safety states will be distinguished by a graphic representation varied in colour (Table 3).

System configurations	State of risk	Monitoring recommendation	Graphic representation
Prevention	Lack of threat	Standard monitoring procedure	transparent
	state of warning	monitoring focused on alerts verification	yellow
Intervention	state of alarm	Full monitoring	orange
	critical state	Immediate monitoring	red

Table 3. Monitoring recommendations depending on the state of risk

Referring to recommendations for the monitoring configuration depending on the state of hazard, for each of the safety states, recommendations for the monitoring mode have been proposed. When no threat is identified, a standard monitoring procedure is implemented (Table 3). This prevention mode assumes a continuous data collection with the use of a fixed-wing NEO3 platform. The warning state indicates an increased level of potential threat and should be considered as an indicator of the areas for a further evaluation. For that reason, field supervision by a specialist and further data collection by the means of the prevention platform is highly recommended in order to verify the intensity of a potential threat. When at least one of the key factors related to safety evaluation shows a continuous rise, the system switches to the first phase of the international mode, namely the state of alarm. Since then, monitoring in a 12 h cycle is recommended with the use of prevention or intervention platforms, depending on the interest area and threat intensity. The last phase indicates the critical level of levee failure risk. In this case, constant, 24 h monitoring is essential in order for the crisis management centres to plan an optimal rescue route. Independently from the aforementioned classifications, the system switches immediately to the interventional mode in case of: (1) people evacuation; (2) defensive action of the embankment (strengthening, sealing, etc.).

4.5. Examples result

The data, which are obtained with the UAV platform and the satellite imagery, are uploaded into the external database, which is linked to the system. As a result, many valuable spatial analyses can be performed. The radar satellite data and high-resolution optical satellite scenes make it possible to generate water masks. However, the main advantage of the radar data over the optical dataset is the ability to penetrate the clouds. The water masks support the monitoring of the water range in rivers. The comparison of the water masks generated from the satellite data obtained in different terms indicates the differences in the water range. If the water range increases, this is a sign to the members of staff that a hazard may occur. For the optical VHRS satellite data, the water ranges are determined based on the NDVI, and for the radar satellite data, the water mask is calculated. The example of using vegetation index to map the range of water is shown in Figure 5.

The UAV data (images and LiDAR point clouds) are used for a more detailed analysis of the levees' condition. The Digital Terrain Models, which are generated from the LiDAR data, are used for the detection of the height differences in levees (Figure 6). Such layer serves as support for the specialist conducting the analysis of the multi-sourced remote data. These differences may result from the damages caused by animals, or may indicate a landslide. They tell the user what place to pay special attention to.

As it can be observed, in Figure 5, many areas with height differences higher than 0.25 m can be identified. This can be due to a few reasons, e.g. interpolation process, the resolution of the DTMs, errors in the acquired data. Therefore, in order to interpret the results of the analysis properly, a specialist in the field of hydrology is needed, who will properly indicate the areas which seem to constitute damage in the levee and those that should be ignored.

The new bare ground detection analysis was conducted based on the aerial images. It is the second layer that should help the end-user in the evaluation of the levee condition. In order to distinguish the bare ground and the vegetation, the NDVI and GRVI were calculated. The results showed that the NDVI gives better results than the GRVI (Figure 6).

Additionally, the studies showed that the threshold for distinguishing the bare ground and vegetation for both the NDVI and the GRVI is not constant. Therefore, in the system, there is a possibility to change the values of the thresholds by the user and choose the best value to detect the bare ground and calculate the differential bare ground raster in order to deliver the new bare ground layer.

The presented products of remote sensing data and their processing in the preventative configuration provide the possibility of conducting a multi-criteria analysis of the flood risk. The result of the analysis provided in the SAFEDAM window of the preventive configuration is presented in Figure 7.

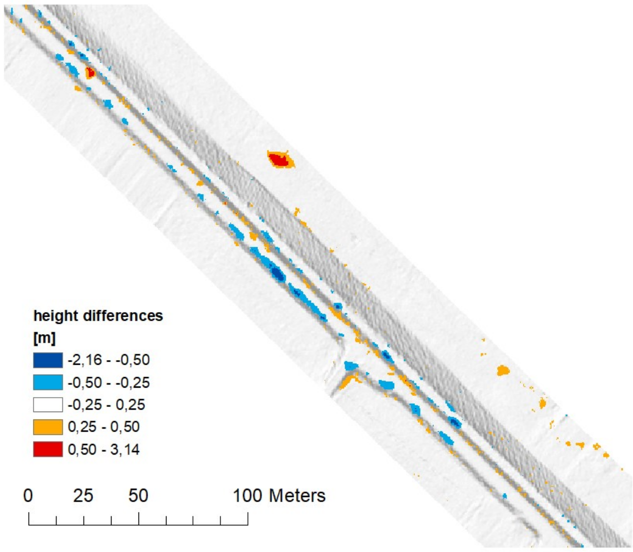

Figure 5. Example of the height differences between the DTMs generated from the airborne and UAV LiDAR

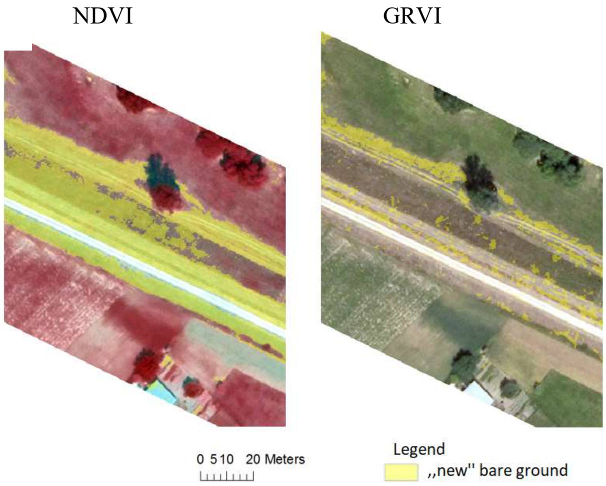

Figure 6. Example of detection of the new bare ground based on the RGB and NIR images

5. SUMMARY AND CONCLUSIONS

During the second year of the project, the work on the methodology of the multi-source remote sensing data application for the assessment of the levee state in the prevention configuration of the SAFEDAM system was completed. The hierarchical methodology of remote sensing data analyses allows for full levee monitoring on a national and local scale. Large scale monitoring, based on the satellite and archived data from the repositories, enable the preselection of levee areas prone to failure for further observation on a local scale. Only a solution based on a hierarchical structure is able to scan a large amount of critical infrastructure with constant and functioning monitoring. The verification of the levee current safety state is conducted using the semi-automatic method based on the remote sensing data obtained from the unmanned UAV platform.

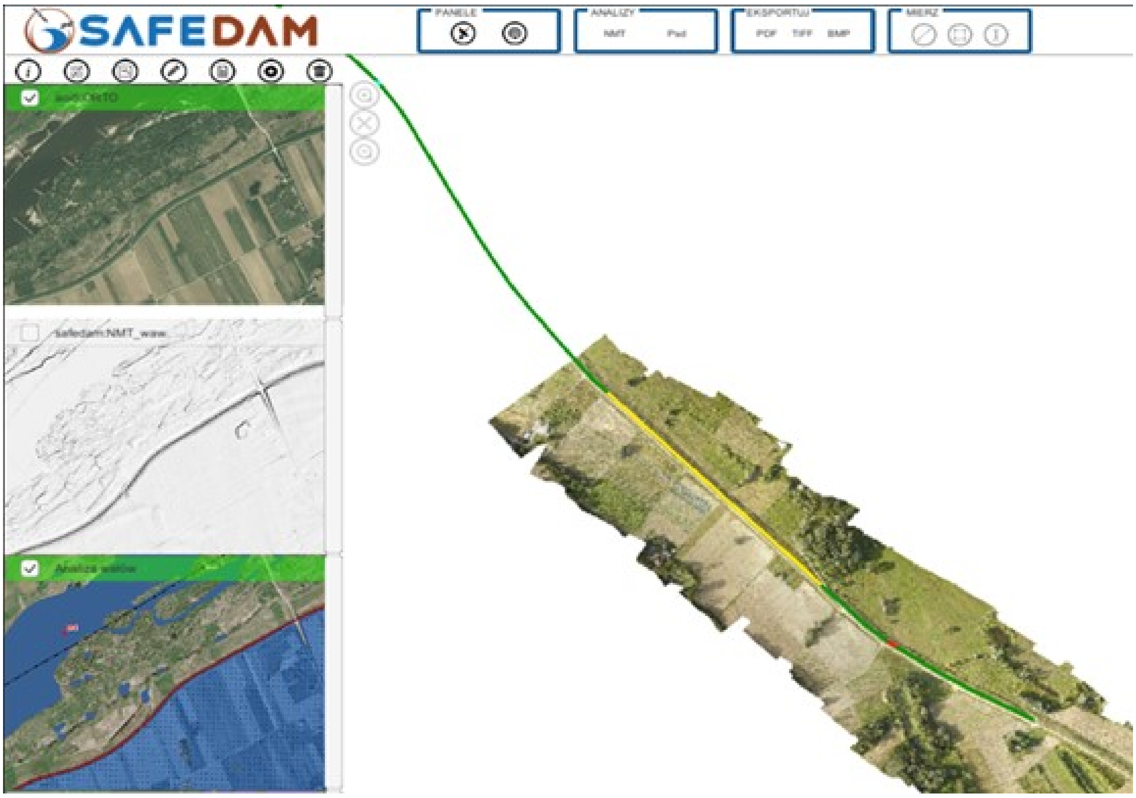

Figure 7. The layout of the SAFEDAM IT system in prevention mode with a layer of final hazard evaluation overlaying ortophoto from UAV-based images

The assessment of the levee state is conducted in the system considering the remote sensing data, flood wave simulation results from flood risk and hazard maps, technical levee condition verified by overflow simulations as well as water level from the water gauges network and geoparticipation portal. The developed system integrates a large amount of various data sources thus ensuring the efficient management of various levees. The results of the preventative mode simulations providing data for the system in intervention mode where it is possible to work with flood hazard and risk maps integrated into one system. Such system simplifies rescue action planning and documentation and provides a full scale problem overview for better crisis management.

ACKNOWLEDGMENTS

Project "Advanced technologies in the prevention of flood hazard (SAFEDAM)" is financed by National Centre for Research and Development in Defense, Security Programme [grant number DOB-BIO7/06/01/2015].

REFERENCES

Kurczynski, Z., Bakula, K. (2013). The selection of aerial laser scanning parameters for countrywide digital elevation model creation. International Multidisciplinary Scientific GeoConference: SGEM: Surveying Geology & mining Ecology Management, 2, 695.

Bakuła, K.; Ostrowski, W.; Szender, M.; Plutecki, W.; Salach, A; Górski, K.; 2016. Possibilities for Using LIDAR and Photogrammetric Data Obtained with An Unmanned Aerial Vehicle for Levee Monitoring. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, XLI-B1, pp. 773-780.

Bakuła, K.; Salach, A.; Zelaya Wziątek, D.; Ostrowski, W.; Górski, K.; Kurczyński, Z. 2017. Evaluation of the accuracy of lidar data acquired using a UAS for levee monitoring: preliminary results, *International Journal of Remote Sensing*, *38*(8-10), 2921-2937.

Eltner, A.; Baumgart, P.; Maas, H. G.; Faust, D. 2015. Multi-temporal UAV data for automatic measurement of rill and interrill erosion on loess soil. *Earth Surface Processes and Landforms*, 40(6), pp. 741-755.

Kurczyński, Z., Bakuła, K. 2013. The selection of aerial laser scanning parameters for countrywide digital elevation model creation. International Multidisciplinary Scientific GeoConference: SGEM: Surveying Geology & mining Ecology Management, *2*, pp. 695-702.

Kurczyński, Z.; Bakuła, K. 2016. SAFEDAM - zaawansowane technologie wspomagające przeciwdziałanie zagrożeniom związanym z powodziami, *Archiwum Fotogrametrii, Kartografii i Teledetekcji*, vol. 28, pp. 39-52.

Kussul, N.; Shelestov, A.; Skakun, S. 2011. Flood monitoring from SAR data. In: *Use of Satellite and In-Situ Data to Improve Sustainability*. Springer, Dordrecht, pp. 19-29

Petrie, G. 2013. Current developments in airborne laser scanners suitable for use on lightweight UAVs: Progress is being made! *GeoInformatics*, 16(8), pp. 16–22.

Pilarska, M.; Ostrowski, W.; Bakuła, K.; Górski, K.; Kurczyński, Z. 2016. The potential of light laser scanners developed for Unmanned Aerial Vehicles - the review and accuracy. *International Archives of the Photogrammetry, Remote Sensing & Spatial Information Sciences*, 42, pp. 87-95.

Pluto-Kossakowska, J.; Łoś, H.; Osińska-Skotak, K.; Weintrit, B. 2017. The concept of SAR satellite data use for flood risk monitoring in Poland, Signal Processing Symposium (SPSympo), Warsaw, Poland, pp. 1–5.

Tralli, D. M.; Blom, R. G.; Zlotnicki, V.; Donnellan, A.; Evans, D. L. 2005. Satellite remote sensing of earthquake, volcano, flood, landslide and coastal inundation hazards. *ISPRS Journal of Photogrammetry and Remote Sensing*, 59(4), 185-198.

Weintrit, B.; Osińska-Skotak, K.; Pluto-Kossakowska, J.; Pilarska, M. 2017. Feasibility study of flood risk monitoring based on optical satellite data, 3rd Disaster Risk Reduction Conference 2017, Warsaw, Poland

Weintrit, B.; Bakuła, K.; Jędryka, M.; Bijak, W.; Ostrowski, W; Zelaya Wziątek, D.; Ankowski, A.; Kurczyński, Z. 2018. Emergency rescue management supported by UAV remote sensing data, *The International Archives of the Photogrammetry Remote Sensing and Spatial Information Sciences,*