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LiDAR ANALYSIS ON THE EXAMPLE OF DĘBINA CLIFF (USTKA GULF)

Iwona Pasamonik

Department of Geoecology and Geoinformation,
Institute of Geography and Regional Studies, Pomeranian University in Słupsk,
ul. Partyzantów 27, 76-200 Słupsk, Poland
e-mail: tylman84@gmail.com

Abstract

The use of new technology, which is airborne laser scanning (LiDAR), allows to analyze changes in the natural environment. Due to its accuracy and precision, this method makes possible to study even small landforms. It is an excellent complement to traditional surveying methods. The analysis deals with Dębina Cliff – the several-kilometers long form located at the coast of the Ustka Gulf. The cliff was developed using LiDAR images and generated DEMs (Digital Elevation Models). Orthophotomaps and topographic maps in scale 1:10 000 proved to be helpful as well. The usefulness of LiDAR images and products for studying small landforms was presented. On their basis, the exact morphometric characteristics of Dębina Cliff was determined. By comparing images taken at different seasons, it was also possible to determine the changes that have occurred during the survey. Calculations and measurements have been developed with a help of GIS software: ArcGIS, QuantumGIS and Global Mapper.

Key words: Dębina Cliff, Ustka Gulf, LiDAR analysis, Digital Elevation Model

INTRODUCTION

Measurements of space require selection of appropriate tools and technologies. The aim of the work is to analyze the products of airborne laser scanning applied to morphometric studiesof selected cliff section of the Baltic Sea coast. This is a fairly new method, which due to its high accuracy and performance, is competitive with traditional methods, and it increasingly complements them. The paper also presents an additional opportunity to use LiDAR products. Due to the fact that the author is owner of LiDAR images taken in different seasons, there was an opportunity to show the changes in this dynamic environment. Having such data, monitoring of the research area can be carried out.

The cliff coast is characterized by dynamic changes in terrain (Florek et al. 2008, 2009a). Region of Dębina Cliff was a frequent subject of research (Florek et al. 2001, 2007, 2009b, 2010, Subotowicz 1982). Research carried out in that part of the waterfront often related to the morphology of the form, as well as to determine the rate of the cliff and the beach changes in seasonal cycles and within multi-year period, often including the role of extreme hydrodynamic phenomena. In these works, a lot of attention was focused on individual factors determining the rate and nature of the coastline change (geological structurehydrodynamic conditions, anthropogenic factors etc.). The authors, when realizing the research, used mainly the surveying measurements of selected cliff profiles, and also recognized the geological structure of cliffs, watching and doing measurements of cliff and beach mesoforms and microforms. The geological structure is described in detail by among others Jasiewicz (1999) and Petelski (2008).

The rate of Dębina Cliff retreat has been given in numerous works. Years 1960-1970 brought an average loss of 0.2-1.8 m/year (Salik 1979), 1971-1983 – 1.6-2.65 m/year (Zawadzka-Kahlau 1994), and 1999-2007 – 0.68-1.4 m/year (Florek et al. 2008). Comparing them with other sections of the cliff on the Polish coast, the rate of retraction is significant. Earlier studies upon morphology and rate of Dębina Cliff retreat performed by means of geodetic measurements can be continued with LiDAR images.

MATERIAL AND METHODS

Documentation made available by the Maritime Office in Słupsk is the key material. It consists of a database of so-called “cloud of points”, i.e. numerical record of X, Y, Z coordinates for reflection points. This is the basic product of the laser scanner work, which allows the Terrasolidsoftware for generating the auxiliary products: Digital Terrain Model (DTM) and Digital Surface Model (DSM). Data were quite detailed: 8 points fell per 1 m^2 on average and the height difference was $\leq$0.15 m (Operat techniczny 2013). In addition, orthophotomaps (2013) and Topographic Map of Poland in scale 1:10 000 were very helpful. The coastal zone corresponding to the administrative border of the Maritime Office in Słupsk has been scanned.

The study consisted of a detailed analysis of Dębina Cliff morphometry. The LiDAR images have been subject to processing in the Global Mapper ver. 16 software. It was used to create the digital terrain model DTM and a number of profiles, which yielded the accurate information about the morphological characteristics of studied form. A similar methodology applied J. Dudzińska-Nowak (2007), when exploring the coastal zone of the southern Baltic Sea by means of laser scanning. Another method was vectorization of contour maps on the background of Raster Topographic Map of Poland (Bakuła et al. 2013) in Quantum GIS ver. 2.8 software. This created the opportunity to produce a further Digital Elevation Model (DEM) in ArcGIS ver. 10 software (Wężyk et al. 2008), by means of which a series of profiles of the area was plotted. Comparison of two digital terrain models (DTM from LiDAR data with DEM from contour vectorization), as well as listing the cross profiles passing through the cliff allowed to carry out a very detailed morphometric analysis of this form. Terrain models and cross sections from LiDAR data provide a picture of the terrain to be much more detailed and accurate as compared to topographic maps. It makes possible to distinguish even minor terrain forms, which cannot be seen on models and profiles of vectorized contour lines, where isolines run quite mildly, whose course allows to reflect only the largest forms and in significant simplification.

The following stage of work was the interpretation of changes occurring within the studied area. Determination of changes was made possible by comparing the images taken at different times. The LiDAR images of the three raids were used, which took place on the following dates: December 2012 (winter), the beginning of June 2013 (late spring), September 2013 (summer-autumn). The image of the area was complemented due to high-resolution orthophotomaps, which proved to be helpful in documenting the changes in terrain sculpture.

THE STUDY AREA

The study area includes the waterfront in the vicinity of Poddąbie and Dębina – area located a few kilometers east of Ustka; locally, this stretch of coast is called the Ustka Gulf (Rudowski and Wróblewski 2012). The gulf is located in the central part of the Baltic Sea coast. It is a significant part of the Southern Baltic Sea, and its coast is located between towns of Łeba and Jarosławiec (Fig. 1).

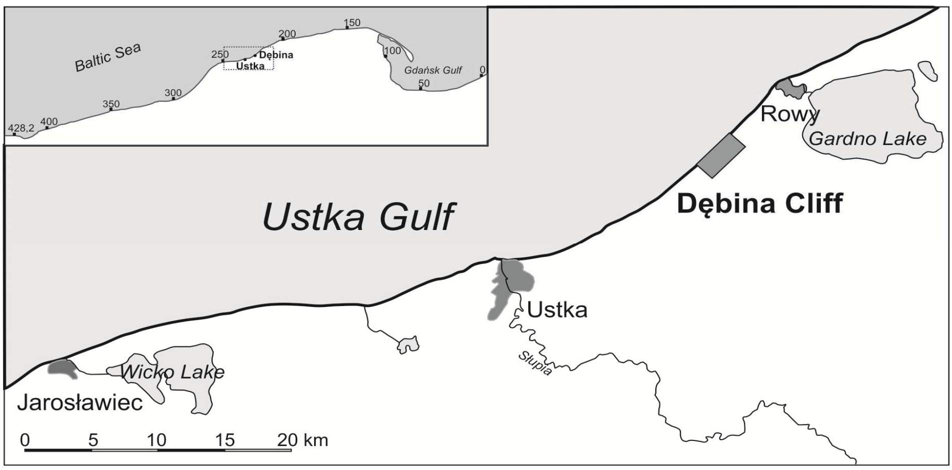

Fig. 1. Location of the study area

The nature of the Ustka Gulf coast is varied and depends largely on the geological structure. This is affected by the Sub-Pleistocene surface, which is characterized by great diversity, and in addition has been transformed by exaration glacier activity. Currently, its shape is dependent on numerous storms.

Dębina Cliff is a small form located in the central part of the Ustka Gulf. It is a very steep form of terrain consisting of two cliff sections: eastern, which is about 3 km long (km 221.250-224.000) and western of 1.5 kilometer length (km 225.750-227.150). They are connected with 2-kilometer fragment of dead cliff (Subotowicz 1982). This area is characterized by considerable height of the cliff coast. The altitudes reach over 30 m.a.s.l. The study analyzes the eastern part of the cliff.

RESULTS AND DISCUSSION

The study area Dębina Cliff is varied. In the analyzed section, there are different forms visible, variable width of the beach, or steepness of the cliff. Figure 2 shows precisely the analyzed area of research. It is presented both in Topographic Map of Poland in scale 1:10 000, orthophotomap, and LiDAR images taken on December 2012. To determine the morphometric parameters on the 3-kilometer stretch, 30 cross profiles (every 10 m) and 5 longitudinal polygonal profiles (2 along the beach, 1 at the crown of cliff, 2 on the cliff) were made. They were created on the basis of LiDAR image in GlobalMapper software. It helped in precise defining the parameters of described stretch of the cliff coast.

In comparison with other sections on the Polish coast, beach on this stretch is quite wide. However, fluctuations in its width within such small segment are significant ranging from 11.35 m to 59.76 m. Comparing all the profiles, the average width of the beach can be calculated, which was 34.25 m. The average thickness of beach sediments is 1.45 m. In some places, it reaches approximately 3.5-4 m, but it is related to the delivery of new deposits from the cliff landslides and shouldn't be regarded as beach.

The slope of the cliff is characterized by high steepness. Like in research by Subotowicz (1982), the slope inclination is about 40º and even up to 60º. Its structure is diverse, there are visible places of sedimentary material landslides, and sometimes the line passes gently downward. Sometimes a“step-wise” shape of the slopes is visible.

The cliff crown is located at different heights. The range of ordinates is very high given the small section of the study area, which is 31.05 m of the relative height. The highest point at the height of 41.15 m.a.s.l. (including aeolian deposits) is located in the central section of the studied area (km 223.180), while the lowest at 10.10 m.a.s.l. is located on the east (km 221.160). Crown of the cliff is clearly visible on the profiles. Comparing with the height of the cliff crown in study from 1970-1980 (Subotowicz 1982), at present it is a few meters higher, because previous studies showed more than 30 m.a.s.l. It is associated with a large loss of Dębina Cliff – the boundary of the crown moved a few tens of meters inland.

Upland of the cliff has a diversified surface. Among others, there are dunes and numerous depressions. Dunes are located in the central and eastern parts of the study area (around 221 and 223 km). They are covered with vegetation. Their size and height varies from small of few meters to a few ten-span ones (Fig. 3, profile 2). The highest altitude was recorded on a dune with a height of 41.81 m.a.s.l. Significant depressions are located on the western part of the area (km 223-224). The land depression sometime reaches 3 m. The largest has a width of more than 205 m and a length of 272 m (Fig. 3, profile 3). Additionally, the sculpture is diversified with roads, forest paths, and drainage ditches. However, these depressions do not exceed 0.9 m, and the roads in some places dominate the area, as are carried out on the embankments. The terrain from the sea level by the cliff up to 600 m inland is shown by the cross sections (Fig. 3, location of profiles in Fig. 2).

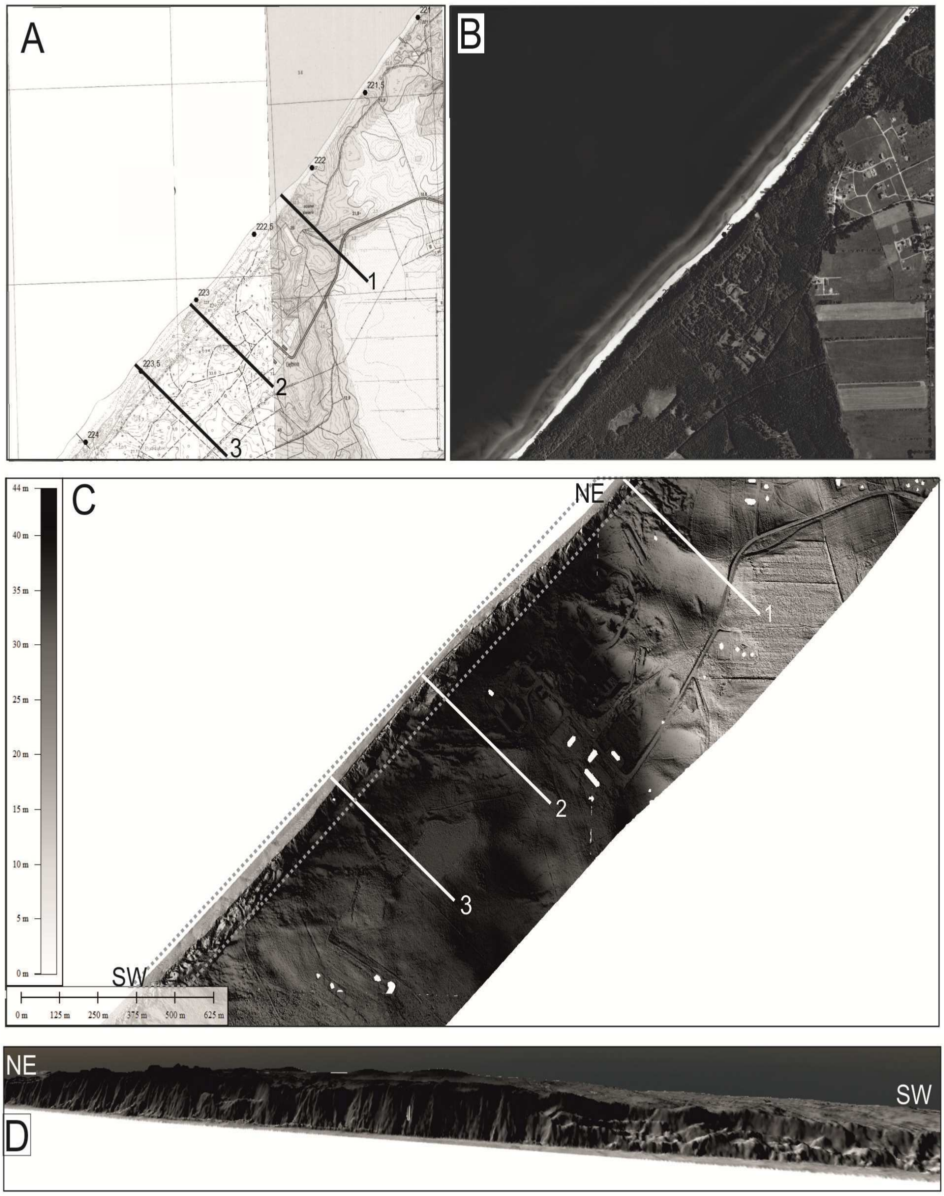

Fig. 2. Study area: A – on Topographic Map of Poland 1:10 000 (1988); B – Orthophotomap (December 2012); C – LiDAR image (December 2012); D – LiDAR image – profile 3d (December 2012); 1, 2, 3– location of profiles

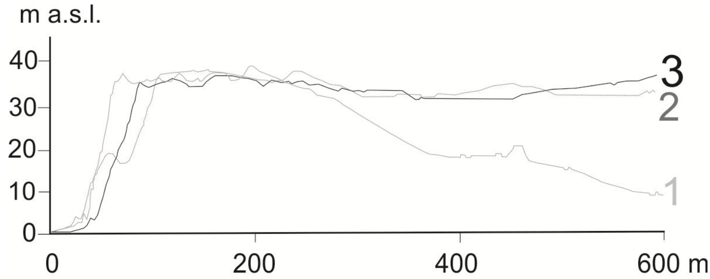

Fig. 3. Cross profiles on the study area generated using LiDAR image, 1-3

In order to compare the changes that have taken place within the beach, slope, and the cliff crown, cross profiles made every 1 km (km 221, 222, 223, 224) generated using LiDAR images No 1-4, 1'-4' and Topographic Map of Poland in scale 1:10 000 (Fig. 4), were applied. The analysis included shorter section (up to 100 m inland), thus the software captured more details of the area profile. Profiles that were based on Topographic Map of Poland in scale 1:10 000 are not as detailed and have more smooth lines. Large declines in the area on the topographic map are marked with edges, often with designation of the decline in meters. Any topographic map does not allow to present the slope sculpture. In contrast, LiDAR images show in detail the structure of the terrain in question. On the slopes, among others, there is visible the accumulation of sedimentary material originating from a landslide or a failure (Fig. 4, profiles 2, 3, and 4). The same is true for the beach. Topographic map of the beach contains almost no contour lines, while LiDAR images illustrate the shape and thickness of the beach. However, topographic map is a valuable source of morphological information. Topographic maps of the area were produced on the turn of nineties of the last century, thus data can be compared with contemporary measurements.

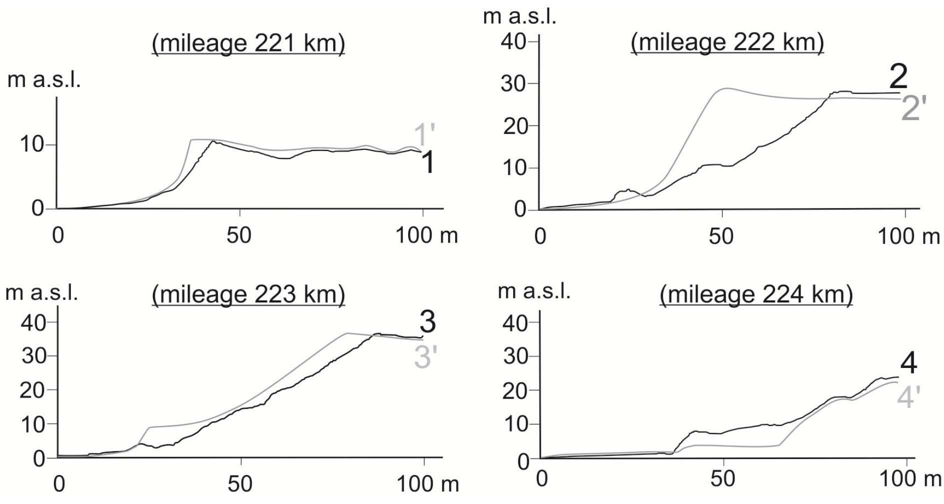

Fig. 4. Cross profiles through Dębina Cliff generated using 1-4 LiDAR image, 1’-4’ Topographic Map of Poland 1:10 000

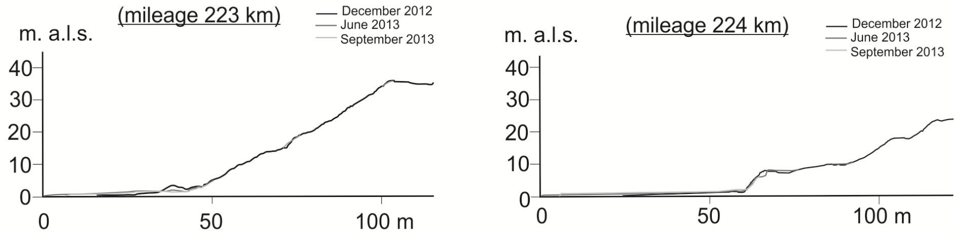

Fig. 5. Cross profiles through Dębina Cliff generated usingin different seasons: profiles December 2012, profiles June 2013, profiles September 2013

The final stage of the work was to analyze the dynamics of the environment and the perception of changes that have taken place between the three raids – period since December 2012 till September 2013. Small changes, despite the very short period of survey, occurred mainly within the beach zone, whereas they are minimal on the slopes and in the crown of cliff. Analysis of the cross profiles reveals that the width of beach was the smallest in December 2012 with difference of several meters (Fig. 5). Between June and September 2013, there were not significant changes in the beach width. Small losses and shifts of sedimentary material were noted in the profiles from slopes and cliff crown in June and September 2013.

CONCLUSIONS

The waterfront zone of studied area, which is located in the central part of the Ustka Gulf, is subject to constant changes. The analysis conducted upon the morphology of selected section of the cliff reflect these changes. Present studies have shown that:

– analysis using LiDAR products are a valuable tool for studying changes in the natural environment; due to great precision and detail; they are a perfect complement to traditional methods of surveying,
– based on GIS software, a wide variety of analyzes can be performed, due to which very detailed information about the morphology of a studied form can be achieved with an accuracy of a few centimeters,
– Dębina Cliff is characterized by varied sculpture; it is a form of steep slopes with many landslides; its height reaches more than 41 m.a.s.l. (including aeolian deposits); the cliff crown is located between ordinates 10-41 m.a.s.l.; width of the beach is variable and ranges from 11 to nearly 60 m wide,
– method for comparing the cross profiles and Digital Terrain Model (DTM) from LiDAR data (ALS), as well as Digital Elevation Model (DEM) created from topographic map from vectorized contour lines along with profiles are excellent tools to conduct research upon the dynamics of forms, as well as changes in the terrain,
– profiles and Digital Elevation Models (DEM) from LiDAR data (ALS) are a very valuable source of morphometric and morphologic data, which allows to see even small landforms that are not visible on the profiles and terrain models built on a basis of Topographic Map of Poland,

– studied waterfront area is characterized by high dynamics of the environment; due to the LiDAR data made at different seasons, it can be monitored, changes can be recorded, and cliff retreat rate can be evaluated; for this type of research, a continuation of the zone monitoring using the laser scanning products is needed.

REFERENCES

Bakuła K., Olszewski R., Bujak Ł., Gnat M., Kietlińska E., Stankiewicz M., 2013. Generalizacja NMT w opracowaniu metodologii reprezentacji rzeźby terenu. (DTM generalization in a development of the methodology for the representation of terrain shape). *Archiwum Fotogrametrii, Kartografii i Teledetekcji*, 25, 19-32, (in Polish).

Dudzińska-Nowak J., 2007. Przydatność skaningu laserowego do badań strefy brzegowej południowego Bałtyku. (Suitability of laser scanning in the Southern Baltic Costal Zone reseach). *Archiwum Fotogrametrii, Kartografii i Teledetekcji*, 17a, 179-187, (in Polish).

Florek W., Grabowska-Dzieciątko A., Majewski M., 2001. Dynamika zmian nadbrzeża morskiego na wschód od Ustki. W: Geologia i geomorfologia Pobrzeża i południowego Bałtyku 4. (Changes of the Baltic offshore to the east of Ustka. In: Geology and geomorphology of the Seashore and Southern Baltic 4). (Ed.) W. Florek, PAP Słupsk, 125-135, (in Polish).

Florek W., Kaczmarzyk J., Majewski M., 2007. Czynniki warunkujące tempo i charakter rozwoju klifów w rejonie Ustki. W: Rekonstrukcja dynamiki procesów geomorfologicznych – formy rzeźby i osady. (Factors conditioning velocity and character of development of cliffs near Ustka. In: Reconstruction of the dynamics of geomorphological processes-landforms and sediments). (Eds) E. Smolska, D. Giriat, UW, PAN, Warszawa, 151-163, (in Polish).

Florek W., Kaczmarzyk J., Majewski M., Olszak I.J., 2008. Zmiany rzeźby klifu w rejonie Ustki jako efekt warunków litologicznych oraz procesów ekstremalnych i przeciętnych. (Lithological and extreme event control of changes in cliff morphology in the Ustka region). *Landform Analysis*, 7, 53-68, (in Polish).

Florek W., Kaczmarzyk J., Majewski M., 2009a. Factors affecting the intensity and character of cliff evolution near Ustka. *Oceanol. Hydrobiol. Stud.*, 37, suppl. 1, 9-25.

Florek W., Kaczmarzyk J., Majewski M., 2009b. Intensity and character of cliff evolution near Ustka. *Quaestiones Geogr.*, 28A/2, 27-38.

Florek W., Kaczmarzyk J., Majewski M., 2010. Dynamics of the Polish Coast east of Ustka. *Geogr. Pol.*, 83, 1, 51-60.

Jasiewicz J., 1999. Glacitektoniczna struktura dupleksu (gardzieńska morena czołowa, klif w Dębinie na zachód od Rowów). W: Ewolucja geosystemów nadmorskich południowego Bałtyku. Glacitectonic duplex structure (Gardno and-moraine, Dębina cliff in the west of Rowy). In: The evolution of geosystems coastal southern Baltic). (Eds) R.K. Borówka, Z. Młynarczyk, A. Wojciechowski, Bogucki Wydawnictwo Naukowe, Poznań-Szczecin, s. 87-93.

Operat techniczny. Monitoring strefy brzegowej Południowego Bałtyku w granicach administracyjnych Urzędu Morskiego w Słupsku, (Monitoring of the coastal zone of the Southern Baltic within the administrative borders of the Maritime Office in Słupsk). 2013. Materiały Urzędu Morskiego w Słupsku, (in Polish).

Orthomaps, 2013. Reference Maritime Office in Słupsk.

Petelski K., 2008. Ewolucja poglądów na budowę geologiczną i powstanie gardzieńskiej moreny czołowej. (Geological structure and the origin of Gardno end-moraine: evolution of ideas). *Landform Ananlysis*, 7, 130-137, (in Polish).

Rudowski S., Wróblewski R., 2012. Potrzeba wzbogacenia toponomastyki brzegu i dna na przykładzie Zatoki Usteckiej. In: Geologia i geomorfologia Pobrzeża i południowego Bałtyku 9. (The necessity of sea coast and bottom nomenclature enhancement on Ustka Bay Example). (Ed.) W. Florek, Wydawnictwo Naukowe AP w Słupsku, Słupsk, 57-59, (in Polish).
Salik K., 1979. Wpływ abrazji na zmiany brzegowe Bałtyku na przykładzie badań klifu Ustka–Orzechowo. (Influence of the erosion on changes of the Baltic coastline, the Ustka–Orzechowo Cliff case study). Instytut Morski, Gdańsk, (in Polish).
Subotowicz W., 1982. Litodynamika brzegów klifowych wybrzeża Polski. (Lithodynamics of Polish cliff coast). Wydawnictwo Zakład Narodowy im. Ossolińskich, Wrocław, (in Polish).
Wężyk P., Borowiec N., Szombara S., Wańczyk R., 2008. Generowanie numerycznych modeli powierzchni oraz terenu w Tatrach na podstawie chmury punktów z lotniczego skaningu laserowego (ALS). (Generation of digital surface and terrain models of the Tatra Mountains based on Airbone Laser Skanning (ALS) point cloud). *Archiwum Fotogrametrii, Kartografii i Teledetekcji*, 18, 651-661, (in Polish).
Zawadzka-Kahlau E., 1994. Determination of changes of South Baltic spits and cliffs. *Bull. Mar. Inst.*, 21, 1, 41-59.

ANALIZA LiDAR NA PRZYKŁADZIE KLIFU DĘBIŃSKIEGO (ZATOKA USTECKA)

Streszczenie

Badania z wykorzystaniem lotniczego skaningu laserowego (ALS – Airborne Laser Scanning, LiDAR – Light Detection and Ranging) są coraz częściej wykorzystywane do analiz środowiska przyrodniczego (Dudzińska-Nowak 2007, Wężyk 2008). Rozwój technologii geoinformatycznych sprawił, że metody lidarowe doskonale uzupełniają metody tradycyjne (geodezyjne i fotogrametryczne), a nawet stanowią dla nich mocną konkurencję. Dzieje się to dzięki wysokiej dokładności i wydajności opracowań. Wynikiem skanowania są tzw. chmury punktów, dzięki którym można wygenerować pomocnicze produkty: Numeryczny Model Terenu (NMT) i Numeryczny Model Powierzchni Terenu (NMPT). Zastosowana technologia sprawia, że wynikami mogą być również zdjęcia wielkoskalowe, na których można dokładnie zobaczyć i poddać analizom nawet niewielkie formy. Taka możliwość pozwoliła na dokonanie dokładnej analizy klifu dębińskiego (km 227, 150-221, 250). Jest to niewielka forma leżąca na wybrzeżu Zatoki Usteckiej około 3 km na wschód od Ustki. Klif opracowano z użyciem zdjęć lidarowych oraz wygenerowanych modeli NMT i NMPT. Pomocne okazały się również ortofotomapy i mapy topograficzne w skali 1:10 000. Zasadniczym celem opracowania było ukazanie przydatności zdjęć lidarowych i produktów LiDAR do badań niewielkich form terenu. Na ich podstawie zostały określone dokładne cechy morfometryczne klifu dębińskiego. Dzięki porównaniu zdjęć wykonanych w różnych okresach możliwe było również określenie zmian, które dokonały się czasie prowadzenia badań. Wykorzystano przy tym zdjęcia lidarowe z trzech nalotów, które odbyły się w następujących terminach: grudzień 2012 (okres zimowy), początek czerwca 2013 (okres późnej wiosny), wrzesień 2013 (okres letnio-jesienny). Pomiary, obliczenia i przekroje poprzeczne wykonano wykorzystując narzędzia GIS w następujących oprogramowaniach: ArcGIS, QuantumGIS oraz Global Mapper.
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