

Article

Determining the Variability of the Territorial Sea Baseline on the Example of Waterbody Adjacent to the Municipal Beach in Gdynia

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Abstract: The purpose of this publication is to analyze the spatial and temporal variability of the territorial sea baseline in sand bottom waterbodies, which were determined twice, in 2016 and 2018, by the Real Time Kinematic (RTK) method. This involves direct measurement of sea bottom coordinates on planned hydrographic sounding profiles using a Global Navigation Satellite System (GNSS) receiver mounted on a pole. The data were the basis for creating Digital Terrain Models (DTM), which were then used to determine the baseline for both measurement campaigns. Subsequently, terrain surface models were compared to determine bathymetry changes in the area under analysis, and an assessment was made of the baseline spatial position change over the previous two years. The measurements have shown considerable spatial and temporal variability of the baseline course along a short section of sandy beach. The territorial sea baseline was very unstable; in some places, it moved by even 20–25 m, landwards and seawards. Therefore, one can suppose that these changes are periodic, and one can conclude that the reliability of the baseline measurements can decrease quite quickly.

Keywords: territorial sea baseline; delimitation of maritime boundaries; geodetic measurements; coastal waters

1. Introduction

Maritime delimitation is an international legal concept which denotes establishing a boundary between states. Regarding maritime areas, a state can determine four types of zones: contiguous zone, continental shelf, exclusive economic zone, and territorial sea [1,2]. Only the territorial sea baseline, which serves as the limit from where the maritime zones are measured, will be analyzed in this paper.

The territorial sea is part of the sovereign territory of the state. It is a belt of coastal waters extending at 12 Nautical Miles (NM) from the baseline (Figure 1) [3,4]. In international regulations related to the maritime industry, two types of baselines are found. The first is a normal baseline, defined as: ... "the low-water line along the coast as marked on large-scale charts officially recognized by the coastal state" [4]. With reference to the Article 5 of the United Nations Convention on the Law of the Sea (UNCLOS), the term "coastline" should be understood as the line where land meets the water. Therefore, the normal baseline is coincident to the coastline (low-water line) as portrayed on the charts officially recognized by the states concerned. The fact that this line is almost always under water makes hydrographic surveys necessary for the accurate determination of the low-water line



(hence the normal baseline) [5]. This line is used where the coast is regular. The second is a straight baseline which can be applied: ... "In localities where the coastline is deeply indented and cut into, or if there is a fringe of islands along the coast in its immediate vicinity" ... "Where because of the presence of a delta and other natural conditions the coastline is highly unstable" [4].



Figure 1. The effect of the baseline to the outer limits of maritime zones. Own study based on: [6].

It is necessary to determine the baseline mathematically in order to establish the outer limit of the territorial sea, which is the state boundary [7–9]. Its determination mainly affects the establishment of the range of sovereign rights of individual states. In the case of Poland, the baseline determination can be considered in the following issues: legal and measurement-related [10–12].

In a legal sense, the outer limit of Poland's territorial sea is established by the domestic legal acts presented in [6]. In view of the dates of these documents (1957–1995) [13] and the variability of the hydrological conditions of the Baltic Sea, it should be stated that Poland currently does not have an actual geographical data set defining the maritime state boundary.

The other issue concerns the methodology of hydrographic measurements on ultra-shallow waters (of the depth below 1 m), i.e., where the baseline is situated [14]. No international standard defines a method of baseline determination, but minimal quality requirements for such measurements are set out in the International Hydrographic Organization (IHO) S-44 standard [15]. Therefore, for many years, baseline measurements have been performed with tachymetric methods [16], satellite methods [17,18], and direct measurements conducted by surveyors on sounding profiles in seawater [19,20]. Over the last dozen or so years, high-resolution satellite images [21,22], Light Detection and Ranging (LiDAR) systems [23], or even Unmanned Surface Vessels (USV) [24,25] have been used to determine the course of the territorial sea baseline.

The purpose of this publication is to analyze the variability of the territorial sea baseline determined twice—in 2016 and 2018—with a geodetic method using a Global Navigation Satellite System (GNSS) receiver on the example of a waterbody adjacent to the municipal beach in Gdynia.

2. Materials and Methods

2.1. Planning Measurement Work

The baseline measurements were carried out in the waterbody adjacent to the municipal beach in Gdynia, which is located in the Bay of Gdańsk. This area is characterized by a typical coastline (straight line sandy section), reinforced with tetrapods and concrete wharves. This is an area with small hydromorphological changes because it is located inside the Bay of Gdańsk, and in its immediate vicinity there is no river mouth that could cause significant changes in the shape of the seafloor. Furthermore, based on long-term research conducted at 35 gauging stations along the Baltic Sea [26], it appears that it is a non-tidal sea because the differences in water levels due to the impact of the tides are small. The minimum tide stood at 3.5 cm at the eastern part of the Bay of Gdańsk (Baltiysk), near the place where the baseline measurements were made.

This research was performed on 23.06.2016 between 08:30 and 18:00, as well as on 19.07.2018 between 11:00 and 14:00. Meteorological conditions that prevailed during the measurements were beneficial, i.e., there was no rain, and the wind did not blow. In order to determine them, short-term weather forecasts were used, which are available on the website: http://www.pogodynka.pl/.

Before research started, the sounding profiles were planned, along which the operator performing the measurement with a GNSS receiver mounted on a pole was supposed to move. Forty main sounding profiles were determined perpendicularly to the shape of the coastline, and the distance between them was 10 m (Figure 2) [27]. The profiles were divided into four sections perpendicularly to the coastline because of the non-linear course of the coast. The above described parallel line method is a common practice used in hydrography because it allows coverage of the entire area with the same accuracy [28,29].



Figure 2. The planning of hydrographic profiles during baseline measurements in Gdynia.

In order to determine territorial sea baseline (according to the Article 5 of UNCLOS Convention), it is necessary to assess the low-water line along the coast as marked on large-scale charts officially recognized by the coastal state [4]. In geographical areas where the tidal range is negligible (for example less than 30 cm) and in non-tidal areas, such as the waterbody adjacent to the municipal beach in Gdynia, the low-water line should be referred to Mean Sea Level (MSL) or another level as closely equivalent to this as is practical and acceptable to Hydrographic Offices [30]. For the purpose of this publication, the low-water line was acquired from the gauging station in the Gdynia marina, situated 200 meters from the measurement site. The minimum water level at the site amounted to 415 cm (on 04.11.1979) and it was referred to the sea level in Kronstadt.

The baseline depth at the measurement time is determined by recording the water level readings. For this purpose, the Institute of Meteorology and Water Management (IMGW-PIB) weather service was used, which provides information on the water levels based on mareograph readings. Under the regulation [31], water levels in Poland can be referred to the Kronstadt vertical coordinate system (PL-KRON86-NH), until 2019, and then to Amsterdam (PL-EVRF2007-NH). The required water level can be determined using the height transformation between the systems PL-EVRF2007-NH and PL-KRON86-NH [32,33]:

$$H_{PL-KRON86-NH} = H_{PL-EVRF2007-NH} - dH,$$
(1)

where:

H_{PL-KRON86-NH}—normal height of a point in the PL-KRON86-NH system [m],

 $H_{PL-EVRF2007-NH}$ —normal height of a point in the PL-EVRF2007-NH system [m], dH—difference of normal heights between the systems PL-EVRF2007-NH and PL-KRON86-NH, which depends on the geodetic latitude (ϕ) and longitude (λ) of a point [m].

2.2. Measurements of the Territorial Sea Baseline

Two measurement campaigns were performed in 2016 and 2018; their purpose was to determine the territorial sea baseline by the geodetic method with a GNSS receiver [34,35]. This research involved an operator conducting the measurement on the submerged beach at predefined depth (Figure 3a). During the first measurement campaign on 23.06.2016, the measurements of the seafloor relief were performed at the following depths: 0 (land-water interface), 20, 40, 60, 79 (baseline), 100 cm. The bathymetric measurements of the waterbody during the second campaign were conducted in a similar manner as in the first series. The gauging station at the site in Gdynia showed 494 cm (on 23.06.2016) and 511 cm (on 19.07.2018) relative to the zero ordinate for gauging station in Kronstadt. These data were the basis for calculating the baseline depth (d_{TSB}) from the following formula:

$$d_{TSB} = H_{CWL} - H_{LWL}, \tag{2}$$

where:

H_{CWL}—current water level in the adopted reference frame [m], H_{LWL}—the lowest water level in the adopted reference frame [m].



Figure 3. Territorial sea baseline measurement (**a**) and recorded measurement points (**b**) by the geodetic method during the second measurement campaign.

The baseline measurements were conducted on 40 sounding profiles planned during the 2016 measurement campaign [20,36]. Since, during the first test series, the operator performing the baseline measurements along the 400 m long section of the beach was doing it for nearly 10 hours, it was decided that the research in the second measurement campaign could be accelerated by increasing the number of team to two members. Two types of GNSS receivers were used in the research: Leica GS15 and Trimble R10. They made it possible to carry out measurements by the Real Time Kinematic (RTK) method, which provides national GNSS geodetic networks (Leica and VRSNet.pl). Thanks to these services, the data were made with the highest possible positioning accuracy of 1–2 cm (Root Mean Square (RMS)). During the first campaign, 313 points were recorded, and 477 during the second (Figure 3b).

At completion of the measurement, the results were processed with Trimble Business Center (TBC) commercial survey software.

3. Results

During measurement, data processing systems were used: Gauss-Krüger projection, Cartesian coordinate system 2000, height system Kronstadt 86, and the quasigeoid model PL-geoid2011 (Table 1).

Parameter	Value	
Country	Poland	
System/zone	2000/18	
Reference ellipsoid	WGS 84	
Semi-major axis of ellipsoid	6378137	
Flattening of ellipsoid	0.00335281067183	
Projection	Gauss-Krüger	
Latitude of origin	0	
Central meridian	18	
False Northing	0	
False Easting	6 500 000	
Scale factor	0.999923	
Azimuth	North	
Grid orientation	Rising northeast	
Height transformation	Geoid	
Geoid model	PL-geoid-2011	
Reference frame	Kronstadt	

Table 1. Processing parameters during territorial sea baseline measurements in the waterbody adjacent to the municipal beach in Gdynia.

Digital Terrain Models (DTM) were developed based on 2016 and 2018 measurement data as Triangulated Irregular Networks (TIN) (Figure 4). A TIN model is created as a result of the triangulation of depth points meeting the Delaunay condition, according to which, a circle determined by three vertices of a triangle cannot contain other depth points, with the exception of degeneracy [37]. Triangle vertices are points of known coordinates. Delaunay triangulation is the dual graph of the Voronoi diagram which has the following property: the distance between each point situated inside a polygon and the nodal point, which is the triangle vertex in the next processing stage, is the shortest [38–40]. It should be remembered that in the TIN method, the high-resolution of the generated DTM model is extremely important. As shown by other studies, the TIN method is more accurate only when the points that were used to generate the DTM model are more concentrated [41–43].



Figure 4. Digital Terrain Models (DTM) of the waterbody adjacent to the municipal beach in Gdynia acquired by the geodetic method in 2016 (**a**) and 2018 (**b**).

In order to analyze changes in bathymetry, a height grid with the basic square of 1×1 m (maximum available resolution) was created based on DTM models. It can be used to compare the normal height (H) of a point during the past two years. The height grid was created using a tool for creating surfaces and height grid, which is available in the TBC software. This function uses the generated DTM model as the base for height interpolation of the point P in the terrain surface, whose projection P' on a horizontal plane lies within triangle A'B'C' (Figure 5).



Figure 5. Illustration of point height determination in a Triangulated Irregular Networks (TIN) model.

The height of the point P is calculated from the formula [44]:

$$H_P = \frac{H_A \cdot S_A + H_B \cdot S_B + H_C \cdot S_C}{S_A + S_B + S_C},\tag{3}$$

where:

H_A, H_B, H_C – normal heights of the triangle ABC,

 S_A , S_B , S_C – areas of the opposite triangles, formed by division of the triangle A'B'C' with line segments connecting the triangle vertices with point P'.

Heron's formula was used to determine the triangle areas (S_A , S_B , S_C). It is used to calculate a triangle area when the lengths of its sides are known. Since the vertex coordinates for the ABC triangle and the rectangular coordinates for point P are given, they can be used to calculate the areas of component triangles. Heron's formula can be noted in the following manner:

$$p = \frac{a+b+c}{2},\tag{4}$$

$$S = \sqrt{p \cdot (p-a) \cdot (p-b) \cdot (p-c)},$$
(5)

where:

p – semi-perimeter of the A'B'C' triangle,

a, b, c – lengths of sides of the A'B'C' triangle.

Creating the height grid resulted in 25244 points for the 2016 model and 21561 points for the 2018 model, which were further used to calculate normal height differences at the same points ($\Delta H_{2018-2016}$). In order to determine the spatial and temporal variability of seafloor relief of the waterbody, only those pairs of points were compared (with the same rectangular coordinates on both DTMs) for which normal heights could be calculated. There were 21322 such pairs of points in the area under study.

In the next stage, a DTM model was created (again using the triangulation model) showing differences in normal heights between points with the same rectangular coordinates (X_{2000} , Y_{2000}). The following formula was used to calculate $\Delta H_{2018-2016}$:

$$\Delta H_{2018-2016} = H_{2018} - H_{2016},\tag{6}$$

where:

 H_{2016} , H_{2018} – normal heights of a point on DTMs based on data acquired by the geodetic method in 2016 and 2018, respectively.

After the height differences between DTM models were generated, a tool for creating contour line, available in the TBC software, was used to mark curves at the following depths: -60 cm, -40 cm, -20 cm, 0 cm, 20 cm, 40 cm (Figure 6). The software generated them as smooth curves using the spline method.



Figure 6. Height differences between DTMs created on the basis of data acquired by the geodetic method in 2016 and 2018.

These data show that the greatest bottom variability in the waterbody adjacent to the municipal beach in Gdynia is observed along the coastline. Differences between normal heights range from –60 to –20 cm (Figure 6). Since the normal heights acquired by the geodetic method in 2016 were subtracted from those measured in 2018, it appears that the coastline moved landwards, which resulted in a decrease in the area of the municipal beach in Gdynia. However, when it comes to the remaining part of the waterbody (not directly adjacent to the coastline), one can see that the variability of the seafloor relief in this area is diversed and ranges from –30 cm to 30 cm, regardless of the distance from the coastline. In order to perform an analysis of bathymetry changes, the waterbody was divided into 12 areas according to height differences every 10 cm (Table 2).

Min. Elevation (m)	Max Elevation (m)	Real Area (m ²)	Percentage of Total Area (%)		
-0.605	-0.600	2.3	0.01		
-0.600	-0.500	172.7	0.82		
-0.500	-0.400	709.6	3.37		
-0.400	-0.300	1227.9	5.83		
-0.300	-0.200	2317.9	11.00		
-0.200	-0.100	3182.2	15.10		
-0.100	0.000	3587.1	17.02		
0.000	0.100	4511.0	21.41		
0.100	0.200	3964.3	18.81		
0.200	0.300	1128.5	5.36		
0.300	0.400	254.6	1.21		
0.400	0.438	12.7	0.06		
	$S_{\rm T} = 21070.7 \ {\rm m}^2$				

Table 2. Division of the waterbody adjacent to the municipal beach in Gdynia with respect to height differences between 2016 and 2018 Digital Terrain Models (DTM).

Table 2 shows that for nearly 2/3 of the terrain area (64.53%), the height changed only slightly (not more than 20 cm), and for nearly 90%, not more than 30 cm. Changes in the normal heights in the remaining waterbody part (11.3% of the total area) were greater than 30 cm, with the majority of this

area being situated along the coast. Apart from the division of the waterbody area with respect to height differences between DTMs, an analysis of changes of its volume was also performed (Table 3).

Table 3. Volume changes of the waterbody adjacent to the municipal beach in Gdynia with respect to height differences between the DTMs.

Min. Elevation (m)	Max Elevation (m)	Erosion Volume (m ³)	Percentage of Total Erosion Volume (%)	Accretion Volume (m ³)	Percentage of Total Accretion Volume (%)
-0.605	-0.600	0	0	0	0
-0.600	-0.500	7.4	0.97	0	0
-0.500	-0.400	47.7	6.28	0	0
-0.400	-0.300	133.1	17.54	1.4	0.08
-0.300	-0.200	211.4	27.85	39.7	2.34
-0.200	-0.100	207.8	27.38	230.3	13.58
-0.100	0.000	117.1	15.43	467.4	27.57
0.000	0.100	34.4	4.53	578.5	34.12
0.100	0.200	0.1	0.01	293.9	17.34
0.200	0.300	0	0	75.7	4.47
0.300	0.400	0	0	8.2	0.48
0.400	0.438	0	0	0.2	0.01
		$V_{TE} = 759.1 \text{ m}^3$		$V_{TA} = 1695.2 \text{ m}^3$	

Table 3 shows that the sand volume increased by 1695.2 m³ and decreased by 759.1 m³ in the area of 21070.7 m² (the municipal beach in Gdynia has a sandy bottom) within the past two years. The landmass balance, i.e., the difference between the total erosion volume (V_{TE}) and the total accretion volume (V_{TA}) shows that the sand volume in the area increased by 936.1 m³. This amount is relatively small because if the excess sand was spread evenly across the entire area, the bottom of the waterbody adjacent to the municipal beach in Gdynia would increase by just 4 cm.

The analyzes also included an assessment of the territorial sea baseline variability within the past two years. The distance between the baseline and the coastline was adopted as the measure of changes of the territorial sea baseline. Since the coastline moved landwards by several meters during the period under analysis, the reference line was determined first, and it was used as the basis to calculate the distance to the baselines. To do this, the coordinates of points measured along the coastline in 2016 and 2018 were used. Subsequently, the data were used to calculate the linear regression coefficients (for the reference line) by the least-squares method from the following formulas [45,46]:

$$b = \frac{\sum (X_C \cdot Y_C) - N_C \cdot \overline{X}_C \cdot \overline{Y}_C}{\sum Y_C^2 - N_C \cdot \overline{Y}_C^2},$$
(7)

$$a = \overline{X}_C - b \cdot \overline{Y}_C,\tag{8}$$

where:

 X_C , Y_C —rectangular coordinates PL-2000 of the points measured along the coastline in 2016 and 2018, N_C —the number of points measured along the coastline in 2016 and 2018,

 \overline{X}_{C} —arithmetic average for the northing coordinates of points measured along the coastline in 2016 and 2018,

 Y_C —arithmetic average for the easting coordinates of points measured along the coastline in 2016 and 2018.

The reference line has the following form:

$$X_{RL} = b \cdot Y_{RL} + a, \tag{9}$$

where:

X_{RL}, Y_{RL} —rectangular coordinates PL-2000 of the points that determine the reference line.

After the reference line was determined, the distances between the approximate line and the baselines were calculated. Lines perpendicular to the reference line were drawn; they can be described by the formula:

$$X_{PL_i} = -\frac{1}{b} \cdot Y_{PL_i} + a_i, \tag{10}$$

where:

 X_{PLi} , Y_{PLi} – rectangular coordinates PL-2000 of the points that determine the i-th line perpendicular to the reference line,

i – numbering of perpendicular lines, increasing southwards.

The formula (10) does not provide the numerical value of parameter a_i because it depends on the distance between successive perpendicular lines. It was assumed for this study that the distance will be 1 m.

The distances between the reference line and the baseline (d_i) were calculated from the coordinates of these lines intersecting with the perpendicular line drawn to the reference line (Figure 7):

$$d_{i} = \sqrt{\left(X_{RL_{i}} - X_{TSB_{i}}\right)^{2} + \left(Y_{RL_{i}} - Y_{TSB_{i}}\right)^{2}},$$
(11)

where:

 X_{RLi} , Y_{RLi} —rectangular coordinates PL-2000 of the reference line intersection points with the i-th line perpendicular to it,

 X_{TSBi} , Y_{TSBi} —rectangular coordinates PL-2000 of the baseline intersection points with the i-th line perpendicular to the reference line.





If the perpendicular line intersected the baseline at more than one point (Figure 8), the coordinates of these lines intersection were averaged first $(\overline{X}_{TSB_i}, \overline{Y}_{TSB_i})$:

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$$\overline{X}_{TSB_i} = \frac{\sum_{j=1}^{k} X_{TSB_{i,j}}}{k},$$
(12)

$$\overline{Y}_{TSB_i} = \frac{\sum_{j=1}^{k} Y_{TSB_{i,j}}}{k},$$
(13)

where:

j—number of the baseline intersection with the i-th line perpendicular to the reference line, k—the number of the baseline intersections with the i-th line perpendicular to the reference line, and subsequently they were used to calculate the distance to the reference line:

$$d_i = \sqrt{\left(X_{RL_i} - \overline{X}_{TSB_i}\right)^2 + \left(Y_{RL_i} - \overline{Y}_{TSB_i}\right)^2},\tag{14}$$



Figure 8. A specific case, in which the line perpendicular to the reference line intersects the baseline at more than one point.

After calculating the distance between the reference line and the baselines (measured in 2016 and 2018), the spatial and temporal variability of the territorial sea baseline were determined by calculating the distance between the baselines ($\Delta d_{2018-2016i}$) using the following formula:

$$\Delta d_{2018-2016_i} = d_{2018_i} - d_{2016_i},\tag{15}$$

where:

 d_{2016i} —distance between the baseline measured in 2016 and the reference line calculated along the i-th line perpendicular to the reference line,

 d_{2018i} —distance between the baseline measured in 2018 and the reference line calculated along the i-th line perpendicular to the reference line.

In Figure 9, there is presented the changes in the territorial sea baseline course in the waterbody adjacent to the municipal beach in Gdynia over two years.

Figure 9 shows that the spatial and temporal variability of the baseline course is quite large. The largest differences were observed in the middle section of the waterbody, where the territorial sea baseline moved landwards by several meters (coastline chainage: 0.125–0.175 km), and even moved by more than twenty meters into the sea (coastline chainage: 0.2 km). Moreover, considerable differences were noted in the southern part of the waterbody (coastline chainage: 0.325 km) between the baselines, from several to even 25 m.



Figure 9. Distances between territorial sea baselines determined by the geodetic method in 2016 and 2018.

Statistically, the baseline has changed with a mean variability of 9.50 m over the two-year period of observation. Thus, it can be claimed that the position of the territorial sea baseline along the waterbody is not stable. This statistical measure was calculated from the following formula:

$$\sigma_{\Delta d_{2018-2016}} = \sqrt{\frac{\sum_{i=1}^{N} \left(\Delta d_{2018-2016_i} - \Delta \overline{d}_{2018-2016} \right)^2}{N-1}},$$
(16)

where:

N-the number of lines perpendicular to the reference line.

At the final stage of the work, it was decided to visualize the course of the baselines, which were determined in 2016 and 2018 (Figure 10). To this end, free Google Earth Pro software was used to map the Earth by superimposing satellite images, aerial photography, and Geographic Information System (GIS) data onto a 3D globe.



Figure 10. The course of the territorial sea baseline of the waterbody adjacent to the municipal beach in Gdynia determined by the geodetic method in 2016 (yellow) and in 2018 (red).

4. Discussion

The purpose of this publication is to analyze the variability of the territorial sea baseline determined twice, in 2016 and 2018, by a geodetic method using a GNSS receiver in the 400 m long waterbody adjacent to the municipal beach in Gdynia. Apart from that, changes of bathymetry in the area under analysis were determined to verify the study results.

These measurements have shown considerable spatial and temporal variability of the baseline course along a short section of sandy beach. Figure 9 shows that the territorial sea baseline is very unstable because, in some places, it moved by even 20–25 m, landwards and seawards. It is particularly noticeable in the middle section of the waterbody, between the coastline chainage of 0.1 and 0.2 km. Such large variability of the baseline may have been caused by successive "shallows" on several profiles (Figure 10). Between the "shallows" there were "depressions" whose depths corresponded to the baseline. Therefore, one can suppose that these local bottom surface elevations change periodically, and one can conclude that the reliability of the baseline measurements can decrease quite quickly. Statistically, the baseline has changed with a mean variability of 9.50 m over the two-year period of observation. Thus, it can be claimed that the position of the territorial sea baseline along the waterbody is not stable.

Table 3 shows that the sand volume increased by 1695.2 m³ and decreased by 759.1 m³ in the area of 21070.7 m² (the municipal beach in Gdynia has a sandy bottom) within the past two years. The landmass balance—i.e., the difference between the total erosion volume (V_{TE}) and the total accretion volume (V_{TA})—shows that the sand volume in the area increased by 936.1 m³. This amount is relatively small because if the excess sand was spread evenly across the entire area, the bottom of the waterbody adjacent to the municipal beach in Gdynia would increase by just 4 cm.

The measured waterbody is adjacent to the Yacht Basin named Mariusz Zaruski in Gdynia, which are approached by vessels with a draft not exceeding 3.20 m. Due to the fact that fine sand is lying on the bottom in this area, this shipping connection may have an impact on the bathymetry changes. North-east and east winds occurring in autumn and winter are another very important hydrometeorological factor; their forces reach even 3–5 on the Beaufort scale. These winds cause the formation of high waves and significant changes in sea levels during this period, which may be up to 1.37 m higher or 0.97 m lower than average. As for the sea currents, in this region along the breakwater, there is a weak north current, which during northern and north-east winds reaches a speed of up to 2 knots [47]. Hence, according to the Authors, the most important hydrometeorological factor that had an impact on bathymetry changes of the waterbody adjacent to the municipal beach in Gdynia and the territorial sea baseline was wind.

The baseline measurements performed by geodetic methods had many limitations, which included low coverage and duration. Therefore, the Authors recommend conducting bathymetric measurements in ultra-shallow waters by the hydrographic method, which involves the use of an unmanned surface vessel (a drone with a dozen centimetre draft) [48–56], on which a GNSS receiver and a Single Beam Echo Sounder (SBES) can be mounted. These measurement techniques enable high precision (1–5 cm (p = 0.95)) hydroacoustic surveys [57–64] performed during a relatively short time. However, one must bear in mind that an unmanned surface vessel cannot measure a whole waterbody [24]. It is caused by the following factors: minimum sounding depth (ca. 30 cm) and vessel draft. Hence, the area between the coastline and the 30/40 cm isobath should be measured by the geodetic method [20] or photogrammetric method with unmanned [65] or manned aircraft [66,67]. Moreover, alternatively, the coastal water depths can be determined by analyzing high-resolution satellite images [68–71].

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