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Specific features of morphodynamic processes in the dumps of the Lithuanian offshore

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Abstract The article analyses the specific features of morphodynamic processes in two dumping sites in the Lithuanian offshore: the deep dump (44–49 m) is situated about 20.4 km south-west of the port gates (at Alksnynė settlement) and the clean soil dump (25–30 m) situated about 11.09 km north-west (at Giruliai settlement). Analysis of collected data revealed that due to low hydrodynamic activity of water mass in the deep dump more than 90% of disposed soil (composed of till – 85%, sand 10% and silt 5%) stabilizes in the discharge area. Relatively small amounts of washed out sediments are transported to the deeper areas (southward and south-westward) and accumulated in the zones of bottom inclination changes. The depths at Giruliai (clean soil dump) are almost half the depth in the deep dump. Because of this the movement of bottom sediments is influenced by the surface waves during extreme storms and hurricanes. In the relatively calm weather period (1994–1998) the greater part of disposed soil (91.3%) stabilized in the discharge area. After the hurricane in 1999 and in the winter in 2001–2002 predominated by extreme storms only 22.4% of disposed soil remained in the site of discharge.

Keywords *Lithuanian offshore, dumping, dredging, sediment.*

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INTRODUCTION

Efficient functioning of many ports in the world, built in the river mouths or on the accumulative coasts, is possible only due to maintenance of sufficient depth in the navigation channels and near the quays. For economic considerations the soil dredged from the port water area is disposed in the sea (according to the data of the International Association of Ports – 86 % in the sea, 11 % in the land and 3 % in some other areas). The storage problem is solved in this way in the Port of Klaipėda and in the neighbouring ports of Riga, Liepaja, Ventspils, Pioniersk, Svetlogorsk, Baltijsk and Gdansk. The problems related with the environmental effects in the dump surroundings can be classified into a few groups on the basis of the London Dumping Convent of 1972 (Review…, 1986) and other works (Research..., 1985; Results..., 1988): oceanographic (physical transformations), chemical and radiation (water and bottom pollution) and ecological (impact on benthos and spawning sites and influence on fishery, recreation, etc.).

Though soil dumping has been a rather long-lasting practice (in some countries even since the 15th–18th centuries) related with many ecological problems it received attention of researchers only in the last quarter of the 20th century (Bokuniewicz, Gordon 1980, Pequeqnat et al. 1981, Alden et al. 1982, Penchev et al. 2003, et al.). In Lithuania the possible impact of soil dumping in the sea on benthos and fishery has been discussed by R. Žaromskis and S. Gulbinskas (1996), and the changes of bottom surface lithology in the dump sites – by S. Gulbinskas (2001). It is impossible to evaluate the character and amplitudes of bottom deformations by analysis of the samples of surface bottom sediments, i.e., by comparison of the lithological composition of disposed soil and background material. Moreover, when the lithological composition of disposed soil and bottom sediments is comparable it is difficult to determine the boundaries of dumped soil dispersion. Therefore, the evaluation of the environmental impact of disposed soil must be combined with morphometric analysis of the bottom. An attempt will be made in the present paper.

STUDY AREA AND OBJECT

A trade and fishing port was established in the Danė River mouth already in the 13th century. Its development was constructed by the Port of Gdansk which was one of the main trading centres of the Hansa Merchant Guild (striving to preserve a monopoly of trading in the Baltic coasts). When the Hansa trading association broke down in 1580 the duke of Prussia Albert Friedrich, protecting the development of the Port of Karaliaučius (Kaliningrad), prohibited the development of the Port of Klaipėda and limited its trading activity. The privilege of navigation returned to Klaipėda in 1657. Ravages wars and fires many times interrupted the development of the port of Klaipėda and the natural port in the Danė mouth was poorly attended before the middle of the 18th century (Žostautaitė 1990).

The first maintenance works were carried out in 1740: cleaning of the Danė River mouth (which was blocked with stones by the Gdansk merchants in 1520), deepening of the river channel and reinforcement of its banks. The port depth reached 3.9 m at that time. More extensive dredging works were assumed in October 1845, after a storm which closed the navigation channel. After the completion of the works the depth of the navigation channel reached 6 m in some places. In 1853 the port obtained a steam dredger (which replaced the horse-drawn one), began an intensive deepening of the navigation channel and moorings and the depth of 5.7 m was kept in the Danė mouth (Žostautaitė 1990). A regular depth of 5 m was kept in the navigation channel of the Klaipėda strait at the beginning of the 20th century and it had reached 6 m by 1923 (Janukonis 1997). In 1925 the navigation

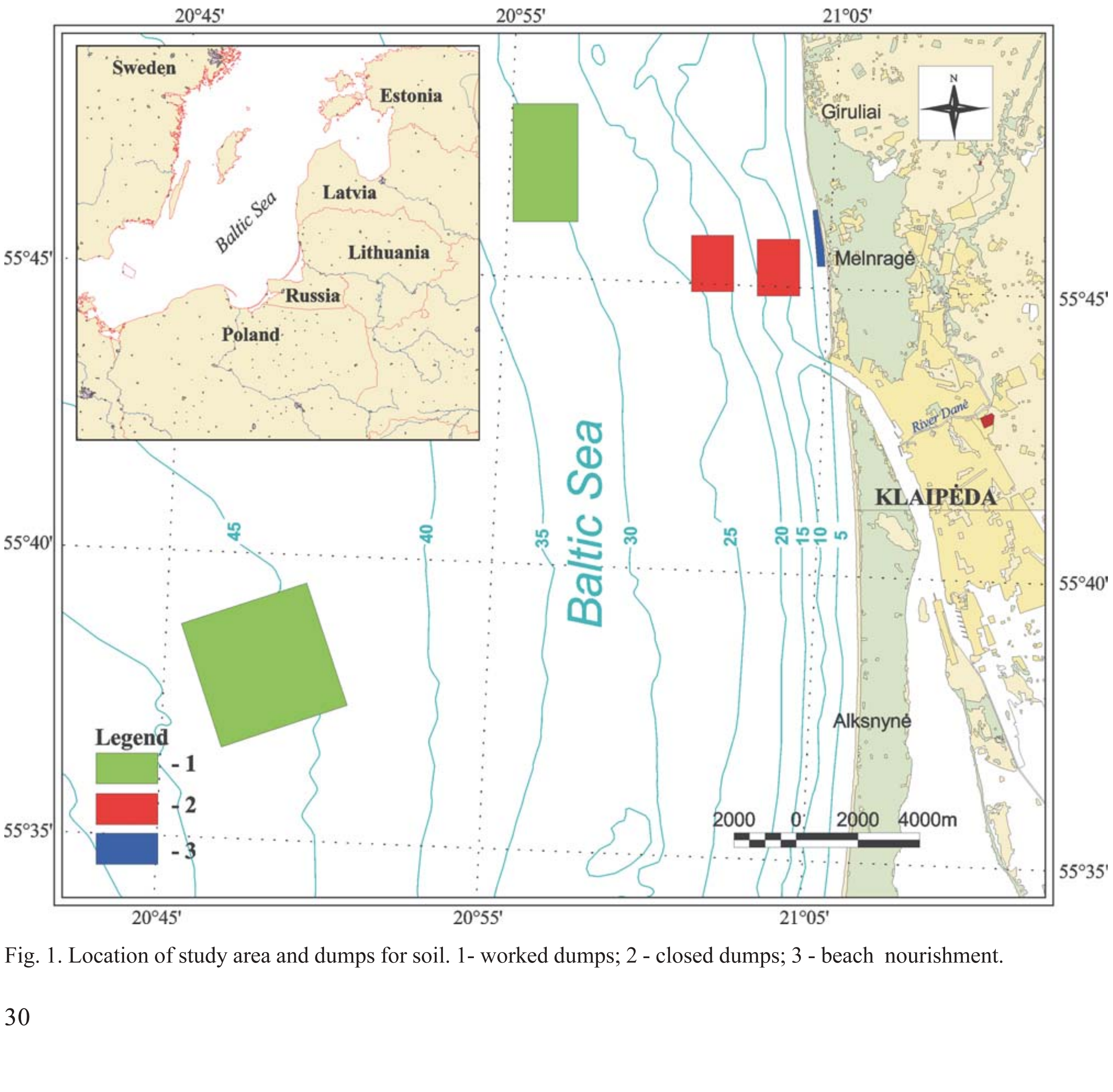

Fig. 1. Location of study area and dumps for soil. 1- worked dumps; 2 - closed dumps; 3 - beach nourishment.

channel was deepened to 6.5 m and in 1939 the depth was 8 m (Kviklys 1991). It must be noted that till the middle of the 20th century dredging works were carried out only in the external and internal entrance channels. At the beginning of the 60-ties the entrance channel was 10–10.5 m deep whereas in 1985–1986, when building of the international terminal was assumed, the depth reached 12–12.5 m. The deepening of the navigation channel to 14 m and its widening to 150 m between the port entrance and Danė mouth was assumed in 1998 in order to be competitive with other East Baltic ports. By now the project depth in the northern part of the port has reached 14 m (Pocius 2004). The bottom is also dredged by some quays (e.g., the depth by the Smeltė quays is increased from 6–8 m to 12 m).

Based on the empirical formula for calculation of the filling rates of the navigation channel (derived by the "Council Marine Channel") Q = 40 (H–5.0) (where Q – annual filling of 100 m wide channel (thou m^3), H – maintained project depth (m)), comparison of bathymetric plans for different years and data from literary sources (Pocius, 2004, Gulbinskas, 2001) we calculated that during the dredging of the port water area and entrance channel (since the middle of the 19th century till October of 2004) the total of 39.43 million m^3 of soil have been removed. Only 1.58 million m^3 (1983–1986) of this amount was stored on the coast – at first in the Kiaulės Nugara Island and later some of it was moved to the Smeltė peninsula and somewhere else. Thus, about 37.85 million m^3 of soil were already dumped in the Lithuanian offshore area. This is a huge amount especially taking into consideration the fact that the average annual input of mineral particles from all rivers falling into the Baltic Sea amounts to 6.155 million t (Geology…, 1976).

Till 1963 the dredged soil (about 6.4 million t) had been disposed in a 10–15 m deep dump about 3.42 km north-west of the port (the distance between the central part of the port gates and the central part of the dump area) (Fig. 1). In order to reduce the filling of the entrance channel (it was assumed that part of the disposed soil returns to the entrance channel) the dump was moved (4.76 km) to a greater depth (18–22 m) in 1963. This dump was used till 1986 and during 1963–1986 about 15.3 million t of soil was disposed in this dump (Gulbinskas 2001).

Beginning in 1987 the dredged soil were disposed in the new dump – about 20.4 km south-west of the port gates (at a depth of 44–49 m). Till October of 2004 were disposed in this dump about 16.2 million m^3 of soil. In order to reduce the soil transportation expenses it was permitted to dispose clean sandy soil in the dump situated closer (11.09 km NW) to the port (at a depth of 25–30 m) (Fig. 1). About 1 million m^3 of soil were disposed in this dump in 1994–2000 (Gulbinskas 2001). A small part (0.537 million m^3) of clean soil was used in 2001 for recultivation of the underwater shore slope (at a depth of 4–7 m) at Melnragė (at a distance of 4.07 km) (Žilinskas et al. 2003).

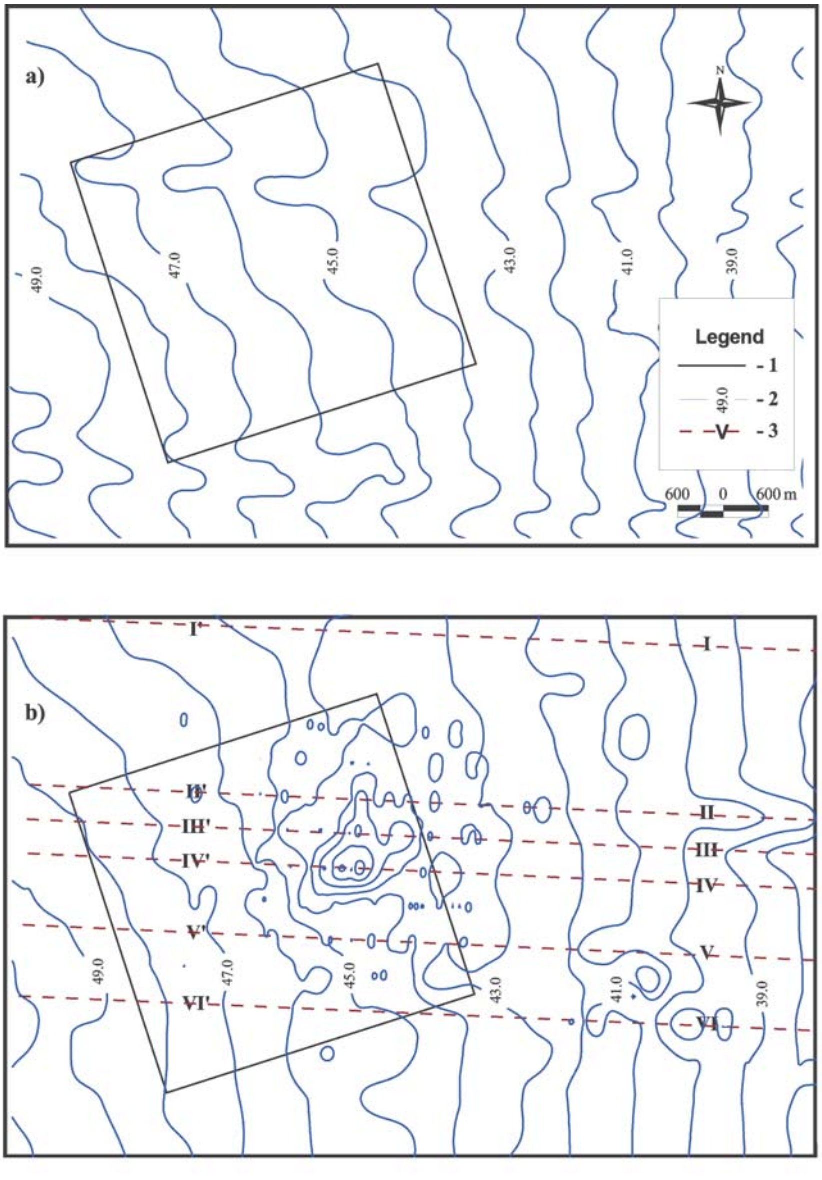

Fig. 2. Bathymetry of dumps area near Alksnynė, a - before exploitation; b - after dumping in 2002. 1 - border of dumps area; 2 – isobath; 3 - profile place and number of profile.

The present work is based on the field data collected by the Department of Marine Research, Institute of Geography, within the programs: Assimilation Capacity of Soil Dumps in the Sea and Environmental Monitoring of the Port of Klaipėda (in 1998, 2001, 2002). The morphometric measuring was done in two operating dumps in the SE part of the Baltic Sea – at Alksnynė (the distant deep dump) and Giruliai (the closer dump) settlements. The area of Alksnynė dump is about 17.8 km² and Giruliai dump – about 7.57 km². The morphometric investigations were made from the research vessel "Vėjas" using echosounder "FURUNO FE-700" (frequency 50 or 200 kHz). The measuring error of bottom relief changes (under favourable hydrometeorological conditions) was 0.10–0.15 m. The vessel co-ordinates were determined using the GPS. The depth of Alksnynė dump was measured in 40 profiles and the depth of Giruliai dump – in 20 profiles.

RESULTS

The dumping site at Alksnynė settlement

About 7.8 million m³ of soil were disposed in the Alksnynė dump before 1998. The disposed soil was composed of mud, till and inequigranular sand and silt. The dumped soil included about 85% of till. The area of noticeable bottom deformations in the Alksnynė dump was 9.85 km² in 1998. Calculation of the volume of bottom deformations (Table 1) revealed that the amount of stabilized sediments in the Alksnynė dump in 1998 was 6.46 million m³ or 82.8% of the total soil. It must be emphasized that before 1996 some of the dredged soil would often be disposed on the way to the dump site (economizing the barge fuel). The first cone-shaped ridges (0.5–1.5 m in height) can be found 4 km from the port gates – at a depth of 28 m. They are found in especially great abundance north of the boundary of official dump region (Fig. 2).

Due to stricter control of the movement of barges since 1996 most of the dredged soil has been disposed in the official dump. Taking into account the amount of soil disposed in the wrong place (about 0.91 million m³) we can conclude that in 1998 about 7.36 million m³ of dumped soil (or 94.4%) were stabilized in the disposal areas. Other 5 million m³ were disposed in the period between 1998 and 2002. In 2002 the bottom transformation areas expanded to 14.5 km² where 11.73 million m³ or 91.6% of disposed soil were stabilized. The area of dumped soil dispersion is, undoubtedly, greater. Moreover it is difficult to determine the small amplitude (0–10 cm) changes with the aid of echosounder. This is pointed out by other authors (Results of the…, 2002). On the other hand these small bottom transformations produce no noticeable influence on the changes of bottom morphology or benthic organisms (Mauer et. al. 1986, Kuznecov 1980, Mokejeva 1988, etc.). The greatest

Table 1. Changes of bottom morphology in the Alksnynė dump in 1998–2002.

Deformation amplitude, m	1998		2002		During 1998 – 2002	
	Area of deformation region, m²	Volume of deformations, m³	Area of deformation region, m²	Volume of deformations, m³	Area changes, m²	Volume changes, m³
Central area						
0,0 – 0,5	6944177	2636237	10475100	4562140	3530923	1925903
0,5 – 1,0	3761880	1375510	6344490	2449842	2582610	1074332
1,0 – 1,5	1851447	659832	3584750	1222644	1733303	562812
1,5 – 2,0	851635	337194	1461900	554672	610265	217478
2,0 – 2,5	511403	220178	791126	326733	279723	106555
2,5 -3,0	372823	159621	524911	199168	152088	39547
3,0-3,5	268539	107191	283837	118701	15298	11510
3,5 - 4,0	164483	57719	193798	77107	29315	19388
4,0 -4,5	72523	24659	117782	39268	45259	14609
4,5 – 5,0	29274	7285	45010	7502	15736	217
> 5,0			3817	636	3817	636
South area						
0,0 – 0,5	124141	112998	881661	364561	757520	251563
0,5 – 1,0	33870	5645	586445	241208	552575	235563
>1,0			385234	64206	385234	64206
Southwest area						
0,0 – 0,5	1091530	668501	1073050	174617	-18480	-493884
0,5 – 1,0	491202	81867	382061	63677	-109141	-18190
Solitary hills						
0,0 – 1,5	1700000	910000	2040000	1266000	340000	356000
Total		7364437		11732682		4368245

bottom deformation region is situated north-east of the relative dump centre. In 1998 its area was about 6.94 km², whereas in 2002 it already reached 10.5 km². The bulk mass of disposed soil (about 5.6 million m³ in 1998 and 9.6 million m³ in 2002) is localized in this region. The highest dissection of the bottom relief was observed in the central part of the region where the absolute height of solitary hills in 1998 often reached 4–4.5 m and in 2002 at the same place even exceeded 5 m. The bottom inclination diversity is also conspicuous in the region under consideration (Fig. 3).

Technogenic hills occupying small areas are widely spread almost over the whole water area north and north-east of the relative dump "centre" and 1.5–4 km from the boundary of dump region. Some places of these hills are 0.5–1.5 m in height and from 30 to 300 m in width. These hills are separated by areas without any bottom deformations. Due to large spread terrain and small area occupied by these hills some of them are not noticeable in the bathymetric plans. However, the total area and volume of such hills were calculated using echograms. Detailed data of the changes of bottom morphology in the Alksnynė dump in 1987–2002 are given in Table 1.

The dumping site at Giruliai settlement

The Giruliai dump (exploited since 1994) is often referred to the clean dumps sand (composed of little polluted or clean sand and silt). About 0.979 million m³ of sand were disposed in this dump between 1994–2000: since the beginning of exploitation till the first series of measuring (24 11 1998) about 0.6 million m³ (1995 – 243461 m³, 1996 – 104711 m³, 1997 – 127369 m³, 1998 – 125125 m³) and till the second series of measuring (26 08 2002) another 0.38 million m³ (1999 – 60000 m³, 2000 – 318338 m³).

Basing on the data of 1998 it was determined that 549320 m³ (or 91.3 %) of disposed sand were stabilized in the Giruliai dump and the area with noticeable deformations occupied 1.55 km². In 2002 the amount of stabilized sand was only 219236 m³ (or 22.4 %) of the disposed sand (despite extra 0.38 million m³ that had been disposed) and the area with noticeable bottom deformations reduced to 0.749 km² (Table 2).

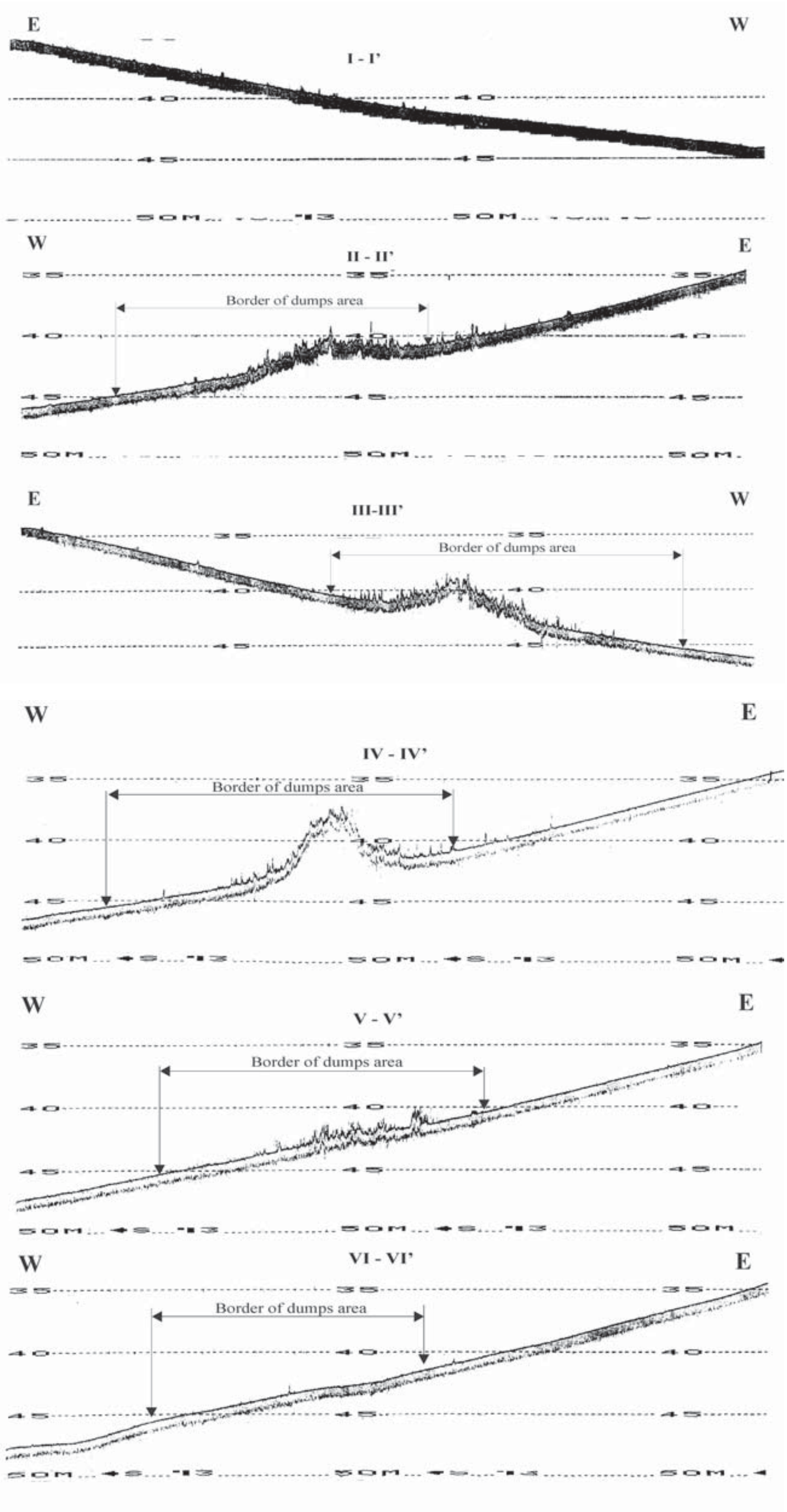

Fig. 3. Profiles of bottom in the Alksnynė (a, b) dump area. Location of profiles are shown in the Fig. 2.

Table 2. Changes of bottom morphology in the Giruliai dump in 1998–2002.

Deformation amplitude, m	1998		2002		During 1998 – 2002	
	Area of deformation region, m^2	Volume of deformations, m^3	Area of deformation region, m^2	Volume of deformations, m^3	Area changes, m^2	Volume changes, m^3
0,0 – 0,25	1548540	306608	748480	139037	-800060	-167570
0,25 – 0,50	930098	175691	384096	64136	-546002	-111555
0,50 – 0,75	499498	65610	147586	15923	-351912	-49689
>0,75	84623	1410	8369	140	-76254	-1270
Total		549320		219236		-330084

Before the beginning of exploitation (in 1994) the isobaths in this region had been relatively parallel (Fig. 4). After the beginning of sand dumping bottom deformations were recorded in the central part of the region between 26 and 31 m isobaths. The maximal amplitude of bottom deformations in the Giruliai dump was 0.8 m (Fig. 5). The water area with bottom deformations is ellipse-shaped. Its NS diameter in 1998 was about 2000 m and EW diameter – 1100 m and in 2002 – 1200 and 920 m respectively (Fig. 4).

DISCUSSION

The amount of disposed soil and its migration from the dump are the main questions to be answered while analysing the problems of physical changes in the dumping areas. The disposed soil dispersion takes two stages: soil dispersion at the moment of disposal and settled soil dynamics.

Soil dispersion at the moment of disposal is predetermined by its lithological composition, hydrodynamic conditions and sea depth in the dump area. This process is fairly well studied and the created models (Clark et. al. 1971, Gordon 1974, Pequegnat et. al. 1981, Penchev et. al. 2003, et. al.) can be easily adapted to different regions (Fig. 6).

Meanwhile the settled soil dynamics is strongly influenced by specific local conditions (bottom morphology and lithology, water mass circulation, etc.) of the dump area. For this reason the disposed soil dispersion is analysed by comparison of two dumps with different local conditions.

The dump area at Alksnynė settlement

The lithological composition of disposed soil (till accounts for about 85 %, sand – 10 % and silt – 5 %) and rather great depth in this part of the sea (44–49 m) are responsible for great stabilization (more than 90 %) of the settled material in the dump site (Figs 2, 3 and 7).

Field data showed that there are two main directions of washout from the central area – southern and south-western. The washed out material accumulates between 49–50 m isobaths in the south-western area and in the 1.0–1.5 m deep depression situated between the 46 and 45 m isobaths in the southern area (Fig. 7). These areas have developed as a result of sediment migration rather than soil disposal. This is proved by a

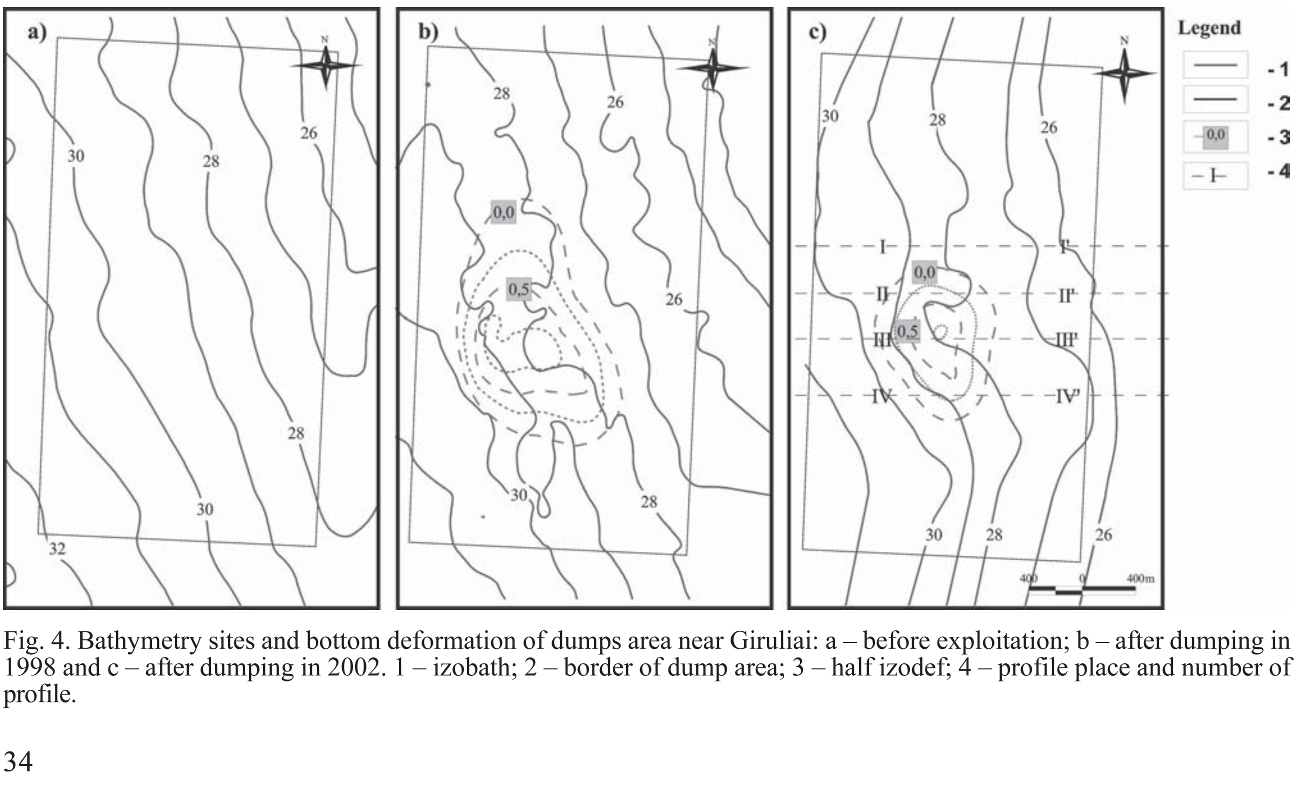

Fig. 4. Bathymetry sites and bottom deformation of dumps area near Giruliai: a – before exploitation; b – after dumping in 1998 and c – after dumping in 2002. 1 – izobath; 2 – border of dump area; 3 – half izodef; 4 – profile place and number of profile.

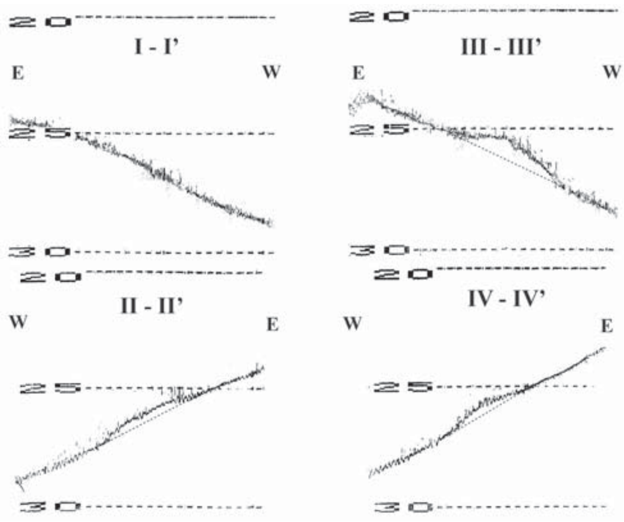

Fig. 5. Profiles of bottom in the Giruliai dumps area. Location of profiles is shown in the Fig. 4.

number of evidences: the form of the areas, low dissection of relief, absence of till hills, and large bottom areas between them without any deformations. It should also be pointed out that the distance of these areas from Klaipėda port is greater than the distance of the main dump even as the common practice was to dispose soils at a possibly shorter distance from the port. The absence of till in the mentioned areas (dominant in the disposed soil) is proved by lithological examination of the bottom sediments – the mentioned areas are accumulations of fine-grained sand and silty fine-grained sand (Gulbinskas 2001). The S and SW directions of washed out material migration can be explained by a specific pattern of inclinations in the study area. The depth in the Alksnynė dump is increasing in S and SW directions. Before the exploitation the average EW inclination of the dump bottom had been i = 0.00096 and NS – i = 0.00023. When during the exploitation time the soil piles reached 4–5 m in height the average inclinations in the indicated directions became even greater (i = 0.0023). It must be noted that similar inclinations had to develop in the eastern and northern slopes of the central area. It seems likely that considerably smaller amounts of washed out material move in these directions settling at the slope bottom where the artificial deepening of the bottom is replaced by natural shoals.

Thus, the accumulation of washed out soil in the SW area between the 49 and 50 m isobaths is conditioned by variations of bottom inclinations. Namely in this place the bottom is even more flat and the inclination reduces to 0.00018, i.e., the bottom slope in this place is by 5.3 times more flat. Sediment accumulation in the southern area is conditioned by a depression which acts as a sediment trap.

Generalizing we can say that due to relatively low hydrodynamic activity (wind induced waves produce slight influence in deep areas) in the near-bottom layer the particles of fine-grained sand and silt, stirred by the near-bottom currents and affected by gravity force and pressure, are transported only toward the deeper areas (in S or SW directions).

Low hydrodynamic activity in this area is proved by relatively small volumes of washed out material (if it is compared with the amounts of disposed soil). The total amount of sediments accumulated in the both areas in 2002 was about 0.9 million m^3 or 7.7 % (in the SW area – 0.24 million m^3, S area – 0.67 million m^3) of the total localized amount. It should be pointed out that taking into account the given recommendations soil disposal in the central and north-western parts of the dumps was activated in 1998–2002. This resulted in the change of the form of the areas (Fig. 7) and in their amounts of sediments: in the S area the amount of sediments continued to increase whereas in the SW area it began to decrease. In our opinion the wash out of sediments from the SW area is related with the change of the spread area. The activated soil dumping in the NW part reduced the sediment movement in SW direction but increased it in NW direction. It is likely that a new area began to develop at the 49–50 m isobaths in the NW part. Unfortunately the measuring area did not include this part of the region.

The dump at Giruliai settlement

The nature of movements of sediments in the Giruliai dump is different from the dispersion in the Alksnynė

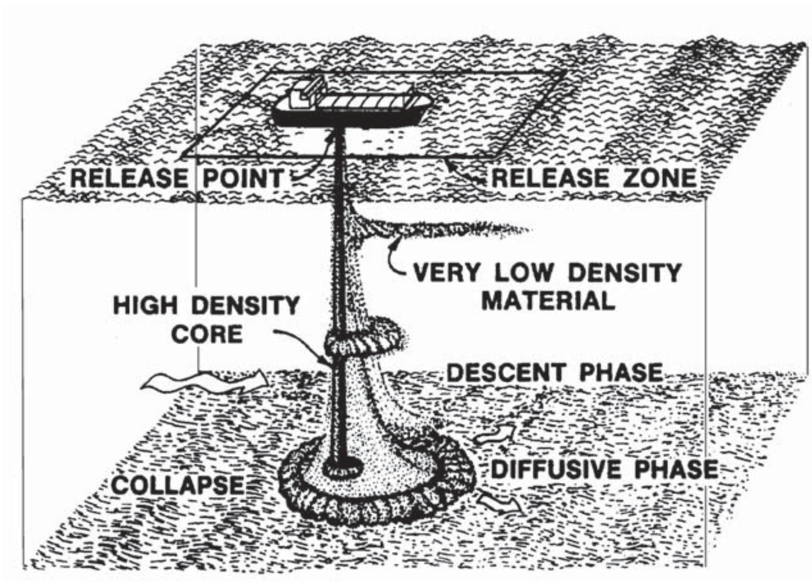

Fig. 6. Transport processes during open-water disposal (after Pequegnat et. al. 1981).

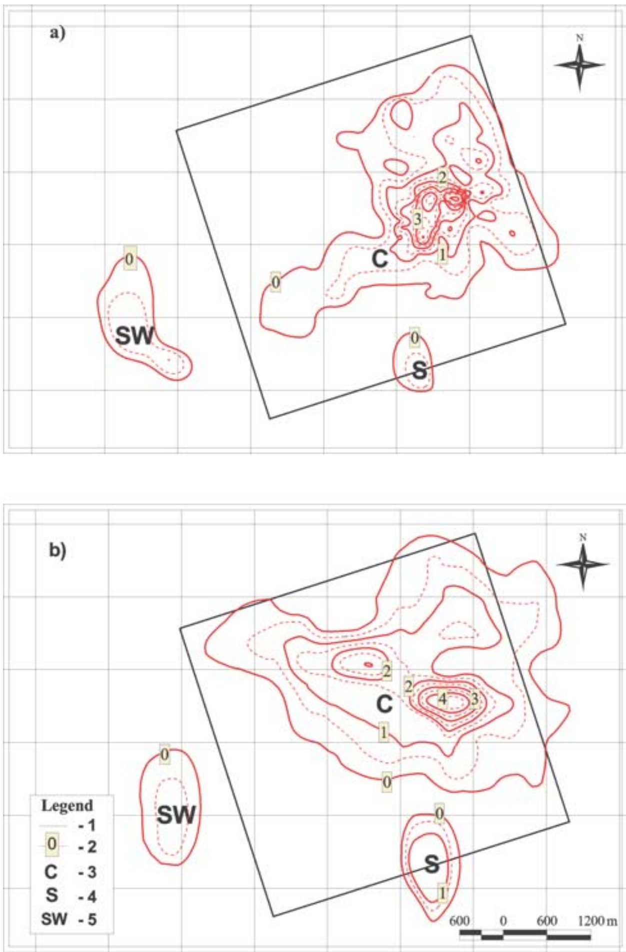

Fig. 7. Bottom deformation of dumps area near Alksnynė: a - 1998, b – 2002. 1 - border of dumps area; 2 – izodef; 3 - central area; 4 - south area; 5 - southwest area.

is slightly reducing). Dispersion of sediments along the isobaths in the Giruliai dump is also proved by lithological analysis (Gulbinskas 2001) which helped to determine that the identified dispersion area has a shape of extended ellipse along isobaths, whereas sediment transport to deeper areas is dominant in the Alksnynė dump.

It should be noted that the more intensive soil dispersion in the Giruliai dump is also predetermined by the lithological composition of disposed soil – traction of sand particles is weaker than that of till particles.

CONCLUSION

Analysis of collected data revealed that due to low hydrodynamic activity of water mass in the deep dump more than 90% of disposed soil (composed of till – 85%, sand – 10% and silt – 5%) stabilize in the discharge area. Relatively small amounts of washed out sediments are transported to the deeper areas (southward and south-westward) and accumulate in the zones of bottom inclination changes. The depths at Giruliai (clean soil dump) are almost half the depth in the deep dump. Because of this the movement of bottom sediments is influenced by the surface waves during extreme storms and hurricanes. In the relatively calm weather span (1994–1998) the greater part of disposed soil (91.3%) stabilized in the discharge area. After the hurricane in 1999 and in the winter in 2001–2002 predominated by extreme storms only 22.4% of disposed soil remained in the site of discharge. The area with noticeable bottom deformations reduced almost twice (from 1.55 to 0.749 km^2). The other difference is related with the intensive sediment transport along the isobaths instead of toward the deeper areas (as in the deep dump). Though the bottom inclinations in the EW direction are 3.3 times as great as in the NS direction the sediments tend to move along the isobaths instead of toward the deeper areas

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