The Sanitary Quality of Water and Sandy Sediments of Selected Streams and the Coastal Area of Gdańsk Bay

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Abstract

This paper presents results of bacteriological investigations concerning coastal seawater and sandy sediments in the Three-city region at the outlet of four streams: Kacza (KaS), Swelina (SwS), Grodowy (GS) and Kamienny (KmS). The numbers of facultative psychrophilic bacteria, mesophilic bacteria and indicator bacteria (coliforms, fecal coliforms, fecal enterococci) were determined. It was found that all streams are carrying fecal bacteriological pollution of human and animal origin which contributes to poor quality of coastal seawater and sandy sediments. The lowest sanitary quality was KaS water, where the number of all indicator bacteria, as a rule, exceeded admissible levels. In sandy sediments of the estuaries of all four streams the average number of indicator bacteria was about one order of magnitude higher than in water. Enterococcus was the bacterial indicator that exceeded single water or sediment sample standards most often.

Keywords: stream and costal water, sandy sediment, bacteriological pollution, indicator bacteria.

Introduction

The coastal zones of the Gulf of Gdansk appear to be very attractive recreation areas. However, enhancement of urbanization of the nearby area has had a negative effect on this environment, especially on the sanitary quality of bathing places located in the region. The microorganisms of fecal origin, including pathogenic ones, are mainly discharged to the coastal zone by wastewater, streams and rainwater run-off. In spite of limited survival rate of bacteria of fecal origin in the marine environment, the constant inflow of these microorganisms creates serious danger to people using the coastal waters for recreational purposes.

Recreational water quality programs worldwide restrict access to recreational waters based on the concentrations of indicator bacteria presence. Governmental and environmental organizations use these monitoring data to take regulatory actions or to grade the recreational water quality at a given beach [1].

In Poland sanitary quality of bathing waters is monitored according to Regulation (2002) [2]. There are, however, no legal regulations demanding any control of sanitary quality of sand and sandy sediments in beach areas used for recreational purposes.

The aim of this study was the evaluation of bacteriological quality of water and sandy sediments of selected streams and costal areas of the Three-city beaches located in the area of inflow of these streams.

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Table 1. Obligatory bacteriological classification of bathing water in Poland [2].

Bacteriological indicator/ analyzed volume	The highest admissible value (recommended value)
Number of *E.coli* bacteria or fecal coliforms / 100ml	1,000 (100)
Number of coliforms / 100ml	10,000 (500)
Number of fecal enterococci / 100ml	400 (100)
Salmonella / 1000ml	0

Materials and Methods

Study Area

The catchment area of analyzed streams — the Kacza River (KaS), Swelina Stream (SwS), Kamienny Stream (KmS) and Grodowy Stream (GS) — are situated at the southern edge of the Oliwa-Darzlubie Forests, in the Seashore Landscape Park area. All of the streams flow into the Bay of Gdansk, between Sopot and Gdynia (Fig. 1a). The most bacteriologically polluted streams in this area are: KaS characterized by high fluctuations of average annual flows (a. a. f. 0.77 – 1.3 m^3/s) and KmS (a. a. f. 0.046 – 0.053 m^3/s) [3]. The sanitary quality of SwS waters (a. a. f. 0.012 – 0.03 m^3/s) has radically improved after construction of a retention reservoir and vegetated ground filter [4]. The average annual flow of GS is in the range 0.015 to 0.018 m^3/s [5].

Location of Sampling Points

The samples of water and sediments were collected from the following four streams: KaS, SwS, KmS, GS and in the coastal area, 20 m to the right of the estuary (sampling points Ka1, Sw1, Km1, G1) and 20 m to the left (sampling points Ka2, Sw2, Km2, G2) (Fig. 1).

All water samples from the streams were collected at 20-50 cm beneath the water surface. In the case when water level was lower than 20 cm, the samples were collected 5 cm above the bottom. The samples of sand were collected from the surface layer of sediments. All the water and sandy sediment samples were taken using sterile samplers and were transported in cool containers at 10°C. The bacteriological tests were carried out within two hours of collection.

In the period from March to July 2001 eight series of sampling in the area of SwS and the KaS and nine series

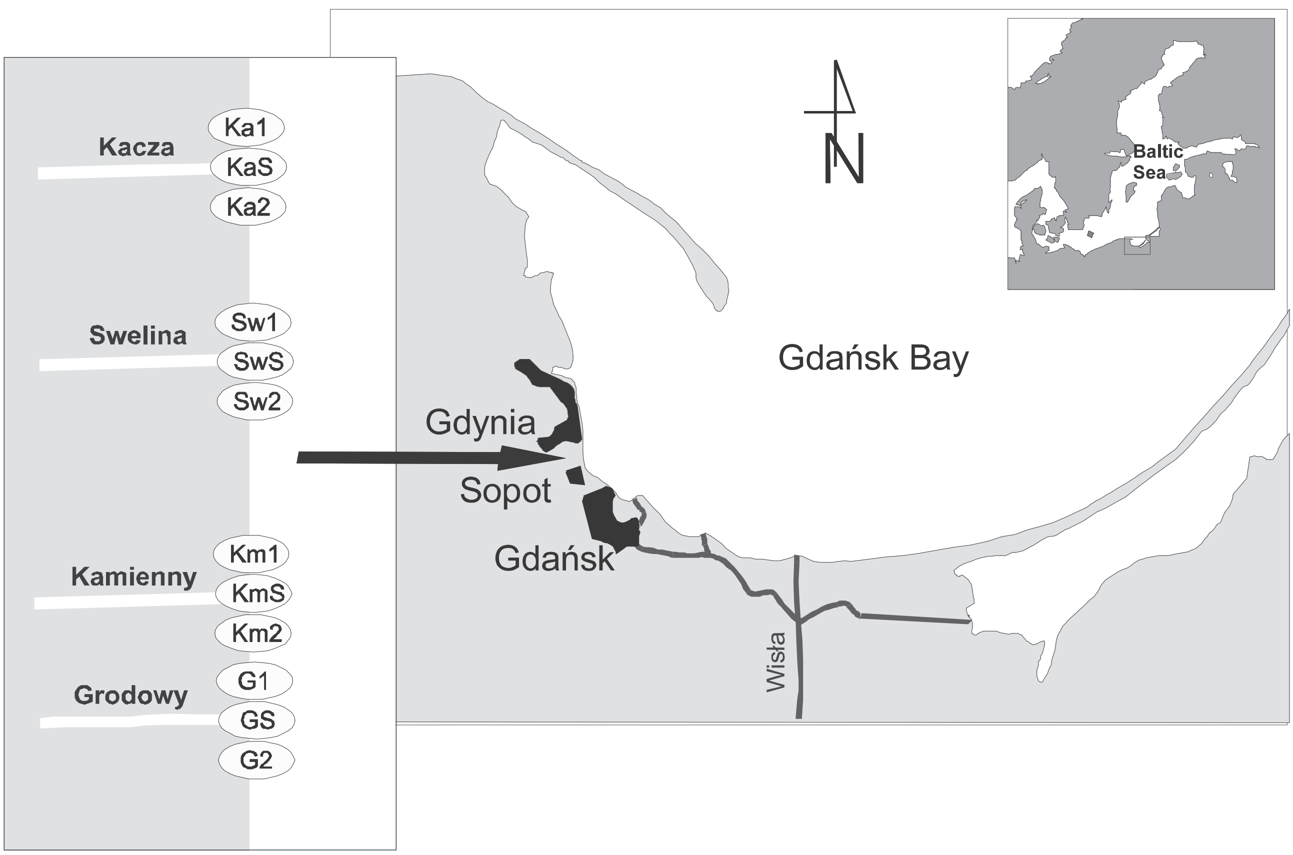

Fig. 1. Study area and checking of sampling points.

in the area of KmS and GS were performed. Altogether, 104 samples of water and 104 samples of sand were collected.

Bacteriological Analyses

A number of facultative psychrophilic, mesophilic and MPN of coliform bacteria, fecal coliform bacteria and fecal enterococci was determined.

Facultative psychrophilic and mesophilic bacteria were determined using nutrient agar at 20°C for 72 h and at 37°C for 24 h, respectively. Fluorocult LMX-Broth nutrient medium, modified acc. to Manafi and Ossmer (Merck) for simultaneous detection coliforms and fecal coliforms, was used [6-9]. High nutritional quality of the broth enabled growth rate of coliforms and by the presence of lauryl – sulfate in large extent inhibits the growth of gram-positive bacteria. Two specific substrata chromogenic: 5-bromo-4-chloro-3-indolyl-β-D-galactopyranoside (X-GAL), which is cleaved by coliforms to blue-green product, and the highly specific for fecal coliforms (producing β-glucoronidase), fluorogenic: 4-methylumbelliferyl-β-D-glucoronide (MUG) are present. Bacteria were cultured for 24 hours at 37°C. In the case of a positive reaction for coliforms the broth turned blue – green in color (X-GAL reaction). Fecal coliforms were distinguished by the presence of β-D-glucoronidase (more specific than lactose fermentation)[10], which decomposes fluorogenic substrate – MUG. In the case of the presence of fecal coliforms the light blue fluorescence of the methylumbelliferyl in the broth (MUG – reaction) was visible under UV light (366 nm). The MUG positive tubes were confirmed for the presence of fecal coliform by indole with Ehrlich liquid. This medium was used in previous investigations in this region [11,12]. Fecal enterococci were determined using Chromocult Enterococci Broth nutrient medium (Merck) at 37°C after 24h incubation.

Calculation and Evaluation of Results

The quantitative and graphical interpretation of results was carried out using Excel and Statistica software. The results were presented in a semi-logarithmical scale denoting the colony forming units (CFU) of total count of facultative psychrophilic and mesophilic bacteria in 1 ml of water or in 1 g of dry sand mass. The coliforms, fecal coliforms and fecal enterococci were indicated at the most probable number (MPN) in 100 ml of water or in 100 g of dry sand mass. The geometrical means, maximal, minimal values and 25-75 percentiles for the total investigation time were determined.

The sanitary quality of water, sand beach and sandy bottom sediments were evaluated according to Regulation [2].

Results

The Facultative Psychrophilic and Mesophilic Bacteria in Water and in Sandy Sediments

The water of KaS and shoreline sites (Ka1 and Ka2 sites) contained the highest facultative psychrophilic bacteria levels. In this area the lowest fluctuations of results (min-max) from $1.0x10^3$ to $3.2x10^4$ CFU/ml occurred. Geometrical average value (GA) ranged from $3.4x10^3$ to $1.0x10^4$ CFU/ml (Fig. 2a). On the contrary, the highest fluctuations of bacteria number ranged between $3.0x10^1$ and $5.8x10^4$ CFU/ml and the lowest GA values ranging from $5.3x10^2$ to $2.0x10^3$CFU/ml in GS site and shoreline sites (G1 and G2) were noted.

Geometrical average value (GA) of facultative psychrophilic bacteria in water of two other streams and shoreline sites of SwS and KmS did not exceed $2.6x10^3$-$4.0x10^3$ CFU/ml and $1.8x10^3$ – $2.3x10^3$ CFU/ml, respectively.

On average, the number of facultative psychrophilic bacteria at bottom sediments was up to one log_{10} higher than in the water (Fig. 2b).

The number of mesophilic bacteria in water samples from all streams changed in the range of $6.0x10^1$ to $7.9x10^2$ CFU/ml and from $1.4x10^2$ to $6.4x10^2$CFU/g d. m. of bottom sediments, with the exception of the bottom sediments in the KaS zone, where bacteria numbers were from 5 to 10 times higher (Fig. 2 c, d).

The Indicator Bacteria in Water and in Sandy Sediments

The highest GA of coliforms both in water, ranging from 2.6 x 10^3 to 8.6 x 10^3/100 ml (Fig. 3a), and in sandy sediments, from 2.3 x 10^3 to 4.5 x 10^4/100g d. m. (Fig. 3b), were observed in KaS, Ka1, Ka2. The admissible value of coliforms for bathing water in 62% of water samples and in 88% of bottom sediment samples, mainly at KaS and Ka2 sites were exceeded.

The zones of SwS, Sw1, Sw2 and KmS, Km1, Km2 were less polluted. The MPN of coliforms ranged from 8.0 x 10^2 to 5.0 x 10^3/100ml in water, and from 3.5 x 10^3 to 4.7 x 10^3/100 g d. m. in bottom sediment, and from 9.8 x 10^2 to 1.5 x 10^3/100 ml in water, and from 1.3 x 10^3 to 2.8 x 10^3/100 g d. m. in bottom sediment, respectively (Fig. 3a, b). The admissible value (for bathing waters) was exceeded only in 14.3% water samples and 28.6% bottom sediments samples at SwS zone, and in zone of KmS 22.2% and 14.8% samples, respectively.

The lowest levels of coliforms in the zone of GS, G1, G2 were occurred (Fig. 3a, b). Only 3.7% of water samples and 14.8% bottom sediment samples exceeded the admissible value.

Similarly, the highest numbers of fecal coliforms (from 3.0 x 10^2 to 2.5 x 10^3/100 ml in water, and from 3.8 x 10^2 to 2.0 x 10^3/100 g d. m. in sediment) were detected in the

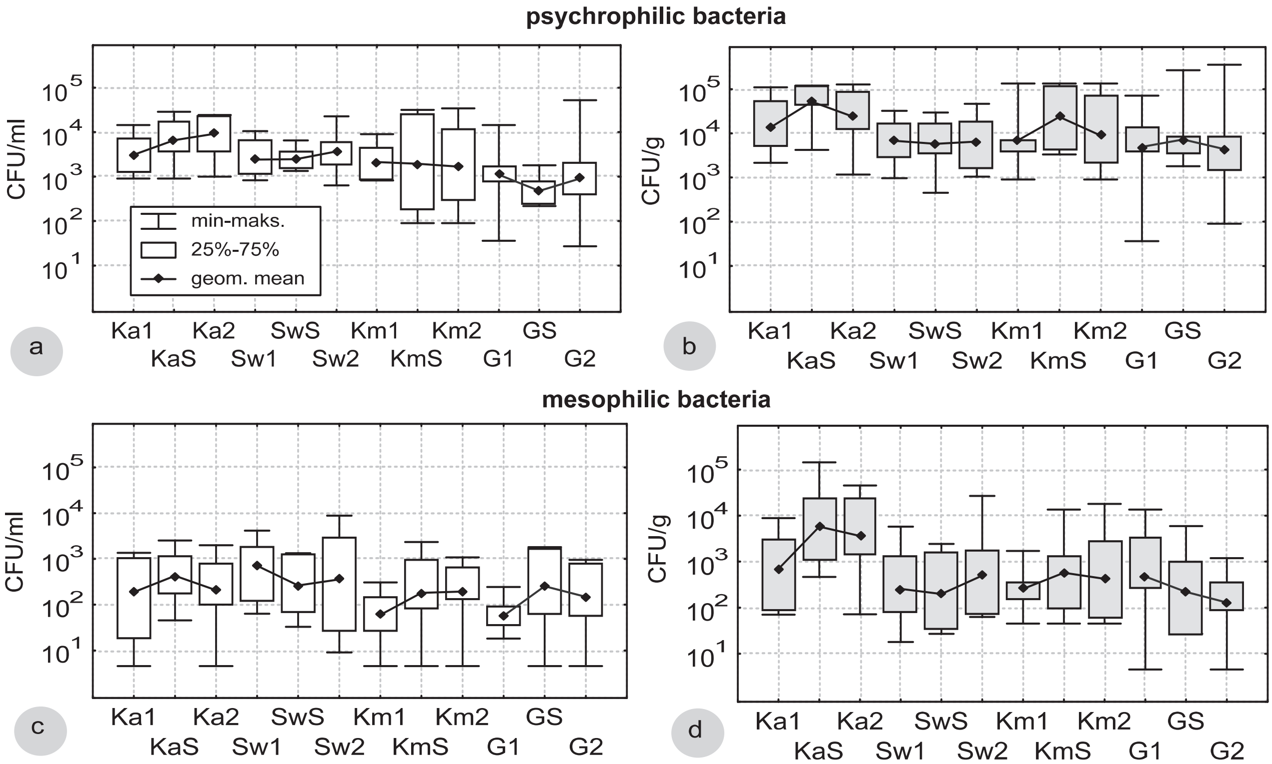

Fig. 2. The number of facultative psychrophilic and mesophilic bacteria in the water (a, c) and in the sandy sediments (b, d).

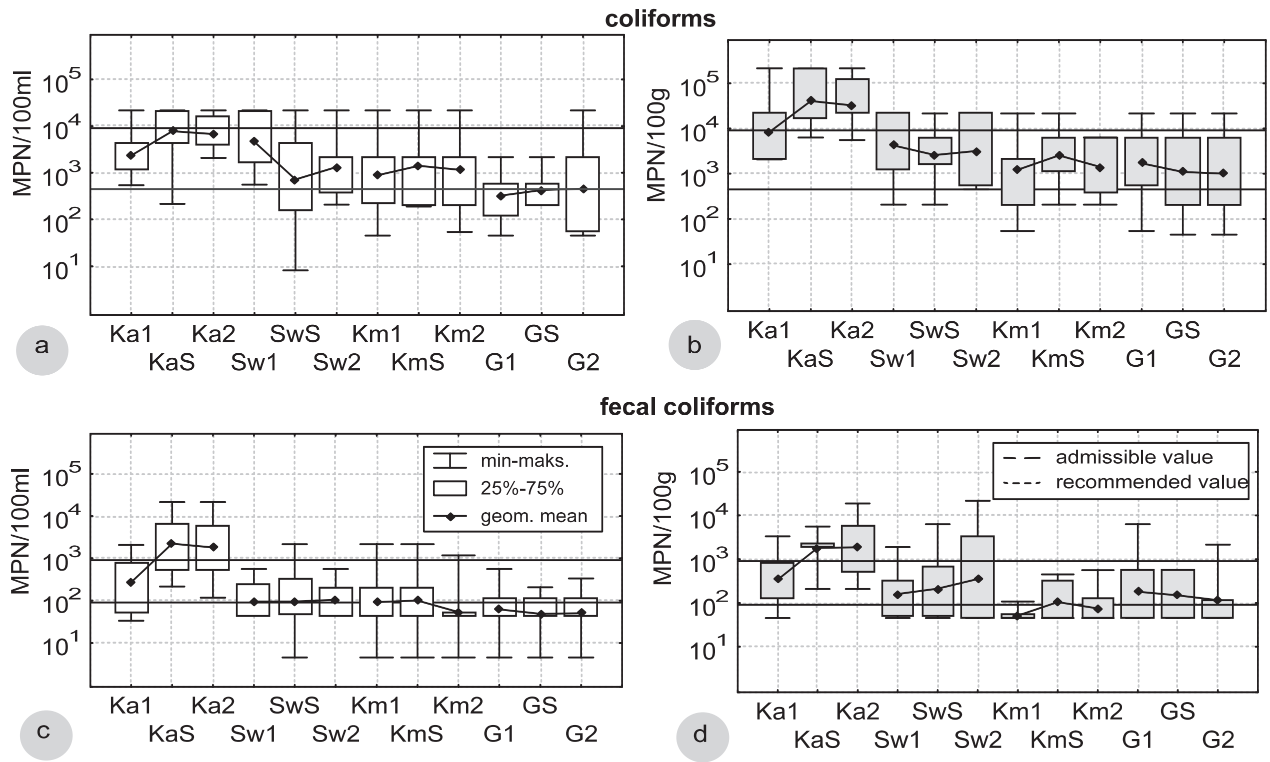

Fig. 3. The number of coliforms and fecal coliforms in the water (a, c) and in the sandy sediments (b, d).

KaS zone (Fig. 3c, d). Especially high MPN values were detected in stream water at KaS site and at the shoreline Ka2 site, where 50% of water samples and 58.3% of bottom sediment samples exceeded admissible value.

The fecal coliforms in water and bottom sediments of streams: SwS, KmS, and GS were on average up to one $\log_{10}$ lower, and only occasionally, with the exception of the bottom sediments of the Sw2 site, admissible value was exceeded (Fig. 3c, d).

The enterococci levels enumerated in water at KaS zone and SwS zone ranged from 1.0 x $10^2$to 7.6 x 10^2/100 ml, and from 2.3 x 10^1 to 7.0 x 10^2/100 ml respectively (Fig. 4a). The standard failures were noted, mainly at KaS (87.5%), Ka2 (87.5%), SwS (14.3%) and Sw2 (28.5%) sites. At all the sampling points of bottom sediments the number of fecal enterococci was significantly higher (from 2 to 32 times) than in water (Fig. 4b).

The standard failures in zones of KaS reached 56.8% results (concerning admissible value for bathing water), 50.1% at the zone of GS, 48.1% at the zone of SwS and at 23.8% at KmS zone.

Discussion

The concentration of indicator bacteria in coastal water used for recreation purposes should indicate its sanitary quality, which is critical for safety of its users. The presence of indicator bacteria in such water indicates the potential possibility of the occurrence of water-borne pathogens. The most frequently used bacteriological indicators are: coliforms, fecal coliforms and fecal enterococci. Determinations of the number of facultative psychrophilic and mesophilic bacteria in water are not involved in routine analysis.

In this investigation the sanitary quality of four streams: KaS, KmS, SwS and GS flowing into coastal waters in the area of bathing places in Gdynia and Sopot, was controlled. At the beginning of the 1980s, most of the bathing places were closed due to poor sanitary conditions. In 1995 the bathing places in Sopot and in 1998 the bathing places in Gdynia (Oksywie and in the Centre) were opened for recreational purposes. At the end, in 1999, the bathing place in Gdynia Orłowo was opened, except the area 1400 meters from the estuary of the KaS, which is still closed [13,14,15].

The results obtained in this study indicate that significantly higher numbers of fecal bacteria are discharged to the coastal waters by KaS.

It was proved that both the stream water and bottom sediments at KaS and Ka2 sites were up to one $\log_{10}$ more polluted than at the Ka1 shoreline site. Undoubtedly, this is the result of the coastline configuration and the neighborhood of the Gdynia-Orłowo pier, where in the close vicinity the small creeks are formed. The underwater part of the pier construction and creeks are influencing the direction of water circulation in this area and are limiting the dilution process. From 12% (Ka1 site) to 88% (KaS site) of water samples exceeded admissible enterococci values, and from 25% (Ka1 site) to 62% (KaS and Ka2 sites) water samples exceeded fecal coliform admissible values. Especially high fecal coliforms numbers were detected in stream water at the KaS and Ka2 sites, where 50% of water samples and 58.3% of bottom sediments samples exceeded admissible value (for bathing waters). Both the human and animal fecal pollution washed from the river catchment areas has a considerable impact on the low sanitary quality of water and bottom sediments of KaS.

More numerous, compared to other streams, numbers of heterotrophic bacteria in water and at bottom sediments of KaS are the result of higher organic water pollution (facultative psychrophilic bacteria), and higher fecal pollution (mesophilic bacteria).

The water and the bottom sediments of the SwS, on average, were less bacteriologically polluted. However, admissible values of indicator bacteria: fecal enterococci in water and coliforms in bottom sediment were periodically exceeded. Relatively good sanitary quality of water SwS is influenced by operation-planted soil filter, which is located in a lower course of the stream [4,16]. The periodical low sanitary state of stream water usually takes place after stormflow events, when a great part of the water escapes the filter.

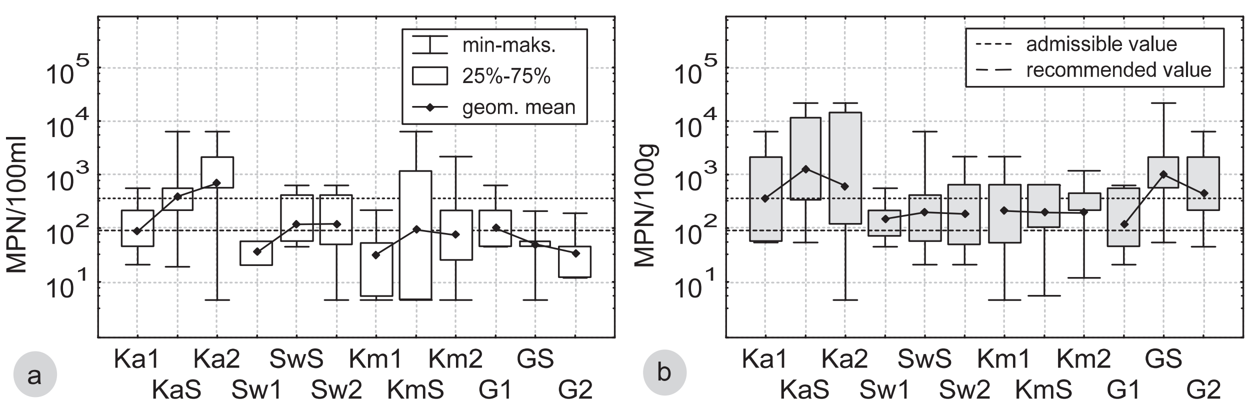

Fig. 4. The number of fecal enterococci bacteria in the water (a) and in the sandy sediments (b).

The fecal coliforms at water of KmS site and GS site, as well as at the coastal sea waters (Km1, Km2, G1 and G2 sites) in up to only 10% of samples admissible values for recreation purposes were exceeded. However, fecal enterococci levels in water of KmS exceeded admissible value in from 22% (KmS site) to 32% of samples (Km2 site), in bottom sediments from 32% (KmS site) to 55% samples (Km2 site), and at bottom sediment of GS in the range of 22% (GS site) to 78% of samples (G2 site). In all water and sediment samples, the fecal enterococci exceeded single water or sediment sample standards most often.

The results of this study suggest that the fecal enterococci, not fecal coliforms, are the more useful indicators of fecal bacteriological pollution of coastal sea waters and bottom sediments. Our results are confirmed by earlier works of Noble et al. [1] and Cabelli [17]. Also, the US EPA [18] has promoted the use of only a single bacterial indicator, fecal enterococci, for determining the sanitary quality of marine waters. It can be explained by a relatively higher survival rate of fecal enterococci than fecal coliforms (in water environment), and better correlation with swimming-associated gastroenteritis connected with fecal pollution of beaches [19,20]. The relationship between enterococci and swimming-associated gastroenteritis has been examined, as well, by Key et al. [21], who have demonstrated a significant dose-response relationship between gastroenteritis and fecal enterococci concentration.

Conclusions

From this study we have concluded that the streams KaS, SwS, KmS and GS, which are discharged to Gdańsk Bay in the area of beaches, contribute to the poor microbiological water quality of coastal zones. The most polluted of the analyzed streams was the KaS, discharging to the coastal seawaters large amounts of organic and fecal contamination. In consequence, the number of indicator bacteria in coastal waters surrounding the river estuary exceeds the permissible level for bathing waters. In the sand in estuaries of all four streams the average number of indicator bacteria was above by about one order of magnitude higher than in water.

The obtained results prove that to evaluate the sanitary quality of bathing places located in the coastal zone, it is necessary to carry out bacteriological tests not only of water, but of sand sediments, as well. It has been also indicated that fecal enterococci are more useful indicators of fecal pollution of this environment.

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