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# ENDANGERING OF GROUNDWATER ON THE MUNICIPAL INTAKES IN GDANSK

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**Abstract:** Groundwater from the Quaternary aquifer on the marine terrace in Gdańsk has been exploited for almost a century, supplying the town with water of good quality. However intensive exploitation in the past and development of the urban area influenced the chemical composition of the water. Hydrogeochemical background for such ions as $Cl^-$, $SO_4^{2-}$, $N/NH_4^+$ has changed and also some organic micro compounds appeared in single wells.

**Key words:** hydrogeology, hydrogeochemistry, groundwater intakes

## 1. INTRODUCTION

The "Czarny Dwór" and „Zaspa" groundwater intakes are two significant well fields supplying Gdańsk in water. They are located along the coastline of the Bay of Gdańsk on a geomorphological unit called marine terrace (Fig.2). The line of wells is situated in a close vicinity of town, bordering directly the urban area and partially being absorbed by the developing town (Fig.1).

Fresh water occurs in this region in Cretaceous, Paleogene-Neogene and Quaternary formations. The Quaternary aquifer plays the main role in water supply, thanks to its high resources and good quality of water. Groundwater from this formation has been exploited for almost a hundred years.

The quality of groundwater in this zone is influenced by both the natural and man-induced factors. The natural factors forming the water's chemical composition are connected with the geological conditions – lithology of the aquifer and of overlying strata (peat in some places) lack of confining layers and thus vulnerability to contamination, and also is strongly influenced by hydrodynamic conditions – intensive lateral inflow from the upland of Kashubian lake District recharges the aquifer with fresh water of good quality. On the other hand low hydraulic gradient on the marine terrace extends the time of contact with the underground environment and also the groundwater exposure to pollution from superficial sources. A natural geogenic factor endangering groundwater quality is also the vicinity of the sea; this natural pollution source can be induced by overexploitation.

Besides geogenic factors influencing potentially or actually the groundwater composition, the Quaternary aquifer is also endangered by human activity. The most visible changes of the groundwater quality have been caused by overexploitation that took place in the past. Other changes or risk for the groundwater quality is connected with previous and current way of the land management. The pollution sources are mostly connected with the town development - roads of heavy traffic running in close vicinity of the wells, petrol stations, waste disposal plant, hospital, transport base, but also with the previous activities hazardous for groundwater. Some of the activities are known – for example allotment gardens which had existed for about 20 years in the closest surroundings of the intake Czarny Dwór and still exist close to the intake Zaspa. The gardens may had constituted a risk of pollution due to excessive use of fertilizers and also due to the existence of incorrectly constructed shallow wells used as cesspools or compost tanks. It is not certain however what other activities hazardous to groundwater took place in the past in this region.

There are symptoms of affecting groundwater by human activity. The symptoms are recorded in changes of hydrogeochemical background of such ions as chlorides, sulphates, ammonia nitrogen, but also in appearing of some organic micro contaminants locally. Due to the aquifer's vulnerability and numerous current and previous pollution sources the groundwater from Quaternary aquifer is endangered.

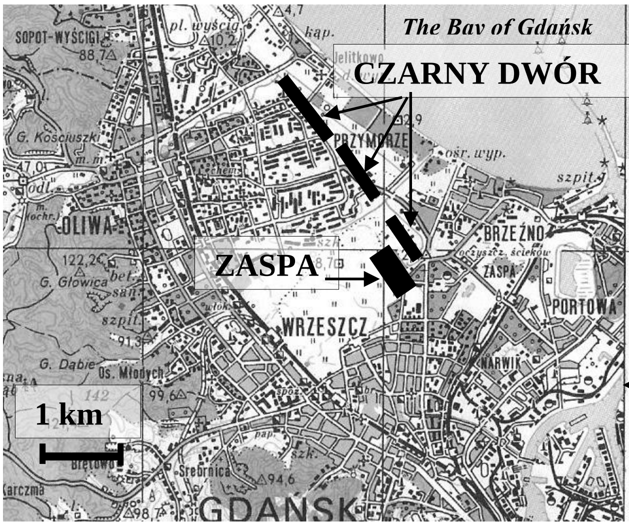


Fig.1Location of Czarny Dwór and Zaspa groundwater intakes on the marine terrace

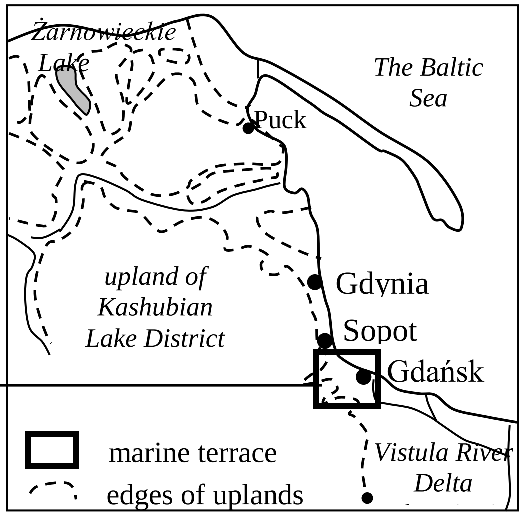


Fig.2 Described area against geomorphological scheme

## 2. HYDROGEOLOGICAL CONDITIONS

In Gdańsk region fresh water occurs in Cretaceous, Paleogene – Neogene and Quaternary formations. These aquifers create so called Gdańsk aquifer system, with common recharge zone on the  Kashubian Lake District and the discharge zone located on the marine terrace, the Vistula River Delta and the area of the Bay of Gdańsk [3].

The Cretaceous aquifer consists of fine-grained, quartz-glauconitic sands of Coniacian and Santonian. It is connected with widespread hydrogeological structure called Gdańsk Artesian Basin [10]. The aquifer occurs  about 150 m below terrain and is 100 - 150 m thick. The average filtration coefficient for this aquifer is 0.5 m/h. The original potentiometric surface on the area of the marine terrace was  5 -  15 m a s l. In 70- ties and 80- ties it considerably dropped due to high exploitation and recently it has recovered.

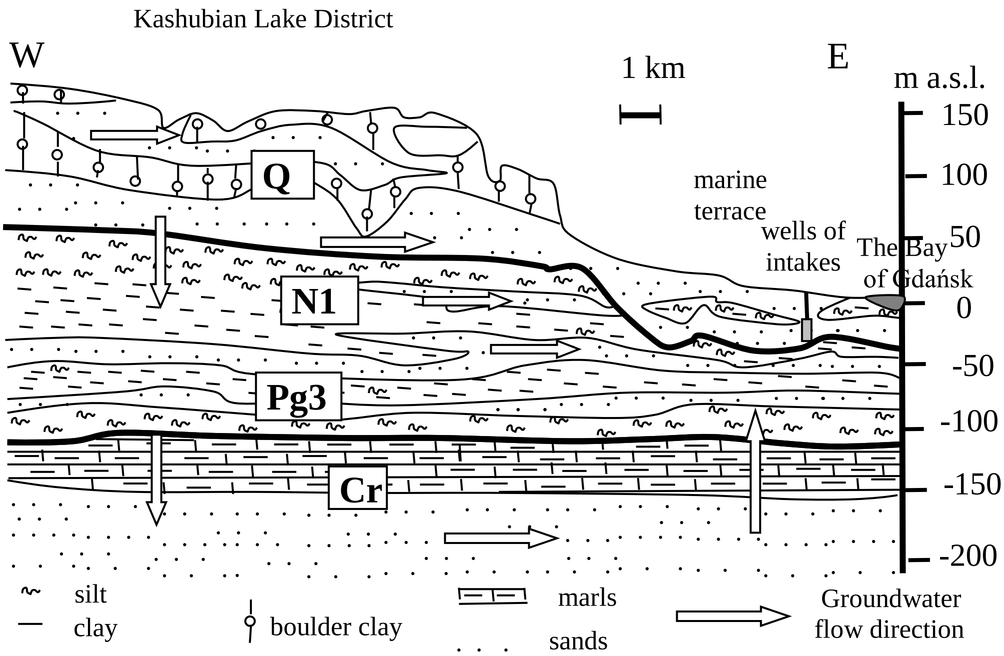


*Fig. 3  Schematic hydrogeological cross-section from the Kashubian Lake District to  the marine terrace  and the Bay of Gdańsk.*

*(Cr – Cretaceous, Pg3 – Oligocene, N1 – Miocene, Q – Quaternary  deposits.*

The Paleogene – Neogene  aquifer consists of varigrained sands, in places with gravel and phosphate concretions of Oligocene and fine grained sands with coal of Miocene. The roof of the Oligocene aquifer is about 60 – 90 m b.s.l. and the thickness doesn't exceed 20 m. The filtration coefficient varies from 0,. 3 to 0.6 m/h. The Miocene aquifer's top is 30 – 40 m b s l, the thickness is about 20 m and the filtration coefficient 0,04 – 0,2 m/h. In some places the Miocene aquifer is in direct contact with the Quaternary aquifer [3].

The most important in the hydrogeological system is the Quaternary aquifer. On the marine terrace it is composed of fluvioglacial sands and gravel, 15 – 30 m thick, originating from Middle Polish glaciation. The Pleistocene deposits are covered by 7- 10 m thick

Holocene sands of alluvial fans, and along the coast by marine sands. The Holocene deposits are interbedded with silts and silty sands in the sea shore area, and partially are covered by 0.5 m – 1.0 m thick layer of peat.  The groundwater flow conditions in the main Quaternary aquifer are very good. Better permeability is observed in the bottom part of the aquifer where average value of filtration coefficient is 1.5 m/h. In the upper part of the aquifer it's average value is 0.4 m/h. Transmissivity of the aquifer reaches 40 $m^2$/ h and potential yield of a given well – 120 $m^3$/h. Groundwater level (in some places potentiometric surface) was originally elevated 7 – 8 m a.s.l. in the part of marine terrace adjoining the upland to about 2 m a.s.l. at the sea shore. The aquifer is recharged mainly by lateral inflow from the Kashubian Lake District and also, to some extent, through atmospheric precipitation and the ascent from deeper aquifers (Fig.3).

## 3. THE INFLUENCE OF EXPLOITATION ON THE GROUNDWATER LEVEL

The groundwater intakes Zaspa and Czarny Dwór exploit mainly Quaternary aquifer. The oldest intake – Zaspa works from 1918. There are 12 wells pumping  water from Quaternary aquifer and also 3 wells catching Cretaceous glauconitic sands. The wells are situated  on a small area (Fig.4) elevated about 6 ma.s.l. in the south – western part of the marine terrace, 1700 m from the shore line.

As it is shown on the Fig.  6, the output from the Quaternary aquifer was quite even till 70-ties of XX$^{th}$ century (~ 400 $m^3$/h), then increased  to 600 – 700 $m^3$/h and in the middle of 80-ties dropped back  to the level around 400 $m^3$/h. From the middle of 80-ties till now the output has varied between  300 and 400 $m^3$/h.

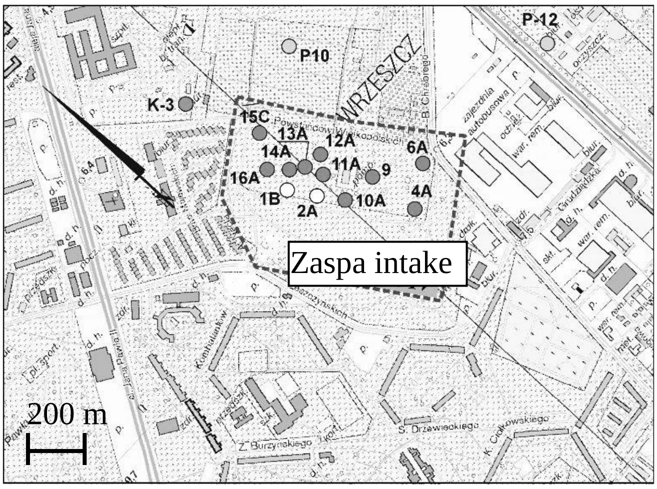


*Fig. 4 Plan of the the Zaspa groundwater intake.*

The Czarny Dwór  intake started groundwater withdrawal in 1965.  The line of wells, 3200 m long is situated 600 –1500 m from the sea shore (Fig.5). The surface of terrain along the line of wells is elevated 4–5 m a.s.l. Czarny Dwór exploits mainly Quaternary aquifer (23 wells in current use, earlier 29) but also Paleogene–Neogene (7wells) and Cretaceous (3 wells).

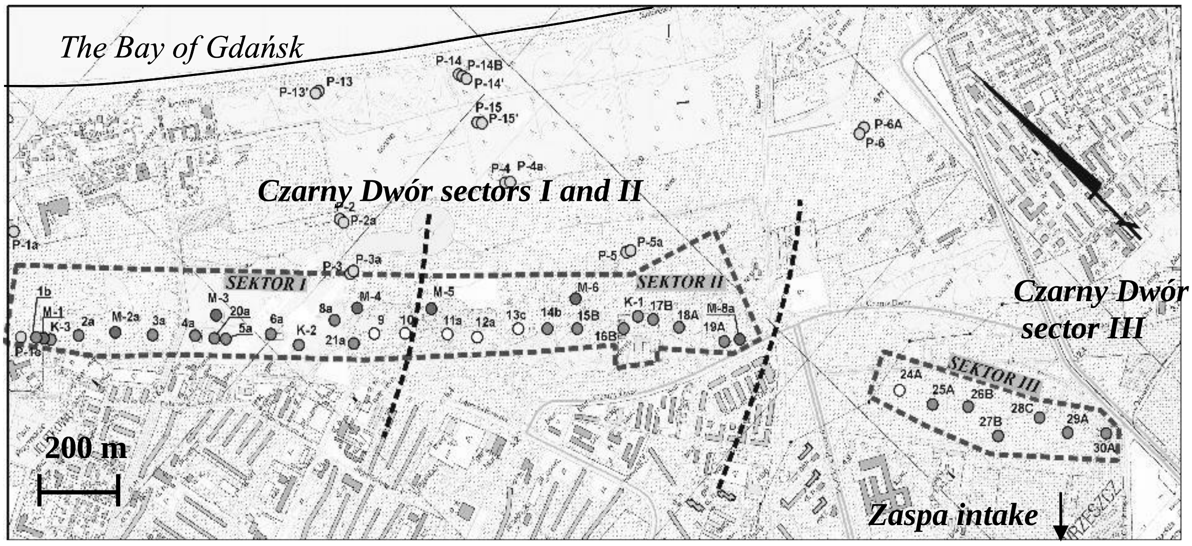


*Fig. 5 Plan of the the Czarny Dwór  groundwater intake.*

The output from the Quaternary aquifer is shown in the graph below (Fig. 6). The yield was very high from the beginning of the intake existence till the middle 80-ties and varied between 1100 and 1200  $m^3/h$, which together with Zaspa intake amounted to 1500 – 1800 $m^3/h$. From 1986 a considerable drop of yield has been observed, because of  switching to water supply system  a new surface water intake in Straszyn. The total output from the two intakes Zaspa and Czarny Dwór has been quite even for the last decade: ~600 $m^3/h$.

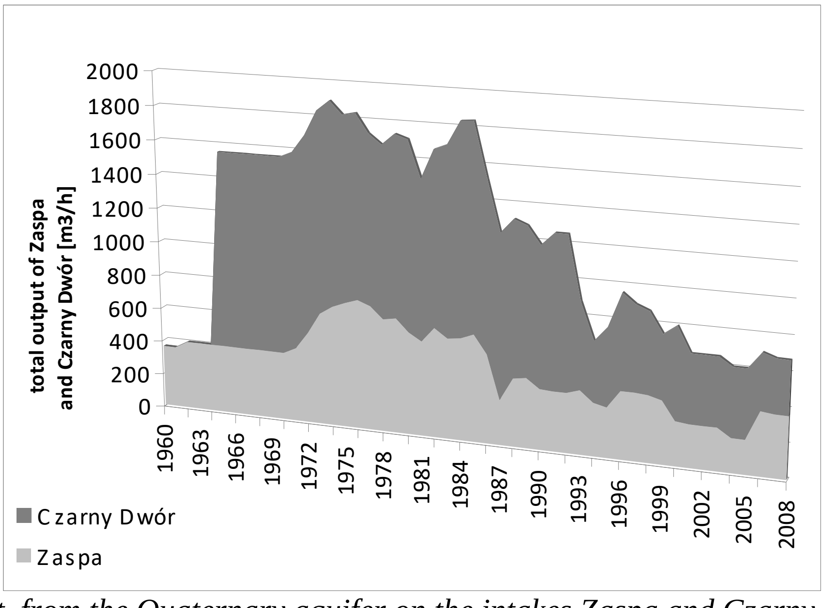


*Fig. 6 Total output  from the Quaternary aquifer on the intakes Zaspa and Czarny Dwór (cumulative graph - the upper line shows the sum of groundwater exploitation)*

The previous intensive exploitation resulted in developing of depression cone spreading under a part of the Bay of Gdańsk. The deepest cone was observed in 1985 when the groundwater table was lowered to approximately 3.5 m b.s.l. in the center of the both intakes and 1.5 m b.s.l. along the shore line, resulting in salt water intrusion to the exploited groundwater.

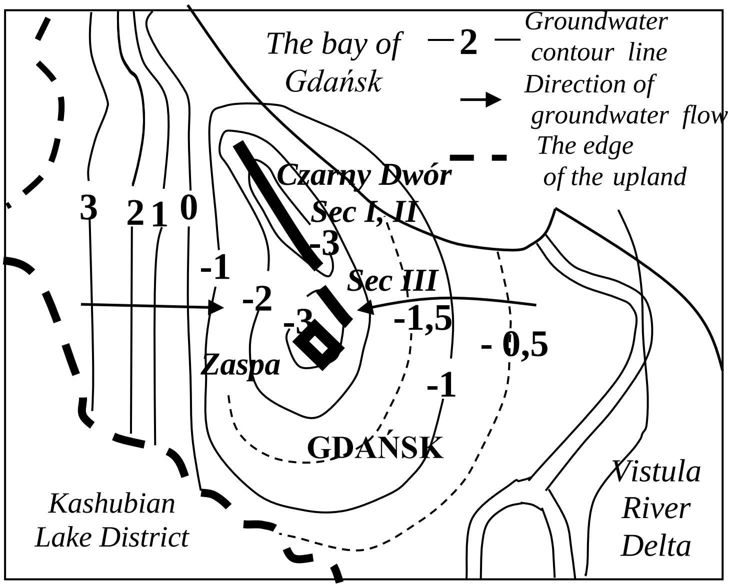


*Fig.7 Groundwater contour lines in the period of the highest exploitation (1985)*

Reduced exploitation has caused rising of groundwater level. In comparison to the state shown on the Fig. 7, groundwater table has risen about 4 meters. Currently (December 2008) the hydroizohipse 1.0 runs beetween the sea shore and the line of Czarny Dwór wells and on the other side of the intake: the hydroizohipse 2.0 m a.s.l. traces more or less the groundwater contour line -2 m a.s.l from 1985.

The present hydrodynamic situation seems to be favourble for the groundwater ptotection, because the upward hydrulic gradient shouldn't allow contaminants from superficial pollution sources to infiltrate downwards to the main aquifer. Also, subsurface waters occuring in some places of the marine terrace wouldn't percolate into the main Quaternary aquifer because of the upward directed hydraulic gradient. The subsurface waters are polluted in some places, which can be stated on the basis of local monitoring around such hazardous objects like petrol stations or transport base. However, the hydrodynamic situation can be changed locally due to intesive exploatation of single wells.

Drop of exploitation, can also influence grondwater quality in another way. Reduction of the aeration zone thickness affects the redox potential and contributes to some hydrogeochemical transformations. For example observed increase of ammonia nitrogen concentration can partly be explained in this way.

## 4. GROUNDWATER QUALITY AND IT'S CHANGES

The Quaternary aquifer is vulnerable to contaminations. Lack of confining layers, numerous pollution sources, exceeded and varied exploataion in the past – all the factors influenced and changed the chemical composition of the groundwater. In order to evaluate the present quality and hazards for Quaternary aquifer, it is important to consider the natural chemical composition and it's changes during the years of exploitation.

Because of the lack of data from the period before exploitation, an approximate hydrogeochemical background was evaluated for the years 1954-70, when the human impact on the groundwater was minimal [9]. The quality determinants taken into consideration were: total hardness, alkalinity, chlorides, sulphates, iron, manganease, ammonia nitrogen and nitrate nitrogen. The choice was limited by the range of the earliest analysis.

The values of background and also the basic statistics for the set of data are presented in the Table 1. The next column shows analogous data for the current quality [7]. The last column characterizes the recharge zone for the marine terrace, which is the Kashubian Lake District (Fig. 3); the hydrogeochemical background was evaluated by Pruszkowska [8].

The comparison in the Table 1 shows, that the chemical composition of groundwater on the marine terrace has a specific character; even in natural conditions concentrations of such ions as sulphates (natural hydrogeochemical background: 10 – 110 mg $SO_4/dm^3$) or chlorides (natural background: 5 – 40 mg $Cl/dm^3$), differed from typical values for the Kashubian Lake District and also in the case of sulphates differed from the values determined by Witczak and Adamczyk [11] as a background for typical natural groundwater: (5 – 60 $mg/dm^3$). Elevated natural background for sulphate ion can be caused by peats covering the aquifer in some places. Peats containing organic matter are rich in sulphur compounds. The influence of peats on sulphate anomalies in groundwater is stated by Kleczkowski [4] and also by other authors. Besides, polygenesis of the main Quaternary aquifer, composed of fluvioglacial and marine sands, also covered in the western part of the area by alluvial fans can influence the natural composition and cause variability of chemical composition [2]. Additionally, low hydraulic gradient on the marine terrace elongates the time of groundwater contact with the diversed underground environment.

Besides, the natural background for the chlorine ion ( 5 – 40 $mg/dm^3$) differs from typical concentrations in groundwater of the recharge zone (0 – 20 $mg/dm^3$) . Elevated (20 – 30 mg/dm$^3$) concentrations were stated even at the beginning of the XX th century, before the intakes existance [1]. This anomalny is an evidence of specific hydrogeochemical character of the area, which is connected with the vicinity of the sea.

Table 1. The comparison of natural and current hydrogeochemical background for the marine terrace and the background of the recharge zone.

| Quality determinant | **Natural conditions marine terrace** | | **Present conditions marine terrace** | | **Kashubian Lake Distr. Natural background > 30m depth** |
|---|---|---|---|---|---|
| | number of data | min - max / mediane<br>**background range** | number of data | min - max / mediane<br>**background range** | |
| total hardness mval/dm$^3$ | 65 | 3.2 – 8.1 / 5.2<br>**3.5 – 7.2** | 239 | 4.1 – 10.2 / 7.1<br>**5.6 – 8.5** | **2.0 – 4.5** |
| alkalinity mval/dm$^3$ | 101 | 3.1 – 6.41 / 4.4<br>**3.3 – 5.7** | 238 | 3.8 – 5.9 / 4.8<br>**4.0 – 5.7** | **1.6 – 5.1** |
| chlorides mg Cl/dm$^3$ | 104 | 2.8 – 74.4 /21.2<br>**5 - 40** | 239 | 16.7 – 148 / 42.2<br>**18 – 70** | **0.0 – 20** |
| sulphates mg $SO_4$/dm$^3$ | 50 | 0 – 133.7 / 62.9<br>**10 - 110** | 238 | 11.2 – 213.7 / 95.6<br>**40 – 160** | **10 – 42** |
| iron mg Fe/dm$^3$ | 101 | 0.05 – 10.0 / 1.0<br>**0.2 – 2.4** | 239 | 0.1 – 5.94 / 1.24<br>**0.3 – 3.0** | **0.0 – 1.3** |
| manganease mg Mn/dm$^3$ | 58 | 0 – 1.5 / 0.15<br>**0 – 0.3** | 239 | 0.07 – 1.27 / 0.18<br>**0.07 – 0.35** | **0.0 – 0.18** |
| ammonia nitr. mg $NH_4$/dm$^3$ | 79 | 0 – 1.11 / 0.04<br>**0 – 0.26** | 239 | 0.01 – 1.23 / 0.34<br>**0 – 0.77** | **0.0 – 0.36** |
| Nitra te nitr. mg $NO_3$/dm$^3$ | 72 | 0 – 15.51 / 0.09<br>**0 – 0.89** | 239 | 0 – 16.52 / 0.44<br>**0 – 0.89** | **0.18 – 0.8** |

The table 1 also shows that the hydrogeochemical background for groundwater of Quaternary aquifer on the marine terrace has changed. This is an effect of anthropopression on groundwater in this region. The shift of background concerns mainly sulphates – the background changed from the range 10 – 110 mg $SO_4$/dm$^3$ to 40 – 160 mg $SO_4$/dm$^3$ , chlorides – natural background 5 – 40 mg Cl/dm$^3$, current: 18 – 70 mg Cl/dm$^3$ and also ammonia nitrogen: the background changed from 0 – 0.26 mg $NH_4$/dm$^3$ to 0 – 0.77 mg $NH_4$/dm$^3$. Besides, higher contribution of some ions in the groundwater composition and differentiated concentrations between wells is observed.

Generally the chemical type of the groundwater exploited at present on the intakes Zaspa and Czarny Dwór is $HCO_3$ –$SO_4$ – Ca and $HCO_3$ –$SO_4$ – Cl – Ca, but also, especially in the northern part of the Czarny Dwór - presents the $HCO_3$ – Ca type, characteristic for the recharge zone (Fig. 8). This fact is connected with the most intensive lateral recharge from the Kashubian Lake District in this area.

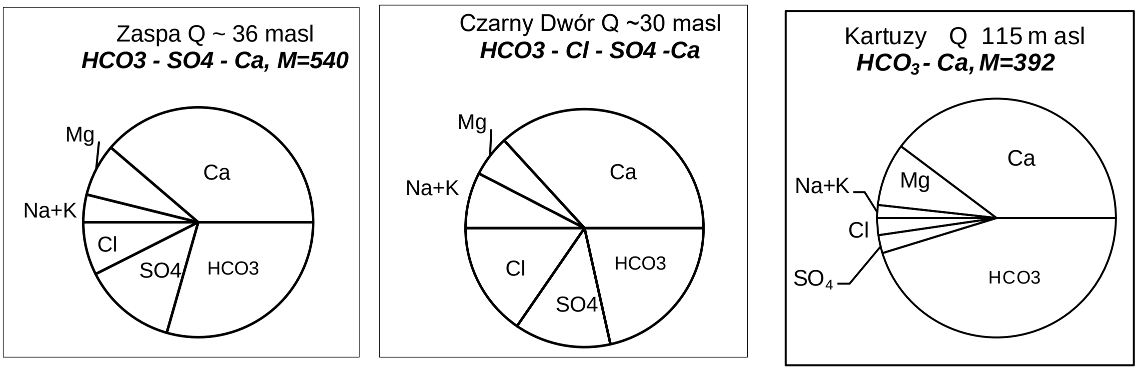


*Fig. 8 Hydrogeochemical types of groundwater from chosen wells of the described intakes and of the recharge zone.*

The increased concentrations of chlorine ion are mainly due to salt water intrusion that took place in 80-ties and at the beginning of 90-ties of the previous century, in the middle part of the intake Czarny Dwór. The intrusion was caused by overexploitation. The Fig. 7 shows the hydrodynamic situation in the year of the highest yield (1985) - the depression cone ranged into the sea and comprised a part of the Bay of Gdańsk. Although the output has been considerably decreased and the intrusion has been stopped, which was confirmed by geophysical investigations led by Swedish – Polish team in years 2002 – 2004 [3 ] the effect of an increased chlorine concentration is still observed in many wells.

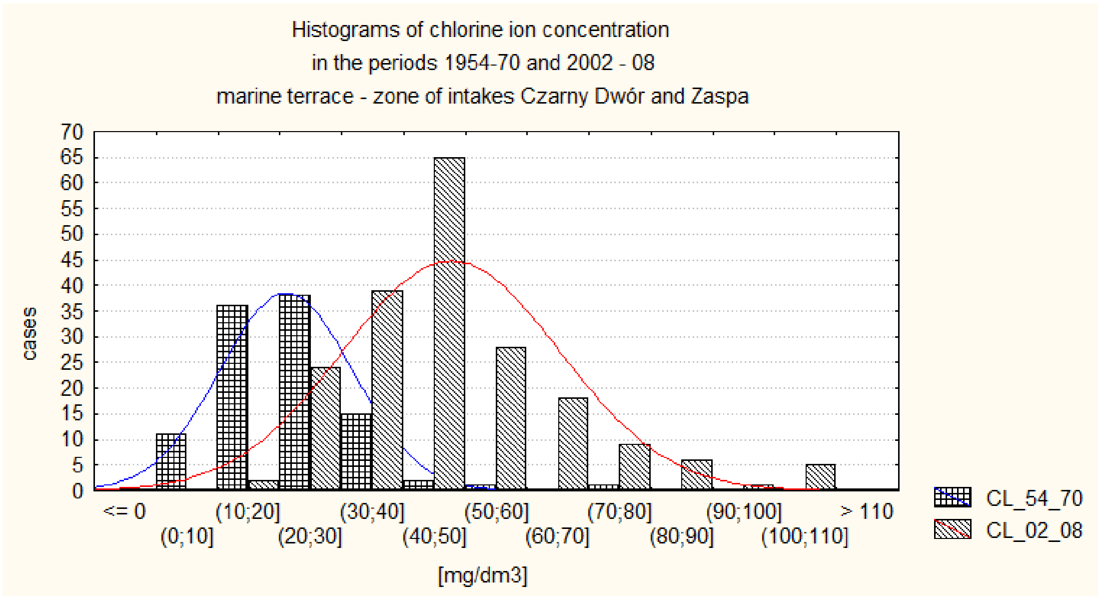


*Fig. 9 Histogram showing increased chlorine ion concentrations in comparison with natural conditions.*

The shift of chlorine ion concentrations recorded in groundwater from the intakes Czarny Dwór and Zaspa is shown in the Fig. 9.

Another symptom of athropopression, quite alarming, is recording of micro compounds such as tetrachloroeten, trichloroeten in some wells of the intake Czarny Dwór. The values determined in the spring 2008 are shown in the table 2. The highest concentrations were stated in the middle part of the sector II (well 15b), and were confirmed between March and July by three other chemical determinations (values between 123 and 164 μg /dm$^3$, as a sum of Trichloroeten and Tetrachloroeten). Also in 3 wells of the sector I (Fig. 10) the concentrations (sum of Trichloroeten and Tetrachloroeten) occured between 2.5 and 10 μg/dm$^3$.

Table 2 Concentrations of 1,2 dichloroetan, trichloroeten and tetrachloroeten in wells of Czarny Dwór intake (March 2008)

| | 1,2 dichloroetan | Trichloroeten | Tetrachloroeten |
|---|---|---|---|
| | | [micrograms/ dm3] | |
| Cz D well 14a | <0,1 | 0,51 | <0,1 |
| Cz d well 15b | <0,5 | **23,3** | **110,2** |
| Cz D well 18a | 0,2 | <0,1 | <0,1 |
| Cz D well19a | <0,1 | 0,1 | <0,1 |
| Cz D well 1b | <0.1 | **2,12** | 0,37 |
| Cz D well 2 | <0.1 | **9,4** | <0,1 |
| Cz D well 21a | <0.1 | **2,38** | 0,44 |
| Cz D well 22a | <0.1 | 0,21 | <0,1 |
| Cz D well 25a | 0,28 | 0,24 | **1,21** |
| Cz D well 26a | <0.1 | 0,24 | 0,37 |
| Cz D well 27a | <0.1 | <0.1 | 0,21 |
| Cz D well 28c | <0.1 | <0.1 | 0,11 |
| Cz D well 3a | <0.1 | 0,33 | 0,47 |
| Cz D well 8a | <0.1 | 0,19 | <0.1 |

Besides the micro compounds described above, also elevated values of benzene were recorded in the sector III of the intake Czarny Dwór (Fig.10). Concentrations exceeding the limits for drinking water (1 μg /dm$^3$) occurred in one well (24). The well 24 was excluded from the water supply system. Actually a decrease of benzene concentrations is observed.

Table 3 Concentrations of benzene in chosen wells of Czarny Dwór intake.

| | benzene [micrograms/ dm3] | | |
|---|---|---|---|
| | 2004 | 2006 | 2008 |
| Cz D st 18 | 0.02 | | < 0,1 |
| Cz D st 24 | **1.25** | 0.86 | |
| CzD st. 26 | 0.47 | | < 0,1 |
| CzD st. 27 | 0.09 | | < 0,1 |

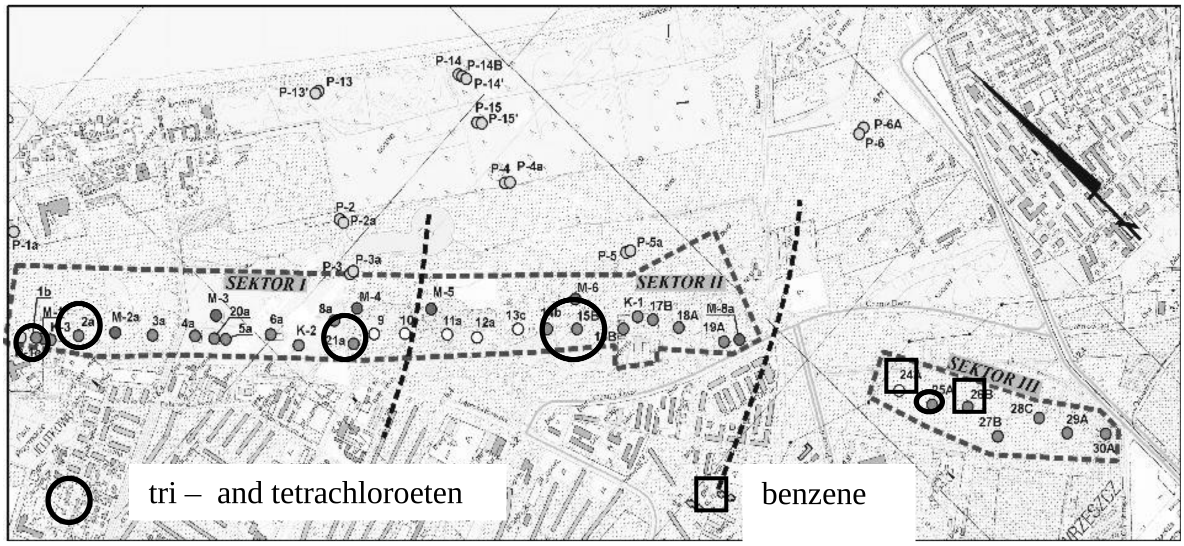


*Fig 10 Location of wells with elevated concentrations aminants.*

It is difficult to indicate the source of pollution at th esides, it is not known when the contaminants appeared in the groundwater beca observations in earlier period of time. There are occasional observations of sor nic micro compounds, for example analysis carried out for Gdańsk intakes in 2002 [9] showed elevated concentrations of n-alcanes $C_nH_{2n+2}$ in one of wells in sector II, especially of docosane. In order to indicate the pollution source and protect groundwater and also for assessment of further hazard local monitoring will be developed and realized.

**5. CONCLUSIONS**

There are many pollution sources on the marine terrace; some of them are identified and existing currently e.g. petrol stations, roads of heavy traffic others existed in the past e.g. an airport in the vicinity of the sector III of the intake (during the second World War it was a military airport), military units that resided in the intakes surroundings many years ago, or sewage disposal plant that had existed for 80 years in the intake Zaspa vicinity and was closed last year. It is probable that some of the sources are responsible for appearing of the micro contaminants in the intakes groundwater. There are also many future hazards connected with the development plans for the area. One of the most serious is the planned road that would run in a very close distance from wells of Czarny Dwór intake. The aim of the new road will be to assure convenient access to the harbor, so intensive traffic is expected and at the same time endangering for the groundwater quality would increase.

In order to protect the intakes it is very important to develop net of observation wells on the directions of groundwater flow to the intakes, taking into consideration the main pollution sources. Besides observations of groundwater composition including micro compounds should be continued.

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