

# THE IMPACT OF SEA-WATER INTRUSIONS ON QUALITY OF SURFACE WATERS IN SMALL COASTAL CATCHMENTS

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## Introduction

Hydrological extremes are often defined as processes caused by hydrometeorological circumstances which differ much from typical weather conditions (Van den Brink *et al.*, 2005). Hydrological changes resulting in floods of various origins can be the effects of such phenomenon in a natural environment (Hall, Andersen, 2002). Such situations are temporal and are related to periodical or episodic changes in geographical conditions (Tarkhov, Treivish, 2007). Storm floods in rivers outlets occur when strong winds blowing from the sea obstruct the flow of the river, cause impoundment and consequently outflow from the river banks. It is often not recognized, that the effect of such storm is not only damming but also intrusion of salty waters. So far such incidents haven't been considered as the extreme events. Sea water intrusion is a phenomenon of penetration of sea waters into coastal aquifers and into surface waters having permanent or periodical connection with the sea. In consequence, a sharp increase of salinity and some other physical and chemical parameters is observed. There is not enough information on how do the intrusions proceed and what are their consequences in coastal catchments of the southern Baltic. The main aim of this study was to assess the impact of these intrusions on surface water quality in the selected small catchments of the river-lake systems. As small catchments, basins with an area up to 110 km<sup>2</sup> have been considered.

## Study area

For the purpose of the research several hydrographical objects and their catchments have been selected (Figure 1). They are situated in the central part of the coast of the southern Baltic, with the exception of Lake Ptasi Raj basin which is located in the Vistula delta. Their catchments areas range from 2.4 km<sup>2</sup> (Lake Ptasi Raj) up to 107.7 km<sup>2</sup> (Lake Wicko).

## Method

The employed method involved performing recurring hydrochemical surveys, accompanied by simultaneous determination of the current hydrological situation. In the years 2002 – 2007, sixteen measurement series in each of the analysed lakes (Lake Bukowo, Lake Wicko, Lake Kopań, Lake Modła and Lake Ptasi Raj) were performed. The measurement sites were localised not only on the lakes, but also on the sea, in the lakes tributaries and in the channels connecting reservoirs with the sea. Water samples were taken from the surface, above the bottom and from the interstitial layer. Water from this last layer was obtained from the surface bottom

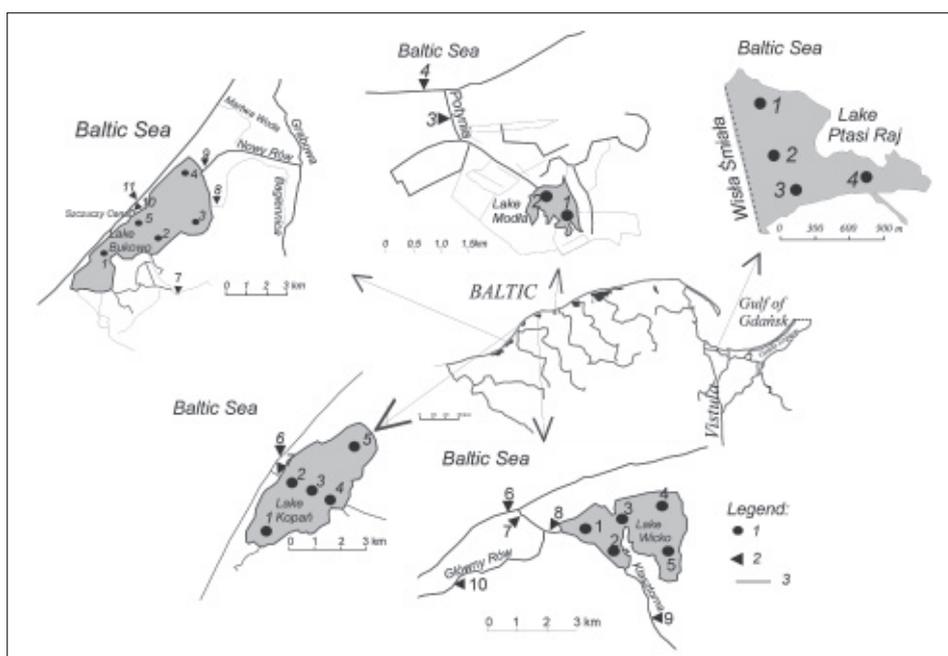


Figure 1. Study area with the location of sampling points: 1 – sampling points on the lake, 2 – sampling points on the sea and the rivers, 3 – rivers and channels

sediment which was collected using Kajak scoop and a centrifuge. Water samples were analysed in the laboratory of the Hydrology Department of the Gdańsk University (chlorides, sodium, potassium, magnesium, calcium, sulphates, hydro-carbonates and specific conductance). The measurements were conducted during normal and extreme weather conditions (storm weather). Water flow was measured at the channel outlets to the sea. Additionally hydrometeorological data (sea water level, water level in lakes, wind direction and wind velocity) were obtained from the Institute of Meteorology and Water Management (IMGW) in Słupsk and Gdynia. The data were collected for the exact days of measurements and for the two days preceding them. The values of water level in lakes and the sea were unified using the same reference system.

## Changes in chloride concentrations

Chloride ions are considered to be the best indicators of the impact of sea water on fresh waters in coastal areas. It is a conservative compound which does not interact with other substances, doesn't oxidize and is not reduced. Additionally it is a good migrant in water environment. In the scientific literature certain threshold values were proposed which could help to assess the scale of sea water influence on quality of continental freshwaters. In Polish surface waters concentration of chlorides stays usually within the range of 20-30 mg·dm<sup>-3</sup>, and intrusion may be observed when these concentrations increase up to around 100 mg·dm<sup>-3</sup> (Appelo, Willemsen, 1987). In this paper the same threshold value has been accepted.

The results of water quality analyses in the selected lakes indicated that there was a very high diversification of chlorides content (Figure 2). The highest observed values were characteristic for Lake Ptasi Raj where concentrations didn't ever fall below 2300 mg·dm<sup>-3</sup>. High chloride content in this lake with the maximum values over 4000 mg·dm<sup>-3</sup> was close to water quality characteristics observed in the Gulf of Gdańsk. This was an interesting observation because even in the largest Polish coastal lake – Lake Łebsko such extreme values haven't been reported (Cieśliński, 2003). Elevated salinity in this small lake may be a result of easy penetration of brackish water from the Gulf of Gdańsk to the reservoir caused by frequent openings of sluices in the dikes separating the lake from the estuary of Wisła Śmiała, inflows of salty ground water and disproportionately small catchment area compared to the lake surface. High chlorides concentrations, however not so high

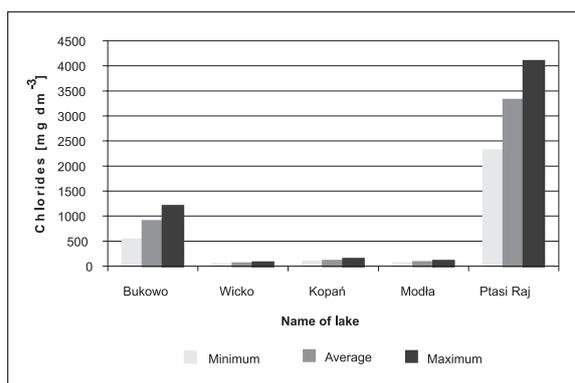


Figure 2. Extreme and mean chloride concentrations in surface water of the selected coastal lakes

as in Lake Ptasi Raj, have been observed in Lake Bukowo. They ranged from about 500 mg·dm<sup>-3</sup> to nearly 1200 mg·dm<sup>-3</sup>. This lake was situated in close distance from the open sea (300 m in straight line).

Other three reservoirs have distinctly different characteristics of chlorides concentration. Mean chlorides concentrations ranged there from 30 mg·dm<sup>-3</sup> (Lake Wicko) to nearly 150 mg·dm<sup>-3</sup> (Lake Kopań). The least salty water was typical for Lake Wicko, although even there water contained more chlorides than it is typical for inland surface water. The weakest influence of the sea on this reservoir can be interpreted as a consequence of the comparatively long distance to the lake from the Baltic Sea through the outlet channel, which additionally was obstructed by several hydrotechnical

constructions. In this lake sea intrusions have never been recorded. Similarly, in Lake Modła, such phenomenon has not been observed and the maximum chlorides concentrations rarely reached 100 mg·dm<sup>-3</sup>. Periodical sea intrusions were, however, recorded in Lake Kopań where they resulted in the highest water salinity of all these three lakes.

## Conclusions

The results of the research indicated that the influence of intrusions on water quality in small coastal catchments is differentiated. The lakes and their catchments which were selected for the purpose of this analysis appeared to be hydrographic objects of very distinct hydrological and hydrochemical conditions. Similar location of these reservoirs (in the coastal zone) and similar hydrometeorological conditions suggested that water quality in extreme situations may be also similar and the differences between the lakes should be only a result of the differences in lakes morphometry, the size of their catchments and the quantity of water inflow from rivers. The research has proved that the mechanism of sea intrusions to lakes in small catchments is much more complicated. Some of the analysed lakes were under strong influence of frequent sea water intrusions, while in other reservoirs such inflows were periodical or even not recorded. Very high concentrations of chlorides in Lake Ptasi Raj cannot be however considered as a consequence of exceptional conditions. Water quality in this lake is a result of permanent and not a unique sea influence (amplified by human impact) and its parameters are on this high level quite stable. A very important factor turned out to be the characteristic of the connection between the specific lakes and the sea, with special reference to channel cross section, flow velocity and waterway continuity.

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