Potential Hydrometeorological Threshold Values of the Coastal Hazard—an Example from the Polish Southern Baltic Coast

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Abstract—This paper analyses the spatiotemporal variability of extreme hydrometeorological events at the Polish coast of the Baltic Sea. Extreme precipitation events and storm surges determine to the largest extent the contemporary transformations of sea coastal geocosystems and represent the major factors that disturb their functioning. The statistical characteristics of these values were computed from the data of six meteorological and tide-gage stations located at the Baltic seaside. Daily data on the amount of precipitation and the sea level for the period of 1966–2009 were used for the study. Annual and daily maximum values of precipitation and sea level are presented for the Southern Baltic coast. The threshold values of the hydrometeorological parameters considered in the study allow assessing the hazard caused by the disturbance of the functional stability of the sea coastal geocosystems.

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INTRODUCTION

The morphogenetic system of the Baltic coast includes various types of land relief [13] which, in conjunction with water circulation, can be considered as autonomous spatial units called geocosystems [12]. The dynamics of weather conditions affect to a large extent the intensity, cyclicity and seasonality of processes occurring in the geographical environment. The contemporary operation of geocosystems within coastal areas is mainly determined by water circulation. The temporal and spatial variation of precipitation and storm surges mainly determines trends of changes within the coastal environment. Extreme hydrometeorological events can be a major factor disturbing geocosystems within sea coastlines [25].

The operation of sea coastal areas is mainly dependent on the dynamics of marine abrasion and intensivity of the impact of subaerial processes that determine mass movements and washing-off [16]. Storm surges and intensive precipitation lead to the destabilization of sea coastlines and disturb their relative dynamic balance.

Precipitation variability in the Baltic region have been studied by many researchers. The authors of [2, 18] reported the variability of precipitation in Lithuania, Latvia and Estonia in the 20th century. Paper [9] analyzes climatic fluctuations and trends in Estonia in the 20th century. Papers [1, 19] reported precipitation trends and the frequency of extreme climate events. The impact of climate changes on the functioning of the Baltic Sea region is also presented in [3, 4, 7]. Dynamics of storms and sea level changes in the Baltic Sea have been investigated in [8, 17, 30, 31]. The authors of [20, 22] studied the relationship between the temporal variability of the seasonal variation of the sea level in the Baltic Sea and climate changes. Paper [27] observed relative changes in the sea level and shoreline displacement in the Southern Baltic. The geomorphological effects of extreme hydro-meteorological events on the Baltic coast were studied in [6, 10, 14, 15, 21, 23].

These studies contribute essentially to the understanding of coastal processes. However, there is a need of defining the threshold values of storm events and maximum sea levels that may lead to the highest damage. The purpose of this study is to define the hydrometeorological phenomena which are the most important for potential coastal instability and derive statistical parameters for them. These parameters help to define the threshold values that may lead to the abrasion of the sea coast as a result of geomorphological
processes such as landslides, slumping processes, subsidence, the washing off and collapse of the moraine cliff.

METHODS

The study area covers the Polish coastal area of the Baltic Sea with the length of nearly 500 km that consists of the main basic seaside types: dunes with spits and cliffs. Dunes and spits cover more than 400 km, and cliffs, nearly 100 km of the coastline. Spit sections located between the sea and its coastal lakes are well developed within the central and eastern part of the Polish Baltic coastline. The Hel Peninsula located in its eastern part is characterized by intensive erosion and flooding during big storms. Wolin and Uznam islands are located in its western part. The sea coastline of Poland has two main bays (the Pomeranian Bay and the Gdansk Bay) and two large lagoons (the Szczecin Lagoon and the Vistula Lagoon) which are linked to the sea by narrow straits. According to the universal decimal classification of the International Documentation Federation [5], the study area belongs to the regions of the Central Lowlands and the Southern Baltic Coastland. Within the Southern Baltic Coastland three macro-regions can be distinguished; they are located in the Polish Baltic Coastland [11] (figure): the Szczecin Coastland (Swinoujscie station), Koszalin Coastland (Kolobrzeg, Ustka and Leba stations) and Gdansk Coastland (Hel, Gdynia/Gdansk stations).

The study uses the data on precipitation and maximum sea levels within the Polish Baltic coastal area based on hydrometeorological measurements performed in the period 1966–2009 at the following stations: Gdynia, Hel, Leba, Ustka, Kolobrzeg, and Swinoujscie. The above stations belong to the national observation and measuring network supervised by the Institute of Meteorology and Water Management in Warsaw. The sea level measurements were conducted at the same locations as meteorological measurements. Only within the Gdansk Bay the data from Gdansk station was applied. The sea level was measured from the level which is 508 cm lower than the zero of Kronstadt. For calculating the amount of precipitation only the days with precipitation of not less than 0.1 mm/day were chosen.

The study specifies the following statistical characteristics for daily precipitation totals and maximum daily sea levels: arithmetic mean \( \bar{x} \), modal \( M_0 \), upper and lower quartiles (\( Q_1 \), \( Q_3 \)), maximum \( x_{\text{max}} \) and minimum \( x_{\text{min}} \) values in observation series, the range of variation (\( R = x_{\text{max}} - x_{\text{min}} \)), standard deviation \( s \), and the coefficient of variation \( V = s/x \times 100\% \). The coefficients of asymmetry (skewness, \( As \)) and concentration (kurtosis, \( K \)) were also determined.

The values of precipitation totals that exceed \( Q_3 + 8(Q_3 - Q_1) \) hereinafter are called outliers. The values that exceed \( Q_3 + 16(Q_3 - Q_1) \) are considered extreme values. The above extreme threshold value for referring precipitation to the extreme event are consistent with 10% probability of precipitation events calculated on the base of the Wakeby distribution.

Outliers for the maximum daily sea level are the values exceeding \( Q_3 + 1.5(Q_3 - Q_1) \), and extreme values are those exceeding \( Q_3 + 3(Q_3 - Q_1) \). The threshold values for referring the sea levels to the extreme ones are consistent with 10% probability of their occurrence calculated on the base of the Gumbel distribution.

The outliers and especially extreme threshold values determined for precipitation and the sea levels may be considered as the hydrometeorological factors of the destruction of geocosystems within the Southern Baltic coast.