Chapter 16
Water Management in the Pomeranian Rivers Estuary Zone on the Background of Hydro-meteorological Conditions

Joanna Fac-Beneda, Izabela Chlost, and Alicja Olszewska

Abstract The modern hydrographic system of Pomerania has been inherited from the postglacial water system. The outflow system, transformed today as a result of erosion and accumulation of rainwater and snowmelt, overlaps with both this inherited drainage system and human activities. A key role in forming the water conditions of the Pomeranian rivers, and especially their estuary sections, is played by the main (Baltic Sea) and regional (coastal lakes) drainage bases. The temporal variability of water resources manifested in their seasonal abundance and resulting from the excessive inflow of allochthonous waters or inhibition in free flow, characteristic for the conditions of the geographical environment of Pomerania, bring flood risks. In the preliminary flood risk assessment, it was necessary to designate risk areas, i.e. those where there is a significant risk of flooding or where high risk is likely to occur. From the point of view of flood prevention, buffer and strategic investments are of great importance which include the reconstruction of old and construction of new flood embankments, engineering channels and construction of flow regulating devices, strengthening of river banks, as well as the construction of retention reservoirs and development of valley retention. No less important are the increase of retention through afforestation, counteracting water erosion in lowland areas, restoration of riverbeds and riverbanks, increasing retention in urban areas.

Keywords Water management · Poland · Pomeranian catchments · Estuary zone · Flood risk · Water pollution

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16.1 Characteristic of the Pomeranian Catchments

The catchments located between the basins of the Odra and Vistula are referred to as Pomeranian [1] and cover part of the Coastal region and the South-Baltic Lake Districts [2] (Fig. 16.1, Table 16.1).

The area includes northern slopes of the Pleistocene moraine plateaus, often in the form of patches, but above all coastal lowlands, ice-marginal valleys and spit forms. This results in an extensive geological and hypsometric diversity conditioning the shaping of water supply areas, and transit and drainage of surface and underground waters. The end moraine hills are built of glacial tills and sands, and their surfaces are often cut with subglacial channels and river valleys [4]. Other depressions are melt-out basins filled with clays and silts or numerous peat-based drains with no outflow. The landscape has pronounced ice-marginal valley forms, among which the Reda-Łeba Ice-marginal Valley dominates. The genetic structure of the ice-marginal valleys is associated with the accumulation of sand-gravel materials, entirely or partially covered with a complex of organic deposits. The coastal lowlands are flat areas built of sands, elevated 2–10 m above sea level. From the north, they are bordered by a range of dunes which separate them from the sea and culminate at 56 m above sea level (Łeba Spit). There are large but shallow coastal lakes in the lowlands. In places where the plateaus reach the sea, the shore shows the cliff nature.

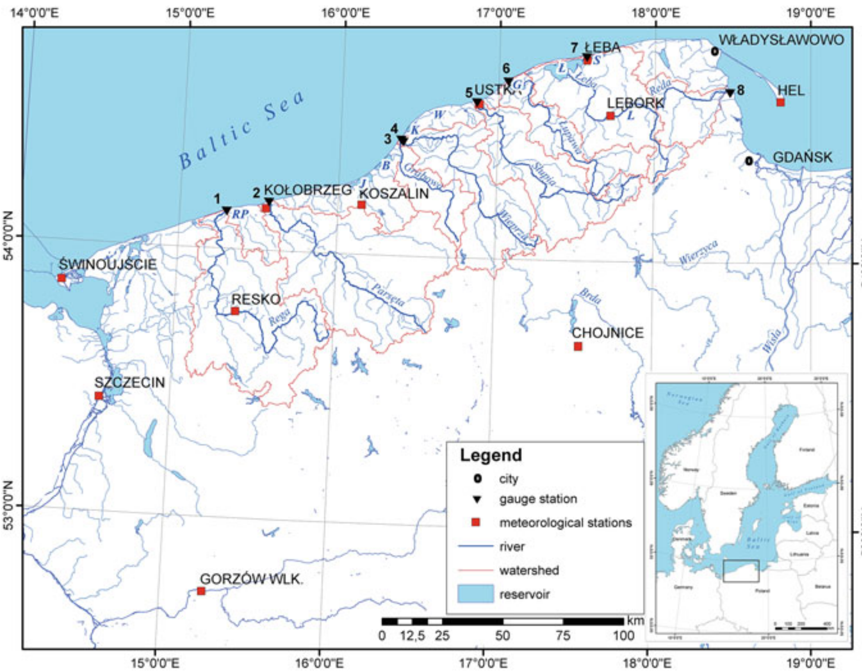

Fig. 16.1 Location of the research area

Table 16.1 Selected characteristics of the analysed rivers [3] (changed)

	River	Gauge station	Distance of the sampling point from the outlet [km]	Catchment area A [km^2]	Drainage Basin A_b [km^2]	$(A/A_b) \cdot 100$ [%]
1	Rega	Trzebiatów	12.9	2628	2724	96.5
2	Parsęta	Bardy	25.0	2955	3151	93.8
3	Grabowa	Grabowo	18.0	439	535	82.1
4	Wieprza	Stary Kraków	20.6	1519	1634	93.0
5	Słupia	Charnowo	11.3	1599	1623	98.5
6	Łupawa	Smołdzino	13.3	805	924	87.1
7	Łeba	Cecenowo	25.2	1120	1801	62.2
8	Reda	Wejherowo	20.9	395	485	81.4

The estuaries of coastal rivers form various hydrographic systems. Some of them go directly to the sea or bay (the Rega, Parsęta, Wieprza with the Grabowa, Słupia, Reda), while others to large coastal lakes (the Łupawa, Łeba).

The modern hydrographic system of Pomerania has been inherited from the postglacial water system [5]. The outflow system, transformed today as a result of erosion and accumulation of rainwater and snowmelt, overlaps with both this inherited drainage system and human activities. The river network can be described as polygenetic. Its diversity is a consequence of a complex deglaciation process, local morphological, lithological and hydrogeological conditions, climate change, contemporary vertical movements, and anthropogenic stress. One of the characteristics of the area is a large share of periodic river network [6]. It mainly concerns spring watercourses. For example, 25% of watercourses in the Łeba catchment are of this type [7]. In the characteristics of the Pomeranian catchment, lakes occupy an essential place (according to Lange 1986 the average lake coverage is 2%). Most often them are flow lakes, which is the evidence of the young age of the river network [8]. The share of lakes (lentical) along river courses, i.e., the limnic index for the Słupia and Łupawa, is about 7% [7]. On the Rega, Parsęta, and Słupia there are large artificial reservoirs that were created at the beginning of the twentieth century. Their characteristic feature is a very high water exchange rate, and the water quality in them directly depends on the quality of river waters. In addition to glacial lakes, in the mouth sections of the Łupawa and Łeba, there are large shallow coastal lakes (Gardno and Łebsko, respectively). There are small watercourses feeding the lakes, most often as canals or drainage ditches. The area surrounding the lakes has been turned into polders. The particular hydrographic attributes of the Pomeranian catchment are natural outflows of groundwater [9–11]. In ice-marginal valleys, which drain deep groundwater horizons, the surplus water that has already been part of the underground water cycle is here again included in the surface cycle. A perfect example can be a fragment of the Reda-Łeba ice-marginal valley near Lębork. In its bottom at the foot of the plateau, edge is Lubowidzkie Lake, which owes its existence to the occurrence of groundwater outflows. Their yield oscillates from just under 0.1 to about 30 $dm^3\ s^{-1}$ [12]. The outflow waters feed the lake in a significant way and quadruple the volume of the flow of the Węgorza (the tributary of the Łeba) flowing through Lake Lubowidzkie.

The catchments of the Pomeranian rivers belong to the richest in flowing water resources in Poland with the relatively stable outflow and high unit outflows [3]. The underground structure has a significant share (over 70%) of underground outflow [7, 13]. This value is much above the average for Poland. For the catchment of the Słupia, the share of underground water supply significantly exceeds the average for Poland and amounts to about 80%, while the average annual value of unit runoff exceeds $q = 10\ dm^3\ s^{-1}\ km^{-2}$ [3]. A high share of underground outflow should be attributed to good conditions of infiltration in numerous areas lacking outflow, and a large thickness of well-permeable surface rock layers. High importance is also attributed to subglacial channels, ice-marginal valleys, and deep-cut river valleys draining deep groundwater [14]. For the South Baltic Lake Districts, including the Pomeranian catchment, the hierarchical organisation of outflow is characteristic. The water cycle here depends more on the zonal factors, and less on local factors. The main river is the axis of the system; in its lower course, it has allochthonous character, while the main river's function consists in draining surplus water coming from the source catchments. Often also several catchments participate in the process of discharging water surpluses. It is the case in the Kashubian hydrographic system (ksh), the Bytów hydrographic system (bsh), and the Drawsko hydrographic system (dsh) [15].

16.2 Atmospheric Inflow

The climate of Pomerania exhibits features attributed to mid-latitudes showing the transitional nature of oceanic and continental influences. What is strongly pronounced here is the predominance of advection of moist air masses from the west, as well as instability, expressed in the variability of weather conditions all year round [16]. However, the range of the Baltic Sea influence and the morphological contrast between the raised and diversified relief of the lake district and the coastal plains are of vital importance in shaping the climate conditions of Pomerania. It is reflected in the distinct climatic regions of this area. It is assumed that the direct impact of the sea is limited to a 20–30 km wide strip of land [17]. The influence of the sea determines radiation and aerodynamic, thermal and hygrometric features of the climate. On the coast, one of the most significant amounts of solar energy in Poland is recorded, both on a yearly and summer basis (from May to August). It is favoured by the summer length of the day and relatively small convection-type overcast. The development of overcast, especially in May and June, is inhibited by the occurrence of the sea breeze circulation. As a result, in the coastal zone, the average annual real sunshine duration is 100 h longer (1700 h) than in the watershed zone separating the northern and southern slopes of Pomerania (1600 h).

Varied wind conditions are the specificity of the studied area. The wind directions and their seasonal variability are typical of the Polish Lowlands, which means that the winds with the component of the western sector (SW, W, and NW) dominate. However, there are relatively strong winds and a small number of windstill days. The dichotomy of the region regarding wind speed is marked. The coastal zone (the Koszalińskie, Słowińskie and Kaszubskie Coastlands) has a high number of days with strong and very strong wind, i.e., $\geq$10 and $\geq$15 m s^{-1}. Winds of this type appear mainly in the autumn and winter seasons and constitute over 19% of days a year. Their share decreases towards the west coast (Kołobrzeg, Świnoujście) to 12–15%. The strongest winds are recorded in Hel, Ustka, and Łeba. Inland, in the Pomeranian Lake District, especially in ice-marginal valleys, there are generally winds of lower velocity, thus the share of weak winds and wind-stagnant days increases. The incidence of days with winds exceeding the threshold of 10 m s^{-1} decreases to about 3%.

Diversification of the relief and the influence of the Baltic Sea determine the spatial distribution and fluctuations in the air temperature. The average annual temperature from the years 1951–2015 is 8.0 °C (Table 16.2) and decreases from SW to NW, ranging from 8.7 °C in the Szczecin area to 7.7 °C in Łeba and Lębork [18]. A clear drop in temperature is recorded in the Kaszubskie Lake District (7.2 °C). The coldest month is January (−0.8 °C), while the warmest month is July (17.3 °C). In the coastal belt, the average annual air temperature ranges are lower than in other parts of the country [19, 20]. It is because the chilled water masses of the Baltic Sea delay the arrival of spring and make the summer cooler. In turn, after warming up, they cause an extension of autumn and a milder course of winter [21]. Thus, the average spring temperature (March–May) is lower than the average autumn temperature (Sept–Nov) even by 3–4 °C [22, 23].

Table 16.2 Annual and seasonal mean of air temperature, the coolest and the warmest month temperature in Pomerania in 1951–2015 [18] (changed)

Station	In Year	January	July	Amplitude	Spring	Summer	Autumn	Winter
Świnoujście	8.4	−0.1	17.5	17.6	7.0	16.7	9.4	0.5
Kołobrzeg	8.1	−0.3	17.1	17.4	6.6	16.2	9.1	0.3
Ustka	7.9	−0.3	17.0	17.3	6.2	16.1	9.2	0.3
Łeba	7.7	−0.7	16.8	17.5	6.0	15.9	8.9	−0.1
Hel	8.0	−0.3	17.3	17.6	5.9	16.5	9.4	0.3
Szczecin	8.7	−0.5	18.1	18.6	8.1	17.4	9.1	0.2
Resko	8.0	−1.1	17.4	18.5	7.3	16.6	8.4	−0.4
Koszalin	7.9	−0.8	17.0	17.8	6.8	16.2	8.7	−0.2
Lębork	7.7	−1.0	17.2	18.2	6.6	16.3	8.5	−0.5
Gorzów Wlk	8.5	−1.2	18.3	19.5	8.2	17.6	8.8	−0.4
Chojnice	7.2	−2.5	17.1	19.6	6.6	16.9	7.6	−1.8
Mean	8.0	−0.8	17.3	18.1	6.8	16.6	8.8	−0.2

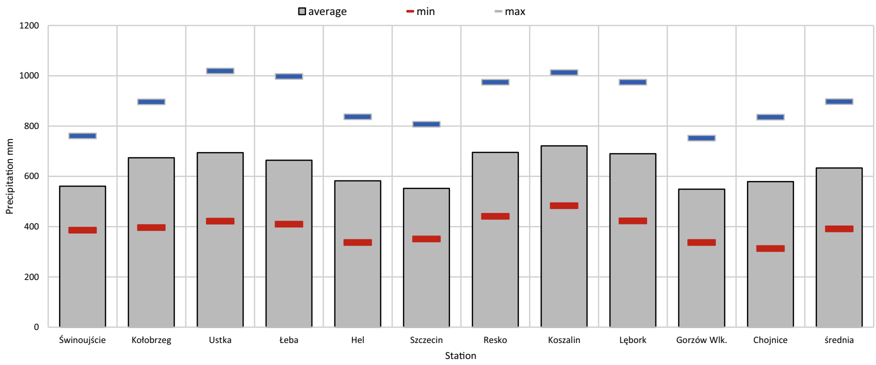

Fig. 16.2 Average, minimal i maximum precipitation Annual and seasonal mean of air temperature, the coolest and the warmest month temperature in Pomerania in 1951–2015 [18] (changed)

The water cycle in Pomerania is determined by atmospheric precipitation. Highly elevated plateaus constitute the main alimentation zone of surface and underground waters in the Pomeranian Lake District and the coastal region. A feature of the distribution of atmospheric precipitation is their temporal and spatial differentiation. The average annual precipitation (1951–2010) reaches 633 mm and ranges from 549 mm in Gorzów Wielkopolski to 721 mm in Koszalin. The variability of annual precipitation totals is on average 62–142% of the multiannual totals, and in individual regions represented by specific weather stations, it is 49–160%. The lowest precipitation is recorded in the eastern and western parts of the coastal area (<640 mm), while the most abundant precipitation is concentrated in the catchments of the Parsęta and Wieprza (>700 mm). Concerning the seasonal distribution, precipitation is mainly represented by the Pomeranian type [18, 24] characterised by descending order: summer, autumn, winter, spring. Thus, the maximum precipitation values are recorded in July or August, while the minima dominate in February, but they also happen in March and April. Another feature of precipitation is the frequency of their occurrence, expressed in the number of days with precipitation ≥0.1 mm. In the Pomeranian Lake District, as well as in the area of the South Baltic Coastlands, the incidence of precipitation is significant and exceeds 170 days per year (Fig. 16.2). Most often, precipitation occurs in the Łupawa and Łeba catchments, reaching the maximum near Lębork (52%). Precipitation is the least frequent on the SW edge of the Parsęta basin (<176 days).

16.3 Surface Inflow

Against the rivers of Poland, the Pomeranian rivers are rich in water resources. They present high total outflows and, at the same time, high outflow stability. The dominant share in the supply of rivers of lake districts constitutes the underground supply, making over 70% of the total [13]. From this value, 60–70% comes from the base

Table 16.3 Mean flow, mean specific runoff and outflow index of Pomeranian rivers in 1951–2015 (data base hydrometric monitoring IMGW-PIB)

River	Gauge station	Period observation	Mean Avg. Q [m^3 s^{-1}]	Mean Avg. q [dm^3 s^{-1} km^2]	H [mm]
Rega	Trzebiatów	1951–2015	20.20	7.64	241
Parsęta	Bardy	1956–2015	27.39	9.49	299
Wieprza	Stary Kraków	1951–2015	15.72	10.20	207
Grabowa	Grabowo	1976–2015	6.46	14.14	446
Słupia	Charnowo	1967–2015	17.81	11.15	352
Łupawa	Smołdzino	1951–2015	8.32	10.31	325
Łeba	Cecenowo	1956–2015	11.72	10.66	336
Reda	Wejherowo	1961–2015	4.32	10.54	332

outflow [25] creating the most stable form of underground supply from deep aquifers. The advantage of the underground supply component results from the presence of favourable infiltration conditions, numerous lakes, endorheic areas, wetlands, as well as significant areas with high ground retention capabilities. These include subglacial channels, ice-marginal valleys (the Grabowa Ice-marginal Valley, Łeba-Reda Ice-marginal Valley, Kashubian Ice-marginal Valley) and lowlands (the Gardno-Łeba Lowland, Karwia Lowland) filled with permanent wetlands. The discharge of the Pomeranian rivers varies depending on the size of rivers, from 4.32 m^3 s^{-1} in the Reda to 27.39 m^3 s^{-1} in the Parsęta (Table 16.3).

The seasonal nature of the outflow is modified by the annual cycle of changes in the volume and forms of supply (Fig. 16.3). Higher outflow rates occur in the winter half-year, culminating in March, while the lowest in the summer months. The minimum values of the coefficient are recorded in August (the Rega, Parsęta, Wieprz, Grabowa Łupawa), in June (the Łeba, Reda) or in both mentioned months they balance (the Słupia). The rivers of the western part of Pomeranian, like the Rega and Parsęta, show much higher variability of the outflow than the rivers of the central and eastern parts. The scale of volatility in the first case ranges from 70–150%, while in the second from 80 to 120% [3]. The distribution of the outflow in the annual cycle qualifies the examined rivers to the hydrological regime of the nival type [25] poorly (the Wieprza, Grabowa, Słupia, Łupawa, Łeba, Reda) or medium-developed (the Rega, Parsęta).

The unit outflow and the runoff layer are measures of the water resources of the examined rivers. All rivers have a unit outflow higher than the average for Poland estimated at 5.6 dm^3 s^{-1} km^2. The highest unit outflow is recorded for the Grabowa and Słupia catchments, respectively 14.14 and 11.15 dm^3 s^{-1} km^2 (Table 16.3), while the lowest in the Rega and Parsęta basins (<10 dm^3 s^{-1} km^2).

The remaining rivers have a unit outflow similar to the average outflow value calculated from the entire analysed area of Pomeranian (10.52 dm^3 s^{-1} km^2). In the case of the runoff layer, the boundary of the water resources of the examined rivers' catchment is determined by the Grabowa River with the highest values of

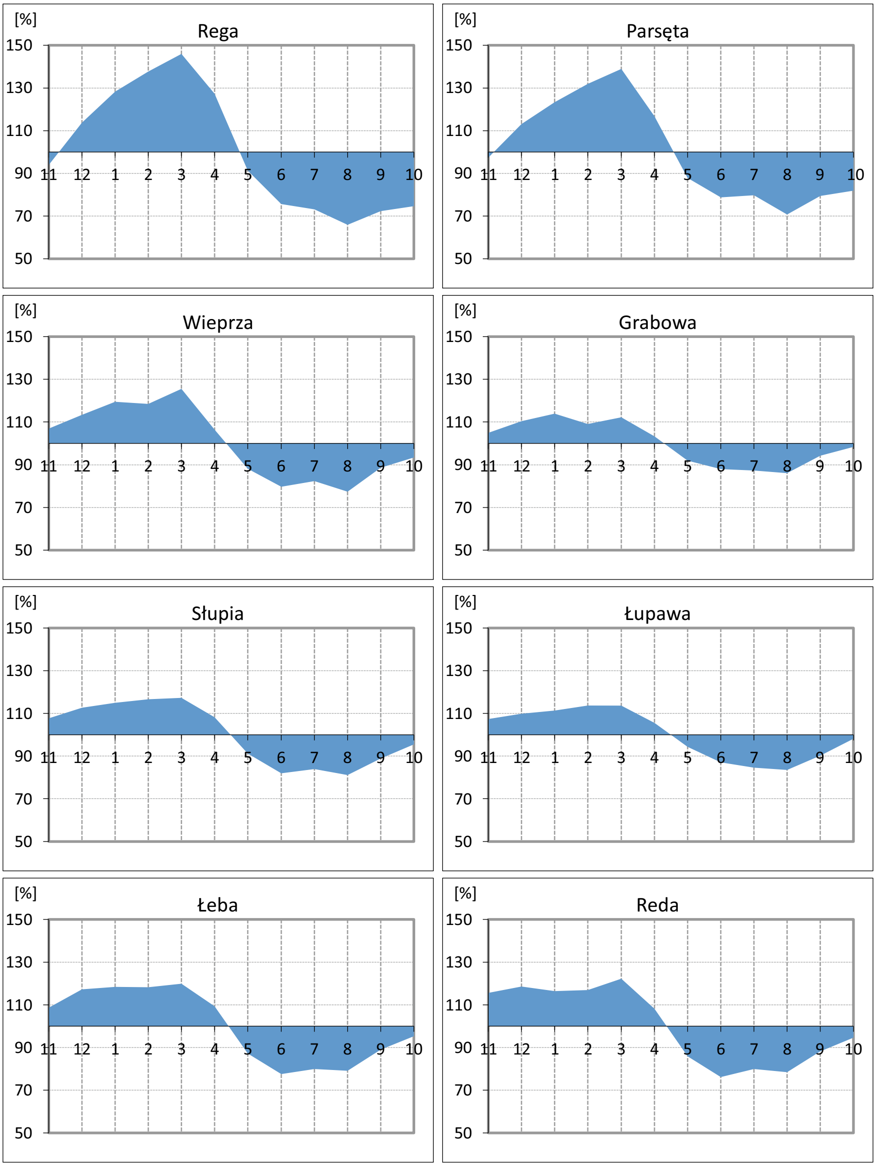

Fig. 16.3 Seasonal variability of outflow in 1951–2015

over 400 mm. To the west of it, the values of the measured indicator are lower and are below 300 mm, with the minimum in the Wieprza catchment (207 mm). In the basins on the eastern side of the Grabowa, the runoff layer is more significant, levelled and oscillates in the range of 325–352 mm.

16.4 Factors of Water Level Variation

A key role in forming the water conditions of the Pomeranian rivers, and especially their estuary sections, is played by the main (Baltic Sea) and regional (coastal lakes) drainage bases. The most critical causes of changes in the level of the southern Baltic waters (Fig. 16.4) include water accumulation and depressions caused by air pressure changes and wind waves as well as hydrological factors associated with the seasonal outflow of land waters.

The average long-term level of sea waters changes from 1951–2000 from west to east in the range from 499 to 502 cm. In the annual cycle, there are elevated water levels in the autumn and winter as well as in summer. In the first case, they are generated by frequent migration of low-pressure centres from the North Atlantic to Europe over the Baltic Sea. They are very dynamic and induce extreme values of sea levels, both maximum and minimum. According to [26] storm surges can reach up to 2 m, even 3 m, which determines the range of absolute amplitudes (Fig. 16.5) [27]. In

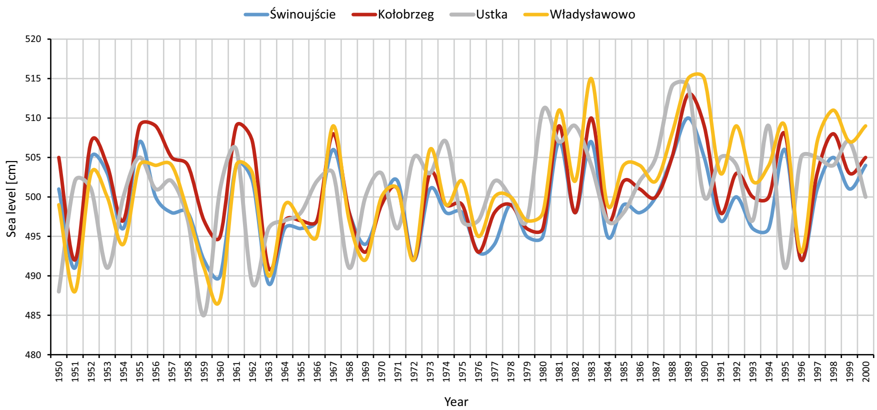

Fig. 16.4 Mean annual sea level on the coast southern Baltic in 1951–2000

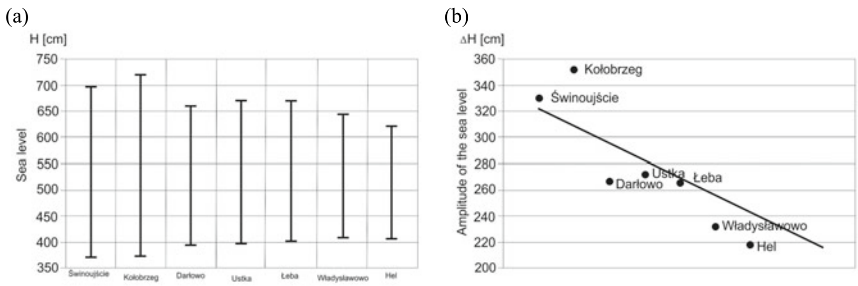

Fig. 16.5 Fluctuation range of the southern Baltic: a – maximum and minimum levels; b – fluctuation amplitudes [29]

the case of the summer, elevated sea levels are related to the increase in precipitation and increase (from the end of runoff of meltwater) inflow to river waters [28]. With spring (April, May), the dominance of the eastern atmospheric circulation causing coastal winds is associated with low average sea levels.

Climate change is accompanied by rising sea levels, and its different rate depends on the location of coastal stations along the Polish coast of the open Baltic Sea [30]. Research indicates that the average annual sea level rise is lower in the western part of the coast (0.07 cm year^{-1} in Świnoujście) and increases towards the east (0.17 cm year^{-1} in Ustka up to 0.23 cm year^{-1} in Władysławowo). On a seasonal basis, the highest increase occurs in winter and spring (especially in February and March), while in autumn and winter months (September, October, and December) there are no upward trends.

The coastal lakes (Resko Przymorskie, Jamno, Bukowo, Kopań, Gardno, Łebsko, Sarbsko), often connected with the sea by engineered sections of rivers (canals), play a unique role in the potamic outflow of the Pomeranian rivers. In practice, this means that the lakes form an extension of the main drainage base on the mainland, constituting a regional base. It is determined by the convergent rhythm of variations in the level of lakes with sea fluctuations, the strongest correlating in the case of Lake Łebsko (Fig. 16.6). At the same time, due to the location of lakes in the lower sections of rivers, they play the role of receivers of water flowing down from entire river basins, but also – which is not very beneficial – pollution.

Additional pressure on these hydrographic objects is exerted by the polder systems with enforced water circulation.

Connection of the rivers with the sea both direct and through lakes has its hydrological and hydrochemical repercussions. The observed, long-term changes in the main drainage base cause an increase in the level of coastal lakes. As a result, they may also influence the decrease of potamic and groundwater outflow towards the sea, and increase the entry of sea waters into the land. Such scenarios are shown by previous research [21]. During short storm surges, sea waters block the free river runoff or invade their course and the lakes located in the coastal zone. So far, the maximum range of intrusions has been noted on the Łeba River for the profile in Cecenów (20 km from the estuary). In storm situations, there may be a direct flood hazard,

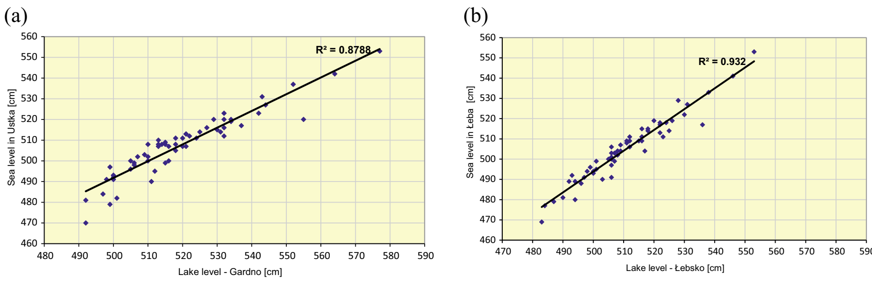

Fig. 16.6 Dependence of water fluctuations of Gardno and Łebsko lakes from the level of the Baltic Sea [31]

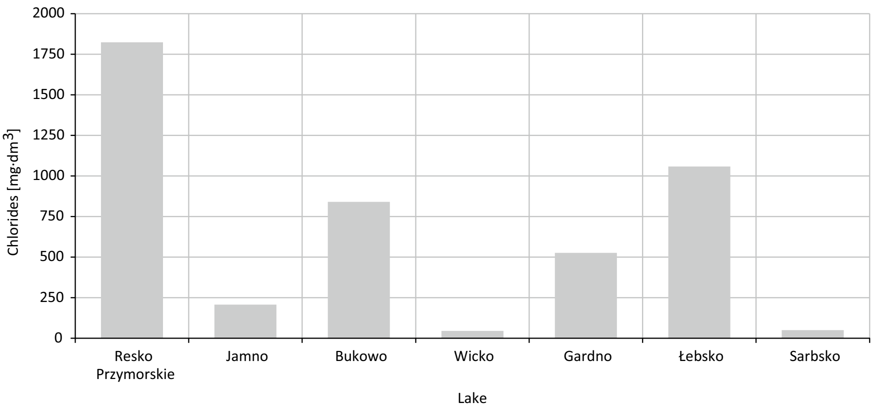

Fig. 16.7 Average values of chloride concentration in coastal lakes in the period 2002–2003 [32]

especially in the areas of coastal lowlands and coastal lakes. It is not uncommon that, as a result of a storm, the estuary sections of the rivers are wholly or partially blocked by sea sands, limiting the potamic outflow to the sea. Such situations are observed at the mouth of the Łupawa or smaller streams of the Karwianka or the channel connecting Lake Kopań with the sea. In unregulated rivers (the Piaśnica), the estuary often changes its location.

Intrusions of sea waters result in changes in physical and chemical properties of the surface and underground waters. The most susceptible to these changes are the waters of coastal lakes, and the primary indicator of the impact of sea waters are the values of salinity (chloride). The highest average salinity is observed in lakes Resko Przymorskie and Łebsko (Fig. 16.7), reaching over 1000 $mg \cdot dm^3$ Cl^-, and the smallest in Lake Sarbsko [32]. The spatial distribution of chlorides shows a decrease in concentrations as we move away from the channels that provide communication between the lakes and the sea. There is a possibility of recording almost entirely fresh water in the reservoir. It applies, among others, to lakes Jamno, Wicko, Gardno, and Sarbsko.

16.5 Pollution Supply

The high content of nutrients and some other substances in the coastal waters of the Southern Baltic is mainly due to the rivers carrying pollution load. Delivery of pollutants (primarily nutrients – forms of nitrogen and phosphorus) to the receiver, which is the Baltic Sea, takes place via rivers, but only a particular part of nutrients from various sources in the basin get to the rivers and then to the receiver. These differences are the result of retention and loss of nutrients in waterways [33]. Retention is understood as temporary retention of biogens within the river valley, and losses as irreversible removal from the river system. Nitrogen retention and loss occur mainly in the source sections (denitrification), and the phosphorus – in the downstream part (sedimentation). Undoubtedly, however, land use in the catchment and the size and location of the point, linear and area pollution sources are responsible for the pollution volume.

The quality of river waters leaves much to be desired. In 2016 the ecological potential of only the Parsęta and Słupia was assessed as good. The remaining rivers had the potential rather moderate (the Reda and Wieprza) or poor (the Łupawa, Łeba, and Rega) [29, 34]. The situation in jcwp (the WFD surface water body) was worse. For all the rivers studied, it was very poor. Causes should be linked to land use. Half of the discussed catchment area is occupied by built-up areas and arable lands, and in the Rega catchment, it is up to 65% (Table 16.4).

According to Corine Land Cover 2012 classification (level 1), the dominant type of catchment land use is the cropland (52.7%) and forest (42.2%) (Table 16.4). In Rega catchment, the total area of cropland is 1705.6 km^2, which is 23.5% of the total area of all discussed catchments. The total area of forest in Parsęta catchmest is 1340.1 km^2. Forests are the dominant type of land use in the Reda and Wieprza catchments (Fig. 16.8). Wetland occupies only 0.2% of the area of all discussed catchments. In the Łeba catchment wetlands covers 17.3 km^2 (which is 1% of the Łeba catchment).

Table 16.4 Landuse in the Pomeranian catchments (according Corine Land Cover 2012)

Landuse		Urban	Cropland	Forest	Wetland	Water	Total
Rega	km^2	90.3	1705.6	931.2	2.5	35.6	2765.2
	%	3.3	61.7	33.7	0.1	1.3	100
Parsęta	km^2	83.9	1634.5	1340.1	2.7	14.8	3075.8
	%	2.7	53.1	43.6	0.1	0.5	100
Grabowa	km^2	8.7	286.6	276.2	1.3	1.4	574.2
	%	1.6	50.0	48.1	0.1	0.2	100
Wieprza	km^2	31.4	768.6	822.5	0.0	16.0	1638.4
	%	1.9	46.9	50.2	0.0	1.0	100
Słupia	km^2	72.1	805.3	719.1	0.4	23.8	1620.8
	%	4.4	49.7	44.4	0.0	1.5	100
Łupawa	km^2	24.0	463.8	388.4	2.2	35.2	913.65
	%	2.6	50.8	42.5	0.2	3.9	100
Łeba	km^2	48.6	914.3	713.2	17.3	86.5	1779.9
	%	2.7	51.4	40.1	1.0	4.9	100
Reda	km^2	47.1	278.8	285.6	2.0	5.7	619.2
	%	7.6	45.0	46.1	0.3	0.9	100
total	km^2	432.9	7266.2	5824.8	30.2	233.0	13,787.1
	%	3.1	52.7	42.2	0.2	1.7	100

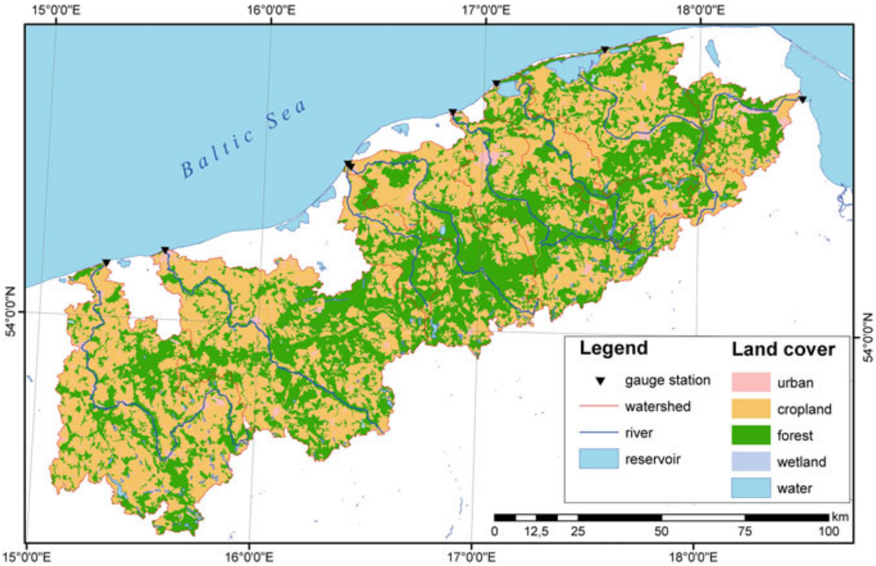

Fig. 16.8 Landuse in the Pomeranian catchments (according Corine Land Cover 2012)

There are three types of pollution sources: point (hotspot), linear and area. The area sources of pollution include: arable land, urban fabric and industrial. The area sources of pollution cover 5387.0 km^2 of the Pomeranian catchments. Only in Rega catchment, the area sources of pollution covers 51.4% of the catchment (1423.1 km^2). The line sources of pollution include: commercial and transport units (road and rail networks). In total the length of primary and secondary roads is 2118.0 km, but the length of rail is 850.3 km. The last group is point sources of pollution from wastewater plant, campsite, gas station or carwash. The biggest threat to water quality is sewage discharges from wastewater plants. There are two wastewater plants in Rega catchment and two in Parsęta catchment (Fig. 16.9). In total, there are at least 185 hotspots in Pomeranian catchments.

16.6 Flood Risk and Prevention

The temporal variability of water resources manifested in their seasonal abundance and resulting from the excessive inflow of allochthonous waters or inhibition in free flow, characteristic for the conditions of the geographical environment of Pomerania, bring flood risks. Due to the formation process, there are different threats from land and sea. Land-induced floods include dangers brought by volatile or widespread atmospheric precipitation and thaw, or by the formation of ice jams on rivers. Sea-induced floods are hazards associated with storm phenomena. Among the mentioned, the primary place is taken by rainfall, usually occurring in the summer (dominance on

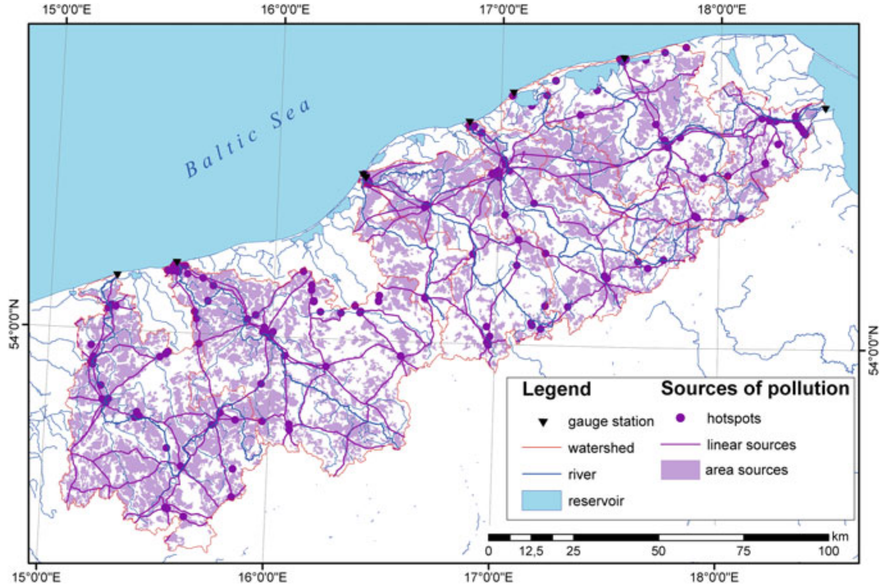

Fig. 16.9 Sources of pollution in the Pomeranian catchments

smaller watercourses), followed by snowmelt and ice jams. In all cases, the situation is highly unfavourable when excess water stagnates in the inter-embankment area, causing the flood banks to wash out. Sea-induced floods are most dangerous during the autumn and winter rapid surges of the Baltic Sea, or the Gulf of Gdansk. Hence, the areas most vulnerable to flooding are the Gardno-Łeba Lowland, Karwieńskie Błota together with the Piaśnica valley, Płutnica Ice-marginal Valley and Kaszubska Ice-marginal Valley. Often, storm surges are accompanied by other phenomena, in combination with which hazards of a mixed, land-sea type with a storm-thaw or storm-ice jam genesis are created. This is when the flood risk is highest. It applies above all to coastal lowlands, the more so because the existing drainage system turns out to be less efficient and useful, due to the opposite directions of water runoff. A separate type of emergency are events related to a failure of hydraulic structures or construction disaster of such structures. It is connected with water and drainage systems based on a gravitational and forced way of draining surplus water using a pump station (the Gardno-Łeba Lowland) or river valleys used for energy purposes (the Słupia, Łupawa). Defects of this kind can be caused by a power shortage or by the recklessness of a human being. The flow of water through the main valleys, especially during surges, is a potential threat to neighbouring areas, both to the risk of flooding and the risk of contamination in case of spilling waters.

In the preliminary flood risk assessment, it was necessary to designate risk areas, i.e. those where there is a significant risk of flooding or where high risk is likely to occur. This assessment was based on hydrography, topography and land use of the area. Information on historical floods and the evaluation of the potential adverse effects of floods that may occur in the future were taken into account. The effect of these activities is the forecast of the long-term development of events, in particular, the impact of climate change on the occurrence of floods. In all catchments discussed, after the year 2000, an increase in the number and location of floods was registered. These were floods on the Reda (2008, 2009), Parsęta (2002), Grabowa (2005), Wieprza (2004), Słupia (2001), Łupawa (2007), Łeba (2002) and Reda (2001). Besides, in 2007 flood occurred on Lake Jamno. At the end of the nineteenth century and the beginning of the twentieth-century floods took place on three rivers: the Parsęta (1874), Łeba (1898) and Wieprza (1914). The Słupia and Łeba experienced high water in 1982 and 1998 respectively.

High and medium (10 and 1%) probability of flooding concerns the Reda. The Słupia, Łupawa, Łeba, Grabowa, Rega, and Wieprza are at risk of flooding with a medium probability (1%) of occurrence (Table 16.5). Low probability applies to the Parsęta and the lakes Jamno, Resko Przymorskie, and Wicko.

All discussed Pomeranian rivers, sections with a total length of 947 km (Fig. 16.10), were classified under the Preliminary Flood Risk Assessments (PFRAs) [35] for the development of flood hazard maps and flood risk maps. The longest section was designated for Rega 0–187 km, then for Słupia (0–148 km), Parsęta (0–142 km), Wieprza (0–133 km) and Łeba (0–126 km). Sections shorter than 100 km were assigned to Łupawa (0–90 km), Grabowa (0–72 km) and Reda (0–49 km).

From the point of view of flood prevention, buffer and strategic investments are of great importance [36]. Buffer investments mainly relate to the reconstruction of old and construction of new flood embankments, engineering channels and construction of flow regulating devices, strengthening of river banks, as well as the construction of retention reservoirs and development of valley retention (Table 16.6). Strategic investments in the catchment areas concerned the increase of their retention through afforestation (comprehensive forest and forestry adaptation projects to climate change), counteracting water erosion in lowland areas, restoration of

Table 16.5 High and average probability of exceedance flow and corresponding water level

River	Gauge station	Avg Q [m^3 s^{-1}] (1951–2010)	High Q [m^3 s^{-1}] (1951–2010)	Maximum flow of exceedance probability Qmaxp% [m^3 s^{-1}] and corresponding water level H [cm]			
				$Q_{10\%}$	$HQ10_{\%}$	$Q_{1\%}$	$HQ1_{\%}$
Rega	Trzebiatów	54.2	87.7	72.9	421	95.2	462
Parsęta	Bardy	80.8	143.0	110.0	435	140.0	460
Grabowa	Grabowo	14.8	21.7	19.1	165	24.5	209
Wieprza	Stary Kraków	41.6	76.7	59.1	442	79.5	504
Słupia	Charnowo	35.9	53.6	44.0	349	58.0	391
Łupawa	Smołdzino	17.1	44.9	24.0	106	36.0	139
Łeba	Cecenowo	28.2	45.9	39.3	284	50.4	327
Reda	Wejherowo	14.0	22.3	19.1	180	24.9	200

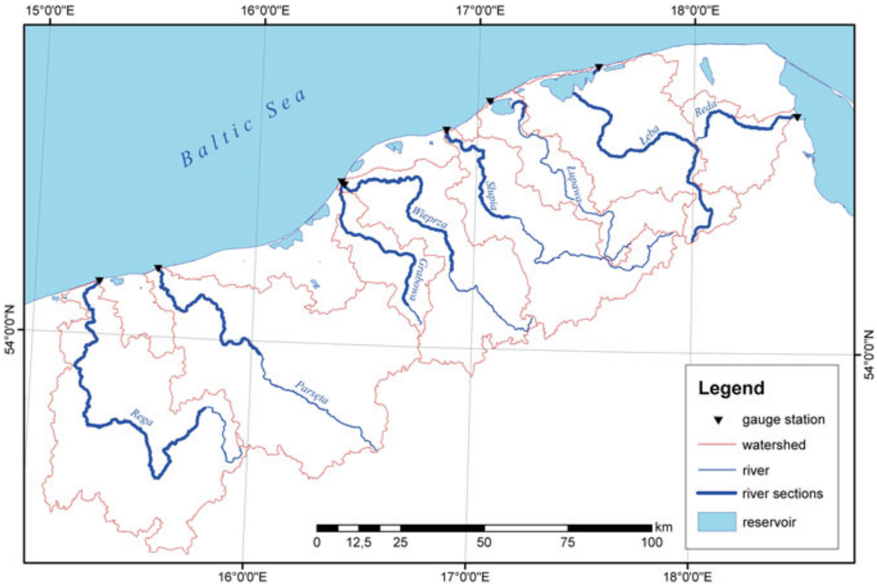

Fig. 16.10 Rivers classified as part of the Preliminary Flood Risk Assessment (PRFAs) [35] for the development of flood hazard maps and flood risk maps

Table 16.6 Buffer investments [34]

Activity	Rega	Parsęta	Wieprza	Reda
Construction of new flood embankments	x			x
Reconstruction of old flood embankments			x	x
Construction of retention reservoirs	x			
Development of valley retention	x			
Engineering channels	x	x		
Construction of flow regulating devices	x			
Strengthening of river banks	x	x	x	

riverbeds and riverbanks, increasing retention in urban areas of over 20 000 residents. For some towns (Resko, Białogard, Sławno, Ustronie Morskie and Trzebiatów), a multi-variant concept of flood protection was implemented. Strategic investments also concern the seashore as a limitation of the identified flood risk, especially in the area of Lake Bukowo and the spit of Lake Jamno.

16.7 Conclusion

The Pomeranian catchments water cycle depends less on local factors is determined by atmospheric precipitation. The favourable infiltration conditions, numerous lakes, endorheic areas, wetlands and significant areas with high ground retention capabilities are providing the underground supply. The annual cycle of changes in the volume and forms of supply modifies the seasonality of outflow and all studied rivers have a unit outflow higher than the average for Poland (estimated at 5.6 $dm^2\ s^{-1}\ km^2$). The highest values (over 400 mm) of the runoff layer of the studied rivers' catchment water resources is determined by the Grabowa River.

The unique role in the potamic outflow of the Pomeranian rivers play coastal lakes which are often connected with the sea by engineered sections of rivers. The lakes form an extension of the main drainage base on the mainland, constituting a regional base. The convergent rhythm of variations in the level of lakes with sea fluctuations also is exerted by the polder systems with enforced water circulation. The long-term changes in the main drainage base cause an increase in the level of coastal lakes, that in result, they may influence the decrease of potamic and groundwater outflow towards the sea, and increase the entry of sea waters into the land.

The high concentration of nutrients and some other substances in the coastal waters is mainly due to the rivers carrying pollution load, but only a particular part of nutrients from various sources in the catchment get to the water.

Retention and loss of the nitrogen occur mainly in the source sections and the phosphorus - in the downstream part. The pollution volume is determined by land use in the catchment and the size and location of the point, linear and area pollution sources.

The flood risks results from temporal variability of water resources manifested in their seasonal abundance and resulting from the excessive inflow of allochthonous waters or inhibition in free flow and because of the existing drainage system turns out to be less efficient and useful, due to the opposite directions of water runoff.

16.8 Recommendation

According to the definition of water management, the work presented includes the determination of water resources in the area of Pomerania, which can be rationally used for the needs of the natural and social environment. Such studies should be repeated periodically, due to unfavorably changing climatic conditions that visibly change also water resources, and thus affect periodic shortages or excess water. The work is addressed to authorities at various levels (local, regional and national) responsible for proper water management, waste management, spatial management and agriculture, which are directly or indirectly dependent on water or affect its quality. The study should be of particular importance for institutions dealing with flood risks and protection, such as Maritime Offices, for water construction enterprises and establishments of municipal economy. Pomeranian rivers are contaminated with nutrients and are the main cause of pollution in the Baltic Sea. Therefore, continuous monitoring of the quality of river waters is important, as well as works aimed at reducing the use of artificial fertilizers in agriculture in Pomerania.

References

1. Stachy J (1980) Odpływ rzek Przymorza na tle odpływu z terenu całej Polski. Stosunki wodne w zlewniach Przymorza i dorzecza Dolnej Wisły ze szczególnym uwzględnieniem gospodarki wodnej jezior. IMGW, Słupsk, pp 13–27
2. Kondracki J (2000) Geografia regionalna Polski. PWN, Warszawa
3. Bogdanowicz R (2004) Hydrologiczne uwarunkowania transportu wybranych związków azotu i fosforu Odrą i Wisłą oraz rzekami Przymorza do Bałtyku. Wyd, UG, Gdańsk
4. Bajkiewicz-Grabowska E, Markowski M, Golus W (2020) Polish rivers as hydrographic objects. In: Korzeniewska E, Harnisz M (eds) Polish river basins and lakes – part I. The handbook of environmental chemistry, vol 86. Springer, Cham. https://doi.org/10.1007/978-3-030-12123-5_2
5. Bajkiewicz-Grabowska E, Golus W, Markowski M, Kwidzińska M (2020) Characteristics of the water network in postglacial areas of Northern Poland. In: Korzeniewska E, Harnisz M (eds) Polish river basins and lakes – part I. The handbook of environmental chemistry, vol 86. Springer, Cham. https://doi.org/10.1007/978-3-030-12123-5_8
6. Bajkiewicz-Grabowska E (2002) Obieg materii w systemach rzeczno-jeziornych. Geografii i Studiów Regionalnych, Warszawa, UW, Wydz
7. Fac-Beneda J (2011) Młodoglacjalny system hydrograficzny. Wyd, UG, Gdańsk
8. Bajkiewicz-Grabowska E, Golus W, Markowski M, Kwidzińska M (2020) The role of lakes in shaping the runoff of lakeland rivers. In: Korzeniewska E, Harnisz M (eds) Polish river basins and lakes – part I. The handbook of environmental chemistry, vol 86. Springer, Cham. https://doi.org/10.1007/978-3-030-12123-5_9
9. Fac-Beneda J (2008) Naturalne wypływy wód podziemnych na obszarach chronionych w północnej Polsce. In: Pociask-Karteczka J (ed) Wody na obszarach chronionych. IGiGP UJ, Kraków, pp 133–141
10. Mazurek M (2010) Hydrogeomorfologia obszarów źródliskowych (dorzecze Parsęty, Polska NW). UAM w Poznaniu, seria Geografia, 92, Poznań
11. Osadowski Z (2010) Wpływ uwarunkowań hydrologicznych i hydrochemicznych na zróżnicowanie szaty roślinnej źródlisk w krajobrazie młodoglacjalnym Pomorza. AP w Słupsku, Bogucki WN, Poznań-Słupsk
12. Fac-Beneda J, Hryniszak E (2006) Wypływy wód podziemnych u podnóży krawędzi pradolinnych. In: Źródła Polski. Wybrane problemy frenologiczne, (ed.) P. Jokiel, P. Moniewski, M. Ziułkiewicz, Wydz. Nauk Geogr. UŁ, Łódź
13. Dynowska I (1972) Typy reżimów rzecznych w Polsce. Zeszyty Naukowe UJ, Prace Geograficzne, 28, Kraków
14. Drwal J (1985) Jeziora w egzoreicznych systemach pojezierzy młodoglacjalnych. Zeszyty Nauk. Wydz. BiNoZ UG, Geogr 14:7–15
15. Fac-Beneda J (2017) Struktura sieci hydrograficznej. In: Jokiel P, Marszelewski W, Pociask-Karteczka J (eds), Hydrologia Polski, Wyd. PWN, Warszawa, pp 116–121
16. Miętus M, Wielbińska D (1996) Średni rozkład ciśnienia atmosferycznego nad Europą i jego modyfikacja w rejonie Morza Bałtyckiego. Wiadomości IMGW 3:85–100
17. Kwiecień K (1959) Próba określania zasięgu wpływu Bałtyku na klimat przyległego Pomorza. Biuletyn PIHM, 9
18. Kirchenstein M (2013) Zmienność temperatury powietrza i opadów atmosferycznych w północno-zachodniej Polsce. Wydawnictwo Naukowe Akademii Pomorskiej w Słupsku, Słupsk

19. Paszyński J (1984) Główne cechy klimatu. In: Augustowski B (ed) Pobrzeże pomorskie. GTN, Gdańsk, pp 169–187
20. Trapp JA (2007) Warunki klimatyczne. In: Czochański J, Lemańczyk J (eds) Aktualizacja opracowania ekofizjograficznego do planu zagospodarowania przestrzennego województwa pomorskiego. Wojewódzkie Biuro Planowania Przestrzennego, Urząd marszałkowski Województwa Pomorskiego, Słupsk-Gdańsk, pp 48–62
21. Miętus M, Filipiak J, Owczarek M (2004) Klimat wybrzeża południowego Bałtyku. Stan obecny i perspektywy zmian In: Cyberski J (ed) Środowisko polskiej strefy brzegowej południowego Bałtyku – stan obecny i przewidywane zmiany w przededniu integracji europejskiej, GTN, Wydział V Nauk o Ziemi, Gdańsk, pp 11–44
22. Friedrich M, Sredzicka B, Jakoniuk J (1980) Klimat województwa słupskiego w świetle potrzeb rolnictwa. Wojewódzki Ośrodek Postepu Rolniczego w Strzelnie, IMGW O/Słupsk, Strzelino-Słupsk
23. Paszyński J, Niedźwiedź T (1999) Klimat In: Starkel L (ed) Geografia Polski, środowisko przyrodnicze. Wyd. Naukowe PWN, pp 288–342, Warszawa
24. Kożuchowski K, Wibig J (1988) Kontynentalizm pluwialny w Polsce: zróżnicowanie geograficzne i zmiany wieloletnie. Wydanie 55 z Acta geographica Lodziensia, Łódź
25. Wrzesiński D, Brychczyński A (2014) Zróżnicowanie reżimu odpływu rzek w północno-zachodniej Polsce. Badania Fizjograficzne, R. V, Seria A, Geografia Fizyczna (A65), 261–274
26. Majewski A (1987) Charakterystyka wód: In: Augustowski B (ed) Bałtyk Południowy. GTN, Wyd. PAN, Wrocław
27. Wiśniewski B, Wolski T (2009) Occurrence probability of maximum sea levels in Polish ports of Baltic Sea coast. Polish Marit Res 16(3):62–69
28. Mikulski Z (1983) Dopływ wód rzecznych do Morza Bałtyckiego. Przegląd Geofizyczny XXVIII 2:65–183
29. Stan środowiska województwa zachodniopomorskiego w roku 2016. Raport 2017 (2017) Wojewódzki Inspektorat Ochrony Środowiska w Szczecinie, Szczecin
30. Girjatowicz JP (2008) Katalog zasolenia i stanów wody polskiego wybrzeża Bałtyku. Wydawnictwo Naukowe Uniwersytetu Szczecińskiego, Szczecin
31. Chlost I (2012) Geograficzne uwarunkowania stosunków wodnych Niziny Gardneńsko-Łebskiej. Rozprawa doktorska, typescript. Katedra Hydrologii UG, Gdańsk
32. Cieśliński R (2011) Geograficzne uwarunkowania zmienności hydrochemicznej jezior wybrzeża południowego Bałtyku. Wydawnictwo Uniwersytetu Gdańskiego, Gdańsk
33. Behrendt H, Opitz D (1999) Retention of nutrients in river systems: dependence on specific runoff and hydraulic load. Hydrobiology 410:111–122
34. Raport o stanie środowiska województwa pomorskiego w roku 2016 (2017) Inspekcja Ochrony Środowiska, WIOŚ w Gdańsku. Biblioteka Monitoringu Środowiska, Gdańsk
35. Raport z wykonania wstępnej oceny ryzyka powodziowego (2011) Projekt ISOK. Informatyczny system osłony kraju przed nadzwyczajnymi zagrożeniami, Tytuł zadania 1.3.1: Wstępna ocena ryzyka powodziowego (WORP), KZGW, Warszawa
36. www.kzgw.gov.pl (2018.11.30)