

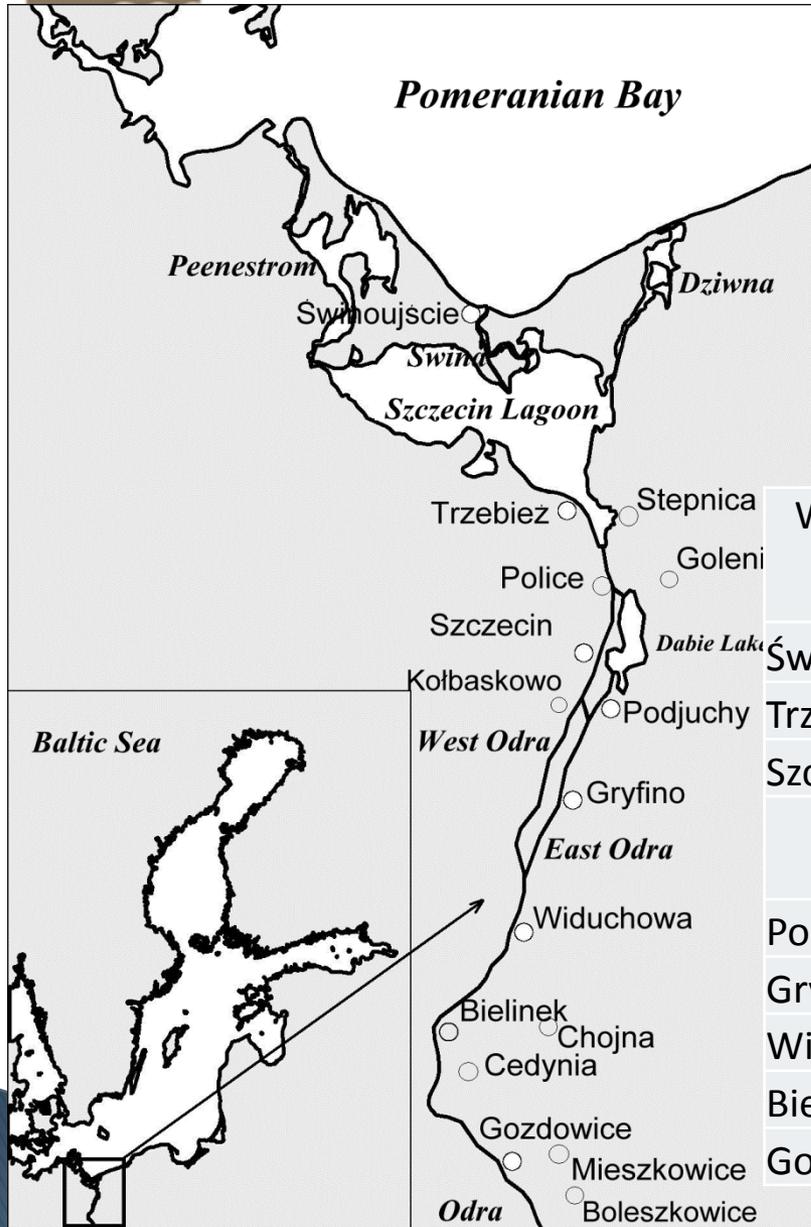


The flood threat from severe high water events in the urban area of the lower Odra River

Zagrożenie powodziowe na obszarach zurbanizowanych w dolnym biegu Odry

Halina Kowalewska-Kalkowska

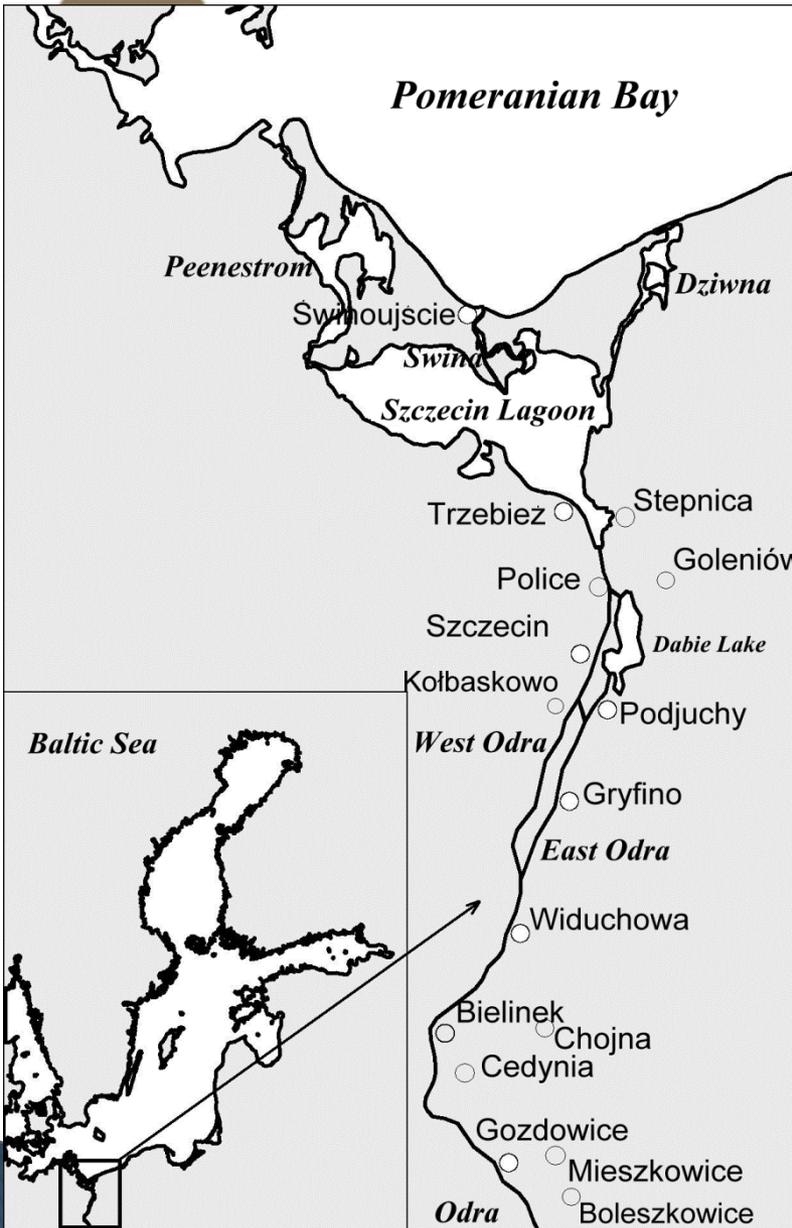
Coastal Marine Hydrography Unit, University of Szczecin,
Mickiewicza 16, 70-383 Szczecin,
e-mail: halkalk@univ.szczecin.pl



The aim of the study:

- ❑ Recognition of causes leading to extreme high water events in the downstream Odra reach
- ❑ Estimation of the urban flood threat on the basis of water level data from 1993-2014.

Water level station	km of the fairway	Commune	Alarm level (cm)	Warning level (cm)
Świnoujście	2.3	Świnoujście	580	560
Trzebież	36.0	Police	560	540
Szczecin	66.5	Szczecin	600	570
	km of the Odra			
Podjuchy	734.0	Szczecin	610	580
Gryfino	718.5	Gryfino	600	570
Widuchowa	701.8	Widuchowa	650	630
Bielinek	672.5	Cedynia	550	480
Gozdowice	645.3	Mieszkowice	500	440



Commune	Character	Surface (sq. km)	Population	Pop. Density (per sq. km)
			The Goleniów Poviát	
GUS (2014)				
Stepnica	town	3	2266	666
	rural	290	2591	9
Goleniów	town	12	22776	1933
	rural	431	12757	30
The Police Poviát				
Police	town	37	33625	901
	rural	215	8286	39
Kołbaskowo	rural	105	11599	110
The Szczecin Poviát				
Szczecin	town	301	408172	1358
The Gryfino Poviát				
Gryfino	town	10	21578	2252
	rural	244	10569	43
Widuchowa	rural	210	5598	27
Chojna	town	12	7344	584
	rural	320	6625	21
Cedynia	town	2	1651	989
	rural	179	2754	15
Mieszkowice	town	5	3603	762
	rural	234	3812	16
The Myślibórz Poviát				
Boleszkowice	rural	130	2937	23

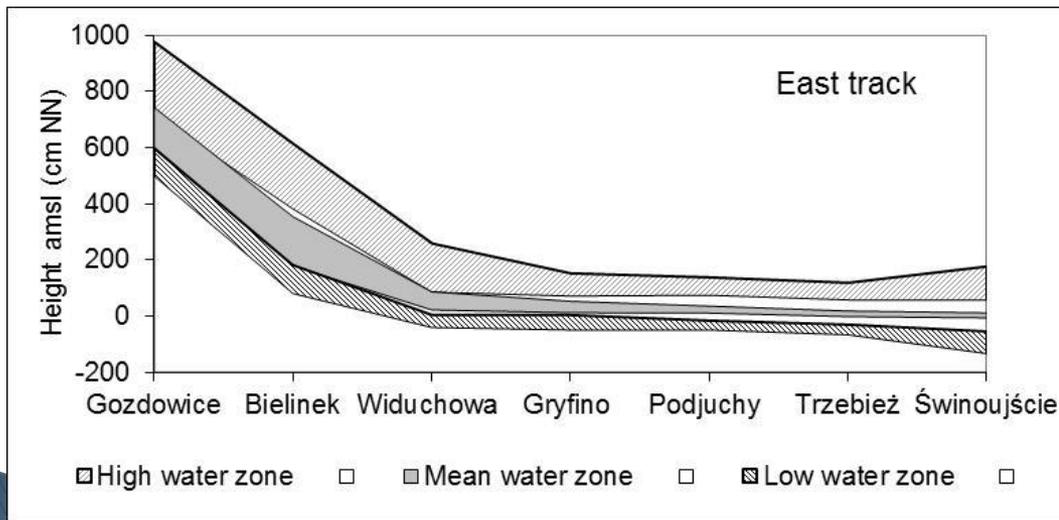
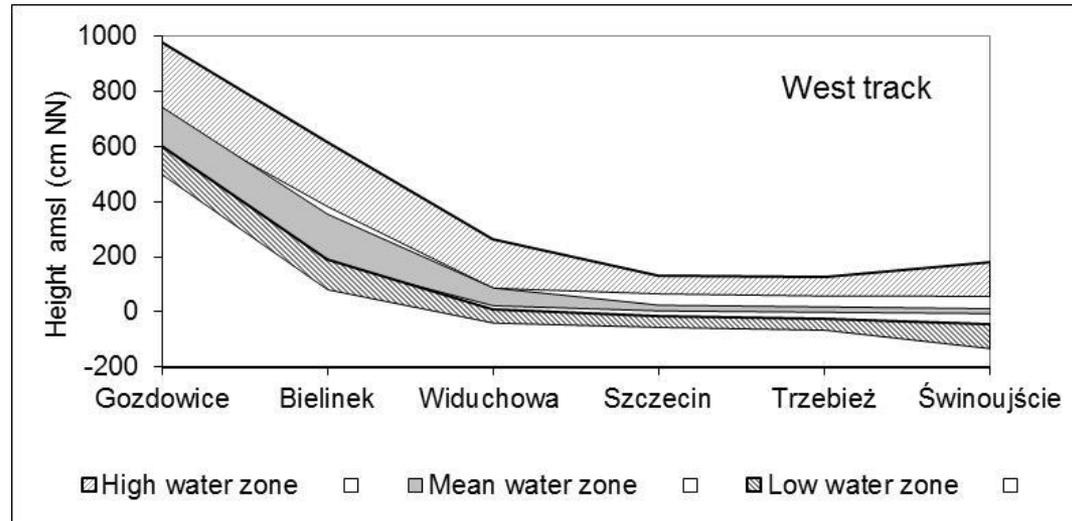


Slope of free water surface in the Odra mouth (1993-2014)

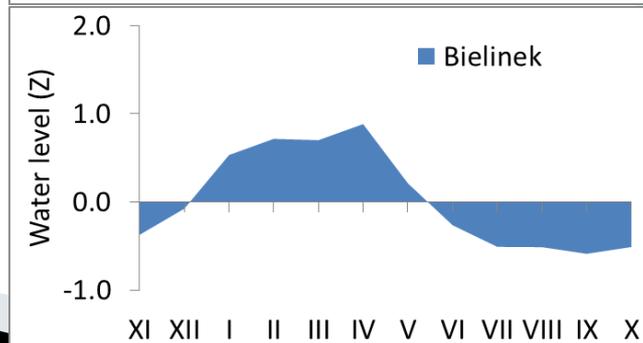
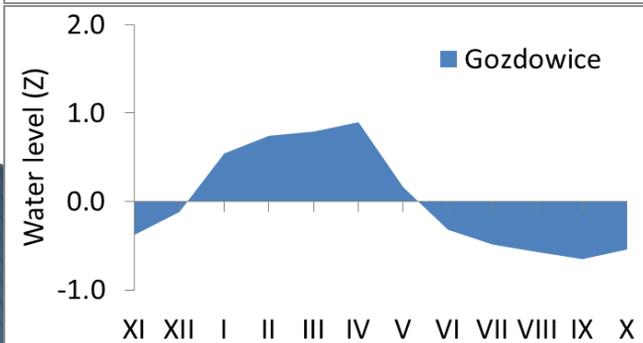
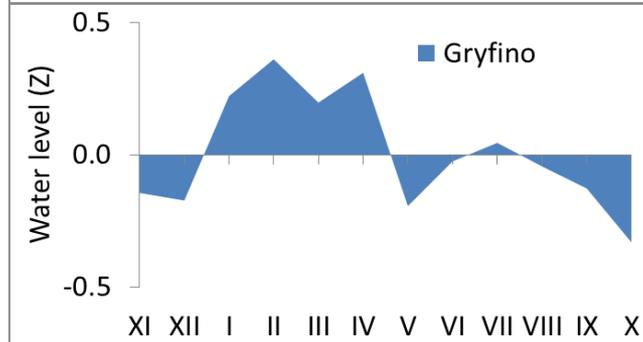
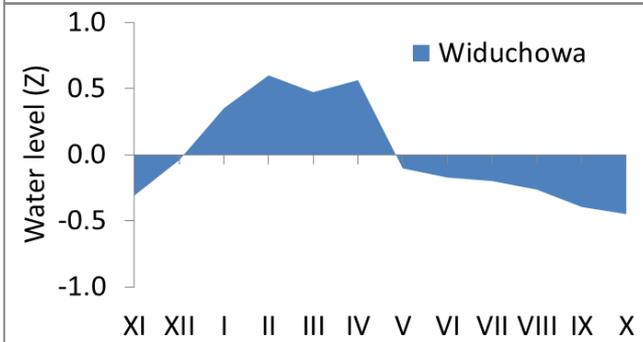
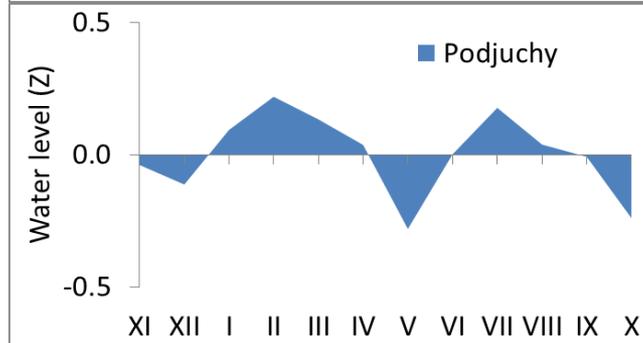
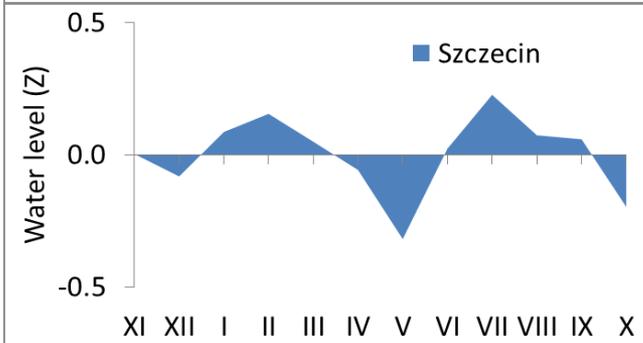
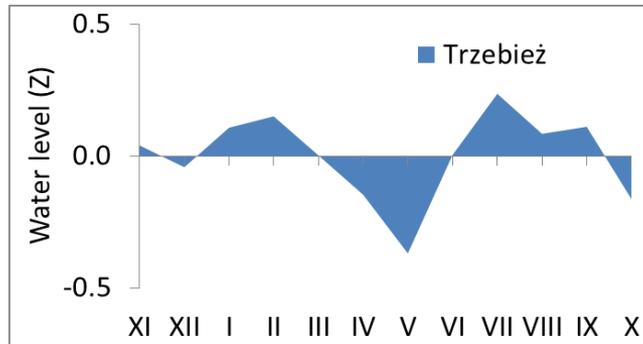
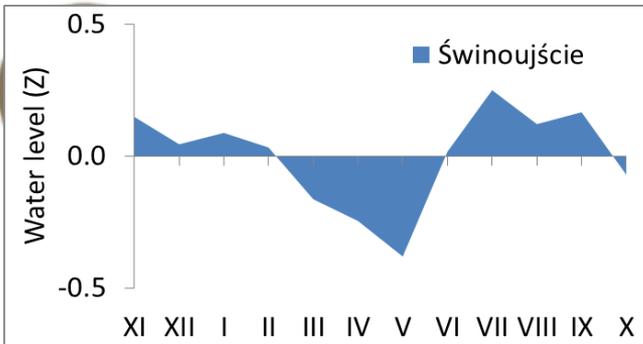


Mean slope of free water surface (‰)

Trzebież-Świnoujście	0.00158
Szczecin-Trzebież	0.00221
Widuchowa-Szczecin	0.00845
Bielinek-Widuchowa	0.06840
Gozdowice-Bielinek	0.14690



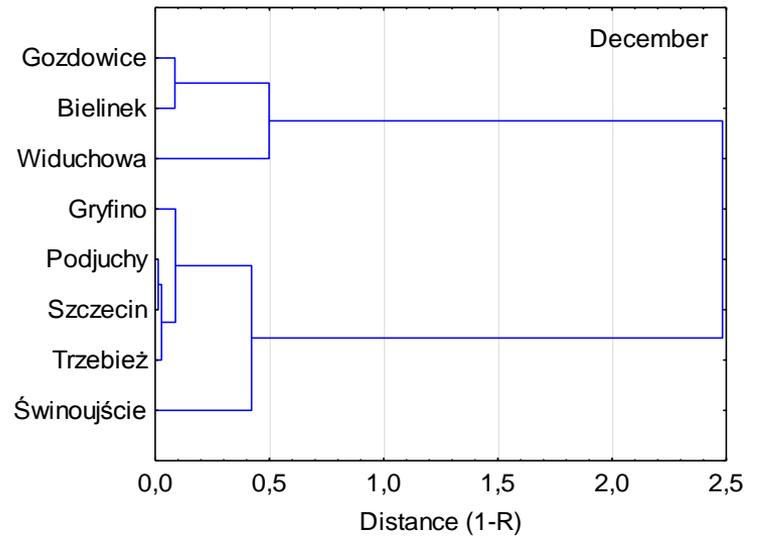
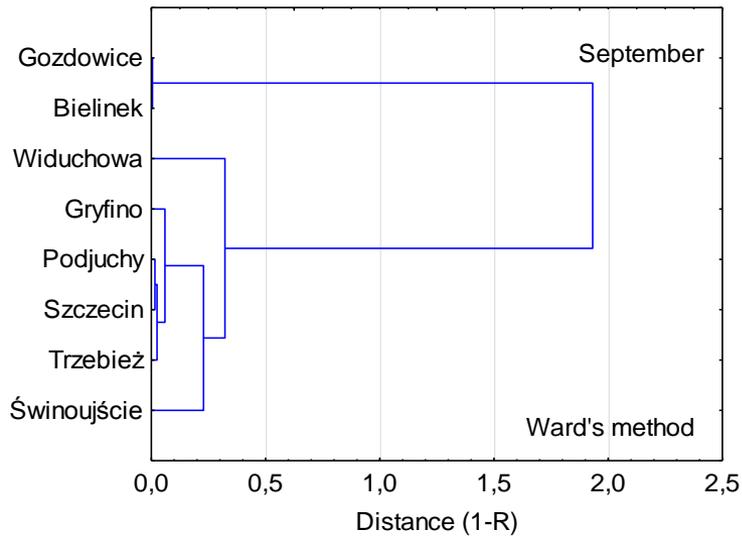
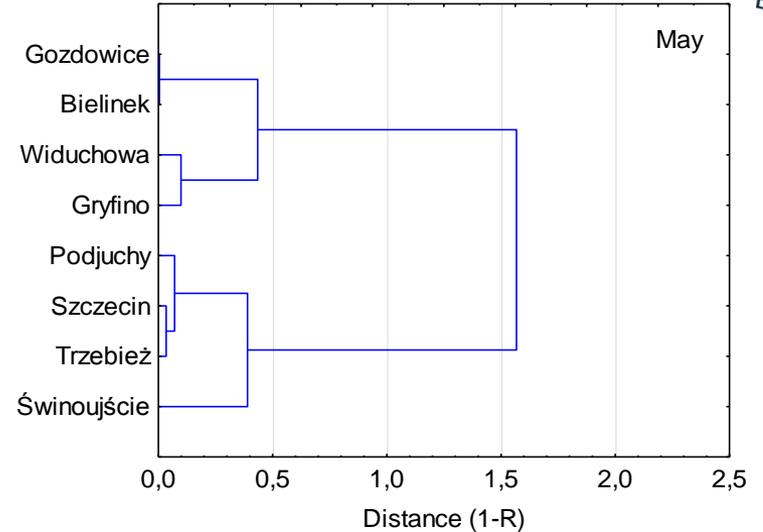
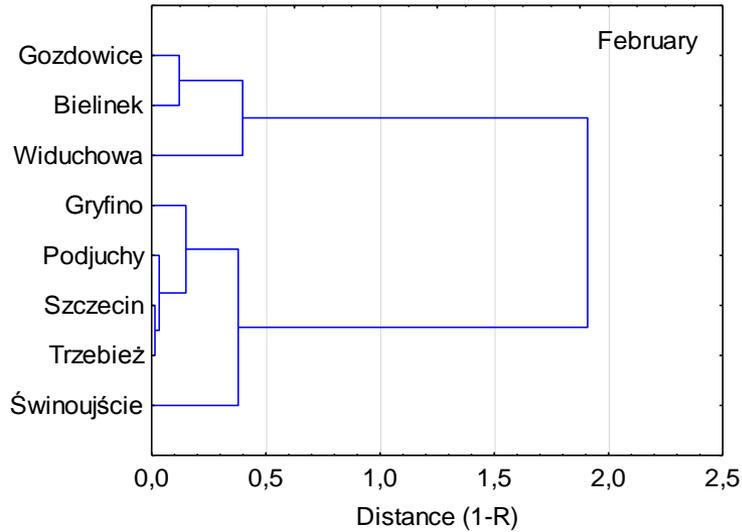
Monthly variability in water level in the Odra mouth area



Z - standardized values of water level readings



Relations between water levels in the Odra mouth area





The causes of high water events in the lower Odra River:

- Storm surges,
- Snowmelt-caused high water events,
- Rainfall-caused high water events,
- Ice jams.



Photos: A.Skowronek



Trzebież (15 Oct 2009)

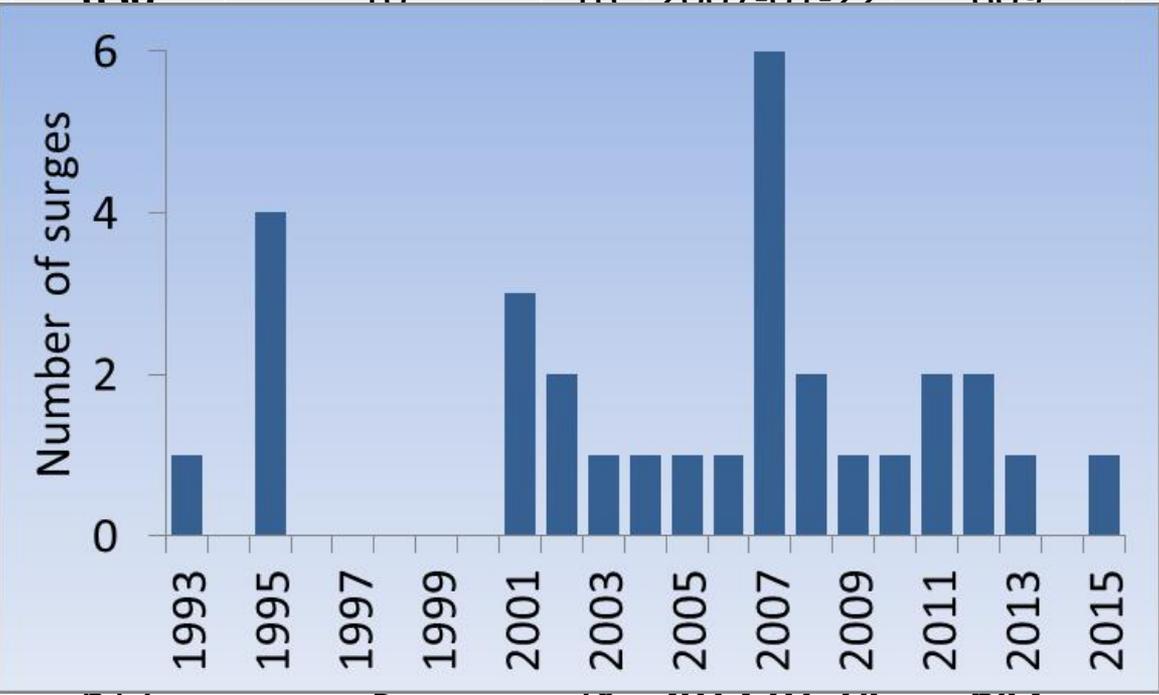




The highest storm surges in Świnoujście in 1993-2015 ($H \geq 600$ cm)



No.	Date	Water level (cm)	No. of hours $H \geq 600$ cm	No.	Date	Water level (cm)	No. of hours $H \geq 600$ cm
1	1993-02-21	650	10	16	2007-01-22	609	3
2	1995-01-03						11
3	1995-04-08						1
4	1995-09-01						3
5	1995-11-04						3
6	2001-11-09						6
7	2001-11-16						4
8	2001-11-23						31
9	2002-01-02						1
10	2002-02-21						7
11	2003-12-06						5
12	2004-11-23						8
13	2005-01-24	612	5	28	2012-01-14	642	32
14	2006-11-01	643	17	29	2013-12-07	612	9
15	2007-01-19	638	2	30	2015-02-08	600	1



Source: No. 1-29 the Harbour Master in Świnoujście, No. 30 – the IMWM data

Note: msl = 500 cm at the water level gauge with respect to the NN height system.



Storm surges in 1993-2014

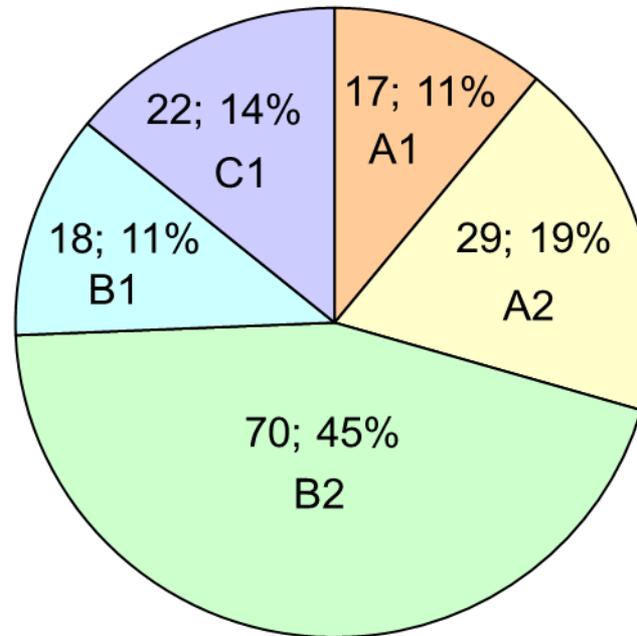


Photo: T.Łabuz



Photo: J.Dudzińska-Nowak

Types of storm surges at the Pomeranian Bay coast

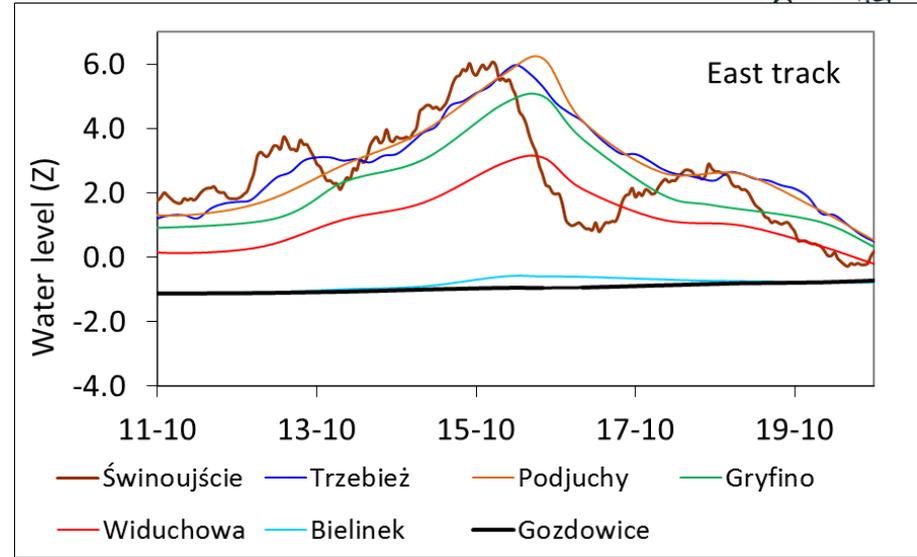
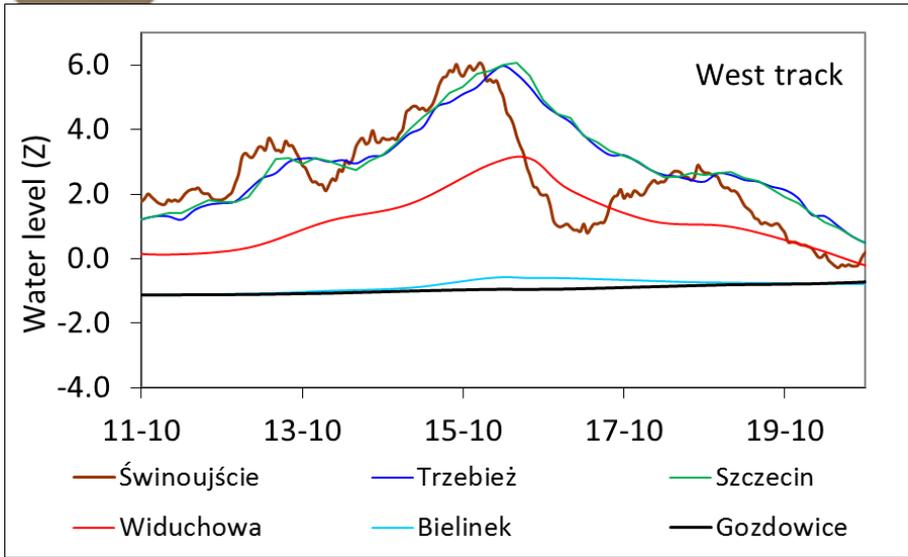
Type A – short-lived high storm surges with rapid sea level changes: (A1) subtype high, (A2) subtype low;

Type B – long-lasting storm surges with slow sea level changes: (B1) subtype high, (B2) subtype low;

Type C – long-lasting very high ($H \geq 595$ cm) extensive storm surges.



The most severe high water event in the Odra mouth area caused by the storm surge on 13-16 October 2009



Water level gauge	Maximum level (cm)	Alarm state exceedance (cm)	Increase in water level (cm)	Alarm state period (hrs.)
Świnoujście	633	53	85	47
Trzebież	625	65	83	120
Szczecin	638	38	84	48
Podjuchy	655	45	94	72
Gryfino	642	42	90	72
Widuchowa	646	-4	90	
Bielinek	283	-267	43	
Gozdowice	269	-231	18	

Z - standardized values of water level readings



Photos: A. Skowronek



The highest Odra River events in 1993-2014 (Gozdowice)

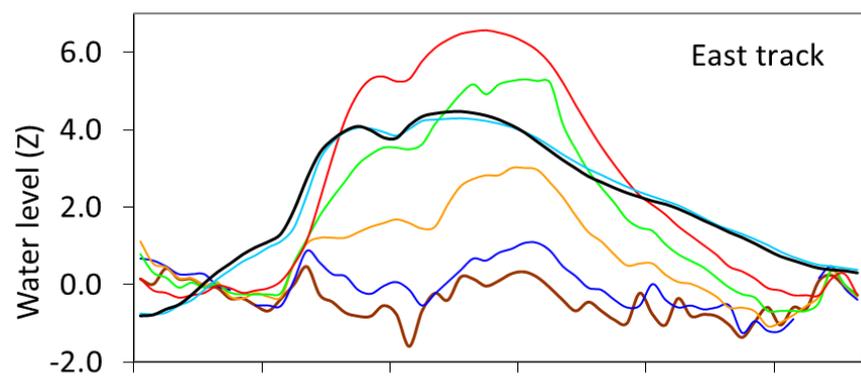
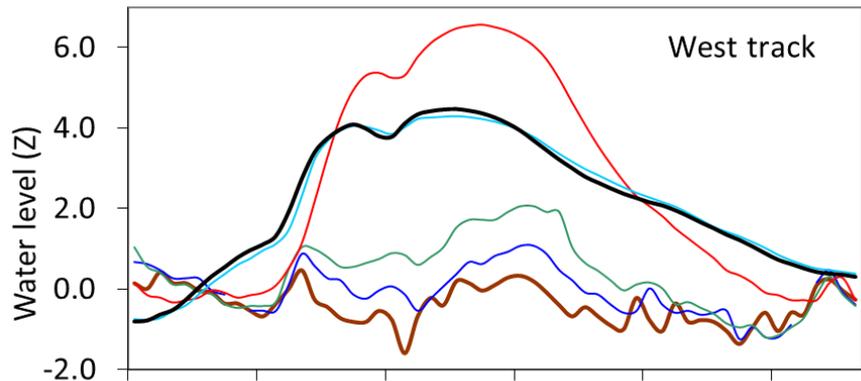


No.	Year	Cause of flooding	Date	Maximum water level (cm)	Number of days with $H \geq 440$ cm	Number of days with $H \geq 500$ cm
1	1997	Rainfall	1997-08-01	659	33	26
2	1999	Snowmelt	1999-03-18	532	38	15
3	2002	Ice blockage	2002-01-16	525	8	1
4	2006	Snowmelt	2006-04-10	545	26	10
5	2009	Ice blockage	2009-12-18	532	1	1
6	2010	Rainfall	2010-05-31	616	34	25
7	2010/2011	Ice blockage Rainfall Snowmelt	2011-01-23	578	98	41
8	2012	Ice blockage Snowmelt	2012-02-03	503	28	1
9	2013	Ice blockage	2013-01-30	529	4	4
10	2013	Snowmelt Rainfall	2014-06-23	510	57	18

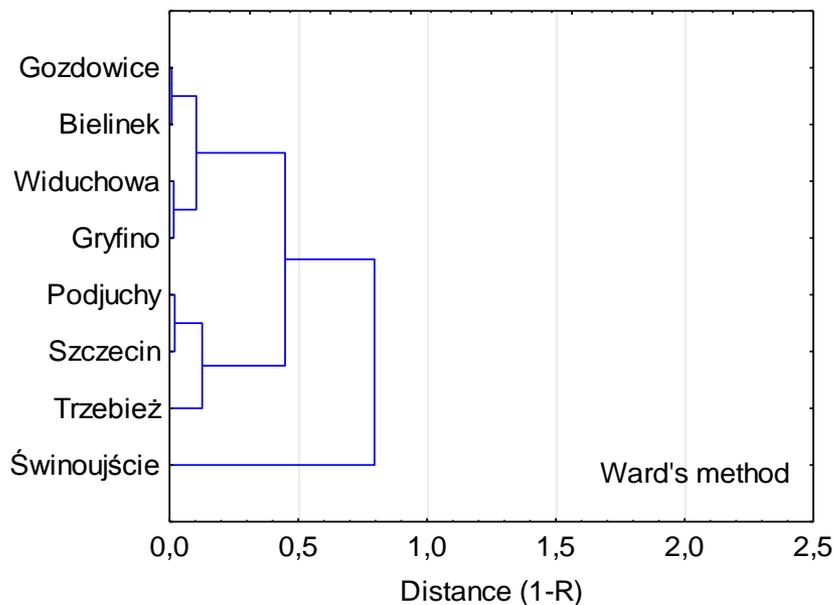




The rainfall mediated Odra flood in summer 1997



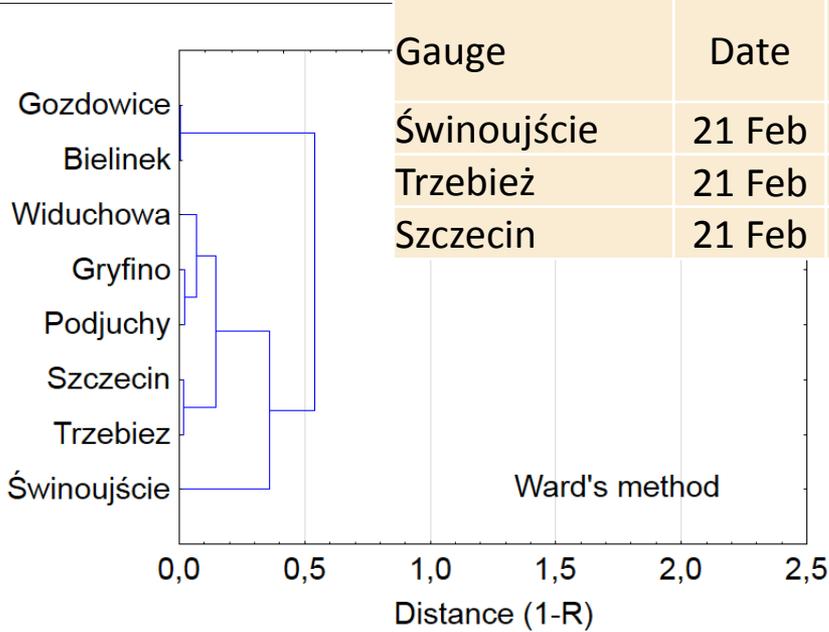
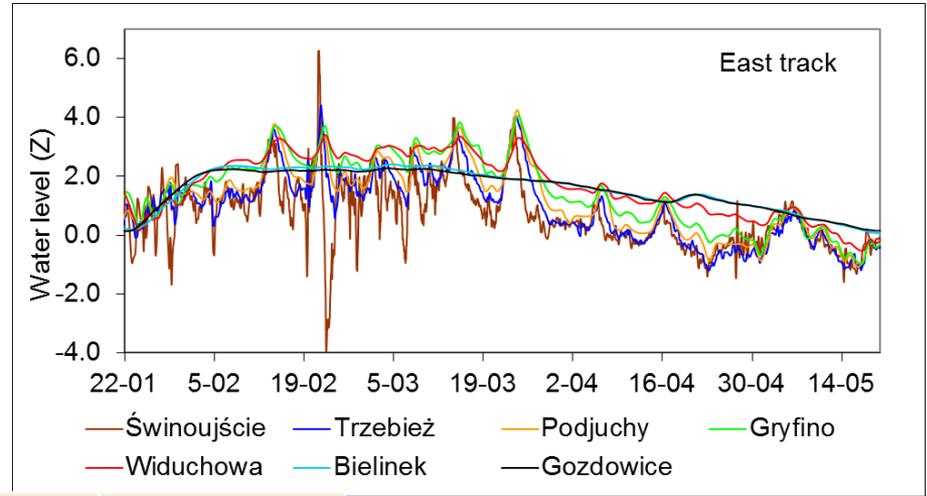
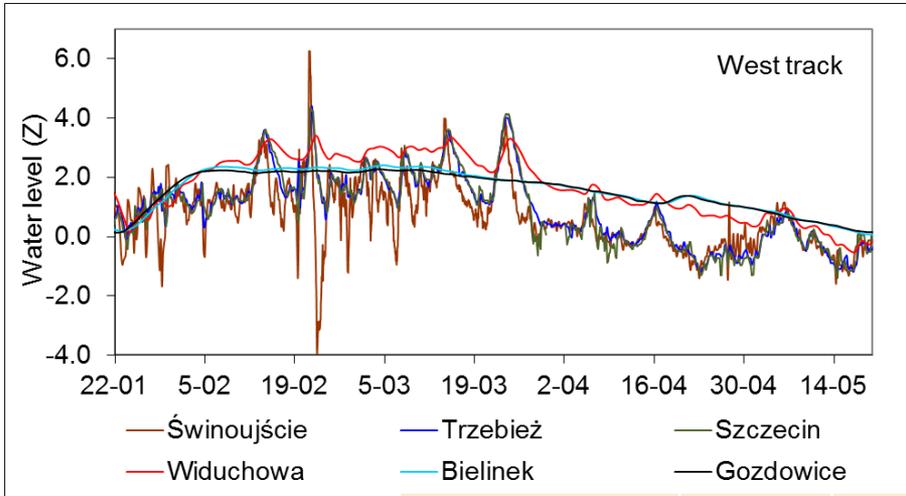
Z-standardized values



Water level gauge	Date	Maximum level (cm)	Alarm state period (days)
Świnoujście	5-6 Aug	515	0
Trzebież	6 Aug	532	0
Szczecin	6-7 Aug	557	0
Podjuchy	5-6 Aug	588	0
Gryfino	6 Aug	649	17
Widuchowa	3 Aug	759	22
Bieleń	1 Aug	712	25
Gozdowice	1 Aug	659	26



Storm surges in the Odra River mouth area during the snowmelt causing Odra flood in 2002



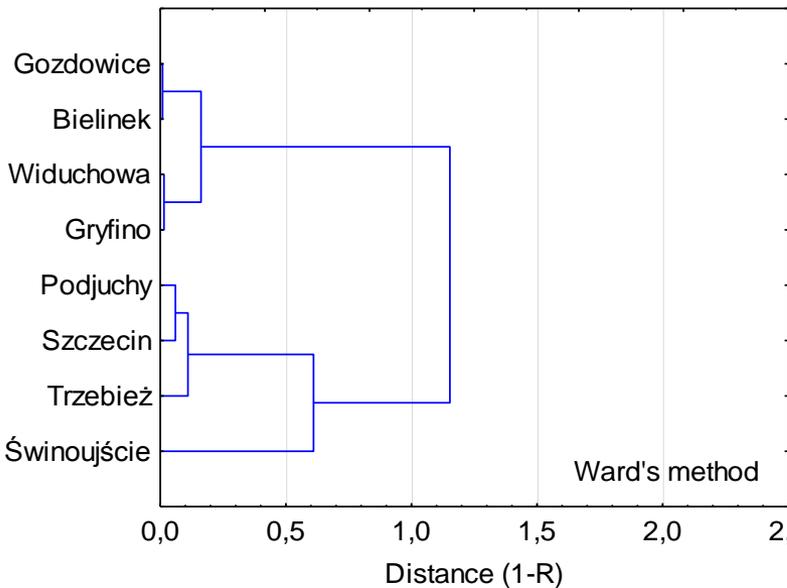
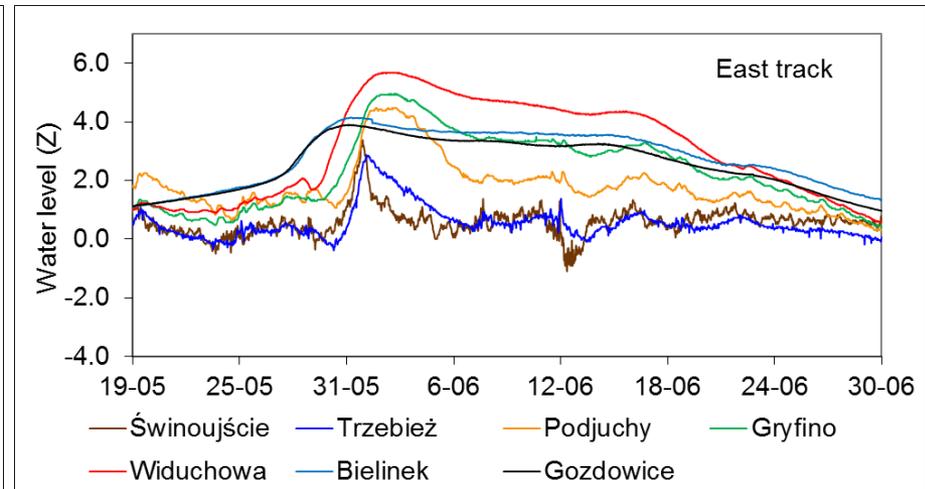
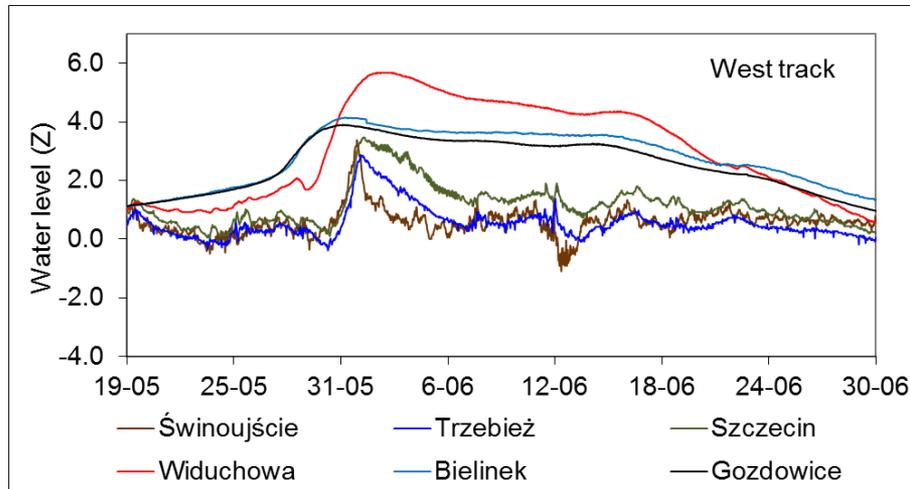
Gauge	Date	Maximum level (cm)	Alarm state period (hrs.)
Świnoujście	21 Feb	640	28
Trzebież	21 Feb	596	252
Szczecin	21 Feb	603	12

Z - standardized values

Gauge	Date	Maximum level (cm)	Alarm state period (days)
Podjuchy	24 Mar	614	1
Gryfino	24 Mar	620	9
Widuchowa	22 Feb	656	4
Białeń	4 Mar	546	0
Gozdowice	4 Mar	493	0



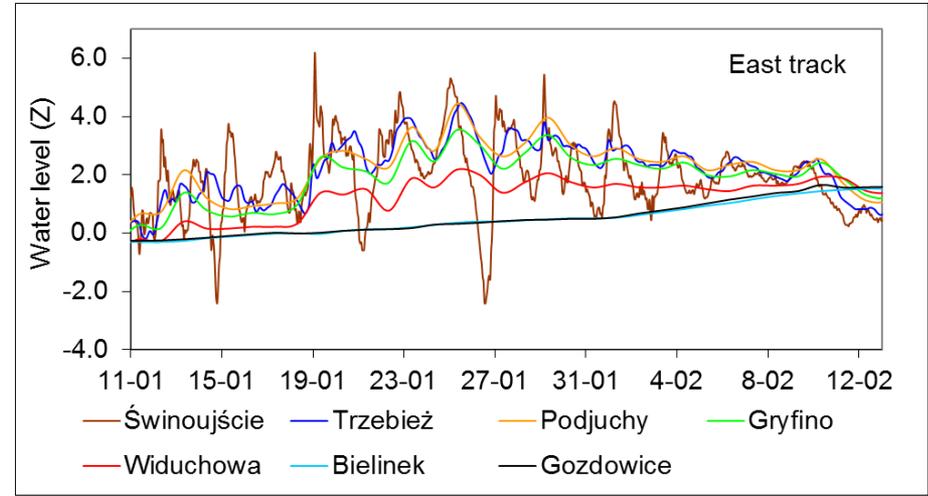
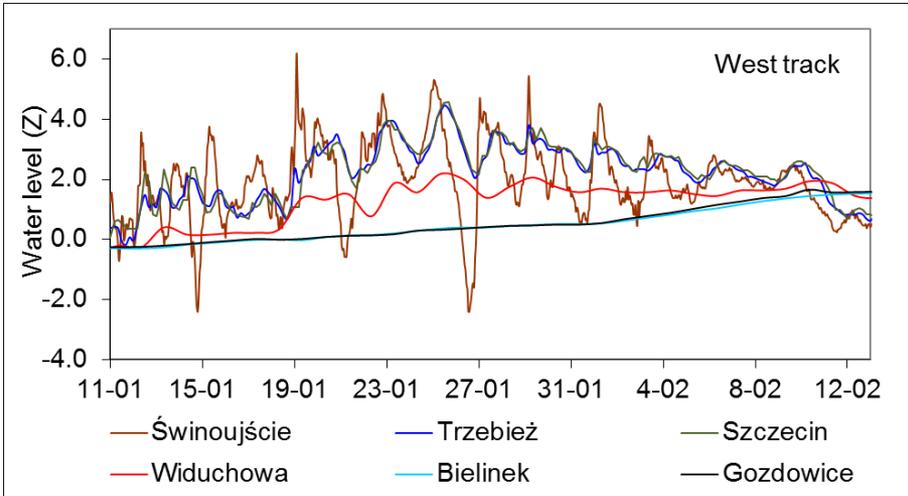
The storm surge in the Odra River mouth area during the rainfall mediated Odra flood in May 2010



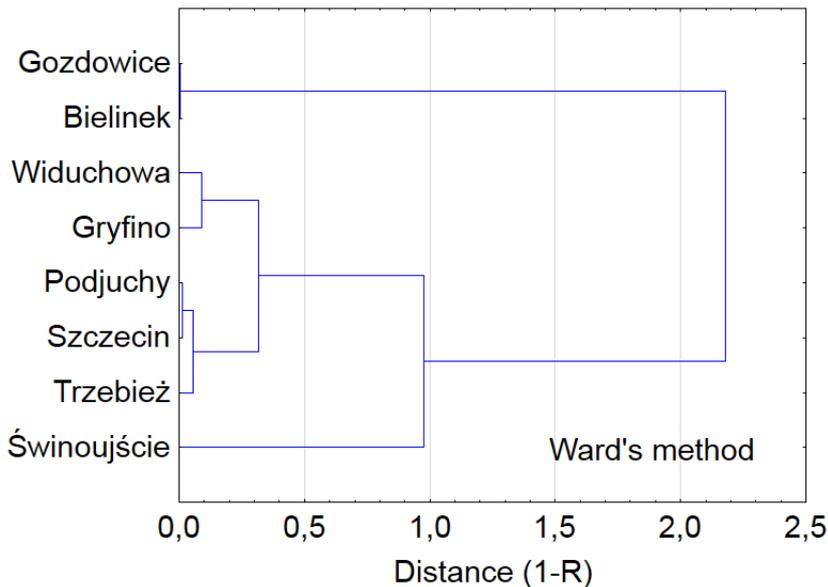
Water level gauge	Date	Maximum level (cm)	Z - standardized values	
			Alarm state period (days)	Water level increase (cm)
Świnoujście	31 May	577	0	70
Trzebież	1 June	565	0	65
Szczecin	1 June	585	0	69
Podjuchy	1 June	619	3	78
Gryfino	2 June	641	13	104
Widuchowa	2 June	730	20	154
Bielinek	31 May	699	27	311
Gozdowice	31 May	616	24	246



Extreme high water in the Odra River mouth area caused by series of 13 surges, one by one, between 11 January and 13 February 2007



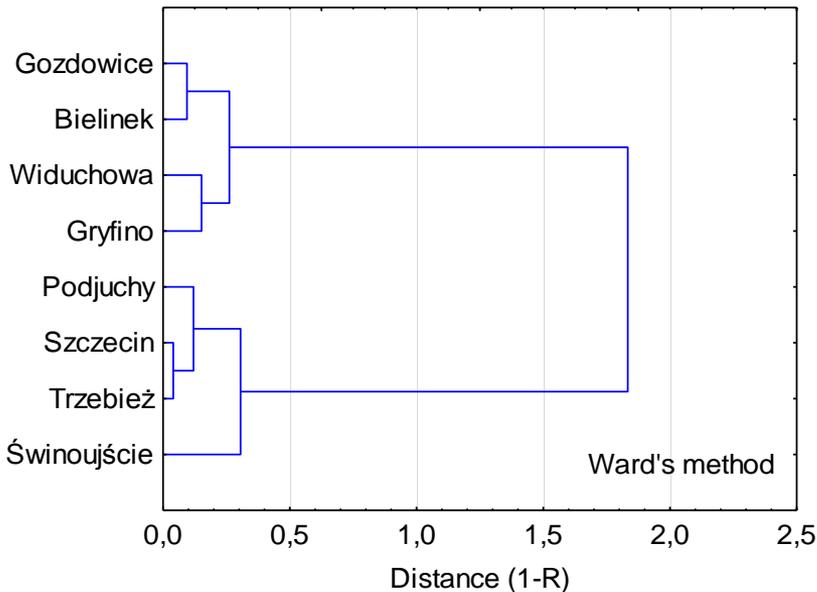
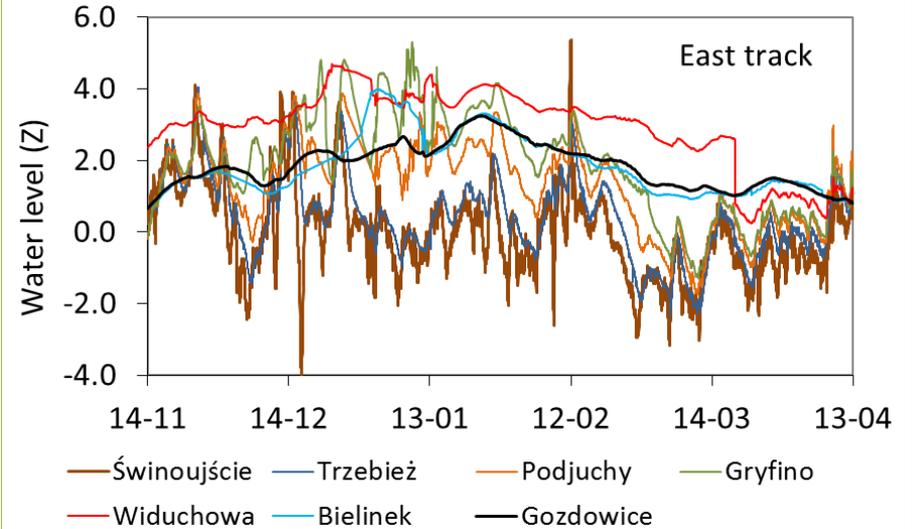
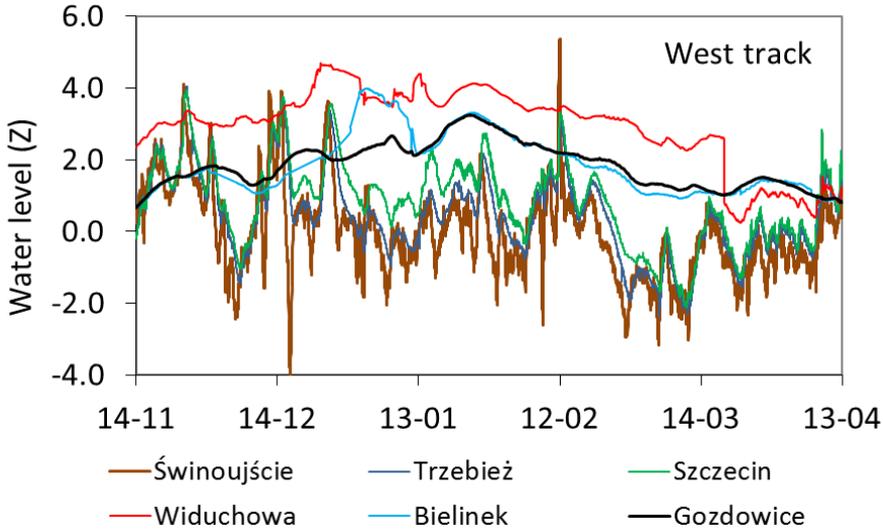
Z-standardized values



Water level gauge	Date	Maximum level (cm)	Alarm state period (hrs.)
Świnoujście	19 Jan	638	91
Trzebież	25 Jan	597	300
Szczecin	25 Jan	608	16
Podjuchy	25 Jan	618	24
Gryfino	25 Jan	608	48
Widuchowa	25 Jan	616	0
Bielinek	13 Feb	470	0
Gozdowice	10 Feb	446	0



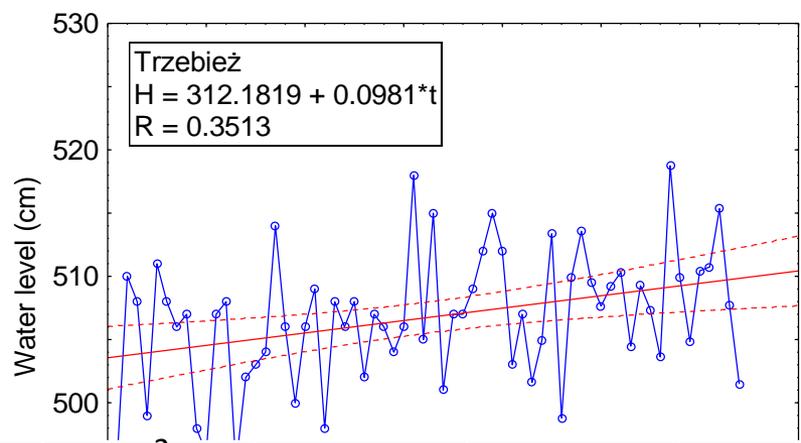
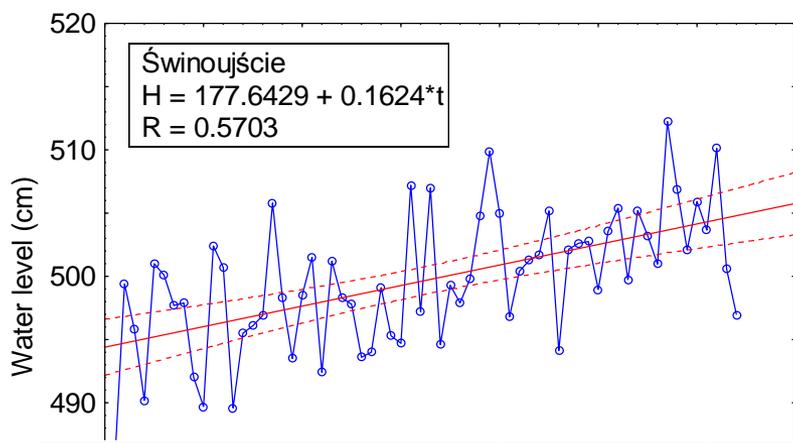
The ice jams and snowmelt-induced Odra flood in winter 2010/2011



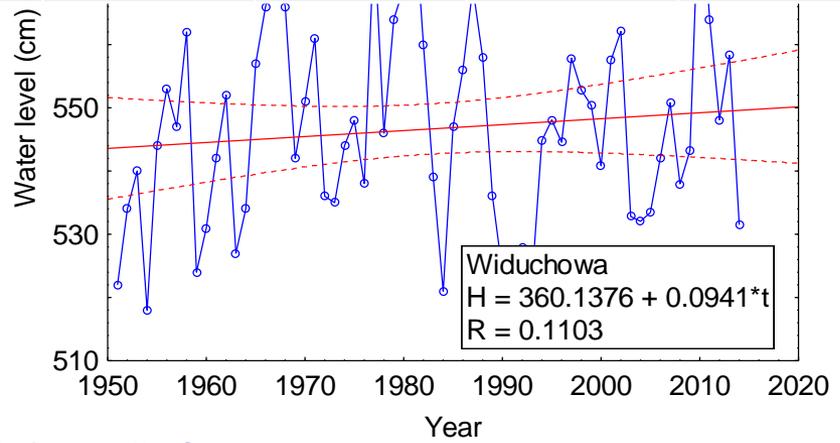
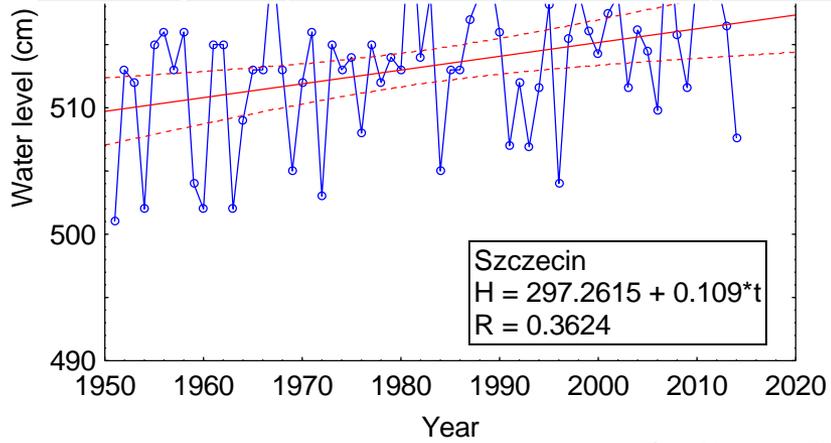
Z-standardized values

Water level gauge	Date	Maximum level (cm)	Alarm state period (days)
Świnoujście	12 Feb	618	8
Trzebież	24 Nov	587	15
Szczecin	24 Nov	595	0
Podjuchy	24 Nov, 25 Dec	608	0
Gryfino	9 Jan	657	37
Widuchowa	23 Dec	767	59
Bielinek	1-2 Jan	703	41
Gozdownice	23-24 Jan	578	41

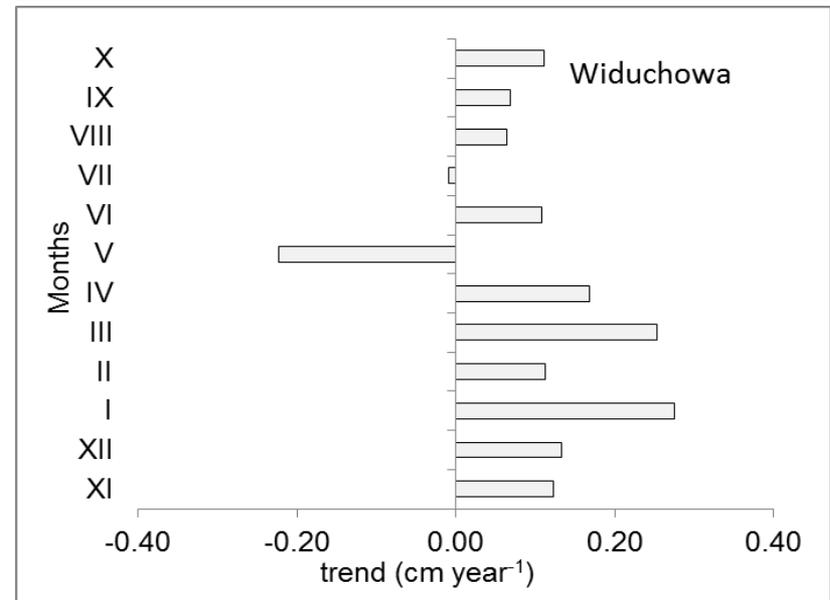
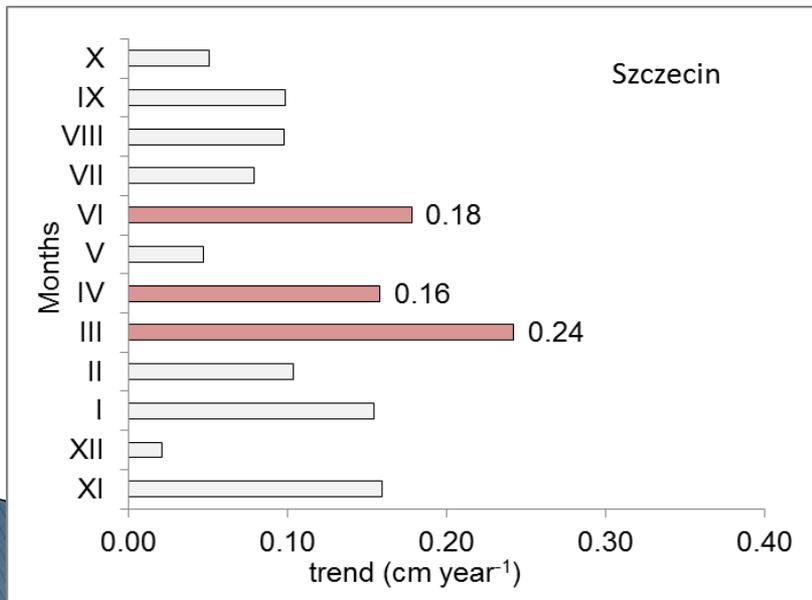
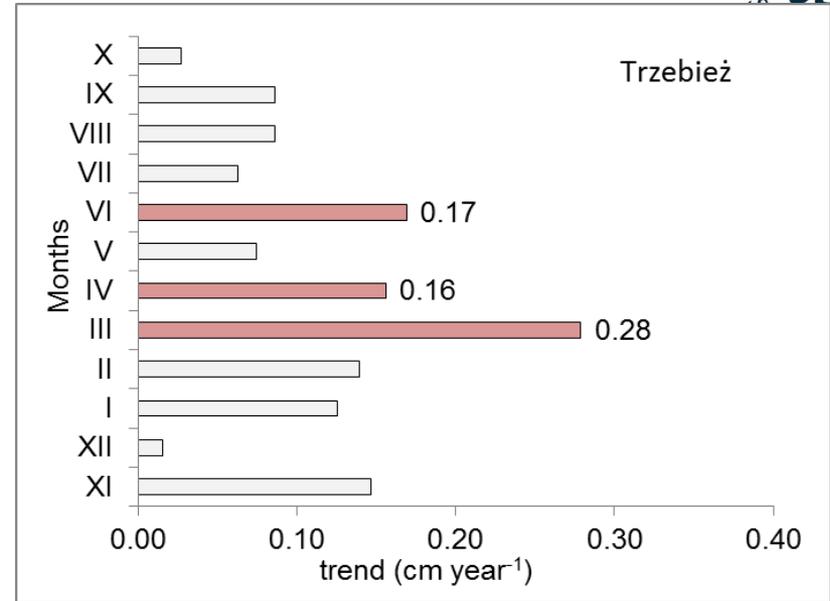
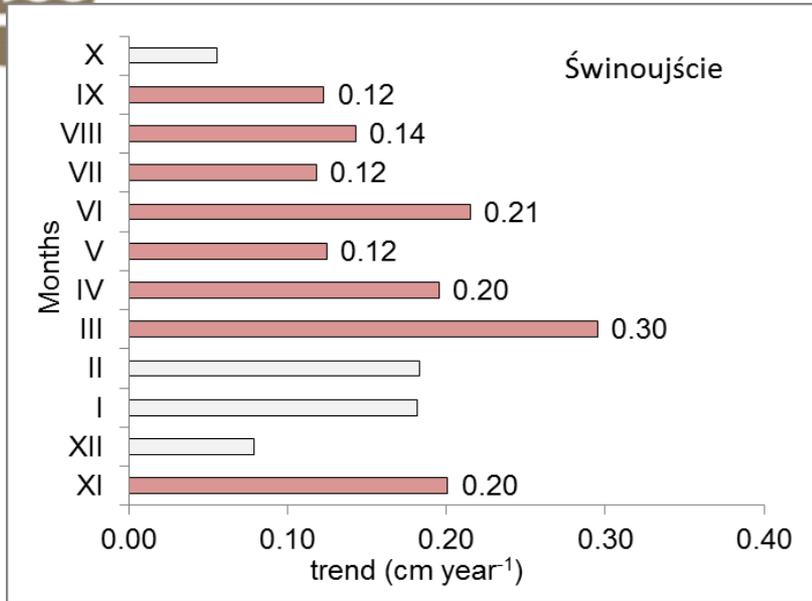
Water level rise in the Odra River mouth (1951-2014)



	Mean (cm)	St. Dev. (cm)	R	R ²	t	p	Rise (cm per year)
Widuchowa	546.6	15.88	0.1103	0.0122	0.8739	0.3856	0.0941
Szczecin	513.3	5.60	0.3624	0.1314	3.0619	0.0033	0.1090
Trzebież	506.7	5.20	0.3513	0.1234	2.9540	0.0044	0.0981
Świnoujście	499.7	5.30	0.5703	0.3253	5.4670	0.0000	0.1624



Water level rise in the Odra River mouth (1951-2014)





Conclusions

In the lower Odra River the flooding threat is posed by storm surges, snowmelt and rainfall events as well as ice jams.

In 1993-2014 the flood threat in the downstream Odra reach substantially increased:

- when storm surges limited the outflow of the Odra River during snowmelt or rainfall events (winter and spring 2002, late spring 2010);
- while ice jams developed during snowmelt periods (winter 2001/2002, 2010/2011);
- when a few surges, one by one, took place at the Pomeranian Bay coasts (January 2005, January 2007, October 2009, January 2012).
- under the condition of the increased water volume in the Baltic Sea (January 2007).

The recent sea level rise at the southern Pomeranian Bay coast, which is 0.16 cm per year in the period of 1951-2014 increases the sea level base from which storm surge can be launched and decreases the free surface of water in the Odra mouth area, which may cause prolonged duration of surges as well as increase in its maximum values. As a result it may pose flooding threat for low-lying urban areas adjacent the lower Odra channels.



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Data sources

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Photo: A.Skowronek



Dziękuję za uwagę

