Scientific Journals
of the Maritime University of Szczecin

Zeszyty Naukowe
Akademii Morskiej w Szczecinie

2019, 58 (130), 61–66
ISSN 1733-8670 (Printed)
ISSN 2392-0378 (Online)
DOI: 10.17402/337

Received: 29.04.2019
Accepted: 06.06.2019
Published: 25.06.2019

The impact of the weather on inland navigation conditions

Emilia Skupień[1]✉, Agnieszka Tubis[1], Todor Bačkalić[2]

[1] Wroclaw University of Science and Technology, Faculty of Mechanical Engineering
27 Wyspianskiego St., 50-370 Wroclaw, Poland
e-mail: emilia.skupien@pwr.edu.pl; agnieszka.tubis@pwr.edu.pl
[2] University of Novi Sad
Department of Traffic Engineering
Trg Dositeja Obradovića 6, 21 000 Novi Sad, Serbia
e-mail: tosa@uns.ac.rs
✉ corresponding author

Key words: inland navigation, navigation conditions, hydrotechnical conditions, water level, weather impact, transport planning

Abstract
The paper presents the impact of the weather on inland navigation conditions. Each mode of transportation depends on the weather, but inland navigation is the one most affected by it. Inland navigation is strongly dependent on the water level in a river bed, which is a result of weather conditions. In Poland the depth of inland waterways is relatively low, but the biggest consideration is the weather which results in the variability of this level. The variability of hydrotechnical conditions results in problems with planning for transportation. It is widely known that water is one of the most important factors in the hydrotechnical conditions of inland navigation and it is directly correlated with the weather. In this paper the authors present the impact of temperature on the duration of the navigation season on the Border Oder, based on research conducted in the years from 2004 to 2018 and the authors also investigated important changes in the weather conditions during last few years. The results showed that the number of navigable days has dropped significantly over the investigated period as a result of changes in the climate.

Introduction

In recent decades, a warmer climate has resulted in various climatic and environmental changes, such as more intensive storms, more severe droughts, less soil moisture, shorter winter ice seasons, significant thinning of sea ice and freshwater ice, reduction in snow cover, thawing of permafrost, glaciers, and ice sheets, earlier onset and larger volume of spring melt runoff, and increased coastal erosion (Huntington & Fox, 2005; Weller et al., 2005; Barry & Gan, 2011; Gobena & Gan, 2013; Kuo, Gan & Gizaw, 2015; Gan et al., 2016). According to the European Drought Observatory (EDO), in 2018 in the belt from Wielkopolska through Germany to France there was a severe shortage of moisture in the soil. In the summer of 2018, beyond Italy, the Iberian Peninsula and southern France, almost the entire continent was affected by drought (Sipiński, 2018).

All of the changes in the climate have a significant impact on navigation conditions on inland waterways. Inland waterway transport is one of the transport modes that is most affected by climate change (Rymsza, 2010). Climate conditions are influenced by such factors as rainfall, wind, temperature, fog, storms, water level and river flows. The transport availability of rivers and the level of their use for transporting not only people, but most of all goods, depends on the prevailing navigation conditions. Therefore it should be the subject of numerous studies; in particular in the face of the current transport policy of the European Union. Currently, it is quite difficult to find the results of any research on the impact of climate change on the transportation

of loads on inland waterways. This applies to publications in the area of climate change as well as inland waterway transport. An example of the few publications on this topic is a study in the literature (Scheepers et al., 2018).

In the literature (Scheepers et al., 2018) the potential impact of climate change on the inland waterway transport of the Mackenzie River Basin (MRB) was investigated through simulations using the Hydrologiske Byrån avdeling för Vattenbalans (HBV) hydrological model. The analyses included temperature, precipitation, streamflow, water levels, discharge volume, snow water equivalent, the actual evapotranspiration, and the number of days that water levels were above certain thresholds. The periods considered were the historic period 1974–2004, and the projected periods, 2041–2070 and 2071–2100. For the most important conclusions of the study carried out by the authors of the research, the following was included:

1. River stations are projected to see an increase in the winter and spring and a decrease in the summer streamflow and water level, because of the increase in evapotranspiration loss offset by the projected increase in precipitation in the summer, and SWE is projected to decrease because there will be more rainfall and less snowfall in a warmer climate. The spring streamflow and water levels are projected to increase because warming will result in the earlier onset of spring snowmelt.
2. Given the projected earlier spring snowmelt, but reduced water levels in the summer, climate change is expected to affect Arctic ferry operations on the Mackenzie River, which could start earlier because a warmer climate will cause the earlier onset of spring snowmelt and higher spring discharge.
3. Given the summer water levels of the Mackenzie River are projected to decrease in the 2050s and 2080s, navigation problems related to low water levels are expected to increase because safe transit through the Mackenzie River depends on its water level.

The authors of a few publications emphasized that the impact of climate change plays a key role on the conditions of inland waterway transport. Some impacts may be positive; for example, the increase in global temperatures may make water transport in Arctic areas possible and economically viable (Johannessen et al., 2004; Somanathan et al., 2007). However, there are also potential negative effects; in particular, inland waterway transport may experience problems related to the higher volatility in water levels in rivers. This particularly applies to countries where inland waterway transport is an important mode of transport. In Europe, this is applicable for countries such as Germany and the Netherlands, where the river Rhine is used to transport large amounts of bulk products and containers. Research in this area has been presented in the literature (Jonkeren, Jourquin & Rietveld, 2011). Also the Danube was analysed for accessibility correlating to climate parameters (Backalic, Maslarić & Skupień, 2018). Meteorological phenomena that affect navigation conditions that have been pointed out in this paper are: fog, wind and ice.

Most authors in the literature emphasized that climate change causes the deterioration of inland waterways (Czaplewski, 2011). Consequently, this leads to the deterioration of shipping conditions. Analyses carried out in this area indicated that inland waterway transport is adversely affected by climate change, and in connection with the regulatory changes resulting from the liberalization of its market, it is included in the group of so-called double losers.

It also should be noticed that only a little attention has been given to the effect of changes in the natural environment on transport costs. Such attention is relevant, however, because it may contribute to the formulation of policies to adapt to these changes (for example: de Groot et al., 2006). Examples of the few studies on the effects of climate change on transport can be found in the literature (Suarez et al., 2005) and (Nankervis, 1999).

The study by Jonkeren et al. (Jonkeren, Rietveld & van Ommeren, 2007) contributes to this field as it focused on the effect of climate change on social welfare through inland waterway transport. The authors concentrated on a part of the European inland waterway transport market, the river Rhine's market. The authors derived the annual welfare effects of low water levels on the river Rhine by employing detailed trip data reported by bargemen between January 2003 and July 2005. They found a considerable effect of water levels on the freight price per ton and the load factor, but the effect on the price per trip was close to zero. Using water level information over a period of almost 20 years, the average annual welfare loss due to low water levels was estimated to be about €28 million. In years with extremely low water levels, such as in 2003, the loss amounted to about €91 million, about 13 per cent of the market turnover in the part of the Rhine market that was considered.

Navigation conditions on the Oder Waterway

The Oder Waterway is the most important waterway in Poland. It links Upper Silesia, a significant economic area of the country, from Gliwice Port, with Szczecin-Świnoujście seaports. One of the factors in its dominant role in Polish inland waterway navigation is the fact that the Oder has significantly better navigation conditions than other rivers and it is connected to Western Europe's waterways.

In the structure of the country's transportation of cargo, inland waterway transport has a negligible share – in recent years it has not exceeded 0.2% and it is decreasing. This is mostly due to the navigation conditions which are poor and most of all, they are not stable.

In recent years, since the Ministry of Maritime Economy and Inland Navigation was set up, the political environment for inland waterway navigation in Poland has changed. Poland has joined the ANG agreement and many legal plans have been created. Thus it is expected, that in the next few years many strategic investments will be made to improve the state of inland waterway navigation in Poland. The considered investments will be to improve the hydrotechnical conditions of Polish waterways (including the Oder Waterway), to achieve an international level of inland waterway.

The Oder Waterway can be divided into 4 sections:

1. Gliwicki Canal and Canalized Oder (between Kędzierzyn-Koźle and Malczyce locks) has been declared to be class III,
2. from Malczyce lock, through the mouth of Nysa Łużycka, to the mouth of the Warta river – free flowing Oder class II,
3. from the mouth of the Warta river to the town of Ognica (to the Szwedt channel), class III,
4. from Ognica to the border with internal sea waters, class V.

Methodology of data processing

During the last few years changes in the climate have been observed all over the world, which also affects inland waterway navigation by affecting the level of water in the rivers. In addition, due to years of neglect and underinvestment, the infrastructure of the Oder Waterway is in poor condition. In this paper, the authors investigated the impact of air temperature on the water level. The presented study focuses on the free flowing section of the Oder Waterway as it is more sensitive to climate conditions than the canalized section. Data for water gauges in Słubice, Gozdowice and Widuchowa were investigated in detail.

The Institute of Meteorology and Water Management has collected data over the years, among other data connected to the water level. To investigate the differences in water level it is important to compare the present data with the past data, but the historical data should also be taken from a long period of time. The authors gathered the data from measurements conducted by the Institute of Meteorology and Water Management over a period of 50 years. The average water level from the investigated gauges in the years 1951–2000 is shown in Table 1.

Table 1. The average water level at selected gauges on the Oder Waterway (IMGW, 2019)

Gauge	Distance along the Oder (km)	Average water level in the years 1951–2000 [cm]
Słubice	584,1	234
Gozdowice	645,3	315
Widuchowa	701,8	546

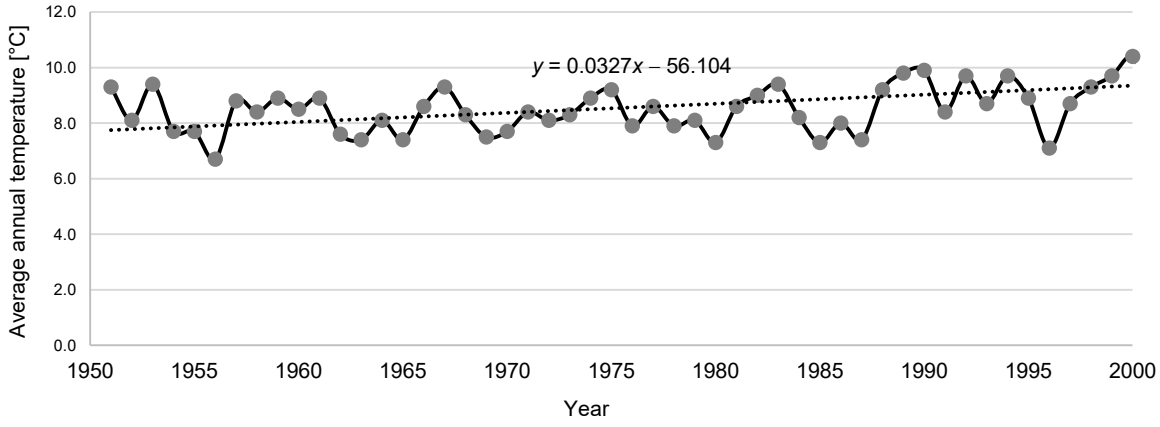

Figure 1. Average annual temperature of the air above the ground in the years 1951–2000 in Poland (IMGW, 2019)

The next step was to visualize the change in the temperature of the air over the same time period. The average annual temperature of the air above the ground in the years 1951–2000 in Poland is gathered in Figure 1. The linear trend line shown in Figure 1, indicates that the average temperature increased by about 2°C over this time.

During the period of the collected data contained in Table 1, the temperature of the air above the ground (shown in Figure 1) and the temperature of the water in the rivers consistently increased. This acted together with other climate phenomena, such as drought, flood and ice surges, which also affects the water level in the river.

Having a reference, the authors chose the gauges and the period to compare. The next step was to gather and present the data collected from Słubice, Gozdowo and Widuchowa for the last 15 years and then compare the results with the historical data, and then calculate the average, minimum and maximum, and check if the trend line showed any tendency either way.

The further data shown came from the Institute of Meteorology and Water Management data base; they were gathered, analysed and the inference was made by the authors.

The impact of the weather on inland navigation conditions on the investigated section of the Oder Waterway

For further investigation, the authors took a closer look at the data from the last 15 years (2004–2018). During this time, the average annual temperature of the air was still increasing (Figure 2).

At the same time, the average monthly temperature at selected gauges was changing periodically and still, an increase was observed (Figure 3). As the investigated gauges are not too far from each other, the temperature at each of them at the same time was similar. The differences are hard to notice in Figure 3, but it does not make it difficult to evaluate.

During the investigated time period, the water level at the Słubice, Gozdowice and Widuchowa

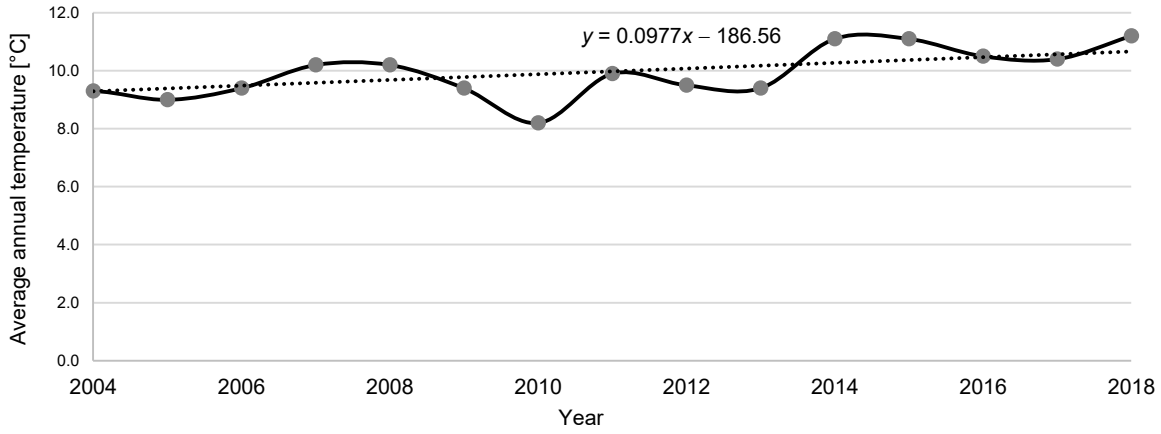

Figure 2. Average annual temperature of the air above the ground in the years 2004–2018 in Poland (IMGW, 2019)

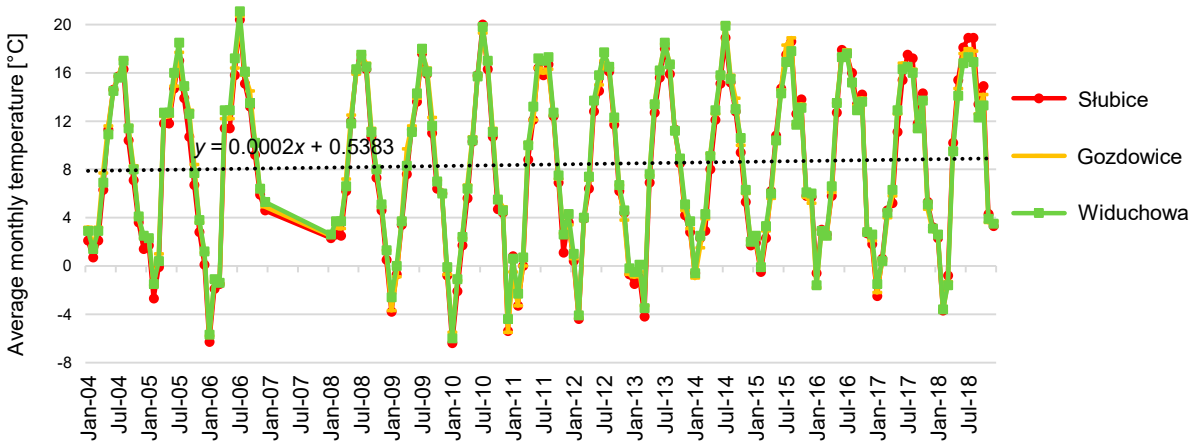

Figure 3. Average monthly temperature of the air above the ground in the years 2004–2018 at selected gauges (Regional Management of Water Management in Szczecin, 2016)

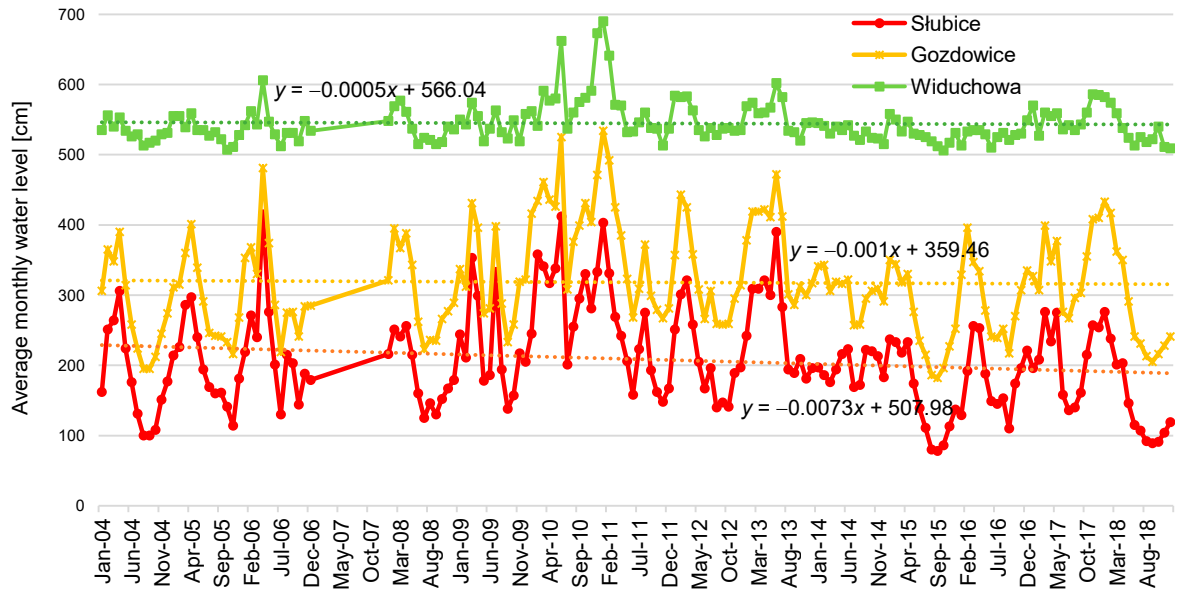

Figure 4. Average monthly water level in the years 2004–2018 in selected gauges (Regional Management of Water Management in Szczecin, 2016)

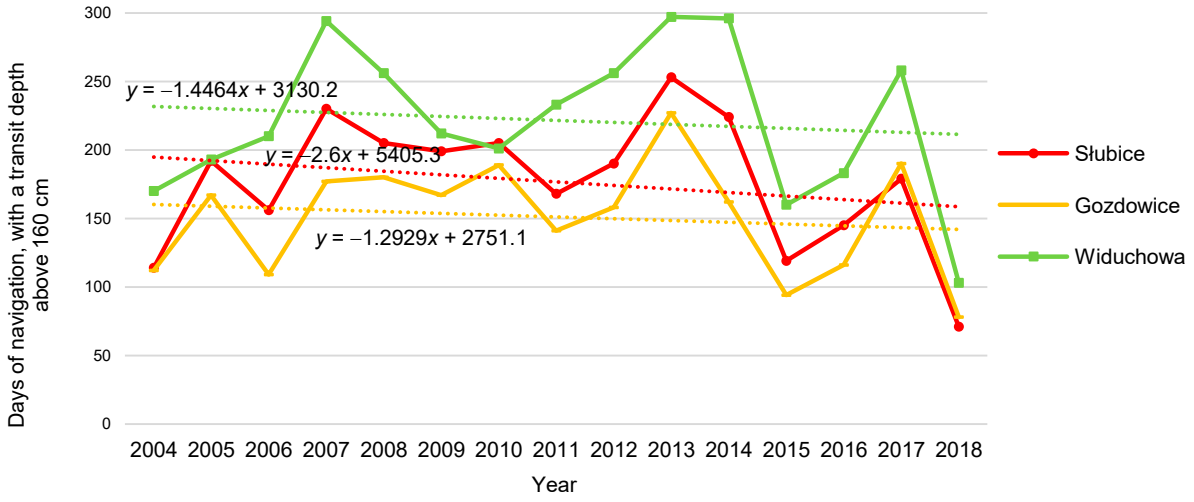

Figure 5. Navigable days, with a transit depth above 160 cm in the years 2004–2018 in selected gauges (Regional Management of Water Management in Szczecin, 2016)

gauges was fluctuating – Figure 4. Some extrema may be seen; at these times extremes floods and droughts occurred, but these climate phenomena are not the focus of this research.

The trend lines in Figure 4 show that the water level in selected gauges, in the past 15 years, was slowly decreasing. It is also noticeable that the decrease in the water level became smaller with the mileage of the Oder. The closer to the sea, the wider the river is, and the smaller the changes in the average water level during the measured years.

Also: the extremes shown in Figure 4 affected the navigation period (at the time of both low and high water levels the navigation route is closed), which is most important from the viewpoint of cargo transportation and effectiveness of inland waterways in Poland.

Figure 5 presents the numbers of navigable days, with a transit depth above 160 cm in the considered gauges and years. The authors chose 160 cm as the depth corresponding to navigation class III, but it could be another depth for which transportation on the waterway could be effective.

The trend lines in Figure 5 indicate that during the last 15 years, in the considered gauges, the number of navigable days was getting smaller. It is important to note that it happened at a faster rate than the water level was dropping. This is due to the fact that climate changes cause both a temperature increase and also the appearance of extreme phenomena.

Conclusions

It is widely known that water is one of the most important factors in the hydrotechnical conditions of inland navigation and it is directly correlated with the weather. In this paper, the authors presented the impact of weather changes on inland waterway transportation. Inland navigation strongly depends on the water level in a river bed. The number of navigable days was a result of the weather conditions: both high and low temperatures. The impact of temperature on the duration of the navigation season was pointed out using the example of Border Oder, based on research conducted in the years from 2004 to 2018.

In Poland the depth of inland waterways is relatively low. Also the variability of hydrotechnical conditions results in problems with transportation planning. This is a reason for the planning of several infrastructure investments by the Ministry of Maritime Economy and Inland Navigation.

As pointed out in this paper: while planning investments in hydro infrastructure (not only on Polish waterways) it is highly important to take into account that the water level in rivers is becoming lower due to the changes in the climate. This is why building several hydro constructions is a challenge; the falling water level in river beds must also be taken into account. The rivers must be able to keep the water in their beds and it is also highly important that they retain it. The other thing is the fact that climate changes also bring extreme phenomena: not only drought but also floods. Therefore the investments must be able to deal with an extremely high water level as well.

The authors plan to continue monitoring the temperature, water level and navigable days on Border Oder, to present further trends in this aspect.

References

1. Bačkalić, T., Maslarić, M. & Skupień, E. (2018) Analysis of navigation accessibility and fairway availability: a case study the middle Danube river. In: A. Sładkowski ed., *Transport Problems 2018: proceedings X International Scientific Conference, VII International Symposium of Young Researchers*. Katowice: Politechnika Śląska, Wydział Transportu, pp. 53–62.
2. Barry, R. & Gan, T.Y. (2011) *Global Cryosphere, Past, Present and Future*. Cambridge University Press.
3. Czaplewski, M. (2011) Podstawowe czynniki kształtowania pozycji żeglugi śródlądowej w systemie transportowym. *Logistyka* 6, pp. 4607–4621.
4. Gan, T.Y., Ito, M., Huelsmann, S., Qin, X.X., Lu, X., Liong, S.Y., Rutschman, P., Disse, M. & Koivosalo, H. (2016) Possible climate change/variability and human impacts, vulnerability of drought-prone regions, water resources and capacity building for Africa. *Hydrological Sciences Journal* 61, 7, pp. 1209–1226.
5. Gobena, A.K. & Gan, T.Y. (2013) Assessment of trends and possible climate change impacts on summer moisture availability in western Canada based on metrics of the palmer drought severity index. *Journal of Climate* 26, 13, pp. 4583–4595.
6. Groot, de R.S., Ierland, van E.C., Kuikman, P., Nillesen, E.E.M., Tassone, V.C., Verhagen, A.J.A. & Verzandvoort-van Dijck, S. (2006) *Climate Change: Scientific Assessment and Policy Analysis; Climate adaptation in the Netherlands* (*Concept report*). Netherlands Environmental Assessment Agency.
7. Huntington, H. & Fox, S. (2005) The changing Arctic: indigenous perspectives. In: *Arctic Climate Impact Assessment*. Cambridge, UK: Cambridge University Press, pp. 61–98.
8. IMGW (2019) [Online] Available from: https://dane.imgw.pl/data/dane_pomiarowo_obserwacyjne/ [Accessed: March 01, 2019]
9. Johannessen, O.M., Bengtsson, L., Miles, M.W., Kuzmina, S.I., Semenov, V.A., Alekseev, G.V., Nagurnyi, A.P., Zakharov, V.F., Bobylev, L.P., Pettersson, L.H., Hasselmann, K. & Cattle, H.P. (2004) Arctic climate change: observed and modeled temperature and sea-ice variability. *Tellus* 56A, pp. 328–341.
10. Jonkeren, O., Rietveld, P. & van Ommeren, J. (2007) Climate Change and Inland Waterway Transport. *Journal of Transport Economics and Policy* 41, 3, pp. 387–411.
11. Jonkreren, O., Jourquin, B. & Rietveld, P. (2011) Modal-split effects of climate change: The effect of low water levels on the competitive position of inland waterway transport in the river Rhine area. *Transportation Research Part A* 45, pp. 1007–1019.
12. Kuo, C.C., Gan, T.Y. & Gizaw, M. (2015) Potential impact of climate change on intensity duration frequency curves of central Alberta. *Climatic Change* 130, pp. 115–129.
13. Nankervis, M. (1999) The Effect of Weather and Climate on Bicycle Commuting. *Transportation Research Part A* 33, pp. 417–431.
14. Regional Management of Water Management in Szczecin (2016) [Online] Available from: http://informator.szczecin.rzgw.gov.pl/pl/ocena_hydrologiczno_nawigacyjna/pliki/ocena_hydro_nawig_2016.pdf [Accessed: March 01, 2019].
15. Rymsza, B. (2010) *Opracowanie wskaźników wrażliwości sektora transport na zmiany klimatu.* Warszawa: Instytut Badawczy Dróg i Mostów.
16. Scheepers, H., Wang, J., Gan, T.Y. & Kuo, C.C. (2018) The impact of climate change on inland waterway transport: Effects of low water levels on the Mackenzie River. *Journal of Hydrology* 566, pp.285–298.
17. Sipiński, D. (2018) *Płytsze rzeki w Europie kolejnym skutkiem zmian klimatu.* [Online] 02 December. Available from: https://www.polityka.pl/tygodnikpolityka/ludzieistyle/1773724,1,plytsze-rzeki-w-europie-kolejnym-skutkiem-zmian-klimatu.read [Accessed: March 20, 2019].
18. Somanathan, S., Flynn, P.C. & Szymański, J.K. (2007) Feasibility of a sea route through the Canadian Arctic. *Maritime Economics and Logistics* 9 (4), pp. 324–334.
19. Suarez, P., Anderson, W., Mahal, V. & Lakshmanan, T.R. (2005) Impacts of flooding and climate change on urban transportation: A systemwide performance assessment of the Boston Metro Area. *Transportation Research Part D: Transport and Environment* 10, 3, pp. 231–244.
20. Weller, G., et al. (2005) *Summary and synthesis of the ACIA. In: Arctic Climate Impact Assessment*. Cambridge: Cambridge University Press.