Impact of cities adaptation to climate change on water resources management on the example of selected cities of the Silesian Agglomeration

S Gałas¹, J Gorgon² and A Galas¹

¹ AGH University of Science and Technology, al. Mickiewicza 30, 30-059 Krakow, Poland
² IETU Institute for Ecology of Industrial Areas, Kossutha 6, 40-844 Katowice, Poland

Abstract. Climate change and the resulting threats create a new challenge for local authorities and residents of cities. The nationwide Project addressed for biggest Polish cities assessed their sensitivity and counteracting capabilities in selected urban areas. Within the Project various actions were proposed. To some extent, the implementation of these activities may, however, threaten the water resources. The paper presents risk assessment and shows the possibilities of rational management of water resources in selected cities of Upper Silesia.

1. Introduction
Climate change adaptation became an important element of urban policy in the member states of the European Union. In Poland climate change challenge preparedness has been presented in Strategic Plan 2020, for climate change adaptation referring to the climate change sensitive sectors and areas. Climate change adaptation of the cities and urbanized areas is key element creating spatial policy at different aspects. 44 Polish cities, in cooperation with the Ministry of the Environment, participated in the project aimed at adapting them to the observed and predicted climate changes. Development of Urban Adaptation Plans (UAP) for cities with more than 100,000 inhabitants in Poland, has been unique complex project introduce by Polish Ministry of Environment. Urban adaptation plans have been the outcome of two-year cooperation between expert teams and urban authorities as well as involvement of groups of stakeholders. The major objective of this Project has been assessment of the sensitivity to climate changes of 44 largest Polish cities and planning adaptation activities appropriate for the identified threats [1].

The particular threats affecting urban areas, related to climate change, is precipitation – torrential rain often resulting urban floods. The other threats for cities there are droughts, extreme temperatures and limitations of air circulation. Many processes related to transformation of cities and development of urban structure strengthen the threats resulting from climate change. Soil sealing and urban sprawl as well as and ecosystems fragmentation reduced retention capacity of urban areas and minimized ability of temperature regulation via processes of evapotranspiration [2, 3, 4].

Strategic Environmental Assessment (SEA) is a decision support instrument that can be contributed to strengthening society commitments to the environment quality, sustainable development, efficient management of resources and innovation economy. Conducting of the SEA is required in all member states of the European Union through the applicable EU Directive 2001/42/EC on assessment of the impact of certain plans and programs on the environment which is implemented in national legislation of each state [5]. The authors of the article took an active part in the preparation Strategic
Environemntal Assessment of Urban Adaptation Plans (SEAUAP) for 8 cities belonging to the Silesian Agglomeration [6].

The research area covered cities in southern Poland: Sosnowiec, Mysłowice, Katowice, Siemianowice Śląskie, Dąbrowa Górnicza, Chorzów, Ruda Śląska and Bytom. The cities are located in the Upper Silesian coal basin, in which the long-term exploitation of hard coal (for over 200 years) has shaped the landscape, functional and spatial structure and had a great impact on the state of the environment. The Silesian Agglomeration is characterized by the highest population density indicator in Poland, Chorzów has 3,262 persons/km² with the average population density in the region 372.9 persons/km² [1].

As part of a detailed analysis of climate and hydrological data, in the years 1981-2015, were in urban adaptation plan of cities, indicated extreme climatic phenomena and their derivatives, which are the greatest threat to the health and life of residents and the proper functioning of cities, including: long periods of no-rain, an increasing number of low rates and deficits of water and the occurrence of local, sudden urban floods. Climate change forecasts for cities have shown, that by 2050, the adverse trends in climate change should be expected to increase [1].

2. Material and methods

The work analyzes the resources and water quality of selected cities, focuses on the basic problems of water management and identifies the natural and anthropogenic factors that cause this state. The main part of the work was based on the SEAUAP data, synthesis of the impact of the proposed adaptation measures of cities on resources and water quality in accordance with the following assessment scale [6]:

- the action will have a positive effect on a given element of the environment (++),
- the action will have a rather positive effect on a given element of the environment (+),
- impact on a given element of the environment is neutral (N),
- the action will have a negative effect on a given element of the environment, but it is possible to minimize this impact (-),
- the action will have a negative effect on the environment and the possibilities of minimizing this impact are limited (--).

While preparing the assessment, the content analysis method and expert methods were used. The main method of analysis and assessment of MPA's environmental impact there were matrix methods. Then conclusions were drawn and possibilities of improving water management in the analyzed cities were proposed.

3. Water conditions

The analyzed area is located in the Vistula River basin and partly in the Odra River. In the Vistula River basin, it covers the partial catchments of the Black Przemsza River with Brynica and its tributary Rawa, White Przemsza River with the Bobrek River and the Przemsza River. In the western part, the area belongs to the Odra River basin, to the Kłodnica catchment.

The hydrographic network is heavily anthropogenic. Rivers, e.g. Kłodnica and Przemsza are regulated along the entire section, including the riverbed. Watercourses are usually used for the discharge of municipal and industrial sewage. Their valleys and riverbeds are adjacent to numerous industrial facilities, including waste dumps as well as railway and road infrastructure. There are extensive drainage areas in the cities under analysis resulting from mining activities. Within the area there are numerous surface water intakes from ponds and rivers, used for industrial purposes by steel mills, mines and power plants. Generally, the water resources of the analyzed area can be defined as scarce while the water demand is high [1, 6, 7].

Based on the quality tests of surface water bodies (SWB) conducted in 2017 by the Provincial Inspectorate for Environmental Protection (IEP) in Katowice, the SWB occurring in the analyzed area was assessed in poor condition. The poor condition of the SWB waters was determined by the predominantly poor or bad status/ecological potential, as well as the chemical status below good. Classification results showed that biological elements still had the greatest impact on the assessment of
the ecological potential of water, including phytobenthos and benthic macroinvertebrates as well as physico-chemical indicators - nitrite nitrogen and phosphate phosphate, chemical - benzo(a)pyrene, fluoranthene and nickel [8].

In the hydrogeological profile of the mentioned area, occur aquifers level in quaternary, tertiary, triassic and upper carboniferous formations [1,6,7]. Water resources have been documented and defined as Major Groundwater Reservoirs (MGR) [9].

The quaternary aquifer level is represented by sands and gravels, which cover is discontinuous and fed by atmospheric precipitation. Threats to the quaternary aquifer are surface and terrain deformations and associated mining settlements. Within this level, MGR 331 Burried Streambed of the Upper Kłodnica River and MGR 455 Dąbrowa Górnicza have been designated. The triassic level has a fracture-karst-pore character and despite many years of drainage through coal and ore mining, it is still the region's main utility level. This level is fed by direct infiltration of rainwater on the outcrops of triassic formations and through quaternary formations. Within this complex, were designated MGR: 329 Bytom, 330 Gliwice and 452 Chrzanów. MGR 329 is exposed and partly degraded. This is the result of the exploitation of Zn-Pb ores and drainage of excavations.

The carboniferous aquifer is heavily degraded due to hard coal mining. Continuously for about 150 years, the rock mass drainage has transformed hydrogeological conditions to a depth of 500 - 1100 m, including a lowering of the water table to a depth of about 150 m. The southern part of Mysłowice includes the border of the local groundwater reservoir (LGR) 457 Tychy-Siersza. The reservoir stretches to east from Mysłowice, where it is an important source of drinking water [10].

The largest anthropogenic transformation of water relations in the country is recorded in the area of Mysłowice and Sosnowiec. The main effects are: sealing of the land surface and impeding the infiltration of rainwater, sealing of the river beds and impeding surface runoff, depression funnel, contamination of surface and underground waters. An indirect effect is an increase in susceptibility to local flooding [1, 6, 7].

Groundwater quality assessment is performed for measuring points in the national and regional network for surface water bodies (SWB). Water level at the measuring point on the analyzed area, in 2016, list class II (good quality water) -IV (unsatisfactory quality water) of five groundwater quality classes [8].

Water management in the region of Upper Silesia faces two extreme challenges, which are excess and shortage of water, generated both by natural factors: periodic surges and low pressure as well as anthropogenic factors: mining activities, sealing of the ground related to land development, changes of relief terrain, irregularities in spatial planning and development, surface water pollution, uncontrolled drainage of the drainage basin. The consequence of these actions are local long or short-term flooding or water deficits [11] (Figures 1, 2).

For the northern part of the Silesian Agglomeration according to The National Hydrogeological Service in 2016, the degree of use of water resources against available resources, was excessive. Supply deficit and lack of reserves were demonstrated. The necessity of conducting resource analyzes was indicated [12]. In comparison with the rest of the country, the disposable groundwater resources are below average [10]. In over 70% are associated with the trias and carboniferous levels, which are strongly threatened by mining activities. In July, was during the years 2018-19 in the Silesia Voivodeship announced the state of hydrological drought [13].
Figure 1. Areas at risk of flooding, Map elaborated by Iwona Owczarska (IETU).

Figure 2. Sealing of soils in urban areas, Map elaborated by Iwona Owczarska (IETU).
4. Assessment of adaptation measures’ impact to climate changes, on the resources and state of water quality of cities

Proper selection of adaptation measures is a key condition for their effectiveness in the climate change adaptation process. The Project has three categories of activities [1]:

- Technical measures - investment measures enabling a city’s quick adaptation to climate change,
- Organizational measures - enforcing changes in spatial planning and management, changes to the local law, development of adaptation guidelines,
- Informational and educational measures - building cooperation, educating and providing information.

Among specific adaptation measures, which we recognize as appropriate for reducing negative effect of climate change there are [14]:

- Introducing system of blue-green infrastructure to urban space,
- Development and maintenance of local green areas like squares, courtyards inside build-up areas, space between dwelling blocks,
- Reuse of existing urban post-industrial areas and transforming them into green public spaces,
- Supporting urban water retention by creation new measures, with the application of proenvironmental solutions introducing water into cities space (fountains, water tanks, water cascades),
- Increasing biologically active areas by limiting impervious surfaces in the city or unsealing them.

As a result of the analysis of all proposed adaptation activities to the climate change of the cities of Upper Silesia, those which have rather positive impact on the resources and quality of water, are described below. These activities were proposed in each of the analyzed cities [6, simplified]:

- Development of planning/urban planning guidelines in shaping public space, considering the impact of climatic factors,
- Development of guidelines and update of strategic and sectorial documents including climate change,
- Including updated climate change forecasts in the city’s strategic and planning documents
- Increasing the share of active biological surfaces by limiting impervious surfaces in the city or unsealing them,
- Construction and development of the blue and green infrastructure system / Development of an integrated system design.

The proposed adaptation measures within the UAP of individual cities, that may have a direct or indirect impact on increasing state of water resources by rationalizing and sealing the municipal economy, increasing retention and biologically active area, as well as promoting saving of water use, were considered to be strongly positive. Most often, the same actions are conducive to improving water quality (Table 1).

- Within the UAP, activities that could lead to increased water consumption, were found to be strongly negative. Activities that change the organization of public transport, which, however, leads to the seizure and sealing of biologically active surfaces, can have a negative impact on water resources. Also, river regulation proposals lead to reduced retention, river regime changes and threat to riverside ecosystems (Table 2).
Table 1. Planned adaptation activities that will have a positive (++) or neutral (N) impact on water resources and/or water quality (simplified, based on [6]).

| City          | Adaptation activities to climate change in cities                                                                                       | Water resources | Water quality |
|---------------|----------------------------------------------------------------------------------------------------------------------------------------|----------------|--------------|
| Ruda Śląska   | Monitoring changes in the river basin together with forecasting, threat analysis and verification of documents regarding water and wastewater management | +              | ++           |
| Siemianowice  | Modernization of storm water drainage system along with the construction of small retention in the city and Information and education activities for the youngest residents, on rational water use during periods of increased demand | ++             | ++           |
| Mysłowice     | Construction / Revitalization / Reconstruction and development of city parks including small storage reservoirs                            | ++             | +            |
|               | Developing rainwater management systems in urban areas                                                                                 | ++             | +            |
|               | Flood protection - reconstruction and maintenance of flood protection devices                                                           | ++             | +            |
|               | Increasing retention of existing rainwater drainage systems                                                                             | ++             | +            |
|               | Preparation of an expertise regarding the specification of the City Water Footprint                                                     | ++             | ++           |
| Dąbrowa Górnicza | Wetland protection as support for protected areas and natural objects                                                                  | ++             | ++           |
|               | Reconstruction of areas for alimentation of underground and surface water intakes and creation of green protection zones                 | ++             | ++           |
|               | Promoting small retention based on a system of subsidies for owners of single-family housing                                              | ++             | ++           |
| Chorzów       | Construction of a system for optimizing water consumption in the city                                                                    | +              | ++           |
| Bytom         | Construction of rainwater retention systems in the city                                                                               | +              | ++           |
| Sosnowiec     | Construction of a system for optimizing water consumption in the city                                                                    | ++             | ++           |

Table 2. Planned activities that will have a negative impact (-) or the possibilities to minimize this impact are limited (--), rather positive (+), neutral (N) impact on water resources and/or water quality (simplified, based on [6]).

| City          | Adaptation activities to climate change in cities                                                                                       | Water resources | Water quality |
|---------------|----------------------------------------------------------------------------------------------------------------------------------------|----------------|--------------|
| Ruda Śląska   | Comprehensive regulation of water relations in the Bielszowice Stream valley                                                            | -              | N            |
|               | Reconstruction of the rainwater sewage system of existing national roads along with integration with receivers                           | -              | -            |
|               | Construction of rainwater retention systems in the city                                                                               | +              | -            |
| Katowice      | Development of the bicycle path system in the city, Katowice                                                                            | -              | N            |
|               | Bicycle Infrastructure                                                                                                                 | -              | -            |
|               | Adaptation of the public transport system to the effects of climate change                                                              | -              | -            |
| Siemianowice  | Construction of rainwater retention systems in the city                                                                               | +              | -            |
5. Summary
Cities provide a more comfortable life. Climate changes (heat, storms, waves of frost) cause that they can become a trap for growing populations. Residents expect a reaction from the Municipal Council/authorities/local government. Actions proposed as part of the UAP are aimed at preparing cities from the technical and organizational point of view and raising the awareness of residents. In the Silesian Agglomeration, the measures proposed at the UAP also help reduce air pollution. They rely mainly on changes to the public transport system, which requires taking up additional space. Preventing flooding and floods reduces retention and causes irreversible changes in river ecosystems, that are already poor in the cities of Silesia.

The implementation of actions must be based on monitoring and assessing of the sensitivity of water resources. It seems, that in this case, cooperation between municipal units is necessary, because the waters do not know any borders (European Water Charter) and require coordination of efforts to meet human needs and protect against floods.

Acknowledgments
The publication of the article is co-financed by the Polish National Agency for Academic Exchange.

References
[1] Project "Development of Urban Adaptation Plans (UAP) for cities with more than 100,000 inhabitants in Poland, implemented in 2017-2019 on behalf of the Ministry of the Environment.
[2] Ecosystem services in the city 2017 Natural capital TEEB, DE
[3] World Meteorological Organization 2019 (Genava: Statement on the State of the Global Climate in 2018)
[4] Zelenakova M, Vranayova Z, Repel A and Kaposztasova D 2018 Surface Runoff in Urban Area–Case Study. In: International Conference on Urban Drainage Modelling (Cham: Springer) pp 152-156
[5] Gałaś S et al. 2013 J. Landsc. Manag. 4 (1) 12-18
[6] Project "Development of Urban Adaptation Plans (UAP) for cities with more than 100,000 inhabitants in Poland, implemented in 2017-2019 on behalf of the Ministry of the Environment. Contractors: Institute of Environmental Protection, National Research
Institute, Institute of Meteorology and Water Management - National Research Institute, Institute for Ecology of Industrial Areas, Arcadis

[7] Bojakowska I et al. 2004 Geoenvironmental Map of Poland - Sheet: Katowice (Warsaw: Polish Geological Institute)

[8] State of the Environment (online)

[9] Kleczkowski A 1990 Map of areas of Major Groundwater Reservoirs (MGR) in Poland requiring special protection 1: 500,000 Krakow

[10] Mikołajkows J, Sadorski A (red) 2018 Informator PSH Główne Zbiorniki Wód Podziemnych w Polsce PIG-PIB Warszawa 413

[11] Woźnica A et al. 2018 Wyzwania związane z wodą na Śląsku - wspólnie zadbajmy o jakość wód. Monografie Śląskiego Aktualne Problemy Gospodarki Wodnej (Katowice: Śląskie Centrum Wody) pp 11-30

[12] Herbich, P, Mordzonek G, Przytula E 2016 Stopień wykorzystania dostępnych do zagospodarowania zasobów wód podziemnych w Polsce (w obszarach bilansowych). (Warszawa: Państwowa Służba Hydrogeologiczna, Państwowy Instytut Geologiczny)

[13] Polish Geological Institute - National Research Institute, Warning of the State Hydrogeological Service (online)

[14] Gorgoń J 2019 Obszary miejsko-przemysłowe wobec zmian klimatu na przykładzie miast centralnej części Górnośląsko-Zagłębiowskiej Metropolii (Instytut podstaw inżynierii środowiska Polskiej Akademii Nauk)