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# THE CAPACITY OF ECOSYSTEM SERVICES IN SMALL WATER RETENTION MEASURES

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ABSTRCT: This study identifies and analyses ecosystem services (ES) in the context of their applicability for drought and flood prevention measures planning undertaken within the framework of small water retention. The results illustrate that ES classified as regulation and maintenance are the most significant because they, one the one hand, contribute the most to improving the flood retention capacity of river catchment areas, whilst on the other hand they provide desirable values that people derive from nature. Furthermore, we also find that the small water retention reservoir is a solution which assures both the best weather hazard prevention as well as the greatest number of benefits.

KEY WORDS: ecosystem services, small water retention, river catchment, AHP

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JEL: Q25, Q57, O22

## Introduction

The measures related to small water retention enable to increase the retention capacity of river areas. Their main aim is to improve the water balance of the catchment, including preventing drought and flood (Mrozik, 2012). However, for most measures it is almost impossible to determine their real impact and (in particular) the effectiveness of their impact on the volume of flow rate during a flood. Hence, from the viewpoint of flood protection, the it is small water retention reservoirs that seem to be more useful to in limited the flooding[1]. It should be also noted that besides the already mentioned regulatory and maintenance services, the small water retention also provides other valuable ecosystem services which may contribute not only to better water management and reduction of flood and drought risks but also to delivering the most beneficial outcomes of high value to society (Wagner et al. 2013). Thus, it has been necessary to shed more light on these issues in respect of a concrete river catchment.

The key questions addressed in the paper are: What kind of ecosystem services can be considered in the planning of raising the retention capacity of the river catchment? To what extent particular ecosystem services can affect the retention capacity of the river catchment and, at the same time, yield measurable social and business benefits, when implementing different measures? In order to provide answers to these questions, the authors analysed the concept of ecosystem services for Poland with a view to their possible application for measures contributing to improving the retention capacity of the river catchment.

## An ecosystem approach to IWRM

Recently observed climate fluctuations coupled with such processes as urbanization and suburbanization (urban sprawl) imply an urgent need for action to maintain a balance between natural resources use and territorial development. Extreme weather conditions such as irregular and heavy rainfall patterns and intensifying droughts often result in local flooding and flash floods (Mrozik, Przybyła 2013). These intensifying events, on the one hand, constitute frequently a serious barrier to the social and economic development of communities, and on the other, seen as a result of human action, may exacerbate a the pressure on the environment, giving rise to the disappearance of ecosystems, loss of biodiversity, reduction of soil water retention

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[1] According to the classification proposed by W. Mioduszewski, this group includes reservoirs with a capacity of up to 0.5 million m$^3$ and a damming height up to 5 m. (Mioduszewski, 2014, p. 19-29 and 2014b, p. 41-51).

capacity, soil degradation etc. In order to protect regions and localities from floods while also preserving biodiversity, sustaining natural resources and providing opportunities for human development, the combination of comprehensive mitigation and adaptation measures is needed to counteract the already emerging effects of climate change and protect against the climate change that is predicted to occur in the future. The rationale behind this is the Integrated Water Resources Management (IWRM) which is applied as a tool assuring solutions to the water crisis under conditions of human interventions as a basis for sustainable development (Mrozik et al., 2014). IWRM is defined as a process that "promotes the co-ordinated development and management of water, land and related resources, in order to maximise the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems" (Handbook..., 2009). It follows that all measures aimed at improving the management of water should integrate ecological, social and economic factors in an equitable way.

Bearing in mind the above-mentioned scope of matters and the objective of this study, it is argued that IWRM should focus on safeguarding and enhancing the water storage potential of a particular area by the use of various solutions which as far as possible take account of ecosystem services. Such an ecologically orientated approach is very crucial and beneficial because places emphasis on the key role of ecosystem functions[2]. A relevant aspect of this approach is that the maintenance of diversity in ecosystems builds "resilience against large disturbances". To put it another way it might be said that the ecosystem needs an integrity understood as an ability to work further in a natural way. Measures of human action have to be taken in an adaptive manner. This means that stakeholders are aware of the fact that ecosystems are complex systems, which are "adaptive" or "self-organising" and that management systems must be able to adapt to change in the system (Jewitt, 2002).

Coming back to the matter of ecosystem functions on water, it is noted that the two basic functions can be considered which provide specific services, i.e. water regulation and water supply (Groot 2002). The former function refers to the impact of natural systems on the regulation of hydrological flows at the earth's surface. The available services offered by this function are, for example, maintenance of natural irrigation and drainage, buffering of extremes in discharge of rivers, regulation of channel flow, and provision of a medium for transportation. The letter function deals with the filtering, retention and storage of water in streams, lakes and aquifers. It is worth

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[2] De Groot defines ecosystem functions as "*the capacity of natural processes and components to provide goods and services that satisfy human needs, directly or indirectly*" (Groot, 1992).

mentioning that the retention and storage capacity depends on the topography and sub-surface characteristics of the involved ecosystem. Ecosystem services resulting from the supply function of water are directly related to the consumptive use of water by, for instance, households, agriculture and industry. Although these services provide vital benefits, it should not be overlooked that they are a part of the hydrological cycle. The traditional approach to water management focuses on a few selected elements of this complex system (including the control of the hydrological cycle) and, consequently, provide specific artificial services. The movement to IWRM enables to consider the complexity of the hydrological cycle more accurately (Jewitt, 2002). This is particularly important while considering the fact that the possibility of natural landscapes to mitigate the negative effects of hazardous weather events is usually neglected (Nedkov, Burkhard, 2012). Thus, the planning and management of retention areas taking into consideration the ecosystem services require a good understanding of the relationships that exist between their function and designs (Reckendorfer et al., 2013). The decision-making process should incorporate nature conservation into water retention designs. Only such an approach makes it possible to sustain the functional and vital values of nature.

## Methodology

This paper provides further evidence for the debate on ecosystems services and their utility to assist flood prevention and mitigation measures, in particular as far as the small water retention is concerned. To this end, it was used a methodology that bases substantially on an qualitative the approach but elements of quantitative approach are also included. It comprises an extended literature review on ecosystems services and the application of the AHP method (*analytic hierarchy process*). This means that the approach applied in the work is twofold. Firstly, we identified those ecosystems services which can be recognized, with regard to analysed measures, as appropriate for enhancing the water retention capacity of the river catchment. To do this we used in particular the concept of ecosystem services for Poland (Mizgajski, Stępniewska, 2012). To the best of our knowledge, the ecosystems services useful for the analysed small water retention measures are presented in table 1. A prominent feature of the study is the belief that ecosystems services can be applied while planning small water retention and choosing the best actions.

Secondly, what follows, we had to examine the range of selected ecosystem services to influence the retention capacity of the river catchment and, at the same time, their impact on socio-economic well-being. All ecosystem services and measures were considered from the main objective point of view, which was maximising the positive impact of ecosystem services in the prevention of drought and flooding. Such a complex problem needs to be addressed through the use of the multi-criteria decision making approach proposed by Saaty. AHP is a very flexible and powerful tool because combines elements of mathematics and psychology. It enables to solve the problems of decision-making which are multi-faceted and described by quantitative and qualitative elements.

AHP is based on a symbolic model that uses a multi-level hierarchical structure of objectives, criteria and alternatives. The design of the structure consists in determining the components (elements) of a problem and grouping them into homogeneous sets. Then, taking into consideration interdependencies existing between them, they are allocated and organized at appropriate levels of the hierarchical structure. In this way, a simplified model of the reality is constructed in which the individual elements of the decision problem are organised separately but at the same time in an inter-related way according to the relationships existing between them (Prusak, Stefanów, 2014). Analysis of the decision-making problem by AHP in the paper was carried out with the following steps:

- creation of multi-level hierarchical structure of the problem – at the highest level an overall objective was determined, at the lowest level alternatives (type of solutions) for reaching the objective were clarified, and at the intermediate level the decision criteria (here ES) affecting the degree of fulfilment of the objective,
- pairwise comparisons of various criteria and alternatives – data were collected from experts[3] which pointed their decision based on the Saaty's scale,
- calculations and generating results by using the software *Super Decision*,
- rating of each alternative (solutions) – classification of particular solutions in the light of the adopted criteria in terms of their contribution to achieving the overall objective and indicating the best solution.

## Description of the research area

A research area allowing the application of AHP and enabling to make the brest decision was the Skórzynka river catchment. It is located within the administrative borders of two rural communes Dopiewo and Tarnowo

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[3] In the analysis the opinions of six experts (specialists in the field of water management, environmental engineering, environment protection and development, spatial planning and economics and management) were used. The aggregation of the results was based on behavioural methods (Prusak, Stefanów, 2014, p. 212-217).

Podgórne and the city of Poznań. The Skórzynka river catchment (of 10 km$^2$ total area) covering 21% of the area of its recipient – the Potok Junikowski – is characterised by an intensive suburbanization manifested by, among others, a dynamic increase of built-up and urban areas at the expense of agricultural land. Residential areas with industrial, service development and transport areas occupy 54%, and agricultural land only 31% of the catchment area. Skórzynka is a tributary of Potok Junikowski which is a surface water body (code PLRW60001718576) in the Warta water region. In turn, Potok Junikowski is defined a heavily modified water body and its state was assessed as bad. Moreover, it is at risk of failing to achieve environmental objectives set out in the Water Framework Directive. In addition, the Skórzynka river catchment is located within a region with the highest needs of developing water retention and the greatest need for irrigation. On the other hand, flooding and droughts are here common natural disasters (Mrozik, 2016, Mrozik et al., 2015).

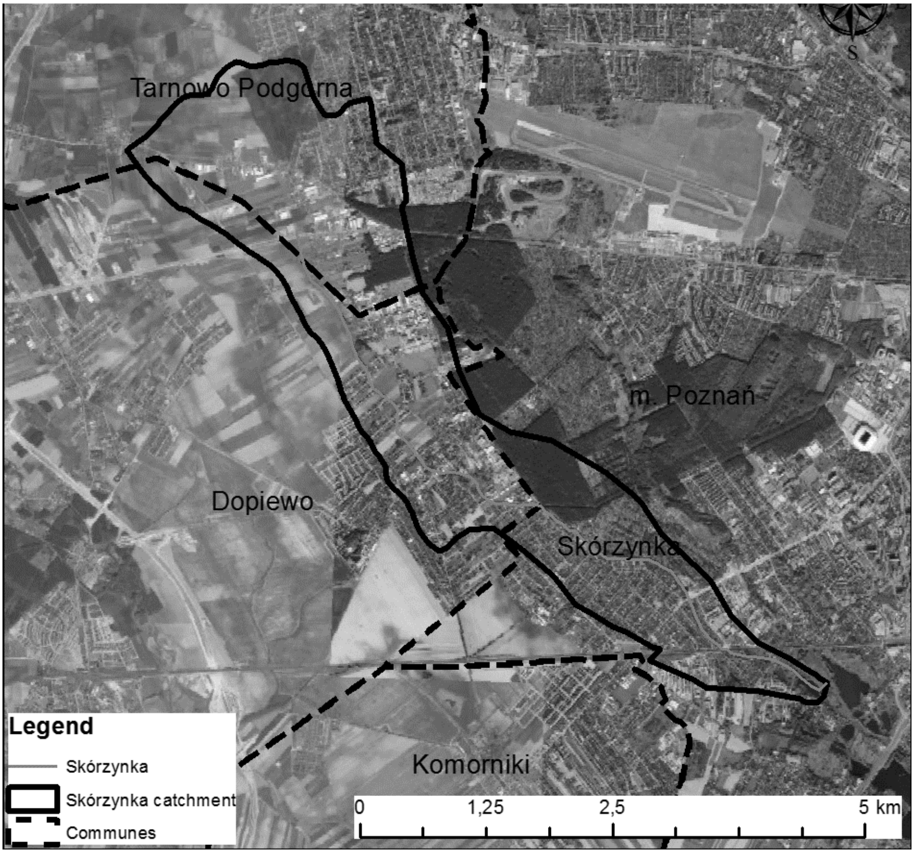

Figure 1. Location of Skórzynka catchment

Source: author's own work.

## Results and discussion

In the paper three types of actions (measures) in a small water retention area were constructing: constricting a small water retention reservoir (V=15000 m$^3$), agrotechnical measures (72 ha) and rainwater harvesting systems (total volume = 15000 m$^3$) (Idczak, Mrozik, 2015). These solutions were analysed in the context of ecosystem services that are adequate to deal with small water retention measures, as shown in table 1.

**Table 1.** Ecosystem services related to small water retention measures*

| | Ecosystem services | Small water retention reservoir | Agrotechnical measures | Rainwater harvesting systems |
|---|---|---|---|---|
| Provisioning | Fish (wild populations) | 1 | 0 | 0 |
| | Aquaculture products | 1 | 0 | 0 |
| | Drinking water | 0 | 0 | 0 |
| | Domestic water use | 0 | 0 | 2 |
| | Irrigation water (consumptive) | 2 | 0 | 0 |
| | Cooling water (non consumptive) | 1 | 0 | 0 |
| | Genetic resources | 1 | 0 | 0 |
| Regulation & Maintenance | Dilution, decomposition, remineralisation and recycling | 1 | 1 | 0 |
| | Attenuation of runoff and discharge rates | 1 | 2 | 1 |
| | Water storage for flow regulation | 2 | 1 | 1 |
| | Local & Regional climate regulation | 2 | 1 | 1 |
| | Water purification and oxygenation | 1 | 1 | 0 |
| | Biological control mechanisms | 1 | 1 | 0 |
| | Maintaining nursery populations | 1 | 1 | 0 |
| Cultural | Landscape character | 2 | 1 | 0 |
| | Cultural landscapes | 2 | 1 | 0 |
| | Wilderness, naturalness | 1 | 1 | 0 |
| | Charismatic or iconic wildlife or habitats | 1 | | 0 |
| | Prey for hunting, fishing or collecting | 1 | 0 | 0 |
| | Scientific | 1 | 0 | 0 |
| | Educational | 1 | 0 | 0 |

* relevance degree of ES to be considered in small water retention measures: 0 – none, 1 – low, 2 – high

Source: author's own work.

The main aim is, certainly, increasing the retention which should contribute to a reduction of the risk of flood or drought, and the improvement of water balance in the catchment. However, other services provided by the examined measures cannot be overlooked.

The aim of soil retention is possibly the permanent stoppage of the rain water in the soil and sustaining and enhancing local water balance. Infiltration of rain water is a significant factor in shaping the surface of ground water. A longer staying of water in soil causes, in turn, a better cleansing of the waters. Additionally, if infiltration is increased, evapotranspiration will be increased. Since evapotranspiration is connected to retention, it has an impact on the bioclimatic equalising functions of the landscape and balances the mesoclimate (Mrozik, Przybyła, 2013).

What clearly emerges from table 1 are the differences between the agrotechnical measures and the small water retention reservoir and also the rain water harvesting system. A possibility of the development of tourism and, especially, recreation on and around small reservoirs is crucial from the ecosystem services point of view. A landscape which lacked lakes, is enriched. The reservoir enables also fishing. In the case of rain water harvesting systems these are noteworthy seen as water resources to be used for household purposes.

In the second step the procedure based on AHP was applied to choose those ecosystem services as well as those measures which in the best possible way contribute to the achievement of the objective set in the study. To put it in other words, the objective was to determine the kind of measures enhancing the retention capacities of the Skórzynka river catchment which enable society to maximise the benefits provided by the ecosystem services. However, in order to make a complex decision, it needs to structure the decision hierarchy descending from the overall objective of the decision, through the various criteria on which subsequent elements depend to the lowest level, setting out all the alternatives concerned, as shown in Figure 2. Categories of ES were used as criteria (attributes) represented at the intermediate level which were to determine the decision. In turn, measures referring of the alternatives of a decision were laid down at the last level of the hierarchy.

Once the hierarchy was structured, the pairwise comparisons of various criteria and alternatives were taken to determine the relative importance of each alternative in terms of each criterion. In such a way the weights for the different criteria as well as alternatives were computed. These actions consisted in quantifying the linguistic choices of the decision makers by using Saaty's scale and in determining the priority vectors. Finally, the rating of each alternative was multiplied by the weights of the criteria and aggregated to get the final ratings. The results are displayed in table 2.

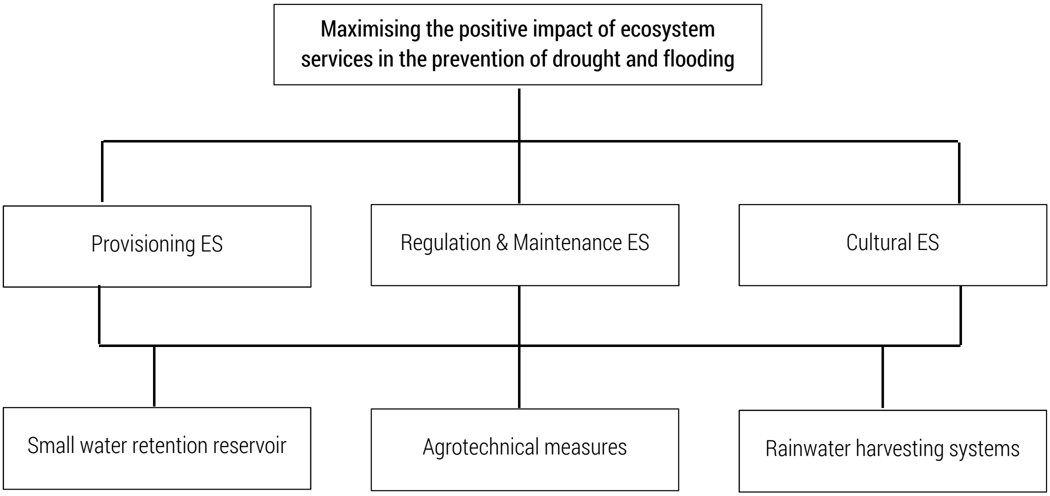

**Figure 2.** A hierarchical structure of the decision problem

Source: author's own work.

**Table 2.** Synthetic indicators of the AHP analysis

| Name of solutions | Ideal indicator | Weight indicator | Rank |
|---|---|---|---|
| Small water retention reservoir (SWRR) | 1,0000 | 0,6802 | 1 |
| Agrotechnical measures | 0,2855 | 0,1942 | 2 |
| Rainwater harvesting systems | 0,1846 | 0,1256 | 3 |

Source: author's own work.

The evidence provided by the AHP analysis show that the solution with the highest priority in the light of the adopted criteria is the small water retention reservoir. This also implies that the SWRR compared with the other technically feasible alternatives has the highest contribution to the achievement of the objective pursued, i.e. reaping the greatest benefits from the ES taken within actions against the drought and flooding in the Skórzynka river catchment. To some extent, this might point out that a technical measure such as SWRR counted among the elements of the hydro-technical system, i.e. caused by human activities, can provide, in the case at hand, the most benefits that people derive from nature. However, this should come as no surprise because nowadays actions taken by humans are designed with the highest respect for the environment to restore the natural and water-dependent ecosystems, which have been damaged by anthropogenic activities. Hence, all activities aimed at increasing the potential retention capacity of a river catchment including SWRR, to some extent, are the most important regulating ecosystem services that may increase or reduce the negative effects of water-related disasters (see table 1). This finding is in line with the literature (Boyd, Banzhaf, 2007; Chee, 2004; Fisher et al., 2009) showing that in particular regulating ecosystem services ensuring protection against flood can generate benefits in terms of flood-damage mitigation, moderation of weather events, regulation of the hydrological cycle and, finally, the protection of human properties.

## Conclusions

What follows from this study is an evidence confirming the prominent role of ES in the field of water retention measures planning aimed on the one hand at preventing and mitigating floods, and on the other at hand conserving water in natural hydro-technical systems to alleviate the effect of droughts. The findings obtained based on the Skórzynka river catchment area highlight the importance of ES and their varied impact on the environment and socio-economic well-being depending on the particular water retention measures considered. To be more precise, the largest number of ES can be provided by SWRR. Moreover, this solution ranks also first among the three investigated alternatives in terms of a simultaneous provision of the highest number of ES and ensuring the highest level of protection against flood and droughts. By referring to these results it is possible to argue that in the research area of the paper SWRR is the best option to be used in counteracting a drought and flooding. But this conclusion is contrary to another study which indicates that the best solution leading to the improvement of the water retention capacity of the Skórzynka river catchment is agrotechnical measures, which should be seen as a priority in programs for adapting to climate changes (Mrozik, Idczak, 2016). It should be noted, nevertheless, that the referenced study focused on the decision-making under certain conditions including, amongst other matters, different criteria. This does not change the fact, however, that, when comparing both studies, it is vital to make an in-depth and complex analysis that allows to assess all the potential costs and benefits resulting from the use of different measures. There is also a need for further research to address the potential trade-offs of planned solutions (i.e. benefits from increased natural water retention versus losses in other services).

Discussing the results further, it is noteworthy that the restoration of the natural water capacity of an each river catchment should be regarded prior to human activity. This is even more crucial as the Skórzynka river catchment covers an area that is highly influenced by urbanization. It is highly unlikely that under such conditions the natural capacities of the catchment can be restored or maintained without substantial additional investments into infrastructures (Arnbjerg-Nielsen, Fleischer, 2009). With all this, in mind the approach presented in the paper focuses on the ecosystem service concept's implementation into the decision making. This holistic approach addresses the cost-benefit-efficient multifunctional water retention measures.

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## The contribution of the authors

Karol Mrozik – 50%
Piotr Idczak – 50%

## Literature

*A Handbook for Integrated Water Resources Management in Basins* (2009), Sweden

Arnbjerg-Nielsen K., Fleischer H.S. (2009), *Feasible adaptation strategies for increased risk of flooding in cities due to climate change*, "Water Science and Technology" No. 60, p. 273-281

Boyd J., Banzhaf S. (2007), *What are ecosystem services?* "Ecological Economics" No. 63, Vol. 2-3, p. 616-626

Chee Y.E. (2004), *An ecological perspective on the valuation of ecosystem services*, "Biological Conservation" No. 120, p. 549-565

Fisher B., Turner R.K., Morling P. (2009), *Defining and classifying ecosystem services for decision making*, "Ecological Economics" No. 68, p. 643-653

Groot R.S. (1992), *Functions of nature: Evaluation of nature in environmental planning, management and decision making*, Groningen

Groot R.S., Wilson M.A., Boumans R.M.J. (2002), *A typology for the classification, description and valuation of ecosystem functions, goods and services*, "Ecological Economics" No. 41, p. 395-499

Idczak P., Mrozik K. (2015), *Wykorzystanie dynamicznego kosztu jednostkowego do oceny efektywności ekonomicznej rozwiązań kształtujących retencję zlewni rzecznej na terenach zurbanizowanych,* "Ekonomia i Środowisko" No. 2(53), p. 92-102

Jewitt G. (2002), *Can Integrated Water Resources Management sustain the provision of ecosystem goods and services?*, "Physics and Chemistry of the Earth" No. 27, p. 889-890

Mioduszewski W. (2014a), *Small (natural) water retention in rural areas,* "Journal of Water and Land Development" No. 20 (I-III), p. 19-29

Mioduszewski W. (2014b), *The analysis of the impact of small retention on water resources in the catchment*, "Journal of Water and Land Development" No. 23 (X-XII), p. 41-51

Mizgajski A., Stępniewska M. (2012) *Ecosystem Services Assessment for Poland – Challenges and Possible Solutions*, "Ekonomia i Środowisko" No. 2 (42), p. 69-71

Mrozik K, Idczak P. (2016), *Optymalizacja procesu decyzyjnego dotyczącego kształtowania zdolności retencyjnych zlewni – przykład metody AHP*, "Studia i Prace WNEiZ" No. 46(2), p. 83-94

Mrozik K. (2012), *Einfluss der Bodenbearbeitung auf das Retentionsvermögen im Teileinzugsgebiet des Flusses Kania, "Wasserwirtschaft"* No. 5, p. 11-15

Mrozik K. (2016), *Assessment of retention potential changes as an element of suburbanization monitoring on example of an ungauges catchment in Poznań Metropolitan Area (Poland),* "Annual Set The Environment Protection" No. 18, p. 188-200

Mrozik K. et al. (2014), *Zintegrowane zarządzanie zasobami wodnymi jako czynnik rozwoju społeczno-gospodarczego*, "Prace Naukowe Uniwersytetu Ekonomicznego we Wrocławiu, Gospodarka przestrzenna Dylematy i wyzwania współczesności" No. 339, p. 130-140

Mrozik K., Przybyła Cz. (2013), *Mała retencja w planowaniu przestrzennym*, Poznań

Mrozik K., Przybyła Cz., Pyszny K. (2015), *Problems of the Integrated Urban Water Management. The Case of the Poznań Metropolitan Area (Poland)*, "Annual Set The Environment Protection" No. 17, p. 230-245

Nedkov S., Burkhard B. (2012) *Flood regulating ecosystem services – Mapping supply and demand, in the Etropole municipality, Bulgaria*, "Ecological Indicators" No. 21, p. 67-68

Prusak A., Stefanów P. (2014), *AHP – analityczny proces hierarchiczny. Budowa i analiza modeli decyzyjnych krok po kroku*, Warszawa

Reckendorfer W. et al. (2013), *Aquatic ecosystem functions of an isolated floodplain and their implications for flood retention and management*, "Journal of Applied Ecology" No. 50, p. 120

Wagner I., Krauze K., Zalewski M. (2013), *Błękitne aspekty zielonej infrastruktury,* "Zrównoważony Rozwój – Zastosowania" No. 4, p. 145-155