Original Research

An Attempt to Introduce Cultivation and Planning Measures into the Decision-Making Process in Order to Improve Water-Retaining Capacity of River Catchments

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Abstract

This paper analyzes the capabilities of introducing cultivation (conservation cultivation, direct sowing) and planning (afforestation, change of arable land and permanent grassland under intensive use into extensively used grassland, introduction of midfield tree planting, establishment of midfield boundary strips with perennial grasses and herbaceous plants, formation of buffer zones for surface water) measures in polish planning documents at local level due to the needs of flood control and drought prevention based on improvement of the natural water-retaining capacity of catchments. Analysis was conducted on an example of uniform water body of surface waters in the Odra River basin (Wielkopolska region) by the application of a GIS-based decision support system. Matrix of the decision-making process includes 9 factors (land use, size of fields, fall of land, inundation areas, water-retaining capacity, dominant component of runoff, drained areas, distance from waters, and Natura 2000 areas).

Keywords: drought prevention, flood prevention, integrated water resource management, spatial planning

Introduction

The European water policy is based on the principles of Integrated Water Resources Management (IWRM), assuming, e.g., that a hydrographic catchment constitutes the primary area for all planning and decision-making activities [1]. In turn, the system of spatial planning in Europe is based on administrative boundaries, hindering a holistic approach to water resource management within the limits of catchments. Carter indicated that there is frequently a lack of cooperation in terms of water resource management between communes or regions within one catchment [2].

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According to the IPCC forecast, in 2080-99 precipitation will increase on average by 15%, while during winter season from 10 to 20%. After 2070 in Poland the mean summer precipitation also will decrease. Moreover, an intensification of precipitation by approx. 25 mm also is forecast. Additionally, an increasing proportion of summer precipitation will be of high intensity. It is forecast that by 2020 the drought frequency will increase two-fold, while up to 2070 it will be as high as five-fold. We may also expect an increased flood hazard, caused particularly by short and intensive precipitation and drought [3-6]. Analysis of rainfall confirming the increase in the number and size of extreme events was conducted, i.e. Przybyła et al. for a small catchment in the Poznań Metropolitan Area and Mrozik for Kania catchment in the southern part of Wielkopolskie Province, both in Warta catchment (Odra River Basin) [7, 8].

Observed and forecast climate changes require comprehensive adaptive actions. The Green Paper from the Commission of the European Communities, *Adapting to climate change in Europe – options for EU action,* mention, e.g., the development of spatial plans as examples of such actions, next to more efficient use of limited water resources [9].

As stressed in the Green Paper, the adaptation to climate change constitutes a challenge for planning agencies of all levels, particularly the regional level. Spatial planning as an interdisciplinary (inter-sector) discipline should play a key role in the adaptation process. Its primary task is to determine the minimum requirements in terms of land development as well as land function and changes in land use. Spatial planning may also play a crucial role in the development of public awareness, the awareness of decision-makers and professionals, and stimulate a more active approach to the problem at all planning levels.

In the European Union legal regulations concerning water resources management are comprised in the Water Framework Directive (WFD) [10]. It imposes on the member states the obligation e.g. to develop a river basin management plan (RBMP). The first RBMP should have been prepared by the end of 2009, and next it should be reviewed and updated every six years. The first plans developed in accordance with the White Paper from the Commission of the European Communities, *Adapting to climate change: Toward a European framework for action* [11], should take into consideration the effects of climate change, while the following plans should fully incorporate the issue of adaptation to climate change. Specific requirements concerning the contents of RBMP were identified in Appendix 7 to WFD. Climate change is not directly addressed in the WFD, while the primary objective of RBMP is to provide good ecological and chemical status of waters. In turn, the issue of climate change was included in the Floods Directive [12]. This directive imposes on stages of the obligation to develop flood risk management plans (FRMP) for river basins. These plans should be prepared by 22 December 2015, taking into consideration the effect of climate change. They should be reviewed every six years and updated as needed to consider the potential effects of climate change on the occurrence of floods.

The objective of the paper is to analyze the capabilities of introduction of cultivation and planning measures in Polish planning documents at the local level due to the needs of flood control and drought prevention based on improvement of natural water-retaining capacity of catchments. Moreover, an attempt was made to apply the decision support system at the local planning level in order to improve water-retaining capacity of catchments by the application of cultivation and planning measures.

Methodology

Tools of spatial planning and planning in water resources management in terms of the incorporation of needs of flood control and drought prevention, based on the improvement of natural water-retaining capacity of catchments, were analyzed for the catchment of the Kania River with total area of 110 km^2, where the agriculturally utilized area comprises more than 80% total area [13]. Additionally, this area is characterized by a high valorization index of agricultural production area (83.8/100), which results in intensive agricultural production. This catchment is located in the 2nd area requirement zone for the development of water harvesting in the basin of the Warta [14], comprising the strongest agricultural centre in Poland. As indicated by Kowalczak [14], in such a zone mainly small-scale retention measures should be applied due to the potentially most efficient use. Moreover, an appropriate modification of water-retaining capacity of the Kania catchment (catchment class 4) as a left-bank tributary of the Koscian Channel of the Obra River, constituting a section of the Mosina Canal[1)] (catchment class 3) may contribute to a reduction of the flood wave on the Mosina Canal, around which areas at risk of flooding were identified.

The Kania catchment is located in three communes: the rural commune of Piaski (47% catchment area), and town and rural communes of Gostyn (46%) and Krobia (7%), comprised in Gostyń county in Wielkopolskie province.

Existing planning documents take into consideration natural methods of enhancing water-retaining capacity to a limited degree. They mainly indicate afforestation, midfield tree and shrub plantings, and erosion prevention or soil protection measures [8]. For the purpose of optimal use of a specific natural water-retaining capacity of a catchment, these procedures need to be mentioned, which have the greatest implementation potential, i.e. have the greatest chance to receive public acceptance and approval of local authorities. Moreover, we need to identify specific areas for which certain procedures are most advantageous from both ecological and economic perspectives, i.e. they are included in the realization principles of sustainable development and spatial order underlying spatial policy, identification of areas for specific purposes and determination of principles for their development and building development [15]. The spatial planning tool should be used also to support environmental compensation [16].

For landscape designers and urban planners it is important to be able to express and communicate their thoughts about the existing world and its potential changes using different types of visualizations [17]. The Decision Support System (DSS) is increasingly becoming a key tool in such a situation. Thanks to the DSS formula, the user does not have to be an expert in the operation of GIS software or modeling, since the interactive user's interface makes it possible to manipulate parameters in a user-friendly manner [18]. In many countries DSS is commonly applied while solving problems connected with planning in spatial development. An addition of spatial reference to data forming, the system and the results obtained in the expert systems and in simulation models, as well as its construction within one programming environment, make it possible to

[1)]The Mosina Canal is a tributary of the Warta, which in turn flows into the Odra.

Table 1. The potential significance of the proposed measurements for environmental protection goals (amended on the basis of Rüter and Reich [25], and Sieker et al. [21]).

Designation	Type of measurement	Preventive flood control	Protection against erosion	Protection of water and soil against pollution	Groundwater recharge	Local bioclimatic balancing features	Protection of biodiversity	Protection of species and habitats	Landscape experience and recovery function
	CULTIVATION								
A1	Conservation cultivation	●	●	◑/●	●	●	◑	○	○
A2	Direct sowing (no-tillage)	●	●	◑/●	●	●	◑	○	○
	PLANNING								
B1	Afforestation	●	●	●	●	●	●	●	●
B2	Change of arable land and permanent grassland under intensive use into extensively used grassland	◑/●	●	●	●	●	◑/●	◑/●	◑/●
B3	Introduction of midfield tree planting	◑	◑/●	●	○/◑	◑	●	●	●
B4	Establishment of midfield boundary strips with perennial grasses and herbaceous plants	◑	◑	◑	◑	◑	●	●	●
B5	Formation of buffer zones for surface waters	◑	◑	●	◑	◑	●	●	●

○ – minor importance, ◑ – medium importance, ● – great importance

considerably extend the operation of such a system [19]. In turn, spatial distribution of parameters in the input and results at the output of the system executed in the geographic information system (GIS) facilitates modeling, visualization of results, and the final decision-making process.

In this study DSS FLEXT was applied, developed by Jin [20] and used by Sieker et al. [21]. The FLEXT program (flexible expert tool) is a system programmed in Visual Basic 6.0 software. Within this study DSS FLEXT was adapted to Polish conditions in order to indicate the optimal measures improving natural water-retaining capacity in agricultural catchments of the Wielkopolska region.

In the decision-making process for agriculturally utilized areas the following measures were included:

- Cultivation:
  A1. conservation cultivation
  A2. direct sowing (no-tillage)
- Planning:
  B1. afforestation
  B2. change arable land and permanent grassland under intensive use into extensively used grassland
  B3. introduction of midfield tree planting
  B4. establishment of midfield boundary strips with perennial grasses and herbaceous plants
  B5. formation of buffer zones for surface waters

The included measurements have an advantageous effect on agricultural landscape both in terms of flood control and drought prevention, as well as objectives of environmental protection (protection against erosion, protection of waters, protection of species and habitats) (Table 1). To select the appropriate measurements, experiences reported by Thiel and Schmidt [22], Röder et al. [23], Sieker et al. [21], and Weiß and Theobald [24] were used. Additionally, these measurements may be supported in Poland using the available financial packages for rural areas within agricultural and environmental programs.

Matrix of the decision-making process includes the following factors:

- land use
- size of fields
- fall of land
- inundation areas
- water-retaining capacity
- dominant component of runoff
- drained areas
- distance from waters
- Natura 2000 areas

Individual factors of the decision-making process were classified using ArcGIS 10.0 software by ESRI. The selection of factors and the method of classification were determined by the availability of individual cartographic data in vector form (the scale of individual maps). Land use was developed on the basis of a topographic map at a 1:10,000 scale, field size was determined on the basis of a cadastre map at 1:1,000 scale, fall of land was determined using ArcGIS (the slope function in the 3D Analyst Tools package) on the basis of a digital elevation model (DEM) at 1:10,000 scale, inundation and drained areas – a hydrographic map at 1:50,000 scale, boundaries of the Natura 2000 area on the basis of layers prepared at the Wielkopolska Regional Spatial Planning Office in Poznań at 1:50,000 scale, distance from waters was determined using ArcGIS (the buffer function – analysis tools).

To determine the dominant components of runoff, the DSS FLAB was used, developed at the IHI Institute at Zittau and repeatedly utilized [21, 26-28]. Key cartographic material in this case comprised soil and agricultural maps at 1:25,000 scale. For the purpose of appropriate classification of Polish soils WRB units were used [29, 30]. In the case of water-retaining capacity the methodology proposed by Sieker et al. [21] was also utilized. For the purpose of a detailed description of water-holding capacity of soils in the catchment, information concerning previous drainage of the soil profile was included. Since the value of field water capacity of soil may also be influenced by the level of the ground water table, the initial retention status in soil takes into consideration the degree of its gravitational drainage after 5, 10, and 15 days. A mathematical description of parameters of water-retaining capacity was facilitated by the formula developed by Genuchten [31]. In order to describe the Genuchten equation, formulas describing dependencies between values of physical characteristics of soils and their retaining capacity were used – the so-called pedotransfer function (PTF) [21, 32]. To determine the gravitational drainage, Richard's equation was applied and hydraulic conductivity was calculated using PTF in accordance with the methodology adopted after Tietje and Hennings [21]. Hydrological considerations concerning water-retaining capacity for selected precipitation require the distinction between surface runoff and infiltration. Infiltration in the porous soil environment is a complex process that depends on both variable spatial soil parameters and factors varying in time, such as precipitation, soil moisture content, and ground vegetation cover. Hydrogeological properties of the subsoil may be determined using permeability and filtration indices [21].

In numerous hydrological models infiltration is described on the basis of the infiltration model by Green and Ampt. Many authors proposed different modifications to this model, which facilitated the incorporation of the horizon system in the soil profile. In this study the assumptions developed by Chu and Mariňo [33] were applied, which included, apart from the soil horizon system, also variation in the course of precipitation.

Modelling of infiltration was performed using Microsoft Excel software for a previously prepared database containing soil characteristics in the Kania catchment. To calculate the water-retaining capacity of the catchment, precipitation data was used, specified on the basis of an empirical formula developed at the Institute of Meteorology and Water Management (IMGW) [34, 35] for 1-, 12-, and 72-hour events with a probability of occurrence amounting to 0.1 and 0.01 [21].

Results

Basing on the decision-making process, maps of the optimal measures improving natural water-retaining capacity may be generated for the catchment, indicating for agriculturally utilized areas those procedures that should be preferred in specific areas. Moreover, in the decision-making process there are indicated areas for which none of the discussed measures are recommendable. These areas comprise mainly forests, built-up areas, and surface waters.

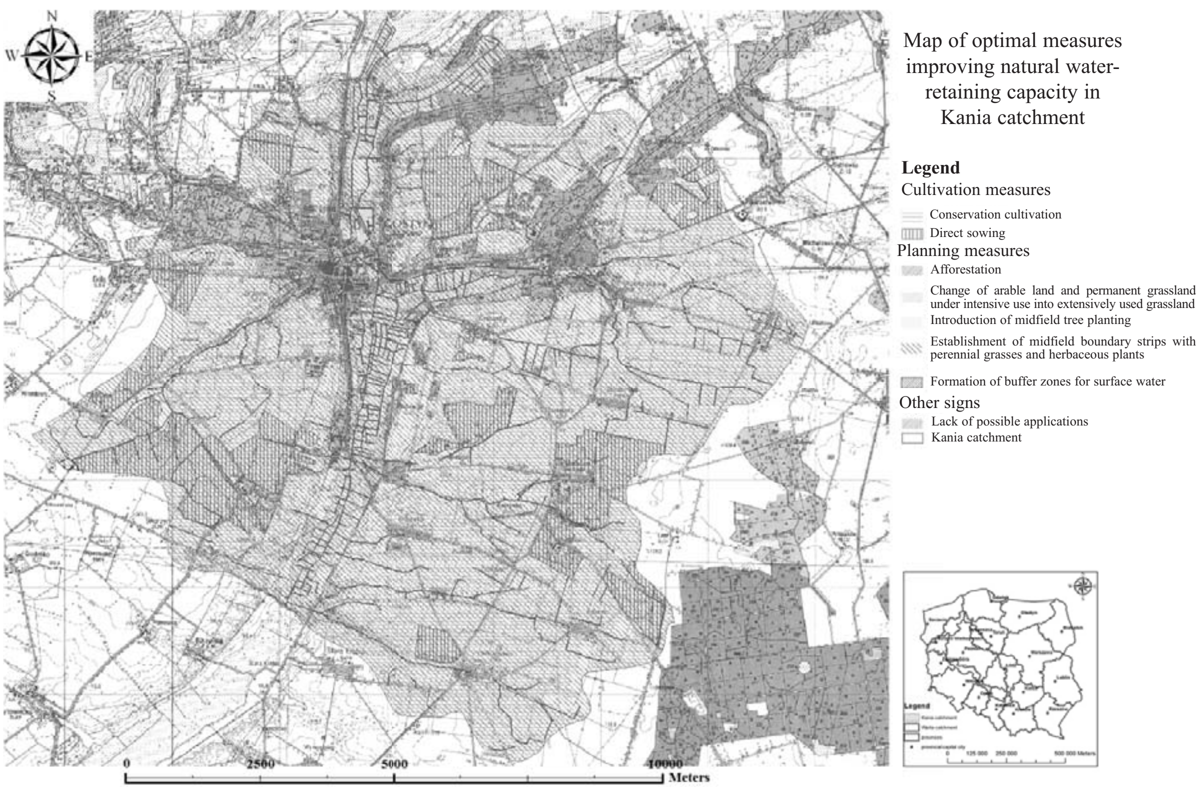

Fig. 1. Map of optimal measures improving natural water-retaining capacity in Kania catchment.

Midfield boundary strips with perennial grasses and herbaceous plants connected with the agricultural and environmental program are most commonly applied, as they are applicable practically in all agriculturally utilized areas in the Kania catchment (87% catchment area). Over a slightly smaller area midfield tree plantings are preferred (79%), which are recommended particularly for arable land. More than half of the catchment area (53%) cultivation measures may be applied, except for no tillage, for which in relation with considerable investment needs criterion excluding fields with an area below 20 ha (16%) was used. Afforestation is preferable mainly on slopes of river valleys due to the considerable fall of land (7.4%), changing arable land and permanent grassland under intensive use into extensive grassland in river valleys (6.4%), while buffer zones only in the immediate vicinity of watercourses (1%) (Fig. 1).

Implementation of WFD and the Floods Directive into the Act of 18 July 2001, the Water Act [36], changes the requirements imposed on planning documents. Carter [2] pointed out the fact that RBMP is not taking place in tandem with spatial plan preparation. In England municipal-level spatial plans follow an approximate 5-yer review cycle and were prepared in 2007 across the country. However, RBMP should be ready by 2009. Planners could not take into consideration the RBMP stipulations in their spatial plans at the local level. At present, documents connected with the Floods Directive also are needed, which have to be incorporated in all spatial planning documents in Poland. However, it needs to be remembered that the development of new planning documents, particularly at the national or regional level, typically takes several years. Five years passed from the decision on the initiation of the procedure to pass a new regional development plan in Wielkopolskie region [37] to its approval. The situation at the national planning level is even worse [38].

Existing planning documents at the local level concerning the Kania catchment to a limited degree take into consideration natural methods to increase water-retaining capacity. These include first of all afforestation and midfield tree and shrub plantings, as well as general erosion control or soil protection measures. In the case of engineering methods (small-scale retention reservoirs), planning documentations are prepared for a specific water investment, while they do not result from conscious long-term strategy for action.

The natural water-retaining capacity of the catchment is of key importance in the modification of water resources in agricultural catchments. Already in the case of 1-hour precipitation at a 5-day period with no precipitation and the probability of precipitation $p = 0.1$ the volume of infiltration in the Kania catchment in areas with the dominant slow component of runoff is 2.2 million m^3 and it is over 2.5 times higher than the volume of the planned small-scale retention reservoir in Gostyn and over 15 times in comparison to the total capacity of small-scale retention objects included in the small-scale retention program (11 weirs, 1 damming gate, 2 small retention village ponds) (Fig. 2).

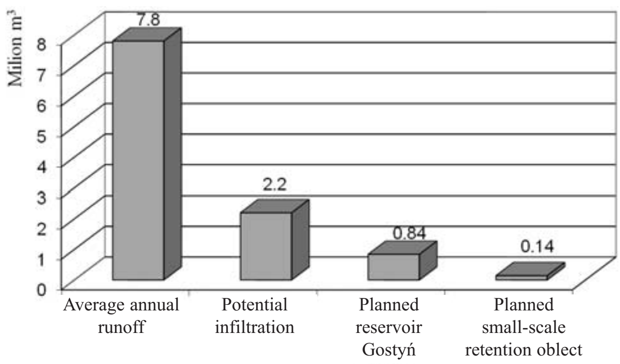

Fig. 2. Comparison of the potential effects of non-technical (the volume of infiltration in the Kania catchment in areas with the dominant slow component of runoff in the case of 1-hour precipitation at a 5-day period with no precipitation and the probability of precipitation $p = 0.1$) and technical (planned small-scale retention reservoir in Gostyń and small-scale retention objects included in the small-scale retention programme – weirs, small retention village ponds) measures and the average annual runoff from Kania catchment.

In areas with a predominant rapid runoff component the application of DSS FLEXT showed that the cultivation measures are not preferable. However, in those areas planning measures may be successfully used in combination with engineering methods, i.e. watercourse damming. The introduction of dual irrigation-drainage land reclamation is recommended. For environmental reasons, it would be optimal not to drain peat and bog soils and leave them in their natural condition, covering them with legal protection with possible extensive agricultural use. The establishment of a new form of nature protection (ecological area, protected landscape area) should be preceded by a comprehensive evaluation of the environmental value of these areas (identification of valuable habitats and species). Implementation of individual measurements, particularly buffer zones, midfield tree and shrub plantings, and afforestation, each time has to be preceded by an environmental analysis that takes into consideration the current condition of the environment and species composition of habitats preferred in a given area.

Conclusions

1. Decision support systems based on GIS technology are useful basic tools in modern spatial planning, facilitating the development of documents for the needs of decision-makers. The application of a decision support system FLEXT at a local level allows us to identify the agriculturally utilized areas where cultivation and planning measures should be preferred in order to improve water-retaining capacity of the river catchment. In the analyzed catchment may be the most widely used establishment of midfield boundary strips with perennial grasses and herbaceous plants related to the agricultural and environmental programs and introduction of midfield tree planting. Additional possibilities of using DSS is provided thanks to the implementation of

the INSPIRE Directive [39], specifying principles of access to spatial information for the realization of EU policies in terms of environmental protection and policies or actions potentially influencing the environment and use of WMS servers. Moreover, using land registries, data programs may be developed for the implementation of individual measures, specifically identifying the target group, for which special incentives and training materials may be prepared. An important role can be played by agricultural and environmental programs providing means for the implementation of methods preventing soil erosion and water pollution. Thanks to their efficient use, water-retaining capacity may be improved, and thus reduction of variation in flows in rivers, amplitude of fluctuations in ground waters, and losses resulting from the occurrence of extreme phenomena.

2. In agriculturally utilized areas, local spatial development plans are not prepared, except for the creation of local spatial development plans for the needs of afforestation or change if farmland and forested areas for other land use. In turn, a study on the conditions and directions of spatial development is not an act of local law and its stipulations are not biding for the inhabitants. Thus, it seems advisable to consider an elevation of the rank of spatial planning studies on conditions and directions of spatial management in order to provide a more effective creation of spatial policy in communes, in accordance with the principles of spatial order and sustainable development.
3. Analyses concerning improvement of natural water-retaining capacity of catchments should be performed at the stage of the ecophysiographic study (prior to the development of planning documents) and next taken into consideration in planning documents at the local level (local spatial development plan, study on conditions and directions of spatial management). For the purpose of improved planning of flood prevention, in accordance with the requirements of the Floods Directive, it is recommended to introduce into the set of spatial planning tools (at the stage of ecophysiographic study) also additional categories of land: areas contributing to an increased flood hazard – with dominant rapid runoff components, and areas contributing to a reduction of flood risk – with predominant slow runoff components.

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