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Original Research Article

RETENTION OF AFFORESTATION AREAS AS PART OF FLOOD PROTECTION - RESEARCH SITE AND METHODOLOGY FOR HEADWATER WATERSHAD IN POLAND

Tomasz ORCZYKOWSKI[1], Andrzej TIUKAŁO
Institute of Meteorology and Water Management, Wrocław, Poland

Abstract

Land use is considered as a non-structural, ecologically beneficial flood protection measure. Forest as one of the land use types has many useful applications which can be observed in detail on www.nwrm.eu website project. It is scientifically proved that afforestation influences flood events with high probability of occurrence. However, it is still to be argued how to measure land use impact on the hydrological response of watershed and how it should be measured in an efficient and quantifiable way. Having the tool for such an impact measurement, we can build efficient land management strategies. It is difficult to observe the impact of land use on flood events in the field.Therefore, one of the possible solutions is to observe this impact indirectly by means of hydrological rainfall-runoff models as a proxy for the reality. Such experiments were conducted in the past. Our study aims to work on the viability assessment, methodology and tools that allow to observe this impact with use of selected hydrological models and readily available data in Poland. Our first reaserch site is located within headwaters of the Kamienna river watershed. This watershed has been affected by ecological disaster, which resulted in loss of 65% of forest coverage. Our proposed methodology is to observe this transformation and its effect on the watershed response to heavy precipitation and therefore change in the flood risk.

Keywords: natural water retention measures, hydrological modelling, land use, flood protection.

[1] Corresponding author: Institute of Meteorology and Water Management - National Research Institute, Parkowa st 30, 51-616 Wrocław, Poland, email: tomasz.orczykowski@imgw.pl, tel. +48713200234

1. INTRODUCTION

Flood protection is a set of organized measures of an adaptive system as a response to identified flood risk. A catalogue of flood management measures involves tools from several disciplines. Afforestation, depending on the function, falls within few categories of this catalogue. Certainly, it is considered as a non-structural, environmental-friendly and overall ecologically beneficial measure. However, the positive environmental and ecological characteristic of forested areas is balanced out with an uncertain effectiveness of this solution in flood risk reduction. It is very difficult to measure this property directly in nature. In general, our studies aim to estimate afforestation impact related to flood protection in Poland. This paper explains the selection of tools and study site which are used to measure forest hydrological effect within headwater areas. The article describes topics in following order: core characteristics of flood risk, discussion concerning afforestation among other natural water retention measures as current approach in flood protection, research on watershad characteristics, definition of selected tools.

2. FLOOD RISK, EXPOSURE AND SENSITIVITY OF SOCIO-ECOLOGICAL SYSTEM

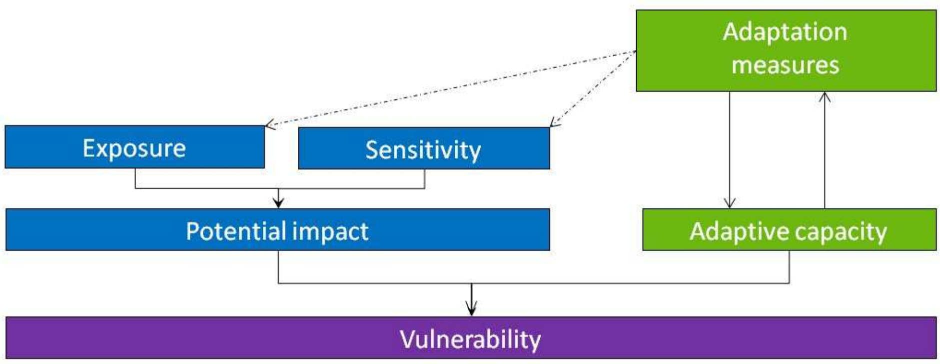

Fig. 1. Vulnerability of socio-ecological system to food risk adapted from [1] after [2]

The International Panel on Climate Change (IPPC) [3] statesthat *'Risk can be described as potential for consequences where something of value is at stake and where the outcome is uncertain, recognizing the diversity of values. Risk is often represented as probability of occurrence of hazardous events multiplied by the impacts if these events occur. Risk results from the interaction of vulnerability, exposure, and hazard'*. The above mentioned exposure, hazard and vulnerability are not strictly defined in literature. The definition depends on the source and the context [1] [3] [2]. Despite this heterogeneity in the terminology, we can assume safely that exposure to natural hazard of a socio-ecological system is one of the main factors that shapes flood risk. Figure 1 presents a schematic diagram of the vulnerability concept in the context of flood hazard. Explaining the diagram bottom up, vulnerability of socio-ecological systems is determined by a potential impact of flood and the system adaptive capacity to absorb this impact. The potential impact is a function of exposure and sensitivity of socio-ecological system elements exposed to flood hazard. The socio-ecological system is understood as being closely related to two components, environmental resources and human activities that are constantly interacting within one geographical space [4]. In this study, definitions of exposure and sensitivity are defined after few authors [2]. Exposure expresses a relation between socio-ecological elements and natural hazard. Sensitivity describes properties of objects exposed to flooding. For example, when a building is affected by flooding, it is exposed to a flowing water of certain depth and velocity, this is exposure. The sensitivity of this building depends on few factors. Provided it is an inhabited single floor house without a rescue plan, then the sensitivity is high. On the other hand, if it is an inhabited two storey house in which the first floor is not inhabited, the building is reinforced against flood hazard, a flood warning system is in place and people do have rescue plan prepared, its sensitivity is much lower. Another factor of the vulnerability depends on the system's adaptive capacity. This includes the ability to accommodate potential damages, to take advantage of opportunities, or to cope with the consequences [1] [5]. Within this context, vulnerability is closely related to resilience of the system. In our study, we investigate the land use as an adaptation measure arising from the system adaptive capacity. The land use, for example afforestation, may be used to mitigate the flood risk by adjusting the exposure of the system. The reduction of exposure by means of land use may take various forms depending on the situation. Simple land use transformation within flood risk area from the housing estate to less valuable property as woodland or green fields reduces the flood risk. Such a solution is a viable option for some areas in certain cases. However, taking into account present development situation, it is necessarily to act also other way around altering the watershed response to the heavy precipitation and therefore reduce the exposure of the system. It is not possible to eliminate flood hazard entirely because it is a natural component of the water cycle. Though, efficient land use management may maximize water retention capabilities of the watershed which may result to slower response and lower peak flows in the watershed after heavy rainfall. This would lead to lower water depth and velocities, smaller flood risk area and therefore to flood risk reduction.

3. EFFICIENT LAND USE SHOULD BE A PRIORITY IN FLOOD RISK REDUCTION, NATURAL WATER RETENTION MEASURES

The European Union (EU) has formulated a long-term strategy to adjust the policies for economically, socially and environmentally sustainable development, its goal is a sustainable improvement of the well-being and standard of living of current and future generations. One of 7 outlined challenges is a sustainable management of natural resources where value of ecosystem services should be recognized and natural resource uses improved in particular forest management [6]. Implementation of the EU environmental directives, especially Water Frame Directive (WFD) and Floods Directive (FD) evidently indicated the need for the guidance on the introduction of the natural water retention measures (NWRM) which are a good supporting tool for realization of EU sustainable development strategy. This resulted in EU policy document [7] which clearly points out multiplicity of environmental benefits from the use of NWRM but also the lack of measurement techniques for the effectiveness of NWRM projects. The European Commision has launched NWRM pilot project at www.nwrm.eu, where NWRM projects constructed through out the EU are listed. This is a valuable source of information on the types of NWRM. The flood risk management plans carried out in Poland, conducted in accordance with the Floods Directive; prefer non-technical, environmentally friendly flood risk reduction measures. For example by moving dikes or a complete dike removal and also by first attempts to increase afforestation for certain catchments. This approach is also conducive to the long-term sustainable development plans of a country promoted by the national policies [8]. It also should be considered as an ecosystem service that serves multiple products to a wider community. Use of those resources to accommodate some of the negative effects of flooding should be a priority from the sustainable development perspective. However, as previously stated, this poses a challenge, which has been only partially addressed so far, namely the need to quantify the effectiveness of land use and land cover related measures in the reduction of a flood risk.

4. CHARACTERISTICS OF RESEARCH WATERSHAD

Due to different mechanisms of water cycling related to the geographic region and topographical setting, forest may influence stream flow characteristics in a variety of manners. Here, we focus on forest in mountain catchment headwaterwhich is considered by NWRM catalogue as having high impact on the flood risk. Our research site is headwater of the Kamienna river located in the western part of the Sudetes Mountains.

Fig. 2. Study area

It is a small watershed of an area 5.7km^2 closed by a stream flow gauge accompanied by a precipitation gauge. Almost 85% of the study site is covered with forest. It is mainly monoculture of *Picea Abies*- a very common species occurring in Polish mountains. The site can be distinguished among other watersheds, as it lies within the region that in early 1980s was affected by ecological disaster which resulted in a loss of large forested areas. Kamienna river watershed, especially the upper parts, was affected by the event to a large extent. We estimate that 65% of the forested area was lost due to the cathastophe. An exact course of this calamity is under investigation. There are few independent sources of information (aerial photography, National Forest Services's records, reports). Stream flow and precipitation data was collected in an hourly time step. Data concerning the observations of stream flow are available for the period 1976 to the present. It shall be noted that the site is subjected to heavy and often precipitation events, as it is located on the western side of the Sudetes Mountains, which face air masses coming from the Atlantic Ocean.

5. HYDROLOGICAL RAINFALL-RUNOFF (RR) MODELS AS A MEASUREMENT TOOL FOR THE ACTUAL LAND USE IMPACT ON FLOOD EVENTS

The need for a detailed information on the actual land use impact on the flood events is obvious [9]. The contribution of certain land use measures to the hydrological processes are well recognized [10] [11], for example sealed areas, where water form mostly a surface runoff. However, the most intriguing and the least recognised are vegetated areas, which constitute for the largest percentage of land cover within most of Polish watersheds. Researchers have been able to prove that afforestation has an impact on river flows, however it is still an on-going debate on what the actually measurable impact on the flood events is [9]. Supporting evidence shows the impact of afforestation on floods with high probability of occurrence [12] [13]. The flood reduction effects on severe floods, from the scientific standpoint, are still unclear [14]. In the past, researchers conducted physical experiments on the afforestation impact using paired watershed experiments or experimental watersheds. Nowadays, technology points in the direction of mathematical modelling tools, namely hydrological rainfall-runoff models. Singular experiments similar to our studies were conducted in the past [15] but it should be noted that for a full understanding of hydrological cycles under Polish environmental conditions this research field must be further explored in detail.

Our research tries to establish suitable models and procedures for prediction of the land use and land cover effectiveness in the Polish environment. It should be recognized that each watershed has its own *'uniqueness of place'* [16], a kind of hydrological *genius loci*, therefore each watersheds should be assessed on a case by case basis in regards to specific tools and methodologies [17; 18].

Also hydrological rainfall-runoff models should be distinguished between easy to use engineering models and models for planning which are more complex but may fit better for research purposes [19].

6. GENERAL OVERVIEW ON HYDROLOGICAL MODELLING

The hydrological cycle is a system that is relatively easy to understand. Measurement and quantification of the processes within this system is far more complicated as the system is complex. For better understanding of these processes, we use hydrological models which help us to test our hydrological concepts and hypotesis. The data availability, advancement in technology and hydrological cycle complexity resulted in numerous hydrological models that have been proposed and developed around the world over the past decades. These models vary in structure from very simple empirical to very complex physical models. A certain view on the classification of the models is shown in the figure 2. However, it should be noted that classification of models is very flexible and varies depending on the context and the author [20].

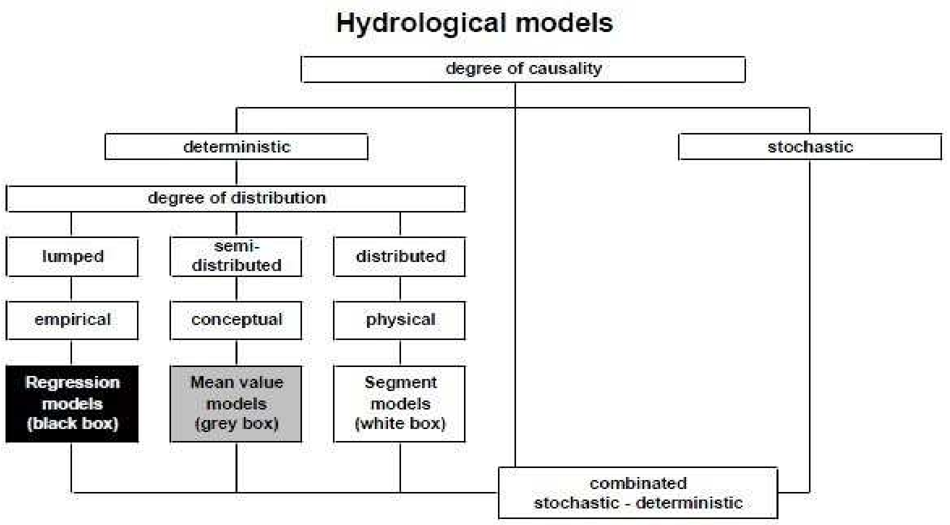

Fig. 3. Illustrative classification of hydrological models [21]

7. SELECTION CRITERIA FOR HYDROLOGICAL MODEL

There is no particular hydrological model that may be used as a dedicated, proven to work in all conditions tool for the land use impact on the flood events.

However, scientists have some evidence on accuracy and correctness of the basic assumption for certain models. Therefore, it has been decided to use a variety of models, more and less popular, to check their sensitivity to land use related inputs and parameters. The most important criteria for model selection in this research is the physicality of the model which means that equations and inputs are designed to correspond with the actual situation within the catchment. At present, researchers are investigating realism of certain hydrological models [22] [23], their experiences may be used to test our models and assumptions. The selection of available hydrological models is wide, therefore we formed several lose and mostly technical requirements that allowed us to narrow down the list. The criteria do not include detailed properties of the model as it is assumed that in course of the study the appropriate model for each study area shall be determined separately. Nevertheless, the criteria for an appropriate model are as follows:

- model is proven to be useful in previous experiments,
- model is well documented (concept of physical processes, used equations, programing code),
- model is based on the assumption that land use and land cover related parameters are a description of physical features and processes,
- inputs and parameters are possible to be obtained from reliable and available data sources,
- inputs and parameters are distributed in space (degree of the distribution may vary),
- model is flexible over time. The optimum is 1h time step to capture the relevant characteristics of the flood events.

Stated requirements arise from the fact that models should give quantifiable answer on the land use change impact in the context of availability of the data. Authors understand that, from the perspective of the present hydrology science, we are not able to obtain the exact and non-disputable results due to multiple constraints (uncertainty in data or logical assumptions and simplifications within the model). However, at this stage it is important for us to establish a certain sensitivity range to the land use and land cover related inputs and parameters.

8. SELECTED MODELS

At present the Institute of Meteorology and Water Management develops a modelling framework that is designed to comprise several hydrological models. The framework is called HYDROPATH [24]. The platform contains

TOPMODEL [25] and FLEX-Topo [26] model implementations. In the near future, the framework will be enhanced by a well researched and very recognizable HBV [27] model implementation which has been used in similar studies [15]. The assumptions used for these models put them on the top of the list of the selected models for this research. The above mentioned models are physically based and semi-distributed. Although, there is a clear logic behind these concepts and it seems to be adequate for the task, there is a general supposition that fully distributed models may capture more accurately the characteristics in question. Therefore, both LISFLOOD [28] and models from WFLOW (29) platform are considered as well. The list of chosen models for the research is still open and the selection in progress.

9. CONCLUSIONS

The Member States of the European Union promote an idea of sustainable development and implement it trough in all related policies and directives. Flood risk management plans, as a result of the Flood Directive, should also place a strong emphasis in this regard. Land use is considered as a non-structural, ecologically beneficial flood protection measure. Afforestation as one of the land use types, has many useful applications which can be observed in detail on NWRM website project. Land use may be applied to alter flood risk with exposure, sensitivity and vulnerability of the socio-ecological system. It has been proved in literature that afforestation influences flood events with high probability of occurrence. However, it is still to be argued how to measure land use impact on the hydrological response of the watershed and how it should be measured in an efficient and quantifiable way. Having the tool for such an impact measurement, we can build efficient land management strategies. Land use impact on the flood events is very difficult to be directly observed in reality. Therefore, one of the possible solutions is to observe this change indirectly with hydrological rainfall-runoff models as a proxy for the reality. Such experiments were conducted in the past. Our study aims to work on the viability assessment, methodology and tools that allow to observe this change with use of the selected hydrological models and readily available data in Poland. Our first research site is located in the Kamienna river headwater, which lost 65% of its forested area. We propose to observe changes in the stream flow characteristics relevant to flood risk with selected hydrological models.

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RETENCJA LEŚNA ZLEWNI JAKO ELEMENT OCHRONY PRZECIWPOWODZIOWEJ

S t r e s z c z e n i e

Użytkowanie terenu jest uważane za nietechniczny, przyjazny środowisku środek ochrony porzeciwopowdziowej. Tereny zalesione jako jeden z typów użytkowania terenu mają kilka zastosowań w ochronie przeciwpowodziowej. Poszczególnym sposobom jego wykorzystania można bliżej się przyjrzeć na stronie projektu Unii Eurpoejskiej, www.nwrm.eu. Jest dowiedzione naukowo, że zalesienie wpływa na hydrologiczną odpowiedź zlewni wywołaną opadem. Jednak nie zostało w pełni określone w jaki dokładnie sposób zalesienie wpływa na tą odpowiedź, a także w jaki sposób można mierzyć efektywność zmiany użytkowania terenu w ochronie przeciwpowodziowej. Pomiary tych charakterystyk w przyrodzie nie są łątwe do wykonania, dlatego autorzy proponują wykorzystanie hydrologicznych modeli opad-odpływ jako narzędzia pomiarowego. Takie podejście było już realizowane w przeszłości, w różnych regionach świata. Nasze badania mają na celu ocenę wykonalności oraz przydatności wyników, wybór odpowiednich modeli matematycznych oraz wypracowanie metody umożliwiającą kwantyfikację wpływu użytkowania terenu do ochrony przeciwpowodziowej za pomocą dostępnych w Polsce danych. Nasz obszar badawczy jest zlokalizowany w górnej części zlewni rzeki Kamiennej w Sudetach Zachodnich. Ta zlewnia została dotknięta klęską ekologiczną w latach 80-tych XX wieku, która skutkowała wymarciem 65% powierzchni lasu w badanym obszarze. W pracy proponujemy obserwację wpływu tej transformacji na hydrologiczną odpowiedź zlewni, a przez to na ryzyko powodziowe.

Słowa kluczowe: naturalna retencja, modelowanie hydrologiczne, użytkowanie terenu, ochrona przeciwpowodziowa

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