IOP Conf. Series: Materials Science and Engineering **245** (2017) 022030 doi:10.1088/1757-899X/245/2/022030

Integrated Water Hazards Engineering Based on Mapping, Nature-Based and Technical Solutions

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Abstract. Climate change is expected to alter average temperature and precipitation values and to increase the variability of precipitation events, which may lead to even more intense and frequent water hazards. Water hazards engineering is the branch of engineering concerned with the application of scientific and engineering principles for protection of human populations from the effects of water hazards; protection of environments, both local and global, from the potentially deleterious effects of water hazards; and improvement of environmental quality for mitigating the negative effects of water hazards. An integrated approach of water hazards engineering based on mapping, nature-based and technical solutions will constitute a feasible solution in the process of adapting to challenges generated by climate changes worldwide. This paper will debate this concept also providing some examples from several European countries.

1. Introduction

Worldwide, climate change is expected to alter average temperature and precipitation values and to increase the variability of precipitation events, which may lead to even more intense and frequent water hazards.

Water hazards may have enormous environmental, social and economic consequences and it is expected that climate change effects will exacerbate their occurrence and impacts in the future. The magnitude of threats attributable to water hazards and climate change and their territorial distribution is at present not fully known [1]. Moreover, the changes in the frequencies of extreme water hazards, such as floods and droughts, may be one of the most significant consequences of climate change [2, 3, 4, 5].

For different parts of the European territory, diverse impacts of climate change can be identified with different consequences on water hazards occurrence, intensity and frequency. While Northern Europe (Norway) should expect more frequent and intense extreme weather events leading to more variable crop yields, Central (Hungary) and Eastern (Romania) European Countries will face most likely extreme temperatures. More important is the problem of combined exposure to water hazards [6].

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An integrated water hazards management is a key aspect in identifying and implementing adaptation and mitigation policies as responses to climate change challenges. Once more, European territorial diversity indicates different levels of capacity to adapt to climate change, Northern European Countries being more prepared in comparison with Central and Eastern European Countries.

Integrated water hazards management is a comprehensive process that goes beyond traditional response to the impact of individual events and hazards. An adequate strategy is a multifaceted problem and will require breaking down the disciplinary borders between engineers, ecologists, agronomists, economists, hydrologists and climate scientist and the efficient and honest involvement of stakeholders.

2. Mapping tools for integrated water hazards management

Usually, water hazards risk maps are addressing only a single type of hazards. In most of the cases, water hazards maps are addressing floods [7, 8] but were also develop similar studies for droughts [9], heat waves [10, 11] as well as for other types of water related hazards.

Unfortunately, most of European territory is exposed to several categories of water hazards. In this case, multiple hazards maps will provide stakeholders an excellent tool to develop new development projects for water hazards effects mitigation or to incorporate water hazards reduction techniques in the existing developments.

Developing a reliable mapping tool for integrated water hazards management is a tricky issue since comparing hazards can prove to be very difficult due to the processes assumed by these hazards and their linked indicators and metrics. Another problematic aspect is represented by the interactions between different categories of water hazards which are leading to cascade effects and coupled dynamics [12]. A third aspect which must be taking into account is the frequency, severity and intensity of different water hazards which are affecting the considered area. An area which is prone to frequent drought and presents risks at temporal humidity excess will need to considered specific actions with focus on water conservation. On contrary, an area prone to frequent water excess will need to identify efficient nature-based solutions in order to mitigate the effects of a drought event.

Nevertheless, the efforts in Central and Eastern European countries have focused on mapping a single type of hazard. Eastern Hungary and Western Romania are frequently affected by temporary humidity excess in parallel with increasing temperatures and risk of aridity. Researchers have focused mainly on identifying solutions for managing water excess, in several cases with negative impact on environment.

For South-Eastern Hungary a complex excess water hazard map was realized using a series of indicators spatially represented by Soil (soil infiltration capacity based on Kreybig Map Series and Várallyay Maps), agro-geology (a complex index considering the depth and thickness of the uppermost aquitard), topography (relief intensity based on 1:25000 Digital Elevation Model, groundwater (the average of the ten highest groundwater levels within 50 years), land use (a numeric coefficient of land use based on CORINE Land Cover (CLC100) database and individually attributed to its categories), hydrometeorology (humidity index (10% possibility of occurrence of root square of sum of monthly weighted precipitation and sum of monthly weighted ETP ratio) [13].

In addition, it was compiled the map of relative frequency of excess water events for multiple regression analysis. Its source was the yearly mapping of the areas damaged by maximal inundation from 1951 to 2008. The serial maps were overlaid providing an independent estimation of the spatial distribution of the most risky areas, as well as the dependent variable of a multiple statistical analysis. Since both its spatial resolution and confidence was weaker than those of the above listed factors, generalized versions of the quantified spatial layers (as independent variables) were jointly analyzed with the relative frequency map in a grid with cell size of 1x1 km^2. Multiple regression analysis was used for the determination of the role of various factors in the formulation of excess water thus providing weights for its stochastic linear estimation by the applied factors. The values coming from the regression equation were multiplied by and added to a constant value which is resulted in the

Complex Excess Water Hazard Index and after that the Complex Excess Water Hazard Map (figure 1) [13].

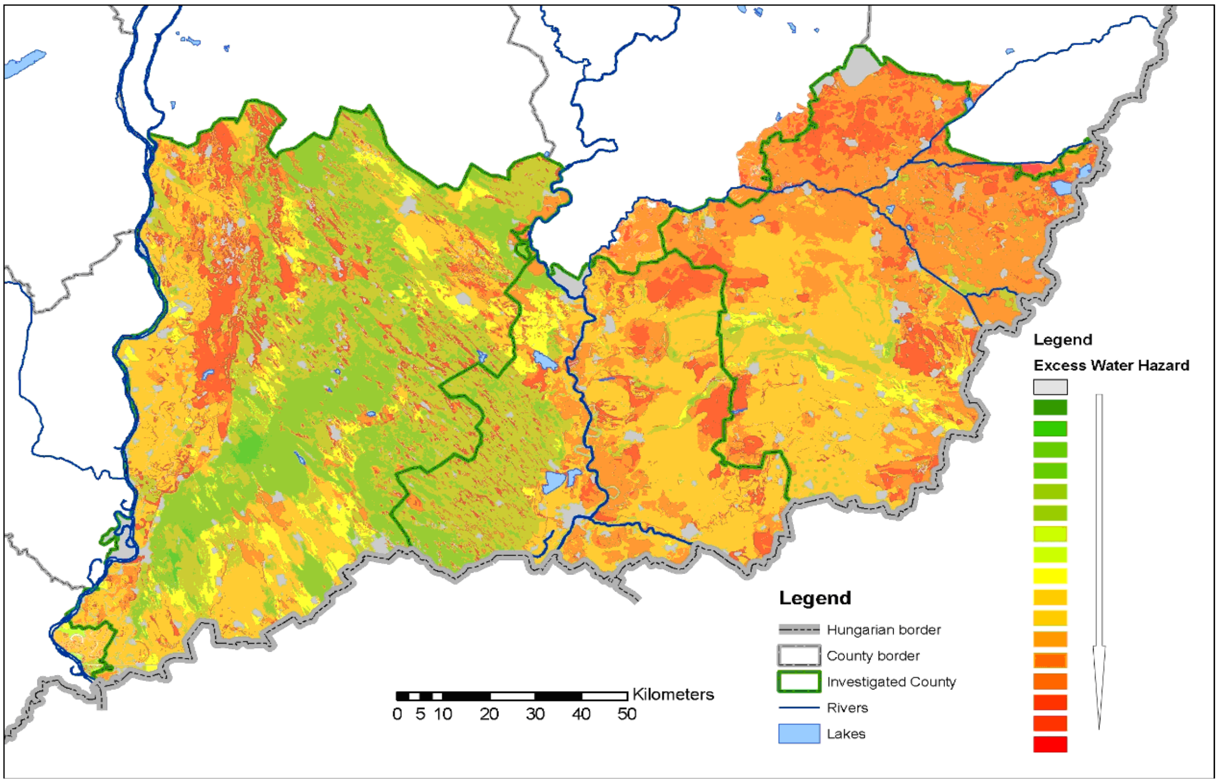

Figure 1. Complex Excess Water Hazard Map for Southern Hungary [13]

Western Romania is also frequently affected by water excess, this periods alternating with drought events of different intensities. The climate of the studied territory is characterized by great complexity and diversity of atmospheric phenomena that often give rise to periods of long lasting high rainfall. Rainfall has a predominant role in the formation and maintenance of excess moisture. The relief is a factor that determines, together with rainfall, flooding and water excess due to its diversity and distribution of natural units according to their average altitude. The phenomena of floods and the excess water occur mainly in low fields and meadows where, because of the plan relief and strong decrease of water flow, they accumulate in large quantities on the surface, flows and stagnate at soil surface. The management of water excess in this area is based on land drainage arrangements which were implemented since the second half of XX century.

Land drainage studies, performed in western Romania for several decades, resulted in land drainage solutions with focus on sub-surface drainage systems. Recently, in the frame of a national funded land drainage research project, it was issued a map where are presented all areas affected by water excess without presenting the intensity of this hazard and giving only some hints on hazard frequency (figure 2) [14].

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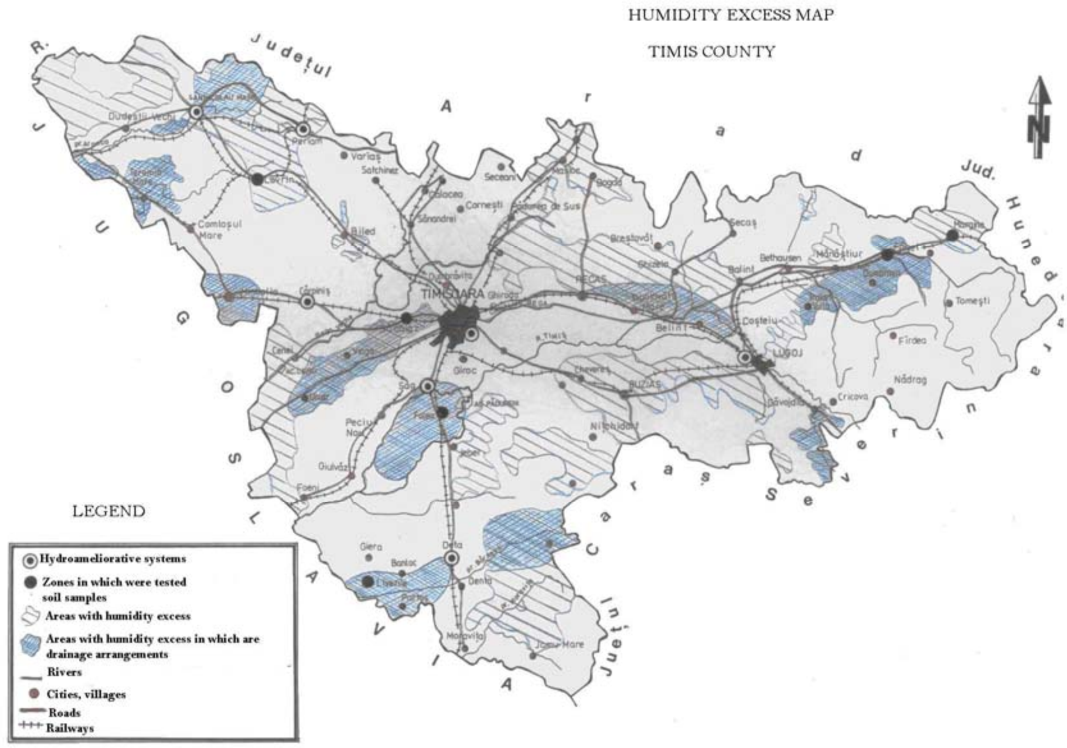

Figure 2. Humidity excess map for Timis County, western Romania [14]

3. Technical tools for integrated water hazards management

Many areas from Central and Eastern Europe are characterized by alternating periods of water shortage with those water excess. This situation may have a major negative impact on agricultural sector where soil water content is critical for crops development.

A technical solution for these cases is represented by implementing land reclamation and improvement systems, which in this case, according to the scientific terminology used in Romania, are based on sub-irrigation and reversible land drainage systems.

Using reversible land drainage and irrigation systems leads to a rational use of these works, ensuring a judicious management of water resources, reducing investment planning and saving electricity. Designing and implementing land drainage and sub-irrigation systems in the frame of reversible functioning of land drainage arrangements implies the application of the general concepts of hydraulic leakage of groundwater towards horizontal agricultural drains.

Dual-purpose land drainage – sub-irrigation systems are currently used on soils with poor drainage to reduce the stress generated by water excess on the exposed cultures. During wet periods this system operates as a drainage system. In this case, the excess water is removed from the field through a system of underground drainage tubes which are discharging in the main drainage tube, or an open channel. If at the channel output it is used a column to adjust the rate of drainage, then the drainage system can function as a sub-irrigation node or controlled drainage. A weir can be used in the control structure in order to make water rising above it before overflowing.

The process called controlled drainage occurs when the structure is used to conserve water by reducing the outer drainage flow and when no additional water is pumped. During dry periods, water can be pumped to the outlet control which is directed back into the drainage network, thus raising the water level in the field. In this way the system is used for sub-irrigation (figure 3).

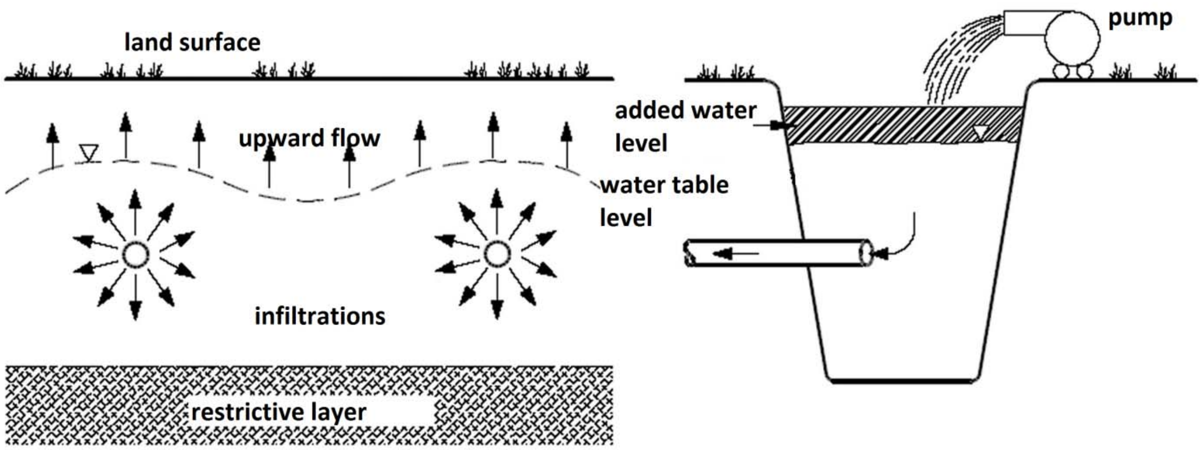

Figure 3. Land drainage system used for sub-irrigation

These systems with double purposes will fluctuate several times during a growing season between land drainage, controlled drainage and sub-irrigation. Because soil properties change frequently, these systems are requiring an intensive monitoring and management system for an efficient operation.

For reversible operation of these systems, the planning process begins with designing land drainage system followed by checking the possibility of using it for sub-irrigation. In order to achieve sub-irrigation, it must be possible the closure of drainage canals with dams to raise water levels in canals which will be the water suppliers for the soil profile through drains, aiming the increasing of soil moisture at the surface between the imposed limits by varying the groundwater level in the soil profile. The factors which must be taken into account in designing a reversible system are: the depth of the root crop tolerance to water pressure, the water retention capacity of the soil, hydraulic conductivity, and the layer location in the soil profile.

Establishing a correct level of water-table is perhaps the most difficult element to achieve in designing a reversible system. Based on the results obtained from field studies it is recommended using a design depth of water-table between 0.6 m for clay soils and 0.450 m for light soils. The plant takes up to 70% of water and nutrients in the first half of the total depth of its root. It is important that moisture provided by sub-irrigation to arrive in this area. The distances between drains should be calculated for land drainage operations before establishing the distance between drains for sub-irrigation.

The distance between drains should be determined by soil characteristics, drains depths, crops roots depths and plant tolerance to water pressure. The limiting factor is the time required to raise the water level in the root area to the desired level. Greater distances between drains means that the system will respond more slowly and thus will need more intensive management. The distance between the drains for effective sub-irrigation is strongly linked to soil hydraulic conductivity and can represents between 25% of the distance required for adequate drainage (in the case of soils with very good natural drainage) up to 200% in case of soils with very poor natural drainage. Several studies were performed for soils affected by humidity excess from western Romania using a variation of Hooghoudt formula for drainage design, in a modified form initially proposed by Fox in 1956 and corrected to actual form by Ernst in 1975. This method uses Dupuit-Forchheimer assumptions of horizontal flow, Skaggs demonstrating that it is adequate for flow modeling in the case of subirrigation [15, 16, 17].

Another approach was proposed by I. David in 1982 based on an improved equation of Ernst formula and which suppose the use of filtering material wrapped around drains for land drainage purposes in this sense being introduced an additional factor on head losses at water entrance in drains [18].

4. Nature-based solutions for integrated water hazards management

An integrated management of drought and flood events needs to be conducted towards ecological sustainability. According to Richter et al. “ecologically sustainable water management protects the ecological integrity of affected ecosystems while meeting intergenerational human needs for water and sustaining the full array of other products and services provided by natural freshwater ecosystems” [19].

After decades of neglect, the importance of protecting and improving ecosystems for reducing disaster risk started to receive attention in the recent years [20]. Nature-based solutions focus on working with nature and, in essence, aim at increasing the natural capital of the ecological systems, for example to reduce flood risk or increase land resilience to drought. To be successful, they must take into account the local socio-ecological systems, so that local communities, landowners and land managers are engaged in order to secure the thresholds of interventions that can effectively reduce the risks from water-based natural disasters [21].

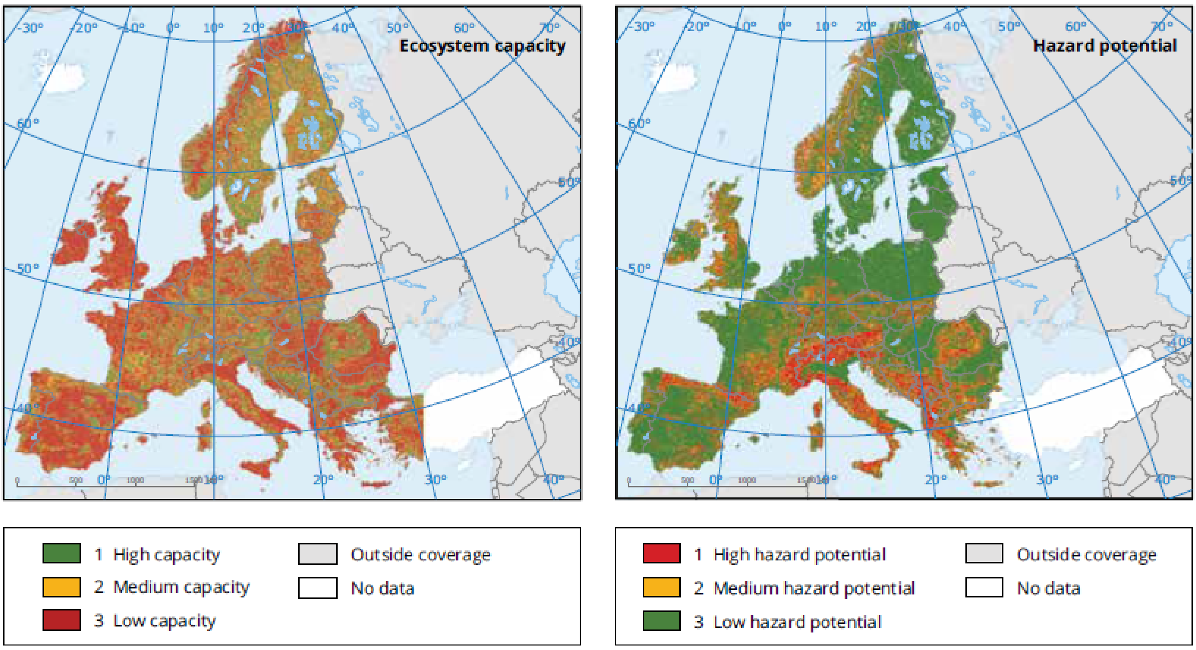

Figure 4. Ecosystem capacity and hazard potential mapped at European level [22]

The concept underpinning nature-based solutions builds on and complements other concepts such as ecosystem approach, ecosystem services, ecosystem-based adaptation/mitigation, and green and blue infrastructure. All of them recognize the fundamental importance of working with nature and using a systemic and holistic approach to environmental change based on an in-depth understanding of the structure and functioning of ecosystems, and the social and institutional context within which they are situated.

Large-scale areas of highest flood hazard can be found in the Danube catchment with its tributary streams, especially in parts of Hungary and Romania. The river networks from these countries are presenting gaps in natural protection against flood hazards. In these areas, both the main rivers (e.g. the Danube) and their tributaries show missing green infrastructure or at least potentially restorable green infrastructure networks.

Some tentative in establishing a nature-based solution for water hazards management were performed in southern Romania. Initially, this area was covered by acacia forests belts, which stabilized the soil and provided the necessary conditions for the formation and manifestation of a local a local wind, warm and wet, which used to bring the necessary rain. These forests were the perfect tool to maintain a balance between water deficit and water excess situations. Unfortunately, two decisions of Romanian Government (273 and 385 from 1962) created to legislative path for clearing the protection belts. The sand dunes from Southern Romania which were previously stabilized became mobile leading to imbalances in local environment. This situation alerted the authorities who permitted a new stage of forest plantations covering around 1600 ha [23].

Some other studies focused on the importance of wetlands in the integrated management of water hazards [24]. Wetlands are among the world's most productive environments and the ecosystem services that they provide include flood and storm surge protection, groundwater recharge, and drought mitigation thus being critical to maintain the ecological character of wetlands to help mitigate and adapt to these impacts.

In western Romania (Timis County) there are several wetlands surrounded by land reclamation and improvement arrangements (figure 5). Using the open surface channels as the elements of a perfusion system, these wetlands can accumulate the drained water from rainy periods, avoiding also the eutrophication of river bodies and providing a useful microclimate for surrounding areas. However, fewer efforts were performed in this direction, mainly due to lack of understanding the ecosystem services provided by wetlands and minimal financial resources [25].

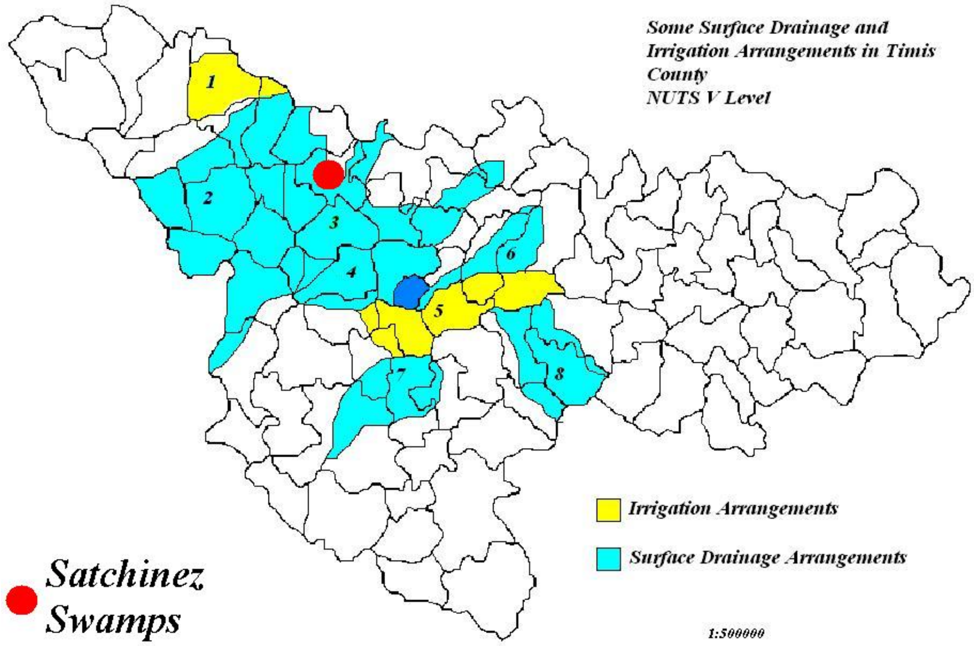

Figure 5. Position of Satchinez Swamps on the map with Timiş County's surface drainage arrangements [25]

5. Results and discussions

At the end of twentieth century as well as the beginning of twenty-first century numerous projects dedicated to research concerning floods management and water scarcity (drought) management have been carried out but were conducted so far in divergent directions without a clear effort towards the development of a concept which integrates elements of green, blue and grey infrastructure.

A balance between structural and non-structural measures to manage floods is required, where the main focus is shifting from large structural solutions to non-structural approaches, thus risk reduction through spatial planning has to be strengthened.

The frequent occurrence of extreme anomalies in natural water supply is a great problem for Central and Eastern European countries requiring effective solutions. An important step towards achieving this aim is the detailed and reasonably accurate mapping of the influential environmental factors of water hazards. The resulted risk maps can be therefore used in numerous land related activities: land use and agricultural planning, water management interventions, water oriented cultivation systems, wetland restoration etc.

Water management interventions can be based on structural (technical) solutions as well as on nature-based solutions. In Central and Eastern Europe there is a wide scientific literature on technical interventions like land drainage and irrigation. In the last decades the focus was on developing more efficient land reclamation and improvement arrangements with the main aim of implementing a judicious use of water resources together with a more attention to environmental factors. Before 1990, especially in former communist countries, the conflicts between practicing an intensive agriculture and the preservation on natural reservations were numerous. However, the XXI century is more dedicated to a harmonized relation between socio-economical needs and the care for nature. Thus, countries like Romania and Hungary implemented the EU legislation for wetlands protection, wetlands which are playing a key role in the integrated management of water hazards by providing important ecosystem services.

6. Conclusions

Integrated water hazards management in not easy to be achieved in a world challenged by climate change effects and with increasing needs for food, energy and preserving basic natural resources. Practical and sustainable solutions exist but they need to be approached in a responsible manner, involving a wide range of stakeholders, bringing together various scientists and integrating elements of grey, blue, green and hybrid infrastructure.

Acknowledgment(s)

The paper resulted from the bilateral project BIL10/23.11.2016, “Adapting to Climate Changes – Solutions for South East Europe (ADAPT-SEE)”, project carried out by “Research within Priority Sectors” program RO14 financed by EEA Grants.

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