Application of the DPSIR Framework for the Assessment of Water Resources in Zadar County, Croatia

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Abstract

Water resources in Croatia, particularly in coastal regions like Zadar County, face significant challenges due to both natural and human-induced factors. The impacts of climate change, along with rapid tourism development, pose threats not only to freshwater systems such as rivers and aquifers but also to the quality of coastal waters. Sustainable water resource management requires balancing ecological, social, and economic needs, while also ensuring these needs can be met in the future. Therefore, it is essential to quantify and assess the current state of water resources, identify potential impacts, and understand how these may evolve over time. The DPSIR (Driving forces, Pressures, State, Impacts, and Responses) framework offers a comprehensive approach for assessing and managing environmental issues, particularly in the context of water resources. It helps identify the links between potential sources of environmental problems and their consequences. In this paper, the DPSIR methodology is applied to Zadar County, Croatia—a region facing potential water-related and environmental challenges. The analysis covers the driving forces influencing water resources, the pressures on water quality and availability, the current state of various water bodies, and the resulting ecological and socio-economic impacts, as well as the responses from different stakeholders. Population growth and tourism development have been identified as the main driving forces, while increased water consumption and wastewater discharge are the primary pressures. Although the current state of water bodies is generally satisfactory, it is subject to change, which could lead to ecological, social, and economic consequences. This paper explores the complex relationship between human activities and water resource management, providing a foundation for more sustainable water management policies in the region.

Keywords: DPSIR, water resources, Zadar County, Croatia, environmental management, water quality, sustainable development

1. Introduction

Water resources in Croatia, particularly in coastal regions like Zadar County, face significant challenges due to both natural and anthropogenic factors. Zadar County, located on the Adriatic coast, includes a variety of freshwater systems such as rivers, lakes, and aquifers. With a growing population, expanding tourism, and agricultural demands, the pressure on these water resources has intensified (Brkić et al., 2017; Knežević et al., 2019). The DPSIR (Driving forces, Pressures, State, Impacts, and Responses) methodology offers an effective tool for understanding and addressing these challenges (Smeets & Weterings, 1999). The DPSIR model helps to structure the analysis of complex environmental systems by categorizing the causes and consequences of environmental degradation and the corresponding responses.

Driving forces considering water resources can include population growth, economic development, agricultural expansion, and tourism (Zupančič et al., 2020). Pressures are usually related to direct human activities that place stress on the environment, such as industrial discharges, wastewater from urban settlements, agricultural runoff, and over-extraction of water (Voulvoulis et al., 2017). Furthermore, State refers to the condition of the environment, specifically the quality and quantity of water resources. It is determined by various indicators such as water levels, pollution levels, and biodiversity of aquatic ecosystems (Ariño et al., 2018). Impacts may involve reduced water availability, degradation of aquatic ecosystems, and health risks to human populations (Vörösmarty et al., 2010), causing environmental, social, and economic consequences. Finally, responses are the actions taken to address the issues identified in the previous components, including legislative measures, technological innovations, public awareness campaigns, and the development of water management strategies (EU Water Framework Directive, 2000).

The DPSIR methodology can be effectively applied in regional water management planning, enabling a systematic analysis and the development of strategies for sustainable water resource management. The application of this methodology allows for an efficient assessment of the state of water resources, which represents a key step in the preparation, selection, and implementation of appropriate measures necessary to achieve sustainability. The use of the DPSIR methodology covers a broad range of applications, particularly in the context of sustainable planning and water resource management. Mejjad et al. (2021) applied the DPSIR framework to analyze groundwater pollution threats from a landfill site in Morocco. In combination with a SWOT analysis, they assessed the impact of waste on water resources and proposed strategies for landfill rehabilitation. Furthermore, Kagalou et al. (2014) combined the DPSIR framework with GIS technology to analyze groundwater quality, resulting in the identification of key pollution indicators linked to anthropogenic activities such as agriculture and industry, and proposed measures for sustainable water resource management.

Bidone and Lacerda (2004) examined sustainability in the coastal area of Guanabara Bay in Brazil, where they used the DPSIR methodology to analyze the causes and consequences of pollution and proposed appropriate measures to improve water management in the area. Gari et al. (2018) investigated water quality issues within the Alto and Medio Dagua community in Colombia, identifying agriculture, mining, logging, and infrastructure development as the main drivers, while pressures included the input of organic matter, sediments, nutrients, and chemical contaminants into water resources.

Zadar County in Croatia is a region facing potential water-related and environmental challenges due to rapid urbanization and tourism

grow. The goal of this paper is to assess the current state of water resources in Zadar County, identify potential impacts, and understand how these impacts may evolve over time and influence the sustainability of water resources. By focusing on the water quality and availability issues, this paper explores the interrelationships between human activities, environmental pressures influencing water resources, and the responses from different stakeholders.

2. Methodology: The DPSIR Framework

The DPSIR (Driving forces, Pressures, State, Impacts, and Responses) framework offers a comprehensive approach for assessing and managing environmental issues, particularly in the context of water resources (according to the European Commission 2012). The DPSIR methodology provides a structured approach for analyzing environmental issues through five interlinked components (EEA, 2005):

- Driving Forces (D): These are the fundamental societal factors that influence the environment. In the case of water resources, driving forces include population growth, economic development, agricultural expansion, and tourism (Zupančič et al., 2020).
- Pressures (P): These are the direct human activities that place stress on the environment. For water resources, pressures can include industrial discharges, wastewater from urban settlements, agricultural runoff, and over-extraction of water (Voulvoulis et al., 2017).
- State (S): This refers to the condition of the environment, specifically the quality and quantity of water resources. The state is determined by various indicators such as water levels, pollution levels, and biodiversity of aquatic ecosystems (Ariño et al., 2018).
- Impacts (I): These are the ecological, social, and economic consequences of the changes in the state of the environment. For water resources, impacts may involve reduced water availability, degradation of aquatic ecosystems, and health risks to human populations (Vörösmarty et al., 2010).
- Responses (R): Responses are the actions taken to address the issues identified in the previous components. This includes legislative measures, technological innovations, public awareness campaigns, and the development of water management strategies (EU Water Framework Directive, 2000).

3. Application of DPSIR Framework in Zadar County

Zadar County is located on the Adriatic Coast in Croatia, covering area of approximately 194 km². Zadar County has around 160.000 inhabitants, with capital City of Zadar nearly 70.000. Every year more than 2 million tourists visit Zadar County, spending more than 15 million days in total. Economic activities of Zadar County are dominantly related to tourism, with some agriculture and fisheries. Most of the population as well as tourists are located on the coastal area. This part of Zadar County is characterized by strong urbanization and lack of modern infrastructure for water utilization and protection. Some islands in Zadar County still rely on local groundwater extraction and rainwater harvesting for water supply. Furthermore, in many parts of Zadar County sewage systems for collection and treatment of wastewater are still missing and untreated wastewater is discharged directly into sea or ground.

Considering the interior of the Zadar County, it is mostly sparsely populated. However, the main watercourse, river Zrmanja is located in the inner part of the Zadar County with average annual discharge of 40 m³/s in the downstream part. Main sources for water supply of Zadar County are related to river Zrmanja catchment area, where springs Čavlinovac, Dorinovac i Sekulića vrelo are used for water collection. Furthermore, catchment area Bokanjac-Poličnik is also used for water extraction from deep wells Bunar 4 and 5, Jezerce, Boljkovac, and spring Golubinka. In addition, some smaller springs are also used for local water supply requirements.

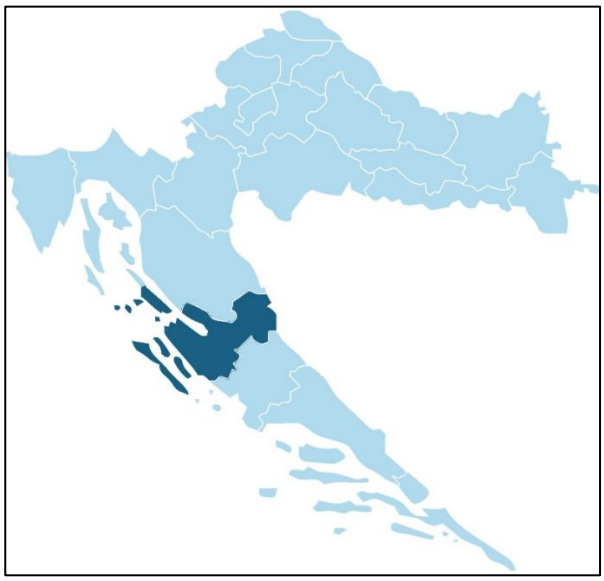

Fig. 1. Location of Zadar County in Croatia

3.1 Driving Forces in Zadar County

Considering the main driving forces influencing water resources in Zadar County, they can be categorized differently due to natural and anthropogenic factors. Major driving force in the Zadar County is the population growth and rapid urbanization. Zadar County, with its extensive tourism industry, is experiencing rapid population growth especially during summer months. Seasonal influxes of tourists place additional demand on water resources, especially during the summer months when water consumption peaks (Lukić et al., 2020). Zadar is a popular tourist destination, attracting millions of visitors annually. Tourism increases water consumption for residential,

recreational, and hotel purposes, while also generating wastewater and contributing to environmental degradation (Jovanović et al., 2019).

Agricultural activities, especially around Vransko lake are also one of driving forces due to use of fertilizers and pesticides, along with irrigation practices, contribute to the depletion and pollution of water resources (Pavić et al., 2015). Finally, climate change impact is also one of the driving forces on water resources of Zadar County due to changes in precipitation patterns and rising temperatures, leading to droughts, reduced river flow, and declining groundwater levels (Grizelj et al., 2020). These driving forces are responsible for changes in hydrological cycle and consequently in groundwater and surface water availability. Also, reduced flow coming from rivers is causing increase in sea salinity, changing the conditions for different species living in coastal areas.

3.2. Pressures on Water Resources

The pressures on water resources in Zadar County are primarily driven by human activities. Increased demand for water supply, especially during summer months is causing pressures on water sources, providing uncertainty in near and far future considering the reliability of existing sources for water supply. Generally, over-extraction from aquifers and rivers can lead to the depletion of freshwater supplies and saltwater intrusion, especially in coastal areas (Marčić et al., 2018). Wastewater discharge in urban areas and tourist facilities where there is no adequate wastewater treatment, leads to contamination of water resources with pathogens and chemicals (Hrvatske vode, 2014) due to discharge untreated or inadequately treated wastewater into the coastal waters as well as freshwater bodies through the ground in the inner part of the Zadar County. Furthermore, use of fertilizers and pesticides in agriculture is causing pollution *(Borojević et al., 2017)* due to surface runoff into rivers and coastal waters as well as infiltration into groundwater aquifers. This can cause eutrophication, which can degrade water quality and harm aquatic life (Ćurlin et al., 2015). Finally, expansion of urban areas and infrastructure developments put pressure on natural water catchments due to land use change, altering the hydrological cycle and increasing surface runoff, which leads to flooding and water quality degradation (Petrović et al., 2017).

3.3. State of Water Resources in Zadar County

Water quality in Zadar's rivers and coastal waters is often affected by nutrient overloads, resulting in algae blooms and the degradation of aquatic habitats. High concentrations of nitrates and phosphates are commonly detected, particularly in areas with intensive agricultural activity (Bojanović et al., 2019). Furthermore, main water sources for water supply in groundwater aquifers of Zadar County are experiencing saltwater intrusion, altering the impact of sea level rise in the future. In addition, some water sources are exposed to high turbidity after heavy rainfall and storms. Considering water availability, groundwater levels are generally declining due to over-extraction. This can cause significant threats in the future to sustainability of local water supplies (Santarina et al., 2018). Considering Zadar County, seasonal droughts have become more frequent, exacerbating water scarcity during the summer months. In contrast, intense rainfall events cause flooding, highlighting the vulnerability of water infrastructure (Kovačić et al., 2020). In 2017., Zadar County has been exposed to catastrophic flood, causing damage more than 150 million € in a single flooding event.

3.4. Impacts of Water Resources

The impacts on water resources in Zadar County can be analyzed through ecological, social, and economic consequences. Ecological impacts can be quantified due to reduced water availability and poor water quality threaten biodiversity in aquatic ecosystems. Species such as freshwater fish and aquatic plants face habitat loss and declines in biodiversity are further detailed by Lazić et al. (2014), while coastal ecosystems experience shifts in species composition due to altered salinity levels and eutrophication (Sović et al., 2017). Potential degradation of water resources in terms of water quality and reduced availiabity can affect tourism activities, a vital sector for the region's economy. Poor water quality and reduced water availability may deter tourists, particularly during the summer season. Additionally, agricultural productivity is impacted by water scarcity and pollution (Pavić et al., 2016). Finally, presence of harmful chemicals and pathogens in untreated wastewater poses a risk to both local populations and tourists (HZJZ, 2020), especially when contaminated water is being released uncontrollably.

3.5. Responses to Water Resource Challenges

Finally, in response to the challenges facing water resources in Zadar County, several measures can be undertaken. At first, water management policies are being developed at the European and national level. Water Framework Directive aims at protecting and improving water quality, with its primary goal is to achieve "good status" for all of Europe's surface and groundwater bodies by addressing pollution, promoting sustainable water use, and ensuring sufficient water resources for both human needs and the environment. Secondly, Republic of Croatia is developing and updating periodically national Water Management Plan (2021-2027), where state of each water body is analyses through regular monitoring activities, and measures for achieving good status of each water body are presented.

Activities which could be done in the future include developing a more regional-oriented water management plan, which will take into consideration specific regional needs and characteristics including a detailed set of measures for local climate change adaptation and more efficient urban planning. Also, activities in the future could include promotion of more sustainable agriculture though more efficient irrigation systems, and also raising public awareness and education through campaigns that promote responsible water use and the importance of water conservation especially in the parts of the Zadar County where water resources are scarce. Finally, technological upgrade and implementation of technological innovations could be one of the main factors in achieving sustainable water resources management in Zadar County. This is related to infrastructural upgrade of sewage networks and wastewater treatment facilities. Also, it is related to implementing solutions for reduction water losses in water supply systems and building water desalinization systems where necessary. Finally, development and implementation of green solutions in urban areas could significantly reduce flood risks in the future.

4. Conclusions

The DPSIR framework provides a valuable tool for understanding and addressing the complex issues surrounding water resources in Zadar County, Croatia. By analyzing the driving forces, pressures, state, impacts, and responses, this study highlights the interconnectedness of human activities and environmental health. The challenges posed by increase of water demand, pollution, and climate change require integrated management strategies that consider both ecological sustainability and socio-economic development this aligns with findings by Vörösmarty et al. (2010), emphasizing the global threat to water security and biodiversity.

The application of DPSIR offers a comprehensive approach to water resource management in the region and can guide future policies aimed at ensuring the long-term sustainability of water resources in Zadar County.

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