A Decision Support Matrix for Water Quality Based Stormwater Management

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Abstract
Extreme weather events and climate change are stressing urban stormwater systems beyond their capacity, posing potential threat to both the built and natural environments. This paper aims to contribute to risk mitigation through evaluating the feasibility of using a decision support matrix for developing an e-monitoring system for stormwater quantity and quality.
The decision support matrix used in the design of the e-monitoring system was created using data from previous water quality research and it assumes that water quality is influenced by the characteristics of the watershed. This premise was put to the test during an investigation of water quality across the catchment of the pilot site in Viimsi Parish, Estonia.
The comparison of the developed matrix and the sampling results revealed that the assumed relationships do not hold on a small catchment and that there is a need for further validation of relationships between surrogate and traditional water quality parameters.

Keywords: stormwater, water quality, case study, e-monitoring

1. Introduction

Climate change and extreme weather, combined with the progression of urbanization, are widely acknowledged to be linked to the deterioration of urban water quality. The inclusion of stormwater issues in various strategic documents developed by the United Nations, European Union, and many national governments attests to the problem's importance. [1-2].

With the advancement of urbanization, previously natural environments have been transformed into artificial surroundings, which often lack greenery and biodiversity. This process of urban expansion and environmental degradation is expected to continue in the coming years, with the UN estimating that by 2050, approximately 68 percent of the global population will live in urban areas. In Europe, this portion may reach up to – 80% [3, 4].

The intensification of environmental pollution is caused by the transformation of precipitation retaining areas, where groundwater recharge, evaporation and evapotranspiration occur, to conductive areas, where surface flow (discharge) dominates. These changes are best characterized through the increased peak runoff [5].

Changes in flow dynamics result in pollutants entering streams at a faster rate causing environmental degradation. For remediation of urban streams, it is necessary to identify the most frequently occurring pollutants and their sources, as well as impose the plan for their management at the source [6].

The aim of this paper is to assess the feasibility of using a decision support matrix to design infrastructure for stormwater quality and quantity monitoring and control. Implementation of this matrix is expected to lower the costs associated to preliminary investigation by narrowing the scope of the problem and leading to site-specific stormwater monitoring and treatment options.

Implementing continuous water quality monitoring solutions based on this matrix may in the future allow to respond quickly to unexpected increases in pollution load, thereby protecting the urban water bodies.

2. Study site description

The study site is located in Viimsi Parish, Estonia, where the annual average precipitation is 700 mm [7]. The site's watershed is approximately 272 ha, and the stormwater system is connected to the Baltic Sea via a network of pipes, culverts, and trenches.

There is currently only one outlet for runoff discharge, and it is quarterly monitored for oil (>5 mg/l) and TSS (> 40 mg/l).

Although the municipality is using some nature-based technologies such as ponds and trenches as well as engineering-based technologies such as oil- and sand traps to manage stormwater, the system is not designed to control runoff quality and quantity. The initial system's goal was to discharge runoff as soon as possible in order to protect the urban environment.

Lately, however, there has been a push towards improving the existing stormwater systems, through the development of a network of sensors coupled with regulating weirs and valves. A key aspect for the urgency of developing such a system is the proximity of the stormwater outfall to the public beach, which may encompass severe public health risks. These risks may be minimized by limiting the outflow of hazardous substances such as heavy metals and oil, pathogens, and eutrophication causing nutrients, such as phosphorus and nitrogen.

It is expected that without intervention into the current state of stormwater management, the continuous urban sprawl and increase in traffic will lead to an increase in pollution and potential hazard to the environment. These fears are mirrored in the reports, which cover the expected population and traffic increase in the area [8, 9].

3. Methods

The decision support matrix based development of e-monitoring system for stormwater quality and quantity was tested in Viimsi Parish, Estonia (Figure 1.). The approach for the pilot site investigations is a combination of data visualization with ArcMap and the use of a decision-support matrix to determine the most common groups of pollutants per land use. The matrix can also be used to investigate the associations between contaminants and key surrogate parameters that can be used for e-monitoring. The types of contaminants, their effect on water quality, and the methods of detection described in the matrix are based on previous studies [10].

The use of the decision-support matrix enables to take the first step towards the development of a new, integrated urban stormwater management infrastructure in Viimsi. A system which utilizes a network of sensors and smart weirs/valves for real-time control and has the potential to control stormwater discharge based on both water quality and quantity.

4. Results and Discussion

The pilot site was divided into five sub-catchments (Figure 1) in order to assess the individual contributions of the sub-catchments as well as the total pollution and hydraulic load discharged into the Baltic Sea. All of these sub-catchments differ in terms of physical characteristics such as land use, topography, and type of stormwater infrastructure implemented. It was expected that the dominant pollutant types also differ.

Figure 1 Viimsi sub-catchments

The aforementioned sub-catchments can be classified into three types based on land use: 1) green spaces 2) grey areas 3) mix of green and grey areas (mixed). The likelihood of certain pollutants occurring in the environment is determined on the basis of the type of land-use (Figure 1) using the decision-support matrix presented in Figure 2.

Table 1 Composition of sub-catchments

Sub-catchment	1	2	3	4	5
Impervious (ha)	28	21	10	10	9
Pervious (ha)	57	23	5	2	3

The following paragraphs describe the solutions for designing e-monitoring within the individual sub-catchments.

Sub-catchment 1

The first monitoring site in Viimsi is in a park, and the stormwater system consists of subsurface drainage pipes, ponds, ditches, and culverts.

This sub-catchment is predominantly green (pervious surface), which allows to retain and infiltrate stormwater. Such areas often prevent the entrance of toxic contaminants such as heavy metals and oil into the water bodies by retaining them within the soil structure. Nevertheless, these pollutants may be released back into environment during periods of prolonged or intensive rainfalls [11, 12]. The occurring runoff may also be a carrier of organic matter and nutrients rich sediments, which may contribute towards the eutrophication in the receiving waterbody.

If nature-based technology is used, some of pollutants within stormwater runoff are treated/removed over time, either through microbiological activity, plant uptake, or sedimentation. However, monitoring the efficiency of such systems with grab sampling is difficult – thus, the use of e-monitoring via surrogate parameters could aid in closing this gap of knowledge.

In order to gain insight into the dynamic relationships between the key pollutants and green areas (Figure 2), grab sampling must be combined with e-monitoring of at least the following parameters:

- TSS / Turbidity
- Conductivity / TDS
- Temperature
- Water level / Flow rate
- pH

Sub-catchment 3, 4, 5

These sub-catchments are located in areas with little greenery, in the proximity of a variety of shops, hotels, and sporting venues and other facilities, as well as one of Viimsi's main transportation arteries. Stormwater is primarily managed at the sites through a network of interconnected pipes that collect and transport runoff to the outfall.

The main types of pollutants coming from areas where grey infrastructure dominates are inorganic pollutants, which include heavy metals, oil, suspended solids, microplastics, and rubber. Because a large portion of these pollutants are transported to the aquatic environment as sediment, it is critical to monitor and limit the transportation of sediments by stormwater [13]. A comprehensive understanding of the monitored parameters can be attained only by combining regular grab and automatic sampling with e-monitoring systems.

The following parameters may serve as useful proxies for assessing water quality in Sub-catchment 3, 4, 5:

- Water level / flow rate
- Conductivity
- Turbidity / TSS
- pH
- Temperature

Assumptions based on data analysis should be made with caution because the results are prone to large uncertainty and variability.

Sub-catchment 2

This sub-catchment may be characterized as mixed type, meaning that the occurring runoff may carry both inorganic and organic constituents. The overall composition of water depends on various parameters, such as rainfall duration, rainfall intensity, frequency of street sweeping, gardening activities, wind speed/direction, and so on.

The sources of the pollutants are as aforementioned in the cases of green and grey areas. The detection and control of pollutants in mixed areas is complicated and requires further research. A helpful forward-looking approach for monitoring mixed areas is to use of a mix of e-monitoring and grab sampling for making meaningful conclusions about the correlation of contaminants of interest.

The following parameters may serve as useful proxies for assessing water quality in Sub-catchment 2:

- Water level / flow rate
- Turbidity / TSS
- Conductivity
- pH
- Temperature

Investigation of stormwater quality

Since there has been no long-term monitoring of stormwater quality in Viimsi, the composition of water quality within the sub-catchments was analyzed in addition to the quarterly monitoring by the municipality.

Temperature, TDS, pH, NO3, conductivity (EC), and flow rate were measured. The observations were collected over the course of seven sampling sessions between October and December. The results are presented in Tables 2 and 3.

Table 2 Measured water quality (average)

Nr.	**1**	**2**	**3**	**4**	**5**	**6**	**7**
℃	6,2	6,2	6,3	5	5,5	5,5	7,8
TDS	626	607	597	553	557	552	566
pH	8,2	8,1	8	8,1	7,8	8,2	8,1
NO_3	10,8	9,3	8,6	7,8	6,4	9,3	11,8
EC	603	581	581	521	571	532	571
Q (l/s)	N/A	N/A	N/A	N/A	0,5	N/A	0,75

Table 3 Measured water quality (max)

Nr.	**1**	**2**	**3**	**4**	**5**	**6**	**7**
℃	9,9	10	9,2	9	9,1	9,4	11,8
TDS	800	671	765	680	620	582	637
pH	8,2	8,3	8,2	8,5	8,0	8,4	8,2
NO_3	17,2	18,4	17,2	14,7	12,1	20,3	30
EC	730	686	663	600	620	603	673
Q (l/s)	N/A	N/A	N/A	N/A	0,5	N/A	0,75

The comparison of values in Tables 1 and 2 indicates that there is very little difference in stormwater consistency from sub-catchment to sub-catchment (aside from nitrates). This contradicts to the assumptions upon which the decision support matrix was built upon (Figure 2).

Because there is no discernible difference in the composition of water samples collected at the various sub-catchments, it is possible to hypothesize that the lack of change in the water composition is due to the proximity and limited scale of the sub-catchments.

5. Conclusion

The purpose of this study was to test the hypothesis that it is possible to create a matrix from previous stormwater quality analysis and apply it to the design of an e-monitoring system.

It was assumed that areas with varying land use would have a relatively high variation in the constituents within the runoff, but this was not the case based on the measurements taken in the scope of this study. The three types of areas – green, grey, and mixed – all had similar water quality, which was unexpected. This could be attributed to the area's small size and the proximity of the investigated sub-catchments to traffic roads.

This study effectively demonstrated that the matrix is not uniformly applicable to all areas, and further research into the relationship between surrogate parameters and traditional water quality parameters is required. It is obvious that the given matrix must be validated and adjusted on a case-by-case basis.

In order to investigate the relationships between water quality parameters and surrogate parameters, and to re-evaluate the contents of decision support matrix an e-monitoring system shall be installed and tested in the near future.

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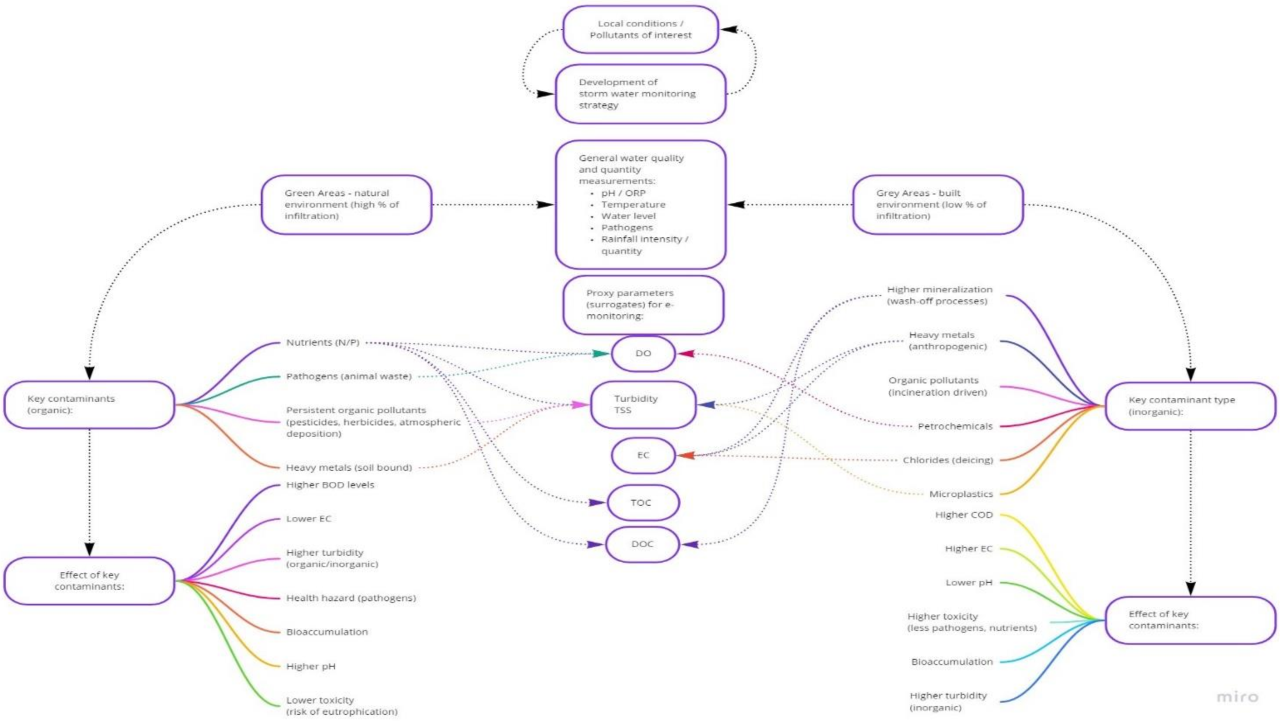

Figure 2 Decision Support Matrix

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