Project title

Urban water management towards a sustainable framework— the investigation of fine-scale urban form effects on stream water quality.

Project team

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Summary

A health urban stream ecosystem provides valuable ecological and social functions such as recreational activities, drinking water, and aesthetic values. Studying stream water quality under a broader social-ecological urban context is challenging because the complex interaction between natural and social factors and the lack of a systematical approach. In this social-ecological context, we propose urban form as a central concept because it connects environmental mechanisms that drive water quality degradation (impervious area composition, configuration, and distribution) and societal decisions to manage water quality (zoning, master plan, and water regulation policy). This study set the first interdisciplinary protocol to investigate and predict urban stream water quality at a fine scale with alternative urban structure and forms, together with a set of natural factors such as weather, soil, and topography. We are a highly interdisciplinary research team, with members from landscape architecture, urban planning, civil engineering, and data science. Together with Huron River Watershed Council as our external partner, we piloted this study in the Huron River Watershed and identified important urban form factors affecting stream water quality. We found urban watersheds with larger areas of brick and concrete pavements, smaller average parcel areas, more medium or high intensity development, and older building ages tended to generate more surface water pollutions. Runoff events with higher pollutant concentrations were more likely to happen in areas with medium to high intensity development on wet and hot days. In addition, we predicted the water quality performance of three land use scenarios in the Scio Township and illustrated how even scenarios describing additional urbanization can be associated with improved water quality if there was sufficient open green space. The outcomes provided essential information for water resource managers and policy makers to come up with actionable and cost-effective solutions for water quality management in the pre-development stage.

Project background and approach

The environmental effects of impervious surfaces on urban stream water quality have been verified that a small increase in the percentage of urban land use can exert a disproportionately large influence on pollutant generation. Given similar impervious surface area, urban landscapes still have high variations in their spatial pattern (i.e., the layout of land uses, street and buildings), which we call it urban form. Urban form connects environmental mechanisms that drive water quality degradation (impervious area composition, configuration and spatial distribution) and societal decisions to manage water quality (zoning, master plan, water regulation), but its influence on stream water quality is inconclusive. In addition, the influence of urban form on stream water quality could be different in different weather conditions, which could imply adaptive planning strategies to mitigate climate change effect on surface water quality.

In this project, we investigated how urban form and its interaction with weather affect water quality indicators including total suspended solid (TSS), total phosphorous (TP), and *E. coli* concentrations in the Huron River Watershed. We further used machine learning models to predict water quality performance for three land use scenarios for Scio Township to demonstrate the how to incorporate water quality prediction in urban planning practice. The sustainable challenge we addressed is to integrate both environmental factors (weather, soil, topography) and social factors (zoning, development intensity, and building and street characteristics) to investigate their interaction effects on stream water quality. The project framework views urban stream water quality degradation as a socioenvironmental issue that could be potentially addressed by smart urban planning and regional development policy.

Our external partner is Huron River Watershed Council (HRWC). HRWC shared common research interest with us on the water quality performance assessment under alternative urban form scenarios. During the project period, HRWC met with the project team monthly to help on data curation, model structure, result interpretation, and policy implication. The other external partner is the Scio Township, providing us with the information of alternative land use plans as the input to the water quality scenario models. Located immediately west of the growing city of Ann Arbor, home to the University of Michigan and a dynamic cluster of technology and automotive firms, Scio Township contains some more intensely developed areas, along with significant agricultural and conservation land. We served the township by providing water quality prediction for alternative planning scenarios that can help make sound decisions leading to better water quality in their future land use plan.

In this project, the interdisciplinary team (landscape architecture, urban planning, civil engineering, data science) collaborated with HRWC to address urban water quality issues towards a sustainability framework. We primarily had two activities: (1) We investigated the joint effects of urban form and weather on stream water quality with a data-driven approach. (2) We incorporated water quality into land use scenario analysis with random forest models. PI Wang was responsible for the first activity and Co-PI Goodspeed led the second activity. Other Co-PIs contributed to theoretical foundation, framework construction and model interpretation.

Findings

Key findings of our project include:

(1) We found significant relationship between urban form and surface water quality to complement existing efforts that focus only on imperviousness or installing BMPs. In general, urban subwatersheds with larger areas of brick and concrete pavements,

smaller average parcel areas, more medium or high intensity development, and older building ages are associated with higher pollutant concentrations.

(2) There is a combined effect between natural factors and urban form in leading to surface water quality degradation. Larger precipitation, higher temperature, and more clay soil all have interaction effects with multiple urban form variables (e.g., percent of medium intensity development, percent of residential, area of concrete pavement) to predict higher pollutant concentrations. Therefore, specific attention should be given to these urban form variables in urban planning process in future climate change scenarios.

(3) The case study of water quality scenario prediction illustrated how even scenarios describing additional urbanization can be associated with improved water quality. For example, with smart planning approaches such as reducing vacant land and increasing open space, e. coli concentration can be reduced even with increasing residential development and road construction.

Outputs

The key output resulting from this research is a scenario planning tool to support decision making among different master plans and zoning options in the Scio Township.
Specifically, we produced a prototype of a tool that can quantify the water quality performance of alternative land use plans. Although limited by the use of general land use categories, the tool documents significant differences between two proposed land use plans for Scio Township. The inputs of this scenario planning tool are urban form variables such as different land use percentages, development densities, and length of different types of streets for multiple planning scenarios. The output is the predicted water quality indicators (TSS, TP, *E. coli*) for those scenarios.

Along with this tool, we also produced an urban environment database with metrics detailing block and parcel characteristics in each subwatershed to comprehensively assess the current conditions of the watershed. Future researchers, planners, and watershed managers can use this database to explore their watershed regarding the urban form and water quality information.

Additionally, we have submitted one peer reviewed journal article in Environment and Planning B led by Co-PI Goodspeed. The other journal article is in preparation by PI Wang and is anticipated to be submitted by the end of 2022. Citations will be available after the articles are published. We also had one oral conference presentation at American Geophysical Union annual conference in 2021. The citation is
Wang, R., Zuo, C., Wu, Q. Goodspeed, R. (2021). The investigation of fine scale urban form effects on stream water quality in the Huron River Watershed. American Geophysical Union (AGU) fall meeting, New Orleans, LA

Outcomes

The outcomes of this project are three folds: (1) We identified key urban form indicators that affect stream water quality (see our Findings 1). It enables both the better framing of urban form related research questions and the formation of land use management priorities; (2) We derived urban planning suggestions towards climate change mitigation by finding urban form indicators that have combined effects with high precipitation and temperature on water quality.

Specifically, concrete pavement, residential development, and medium to high intensity development should be given more attention to in summer high rainfall events. (3) We submitted a related proposal to NSF HEGS in summer 2021 namely "Beyond Imperviousness: Assessing Urban Form Impacts on Stormwater Quality and the Co-Benefits in a Socioecological Framework." We were not funded this time and will revise and resubmit in 2022.

Part 2: The following sections are for internal program tracking and program improvement and **will not** be shared publicly.

Project personnel details

This includes more detailed contact information than what is included in the public content section

- If there have been changes to project personnel (i.e., researchers, partners, and students) not already reported during the mid-project check-in report, please list names and email addresses. For U-M students, please also indicate degree program.

We include students' information in this session. Five research assistants worked for this project. They are:

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We also include personnel from HRWC contributing to this project.

Ric Lawson, rlawson@hrwc.org

Andrea Paine, apaine@hrwc.org

Budget

- Provide information on budget expenditures.

We stick to the original budget plan, as shown below. In addition, PI Wang used other sources of funding to pay our external partner HRWC $1,780 for their hourly working.

Hourly Temporary Research Assistants - SEAS $6,518

Hourly Temporary Research Assistants - Urban Planning $2,771
Fringe Benefits FICA 7.65% $711

Evaluation

As we proposed, we could measure the success of our urban form database by evaluating the number of explanatory variables in the urban environment database and whether these urban form variables can serve as a more nuanced exploration of imperviousness. As the results, we have more than 100 urban form variables complied in the database and there was no missing data. We expect this database could be used by other researchers and planners to understand the relationship between urban form and water quality in the Huron River Watersheds.

Regarding the success of model, performance metrics were comparable to the state-of-the-art water quality machine learning model. After the train and test split, test set R^2 values were 0.71 and 0.73 for TP and TSS, respectively. The predicting accuracy (test set R^2=0.36) was relatively lower for *E. coli*. With log value of pollutant concentration as the predicting outcome, we also calculated the exponential value of percentage bias to indicate how much the predicted water quality deviated from the measured water quality. The exponential values for percentages bias of TP, TSS and *E. coli* were 1.22, 1.49, and 1.74, respectively. The bias was smaller than 2, indicating that the predicted concentration was between half and two times the measured concentration.

In the long run, we will use the citation of published journal articles and success of external grant proposal as the measurement of success.