Project Title

Bacteria Removal from Stormwater Runoff Using Steel Byproduct Filters

University

South Dakota State University

Principal Investigators

Guanghui Hua (PI)
Associate Professor
South Dakota State University
Phone: (605) 688-6957
Email: guanghui.hua@sdstate.edu
ORCID: 0000-0001-6466-7451

Kyungnan Min (Co-PI)
Lecturer
South Dakota State University
Phone: (605) 688-4918
Email: kyungnan.min@sdstate.edu
ORCID: 0000-0003-1591-0915

Christopher Schmit (Co-PI)
Professor
South Dakota State University
Phone: (605) 688-6252
Email: christopher.schmit@sdstate.edu
ORCID: 0000-0003-0208-4060

Research Needs

Stormwater runoff generated from highways, urban areas, and agricultural settings may contain various pollutants including suspended solids, nutrients, heavy metals, hydrocarbons and microbial pathogens. Stormwater runoff with large quantities of contaminants can deteriorate water quality of receiving water bodies and threaten public health. The US Environmental Protection Agency estimated that stormwater from urban areas has led to water quality deterioration of 13% of river segments, 18% of lakes, and 32% of estuaries surveyed (USEPA, 2002). South Dakota Department of Environment and Natural Resources (SDDENR) assessed about 5,916 stream miles in South Dakota from 2012 to 2017, and the results showed that 73.5% of assessed stream miles did not support one or more beneficial uses (SDDENR 2018). Nonsupport for fishery/aquatic life uses was caused primarily by total suspended solids from nonpoint sources and natural origin. Nonsupport for recreational uses was primarily caused by Escherichia coli (E. coli) contamination from livestock and wildlife contributions. SDDENR also

assessed 171 of the 575 lakes and reservoirs assigned recreation and/or fish life beneficial uses (SDDENR 2018). An estimated 84.3% of the assessed lake acreage did not support all assigned beneficial uses. One major cause is excessive algae growth due to nutrient enrichment from watershed scale nonpoint sources. As we continue to expand urbanization, transportation, and agricultural production to support population growth, stormwater runoff from various sources may lead to increased contamination of surface waterbodies in the future. Thus, there is an urgent need to improve management of stormwater runoff to protect natural water resources.

Many best management practices (BMPs) have been developed to mitigate the negative impacts of stormwater runoff. These BMPs include roadside vegetation ditches, runoff detention ponds, bioretention, infiltration trench, constructed wetlands and other engineered treatment systems (Clark and Pitt, 2012). Many of these BMPs are designed to control the volume of runoff and trap suspended particles. These conventional BMPs are generally not effective in removing other pollutants such as E. coli, nutrients and heavy metals. Media filtration is an emerging stormwater treatment technology that has shown great potential to remove multiple contaminants from non-point source pollution. A variety of filtration materials have been evaluated for stormwater treatment, including natural minerals (e.g., calcite, limestone, and zeolite), industrial byproducts (e.g., steel slag, fly ash, and drinking water treatment residuals), and commercial synthetic products (Seelsaen et al., 2006; Chardon et al., 2012; Prabhukumar 2014; Lalley et al., 2016; Soleimanifar et al., 2016). Many of the prior studies that evaluated stormwater media filtration focused on nutrients and metals. Few studies have examined materials that are effective for fecal indicator bacteria, such as E. coli removal. Microbial pathogens in stormwater runoff are becoming a primary source of water quality impairment in receiving water bodies. E. coli are linked to increase risks of waterborne diseases during recreational exposure. There is a need to develop low-cost technologies to remove E. coli and other pathogens in stormwater to protect public health.

Several studies have evaluated the use of natural minerals, biochar, bioretention media and iron-coated sand for E. coli removal from stormwater. Prabhukumar (2014) performed column experiments to evaluate the contaminant removal of selected media materials. The results showed that calcite was most efficient for nutrients and suspended solids removal, zeolite was highly effective in removing E. coli, and iron fillings were effective in removing nutrients and metals. Zhang et al. (2010) and Mohanty et al. (2013) compared E. coli removal by conventional bioinflitration systems and the systems with iron coated sand. The results showed that iron coated sand could significant enhance the capture of E. coli. Biochar amended biofilters also showed improved ability to remove E. coli from stormwater (Mohanty et al., 2014). Most of the prior studies on media filtration for E. coli removal focused on laboratory-scale batch or column experiments. Few have applied this technology in real world applications.

Recycled steel byproducts are a new group of industrial byproducts that can be used for stormwater runoff treatment (Goodwin et al., 2015; Hua et al., 2016; Sellner et al., 2019). Steel byproducts include various forms and sizes of steel wool, chips, and turnings that are generated as waste materials from steel machining, cutting, and grinding processes. These steel processing waste materials are typically landfilled or recycled back into the steel making industry. Recycled steel byproducts have shown high capacities for phosphate adsorption due to their high iron content (Hua et al., 2016). The surface of steel byproducts may consist of various forms of positively charged iron oxides, which could be used to adsorb negative charged bacteria (Zhang

et al. 2010). Thus, recycled steel byproducts potentially offer a low-cost and locally available solution for E. coli removal in stormwater runoff.

Research Objectives

In this study, we will conduct laboratory and field experiments to investigate the performance of recycled steel byproduct filters to remove E. coli from stormwater runoff. Steel slag, another industrial byproduct that has been used for stormwater filtration, will be used as a supporting material to mix with steel byproducts to reduce clogging potential. An existing field-scale steel byproduct filter will be used to evaluate the long-term performance of the filter for stormwater treatment. The objectives of this study are to:

1. Provide a state-of-the-art review of E. coli removal from stormwater using the media filtration technology.
2. Construct lab-scale filters with steel byproducts and steel slag, and determine their efficiency for E. coli removal from stormwater.
3. Add new filter materials (steel byproducts and steel slag) to an existing field-scale steel byproduct filter located at a stormwater detention pond.
4. Evaluate the long-term performance of the field-scale steel byproduct filter for E. coli removal from stormwater.
5. Provide recommendations on the application of steel byproduct filtration for E. coli removal from stormwater runoff.

Research Methods

This research will be conducted through a literature review, laboratory column experiments, and field scale experiments to achieve the objectives. A comprehensive literature review will be conducted to summarize the latest developments in using media filtration for E. coli removal from stormwater runoff. This review will include different filter materials designed for non-point source indicator bacteria control, and factors that may affect E. coli removal by filters under field application conditions. A focus of this review will be on iron oxide based materials for E. coli adsorption. The results of this review will help the design of the laboratory and field scale experiments for E. coli removal using recycled steel byproducts.

We plan to collect recycled steel byproducts from a recycling company in Minnesota and steel slag from a steel making company in Nebraska. Both materials from these two locations have been used by the PI in previous stormwater treatment studies. After we receive the filter materials, standard sieving procedures will be used separate them into different size groups (e.g., 1mm – 10 mm). Laboratory column reactor will be constructed using Omnifit fixed-bed glass columns. A multi-channel peristaltic pump will pump E. Coli containing solutions through the column reactors to evaluate the impact of particle size, mixing ratios of steel byproducts and steel slag, and intermittent flows on E. Coli adsorption.

We will add new filter materials, steel byproducts and steel slag, to an existing field-scale stormwater filter structure in a stormwater runoff detention pond located in the City of Brookings, SD. We plan to collect at least 8 storm event samples in 2019 and 2020 to determine the long-term performance of the filter for E. coli removal. In addition to E. coli, the pH, iron

concentration, nitrate, and phosphate in the filter influent and effluent will be also analyzed for each storm runoff samples to determine the removal of multiple contaminants by the filter.

Expected Outcomes

This research focuses on developing a media filtration technology for E. coli removal from stormwater runoff. E. coli bacteria from stormwater runoff have cause water quality impairment of surface water bodies. The development of low-cost filtration technology for E. coli removal from stormwater runoff has significant implications in surface water quality improvement and public health protection. The expected outcomes of this project include:

1. A media filtration technology using recycled steel byproducts that can be used to remove E. coli from stormwater runoff.
2. An understanding of the long-term performance of a field-scale steel byproduct filter.
3. Recommended application conditions of steel byproduct filtration for E. coli removal.

Relevance to Strategic Goals

The proposed project and its expected outcomes are directly related to the strategic goals of Environmental Sustainability and Livable Communities. This research aims to develop a steel byproduct filtration BMP to reduce the concentrations of E. coli in the runoff from highways and urban areas. The steel byproduct filtration is a highly promising technology than can reduce the environmental impact of transportation and urban development to protect natural water resources.

Educational Benefits

Two graduate students will work on this project under the direction of PIs and receive training on water quality control, experimental design, and analytical skills. This study involves environmental engineering, stormwater management, field reactor design, and water quality analyses, which provide great training opportunities for the students. The students will learn about developing an innovative engineered solution for an important water quality issue, which will improve their critical thinking and problem solving ability. The students will present the results at regional and national conferences, and prepare at least one manuscript for a peer-reviewed journal. These opportunities will improve students' skills in written and oral communication.

Technology Transfer

The findings of this project will be transferred to other researchers, professionals and practitioners through conferences, meeting presentations, and publications.

1. We will present the result of study at the annual Eastern South Dakota Water Conference, and other regional and national conferences.
2. We will present the results to the water quality managers and stormwater engineers at the City of Brookings and East Dakota Water Developments District.
3. A master thesis will be developed based on the results of this project. This thesis will be available to the public through Open Prairie, the South Dakota State University public access institutional repository.

4. We will submit manuscripts to peer-reviewed journals based on the results of this project.

Work Plan

Task 1 Literature Review on Stormwater Filtration for E. coli Removal

A comprehensive literature review will be conducted to summarize the latest developments in using media filtration for non-point source microbial pollutant control. This review will focus on media filtration technologies for stormwater management, low-cost filtration materials for E. coli adsorption, and field applications of stormwater filters.

Task 2 Construct Steel Byproduct Filters and Conduct Column Experiments

We will construct laboratory column filters to evaluate E. coli adsorption under continuous flow conditions. Recycled steel byproducts will be collected from a metal recycled company in Marshall, Minnesota. Steel slag will be collected from a steel making company in Norfolk, Nebraska. These two materials have been used for previous stormwater treatment studies by the PIs. Steel slag is used to support steel byproduct filters to reduce their clogging potential. E. coli solutions will be prepared by a standard laboratory growth method using a commercially available E. coli strain. The impact of mixing ratios of steel byproducts and steel slag, particle sizes, initial E. coli concentrations, intermittent flows, and flow rates on E. coli adsorption will be evaluated during the column experiments.

Task 3 Evaluate Long-term Performance of a Field Scale Steel Byproduct Filter

A field scale stormwater filter has been installed in a stormwater detention pond in the City of Brookings, South Dakota. We will add new filter materials including steel byproducts and steel slag to this filter structure. The influent and effluent of the field filter will be monitored during storm events. We plan to collected samples from at least eight storm events at different seasons during this project to evaluate the long-term performance of the filter.

Task 4 Project Reporting

The PIs will write and submit the final report. The reports will summarize the experimental results and recommendations for the application of steel byproduct filtration for E. coli removal from stormwater runoff.

Table 1 presents the proposed project schedule.

Table 1 Proposed Project Schedule								
Tasks	Months							
	1-3	4-6	7-9	10-12	13-15	16-18	19-21	22-26
1. Literature Review	▓	▓						
2. Column Experiments		▓	▓	▓	▓			
3. Field Scale Experiments		▓	▓	▓	▓	▓	▓	
4. Project Reporting								▓

Project Cost

Total Project Costs: $156,454
MPC Funds Requested: $78,108
Matching Funds: $78,346
Source of Matching Funds: East Dakota Water Development District ($30,000; cash match)
                            and SDSU ($48,346; faculty time in-kind match)

References

Chardon, W.J., Groenenberg, J.E., Temminghoff, E.J., and Koopmans, G.F., 2012. Use of reactive materials to bind phosphorus. Journal Environmental Quality 41(3), 636-646.

Clark, S.E., Pitt, R., 2012. Targeting treatment technologies to address specific stormwater pollutants and numeric discharge limits. Water Research 46 (20), 6715-6730.

Goodwin, G.E., Bhattarai, R., Cooke, R., 2015. Synergism in nitrate and orthophosphate removal in subsurface bioreactors. Ecological Engineering 84, 559-568.

Hua, G, Salo, M.W., Schmit, C.G., Hay, C.H., 2016. Nitrate and phosphate removal from agricultural subsurface drainage using laboratory woodchip bioreactors and recycled steel byproduct filters. Water Research 102, 180-189.

Lalley, J., Han, C., Li, X., Dionysiou, D.D., Nadagouda, M.N., 2016. Phosphate adsorption using modified iron oxide-based sorbents in lake water: kinetics, equilibrium, and column tests. Chemical Engineering Journal 284, 1386-1396.

Mohanty, S. K., Torkelson, A. A., Dodd, H., Nelson, K. L., Boehm, A. B., 2013. Engineering solutions to improve the removal of fecal indicator bacteria by bioinfiltration systems during intermittent flow of stormwater. Environmental Science and Technology 47, 10791-10798.

Mohanty, S.K., Cantrell, K.B., Nelson, K.L., Boehm, A.B., 2014. Efficacy of biochar to remove Escherichia coli from stormwater under steady and intermittent flow. Water Research 61, 288-296.

SD DENR The 2018 South Dakota Integrated Report for Surface Water Quality Assessment, South Dakota Department of Environment and Natural Resources, Pierre, SD, 2018.

Seelsaen, N., McLaughlan, R., Moore, S., Ball, J.E., Stuets, R.M., 2006. Pollutant removal efficiency of alternative filtration media in stormwater treatment. Water Science and Technology 54, 299-305.

Sellner, B.M., Hua, G., Ahiablame, L.M., Trooien, T.P., Hay, C.H., Kjaersgaard, J., 2019. Evaluation of industrial by-products and natural minerals for phosphate adsorption from subsurface drainage. Environmental Technology 40, 756-767.

Soleimanifar, H., Deng, Y., Wu, L., Sarkar, D., 2016. Water treatment residual (WTR)-coated wood mulch for alleviation of toxic metals and phosphorus from polluted urban stormwater runoff. Chemosphere 154, 289-292.

US EPA National Water Quality Inventory 2000 Report. United States Environmental Protection Agency, Washington, D.C., 2002.

Wium-Anderson, W., Nielsen, A.H., Hvitved-Jacobsen, T., Kristensen, N.K., Brix, H., Arias, C., Vollertsen, J., 2012. Sorption media for stormwater treatment-A laboratory evaluation of five low-cost media for their ability to remove metals and phosphorus from artificial stormwater. Water Environment Research, 84 (7), 605-616.

Zhang, L., Seagren, E.A., Davis, A.P., Karns, J.S., 2010. The capture and destruction of Escherichia coli from simulated urban runoff using conventional bioretention media and iron oxide-coated sand. Water Environment Research 82, 701-714.