Science of the Total Environment 580 (2017) 168–177

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

Citizen science-based water quality monitoring: Constructing a large database to characterize the impacts of combined sewer overflow in New York City

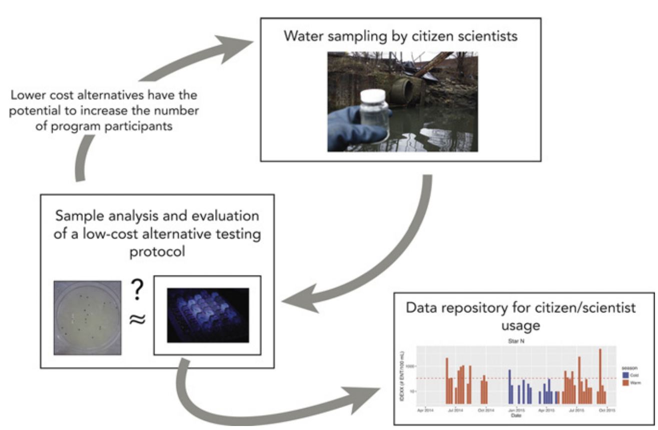
David J. Farnham [a,*], Rebecca A. Gibson [b,1], Diana Y. Hsueh [b], Wade R. McGillis [b], Patricia J. Culligan [c], Nina Zain [d], Rob Buchanan [e]

[a] *Department of Earth and Environmental Engineering, Columbia University, 918 S.W. Mudd, Mail Code: 4711, New York, NY, USA*
[b] *Department of Geochemistry, Lamont Doherty Earth Observatory, 61 Route 9W, – PO Box 1000, Palisades, NY, USA*
[c] *Department of Civil Engineering and Engineering Mechanics, Columbia University, 610 S.W. Mudd, Mail Code: 4709, New York, NY, USA*
[d] *The River Project, Pier 40 at West St. & Houston St, 2nd Floor, New York, NY. USA*
[e] *Steering Committee, New York City Water Trail Association and Coordinator, Citizens Water Quality Testing Program, USA*

HIGHLIGHTS

- A citizen science water quality sampling campaign to construct a database
- Data show elevated enterococci concentrations following days of rainfall.
- A cost/time efficient alternative pathogen detection method shows potential.
- Discussion of barriers to citizen science proliferation in water quality testing

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 16 September 2016
Received in revised form 17 November 2016
Accepted 17 November 2016
Available online 24 December 2016

Editor: D. Barcelo

ABSTRACT

To protect recreational water users from waterborne pathogen exposure, it is crucial that waterways are monitored for the presence of harmful bacteria. In NYC, a citizen science campaign is monitoring waterways impacted by inputs of storm water and untreated sewage during periods of rainfall. However, the spatial and temporal scales over which the monitoring program can sample are constrained by cost and time, thus hindering the construction of databases that benefit both scientists and citizens. In this study, we first illustrate the scientific value of a citizen scientist monitoring campaign by using the data collected through the campaign to characterize the seasonal variability of sampled bacterial concentration as well as its response to antecedent rainfall. Second, we

Abbreviations: NYC, New York City; EPA, Environmental Protection Agency; CSO, combined sewer overflows; CSS, combined sewer system; MPN, Most Probable Number; CFU, Colony Forming Units; TNTC, Too Numerous To Count; WWTP, wastewater treatment plant; FIB, fecal indicator bacteria; CWQT, Citizen's Water Quality Testing Program; NYCWTA, New York City Water Trail Association; CU, Columbia University; FWW, FreshWater Watch; HSBC, Hong Kong and Shanghai Banking Corporation; NYC DEP, New York City Department of Environmental Protection; ENT, enterococci.

* Corresponding author.
E-mail addresses: djf2137@columbia.edu (D.J. Farnham), rgibson@ldeo.columbia.edu, rebecca.a.gibson@duke.edu (R.A. Gibson), dhsueh@ldeo.columbia.edu (D.Y. Hsueh), mcgillis@ldeo.columbia.edu (W.R. McGillis), pjc2104@columbia.edu (P.J. Culligan), nina@riverprojectnyc.org (N. Zain), avironvoile@gmail.com (R. Buchanan).
[1] Current address: Duke University School of Medicine, Box 102005 Durham, NC, USA.

http://dx.doi.org/10.1016/j.scitotenv.2016.11.116

Keywords:
CSO
Water quality
Fecal indicator bacteria
HyServe Compact Dry ETC
IDEXX Enterolert
Citizen science

examine the efficacy of the HyServe Compact Dry ETC method, a lower cost and time-efficient alternative to the EPA-approved IDEXX Enterolert method for fecal indicator monitoring, through a paired sample comparison of IDEXX and HyServe (total of 424 paired samples). The HyServe and IDEXX methods return the same result for over 80% of the samples with regard to whether a water sample is above or below the EPA's recreational water quality criteria for a single sample of 110 enterococci per 100 mL. The HyServe method classified as unsafe 90% of the 119 water samples that were classified as having unsafe enterococci concentrations by the more established IDEXX method. This study seeks to encourage other scientists to engage with citizen scientist communities and to also pursue the development of cost- and time-efficient methodologies to sample environmental variables that are not easily collected or analyzed in an automated manner.

1. Introduction

Citizen scientist engagement in environmental data collection is a co-beneficial activity in which laymen can help build large datasets of environmental parameters that are not automatically collectable due to technological or budgetary constraints. Enhancements in public learning and civic engagement often come out of such programs, most notably increased understanding in certain aspects of scientific literacy and thought processes (Price and Lee, 2013; Trumbull et al., 2000) and legislature/advocacy participation (Cornwell and Campbell, 2012; Overdevest et al., 2004). Mature and successful citizen scientist engagement exists in both the astronomy and ornithology disciplines, e.g. volunteers have classified galaxies for the Sloan Digital Sky Survey (Lintott et al., 2011, 2008) and observed the procreation and breeding biology of birds (Ornithology, 2011).

Water quality monitoring campaigns, however, have utilized citizen science less. Several exceptions include measuring underwater diffuse attenuation (Bardaji et al., 2016), nitrate, ammonium and dissolved organic nitrogen in surface waters (Breuer et al., 2015), sea surface temperatures (Brewin et al., 2015), and FreshWater Watch, which was spearheaded by the Earthwatch Institute with support from Hong Kong and Shanghai Banking Corporation (HSBC). FreshWater Watch's focus has been to examine the health of various freshwater ecosystems globally using citizen scientists (Thornhill et al., 2016). Even less work has been put into monitoring water quality to assess aquatic and human exposure to harmful pathogens and/or pollutants (Stepenuck et al., 2011), including those arising from combined sewer overflows (CSOs). Bacteria testing, which often requires the incubation of samples in a laboratory, is an active area of interest for both scientists attempting to understand the impacts of CSO contamination in urban waterways (Brosnan et al., 1996; McLellan and Salmore, 2003) and citizen groups eager to make informed choices about participating in water-based recreational activities. Resolute sampling campaigns and the construction and curation of spatially distributed datasets are critical because of the spatially and temporally heterogeneous nature of fecal bacteria in urban waterbodies, which arises in part because of the distributed nature of point discharges from combined sewer systems (CSSs) (EPA, 2004). As such, increased formal engagement of citizen scientists in bacteria monitoring campaigns is a win-win for citizen and scientific communities.

This study is a unique example of the use of citizen science-based monitoring of fecal indicator bacteria (FIB) concentrations in waterbodies of the greater New York City area to a) inform scientific inquiries and b) to construct a practically useful data repository for citizen groups with a vested interest in the bacteria concentrations in the water (e.g. kayakers, rowers and other recreational users). In the present study, we use citizen sourced data to characterize the concentration of the FIB enterococci (ENT) across space and time by 1) computing the percentage of samples that showed levels of ENT above the acceptable threshold for recreation, 2) evaluating the seasonality of ENT concentrations at the sites that citizens sampled year-round, 3) discussing the spatial and temporal correlation structures in ENT concentrations among the sites, and 4) investigating whether ENT concentrations sampled the day after a precipitation event were elevated compared to those sampled the day after dry days.

A barrier to the expansion of citizen science monitoring campaigns such as the one showcased in this study is the cost of the sampling kits and the need for specialized laboratory equipment. We address this by evaluating the use of a cheaper and less time-intensive alternative testing protocol to the current protocol through a paired sample analysis. Specifically, we ask: how well does the HyServe testing protocol correspond to the currently used IDEXX testing protocol with regard to concentrations being above or below the critical threshold for recreational activity?

In the following sections we outline the combined sewer systems in the context of NYC and introduce the citizen science group engaged in this project. We then describe the materials and methods used in the study. Next, the results are presented and discussed before the study conclusions are provided.

2. Combined sewer overflows and citizen science monitoring

Public sewer designs heavily influence the quality of surrounding waterways. Over 700 communities in the United States have combined sewer systems, where a single network of pipes collects domestic, commercial, and industrial wastewaters together with storm water runoff. On a dry day, effluent from buildings gets transported to a wastewater treatment plant (WWTP) where the water is treated and discharged into the adjacent waterway. During precipitation events, the additional stormwater combines with building wastewater, sometimes exceeding WWTP capacity and results in the release of a mix of wastewater and stormwater into the surrounding surface waterways at designated outfall points. The EPA defines these discharge events as CSOs and estimates that CSO events result in the release of approximately 850 billion gallons (3.2 billion m^3) of untreated wastewater and stormwater per year across the U.S. (EPA, 2004).

The discharge of untreated wastewater into nearby surface waters via CSOs has major environmental consequences for receiving waterbodies. CSOs can contribute oxygen depleting organic material, total suspended solids, toxics, nutrients, floatables and trash, steroid hormones, wastewater micropollutants, and pathogens harmful to human health to the receiving waterbody (Alp et al., 2007; Donovan et al., 2008; Eganhouse and Sherblom, 2001; EPA, 2004; Miskewitz and Uchrin, 2013; Phillips and Chalmers, 2009; Phillips et al., 2012). The environmental impacts of CSOs on water quality can include eutrophication and hypoxia, making ecosystems uninhabitable to aquatic fauna. The severity of CSO impact varies significantly based on a suite of natural and built environmental factors including CSO outfall design, rain history, waterbody type, and land cover. For example, a large, urban environment like NYC generates frequent CSO events via excess storm water runoff from its predominantly impervious land cover.

CSO discharge poses particular problems for recreational users of receiving waterbodies. Exposure to fecal contamination in untreated wastewater has been linked to gastrointestinal illness and less often respiratory illness (Byappanahalli et al., 2012), which associate with symptoms including fever, nausea, stomachache, diarrhea, or vomiting. The prominence of CSO events, in conjunction with the evident link