Vulnerability Analysis: Boston Beach to Fecal Contamination Induced by Human Activities

How does analysis match real beach water quality and what are important factors

Data Sources:
Lambert conformal conic projection. MassGIS, MWRA, US Census, Google map.

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Introduction

Swimming is a popular recreational activity on marine beaches. However, beachgoers are susceptible to pathogen exposure if the waterbody was polluted (DPH, 2018). US Environmental Protection Agency reported that fecal contamination in recreational water is the major cause of gastrointestinal illnesses among swimmers (USEPA, 2012).

Factors that can cause fecal contamination to beach water were identified but not determined: Sanitary Sewage Overflow (SSOs), public beach accessibility, urban farms that raise animals, and environmental factors such as wildlife, vegetation and rainfall (Turgeon, 2012). Current literature didn't provide a comprehensive list of risk factors and their relative importance.

Boston is located at eastern Massachusetts. It is a thriving port city with many marine beaches along the east coast. Environment Massachusetts Research & Policy Center reported that 223 of 583 monitored beach sites were unsafe for at least one day in 2018 (Hellerstein, 2019). Marine beaches in Boston area are listed as having highest number of bacteria exceedances in 2018 (DPH, 2018), accessed by DPH criteria of enterococci > 104 counts/ml as unsafe. The aim of this project is to estimate how vulnerable are beaches in Boston to fecal contamination induced by human activities, and whether the outcome vulnerability scores (VS) match with real fecal content measured during 2016—2019.

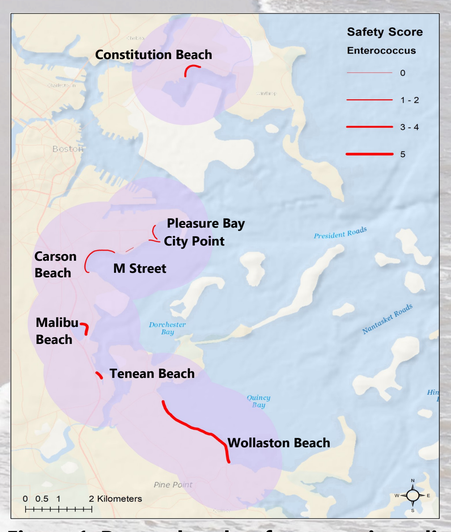

Figure 1. Boston beach safety score in reality by enterococcus content, 2016—2019. Scores were assigned based on average days of having enterococcus > 104 c/ml, and the percentage of bacteria exceeding the standard level of 104 c/ml, during June—August.

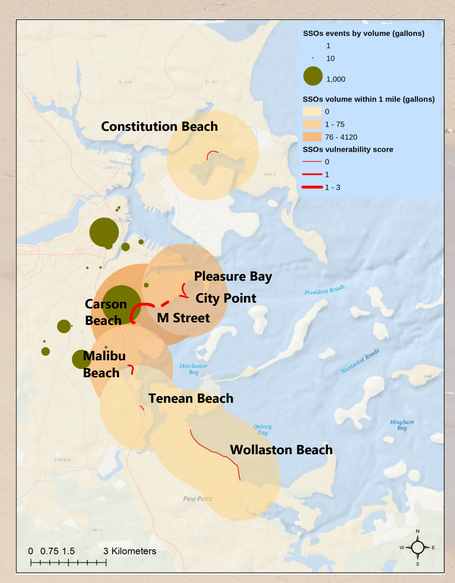

Figure 2. Boston beach vulnerability scores by SSOs volume within 1 mile distance. Only SSOs events within the target sub-basin were counted. SSOs sites were sized by overflowed volume.

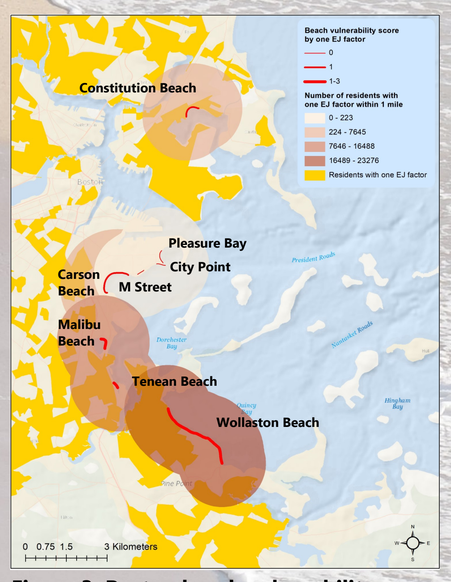

Figure 3. Boston beach vulnerability scores by population with one EJ factor within 1 mile distance. EJ = Environmental Justice. One EJ factor means being either minority, low income, or English isolation.

Data

Data used in this project are from following departments and websites:

- **MassGIS**: Seaport sites in Boston, shapefile; Environmental justice 2010 populations, shapefile; Drainage sub-basins in Boston, shapefile.
- **Massachusetts Water Resource Authority**: Marine beach sites in Boston, shapefile; SSOs sites in Boston, 2018, table; Boston beach rainfall (2016-2019, June—August), table; Beach enterococcus content data (2016-2019, June - August), table.
- **US Census Bureau**: MA population by census tract, ACS, 2017, 5 year estimates, table.
- **Google map**: Farms in Boston that raise animals, geographic coordinates.

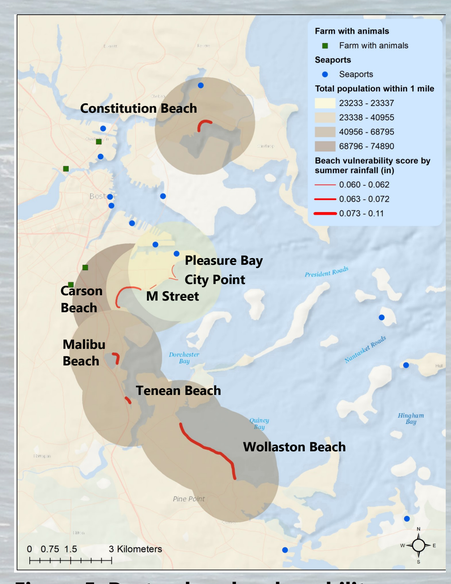

Figure 5. Boston beach vulnerability scores by summer rainfall (2016-2019, June-August). Also shows total population, seaports, farms counts within 1 mile distance.

Table 1. Risk factors and there assigned vulnerability scores.

Risk factor	Value/Assigned VS
SSOs volume (gallon)	0/0; 45, 75/1; 4120, 4057 /3
Farms with animals	Within sub-basin /1; Not within sub-basin/0
Rainfall (inch, June –Aug)	0.0624/1; 0.0722/2; >0.0722/3
Total population	>23337/1; 23338 – 40955/2; 40956 - 68795/3; 68796 /4
Seaport	0/0; 1/1; 2/2
People with one EJ factor	0 – 223/0; 224 – 7645/1; 7646 – 16488/2; 16489 - 23276/3
People with two EJ factors	0/0; 1 – 4124 /2; 4125 - 6937/4; 6938 - 11541/6
People with three EJ factors	0/0; 1-1497/3; 1498 - 4558/6

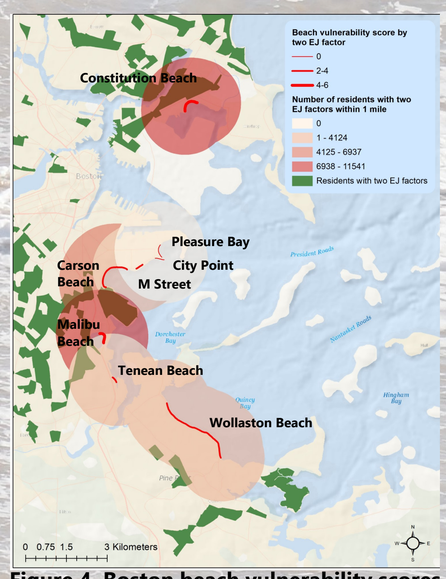

Figure 4. Boston beach vulnerability scores by population with two EJ factors within 1 mile distance. EJ = Environmental Justice. Two EJ factor means having the combination of any two factors: being minority, low income, or English isolation.

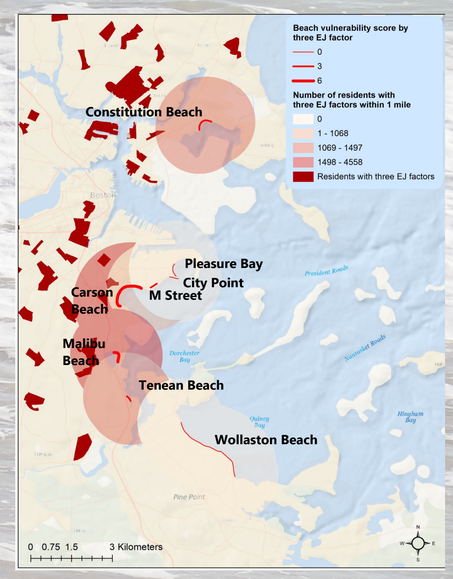

Figure 5. Boston beach vulnerability scores by population with three EJ factors within 1 mile distance. EJ = Environmental Justice. Three EJ factor means being minority, low in-

Methods

Unweighted vulnerability analysis was conducted on eight beaches in Boston: Carson, City Point, Constitution, M Street, Pleasure Bay, Tenean, and Wollaston beach, using ArcMap Desktop 10.6.1.

- Sites of SSOs, farms that raise animals and seaports were identified by geocoding.
- 1 mile, undissolved buffer was created around each beach.
- Other layers were joined to the buffer to identify risk factors within 1 mile around each beach: SSOs total volumes, seaport counts, farm counts, total population counts, population counts by EJ factors (minority, low income, and English isolation), and average rainfall.
- VS was assigned to each risk factor, **Table 1.** Graduated color was used to visualize VS for each factor. Total VS was calculated by adding all separate VS.

A reality score (RS) for each beach was also calculated based on the number of days having unsafe bacteria level (score 0-3), and the percent of bacteria exceeding the safety level (score 0-3). Total VS (score 0-6, added), and separate VS for each risk factor were compared to RS.

Results

Based on RS (**Figure 1**), beach water quality by enterococcus content can be ranked as: Malibu (5) = Tenean (5) = Wollaston (5) > Constitution (4) > Carson (2) = City Point (2) = Pleasure Bay (2) > M Street (0). Beach VS for each risk factor are displayed in **Figure 2-6**. Based on calculated total VS (**Figure 7**), beach vulnerability to fecal contamination can be ranked as: Malibu (22) > Carson (21) > Constitution (17) > M Street (14) > Tenean (13) > Wollaston (11) > Pleasure Bay (6) > City Point (5).

It is observed that total VS, SSOs VS, Three EJ factors population VS didn't match the RS. However, One EJ factor VS and VS from summer rainfall matched RS. Two EJ factors VS partially matched RS.

Conclusion/discussion

The result VS didn't match with RS, when only including human activity risk factors as previously described, and rainfall as the sole environmental factor. This indicated that other human activities, and environmental factors (e.g. vegetation, wildlife, etc.) might play important roles in beach water fecal contamination in Boston.

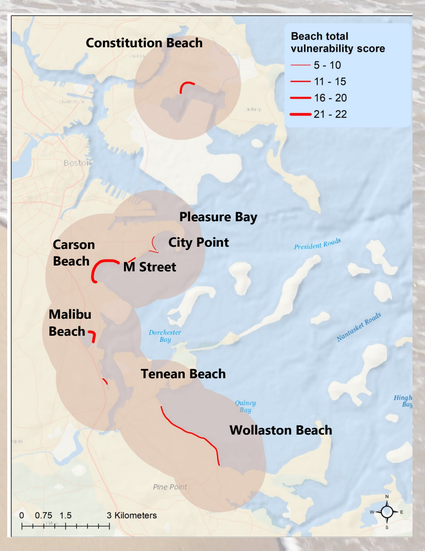

Figure 7. Boston beach total VS.

It seems that EJ population living within 1 mile, and rainfall are better indicators of beach water enterococcus content, compared to SSOs. This project adds to current knowledge that people susceptible to EJ and living near beach contribute greatly to beach water fecal contamination. This indication is logical because this population are less likely to travel far for recreational purposes. Future research can consider more detailed EJ factors and expend buffer distance to further confirm this indication. This project is subjected to many limitations. Key limitation is not taking sewage canal routes into analysis.

Reference: 1. Massachusetts Department of Public Health. (2019). *2018 Massachusetts Beach Testing Results: Annual Report*. 2. *Recreational Water Quality Criteria*. LEARN: What Affects Human Health at the Beach | US EPA. (2019). Retrieved 12 December 2019, from https://www.epa.gov/beaches/learn-what-affects-human-health-beach 3. Turgeon, P. (2019). Monitoring Recreational Waters: How to Integrate Environmental Determinants. Retrieved 12 December 2019. 4.At Massachusetts' beaches, unsafe water could make you sick. (2019). Retrieved 12 December 2019, from https://environmentmassachusetts.org/news/mac/massachusetts%E2%80%99-beaches-unsafe-water-could-make-you-sick#