Science of the Total Environment 571 (2016) 67–76

Contents lists available at ScienceDirect

Science of the Total Environment

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

Association of land use and its change with beach closure in the United States, 2004–2013

Jianyong Wu [a,*], Laura Jackson [b]

[a] Oak Ridge Institute for Science and Education (ORISE) Fellowship Participant at US EPA, Office of Research and Development, Research Triangle Park, Durham, NC 27711, USA
[b] US EPA, Office of Research and Development, National Health and Environmental Effects Research Laboratory, Research Triangle Park, Durham, NC 27711, USA

HIGHLIGHTS

- The impact of land use and its change on beach closure was examined in 10 years.
- Urbanization and agriculture development may impair beach water quality.
- Afforestation may reduce beach closure frequency by protecting water quality.

GRAPHICAL ABSTRACT

ARTICLE INFO

Article history:
Received 31 May 2016
Received in revised form 15 July 2016
Accepted 16 July 2016
Available online xxxx

Editor: D. Barcelo

Keywords:
Beach water quality
Land cover
Land use change
Urbanization
Ecosystem health

ABSTRACT

Land use and its change have great influences on water quality. However, their impacts on microbial contamination of beach water have rarely been investigated and their relationship with beach actions (e.g., advisories or closure) is still unknown. Here, we analyzed beach closure data obtained from 2004 to 2013 for >500 beaches in the United States, and examined their associations with land use around beaches in 2006 and 2011, as well as the land use change between 2006 and 2011. The results show that the number of beach closures due to elevated indicators of health risk is negatively associated with the percentages of forest, barren land, grassland and wetland, while positively associated with the percentages of urban area. The results from multi-level models also indicate the negative association with forest area but positive association with urban area and agriculture. The examination of the change of land use and the number of beach closures between 2006 and 2011 indicates that the increase in the number of beach closures is positively associated with the increase in urban ($\beta = 1.612$, $p < 0.05$) and agricultural area including pasture ($\beta = 0.098$, $p < 0.05$), but negatively associated with the increase in forest area ($\beta = -1.789$, $p < 0.05$). The study suggests that urbanization and agriculture development near beaches have adverse effects on beach microbial water quality, while afforestation may protect beach water quality and reduce the number of beach closures.

1. Introduction

Swimming in natural waters (e.g., oceans, lakes, or rivers) is one of most popular recreational activities in the United States. It was

* Corresponding authors at: 109 T.W. Alexander Driver, Research Triangle Park, Durham, NC 27711, USA.
E-mail addresses: wu.jianyong@epa.gov (J. Wu), Jackson.Laura@epa.gov (L. Jackson).

http://dx.doi.org/10.1016/j.scitotenv.2016.07.116
0048-9697/

estimated that there were 88 million people aged 16 years or above who swam in natural waters annually (NSRE, 2004; Collier et al., 2015). However, exposure to pathogens (e.g., *Salmonella* spp., *Shigella* spp., *Cryptosporidium*, *Giardia*, adenovirus and norovirus) in recreational waters can lead to a variety of adverse health outcomes (Craun et al., 2005; Heaney et al., 2009; Soller et al., 2010; Hlavsa et al., 2014). Beach sand can serve as a vehicle for microbial transport from and to beach water, thus affecting human health (Solo-Gabriele et al., 2016; Vogel et al., 2016; Whitman et al., 2014). A common ailment is acute gastrointestinal illness (AGI, e.g., diarrhea). Besides AGI, respiratory illness, rash, eye aliments and earaches have also been reported (Heaney et al., 2009; Sanborn and Takaro, 2013; Wade et al., 2013; Collier et al., 2015). According to data from the U.S. Centers for Disease Control and Prevention (CDC), the outbreaks associated with recreational waters (including swimming pools and small lakes) in the United States have varied from 10 to 90 each year and have displayed an increasing trend since the 1980s (Hlavsa et al., 2014).

To protect public health and reduce the number of outbreaks associated with recreational waters, the Beaches Environmental Assessment and Coastal Health Act (BEACH Act) was passed in 2000, which required beach regulators to develop a formal plan to assess beach water quality and to notify the public if recreational waters are unsafe (e.g., water quality criteria are violated). Based on the Act, *Enterococci* as a microbial indicator for marine waters and either *Escherichia coli* (*E. coli*) or *Enterococci* as an indicator for freshwaters are monitored and assessed. These two types of bacteria are common indicators for fecal pollution (Ashbolt et al., 2001; Committee on Indicators for Waterborne Pathogens, 2004; U.S.EPA, 2003; Wu et al., 2011) and may be associated with waterborne illness (Cabelli et al., 1979; Wade et al., 2006). Accordingly, one class of beach advisories or closures is issued contingent on whether the concentrations of these indicators exceed recreational water quality criteria. Beach monitoring and advisories are important public health measures to protect beachgoers and swimmers from exposure to pathogens, thus reducing the number of recreational water-related illness (Nevers and Whitman, 2010; Rabinovici et al., 2004).

High levels of microorganisms in water often follow extreme weather events. A clear relationship between heavy rainfall and deterioration of beach microbial water quality has been observed in southern California as well as in Florida (Ackerman and Weisberg, 2003; Brownell et al., 2007). Besides extreme weather events, the proximity of certain land uses to beaches may also have great influence on beach water quality. Microbial contaminants that lead to beach closures and human illness come mainly from land, either from discrete point sources or from diffuse non-point sources (Efstratiou, 2001; Marsalek and Rochfort, 2004). Several land use types, including forest, grassland and wetland, may reduce the transport of microbial contaminants from land to water through their function of filtration, an ecosystem service. For example, wetlands can effectively remove microorganisms from wastewater (Guan and Holley, 2003; Hill and Sobsey, 2001). Recently, studies have suggested there are positive associations between certain land uses (e.g., urban and agricultural areas) and microbial water contamination (e.g., Bradshaw et al., 2016; Cloutier et al., 2015; Didonato et al., 2009; Gotkowska-Płachta et al., 2016; Liang et al., 2013; Schreiber et al., 2015; Smith et al., 2001; Verhougstraete et al., 2015; Wu et al., 2016). It is also well known that the percentage of impervious cover (e.g., roads, parking lots, rooftops) in a watershed has impacts on water quality (Brabec et al., 2002; Long and Plummer, 2004), with observable water quality degradation when imperviousness is 10% or greater (Brabec et al., 2002). As a result, it is expected that land use will have considerable influence on beach microbial water quality. However, to date, studies on impacts of land use on beach microbial contamination are rare, and few researchers are aware of the relationship between land use and beach closures.

In this study, we investigated 10 years of beach closures for >500 beaches in the United States. The objectives of this study were to characterize the spatial distribution and temporal trend of beach closures in the United States, to examine the relationship between land use and beach closures, and to examine the association of beach closures with land use change. This is the first assessment of the impacts of land use and its change on beach closure decisions, which provides important information for understanding the potential benefit of ecosystem services and sustaining beach water quality through natural habitat management.

2. Method

2.1. Beach closure data

Beach closure data were obtained online through EPA's Beach Advisory and Closing Online Notification (BEACON) system. In the BEACON database, beach closure information has been recorded for >1000 beaches since 2000 and up to 6000 beaches by 2015. Each beach was given a geographic location, identification number, beach status, length and other information. For each beach action, the action type, start date, end date and reasons were recorded. In this study, we selected all data on beach closures due to elevated bacteria from 2004 to 2013. Because most beach closures occur during summer season, we focused particularly on beach closures during June, July and August to examine the associations of beach closures and land use and its change. In total, 536 beaches were included in the study (Fig. 1).

2.2. Land use data

The National Land Cover Database (NLCD) 2006 and NLCD 2011 were used to obtain land use information for these beaches. NLCD datasets were generated based on the classification of Landsat imagery with a spatial resolution of 30 m (Fry et al., 2011; Homer et al., 2015). For these beaches, 8 major classes (water, developed land, barren land, forest, shrubland, herbaceous, planted/cultivated, and wetlands), and 15 subclasses were identified. Considering different ecosystem functions of these classes, we reclassified the land use into 9 classes, including water, open land (open developed land, e.g., golf courses, airports), urban, barren land, forest, shrubland, grassland, agriculture and wetland, by dividing developed land into open land and urban area (Table 1). Agriculture includes cultivated crops and pasture, which may comprise areas of grasses used for livestock grazing. In the grassland class, the areas of grasses are not subject to intensive management but may be used for grazing.

2.3. GIS processing for land use calculation

A point layer was created for the beaches of interest based on their centroids using ArcGIS 10.3 (ESRI, CA) and then matched with NLCD 2006 and NLCD 2011 images with appropriate map projection (Albers Conical Equal Area projection). Two methods were used to calculate land use components around each beach. First, around each beach centroid, buffers with the radii of 2 km, 5 km and 10 km were created and used to clip both NLCD 2006 and NLCD 2011 images. The percentage of each land use class was calculated in each buffer. These three radii were chosen because land use components may vary with area and these radii present small, medium and large landscapes, respectively, around beaches.

In the second method, we linked each beach to a sixth-level hydrologic unit using its unique hydrologic unit code (HUC). We then calculated the percentage of each land use type in that hydrologic unit. A sixth-level hydrologic unit (HUC12) is a subwatershed delineated by USGS according to surface hydrologic characteristics using a standard hierarchical system. The HUC12 map was obtained from the National Hydrography Dataset (NHD) Plus, Version 2 (Moore and Dewald, 2016).