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Environmental indicators of oyster norovirus outbreaks in coastal waters

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ABSTRACT

This paper presents an artificial intelligence-based approach to identifying environmental indicators of oyster norovirus outbreaks in coastal waters. It was found that oyster norovirus outbreaks are generally linked to the extreme combination of antecedent environmental conditions characterized by low water temperature, low solar radiation, low gage height, low salinity, strong wind, and heavy precipitation. Among the six environmental indicators, the most important three indicators, including water temperature, solar radiation and gage height, are capable of explaining 77.7% of model-predicted oyster norovirus outbreaks while the extremely low temperature alone may explain 37.2% of oyster norovirus outbreaks. It is, therefore, recommended that water temperature in oyster harvesting areas be monitored in the cold season and particularly the extremely low temperature during a low gage height be used as the primary indicator of oyster norovirus outbreaks. The findings are of profound significance to reducing the public health risk of norovirus outbreaks associated with consumption of oysters.

1. Introduction

Norovirus is an extremely contagious virus (Hall et al., 2011) involving six genogroups (I-VI). GI and GII (particularly genotype GII.4) are responsible for most shellfish-related norovirus outbreaks (Campos and Lees, 2014; de Graaf et al., 2016; Patel et al., 2009). Climate change-induced extreme weather conditions might cause transnational epidemics and the emergence of new norovirus strains due to high infectivity and efficient transmission of the virus (Rohayem, 2009; Siebenga et al., 2009). While it has long been recognized that oysters are one of norovirus sources (Le Guyader et al., 2006; Wang and Deng, 2012, 2016), the environmental conditions controlling oyster norovirus outbreaks has rarely been reported due to the lack of effective methods for the detection of norovirus contamination in large oyster growing areas (open coastal waters). As a result, norovirus has been a constant and worldwide threat not only to the public health but also to the shellfish industry. In terms of the threat to the public health, norovirus is the cause of half of all gastroenteritis outbreaks worldwide (Hall et al., 2011) and it causes 58% of foodborne illnesses in a typical year in the United States. In addition, norovirus imposes $2.3 billion in economic burden in a typical year due to deaths, non-hospitalized cases, and hospitalizations in the United States alone (Hoffmann et al., 2015). In terms of the threat to the shellfish industry, oyster norovirus outbreaks often force closures of oyster beds for an extended period (generally three weeks to a couple of months) and subsequent nationwide or even worldwide recalls of implicated oysters. For instance, unprecedented oyster norovirus outbreaks from January–April 2017 in the Pacific Northwest made hundreds of oyster consumers sick in Canada and the U.S.A. (http://www.kingcounty.gov/depts/health/communicable-diseases/disease-control/outbreak/oysters.aspx; https://norocore.ncsu.edu/an-ongoing-norovirus-outbreak-tied-to-oysters-in-british-columbia). Similar epidemic incidence and oyster recalls are reported almost every year and a single nationwide oyster recall may cost millions of dollars (http://www.nola.com/environment/index.ssf/2013/01/oysters_soon_might_never_cause.html).

While oyster norovirus outbreaks are generally attributed to failing septic systems, malfunctioning wastewater treatment plants, stormwater runoff, dumping of boat sewage waste, and vomiting overboard near shellfish beds (Burkhardt and Calci, 2000; Flannery et al., 2012; Goblick et al., 2011; Le Guyader et al., 2006), specific causes of individual oyster norovirus outbreaks were rarely reported and frequently considered "mysterious." The authors' research group (Shamkhali Chenar and Deng, 2017; Wang and

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Deng, 2016, 2012) found that six environmental factors, including precipitation, temperature, solar radiation, gage height, wind, and salinity, affect oyster norovirus outbreaks. However, the specific environmental conditions, which trigger oyster norovirus outbreaks, remain unclear. The primary objective of this paper is to identify the most important environmental indicators and critical environmental conditions controlling oyster norovirus outbreaks. The indicators could be used to develop a predictive model for supporting the risk control.

2. Methods

2.1. Data collection and processing

Various datasets used in this paper were collected for important oyster harvesting areas along the Gulf Coast of Texas, Louisiana, and Mississippi, including 30 areas in Louisiana, the Copano Bay and the San Antonio Bay in Texas, and Area 2C in Mississippi, the United States (U.S.). Specifically, historical norovirus outbreak records, associated with the consumption of raw oysters, were collected through the Louisiana Department of Health and Hospitals (http://www.dhh.louisiana.gov/), the U.S. Food and Drug Administration (https://www.fda.gov/), and Centers for Disease Control and Prevention (https://www.cdc.gov/) (Table 1). Corresponding time series environmental data from 1996 to 2014 were gathered for six independent environmental variables, including water temperature (T), solar radiation (SR), gage height (GH), salinity (S), rainfall (R), wind speed and direction (W). These environmental predictors were selected because they control oyster norovirus outbreaks (Shamkhali Chenar and Deng, 2017; Wang and Deng, 2016, 2012). The National Water Information System (Mapper) of U.S. Geological Survey (USGS) (https://maps.waterdata.usgs.gov/mapper/index.html) was used for collection of daily data (including daily maximum, minimum, and mean) for water temperature, gage height, and salinity along the Gulf Coast. The daily data can be downloaded on the USGS Mapper by selecting a site (such as 073745275) located in an oyster growing area, clicking "Access Data" and then "Daily Data", checking the boxes next to Temperature (Max., Min., Mean), Gage height (Max., Min., Mean), and Salinity (Max., Min., Mean), selecting "Begin date" and "End date", and finally clicking "GO" button. Likewise, the data for daily precipitation, hourly wind speed and direction were obtained from the Climate Data Online portal of the National Oceanic and Atmospheric Administration (NOAA) National Centers for Environmental Information (https://www.ncdc.noaa.gov/cdo-web/). The daily precipitation data can be downloaded on the website by clicking Data Tools > Find a Station, entering "Louisiana" in the box Enter Location, selecting "Daily Summaries" under Select Dataset and then " Precipitation" under Data Categories and "Date Range" under Select Date Range. By selecting the desired station along the Gulf Coast and clicking ADD to Cart, the daily precipitation data in CVS format can be sent to the entered email address. Similarly, the hourly data for wind speed and direction can be gathered from the Climate Data Online portal by clicking Data Tools > Marine Data and selecting the data range and the area of interest, and pressing "Search" button. Finally, wind data are sent to the entered email address after clicking the station, specifying the date, and certifying the data. The wind data are also accessible on the NOAA TIDES CURRENTS webpage (https://tidesandcurrents.noaa.gov/stations.html?type=Meteorological+Observations). Data can be downloaded by selecting the station, clicking "Data Inventory", selecting "Wind", entering data range, unit, interval, and finally pressing "Data only" button. Solar radiation data (total solar radiation) were downloaded from the Louisiana Agriclimatic Information System website (http://weather.lsuagcenter.com/charts.aspx?r=2). The hourly data can be downloaded on the website by clicking on Reports > Hourly summary, selecting the station name, start and end date, and finally pressing "Go" button. Data can be downloaded as CSV or Excel formats by clicking on the corresponding icons. The data for daily maximum, daily minimum, daily change, and daily average of individual environmental predictors were derived from the hourly time series data. The data were then normalized using feature scaling to a range of 0–1 to eliminate effects of datum at different data source stations.

Wang and Deng (2016) found that offshore wind can increase the concentration of norovirus in oyster growing waters by enhancing the transmission of virus from the land to the sea and reducing water depth over oyster beds. In order to quantify the effect of the site-specific onshore/offshore wind on norovirus outbreaks, a dimensionless wind direction index was defined such that the wind direction index is 0 for all onshore wind directions while the wind index varies from 1. 0 (if the wind direction is perpendicular to the shoreline) to 0.0 (if the wind direction is parallel to the shoreline) for offshore wind directions. Since the wind direction index varies in the range of 0.0–1.0 for any offshore wind directions, the combined effect of wind speed and direction on norovirus outbreaks is described with a single variable: the product of wind speed and wind direction. The product is simply defined as wind.

2.2. Selection of potential environmental indicators for oyster norovirus outbreaks

Screening of important environmental indicators of oyster

Table 1
Reported norovirus outbreaks in oyster growing areas along Gulf of Mexico coast.

Dataset	Outbreak period	Location
Data used in model development	25 January 1996–23 February 1996	Area 6 and 7, Louisiana
	22 December 1996–3 January 1997	Area 6 and 7, Louisiana
	1 March 2002–31 March 2002	Area 1, Louisiana
	12 March 2002–28 March 2002	Area 6 and 7, Louisiana
	1 February 2007–24 February 2007	San Antonio Bay, Texas
	10 December 2007–21 December 2007	Area 3, Louisiana
	16 November 2009–25 November 2009	San Antonio Bay, Texas
	6 March 2010–24 March 2010	Area 7, Louisiana
	20 March 2010–25 March 2010	Area 3, Louisiana
	27 March 2010–30 March 2010	Area 13, Louisiana
Data used in model validation	5 January 2009–14 January 2009	Area IIC, Mississippi
	24 February 2009–5 March 2009	Area IIC, Mississippi
	26 April 2012–8 May 2012	Area 23, Louisiana
	28 December 2012–4 January 2013	Area 30, Louisiana
	26 December 2013–9 January 2014	Copano Bay, Texas