Exploring climate change impacts on respiratory illnesses arising from red tides in Florida Gulf Coast with economic analysis

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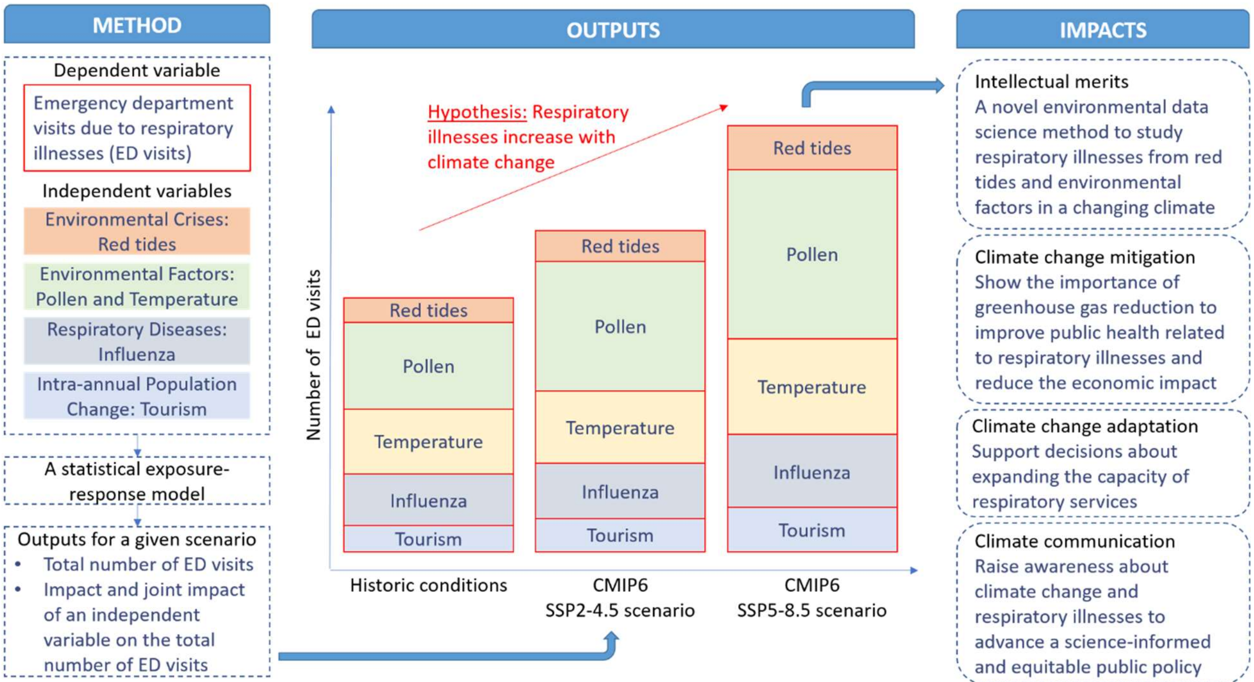
Visual Abstract



Respiratory illnesses due to environmental factors such as red tides, pollen, and temperature are expected to increase under CMIP6 scenarios of moderate emissions (SSP2-4.5) and high emissions (SSP5-8.5)

Project Summary

Background. Understanding impacts of climate change on respiratory illnesses arising from red tides, which are marine harmful algal blooms (HABs), is important but challenging research. Red tides result in potent brevetoxins, which are linked to respiratory illnesses in humans. Epidemiologic studies show that aerosolized brevetoxins are linked to upper airway disease and chronic and acute bronchitis. The cost of illness due to red tide events leads to significant economic impacts on public health. Yet impacts of climate change on respiratory illnesses related to red tides (and HABs in general) have not been well understood.

Objective. The study objective is to understand the scale of increase of respiratory illnesses arising from red tides in a changing climate, given interactions with other environmental factors that are pollen and temperature. These enable assessment of economic impacts of respiratory illnesses associated with red tides and pollen, as these economic impacts have not been well understood and quantified.

Methods. To study respiratory illnesses associated with red tides under future climate scenarios, we will develop a statistical exposure–response model to express the relationships among respiratory illnesses with several variables that are red tide events, pollen, air temperature, influenza, and tourism. Our preliminary research results show that these variables can explain the number of respiratory-specific diagnoses in the emergency department. Based on the model, we will explore future conditions based on three scenarios of red tide bloom levels: low, medium, and high. We will also project pollen and air temperature under two shared socio-economic pathways (SSP) scenarios of the Coupled Model Intercomparison Project Phase 6 (CMIP6). These SSP scenarios represent different greenhouse gas scenarios as well as mitigation and adaptation preferences. Subsequently, we will conduct an economic analysis based on the marginal costs and lost productivity of illness to quantify respiratory illnesses costs associated with red tides and pollen.

Outputs. This project will provide a novel approach of environmental data science that captures the interrelations between red tides, pollen, and temperature, and their individual contribution to respiratory illnesses under climate change scenarios. Future trends of respiratory illnesses arising from red tides and pollen will be produced for the Florida Gulf Coast and the associated costs will be quantified under different climate scenarios. The project findings will be disseminated not only to the scientific community, but also to the public through a climate communication campaign.

Impacts. While the field of HABs and public health has matured with respect to historic conditions, health impacts due to HABs are unclear as climate change intensifies. The project will address this gap and consider the joint impacts of HABs and other environmental factors in alignment with the National Academy of Medicine's Grand Challenge on Human Health and Climate Change. The proposed environmental data science method will advance knowledge about respiratory illnesses arising from red tides and pollen in a changing climate and can be readily adopted at many locations with red tide occurrence. The proposed research is needed for understanding how reduction in greenhouse gas emissions can improve public health with respect to respiratory illnesses arising from environmental factors such as red tides, pollen, and temperature. Understanding these future trends and the scale of associated economic losses is needed to make rational choices about climate change mitigation. Additionally, this will assist the health care sector to make informed decisions about expanding the capacity for respiratory services and other adaptation measures particularly for higher risk groups. Moreover, the project will train two graduate students at Florida Gulf Coast University and Florida State University. The students will work in an interdisciplinary project that connects climate change, environmental factors, epidemiology and public health, and economics. The project will help raise awareness about climate change and public health, which is imperative for advancing a sound science informed and equitable public policy.

Project Description

1. Introduction

Climate change poses a profound threat to public health. Driven by factors like fossil fuel combustion, land-use changes, and industrial activities such as steel and cement production, the resulting increase in greenhouse gases (GHGs) is causing global warming. This is leading to rising air temperatures, increased surface-ocean heat content, acidification, deoxygenation, melting glaciers, sea-level rise, intensified storms, and altered vegetation patterns. Collectively, these changes threaten essential determinants of public health, including clean air, safe drinking water, sufficient food, and secure shelter (World Health Organization, 2021). This proposal specifically addresses the impacts of climate change on air quality and the associated costs to public health in coastal regions. It focuses on respiratory illnesses linked to marine harmful algal blooms (HABs), particularly red tides, in the West Florida Shelf—a region highly vulnerable to sea-level rise, hurricanes, and extreme rainfall (Balaguru et al., 2022; Gori et al., 2022; Maliva et al., 2021).

Red tides, caused by the dinoflagellate Karenia brevis, are a significant public health concern in Florida and other coastal regions. This toxic protist produces brevetoxins, potent neurotoxins that can cause respiratory irritation when inhaled via aerosolized sea spray. These toxins are linked to respiratory conditions such as bronchitis, pneumonia, and asthma (Abdullah et al., 2022; Fleming et al., 2009; Kirkpatrick et al., 2006). The economic impacts of these health issues, especially in terms of emergency department visits, are well-documented (Hoagland et al., 2009). However, while there is substantial understanding of the relationship between red tides and respiratory illnesses, the future impacts of climate change on these illnesses and their associated economic costs remain poorly understood and inadequately quantified (Diaz et al., 2019; Hoagland et al., 2009, 2014; Kouakou & Poder, 2019).

We hypothesize that climate change will exacerbate respiratory illnesses linked to red tides, driven by increased HABs and interactions with other environmental factors such as pollen and air temperature. Historical data show that public health impacts from HABs have risen since the 1980s due to climate-driven changes like warming, deoxygenation, and eutrophication, with regions like the Texas Coastal Bend experiencing a significant increase in red tide frequency (Bindoff et al., 2019; Tominack et al., 2020; Wells et al., 2020). These trends are predicted to worsen, particularly in vulnerable communities, due to the increasing frequency, intensity, and duration of HABs (Gobler, 2020; Hallegraeff, 2010, 2010). Additionally, climate change-induced increases in air temperature and pollen levels are significant risk factors for respiratory diseases, as shown by studies linking large temperature ranges and pollen to higher incidences of bronchitis and asthma (D'Amato et al., 2014; Figgs, 2020; Pesce et al., 2016; Xie et al., 2017; Zhang & Steiner, 2022). Understanding these combined effects is crucial, as factors like red tide cell counts, air temperatures, pollen, and influenza outbreaks significantly influence respiratory-related emergency visits (Hoagland et al., 2009). Despite this understanding, there remains a critical gap in predicting how these interactions will evolve under future climate scenarios, which is essential for effective public health planning.

We propose an environmental data science approach to advance knowledge about respiratory illnesses arising from red tides under changing climate conditions. Like Hoagland et al. (2009), we hypothesize that there is a relationship between respiratory illness visits to hospital emergency departments (ED visits) and red tides, as well as other environmental factors like pollen, air temperature, influenza prevalence, and tourism. While historic data provide evidence for the increasing public health impacts from HABs over the past several decades(Bindoff et al., 2019), the future impacts of climate change on these illnesses are poorly understood. A novel aspect of this proposal is that we will consider respiratory illnesses arising from red tides, environmental factors like temperature and pollen, and their combined effect in the context of advances in climate change research.

This study examines the impact of red tide bloom levels and other socio-environmental factors on respiratory illnesses under different climate pathways. This study examines scenarios of red tide bloom levels and other socio-environmental factors with respect to respiratory illnesses, under different climate pathways. Quantitatively projecting the distribution of red tides is challenging due to the uncertainty in how diverse climate drivers will interact(Ralston & Moore, 2020). To address this, we will explore future red tide conditions based on three framed scenarios of bloom levels: low, medium, and high. A framed scenario is an exploratory scenario that describes "what could happen?"(Maier et al., 2016). The proposal also addresses the challenge of projecting relevant environmental factors that control respiratory illnesses (such as pollen and air temperature) using shared socio-economic pathways (SSP) scenarios from the Coupled Model Intercomparison Project Phase 6 (CMIP6). SSP scenarios are predictive scenarios that describe "what will happen?" (Maier et al., 2016). Specifically, we will project pollen and air temperature under SSP2-4.5 and SSP5-8.5 scenarios. The numbers 4.5 and 8.5 represent radiative forcing levels, or the difference between the amount of energy entering and leaving the atmosphere, under these scenarios. SSP2 is the "Middle of the Road" scenario, representing medium challenges to mitigation and adaptation, while SSP5 is the "Fossil-fueled Development – Taking the Highway" scenario, representing high challenges to mitigation and low challenges to adaptation(Riahi et al., 2017). This study will be one of the pioneering efforts to use CMIP6 scenarios to study the relationship between temperature, pollen, and respiratory illnesses. To integrate the socio-environmental factors, this study will develop a statistical exposure–response model to predict respiratory illnesses based on these socio-environmental factors and will conduct cost analyses for these scenarios. This is to evaluate the economic impact of increased respiratory illnesses under varying climate conditions.

Leveraging this environmental data science approach, our research questions include:

- Will climate change increase the costs of respiratory illnesses arising from red tides given different bloom levels?
- What are the potential trends of respiratory illnesses in the Florida Gulf Coast caused by pollen under different climate scenarios?
- What are the potential trends of respiratory illnesses in the Florida Gulf Coast due to increased air temperatures under different climate scenarios?

This study will not only address these questions, but also pave the way for future research on the combined impacts of multiple environmental factors on public health.

The primary objective of this research is to quantify the impact of climate change on respiratory illnesses associated with red tides and other environmental factors in the West Florida Shelf. This includes:

- Developing statistical exposure–response model that predicts respiratory illnesses given different socio-environmental factors including red tides, pollen, air temperature, influenza, and tourism.
- Assessing the influence of climate change on key environmental factors like red tides, and pollen air temperature, and their combined effect with red tides on respiratory health
- Estimating the potential economic costs associated with these health impacts.

This novel approach will provide critical insights into the public health risks posed by climate change and inform strategies to mitigate these impacts, including the potential benefits of reducing GHG emissions on public health.

2. Method

Methods. We will use a statistical exposure–response model to explore the hypotheses about the relationship between respiratory illnesses and bloom events based on ED visits (Hoagland et al., 2009)

$$ED_t = f(\mathrm{H}_{\mathrm{t-1}}, W_t, D_t, T_t, \varepsilon_t) \quad (1)$$

where t indexes time interval; ED is the number of ED visits due to respiratory illness in a local hospital; H is the red tide cells counts in the study area; W is a vector of environmental and weather variables, which are pollen and air temperature; D is a measure of regional respiratory disease outbreaks that is influenza; T is a measure of intra-annual population change, which is due to tourist visits; and ε_t is the residual errors. The Granger causality test will be used is a statistical hypothesis test for determining whether one time series is useful in forecasting another. Equation (1) is solved using vector autoregression (VAR), which is a statistical model that captures the relationship between multiple variables change over time. We will use VAR(p) with automatic selection of lag p. All variables are endogenous variables, such that each variable is determined by its relationship with other variables. As such, we can estimate the contribution of each variable (i.e., red tide cell counts, pollen, and air temperature) to the total number of ED visits. We will conduct this analysis from 2005 to 2014 using historic data for all variables. Using a sample of one-year data and the Python module statsmodels for statistical modeling, we developed and tested the VAR(p) model in Eq.1 (https://bit.ly/HABs-Health). Historic data will be used to parameterize the statistical exposure-response model to be used for future projections, and Figure 1 shows the inputs and outputs of the projects.

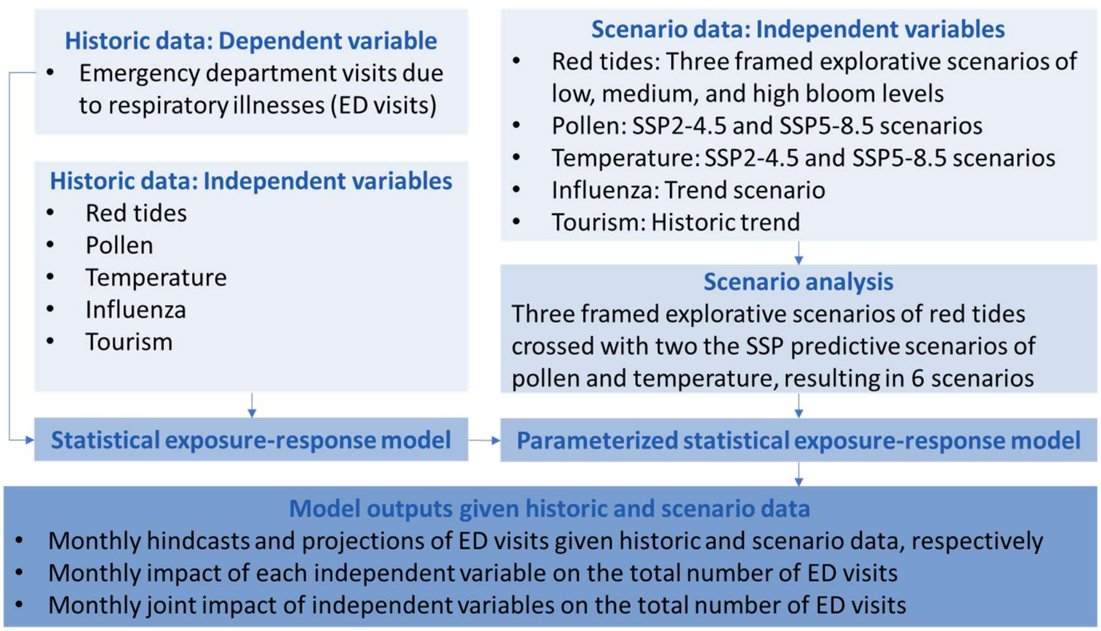


Figure 1. Data, models, and outputs of historic and scenario analyses

We will forecast monthly ED visits from 2015 – 2100, which will be aggregated as five-year averages. From 2015 to 2100 we will use three bloom levels of low, medium, and high, based on historic data with a five-year period. This is following the bloom level definition of Maze et al. (2015) and the concentration levels of Florida Fish and Wildlife Conservation Commission - Fish and Wildlife Research Institute (FWC-FWRI, 2022b). For air temperature and pollen, we will use CMIP6 scenarios of SSP2-4.5, and SSP5-8.5. We will use a five-year period of historic data to present future tourism activities. We will trend historic influenza outbreaks for future conditions based on data from Liu et al. (2020), which illustrates that in some regions of northern mid-latitudes in a warming climate, rapid weather variability in autumn will continue to strengthen. This suggests increased risk of 20% to 50% for influenza outbreaks in some highly populated regions (Liu et al., 2020). For future conditions, we will use a five-year corrected historic data of influenza. We will use non-trended influenza data for comparison. Using the model in Equation (1), we will forecast ED visits from 2015 – 2100 for the six scenarios that are three bloom level scenarios crossed with two CMIP6 scenarios for air temperature and pollen (Figure 1). As such, we can compare the future change in ED visit trends for the six scenarios.

To understand the economic impact of respiratory illnesses, we will estimate the cost of illnesses as the sum of marginal costs of ED visits and lost productivity during illness period based on hospitalized and recuperate days (Hoagland et al., 2009, 2014). We will consider respiratory ailments due to aerosolized brevetoxins during the historic period, and due to pollen during the historic and future periods. However, this model can be used in later projects to estimate future cost of respiratory ailments due to aerosolized brevetoxins, based on predictive red tide scenarios. As a proof-of-concept study, this project will only consider ED visits, and a in later study we can additionally account for hospital inpatients.

Data. The study area is Sarasota County, Florida. Data for implementing Equation (1) in the study area will be processed at a monthly interval for the historic period (2005-2014) and future period (2015-2100). We collected daily ***ED visit data*** from Sarasota Memorial Hospital (SMH), which is the closest hospital to the coastline in Sarasota County and serves about 63% of the county's population (Hoagland et al., 2009). ***Red tide data*** are referred to as cell counts of Karenia Brevis collected from 2005 to 2022. This publicly available data can be downloaded from NOAA Harmful Algal Blooms Observing System (HABSOS, 2022), and the continually updated database can be requested from FWRI (FWC-FWRI, 2022a). The fact that cell count data are generally based on event responses sampling and can be non-systematic and non-uniform, was considered in bloom data analysis (Elshall, 2021). ***Pollen data*** were obtained as daily pollen counts, which is pollen grains per cubic meter of air for the period of 2005 to 2015 from the American Academy of Allergy, Asthma & Immunology. The data are collected using the Burkard 7-day pollen collector in the regional sampling station at the University of Florida, Gainesville. For future pollen data, we will extract the Sarasota County data from the dataset of Zhang and Steiner (2022), which is projected pollen magnitude over the continental US under the SSP2-4.5, and SSP5-8.5 scenarios. Daily average air ***temperature data*** was obtained from the New Pass Weather Station (27.19°N, 82.34°W), where the data are publicly available from 2004 to present (Mote Marine Laboratory, 2022). Near surface air temperature for scenarios SSP2-4.5, and SSP5-8.5 will be obtained for Sarasota County from the NASA Earth Exchange Global Daily Downscaled Projections archive (NEX-GDDP, Thrasher et al., 2022). We will use the outputs of all available downscale projections for different global climate models with a simple ensemble average. For ***influenza data***, we will obtain weekly influenza virus outbreaks data for the South Atlantic Region from the U.S. Centers for Disease Control and Prevention (CDC) from 2005 to 2015. The data is a measure of the percentage of specimens testing positive for influenza within a particular week, and the data is available for the epidemic period of October through May based on the assumption that the minimal outbreaks periods have little or no influenza cases(Hoagland et al., 2009). For ***tourism data*** we obtained monthly data on Sarasota County monthly hotel occupancy rates and the number of units by lodging type from 2005 to 2015 from the Sarasota Convention and Visitors Bureau. Assuming two residents per unit, we obtained a monthly estimate of the temporary resident population by summing the number of occupants in all units. We will have access to all the data needed for the project.

3. Expected results, previous support, and timeline

Deliverables. ***Dataset creation****:* A comprehensive dataset showing the trends of economic costs associated with respiratory illnesses arising from red tides in the study area from 2005 to 2100. This will be provided under three bloom levels across SSP2-4.5 and SSP5-8.5 scenarios for environmental variables such as pollen and air temperature. Additional datasets depicting the trends of respiratory illnesses and associated economic costs arising from pollen in the study area, under the same scenarios and time frames. ***Publications and presentations****:* At least one peer-reviewed publication in a high-impact journal like *Science of the Total Environment* or *Environmental Health Perspectives*. A conference abstract submission to the American Geophysical Union (AGU) Annual Meeting, a leading conference in Earth science research. ***Public engagement****:* A public awareness and climate communication campaign, including a blog post, a ResearchGate project, a 5-minute YouTube video summarizing the project, seminars at Florida Gulf Coast University (FGCU) and Florida State University (FSU), and coverage by media outlets through The Water School at FGCU.

Outputs. ***Research findings****:* Detailed analysis of the relationship between red tides, pollen, air temperature, and their impact on respiratory illnesses in the Florida Gulf Coast, providing new insights into how these factors interact under different climate scenarios. Quantified projections of respiratory illness trends and economic impacts from red tides and pollen through 2100 under varying climate pathways.

Outcomes. ***Enhanced understanding****:* A deeper understanding of how climate change will affect respiratory illnesses related to red tides and pollen, informing public health strategies and resource allocation. New knowledge that will support the healthcare sector in planning and expanding respiratory services, particularly for at-risk populations.

Impacts. ***Policy and public health implications****:* The research will contribute to policy discussions by providing evidence on the potential benefits of greenhouse gas (GHG) emissions reductions on public health. The findings will help policymakers and stakeholders make informed decisions regarding climate change mitigation and adaptation strategies, with a particular focus on public health. ***Educational and professional development****:* This project will train two graduate students in interdisciplinary research, combining environmental data science, Earth system modeling, epidemiology, and public health economics, thereby enhancing their career prospects and contributing to the future workforce in these fields. The project will foster collaboration between FGCU and FSU, creating a model for interdisciplinary research that bridges gaps between climate science, public health, and economics.

Previous support. This project will leverage on an existing National Science Foundation (NSF, Award # 1939994, 2019 - 2023) project about red tide modeling using Earth system models (Elshall et al., 2022a, 2022b, 2022c). The NSF project has a very limited scope with respect to health impact assessment. We collected and analyzed respiratory illnesses data from a regional hospital.

Timeline. The contribution of the PI at FGCU (Elshall), Co-PI at FSU (Ye), Co-PI at FSU (Harrington), one graduate student at FGCU (G1), and one graduate student at FSU (G2) are as follows.

Task	**2023**		**2024**	
	Q3	**Q4**	**Q1**	**Q2**
(1) Process red tide data (Elshall, and G1)				
(2) Process data of ED visits, influenza, and tourism (Ye, and G2)				
(3) Process pollen data (Elshall, and G1)				
(4) Process temperature data (Ye, and G2)				
(5) Conduct data analysis using VAR model (Elshall, Ye, G1, and G2)				
(6) Conduct economic analysis (Harrington, G1, and G2)				
(7) Prepare journal paper, conference abstract, outreach campaign (All team)				
(8) Prepare annual report (Elshall)				

Contingency plan. ***Data availability and quality:*** Insufficient or low-quality data for pollen could compromise the study's period, which can be addressed by reducing study period or using machine learning to estimate missing data or enhance the resolution of existing datasets. ***Methodological challenges:*** Another risk is that the statistical exposure–response model may not perform as expected due to complexities in modeling the interactions between multiple socio-environmental factors, which can be addressed by exploring other modeling approaches such as machine learning and engaging with statisticians to refine the approach. ***Graduate students' recruitment:*** There might be a difficulty in finding a graduate engineering student at FGCU with the necessary interest or data science skills, which can be addressed by expanding recruitment to students from water school, computer science or mathematics, who may have the necessary data science skills. If there is an interested candidate who lacks data science expertise, we will provide targeted training to build the required skills.

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