Predicting NO2 concentrations

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Abstract

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1. Introduction

NO_2 is defined by the U.S. Environmental Protection Agency (EPA) as a criteria air pollutant, meaning it poses a risk to human and environmental health. The primary National Ambient Air Quality Standard (NAAQS) for NO2 is set at a 53 ppb annual average [1]. NO2 can cause respiratory irritation and can aggravate respiratory diseases such as asthma (US EPA, n.d., B). NO2 can also react with other chemicals in the atmosphere to form both particulate matter (PM) and tropospheric ozone (US EPA, n.d., B). PM and ozone are also criteria air pollutants and are harmful to human health. NO2 also contributes to the formation of acid rain, smog, and nutrient pollution in coastal waters (US EPA, n.d., B). The primary source of NO2 emissions is fossil fuel combustion, particularly from traffic and power plants (US EPA, n.d., B).

Therefore, understanding and predicting the spatial variability of NO2 emissions is of great importance to public health. However, prediction of air quality can be complicated due to the number of factors that affect local air quality, ranging from meteorology to land use. Machine learning models are a useful tool to interpret and find relationships in complex data.

[introduce Bechle study...] Bechle et al (2015) explores the impact of.. [Grace please add here]

This report proposes a machine learning model to predict NO2 concentrations spatially. First, a literature review was undertaken to understand what machine learning models have typically performed well in predicting air quality. Next, an exploratory data analysis (EDA) was performed on the Bechle et al (2015) dataset. Finally, multiple linear regression, neural network and random forest models were built and results were compared to see which method had the lowest mean-squared error (MSE).

2. Methods

2.1 Literature Review

There are a number of studies examining how machine learning models can be used to predict air quality. Seven studies were examined as part of this literature review, and can be broadly categorized into 2 areas: predicting PM2.5 and predicting the Air Quality Index (AQI)/ Air Pollution Index (API). One exception is that one of the studies examining AQI also predicted NOx concentrations.

2.1.1 PM2.5

Chen et al (2018) explored the use of random forest models to predict PM2.5 concentrations spatially in China and compared them to multiple linear regression and generalized additive models. Random forest models are non-parametric learning algorithms, and have been shown to have high accuracy. While the study began with a large number of predictors, these were narrowed down to ground-based measurements, satellite retrieved AOD data, urban cover data and meteorological data.The random forests model had the greatest predictive power of all the models considered, with a RMSE of

28.1 µg/m3 on a daily scale (R2 = 83%), improving to 10.7 µg/m3 (R2 = 86%) and 6.9µg/m3 (R2=86%) on monthly and annual time-scales, respectively.

Xu et al (2018) likewise considered a number of machine learning models for PM2.5 prediction in British Columbia, Canada. 8 models were examined in this study: 1) multiple linear regression (MLR), 2) Bayesian Regularized Neural Networks (BRNN), 3) Support Vector Machines with Radial Basis Function Kernel (SVM), 4) Least Absolute Shrinkage and Selection Operator (LASSO), 5) Multivariate Adaptive Regression Splines (MARS), 6) Random forest (RF), 7) eXtreme Gradient Boosting (XGBoost), and 8) Cubist.The predictors included humidity, temperature, albedo, normalized difference vegetation index (NDVI), height of the planetary boundary layer (HPBL), wind speed, distance to the ocean, elevation, and calendar month beside the ground level monthly averaged PM2.5 data collected from 63 stations between 2001 to 2014 as well as 3km resolution AOD data from MODIS. This study found that the cubist model had the highest accuracy (RMSE =2.64 microg/m3 and R2=0.48) and the the MLR had the lowest accuracy (MSE = 3.24 µg/m3 and R2=0.22). The predictors with the most influence were monthly AOD and elevation.

Enebish et al (2020) considered 6 different machine learning models for PM2.5 prediction in Mongolia: 1) RF, 2) gradient boosting, 3) support vector machine (SVM) with a radial basis kernel, 4) multivariate adaptive regression splines (MARS), 5) generalized linear model with elastic net penalties (a type of MLR), and 6) generalized additive model. These models were run for annual data, cold season and warm season. Parameters considered were air pollution monitoring data, meteorology, land use and population. Across all time periods, the RF had the best R2 and RMSE values. Over the entire period using the hold-out test set, RF had a RMSE of 12.92 (R2 = 0.96), and the cold season and warm season had RMSE of 21.23 (R2 = 0.92) and 7.44 (R2 = 0.84), respectively.

A common limitation of all three studies is the volume of missing data. In Chen et al (2018), the model had only two years of ground-based measurements to train the model on (2014-2016), and then predicted PM2.5 concentrations for a ten year period (2005 to 2014). Xu et al, 2018 also discussed the challenge of missing data, averaging hourly and daily measurements where available to monthly concentrations to use in model development. Finally Enebish et al, 2020 discussed there being few air quality monitoring stations and insufficient data to well represent the high seasonal variability of PM2.5 concentrations.

Additionally, all studies considered meteorology when constructing the machine learning model. The dataset in our study does not include meteorology, potentially leaving out an important predictive factor.

2.1.2 AQI/API

2.1.3 Comparison of PM2.5 and AQI/API studies

PM2.5	Both PM2.5 and AQI
MLR (Xu et al, 2018; Enebish et al, 2020; Chen et al, 2018)	**RF** (Chen et al, 2018; Xu et al, 2018; Singh et al, 2013; Liu et al, 2019; Enebish et al, 2020)
LASSO (Xu et al, 2018)	**Neural Network** (Azid et al, 2014; Xu et al, 2018, Gu et al, 2020)
MARS (Xu et al, 2018; Enebish et al, 2020)	**SVM** (Xu et al, 2018; Gu et al, 2020; Liu et al, 2019; Enebish et al, 2020; Singh et al, 2013)
Gradient Boosting (Xu et al, 2018; Enebish et al, 2020)	

PM2.5	Both PM2.5 and AQI
Cubist (Xu et al, 2018)	
Generalized additive model (Enebish et al, 2020; Chen et al, 2018)	
Mixed effects models (Chen et al, 2018)	

2.2 Exploratory Data Analysis

2.3 Model

2.3.1 Multiple Linear Regression

2.3.2 Neural Networks

2.3.3 Random Forest

3. Results

4. Discussion

References

1. **Primary National Ambient Air Quality Standards (NAAQS) for Nitrogen Dioxide**
   OAR US EPA
   US EPA (2016-07-01) https://www.epa.gov/no2-pollution/primary-national-ambient-air-quality-standards-naaqs-nitrogen-dioxide