A Global Investigation of the Relationship between Economic Growth and Air Quality

Introduction

Air quality has been for years one of the major concerns worldwide. According to the statement from World Health Organization, an estimated 4.2 million deaths per year are attributable to ambient air pollution. Currently, only about 9% of the world's population lives in places where air quality levels do not exceed WHO limits.

An interesting phenomenon is that currently, the most severe ambient air pollution events are happening in countries with economic statuses that are not so advanced but are experiencing significant economic growth during the past few decades. Some of the examples include China, Brazil, India, etc. Another interesting phenomenon is that some developed countries have experienced extremely severe ambient air pollution during the 20th century, such as the St. Louis Smog (1939), Donora Smog (1948), and New York City Smog (the 1950s to 1960s) in the U.S., and the Great Smog of London (1952) in the UK. However, the air quality in those developed countries has been improved significantly over the past few decades.

These phenomena make me wonder if ambient air pollution is one of the inevitable by-products that come along with economic growth. Therefore, this project will study the air quality changes worldwide within about thirty years and investigate the relationship of air quality with economic growth at the same time scale. Geo-visualization will be utilized as the primary approach to communicate the data and to reveal the principles behind the phenomenon to viewers.

The intended audience of this project is the general public with varied educational backgrounds as well as professionals with relevant knowledge. Hopefully, whoever is interested in this topic can find some valuable insights in this study.

Currently, there are some studies that aim at revealing the relationship of the economic development and air quality changes. For instance, Dinda et al., (2000) did an empirical study on air quality and economic growth and concluded that a higher per capita income level would cause less pollution. There is a geo-visualization project using observable done by Owen Campbell to study inequality faced by African Americans and other minorities in the U.S. They came to the conclusion that the counties with the best air quality are those with low African American populations (https://observablehq.com/@ocampbe8/a-geographical-look-at-inequality-in-the-united-state). Research done by Chen and Xu (2017) shows that there is not direct environmental Kuznets curve relationship between air pollutant concentration and gross regional product per capita in the provincial capital cities of China. In addition, there are projects that map the changes of an economic or air quality index over decades such as the collaboration project of Global Air (https://www.stateofglobalair.org/contributors) done by the Health Effects Institute (HEI), the Institute for Health Metrics and Evaluation (IHME), and University of British Columbia and the interactive global GDP growth map (https://data.worldbank.org/indicator/NY.GDP.MKTP.KD.ZG?end=2019&start=2019&view=map) developed by the World Bank.

However, the aforementioned studies and projects are either too professional for the general public to understand or fail to take into account both the air quality and the GDP growth. To fill the gap, this project aims at developing a set of geo-visualizations that can display air quality and GDP growth at the same time but also are interactive and user-friendly. Some of the research questions this study intended to answer include what is the trend of annual PM 2.5 exposure in some of the developed countries over the last three decades? Similarly, what is the trend of annual PM 2.5 exposure in some of the developing countries over the last three decades? I am also interested in how the air quality changes over years in countries showing significant economic growth and how the annual GDP growth rate changes in countries with good air quality.

Data and Methodology

There will be three types of data used in this study. The first one is the global air quality dataset. Admittedly, there are many other air pollutants such as ozone and PM10. However, in this study, I will focus exclusively on PM2.5. The mean annual exposure (micrograms per cubic meter) data from 1990 to 2017 for PM2.5 will be obtained from the World Bank (https://data.worldbank.org/indicator/EN.ATM.PM25.MC.M3?end=2017&start=2017&view=map&year=2000). The data downloaded from the World Bank has the records for 1990, 1995, 2000, 2005, and 2010-2017. Instead of working on records of every year in the dataset, I will focus on data in 1990, 1995, 2000, 2005, 2011, and 2017.

The second type of data used in this study is the index that reflects the economic growth of a country. Here, I chose the Annual GDP Growth as it is one of the most widely adopted indexes in economic analyses. This data will also come from the World Bank (https://data.worldbank.org/indicator/NY.GDP.MKTP.KD.ZG?end=2019&start=2019&view=map). I will use the air quality data and the GDP growth data collected in the same year. Finally, the base map of each country comes from the 1:110m Cultural Vectors of Natural Earth Data (http://www.naturalearthdata.com/downloads/110m-cultural-vectors/). The vector data downloaded have to be converted into GeoJSON using QGIS. In this project, most data I will be dealing with are abrupt (when crossing the country border) and continuous. Therefore, Choropleth mapping will be a favorable data visualization approach. Furthermore, in order to show the relationship between PM2.5 concentration and GDP growth, I will display a bivariate choropleth map along with will small multiple choropleth maps to facilitate the comparison of the changes over years and the discovery of trends mentioned in the introduction section. In addition, the year of which the interface shows the map will be determined and changed by the user to be space-saving. It is worth mentioning that data used in this project are already normalized data although without an explicit declaration. For example, it makes no sense to divide the annual GDP growth or PM2.5 concentrations by the population or the area of a country.

User Study

I created a questionnaire to collect feedback from targeted audiences for evaluating the usability of the interactive map. Here, the intended audience refers to those who are experienced in analyzing maps and visualizing geo-information. The questionnaire includes seven questions which can be divided ***into target screening, the user experience with the maps,*** and ***the spatial patterns discovered by users.*** To alleviate the mental burden of the audience, I followed the suggestion from Qaultrics.com to limit the number of text-entry questions to three. Table 1 shows the detail of my questionnaire.

Table 1. Questionnaire for usability evaluation

Question ID	Question	Question Category	Purpose
Q1	How would you describe your level of experience with analyzing maps and geo-visualization?	multiple choice	audience screening
Q2	Have you ever created interactive maps before?	multiple	audience

		choice	screening
Q3	How effective do you think the color pattern of the project is?	multiple choice	user experience
Q4	Can you name three countries with high PM 2.5 exposure and high annual GPD growth in 2017?	text entry	spatial pattern
Q5	Do you find any interesting trends of the PM2.5 and the annual GDP growth in developed countries such as the U.S., Canada, and countries in Western Europe?	text entry	spatial pattern
Q6	Do you find any interesting trends of the PM2.5 and the annual GDP growth in developing countries such as China, India, and countries in Africa and South America?	text entry	spatial pattern
Q7	Do you prefer the bivariate map to the left or the small multiple choropleth maps to the right?	multiple choice	user experience

By the time this paper is finished, I received feedback from nine users. All users indicated that they are very or moderately experienced with analyzing maps and geo-visualization and have created some interactive maps before. Based on the answers to the first two questions, these users satisfy my requirements of the intended audience and therefore their following answers are valid. In question 3, seven users thought the color pattern is extremely or very effective while the other two chose "moderately effective" and "slightly effective" respectively. Due to the limited questions, I was not able to ask for their reasons but was wondering whether it is because of the map size. The colors used in the interactive maps are orange and blue, which should be color-blind safe. In addition, three categories for GDP growth and PM 2.5 along with the black boundary line make the color in each country quite distinguishable. However, because there are too many small countries in Europe and I am showing three world maps on the same page, this makes it a little difficult to recognize each of those small countries in Europe. Similarly, the answers to question 7, where three preferred both the bivariate and small multiple maps, three preferred the small multiple maps, and the other three preferred the bivariate map, are also intriguing. For questions related to spatial patterns, all answers came to the conclusion that developed countries have low to moderate GDP growth while having low PM 2.5 exposure. By contrast, viewers discovered that many developing countries have relatively high values of annual GDP growth and PM2.5 exposures. For instance, for the answer to question 4, they mentioned Egypt, Iran, China, India, Bangladesh, Turkey, etc.

Results and Discussions

The interactive map shows that high annual GDP growth over the last three decades occurred mainly in East, South, and Southeast Asia, Mid- and South Africa, and some countries in South America and Europe. Most countries in East and South Asia such as China and India, have been suffering from high PM 2.5 exposures during the past three decades while experiencing a continuous high GDP growth in the meantime. By contrast, the relationship between the two indexes is not so obvious for many countries in Africa as although they also suffer from poor air quality, they did not have significant GDP growth. This finding indicates that the major reason for the high PM 2.5 exposures for Asian and African countries are not likely to be the same. Some South-Asian countries such as Malaysia and Indonesia, also experienced high economic growth during the past three decades while managed to remain at a low PM 2.5 exposure level. One possible explanation could be the location. As these countries are surrounded by the ocean and near the equator, they receive sufficient precipitation and winds to keep the air clean. Another possible reason could be the industrial structure. Many South-Asian countries depend heavily on tourism-related service industries. Compared to traditional industries and agricultural industries, service industries are much more environmentally friendly and therefore cause far less pollution. Most developed countries in North America, Europe, and Oceania have been having low to moderate annual GDP growth while having the best air quality over the study period. The author believes that this is because those countries experienced their most pollutant developing stages in the mid-20th century. After that, not only did those countries greatly limit the development of high-polluting industries in their mainland but also put great efforts and resources into environment maintenance and repairmen.

Due to limitations to the air quality data, the visualization can only start from 1990 and making the long-term comparison (i.e. comparing from 1960) impossible. As we know, some of the developed countries such as Japan and France showed their highest economic growth during the 1960s to 1970s. The interactive maps could have been more reflective if corresponding data in those years are available. In addition, there are some missing values in the data and they could interfere with further analyses. Also, because the base map and other data do not come from the same source, there are some issues associated with the data connection between the map and the data files that need to be resolved. Last but not least, the impacts of economic growth on the environment including the air quality are not in a real-time manner. For instance, large-scale land-use changes and building factories can have a quick impact on the GDP growth in the same year as soon as the agricultural or industrial activities start. However, the impacts of those activities on the environment won't appear as quickly because only when the accumulated impacts exceed the threshold of the natural adjusting capacity of the environment will we see those impacts. Given the natural adjusting capacity and pace vary significantly among regions, it will be very difficult or even impossible to derive a worldwide relationship between annual GDP growth and its delayed impacts on the environment in this project.

Therefore, building a mathematical relationship between the annual GDP growth and the delayed air quality and determining its pattern worldwide is a great topic for future work. Also, what I learned from the usability evaluation is that it is a good idea to use structured question sets to dig further based on the user's answers to the previous questions.

Reference

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