Mapping PM 2.5 Air Pollution in Texas

Zhipeng Xing

Course Project Report for CE 394K.3 GIS in Water Resources

Fall Semester 2013

Contents

Introduction

Particulate matter, PM, is an air pollutant and is defined as "a mixture of solid and liquid particles suspended in air" by WHO (2013). PM is listed as one of the six common air pollutants by the United States Environmental Protection Agency (USEPA) together with ozone, carbon monoxide, nitrogen oxides, sulfur dioxide, and lead. Particulate matters that are larger than 2.5 μm and smaller than 10 μm in diameter, are defined as "inhalable coarse particles" and denoted by PM 10. Particulate matters that are smaller than 2.5 μm in diameter are defined as "fine particles" and are denoted by PM 2.5.

The pollutant source includes automobile exhausts, soil-fuel burning, cooking/smoking, erosion of roads and many more. PM 2.5, due to its extreme small size, can travel deeply into human respiratory system and reach lungs, causing various adverse health effects. Despite the commonly identified symptoms such as nose/eye irritation, coughing and sneezing, and aggravated asthma, researchers found other shocking and serious health effects. Dockery (et al. 1989) found that inhalable particles are specially more harmful to children and Schwartz (et al. 2002) concluded in his study that by controlling PM 2.5 pollution, less premature mortality would occur.

The public has been paying great attention to PM 2.5 level and different countries/area have set the limits for particulate matters. Table 1 below summarizes the current standards.

Table 1. Current limits for particulate matters.

	PM 10 ($\mu g/m^3$)		PM 2.5 ($\mu g/m^3$)	
	Yearly Average	Daily Average	Yearly Average	Daily Average
European Union	40	50	25	None
Hong Kong	55	180	None	None
Japan	None	100	15	35
South Korea	50	100	25	50
United States	None	150	12	35
WHO	20	50	10	25

Of all the limits, WHO standards are the most stringent. The limits in the United States are set by USEPA.

As the public are getting more and more concerned about our air quality, the goal of this study is thus to gather PM 2.5 information for Texas, and to use GIS as a tool to create a visual representation of PM 2.5 pollution on maps. Upon successful completion of this study, the following objectives should be achieved:

- Create a monthly PM 2.5 pollution map and identify the most polluted areas;
- Identify possible factors that contribute to high PM 2.5 concentration;
- Identify PM 2.5 distribution pattern over a selected study area;
- Find correlation between PM 2.5 concentration and other meteorological parameters (temperature and precipitation); and
- Discuss possible future improvements.

Data Source

The data used in this study was obtained from Texas Commission on Environmental Quality (TCEQ) website (http://www.tceq.state.tx.us/cgi-bin/compliance/monops/select_year.pl). The TCEQ website keeps records of hourly data and they can be downloaded as a table. TCEQ divides Texas into 16 zones and each zone have different numbers of monitoring stations that sample meteorology data. Each monitoring site collects data every five minutes and hourly data are calculated as the average of the five minute data. PM 2.5 data are usually available after 2000.

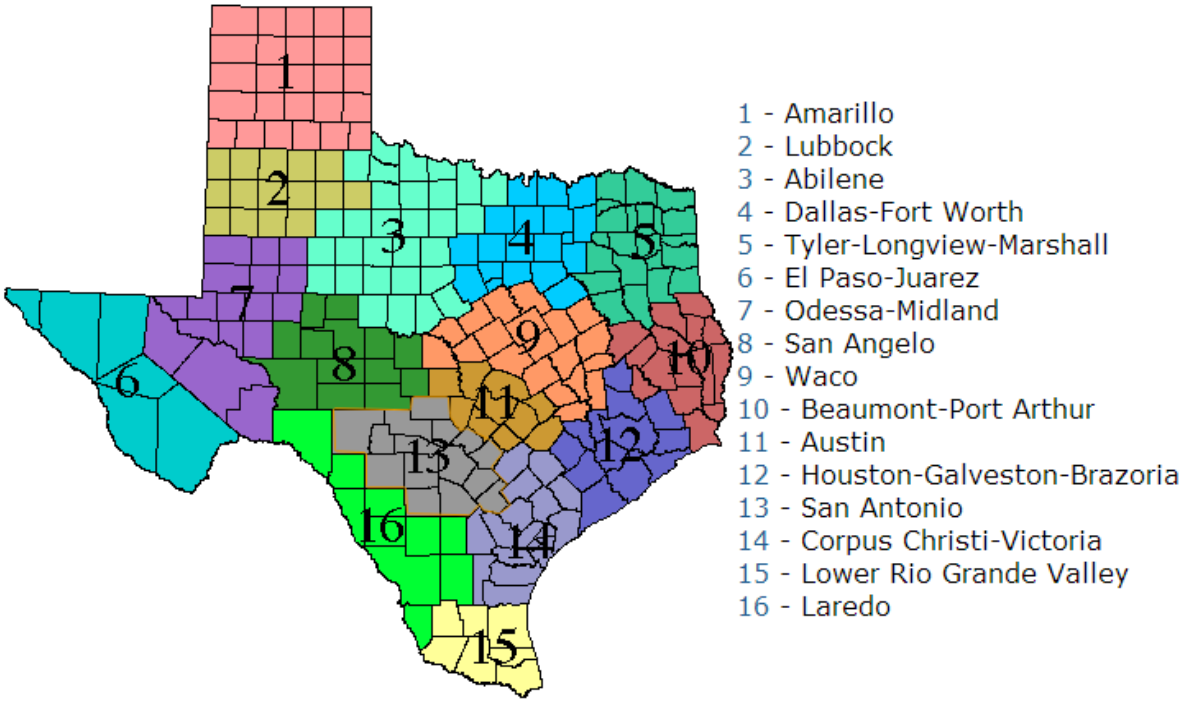

Figure 1. Texas 16 monitoring zones defined by TCEQ.

The number of sites in each zone that samples PM 2.5 data is also different. For example, there are 11 monitoring sites in 12-Houston-Galveston-Brazoria area that collect PM 2.5 data but there is none in 8-San Angelo area. Usually there are more sites monitoring PM 2.5 data in more populated areas such as Houston, Dallas-Fort Worth, Austin, and San Antonio. To evenly represent each area, 18 sites are selected in this study to represent 18 cities/areas and they are shown in Figure 2.

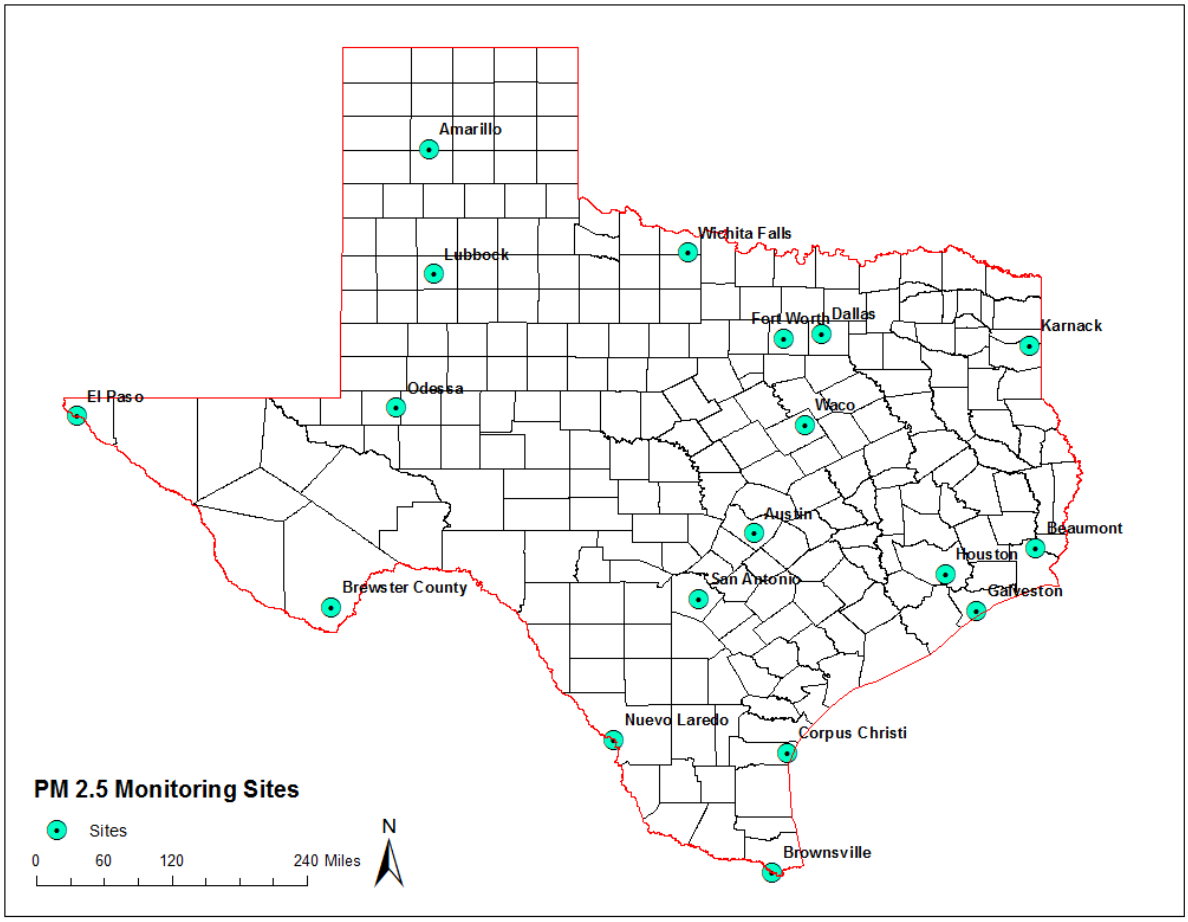

Figure 2. 18 PM 2.5 Monitoring Sites selected for this study.

Results and Discussion

Texas PM 2.5 Monthly distribution 2013

2013 Monthly average data for each site is calculated based on daily data and they are below shown in Table 2. El Paso, Houston, and Nuevo Laredo are the 3 most polluted areas based on the yearly average value. None of these 18 cities/areas reaches the EPA limit of 12 $\mu g/m^3$ on average annually.

As the data obtained from TCEQ website are point data, they are converted to area data by using Interpolation tool (Spatial Analyst Tools) in ArcMap. The interpolation method applied in this study is Inverse Distance Weighted (IDW). The maps generated for each month clearly illustrate the trend in each area as well as for the whole states throughout the year. Figure 3 shows the monthly maps from January 2013 to October 2013.

Table 2. Texas 2013 Monthly PM 2.5 concentration.

City/Area	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Year Ave
Amarillo	4.37	4.45	6.42	6.42	7.19	9.37	7.57	7.73	6.02	4.65	6.48
Lubbock	4.92	5.22	8.54	8.32	9.51	14.28	8.27	8.24	6.62	5.77	7.97
Wichita Falls	5.88	5.01	5.81	6.76	8.23	8.96	9.97	9.35	10.41	6.21	7.73
Fort Worth	8.51	7.04	8.75	9.18	11.10	11.93	11.44	13.40	11.39	7.32	10.15
Dallas	7.71	6.39	7.70	9.49	10.99	11.47	11.16	13.10	11.11	7.14	9.67
Karnack	6.82	6.56	9.55	8.47	8.47	10.51	10.79	12.69	11.41	6.91	9.26
El Paso	9.98	12.91	12.37	19.19	13.56	17.18	9.46	7.80	6.46	7.18	11.82
Brewster County	3.93	3.84	6.50	8.22	7.70	8.85	6.41	6.81	4.30	5.33	6.22
Odessa	5.73	5.46	8.80	9.52	9.88	11.73	8.32	8.75	6.29	6.63	8.18
Waco	5.37	5.37	6.81	8.41	9.34	10.67	10.15	11.93	8.83	6.04	8.76
Beaumont	8.45	8.18	8.73	9.11	9.75	11.10	12.41	11.89	10.68	8.32	10.01
Austin	8.11	6.63	7.94	9.81	10.97	11.11	10.31	11.36	7.19	6.40	9.07
Houston	9.86	9.56	11.25	10.87	10.99	13.18	13.48	13.48	9.77	10.06	11.29
Galveston	7.66	6.79	7.15	6.91	7.83	9.46	8.73	8.53	6.01	4.90	7.46
San Antonio	7.55	6.55	8.27	11.83	13.51	13.26	12.10	12.09	8.17	7.70	10.19
Corpus Christi	6.02	8.94	8.56	9.95	10.82	12.30	10.78	9.94	6.30	5.33	8.93
Brownsville	7.27	10.52	8.72	12.44	13.55	11.72	10.40	10.02	6.13	6.36	9.79
Nuevo Laredo	8.31	8.38	10.83	13.18	17.40	12.70	11.21	10.82	7.10	7.35	10.72
Texas Average	7.02	7.10	8.48	9.89	10.60	11.65	10.16	10.44	8.01	6.65	9.09

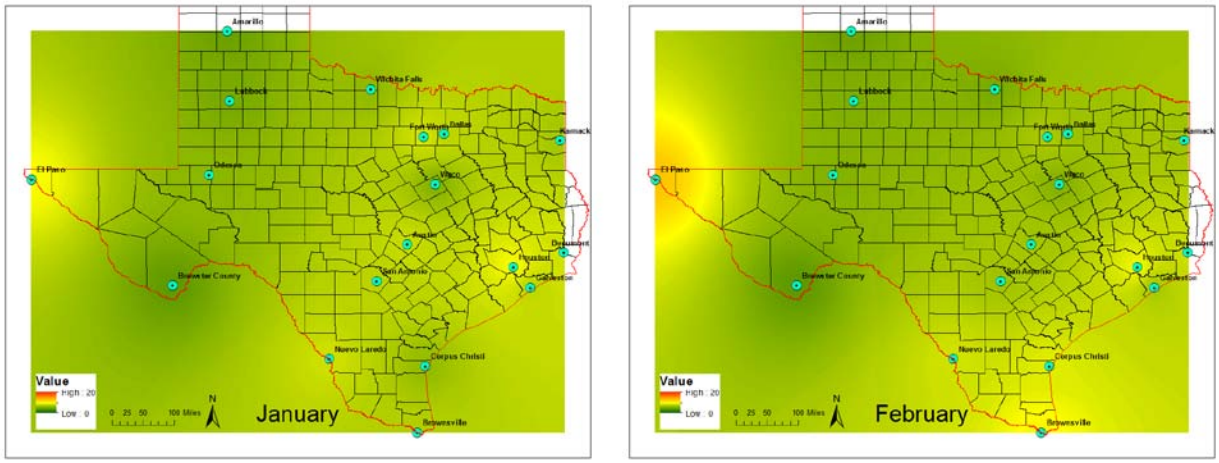

Figure 3. 2013 Monthly (January-October) PM 2.5 maps in Texas.

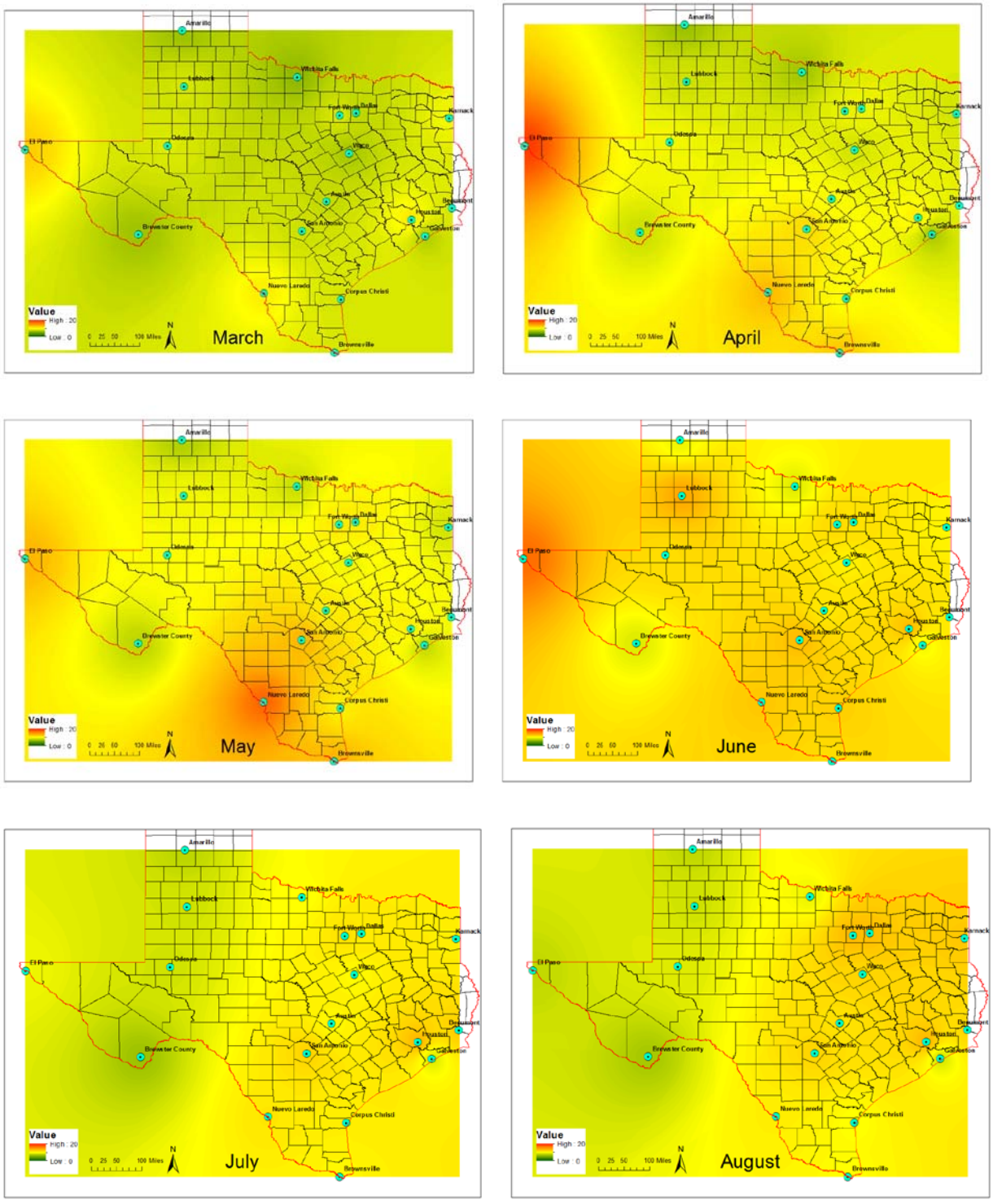

Figure 3. 2013 Monthly (January-October) PM 2.5 maps in Texas. (Continue)

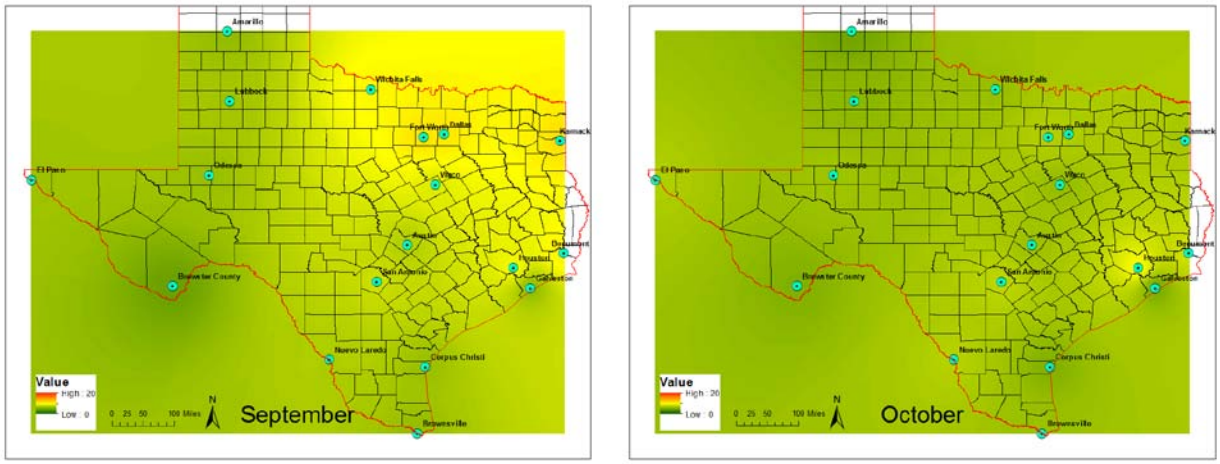

Figure 3. 2013 Monthly (January-October) PM 2.5 maps in Texas. (Continue)

Low PM 2.5 concentration is represented by green and high PM 2.5 concentration is represented by red. From Figure 3, it is obvious that in January, all the areas in Texas have low PM 2.5 concentration (no value higher than 10 $\mu g/m^3$ in any area). Starting from February, the maps start to turn yellow, indicating the increase of PM 2.5 concentration. Most areas become yellow/red in May and June, reaching the highest concentration. In September, the PM 2.5 concentration decreases, the color of the map changing back to green. The maps indicates that the PM 2.5 concentrations are high in the summer months, which is also indicated by Texas monthly average value in Table 2. (link to time series GIF: https://www.dropbox.com/s/fh5kbzinuwyhbyu/AllMonth.gif)

The more polluted areas are easily identified from the maps in Figure 3. The areas that have higher PM 2.5 concentration, indicated by red/yellow, include El Paso, Nuevo Laredo, Dallas, San Antonio, and Houston. El Paso, Nuevo Laredo, and Houston have the highest yearly concentration as shown in Table 2. This is expected by considering the major sources of PM 2.5 being automobile exhausts and human activities. Dallas, San Antonio, and Houston have large populations and more human activities (driving, industry, cooking). PM 2.5 concentration in these more populated cities are thus reasonably higher than other areas. While El Paso and Nuevo Laredo do not have a large population, the PM 2.5 concentrations in these two cities are still among the highest. This is due to the fact that there is heavy traffic going through both cities. Nuevo Laredo is on Texas Mexico border and IH-35 starts there. Trucks carrying goods from one side travel to the other side through the city and they constitute as the major source of PM 2.5 pollution. This is the similar case for El Paso. El Paso is on the border of Texas, New Mexico and Mexico with IH10 going through. Heavy traffic is the major reason that El Paso and Nuevo Laredo have high PM 2.5 concentrations. The lowest concentration is at Brewster County monitoring site (green throughout the year on the maps). This site is located in a scarcely populated area, the Big Bend National Park, so there is least PM 2.5 pollution there.

As mentioned in the introduction, EPA has set a daily average limit of 35 $\mu g/m^3$ and a yearly average limit of 12 $\mu g/m^3$. The PM 2.5 concentration in Texas is within limit in both cases. Nevertheless, there are days that the concentration is higher than 12 $\mu g/m^3$ (hereafter denoted Limit). The number of days over Limit can be used as another tool to identify the seriousness of pollution. Figure 4 shows the population and days over Limit for each city/area. Again, large population is a direct indicator of high

concentration (Houston, San Antonio). Traffic, in the case of El Paso and Nuevo Laredo, is the deterministic factor for PM 2.5 pollution.

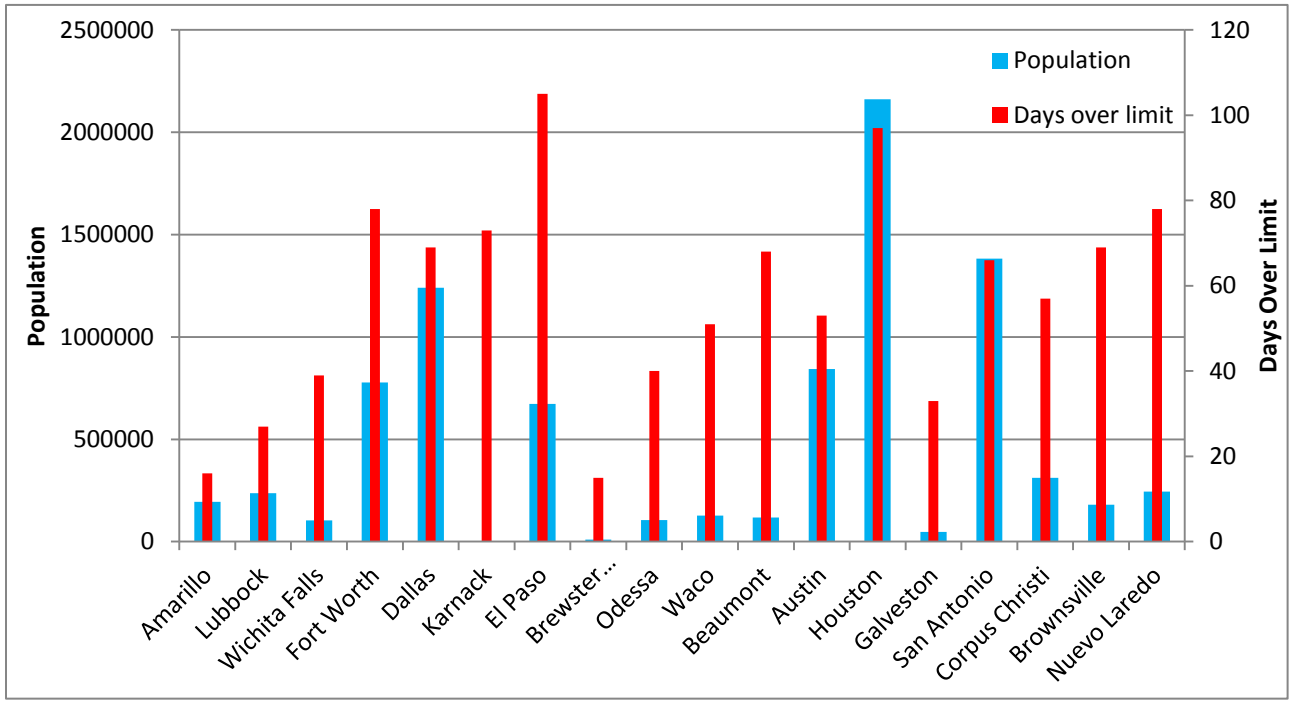

Figure 4. Population and day over Limit for each city/area.

San Antonio PM 2.5 daily/hourly distribution

San Antonio area is selected as the local study area because there are 7 monitoring sites in this area that sample PM 2.5 and these site are spatially more evenly distributed than other areas (e.g., the 11 site in Houston area are clustered in the East side of Houston). Figure 5 shows the 7 monitoring sites in San Antonio area. Two sites are called out for later analysis.

A daily time series map is created using GIS to demonstrate the daily PM 2.5 change at these 7 monitoring sites in September and October (link to video: http://youtu.be/OPGDZa_2sQ8). Higher concentration is denoted by circle with larger diameters and vice versa. The time series shows that for most days, the concentrations at different sites are not significantly different. This suggests that PM 2.5 particles are evenly distributed over this studies area. While in the last section, different areas in Texas have obviously different PM 2.5 levels at a give time, the concentration stays within a much narrower range for the San Antonio area. Sometimes a higher concentration would occur at the sites that are close to the center of the city. As the center of the city is most populated with a lot of traffic, the higher PM 2.5 concentration is expected.

Figure 6 shows the interpolated PM 2.5 concentration in one day at two different time. The uniform color on the maps indicates PM 2.5 concentration is about the same at different site, reaffirm the

fact that in this study area, PM 2.5 is evenly distributed. A possible explanation is that the concentration variation decreases as the area under concern becomes smaller. Another time series map showing hourly change in four days from 10/28/20013 to 11/01/2013 is also created for direct visual representation (link to time series GIF: https://www.dropbox.com/s/anvb59c7ohqp8m1/OctNob.gif).

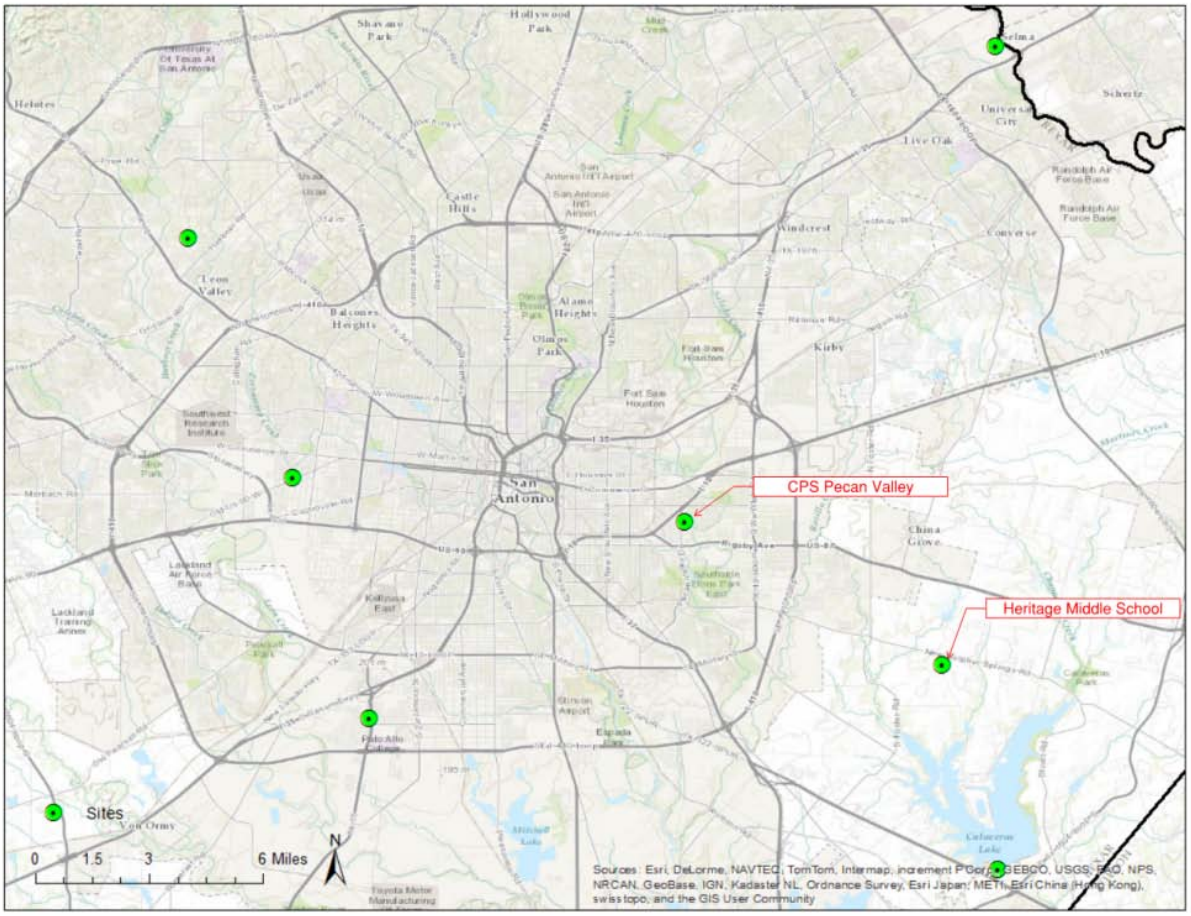

Figure 5. PM 2.5 monitoring sites in San Antonio Area

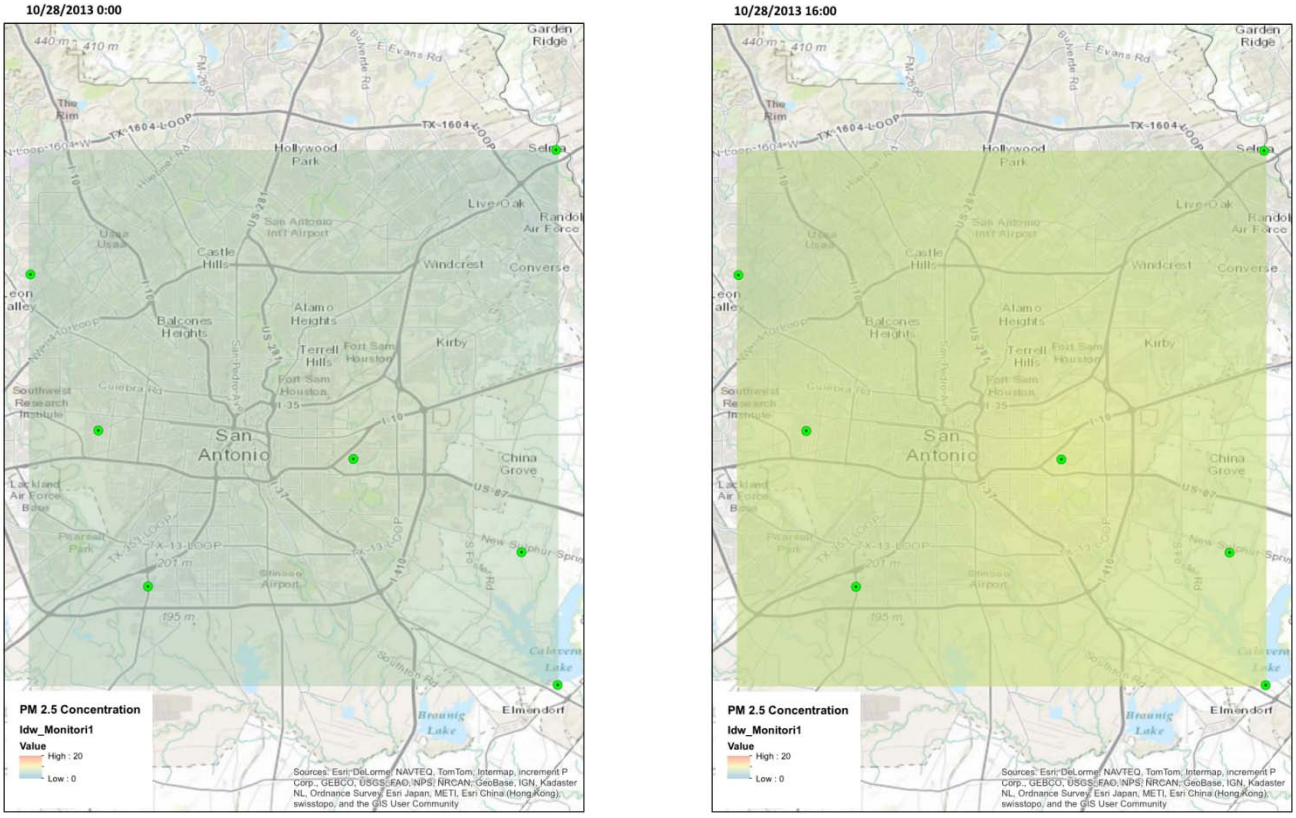

Figure 6. PM 2.5 distribution at two time point 10/28/2013 0:00 and 10/28/2013 16:00

Correlation with Temperature and Precipitation

The monitoring site also samples other pollutants as well as meteorological data. As PM 2.5 is an air pollutant, other meteorology parameters, such as temperature, precipitation, wind speed and direction, and humidity, could have effect/correlation with PM 2.5 concentration. Among all these parameters, temperature and precipitation are selected to investigate their possible relation with PM 2.5 level.

Among the 7 sites in San Antonio area, only two of the sites keep record of temperature and precipitation. As being called out in Figure 4, they are site CPS Pecan Valley and Heritage Middle School. The data of PM 2.5 concentration, temperature, and precipitation for CPS Pecan Valley are obtained and presented in Figure 7 and Figure 8. The figures for Heritage Middle School data is in Appendix A.

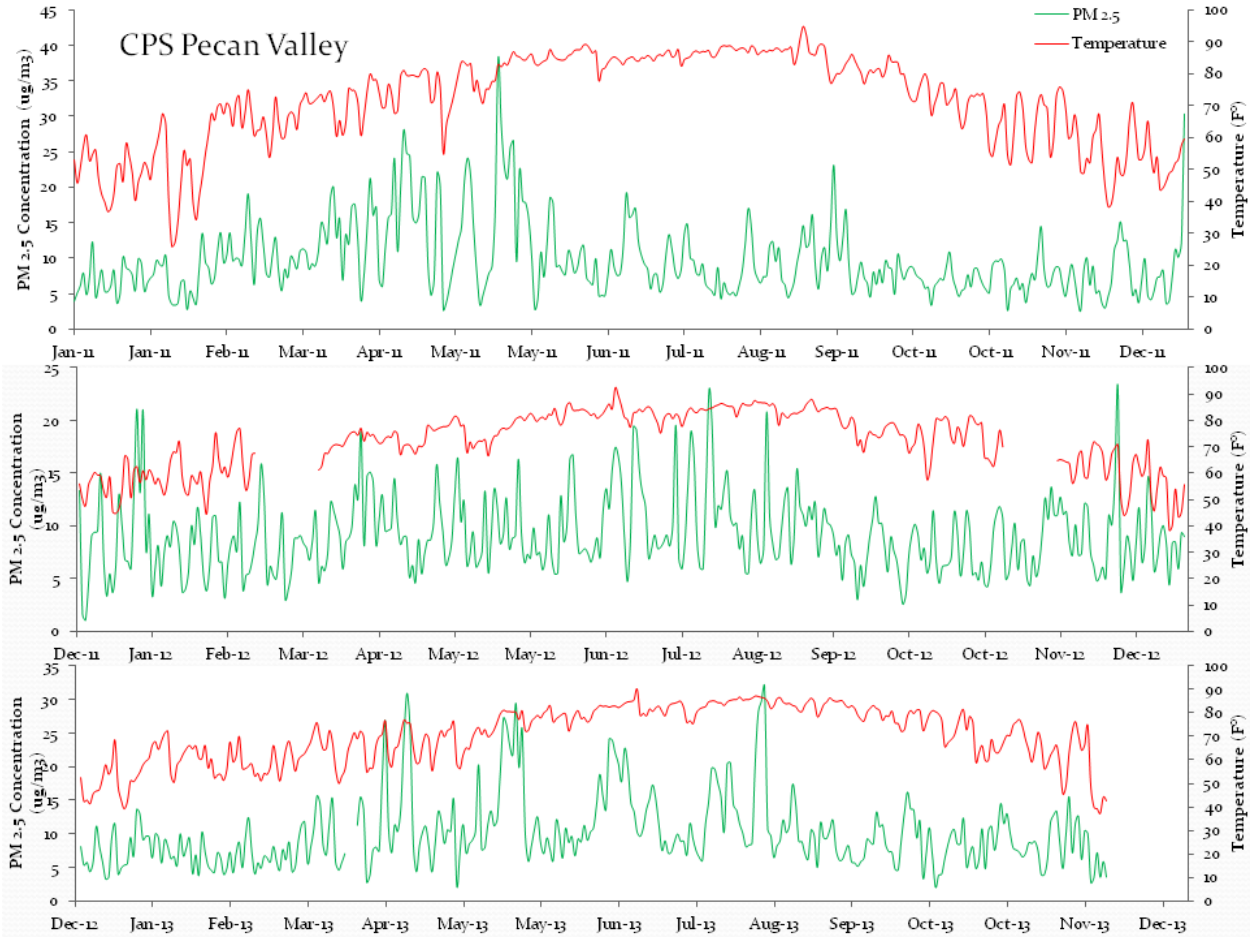

Figure 7. PM 2.5 and temperature at CPS Pecan Valley in 2011, 2012, and 2013.

As illustrated in Figure 6, PM 2.5 concentration fluctuates tremendously on a daily bases. Within one month, the daily average value could be as high as 30 μg/m^3 and as low as 5 μg/m^3. Most peak values of PM 2.5 occur in summer months, when temperature is high. Winter months also see some peak values but at a much lower frequency. The trend in this particle site is very similar to that was identified above for the whole state of Texas: higher PM 2.5 concentration at summer time. It is to be noticed that there are some extreme values for PM 2.5 concentration during May 2011. By counting the days that are above Limit, it is easily found that the more polluted days are in April, May, June, July, and August. The days over Limit for both sites are shown in Table 3. Temperature is thus an indicator of PM 2.5 pollution. When the temperature is consistently high for a period of time, the PM 2.5 level is also high.

Table 3. Days above Limit each month in 2011, 2012, and 2013.

	CPS Pecan Valley			Heritage Middle School		
	2011	2012	2013	2011	2012	2013
January	1	7	2	0	4	0
February	6	1	1	5	1	0
March	**12**	3	3	**11**	2	4
April	**21**	**10**	**9**	**20**	**9**	**7**
May	**18**	**7**	**13**	**18**	**7**	**10**
June	3	**8**	**13**	3	6	**13**
July	**8**	**11**	**13**	**8**	**12**	**9**
August	7	**8**	**8**	**9**	**9**	6
September	5	1	5	6	5	0
October	0	0	3	0	0	0
November	1	4	4	1	0	0
December	6	3	N/A	3	3	N/A

Figure 8 shows the PM 2.5 concentration and the precipitation for the year 2011, 2012, and 2013. The blue peaks represent precipitation and most blue peaks are followed by a dip in the PM 2.5 concentration. Table 4 summarizes how many precipitations there are and how many dips there are following precipitation for both sites in the last three years. About 70% of the time after it rains, the PM 2.5 concentration drops, indicating better air quality. So rain could be a beneficial factor in bringing down PM 2.5 air pollution.

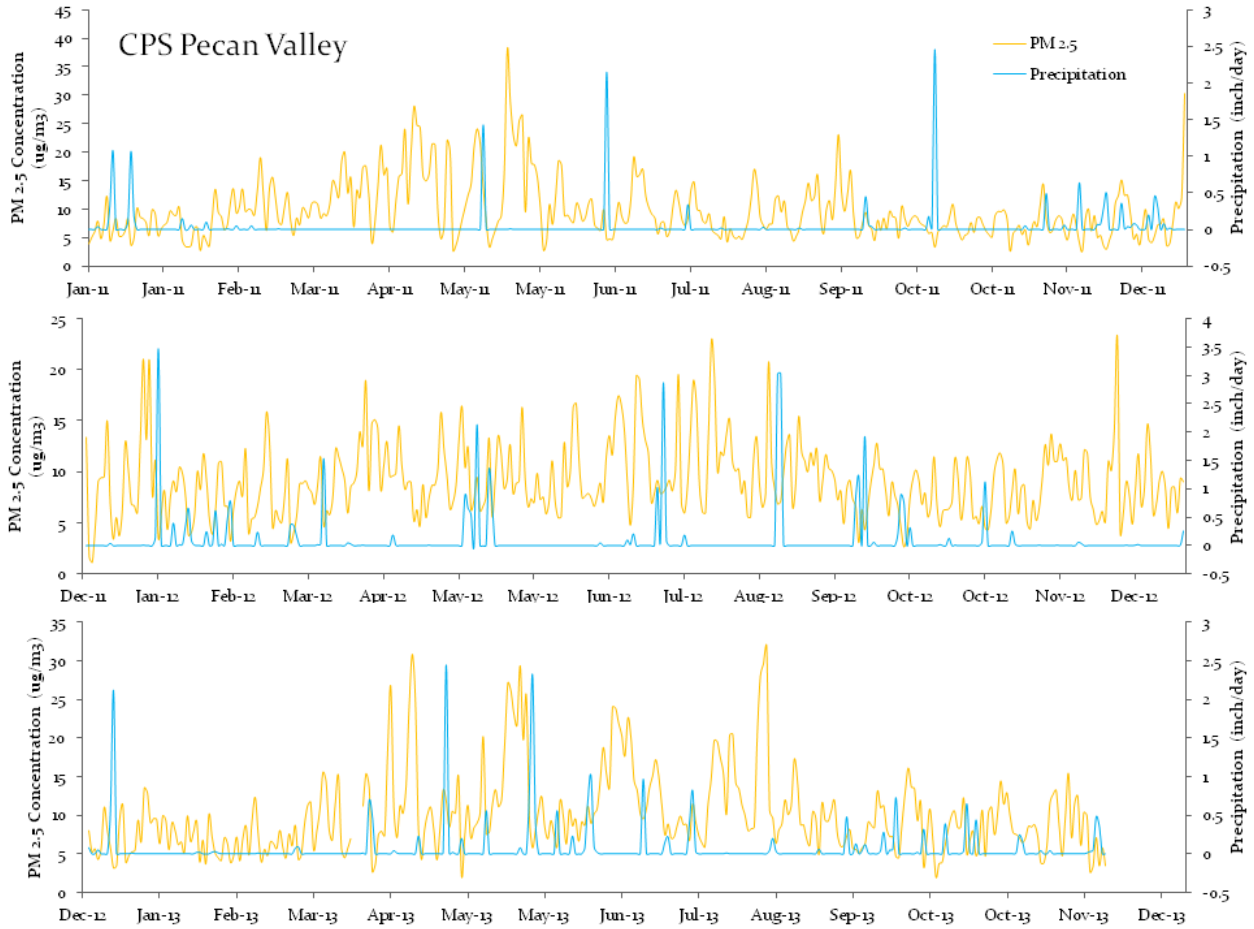

Figure 8. PM 2.5 and precipitation at CPS Pecan Valley in 2011, 2012, and 2013.

Table 4. Precipitation times and dip times in 2011, 2012, and 2013.

	CPS Pecan Valley			Heritage Middle School		
	Precipitation	Dips in PM 2.5	Percentage	Precipitation	Dips in PM 2.5	Percentage
2011	47	33	70%	51	35	69%
2012	79	58	73%	61	47	77%
2013	87	61	70%	76	55	72%

Conclusion

This study employed ArcGIS to create PM 2.5 pollution map for Texas. The yearly average concentration in the selected 18 monitoring sites are well below the USEPA limit of 12 µg/m^3, suggesting that PM 2.5 is not a serious air pollutant in Texas. Houston, El Paso, Nuevo Laredo, Dallas, and San Antonio, these areas are identified as the more polluted areas based on the maps produced as well as the

data available. Large population and heavy traffic are two major contributors to high PM 2.5 level. By looking at San Antonio area, it can be concluded that PM 2.5 concentration do not vary over a smaller area (e.g. a city) at a specific time. Temperature and precipitation are found to be correlated with PM 2.5 concentrations. Higher temperature usually indicates a higher PM 2.5 level and precipitation could contribute to the decrease of PM 2.5 level. ArcGIS in this study proved to be a valuable tool to visualize data and make the digital facts more obvious to the observers.

There are a few future improvements that could be added to this study. As noted by USPEA, wind direction and speed can affect the fate and transport of the particulate matters, so an evaluation of these parameters can help us better understanding the distribution and pattern of PM 2.5. At the same time, though the PM 2.5 level is below the EPA limit, it does not necessary mean that the air quality is satisfactory. For example, the ozone level in San Antonio is at 80 ppb, which is already higher than federal standard at 75 ppb ("TCEQ: Eagle Ford," 2013). An ozone map, could also be developed using ArcGIS by interested parties for further use.

Reference

Dockery, D.W., Speizer, F.E., Stram, D.O., Ware, J.H., Spengler, J.D., and Ferris, B.J., Jr. 1989. Effects of Inhalable Particles on Respiratory Health of Children. *American Review of Respiratory Disease*, 139: pp. 587-594.

Schwartz, J., Laden, F., and Zanobetti, A. 2002. The concentration-response relation between PM 2.5 and daily deaths. *Environ Health Perspect*, 110(10): 1025–1029.

TCEQ: Eagle Ford Gas Pollution Making San Antonio Smog Worse. (2013). Retrieved 12/01/2013 from http://www.downwindersatrisk.org/2013/07/tceq-eagle-ford-gas-pollution-making-san-antonio-smog-worse/

Texas Commission on Environmental Quality (TCEQ) data online. http://www.tceq.state.tx.us/cgi-bin/compliance/monops/select_year.pl

US Environmental Protection Agency. Particulate Matter. Retrieved11/25/2013 from http://www.epa.gov/airquality/particlepollution/index.html

World Health Organization regional office for Europe. 2013. Health Effects of Particulate Matter.

Appendix A. Site Heritage Middle School PM 2.5, temperature and precipitation data.