ESTIMATING PARTICULATE MATTER CONCENTRATIONS (PM10) FROM AEROSOL OPTICAL DEPTH OVER THE EMIRATE OF ABU DHABI, UNITED ARAB EMIRATES

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Abstract: Scientific research on air pollutants, especially particulate matter (PM), have been an active area of investigation in the past few decades. This is particularly so due to their profound health effects. Airborne particulate matter is generally known as the total sum of all solid and liquid particles suspended in the air. They are regarded as complex mixture from both organic and inorganic particles, that can come from smoke, dust, soot or liquid droplets for instance. Many of these air suspended particles are hazardous to humans and can cause series health problems. PM vary greatly in size (usually the aerodynamic diameter) and are traditionally known as coarse and fine particles. Coarse materials usually vary in size between 2.5 - 10 micrometers, usually termed PM10, and are sometimes the result of the breakup of even larger materials. Air quality continuous monitoring has become a challenge in many countries. It has always been achieved with networks of ground monitoring stations and the use of models that evaluate emissions and predict changes in air quality. These ground monitors often miss pollution that is not within the sampling area of the measurement and are unable of capturing pollution for a large spatial domain and as such miss the spatiotemporal variation of air pollutants. Moreover, these ground monitors are expensive and require regular maintenance.

Satellite remote sensing provides an alternative solution for the air pollution point measurements. It has been shown in the literature that there is high level of correlation between atmospheric optical depth (AOD) and PM10 concentrations. The primary objectives of this research are to develop statistical correlation and regression models between satellite data estimated AOD and ground based PM10 measurements over the emirate of Abu Dhabi in the United Arab Emirates. The development of such models, allow the estimation of PM10 levels over a wide spatial area and on continuous daily frequency. For this task the AOD product from the Moderate Resolution Imaging Spectroradiometer (MODIS) (Levy et. al. 2007; Levy et. al. 2015) and ground stations measurements of PM10 were correlated and regressed to develop statistical estimation models. The ground based measurements are provided through an extensive network of field measuring stations well distributed between residential areas, industrial and desert areas spanning the whole study area. The preliminary results show that MODIS AOD are showing reasonably high correlation with ground based PM10 measurements. The resulting regression models were used to generate PM10 maps over the study area. The resulting maps show that areas of small to medium scale industries are portraying the highest levels of PM10 in comparison to desert areas. Urban areas in close proximity to desert surfaces show much higher levels in comparison to urban areas not in such closer proximity. It can be demonstrated that the developed methodology can be effectively used to generate daily PM10 estimates over a wider spatial area on continuous daily basis. Furthermore, this methodology can be used to study the spatio-temporal variation of PM10 over the study area.

Keywords: Aerosol optical depth, particulate matter, air pollution, ground based measurements.

1. INTRODUCTION

Air pollution has become and increasing problem worldwide particularly in areas with high population concentrations, areas with strong industrial activities and also within arid and semi-arid regions. The formation of such air pollutants depends upon the sources of their precursors whether it is natural or anthropogenic. PM10 usually comes from sources such as construction sites crushing or grinding operations, dust mobilized by vehicles on roads and meteorological factors such as fog and fumes. PM2.5 sources are quite diverse as well and include for example combustion from vehicles, power plants, forest fires and some industrial processes. The challenges of meeting air quality standards in any region are impacted by identifying theses sources and further identifying the trans-borders transport of these pollutants.

Furthermore, air pollutants express a wide range of spatiotemporal variations in any one region making it difficult to properly model and predict (Omari et. al. 2019). Identifying the spatiotemporal distribution of PMs would help in the assessment of the population levels of exposure and significantly aid in identifying the sources and formation of air pollutants in the areas.

This study attempts to develop statistical correlation models between the aerosol optical depth and air pollutants over the emirate of the Abu Dhabi in the United Arab Emirates. AOD can be accurately estimated from satellite data, albeit, at a very coarse scales. Several AOD global products exist and are of particular interest for this study. Of great interest to this study is the recently released 1 KM MODIS AOD product is the latest from several much coarser resolution AOD products. This AOD product is used along with ground based measurements of PM10 and PM2.5 to develop statistical correlation and regression models to allow the accurate prediction of air pollutant over the area.

2. STUDY AREA AND DATA

2.1 Study Area

The UAE is located at the north eastern part of the Arabian Peninsula between latitudes 22˚ 50′- 26˚ 4′ N and longitudes 51˚ 5′ - 56˚ 25′ E with a total area of about 83,600 km^2. It is a union made up of seven emirates where the emirate of Abu Dhabi is the largest in terms of land size and population. Regional climate in the UAE includes coastal, mountain, and desert climate along with precipitation scarcity all year around except with sporadic low precipitation rainfall in the winter. Deserts cover a significant portion (about 80 percent) of the total UAE area and are predominantly occupied with different types and shapes of sand dunes. Sand dunes are particularly common in the southern and western parts of the country making them a dominant landscape feature in the UAE.

The emirate of Abu Dhabi (figure 1) is located on the western part of the country and covers an area of 67,340 km² approximately slightly more than 75% of the total country land area. It is bordered by Saudi Arabia from the south and west and Oman from the east. Sand dunes and salt flats are the dominant features in the landscape with isolated mountains along the border with Oman. The emirate includes major urban cities such as the city of Abu Dhabi, the capital city, Madinat Zayed in the west. The emirate is also the major oil onshore hub for the country's production of oil and gas. The dominancy of sand and sand dunes in the emirate makes it frequently exposed to major dust outbreaks that help transporting aerosols. Dust storms could significantly affect air quality by transferring airborne particles and heavy metals like: Pb, As, V, and Se from industrial to residential areas or even across international borders (Farahat et al. 2016).

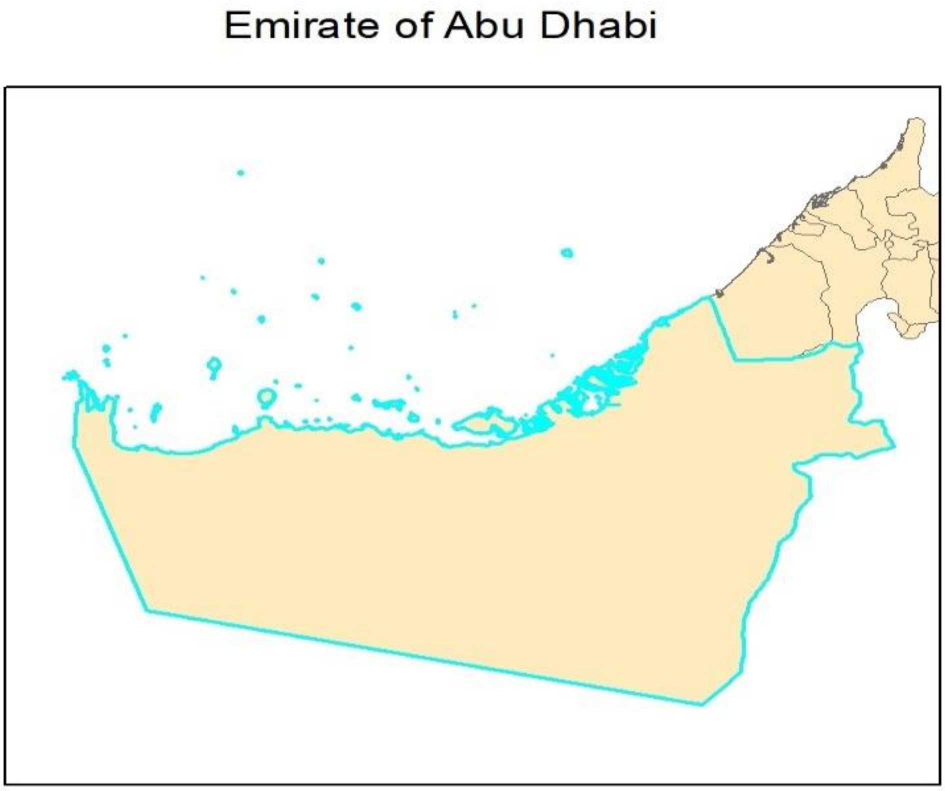

Figure 1: Emirate of Abu Dhabi

2.2 Particulate Matter Data

The PM10 and PM2.5 data was obtained from the Abu Dhabi Environment Agency (AED) measured through its extensive network of air monitoring stations. The network consists of 20 measuring stations spread throughout the emirate of Abu Dhabi and covering major urban population centers within the emirate, cities with low population in addition to stations in close proximity to the major hydrocarbon industry (Table 1).

Table 1: PM10 and PM2.5 Measuring Stations Locations

Station ID	Station Name	Latitude	Longitude
1	Hamdan Street	24.49	54.36
2	Khadejah School	24.48	54.37
3	Khalifa School	24.43	54.41
4	Baniyas School	24.32	54.64
5	Al Ain Islamic Institute	24.22	55.73
6	Al Ain Street	24.23	55.77
7	Bain Al Jessrain	24.40	54.52
8	Khalifa City A	24.42	54.58
9	Zakher	24.16	55.70
10	Sweihan	24.47	55.34
11	Al Tawia	24.26	55.70
12	Al Qua'a	23.53	55.49
13	Liwa Oasis	23.10	53.61
14	Ruwais	24.09	52.75
15	Habshan South	23.75	53.75
16	Bida Zayed	23.65	53.70
17	Gayathi School	23.84	52.81
18	Mussafah	24.35	54.50
19	Al Mafraq	24.29	54.59
20	E11 Road	24.04	53.89

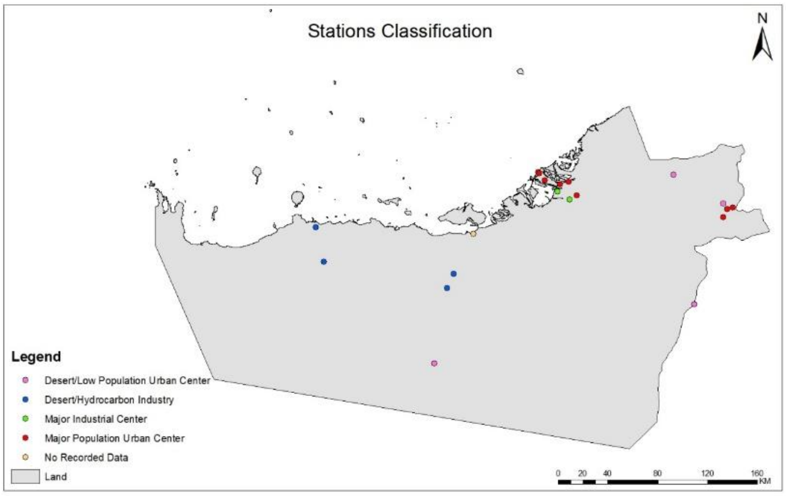

Figure 2: Air pollution monitoring stations locations

2.3 Satellite Data

Several approaches to derive AOD from MODIS data have been suggested in the last decade allowing aerosol monitoring and analysis with high resolution at regional scale. Upon these approaches, the spatial variability of AOD was successfully assessed using the standard MODIS AOD product (MOD04) or Terra and (MYD04) for Aqua using the dark target algorithm (Kaufman et al, 1997 and Levy et al, 2007). The late approach has been complemented with the Deep Blue algorithm (Hsu, 2014) used mainly over bright surfaces such as deserts. The newly advanced multiangle implementation of atmospheric correction (MAIAC) algorithm was developed for AOD retrieval over both bright and dark surfaces from MODIS data at 1 km resolution (Lyapustin et al., 2011). The algorithm uses time series analysis based on spectral regressions in the blue (0.47 mm) and shortwave infrared (2.1 mm) bands taking into account the bidirectional properties of surface reflectance. AOD retrieval using this approach assumes that surface reflectance remains stable considering a time series of 16 days. This can be true in arid region where landcover is almost the same throughout the year. The MAIAC product (MCD19A2) has demonstrated improvement in accuracy over brighter surfaces (Lyapustin et al., 2011). MAIAC data can be freely accessed via NASA LAADS DAAC website (https://ladsweb.modaps.eosdis.nasa.gov). A collection of daily MCD19A2 for the year 2017 is downloaded and used in this study.

3. RESULTS AND DISCUSSIONS

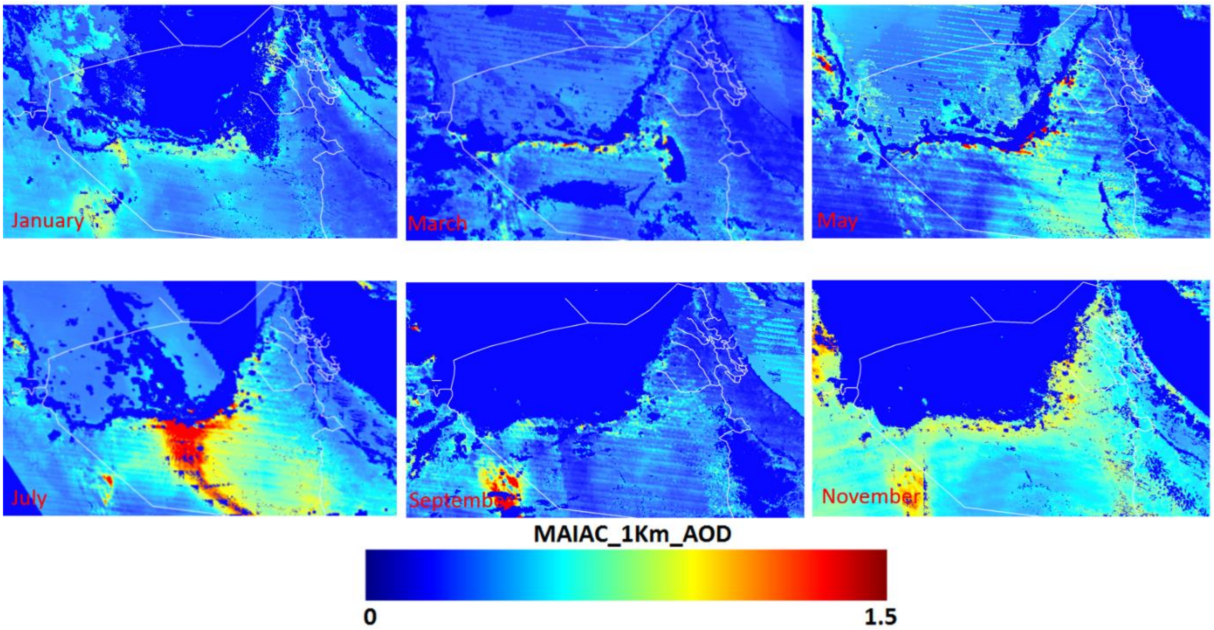

Figure 3: Average monthly AOD over the study area

Figure 3 shows the average monthly MODIS AOD product over the study area for only six months of the year 2017. Careful visual investigation of the MODIS data reveals that AOD is extremely high during the summer, and this should be expected. The study area is predominantly covered with desert surfaces and extensive sand storms activities intensifies during the summer leading to rise in the AOD.

Each air pollution monitoring station was identified in the MODIS image using the stations latitude and longitude. The average monthly PM10 and PM2.5 of each station was correlated with its corresponding AOD. Figures 4 (a-b) and 5(a-b) shows the resulting statistical correlation results.

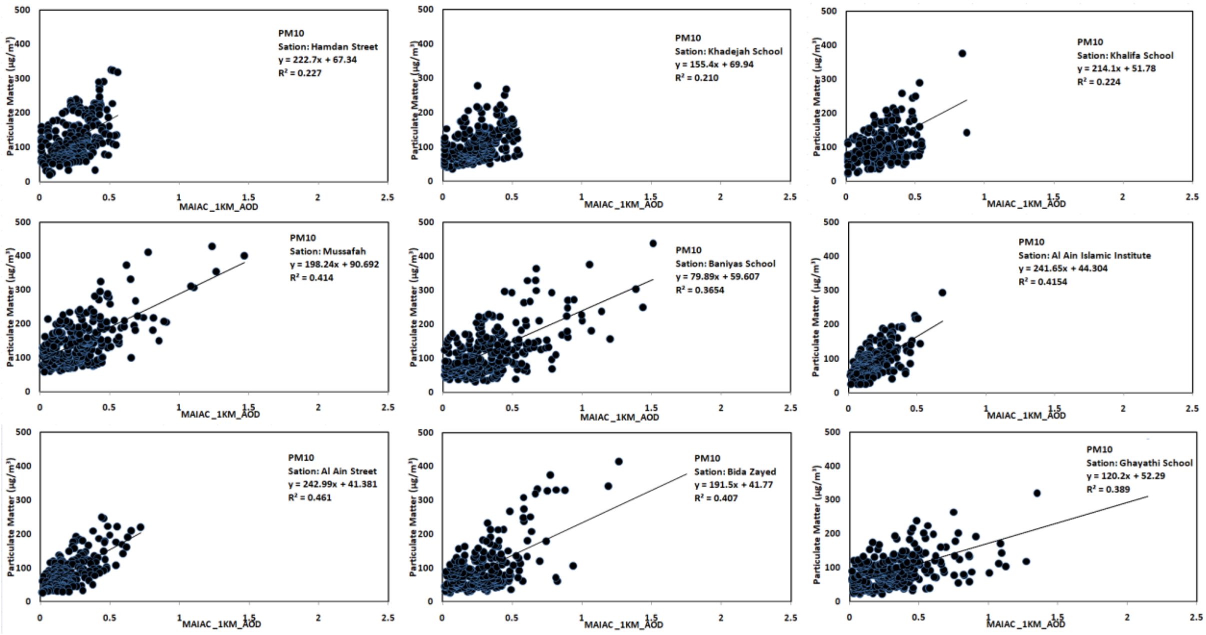

Figure 4(a)

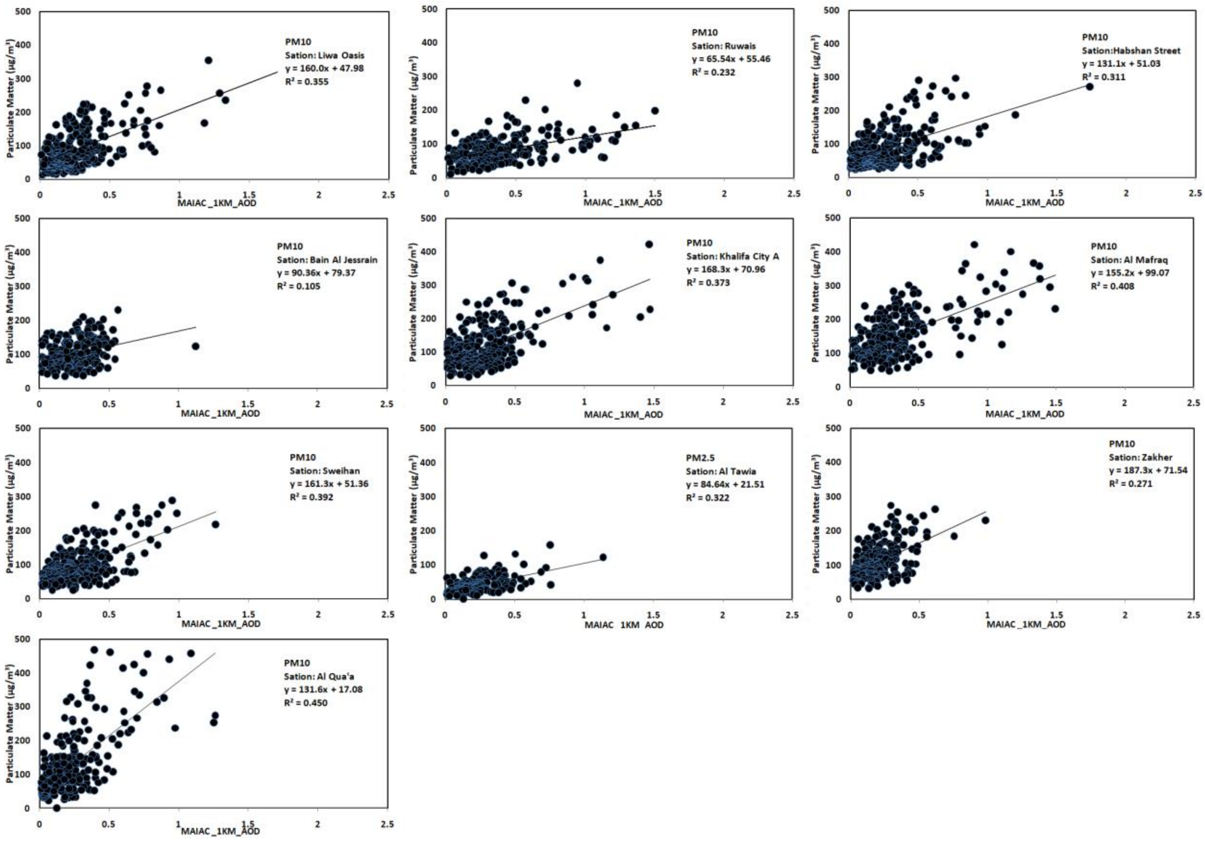

Figure 4 (b)

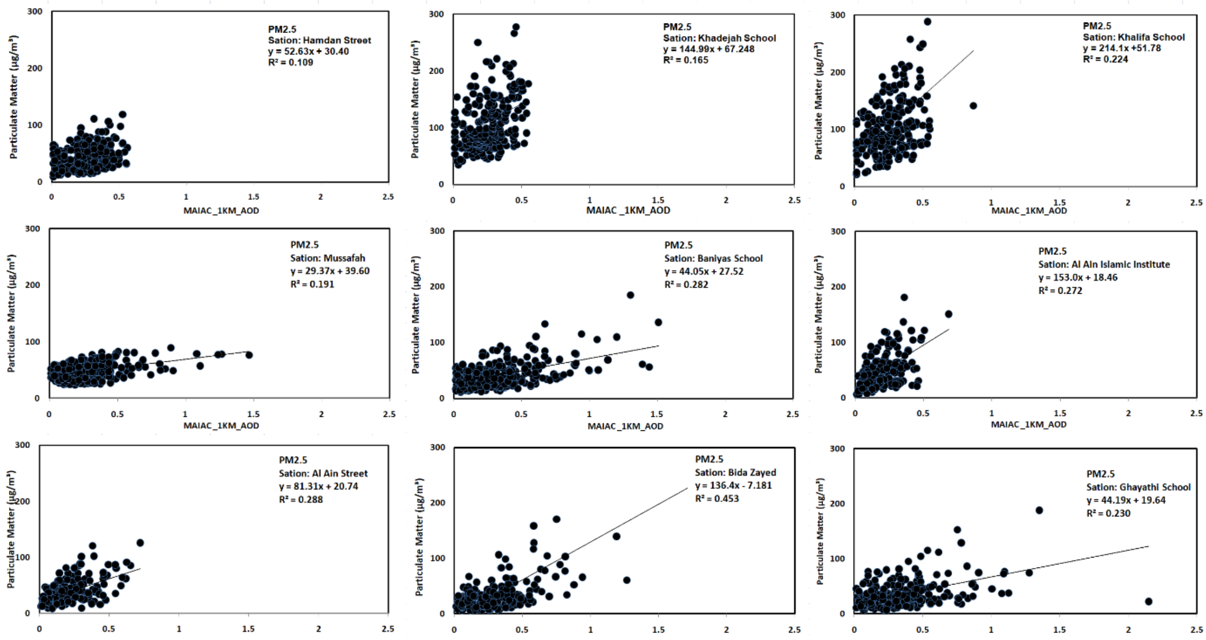

Figure 5(a)

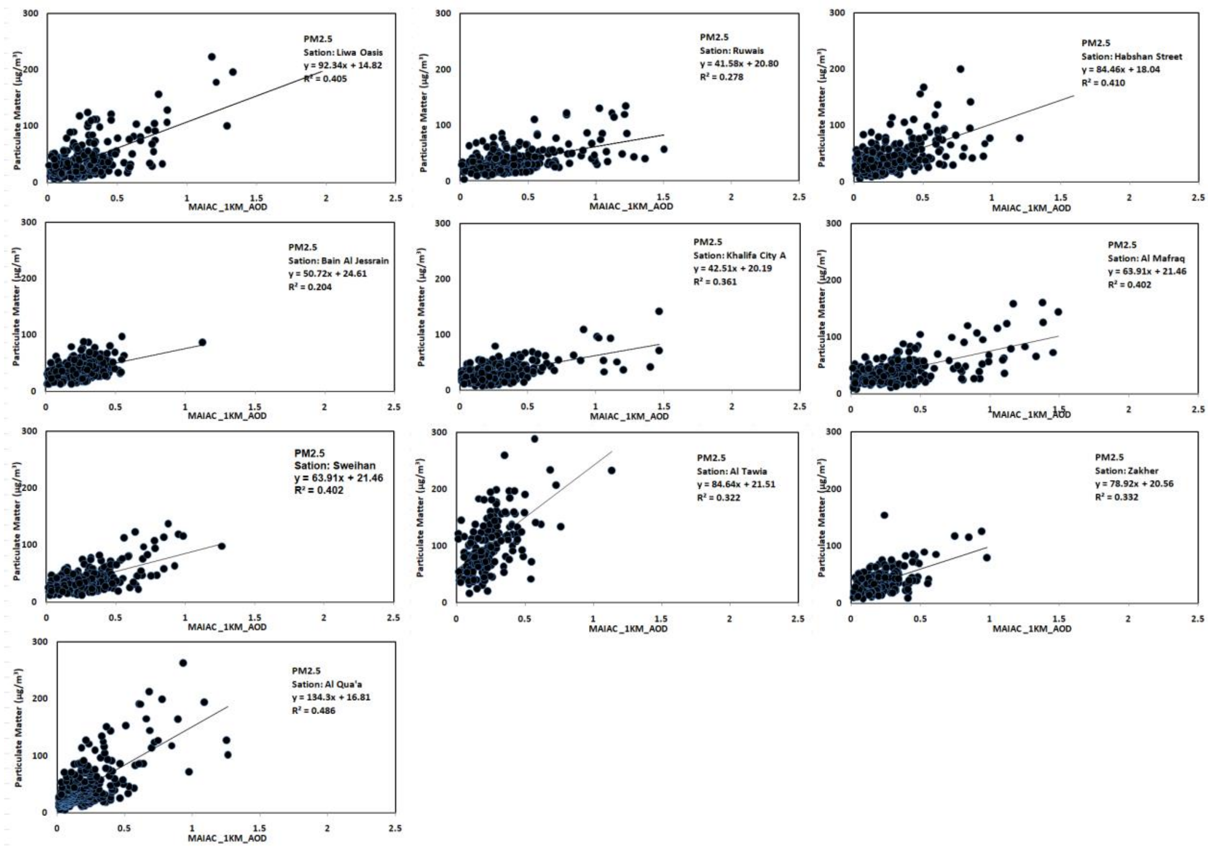

Figure 5(b)

The regression R^2 between PM10 and AOD and PM2.5 and AOD for the measuring stations ranged between 0.2 to 0.5 showing reasonable correlation between the variables. These numbers while are low in magnitude they are in line with numbers reported in similar studies. The results suggest that further improvements might be necessary to portray much higher R^2 numbers.

4. CONCLUSIONS

Moderate correlations between AOD and PMs are observed within the emirate of Abu Dhabi, UAE, however. The R^2 of the relation between PMs and AOD are consistent with those reported in previous studies. Further, there is quite a considerable disparity in the R^2 between the different air pollution monitoring stations. While these correlations are not strong the study presumes that additional atmospheric parameters might need to be incorporated in future studies in order to portray a much stronger correlation. Meteorological variables such as wind direction and speed might be significant variables that current models do not take into account.

5. REFERENCES

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