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Estimation of the background $PM_{2.5}$ concentrations in megacities in Iran

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1. INTRODUCTION

Urban air pollution is a major environmental problem in the developing countries of the world. This is a widespread problem in megacities due to their rapidly expanding economic and industrial developments. Particulate Matter with diameter of less than 2.5 micrometers ($PM_{2.5}$) pollution as a criteria air pollutant cause adverse health effects such as asthma, allergies, cardiovascular and respiratory disease and morbidity, and environmental impacts, such as reducing visibility and affecting climate and ecosystems(Reiss, Anderson et al. 2007).

Air pollution, especially $PM_{2.5}$, is a main environmental risk factor for morbidity and disease in Iran(Amini, Trang Nhung et al. 2019). Currently, fine PM is the main cause of critical air pollution episodes in most of the megacities in Iran, in order that, $PM_{2.5}$ has exceeded standard levels more than one-third of the days during recent years in Tehran, the capital of Iran(AQCC 2015).

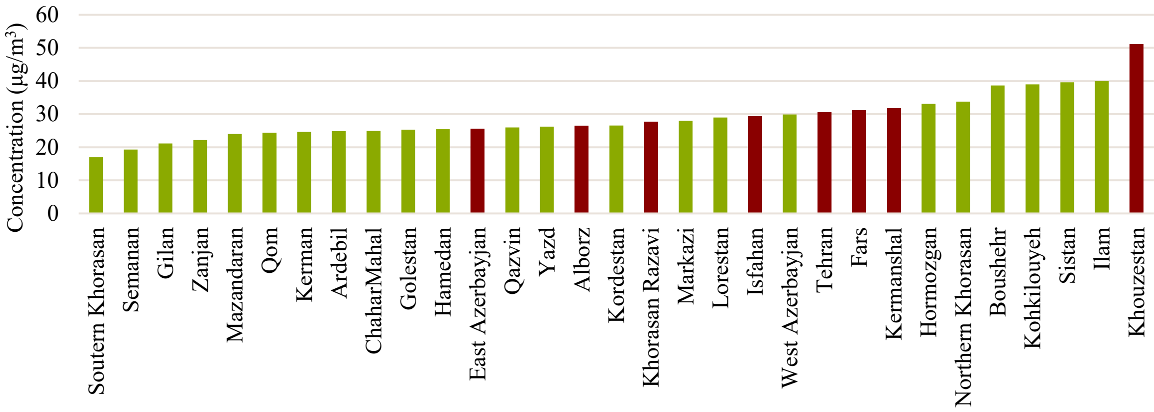

Figure 1 Provincial 3-year annual PM2.5 concentrations (Mohebbichamkhorami, Arbabi et al. 2020)

Moreover, Iran is located in an arid/semi-arid area and likely has a high background level of particles due to the prevalence of dust. Therefore, the fine PM concentration plays a significant role in occurrence of polluted days in different parts of Iran. Figure 1 shows the provincial 3-year annual $PM_{2.5}$ concentrations. The dark red items represent the concentrations at the selected case studies in this research.

To manage this issue, pollutant dispersion modeling is an effective tool for simulating the distribution of the pollutant concentration and predicting the effectiveness of pollution control policies and measures (Munir, Mayfield et al. 2020). However, a prerequisite for a valid pollutant dispersion modeling is to consider the natural concentration of pollutants from non-anthropogenic emission sources. Due to lack of in-site measurements or source apportionment (SA) results, this information is merely available.

The main focus of this study is to assess the fine PM background concentration through remote sensing and validate this result by SA studies in Iran. We work with AOD and $PM_{2.5}$ concentration in eight megacities and with the help of dust concentration, as a major component in SA, we extract the background $PM_{2.5}$ concentration in these cities.

The results of this study can be used for choosing the best management strategies for dust control and provide comprehensive insight to anthropogenic and non-anthropogenic emission sources of fine PM in Iran.

2. METHODOLOGY

In this research, the remote sensing technique is used to estimate the background $PM_{2.5}$ concentrations from natural dust in eight megacities in Iran including Tehran, Isfahan, Ahvaz, Tabriz, Shiraz, Mashhad, Karaj.

The reference point for analyzing the concentration of background emission are set to be upstream of typical wind direction of the area. The estimation is based on the correlations between inside-city and reference point, AOD values as well as the correlations between inside-city AOD values and $PM_{2.5}$ concentrations. The derived AOD-based background $PM_{2.5}$ values are then calibrated with the measured dust concentrations from the SA results. The proposed method is applied in 5 steps which is clarified in Figure 3.

Figure 2 Distribution of the selected case studies

The monthly average concentrations are validated for Tehran through comparison with dust concentrations from SA studies. The derived calibration factors are then applied to the remote sensing-based estimates of the other case studies.

2.1 Reference point selection

In selection of a reference point for the purpose of estimation of the background $PM_{2.5}$ concentration, the selected point should not be affected by the nearby anthropogenic emissions. Therefore, it should be located upstream of the typical wind, far enough from the emission sources, while near to the city. More variability of the concentration with meteorological variations may be used as an indicator of dependency of the observed concentration/AOD to the man-made emissions which are constant during a year. As a result, histograms of the AOD of the potential points are compared to select the most appropriate condition for non-anthropogenic concentrations. Figure 4 shows more variations of AOD in the west reference point than the east one, as an indicator of higher sensitivity to the natural and meteorological conditions.

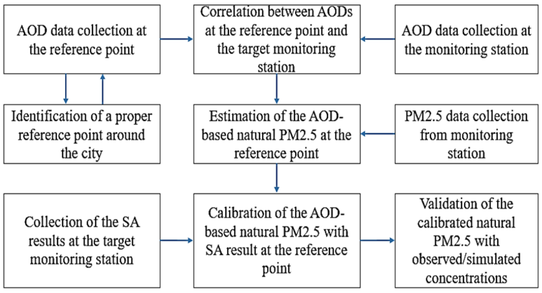

Figure 3 The proposed procedure for estimation of the background $PM_{2.5}$ concentrations based on AOD.

2.2 AOD data collection and adjustment

The conventional 10-km MODIS AOD products in our case studies, which are urban areas with different sources of pollution, cannot illustrate the result of background emission in specific points in the cities. A finer resolution AOD is highly required in the air quality study to resolve gradients in $PM_{2.5}$ distribution across urban regions. These needs arise in the areas with cold and humid climates with a high number of cloudy days. So, a new Multi-Angle Implementation of Atmospheric Correction (MAIAC) AOD product with 1-km resolution is used. MAIAC processing includes cloud masking, deriving column water vapor, and retrieval of aerosol parameters over land at 1 km resolution. This is accomplished by using the time series of MODIS measurements and simultaneous processing of a group of pixels in fixed 25 × 25 km2 blocks (Hu, Waller et al. 2014).

In this study, a day-to-day AOD measurement was observed for each city.

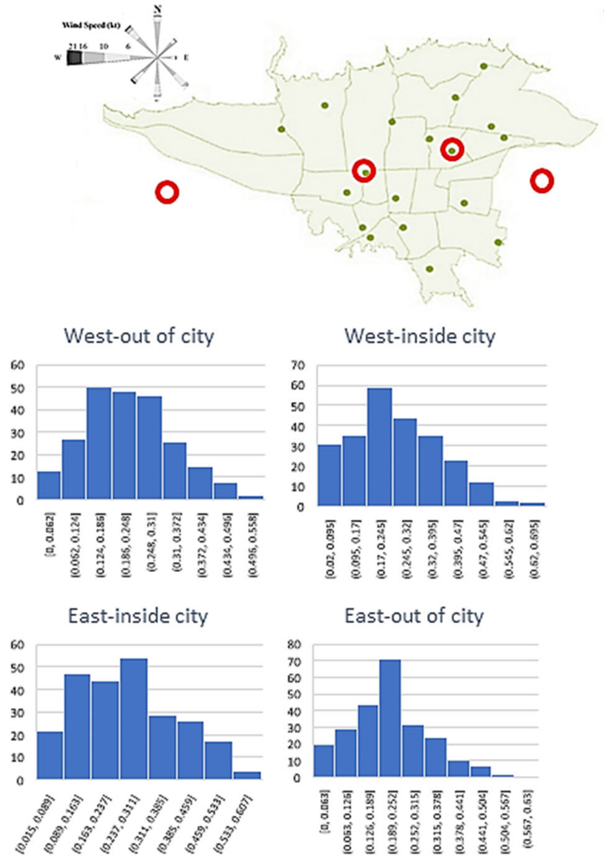

Figure 4 Histograms of AOD during a year for different points inside and outside of the city. Higher variations in the reference point in the west of the city shows higher dependency of AOD to the natural and meteorological conditions.

Excluding the unavailable data on cloudy days, other AODs at the selected station for comparing AOD to $PM_{2.5}$, and AODs in the reference point for monitoring the background concentration were extracted.

2.3 $PM_{2.5}$ data collection and adjustment

Hourly $PM_{2.5}$ concentrations at different monitoring stations in each of the megacities are available from the website of the Iran Air Pollution Monitoring System[1]. $PM_{2.5}$ concentrations are routinely monitored in these stations and after gathering and cleaning the data, $PM_{2.5}$ concentrations in the nearest station

[1] https://aqms.doe.ir

to our reference point for monitoring background emission were selected.

2.4 Calculation of the AOD-based non-anthropogenic $PM_{2.5}$

As a first guess of the trend for variations of the $PM_{2.5}$ background concentrations during a year ($NatPM_{2.5_{AOD,t}}$), the ration of the AOD at the reference point ($AOD_{ref,t}$) which is mostly induced by natural dust, to the AOD at the inside-city point ($AOD_{city,t}$) which is induced by anthropogenic and non-anthropogenic emission sources, is multiplied in the observed $PM_{2.5}$ concentrations inside the city ($PM_{2.5_{obs,t}}$).

$$NatPM_{2.5_{AOD,t}} = \frac{AOD_{ref,t}}{AOD_{city,t}} \times PM_{2.5_{obs,t}}$$

(Equation 1)

2.5 Calculation of the calibration factors with SA results

The derived natural $PM_{2.5}$ concentration from the previous step ($NatPM_{2.5_{AOD,t,l}}$) is then calibrated with the analyzed dust concentrations from the $PM_{2.5}$ SA studies ($NatPM_{2.5_{SA,t,l}}$).

$$CF_t = \frac{NatPM_{2.5_{SA,t,l}}}{NatPM_{2.5_{AOD,t,l}}}$$

Equation 2

The SA results are derived from the sampling campaign and running chemical analysis in the considered area. Generally, dust concentration is one of the main PM sources in source identification studies in Iran, due to local deserts and regional dust storms (world's dust belt) (Kamali, Zare Shahne et al. 2015, Arhami, Hosseini et al. 2017) (Ghotbi, Sotoudeheian et al. 2016). There is a comprehensive SA study which was done in Tehran, capital of Iran (Arhami, Hosseini et al. 2017).In the present study, the monthly dust concentrations from the last SA were considered as the natural fine PM for extracting the calibration factor in Tehran (Arhami, Shahne et al. 2018).

2.6 Calibrating the results

The derived calibration factors for different months during a year (CF_t) are used for calculation of the actual background $PM_{2.5}$ concentrations ($NatPM_{2.5_t}$) for the city under study for the $NatPM_{2.5_{AOD,t}}$.

$$NatPM_{2.5_t} = NatPM_{2.5_{AOD,t}} \times CF_t$$

Equation 3

However, lack of access to the actual background $PM_{2.5}$ measurements and SA results has limited the individual calibration of the derived concentrations for different cities. Therefore, the derived CF_t for Tehran are used for estimation of $NatPM_{2.5_t}$ in other cities as well.

2.7 Validation of the results

Finally, the estimated values of the background $PM_{2.5}$ concentrations are validated with the provincially averaged $PM_{2.5}$ concentrations from surface observations or global simulations. For instance (Alizadeh-Choobari, Ghafarian et al. 2016), have provided the results of simulated annual mean dust concentration averaged over the period from 1991 to 2010 over Iran.

3. RESULTS and DISCUSSION

The AOD values are not available for most of the cloudy days in cold months. Therefore, the coverage of the available data is not uniform for different months during a year. Moreover, the $PM_{2.5}$ background concentrations from SA studies are available for monthly averaged values. Therefore, the monthly averaged AOD and $PM_{2.5}$ data were used to avoid monthly biased correlations.

2.1 Raw data analysis

Results of the raw data analysis show that $PM_{2.5}$ concentrations at highly polluted points (e.g., Sharif station in west Tehran) are not correlated with AOD observations nor background $PM_{2.5}$ concentrations from SA results. However, there are positive and meaningful correlations between AOD at the reference point, the city, and the actual background $PM_{2.5}$ concentrations from SA.

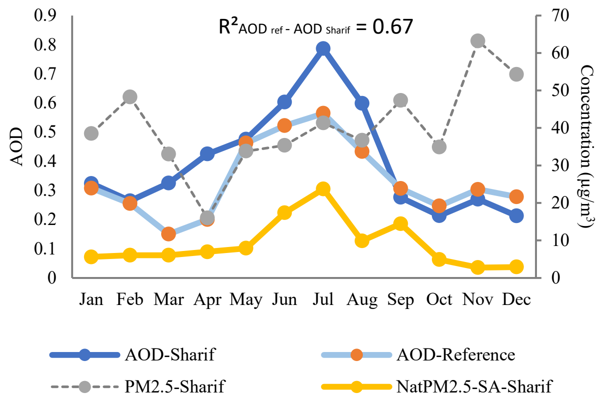

Figure 5 Variations of AOD, $PM_{2.5}$ and background $PM_{2.5}$ for Tehran

This result supports the idea that although AOD may not be an accurate proxy for $PM_{2.5}$ concentrations in the urban areas, it may be a good approximation of natural $PM_{2.5}$ concentrations.

2.2 Variations of the CF_t

Comparison between the AOD-based background $PM_{2.5}$ estimates and the observed background $PM_{2.5}$ concentrations from SA shows that the AOD-based background $PM_{2.5}$ estimates are more accurate in warm months, in which sand and dust storms are more frequent.

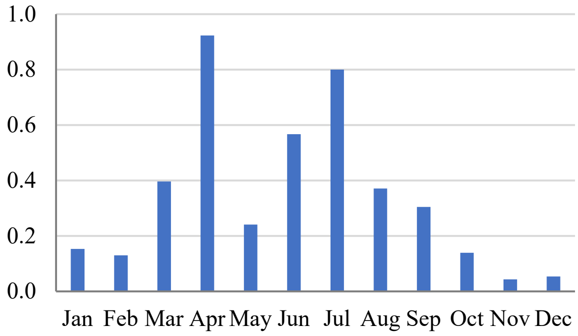

Figure 6 Variation of CF_t for Tehran during 2018

As it is shown in Figure 6, the derived AOD-based estimates need less calibration to represent the actual background $PM_{2.5}$ concentrations in warmer months.

2.3 AOD-based background $PM_{2.5}$

Figure below shows the variation of the derived background $PM_{2.5}$ for the studied cities during 2018.

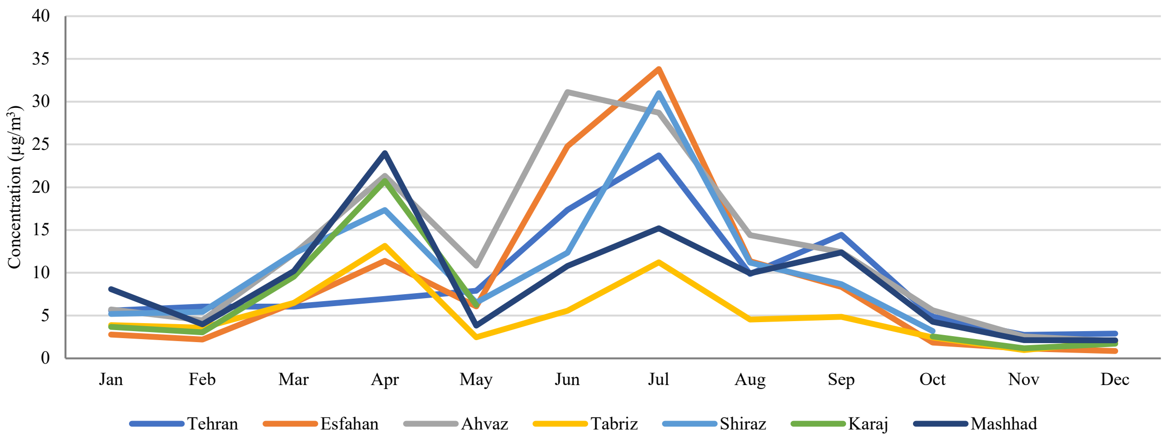

Figure 7 Variations of monthly averaged background PM2.5 concentrations during 2018

5.4 Validation of the results

In order to validate the derived results with other estimation methods, simulated natural $PM_{2.5}$ concentrations over Iran are compared with the AOD-based estimates of the background $PM_{2.5}$. The comparison shows that the derived values agree with the simulated values in the literature.

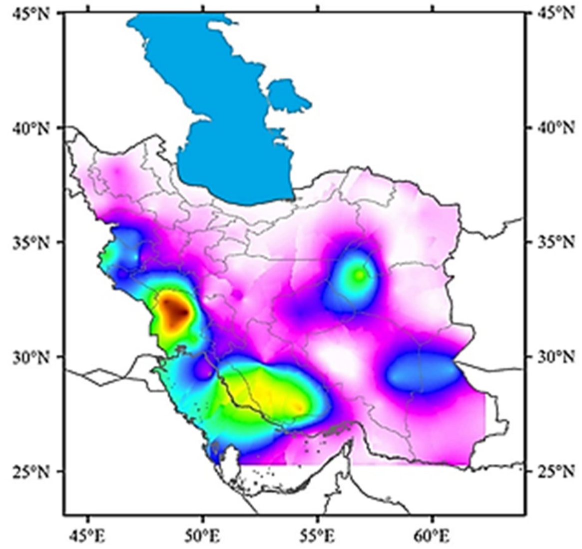

Figure 8 Simulated dust concentration over Iran (from:)

Our results show that almost none of the studied megacities in Iran meet the new WHO $PM_{2.5}$ guidelines, even without any anthropogenic emissions, while the old standard limit may be fulfilled with proper air quality management. Also, a comparison of the results between climates and cities confirms that natural sources have more shares in dry regions than wet climates. (Figure 9)

3. CONCLUSION

The main focus of this study was to use the remote sensing technique to estimate the background $PM_{2.5}$ concentrations from natural dust in eight megacities in Iran.

This research, for the first time, used RS data to estimate the background $PM_{2.5}$ concentrations over the main Megacities in Iran. As a result, the monthly background $PM_{2.5}$ concentrations are reported for the eight main megacities in Iran. This may serve as a valuable input for future pollution dispersion modeling in these case studies.

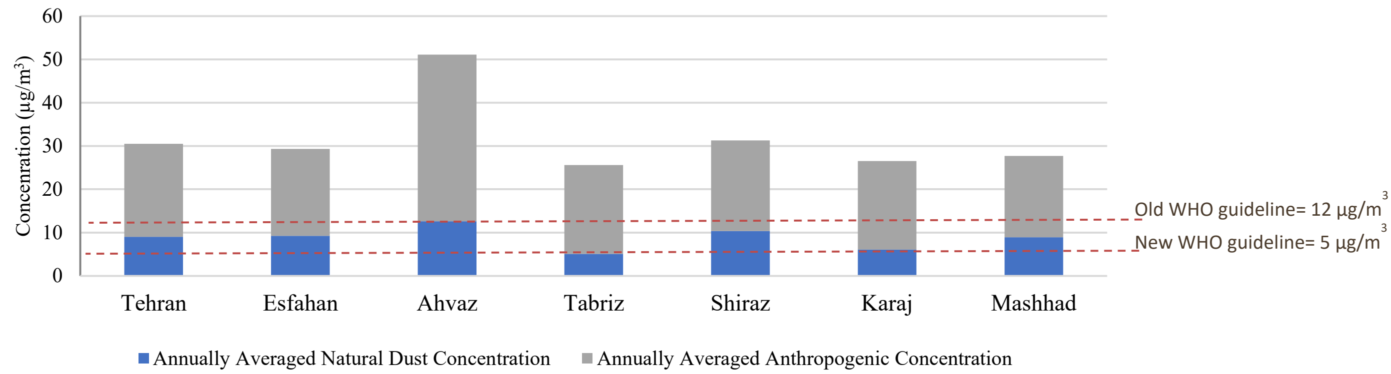

Figure 9 Annually averaged natural dust concentration proportional to the total observed concentrations

As one step forward, our results provide rough estimates of background $PM_{2.5}$ concentrations which may be helpful, though further precise modeling of relationship between RS data and surface concentrations is recommended.

4. ACKNOWLEDGEMENT

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