Statistical Forecast Applied to Two Macao Air Monitoring Stations

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Abstract. The levels of air pollution in Macao often exceeded the levels recommended by WHO. In order for the population to take precautionary measures and avoid further health risks under high pollutant exposure, it is important to develop a reliable air quality forecast. Statistical models based on multiple regression (MR) analysis were developed successfully for Macao to predict the next day concentrations of PM_{10}, $PM_{2.5}$, and NO_2. All the developed models were statistically significantly valid with a 95% confidence level with high coefficients of determination (from 0.89 to 0.92) for all pollutants. The models utilized meteorological and air quality variables based on five years of historical data, from 2013 to 2017. The data from 2013 to 2016 were used to develop the statistical models and data from 2017 were used for validation purposes. A wide range of meteorological and air quality variables were identified, and only some were selected as significant dependent variables. Meteorological variables were selected from an extensive list of variables, including geopotential height, relative humidity, atmospheric stability, and air temperature at different vertical levels. Air quality variables translate the resilience of the recent past concentrations of each pollutant and usually are maximum and/or the average of latest 24-hour levels. The models were applied in forecasting the next day average daily concentrations for PM_{10}, $PM_{2.5}$, and NO_2 for the air quality monitoring stations. The results are expected to be an operational air quality forecast for Macao.

Keywords: Air Quality, Modelling, Monitoring, Management, Air Pollutants, Particulate Matter, Ozone, Nitrogen Dioxide

1. Introduction

The region of Macao is located in the southern part of China and the land area is extremely limited due to geographical restraint and the rapid growth of population. The United Nations World Prospects Report had listed Macao as the number one most densely populated region in the world [1]. The land

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area of Macao is 30.8 km^2 with a total population of 653,100, which equivalent to a population density of 21,100 inhabitants/km^2 [2]. The levels of particulate matter (PM_{10} and $PM_{2.5}$) and nitrogen dioxide (NO_2) in Macao are extremely high and often exceeded the established limit values recommended by World Health Organization (WHO) Air Quality Guidelines (AQG). Numerous studies showed that exposure to these pollutants have increased hospital admissions and emergency room visits and leading even to death from heart or lung diseases [3]. Therefore, it is very important to develop a reliable prediction methodology for the concentration of PM_{10}, $PM_{2.5}$, and NO_2 in Macao, which can provide health alert in advance of a pollution episode. As shown in Figure 1 and Figure 3, the annual levels of PM_{10} and $PM_{2.5}$ have been on a steady decline. Figure 2 and Figure 4 show the monthly levels of PM_{10} and $PM_{2.5}$ concentrations, which reach higher levels during the winter season and lower levels during the summer season. In addition, Figure 5 shows the annual NO_2 concentrations, without a clear trend. Figure 6 shows the monthly levels of NO_2, also reaching a peak during the winter season and its lowest during the summer season. The station of Macao Roadside is the most traffic intense site in Macao, being vehicle emissions the primary source in this location. Therefore, it is very important to forecast pollutants such as PM_{10}, $PM_{2.5}$, and NO_2, which can relate with vehicle emissions[4]. Taipa Ambient is an ambient background air quality station representative of Macao. This station is located at Taipa Grande, also the headquarters of Macao Meteorological and Geophysical Bureau (SMG). This station sets a baseline for the background levels of PM_{10}, $PM_{2.5}$, and NO_2 in Macao. Results from both stations allow a comparison between roadside and background concentrations.

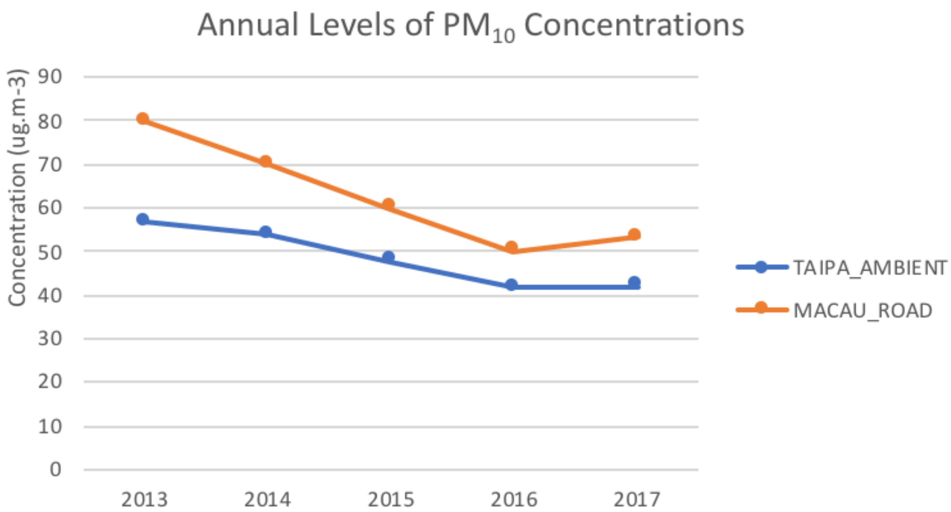

Figure 1. Annual levels of PM_{10} concentrations (2013-2017 data)

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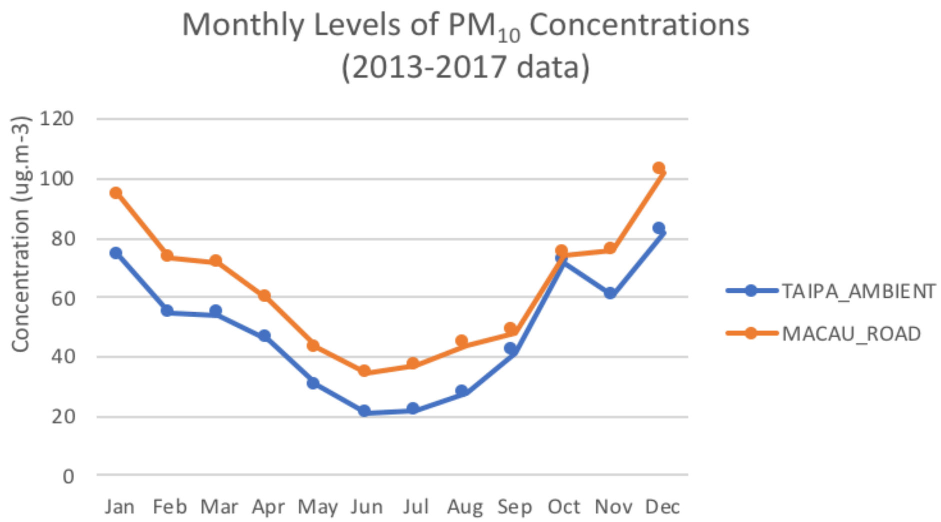

Figure 2. Monthly levels of PM_{10} concentrations (2013-2017 data)

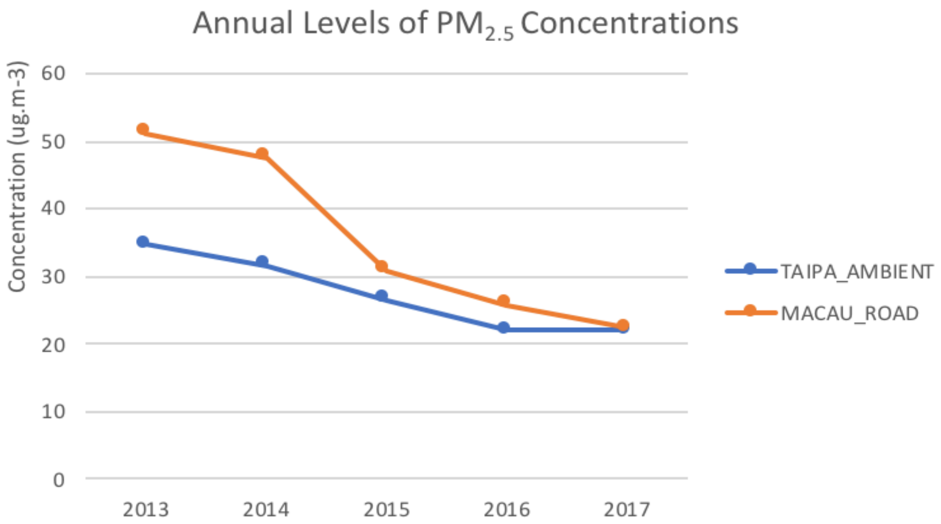

Figure 3. Annual levels of $PM_{2.5}$ concentrations (2013-2017 data)

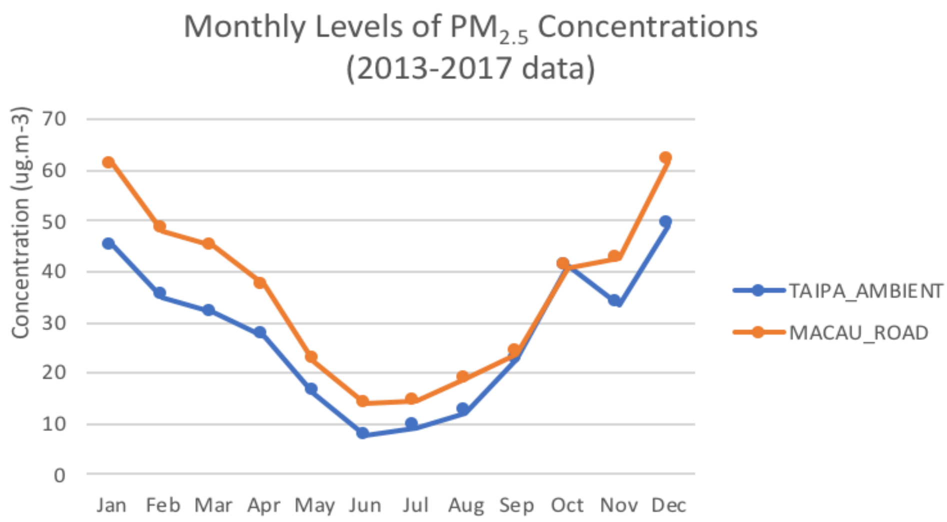

Figure 4. Monthly levels of $PM_{2.5}$ concentrations (2013-2017 data)

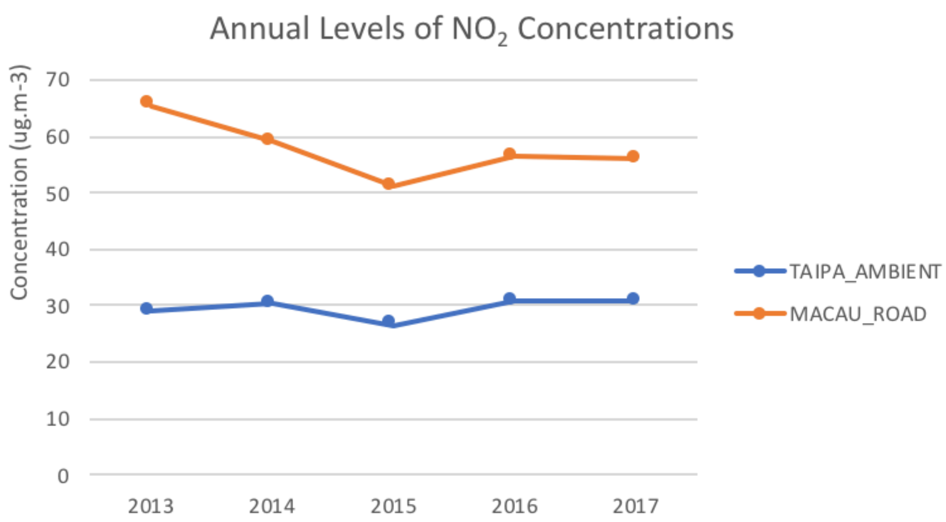

Figure 5. Annual levels of NO_2 concentrations (2013-2017 data)

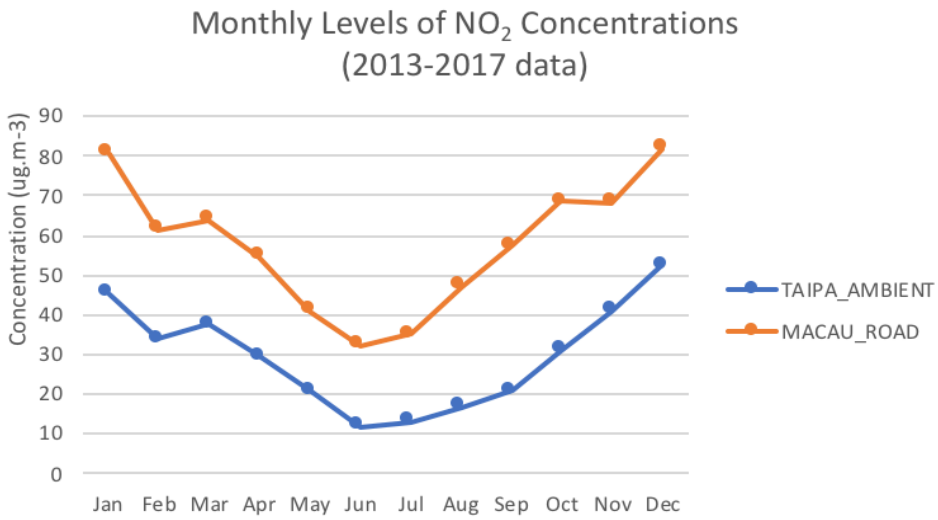

Figure 6. Monthly levels of NO_2 concentrations (2013-2017 data)

2. Material and methods

Air quality forecast was performed using statistical methods based on data series analysis. A combination of standard statistical methods was the process selected for this paper. As showed in previous work [5–7], statistical models based on multiple regression (MR) analysis were developed to forecast the average daily concentration for PM_{10}, $PM_{2.5}$ and NO_2 for the next day. This paper presented the air quality forecast of the average daily concentration for PM_{10}, $PM_{2.5}$ and NO_2 for the next day, in the air quality monitoring stations of Macao Roadside and Taipa Ambient. A four-year period (2013-2016) was selected as the fitness period for the models, while another period (2017) was selected for the validation of the model. Figure 7 shows the flowchart of the model development for the air quality forecast using statistical methods. The process of model development begins with the collection of air quality data and meteorological observations. Later, the air quality data was used to compute daily concentrations of PM_{10}, $PM_{2.5}$ and NO_2. The meteorological parameters that are necessary to build the model was extracted from the pool of surface observations (weather stations) and upper air observations (soundings). These data go through the analysis of multiple regression (MR) for model development. The final step is to perform model validation to ensure the accuracy of the air quality forecast.

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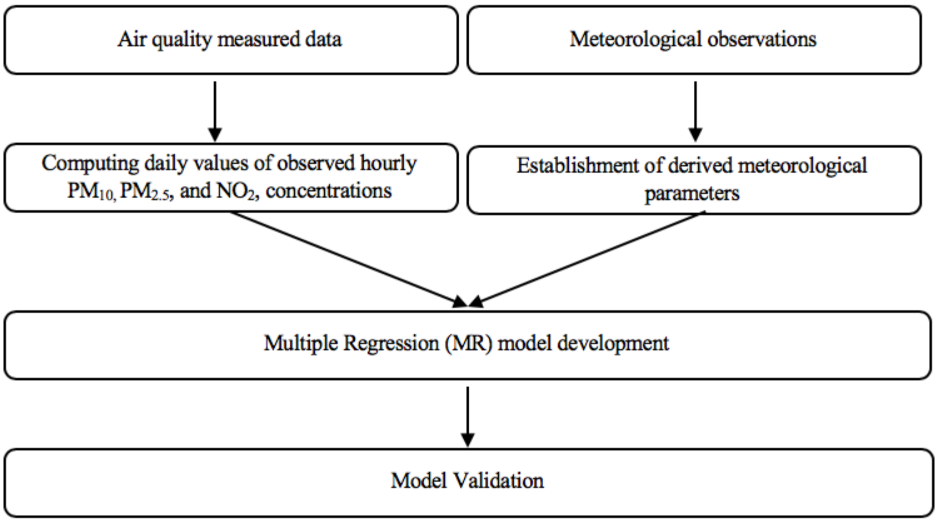

Figure 7. Flowchart for model development of air quality forecast by statistical methods

3. Results and discussions

Table 1 shows the different variables and model equations used for developing the air quality forecast in Macao Roadside and Taipa Ambient air quality monitoring stations. Table 1 shows that all pollutants have a highly correlated relationship with past concentration levels (PM_{10}_16D1, $PM_{2.5}$_16D1 and NO_2_16D1, as the average of the hourly values between 16:00 H of yesterday and 15:00 H of today (μg/m^3)). PM_{10} and $PM_{2.5}$ are also related with geopotential height at 850hPa (H_850 in m), and average relative air humidity (HRMD in %). NO_2 has a highly correlated relationship with past concentration levels (NO_2_16D1 in μg/m^3), geopotential height at 850hPa (H_850 in m), atmospheric stability at 925hPa (STB_925 in °C), and minimum relative air humidity (HRMN in %).

Table 1. Variables and Model Equations for Each Pollutant in Macao Roadside and Taipa Ambient Air Quality Monitoring Station

Station	Pollutants	Model equations
Macao Roadside	PM_{10}	PM_{10} = 0.900 x PM_{10}_16D1 + 0.019 x H850 – 0.270 x HRMD
	$PM_{2.5}$	$PM_{2.5}$ = 0.934 x $PM_{2.5}$_16D1 + 0.009 x H850 – 0.128 x HRMD
	NO_2	NO_2 = 0.900 x NO_2_16D1 + 0.012 x H850 – 0.168 x HRMN
Taipa Ambient	PM_{10}	PM_{10} = 0.891 x PM_{10}_16D1 + 0.018 x H850 – 0.261 x HRMD
	$PM_{2.5}$	$PM_{2.5}$ = 0.918 x $PM_{2.5}$_16D1 + 0.009 x H850 – 0.128 x HRMD
	NO_2	NO_2 = 0.915 x NO_2_16D1 + 0.004 x H850 + 0.758 x STB925

Figure 8 shows the graph of the model validation for the MR models of NO_2 concentrations in Macao Roadside air quality monitoring station in 2017.

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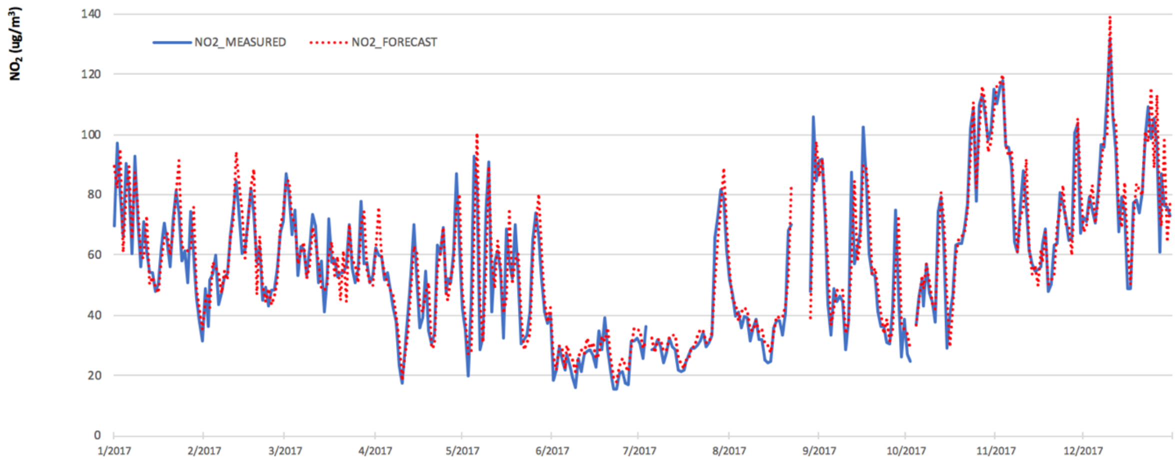

Figure 8. Observed and predicted NO_2 concentration values using MR models in Macao Roadside (2017)

Figure 9 shows the graph of the model validation for the MR models of $PM_{2.5}$ concentrations in Taipa Ambient air quality monitoring station in 2017.

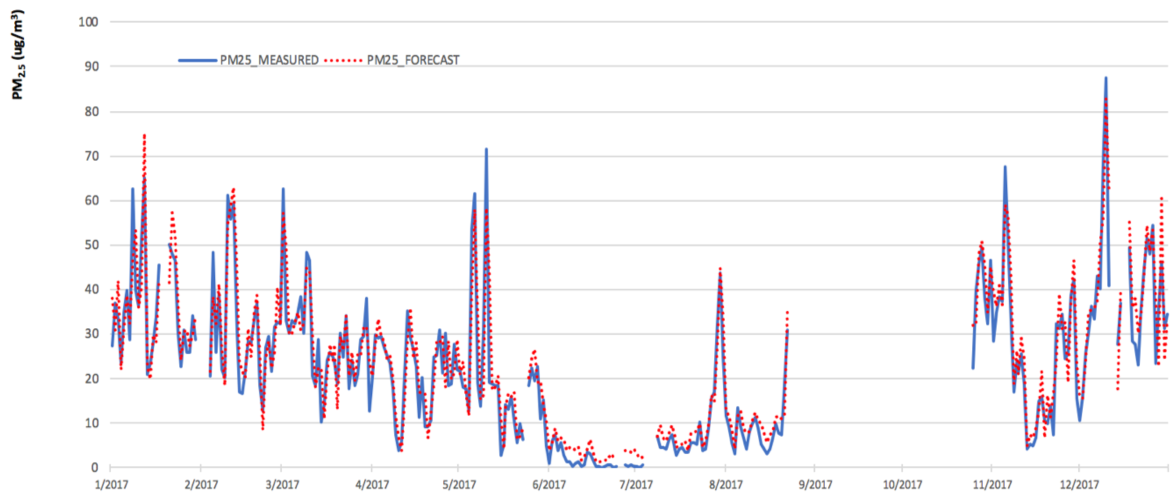

Figure 9. Observed and predicted $PM_{2.5}$ concentration values using MR models in Taipa Ambient (2017)

Table 2 shows the model performance indicators of PM_{10}, $PM_{2.5}$, and NO_2 for Macao Roadside and Taipa Ambient air quality monitoring stations. The model performance indicators include coefficient of determination (R^2), root mean square error (RMSE), absolute error (MAE), and BIAS. The results obtained from MR models perform a coefficient of determination between 0.89 and 0.91 for Macao Roadside and between 0.89 and 0.92 for Taipa Ambient. The best performance indicators were obtained, globally, for the air quality forecast at Taipa Ambient for all pollutants. All the developed models were built using MR.

Table 2. Model Performance Indicators

Station	Pollutant	Performance indicators			
		R^2	RMSE (µg/m³)	MAE (µg/m³)	BIAS (µg/m³)
Macao Roadside	PM_{10}	0.91	9.2	6.6	1.5
	$PM_{2.5}$	0.90	5.9	4.0	1.5
	NO_2	0.89	7.9	5.8	0.9
Taipa Ambient	PM_{10}	0.92	6.8	4.5	1.1
	$PM_{2.5}$	0.89	5.0	3.2	1.1
	NO_2	0.90	6.1	4.4	0.4

The models developed allow for a better understanding of different variables and the relationship between them. The variable that explained most of the variability for PM_{10}, $PM_{2.5}$, and NO_2 is the concentration of 16D1.

4. Conclusions

The work presented is a statistical method to forecast air pollutants concentrations, based on a detailed analysis of both historical meteorology and air quality variables concerning PM_{10}, $PM_{2.5}$, and NO_2. The final objective was to develop a daily air quality forecast using statistical methods to predict the next day daily average concentration, within Macao region, for the roadside location of Macao Roadside station and the background location of Taipa Ambient station. The models used independent variables including the average of the hourly concentrations between 16:00 of yesterday and 15:00 of today for PM_{10}, $PM_{2.5}$ and NO_2, geopotential height at 850 hPa, relative air humidity, and atmospheric stability at 925 hPa. The use of statistical models was successful in forecasting the average daily concentrations, with MR analysis for the referred pollutants, for both Macao Roadside and Taipa Ambient air quality monitoring stations, being obtained satisfactory performance indicators, such as R^2 values above 0,88.

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