MAPPING OF GROUND-LEVEL OZONE DISTRIBUTION AND DETERMINING SUITABLE LOCATIONS FOR MONITORING STATIONS IN THE NATIONAL CAPITAL REGION, PHILIPPINES

Areanne Katrice K. Umali (1), Iris Anne M. Ventura (1), Edgardo G. Macatulad (1)

[1] Department of Geodetic Engineering, College of Engineering,
University of the Philippines Diliman, 1101, Quezon City, Philippines
Email: katriceumali@gmail.com; imventura@up.edu.ph; egmacatulad@up.edu.ph

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ABSTRACT: Ground-level ozone (GLO) pollution poses serious risk to human health such as eyes, nose, and throat irritation which can aggravate existing heart and respiratory conditions. It also affects vegetation and crop yield. Yet at present, minimum research has been done about it in the Philippines. The mapping of GLO spatial distribution is essential in assessing its nature as a pollutant, thus coming up with possible ways to monitor it is necessary. This includes the establishment of a useful GLO monitoring network. Having knowledge and ability to monitor the GLO distribution would be a first step in finding solutions to further study and reduce its harmful effects, and to improve air quality. In this research, the National Capital Region (NCR) was selected as study area and three (3) previously existing GLO monitoring stations were inspected. However, these stations have incomplete data and have already stopped operation since 2018. Thus, one objective of this research is to address the challenge in the availability and completeness of ground-level ozone data by utilizing statistical equations for imputation of missing ozone data values and Geographic Information Systems (GIS) to create the GLO spatial distribution gradients of the study area. A second objective is to identify suitable sites by implementing GIS-based multi-criteria decision analysis with Fuzzy Analytical Hierarchy (FAHP) approach to integrate importance of each determined criterion affecting the GLO concentration, namely: (1) population; (2) meteorological factors, which include relative humidity, wind direction, wind speed and temperature; and (3) source of precursors, including proximity to major roads and proximity to industrial sites. Three experts in the field of environmental science and air quality management were consulted and it was determined that population had the most impact in identifying suitable sites, followed by proximity to sources of GLO precursors, and lastly meteorological factors. From the final suitability analysis result, the cities identified with high suitability for GLO monitoring stations are Navotas and Manila. The mapped spatial distributions were compared to the identified suitable sites and it was noted that two of the previously existing monitoring stations located in Quezon City and Valenzuela were not among the identified high suitability municipalities, but are included among the moderately suitable locations. The identified locations may still be refined through addition of other criteria, such as security and budget. However, the current results may already be particularly helpful and applicable for the preliminary screening of possible locations of monitoring stations.

1. INTRODUCTION

1.1 Background

Air pollution continues to hinder achieving one of the basic requirements of human health which is clean and breathable air. The health effects of air pollution are serious. According to the World Health

Organization (WHO) Assessment of the Burden of Disease due to Air Pollution for 2016, 4.2 million people die prematurely every year because of the urban outdoor and indoor air pollution. In 2018, WHO released a study that shows that the Philippines ranked 3rd in having the greatest number of deaths due to air pollution. These deaths are largely a result of increased mortality from stroke, heart disease, pulmonary disease, lung cancer and acute respiratory infections (WHO, 2018). Ironically, according to the 2018 World Air Quality Report of the IQAir Air Visual who provides an open access to real-time air quality information, the Philippines belong to the cleanest countries in Southeast Asia. This report may be a misrepresentation of the air quality in the country due to incomplete data. The report was based only on public air quality data aggregated by the IQAir AirVisual information platform and was supplemented by the datasets from government sources available.

1.2 Ground-level ozone

Ground-level ozone (GLO), like other air pollutants, imposes grave effects on human health. High concentrations of this is considered dangerous with effects on human health such as irritation to the eyes, nose, and throat which can aggravate existing heart and respiratory conditions. According to an article in South China Morning Post, Professor Wong Tsz-Wai of the Chinese University of Hong Kong's public health school mentioned that "while the health impact [of ozone] is not as high as that of particulate matter, it has a major short-term impact." (Kao, 2018). GLO is considered to be a big problem since it is not a primary pollutant that directly comes out of exhaust pipes or chimney but is instead formed by a mixed of pollutants from multiple sources and its production is accelerated by sunlight (Liu, 2018).

1.3 Ground-level ozone monitoring systems in the Philippines

The Environmental Management Bureau of the Department of Environment and Natural Resources (DENR-EMB) is observing the air quality of the entire country through monitoring pollutants including GLO using the sensors in their monitoring stations. In the National Capital Region (NCR), there were a total of eight monitoring stations available, but all are now non-operational since 2018 according to DENR-EMB. Only three (3) of the monitoring stations have acquired observations for a longer period of time: De La Salle University Taft, DPWH Timog, and PLV Valenzuela City. Data of GLO concentrations for years 2014 to 2017 was acquired for this study.

1.4 Scope of the study

Due to the negative impacts of ground-level ozone to the population and vegetation, mapping its spatial variation will aide in understanding the phenomenon and its relationship with environmental variables, i.e. temperature, wind speed, and relative humidity. Likewise, developing a GIS-based map for the ground-level ozone may be used to further identify suitable areas for additional monitoring station, which can improve the analysis of its variation and may give enough knowledge on how to strategize human activities to conserve the air quality and to build sustainable communities. This study aims to map the spatial distribution of the available ground-level ozone observations from 2014 to 2017 as an initial step in visualizing the ambient ozone pollution in NCR. It also aims to determine possible suitable locations of initial ground level ozone monitoring stations based on the basic criteria or factors affecting ozone concentration and production as stated by the EPA.

2. MATERIALS AND METHODS

2.1 Statistical imputation of missing ozone data values

The GLO data from DENR-EMB were incomplete for some years because of equipment malfunctions, thus imputation for the missing values is necessary. Through consultation with the UP School of Statistics three (3) statistical methods were suggested, which accounts for the trend and seasonality of the ozone concentrations.

The first method is the Mean Seasonal imputation. In this method, the seasonal component is removed first, values are imputed with measures of central tendency (eg. mean and median) of the whole data set, then seasonality is reintroduced. The second method is Last Observation Carried Forward (LOCF) Seasonal. It removes the seasonal component first, imputes the missing values by carrying the last value present in the data forward to the gaps of the missing values. The trend is replicated well over time. Seasonality is reintroduced afterwards.

The third method is the Kalman Filter. It also removes the seasonal component and then applies the Kalman filter algorithm. The Kalman filter algorithm consists of an iterative process. First, it uses initial estimated values for time (k) equal to zero. These values are projected for the future time and errors are projected. These prior values are used to update or correct the measurements. The outputs from the measurement update will be again the input for the time update where time for this step has progressed (k+1). This algorithm predicts values based on the joint probability of known values while taking into account the statistical noise. It reintroduces seasonality after.

Accuracy of the imputation methods was predicted using the Mean Absolute Percentage Error (MAPE). It is a statistical measure for forecast systems. The error in percentage was computed using the Equation 1 shown below.

$$\mathrm{MAPE} = \frac{1}{\mathrm{n}}\sum_{\mathrm{i}=1}^{\mathrm{n}} \frac{|\mathrm{X_i}-\mathrm{Y_i}|}{\mathrm{X_i}} \; where\ \mathrm{X_i}\ and\ \mathrm{Y_i}\ are\ the\ i^{th}\ actual\ and\ imputed\ value \quad \text{(Eqn. 1)}$$

2.2 Determining suitable locations for GLO monitoring stations

Criteria that affect the concentration and production of ground-level ozone was first determined by reviewing local and international policies and guidelines. The specific criteria data are then mapped annually per season in order to visualize, identify and characterize their traits and relationship to each other. Ozone concentrations are higher during warmer months (Tiwari et al., 2008). After mapping, a statistical analysis in the form of multi-criteria decision-making process of the Fuzzy Analytical Hierarchy Process was performed in order to calculate and determine the weights and importance of each criterion. The computed weights were then used in the site suitability analysis in order to pinpoint which municipalities are best to contain the monitoring stations.

2.2.1 Preparation of criteria maps: Table 1 below shows the list of the criteria, its corresponding sub-criteria and the description of each. The criteria selected were the population, meteorological factors, and sources of precursors (VOC and NOx) for which are the main factors found to contribute to the production of ground-level ozone.

Table 1. Criteria and sub-criteria for site suitability of GLO monitoring stations

Main criteria	Sub-criteria	Description
Population	(n/a)	It is a must to take into account the effects of the exposure to human health of the ozone concentrations. Areas with high population is in need of monitoring stations. Furthermore, it may be a source of small concentrations of VOCs and NOx accounting from their daily usage of household products (eg. cleaning agents, paints, household-level burning gas)
Meteorological Factors	Relative Humidity	According to the EPA and other literatures, downwind areas or areas along the same direction of the wind, low relative humidity or dry conditions, and high temperatures all affect the formation of GLO.
	Wind Direction	
	Temperature	
Sources of Precursors (VOCs and NOx)	Major roads with heavy traffic volume	Since the data on the actual readings of VOCs and NOx concentrations are unavailable in NCR, the research has instead focused on their possible sources such as primary roads that experience heavy traffic volume and major manufacturing economic zones or industrial sites
	Proximity to industrial sites	

Individual maps for temperature and relative humidity were generated using Inverse Distance Weighting (IDW) method of interpolation. Daily wind speed and direction data for 2014 to 2017 was obtained from Philippine Atmospheric Geophysical and Astronomical Services (PAGASA). The data was sorted annually for the wet and dry seasons in the Philippines, Table 2 shows the corresponding months and prevailing wind directions for each season.

Table 2. Wet and Dry Seasons in the Philippines and their prevailing wind directions

Season	Months	Wind Direction (Blowing to)
Wet Season	May to October	West/Southwest – Hanging Habagat
Dry Season	November to April	East/Northeast – Hanging Amihan

WindNinja, a computer program that is specifically designed to simulate the effect of terrain on wind flow was utilized to generate the interpolated wind speed and wind direction data, using elevation data as input. The elevation data was obtained from National Mapping and Resource Information Authority (NAMRIA). Using the interpolated output from WindNinja, the Zonal Statistics tool was used in order to identify the major direction of wind for each municipality per season.

The requested data on the ozone precursors was incomplete, thus proximity primary roads and location of major industrial sites, which are responsible for great emissions of the VOC and NOx in urban areas, were considered as representative data. The Annual Average Daily Traffic (AADT) of years 2014-2017 was gathered from the Metropolitan Manila Development Authority (MMDA). According to EPA, it is important to minimize destructive interferences from sources of NOx such as roads, since NOx easily reacts with ozone. Due to this they provided minimum separation between equipment and roadways depending on the average daily traffic volume shown in Table 3 below.

Table 3. Minimum separation distance between probes and roadways for urban scale ozone

Roadway average daily traffic, vehicles per day	**Distance (in meters)**
10,000	10
15,000	20
20,000	30
40,000	50
70,000	100
110,000	250

Maps of the proximity to industrial sites were created by acquiring their locations in NCR and a Euclidean distance from 100 m, 500 m and 4000 meters were created, in accordance to EPA's guidelines in monitoring the possible sources of ground level ozone.

2.2.2 Determination of weights through FAHP: The Fuzzy Analytical Hierarchy Process of Fuzzy AHP was used in this research to determine the criteria weights. After selecting the criteria levels and their components, a corresponding questionnaire was created using the breakpoints for the AHP. For this research, the steps of FAHP by geometric mean was followed for the weight calculation (Buckley, 1985). Three (3) experts/respondents were consulted for the FAHP weights determination: Mr. Reyson M. Abad and Mr. Joel Tugano from DENR-EMB, and Mr. Thomas Mccurdy fomr US EPA. The resulting individual weights were then averaged to get the final weight for each criterion.

3. RESULTS AND DISCUSSION

3.1 Statistical analysis for GLO interpolation

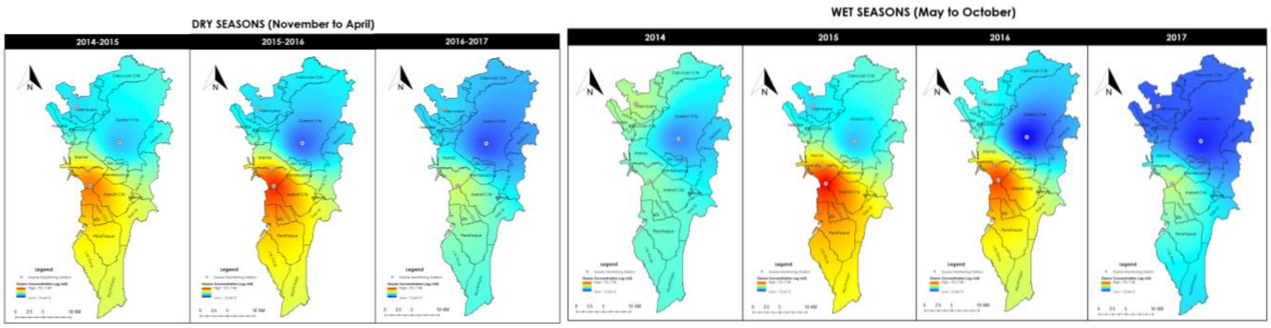
Table 3 below shows the computed MAPE using Equation 1 discussed previously. In predicting the missing values, LOCF is the best out of the three methods with the least percentage error (45.38%) for all stations. The imputed values from this method was chosen to be used in spatial distribution of ozone concentrations. The MAPE for different stations depended on the nature of missing data. DPWH and PLV stations have more missing values than DLSU which explains why they have higher percentage error.

Table 3. Computed mean absolute percentage error for statistical imputation

Station	**Kalman Filter**	**LOCF**	**Mean Seasonal**	**Average**
DLSU	24.37%	20.99%	41.39%	**28.92%**
DPWH	45.23%	42.26%	67.35%	**51.61%**
PLV	75.56%	72.91%	81.62%	**76.70%**
AVERAGE	**48.39%**	**45.38%**	**63.46%**	**52.41%**

3.2 GLO distribution maps

Figure 1 below show the interpolated GLO concentrations using the 2014-2017 data from the three (3) monitoring stations with imputed data using LOCF for dry and wet seasons, respectively.



(a) (b)

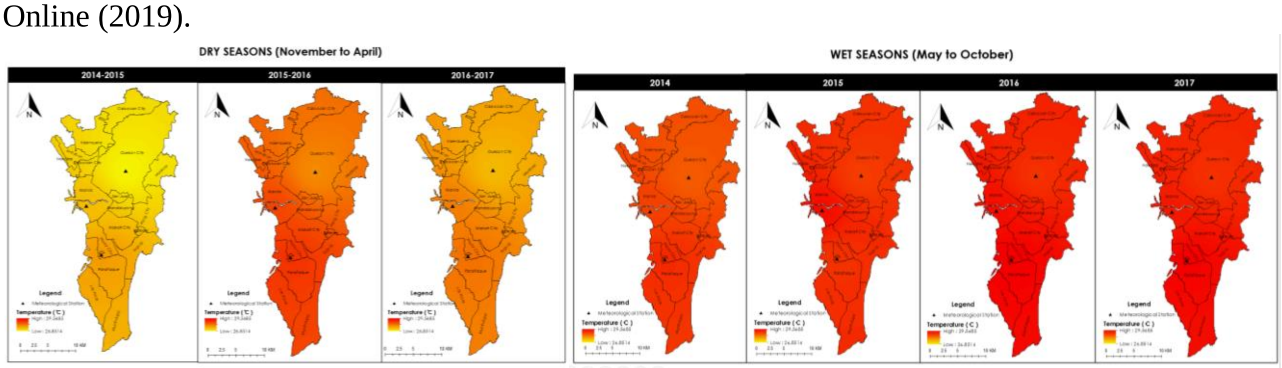
Figure 1. Interpolated GLO concentrations for the 2014-2017 (a) dry seasons and (b) wet seasons

For the dry seasons, it can be observed that high concentrations are present mainly on the lower half of Metro Manila while the lower concentrations are at the upper half. The lowest observed value is 20.0447μ/m^3, experienced during the dry season starting from 2016 until 2017, and highest is 93.0717 μ/m^3, experienced in dry season starting from 205 until 2016

The wet seasons appear to exhibit the same trend with the dry season except in the year 2014 where the majority of low concentrations are focused in the upper east side of Metro Manila focusing around the Quezon City area, and the higher concentration are distributed in the remaining parts of Metro Manila. The lowest observed value is 12.6612 μ/m^3and the highest observed is 95.1748 μ/m^3. The highest concentration of ozone was experienced during the wet season of year 2015 and the lowest was during the dry season of year 2015-2016. This may due to the different natural phenomena experienced during different seasons. Wet seasons can be influenced by the long-range transport of ozone brought by the wind during cyclones from the adjacent countries.

3.3 GIS suitability criteria maps

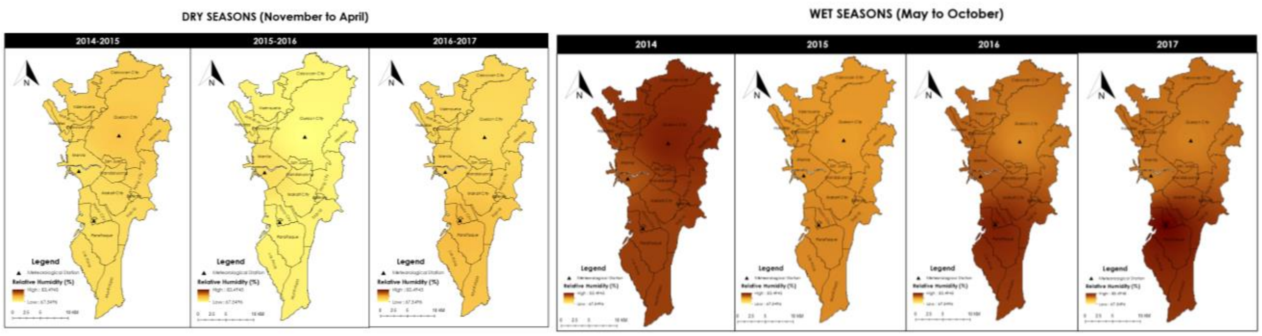
3.3.1 Temperature: The interpolated temperature maps generated using the daily average data from PAGASA shown in Figure 2 indicates that the temperature is hotter during the wet seasons but it only ranges in a small interval, 26. 8514℃ to 29.5685℃. This range is slightly higher than that of the dry season, this may be influenced by many factors like in the uncertainties derived from the IDW interpolation of the station site data. The same trend of higher temperatures during the wet season is also observed with the raw temperature readings of the stations. Nevertheless, this is also observed to be within the range of the averaged values measured in the same months from World Weather Online (2019).



(a) (b)

Figure 2. Interpolated Temperature Map for 2014-2017 (a) dry seasons and (b) wet seasons

3.3.2 Relative Humidity: Figure 3 show the mapped relative humidity for dry and wet season, respectively. Dry season relative humidity readings range from 67.5496% to 73.6077%. Dry seasons has relatively lower percentage of relative humidity that the wet seasons which indicates and confirms the dryness or the low amount of water vapor present in the air during the dry season.



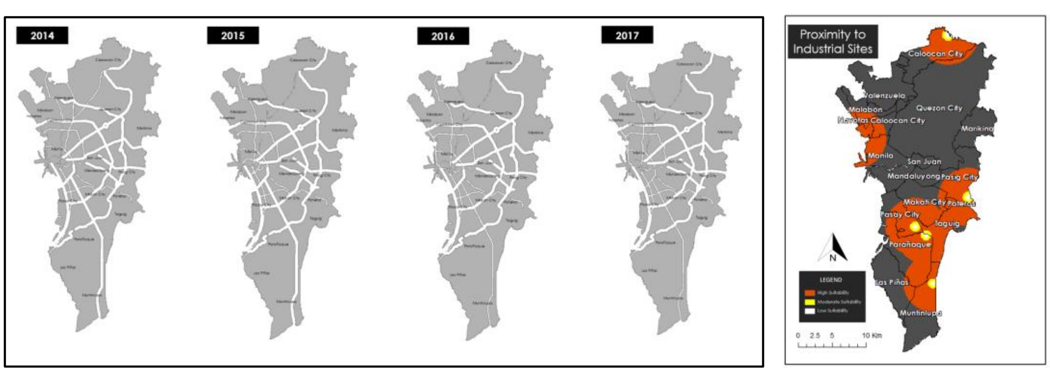
(a) (b)

Figure 3. Interpolated Relative Humidity Map for 2014-2017 (a) dry seasons and (b) wet seasons

Wet season relative humidity readings range from 76.0217% to 83.4945%. Consistent higher percentage of relative humidity can be shown in the maps comparing on the dry seasons. For 2016 and 2017, a visible difference on the percentage was experienced by the lower and upper half of Metro Manila.

3.3.3 Population: The population distribution shapefile was acquired from the AsiaPop spatial dataset through the PhilGIS website. According to the WorldPop (2013), they used the random forest estimation which is a dasymetric modeling approach to generate a gridded prediction of population density at ~100m spatial resolution.

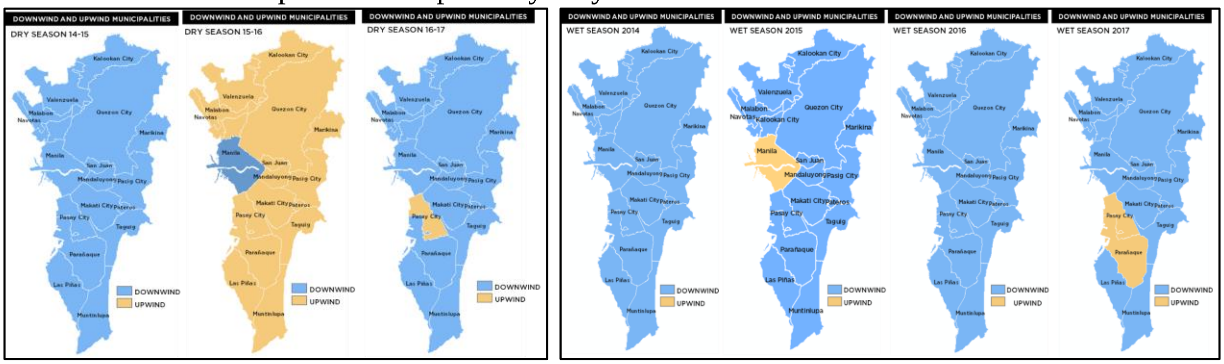
3.3.4 Proximity to Major Roads and Industrial Sites: A buffer zone of the minimum separation between equipment and roadways based on the average daily traffic volume was created for proximity to major roads criteria, shown in Figure 4(a) below. For the proximity to industrial sites, as shown in Figure 4(b) it can be noted that Caloocan, Navotas, Malabon, Pasig, Northeastern Manila, Makati, Taguig, Paranaque, Pasay, Muntinlupa, and the southeastern side of Las Pinas are within the suitable locations in terms of proximity to industrial sites. The distance of 500-4000m is based on EPA's monitoring network design manual.



(a) (b)

Figure 4. Buffer zones for criteria (a) proximity to roads and (b) proximity to industrial sites

3.3.5 Wind Speed and Direction: Examining the resulting maps shown in Figure 5(a) which are for the dry season wherein the prevailing wind should be blowing West/Southwest (Habagat), in 2014-2015 all municipalities are downwind, in 2015-2016 only Manila experienced downwind, and in 2016-2017 all municipalities except Pasay City are downwind.

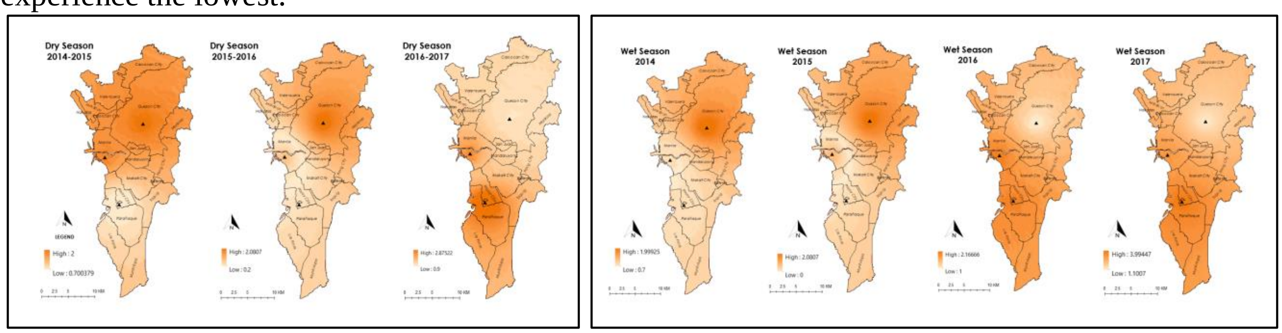


(a) (b)

Figure 5. 2014-2017 Downwind and upwind areas for the (a) dry seasons (b) wet seasons

In Figure 5(b) which shows the wet season wherein the prevailing wind should be blowing East/Northeast (Amihan), it can be seen that in 2014 all municipalities are downwind, in 2015 all of NCR except Manila were downwind areas, in 2016 all municipalities are again downwind, and lastly, for 2017 all municipalities except Pasay and Paranaque are downwind.

Figure 6 show the interpolated wind speeds for each municipality. The wind speed experienced by the NCR for years 2014-2017, ranges from 0-4 m/s. For the dry season of 2014-2015, the highest wind speed is experienced in the upper half of NCR specifically in QC and Manila as well as neighboring municipalities, while the lowest is experienced by the lower half specifically in Paranaque, Pasay and Las Pinas. In 2015-2016, the highest wind speed is experienced by Quezon City and the lowest is in some parts of Manila. In 2016-2017, Paranaque, Pasay, and Las Pinas experience the highest while Quezon City, Caloocan, and some neighboring municipalities experience the lowest.



(a) (b)

Figure 6. Wind speed per municipality during (a) dry seasons (b) wet seasons

Looking at the maps in Figure 6(b), in 2014 the upper half of NCR experienced faster winds with Quezon City experiencing the fastest, and the lower half experienced lower wind speeds specifically in Pasay and Paranque areas. In 2015, Quezon City, Pasay, and some parts of Paranaque experience the highest wind speed while Manila experienced the lowest. In 2016, Quezon City experienced the lowest while the municipalities below it experienced faster winds. Lastly, in 2017, the central part of

Quezon City again experienced the lowest wind speed while the municipalities below it experienced the opposite.

3.4 Suitable locations for GLO monitoring stations

Using the FAHP method, the weights for performing suitability analysis was calculated from the experts' ranking of each criteria. Table 4 below show the final local and global weights for the main and sub criteria, as well as the local and global rank for each.

Table 4. Local and global weights and ranks for all criteria from FAHP

Criteria	Weight	Sub-criteria	Local weights	Global weights	Local rank	Global ranks
Population	0.37	-	-	0.37352	-	1
Source of VOCs and NOx	0.34	Roads	0.879113	0.30129	1	2
		Indus. Sites	0.120887	0.04143	2	3
Meteorological factors	0.28	Rel. Humidity	0.124356	0.03529	3	6
		Wind Dir.	0.510185	0.14477	1	4
		Wind Speed	0.261813	0.07429	2	5
		Temp.	0.103646	0.02941	4	7

For the site suitability analysis, the global weights derived from the Fuzzy Analytic Hierarchy Process were applied to their respective criteria using the Weighted Sum tool in GIS. Figure 7 below shows the produced final site suitability map for the ground-level ozone monitoring stations. It was obtained by averaging all seven maps from the wet and dry seasons. Navotas and Manila came out as the most suitable sites while almost the rest of Metro Manila are moderately suitable sites.

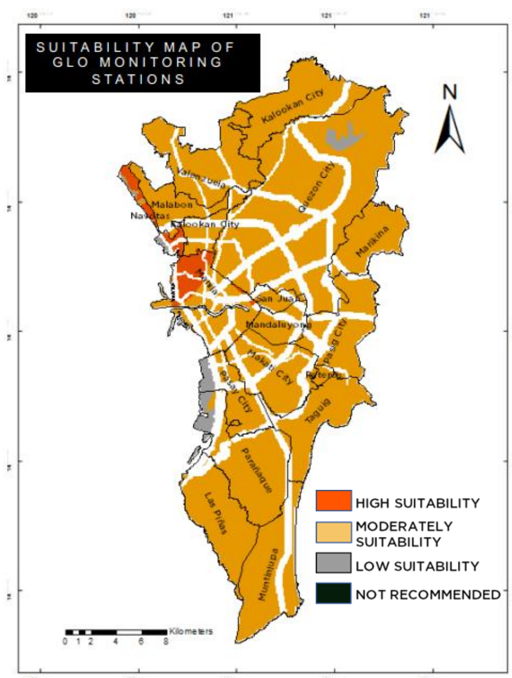


Figure 7. Location of suitable sites for ground level ozone monitoring stations

4. SUMMARY AND CONCLUSION

According to the methodology applied in this paper, the most important criterion for determining the initial suitable locations for ground level ozone monitoring is (1) population, followed by the sources of its precursors: (2) proximity to roads and (3) proximity to industrial sites, then the meteorological factors come last with (4) direction, (5) speed, (6) humidity, and (7) temperature. It might also be worth noting that two of the previously existing monitoring stations located in Quezon City and Valenzuela are not within the assessed suitable municipalities. The suitable municipalities suggested in this paper might be useful in setting up new stations in the future. Despite having a definitive location at the municipality level, the criteria used in this study remain to be the basic components of locating the suitable sites and the process of providing for a more specific location requires a multi-dimensional analysis of the these factors together with others not included in this study such as security, budget, etc. This research is particularly helpful and applicable for the preliminary screening of possible locations based on the core criteria listed by EPA.

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