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An Air Quality Risk Evaluation Method for Metro Manila using Spatial Analytic Hierarchy Process

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Abstract: Air pollution and health has been jointly studied for years and their correlation have been proven in the literature. In this regard, the Philippine government is regularly quantifying air quality pollutants for legislation and policy making. Currently, the reported values are only in terms of concentration and pollutant loading. To establish a better model for health risk, two parameters are combined – hazard and exposure indices. The Analytic Hierarchy Process (AHP) technique coupled with Geographic Information System (GIS) was used to derive the composite score for the risk index. The hazard index evaluated the mitigating strategies of the government in terms of source (mobile, stationary, and area sources) and pollutant loading (SO_x, NO_x, and PM). The 450 policy scenario projected emission values and was used as reference value for hazard index. A value for exposure index was achieved by considering the location sensitivity, population density, and population sensitivity. Risk matrix was used to combine the indices and this model was applied to cities of Metro Manila.

Key Words: air pollution risk; hazard index; exposure index; AHP; GIS

1. INTRODUCTION

1.1. Air Pollution and Health

The World Health Organization stated that most cities worldwide exceeded the concentration limit set by international standards (WHO, 2014). A good indicator of high concentration of particulates in an area would be the decreased visibility of the skyline and may even be observed by the naked eye. Unfortunately, this unsightly view is also common in the Metro Manila skyline. Global health statistics had supported the notion that air pollutants and minute particles were detrimental to human health, affirming that majority of the leading diseases causing death were respiratory-related. The Philippines had not been an exception and according to Philippine Health Statistics (DOH, 2010), the primary causes of morbidity and mortality in 2010 were mostly respiratory infections (i.e. acute respiratory infection, acute lower respiratory tract infection, pneumonia, and bronchitis). These diseases were eventually consistent throughout the regions. Health statistics had also shown that some citizens (i.e. infants, lower age group, and old age) were more vulnerable to unhealthy levels of air pollutants compared to others, thus, more prone to respiratory infections.

Quantification of air pollutants had been one of the main targets of the Department of Environment and Natural Resources (DENR), specifically the Environmental Management Bureau (EMB). For awareness of the whole community, public access to current real-time air quality monitoring of Metro Manila was provided through a website (EMB, 2016) and these estimates were included in the daily local news. National status reports, as required by the Clean Air Act of 1999 (DENR, 2000), were also released every three years for an extensive inventory of emission count and some evaluations on promulgated policies. The Bureau trusts that knowing the air quality level of an area would promote public awareness and stimulus to the community, organizations, and local government units to resolve the underlying air pollution problems through legislation and policy making.

To extend this monitoring strategy approach, the objectives of this study include: first, to derive a composite score for the health risk index of an area by considering hazard and exposure indices and using Analytic Hierarchy Process (AHP) technique coupled with Geographic Information System (GIS), second, to implement this method in determining the risk levels of cities in Metro Manila; and lastly, to be able to assist in establishing priorities of stakeholders in deciding strategic plans for air pollution mitigation.

2. Analytical Hierarchy Process (AHP) and Geographic Information System (GIS)

Two analytical tools were used in the proposed model for air quality health risk – Analytical Hierarchy Process (AHP) and Geographic Information System (GIS). AHP is a multi-criteria decision analysis (MCDA) tool that enables the decision maker to develop a certain hierarchy of alternatives or factors according to priority or importance. It was designed by Saaty (2008) to cope with both the subjective and qualitative attributes of a given problem, deriving weights using pairwise comparisons. Through a survey, the decision maker or stakeholder decides a score using fundamental scale on how dominant an element is to another. The priority vector or Eigen values that defines the relative preferences can then be obtained through Eigen vector method.

Several studies were already made using AHP to describe the risk or vulnerability of certain areas to air pollutants present in the atmosphere and this study was inspired by the work of Khan and Sadiq (2005). In their case, they combined hazard (concentration of air pollutants) and exposure (population density, location, and population sensitivity) parameters. Definition of a 5-tuple fuzzy set was able to determine the risk levels as very low, low, medium, high, and very high. Essentially, this study was used as guide but with modifications on the parameters which would be described in succeeding sections.

GIS, on the other hand, is basically a computer-based tool used to collect, store, manipulate, and display spatial reference information (Bunch, 2012). Processing and manipulating geospatial data enhances the understanding of geographical measurements and assists in data analysis. Some common GIS operations are statistics, query optimization, and digitizing. It is also possible to provide a common ground for both the technical and layperson by communicating the information spatially and visually since GIS is able to store geographically large referenced data.

Two parameters were evaluated using AHP and GIS: hazard and exposure indices. Hazard index was estimated using the pollutant loading of sulfur compounds (SOx), nitrogen compounds (NOx), and particulate matter (PM) per source. Exposure index was assessed in terms of population sensitivity, population density, and location sensitivity.

2.1. Hazard Index

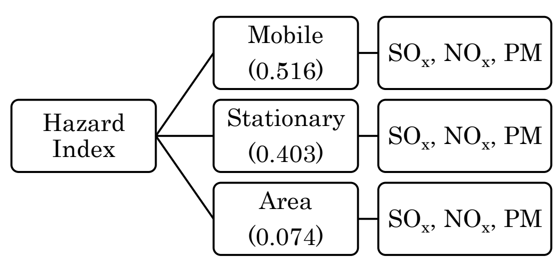

Fig. 1. Hazard index hierarchy tree

To determine the risk level, hazard and exposure indices was initially calculated separately. The hazard index (fig. 1) measures the pollutant loading of three criteria pollutants (SOx, NOx, and PM) and their sources (stationary, mobile, and area) as decribed in Table 1. These pollutants are known to cause bronchoconstriction, emyphysema, airway inflammation, aggravation of heart disease, and many more health complications (USEPA, 2015). To represent, the priority preferences of the stakeholders, values of Eigen vectors were included in fig. 1. It was expected that mobiles sources would have the highest priority since the transport sector had been the major contributor to air pollution according to the previous national air quality status reports from DENR (EMB, 2012). Detailed emission inventories had utilized factors to estimate the relationship from source to recipient or activity and convert it to the obtained quantitative values.

Table 1. Definition of pollutant source (EMB, 2009)

Mobile: any vehicle/machine propelled by or through redox reactions used for conveyance or transportation (e.g. cars, UVs, trucks, and buses)
Stationary: any building or immobile structure, facility, or installation which emits or may emit any air pollutant (e.g. electricity-generating plants)
Area: relatively large areas of specific activities that generate significant amounts of air pollutants (e.g. busy roads, hubs, and construction sites)

For comparison, the projected emission ceilings from the 450 policy scenario was used as reference to estimate an area's pollution level.

2.1.2. 450 Policy Scenario

In the World Energy Outlook (Cofala et al., 2012), energy pathways or scenarios were characterized using the analytical tool IIASA GAINS model. The assumption was that in the next 25 years, the 25 world regions (individual countries or groups with similar policies and emission characteristics) would completely implement policy commitments in a cautious manner to achieve the commitment to limit the global increase in average temperature to 2°C. One of these pathways is the 450 policy scenario.

The 450 policy requires long-term stabilization of the atmospheric concentration of greenhouse gases at below 450 parts per million (ppm) of carbon-dioxide equivalent (CO_2-eq), thus the name. In order to achieve this goal, further policy commitments was assumed to be made. Energy system measures (i.e. reduction of fossil fuel use) aimed at reduction of CO_2 emissions cause an important decrease of emissions of air pollutants, i.e. SO_x, NO_x, and PM. At any level, local air pollutants increase respiratory diseases and shorten life expectancy. This pathway or scenario was chosen as basis because of assumption of a strong policy commitment and a proposed definite target. Being part of ASEAN9 region (India not included because of high emission contribution), the scenario had projected ceiling values (Table 2) for SO_x, NO_x, and PM emissions.

Table 2. Projected values of 450 policy scenario

Pollutant	SO_x	NO_x	PM
Ceiling (tons/yr)	1349000	2447000	1893000

2.2. Exposure Index

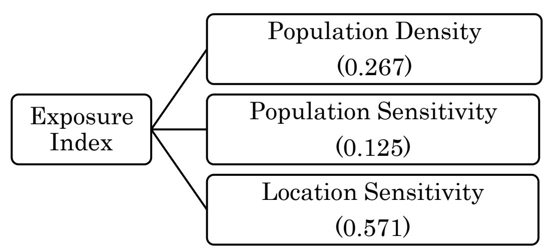

Fig. 2. Exposure index hierarchy tree

Basis of this hierarchy were adapted from the works of Khan and Sadiq (2005) and Nadal (2011). AHP was applied in the second level to assess preference among the exposure parameters: location sensitivity, population density, and population sensitivity. Population density is simply the number of people per land area. Higher population densities pose higher risk of exposure. Population sensitivity refers to the percent of sensitive population, that is, children below 14 years old and adult that are 75 years and older, vulnerable to air pollution diseases. Age range was chosen based on data available from the National Statistics Office (DOH, 2010). However, location sensitivity (Table 3) needed to utilize GIS to identify areas for prioritization based on land use (e.g. very low to very high residential area, open space, commercial, transportation, industrial, etc.). It pertains to areas that holds sensitive population.

Each land use could be clearly identified on the spatial data provided by NAMRIA (2008) and were further classified into categories according to sensitivity. Using GIS, attribute operations were performed to compute for the areas and percent distribution per land use in each class per city. These were used as input values to determine location sensitivity.

Table 3. Location sensitivity classification

Land Use Class	Areas Included
1	Open space, agricultural land, grassland, forest land, water-related
2	Industrial, transport and service facility
3	Park & recreational, government and quasi-public, commercial and business, very low and low residential, military
4	Medium residential, Informal settlers, Educational & cultural, Religious & cemetery
5	Health and welfare, very high and high residential

Table 4. Risk matrix

		Exposure		
		Low (0.00-0.69)	Medium (0.69-0.85)	High (0.85-1.00)
Hazard	Low (0.00-10.16)	Good	Fair	Unhealthy
	Medium (10.16-20.32)	Fair	Unhealthy	Very Unhealthy
	High (20.32-30.48)	Unhealthy	Very Unhealthy	Emergency

3. RISK LEVEL OF METRO MANILA

To evaluate the risk level of Metro Manila cities, pollutant loading in tons per year and per source for every city from DENR (EMB, 2014), population and health statistics from Philippine Statistics Office (DOH, 2010), and geospatial data from NAMRIA (2008) were measured. Hazard and exposure indices, as explained above, were acquired using AHP and GIS techniques. Air quality experts from the government were asked to act as stakeholders for weighing the parameters. Since risk in the study is a function of two parameters, a cross matrix from Khan and Sadiq (2005) was adapted and the cities were conveniently classified into good, fair, unhealthy, very unhealthy, and emergency levels (Table 4). Finally, the tabulated results were graphically presented with a risk map.

Table 5. Metro Manila risk levels

City	Hazard Index	Exposure Index	Risk Level
Pateros	Low	Low	Good
Navotas	Low	Low	Good
Paranaque	Low	Low	Good
Makati	Low	Low	Good
Malabon	Low	Low	Good
San Juan	Low	Medium	Fair
Las Pinas	Low	Medium	Fair
Taguig	Low	Medium	Fair
Mandaluyong	Low	Medium	Fair
Muntinlupa	Medium	Low	Fair
Manila	Low	High	Unhealthy
Caloocan City	Low	High	Unhealthy
Valenzuela	High	Low	Unhealthy
Marikina	Medium	Medium	Unhealthy
Pasig	High	Medium	Very Unhealthy
Pasay	High	Medium	Very Unhealthy
Quezon	High	Medium	Very Unhealthy

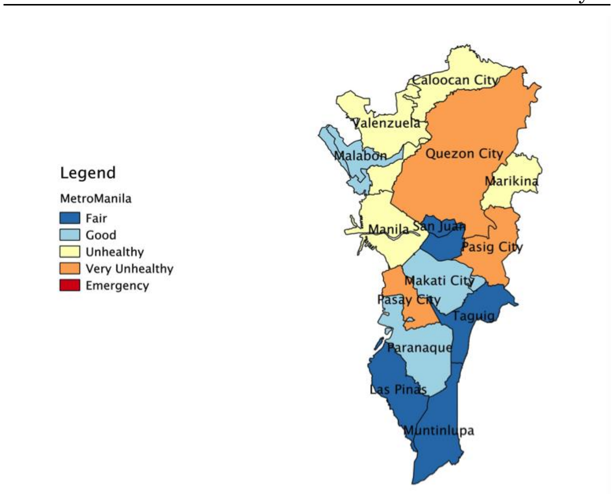

Fig. 3. Metro Manila risk level map

As an effective communication tool, the risk map revealed which cities should have further consideration in their air pollution strategies. Cities of Quezon, Pasay, and Pasig had the highest risk level in Metro Manila. Their hazard indices were also considered high. Normally stakeholders could criticize that this was the result of high concentration of air pollutants and that a plan for mitigation (i.e. use of biofuels, use of green infrastructure, control of dust from construction, regulation of effluents) would suffice. But due to the exposure parameters considered, other angles of analysis were actually introduced in the equation. A sample observation could be done in Manila with its land use information (fig. 4). Table 3 defines the land use classes, categorized with increasing location sensitivity as class went higher. Since classes 3,4, and 5 were mainly composed of residential areas and other equally sensitive spots, Manila had obtained a high exposure index. Policies could target these areas to control air pollution as they could be classified as well as area sources. Another approach would be through provision of strategic direction for sustainable land use. This might address the population density issues. Not only the high density areas pose higher risks but also the lack of open space in Metro Manila in general. It would be inevitable that aligning programs with other sectors could develop collaboration among stakeholders and enhance compatibility of action plans.

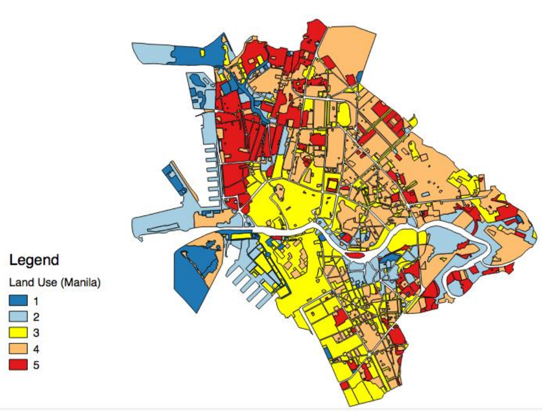

Fig. 4. Land use classification of Manila

The risk model assumed that each pollutant directly contributed independently per source to health risk and chemical interactions was insignificant. Hazard index based on pollutant loading was set to be not differential with respect to height and not affected by topographic patterns. These should be noted if concentrations were used, therefore, using the loads instead measured from stack testing enabled the accounting for the total amount or weight of emissions. Consequentially, the simplified operations primarily emphasized and centered on the prioritization preferences of stakeholders – air quality experts which were government officials participating directly in decision-making of policies and regulations. It would be safe to say that based on the government's current priority targets in air pollution, this was the resulting risk level of each area.

4. CONCLUSIONS

Various studies had been done to prove the relationship between air pollution and health. Current status reports focus only on the emission amount of air pollutants in tons per year. Using the proposed model, risk level of each city was quantified through composite score of hazard and exposure indices, and classified into a descriptive manner, (i.e. good, fair, unhealthy, very unhealthy, and emergency). Aside from the pollutant hazard, human or social parameters were also highlighted as the exposure index and captured its uncertainty factors in relation to air pollution. This provided a reliable representation of air pollution risk. AHP was able to incorporate the subjective preference of the government in the analysis of both hazard and exposure indices and GIS supported these findings. The model could be a new tool to support the assessments done by the government and help decision makers and policymakers to decide on what regulations to implement or improve.

The study could be further improved if instead of cities, airshed would be analyzed. Airsheds are parts of atmosphere that behaves in a coherent way with respect to the dispersion of atmospheric emission (DENR, 2009). It would cover not only Metro Manila but other regions as well. Because of the major limitation of the study, another important improvement would be the completeness emission inventory of every area and updated statistics and spatial data. Not all regions are able to compile emissions to achieve complete coverage of all sources due to limitations of resources.

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