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Socio-Environmental Agent-Based Simulation on the Livability of Two Cities

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Abstract

The need for methodological advances in research as an important tool for instantaneous and better understanding on the dynamic and heterogeneous behavior in socio-environmental systems is increasing. In this paper, the greenhouse gas (GHG) emissions and mitigation rates, and their effect to human inhabitants of two mega cities namely, Metro Manila, Philippines and New York City, USA were studied. A simple framework to develop agent-based simulations using NETLOGO version 5.2.1 systematically was conducted. Factual data was introduced and then considered for the application for a dynamic model of GHG emissions and its effect to human population considering the mitigation programs implemented. The model came out to be reliable in projecting the livability of the two mega cities with a margin of error of approximately $\pm 7\%$. Results showed that Metro Manila has higher livability compared to New York City by 6%. The results are quite alarming which suggest more involvement from the human inhabitants to GHG mitigation programs considering that the livability of the cities are mainly dictated by the population growth as observed. However, it has to be noted that the chance of involvement of the population should not go beyond the carrying capacity of an ecosystem.

Keywords: *Greenhouse gases (GHG); Livability; Metro Manila; New York City*

Introduction

Air pollution has long been recognized as a potentially lethal form of pollution. Greenhouse gases (GHG) emissions may compose carbon monoxide (CO), carbon dioxide (CO2), NOx, SOx, and particulate matters (PM) (Ledley et al., 1999). GHG are primary contributors of air pollution warms the surface and the atmosphere with significant implications for rainfall, retreat of glaciers and sea ice, sea level, among other factors (Ramanathan and Feng, 2009). About 30 years ago, it was recognized that the increase in tropospheric ozone from air pollution (NOx, CO and others) is an important greenhouse forcing term (Ramanathan and Feng, 2009). Greenhouse gases (GHG) in urban areas has been identified to come from different emission sources. They are categorized either as mobile, area, or stationary sources (EMB-NCR, 2011). Mobile sources may include running emissions, cold start, hot start, exhaust, and evaporative emissions (EMB-NCR, 2011). Area source emissions may come from structural and automobile fires while stationary sources come mainly from the combustion of residual oils (EMB-NCR, 2011). Major global problem dealing with air pollution is less recognized neglecting its possible effect to the livability of an area (Giap and Yew, 2014).

The need for methodological advances in research as an important tool for instantaneous and better understanding on the dynamic and heterogeneous behavior

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in socio-environmental systems is increasing. An approach to use agent-based simulation on a computer system is considered to be an effective method. Simulation with dynamically interacting heterogeneous agents is expected to re-produce complex phenomena in air pollution and mitigation. This also helps to test various controlling methods, evaluate systematic designs, and obtain fundamental elements which produce interesting phenomena for future analytical work (Mizuta and Yamagata, 2001).

Related literatures and current livability programs shows that livability is generally thought of as having multiple dimensions. Livability is derived from the word “livable” which means broadly as “suitability for human living” (Merriam-Webster, 2017). For instance, a definition provided by the Victoria Transport Policy Institute (VTPI) claims that livability is affected by a community’s public safety, environmental quality, community cohesion, friendliness, aesthetics, accessibility, pride, and opportunity” (VTPI, 2010). In addition, types of livability objectives may include (1) environmental goals (such as air quality, open space, and greenhouse gas emissions); (2) economic goals (such as economic revitalization and development), land use goals (such as compact, mixed use development); (3) transportation goals (such as walkability, accessibility, and transportation choices); (4) equity goals (such as affordable housing and mixed-income communities); and (5) community development goals (such as sense of place, safety, and public health) (Fabish and Haas, 2010).

In this paper, the greenhouse gas emissions and mitigation rates, and their effect to human inhabitants of two mega cities namely, Metro Manila, Philippines and New York City, United States of America were studied. A simple framework to develop agent-based simulations using the open source, NETLOGO version 5.2.1 systematically based on factual data gathered was introduced and then considered for the application for a dynamic model of greenhouse gases (GHG) emissions and its effect to human population considering the mitigation programs implemented. This study aims for early prediction of livability of two mega cities and eventually do something out of it (e.g. increase mitigation measures) at an earliest possible time considering the population growth rate, mitigation programs of the government, and GHG emission rates.

Methodology

Parameters. Parameters are classified as set values and process values. Set values initially provided on the NETLOGO version 5.2.1 came from factual data available on reputable sources as of year 2010. These include initial population, average population growth rate per annum (in percent), number of greenhouse gases (GHG) sources, GHG emission rates (in metric tons per annum), and mitigation measures or programs (from the budgetary allotment of an implementing agency of a government, in percent). On the other hand, process values include count of people and the number of years (correspond to the projected livability of a city).

How it Works. This model has its roots from the predator-prey equilibrium condition in an ecosystem wherein agents representing people, GHG pollutants and mitigation elements compete for resources. Dynamic interactions of these elements through time can be explored through this model. Behaviors of multiple generations of agents can be analyzed: irregular reproductive success of the population of people which generates regular oscillations in population size might lead to possible extinction; pollution inhibit the population density while the number of emitters and rate of emission stimulate the increase in pollution.

In the work of Felsen and Wilensky (2007), ‘Power Plants’ indicate pollution sources, which releases pollution into the environment. In this work, ‘Emission Sources’ also create pollution but is now a general term which include stationary sources, mobile sources and area sources. The reproduction of

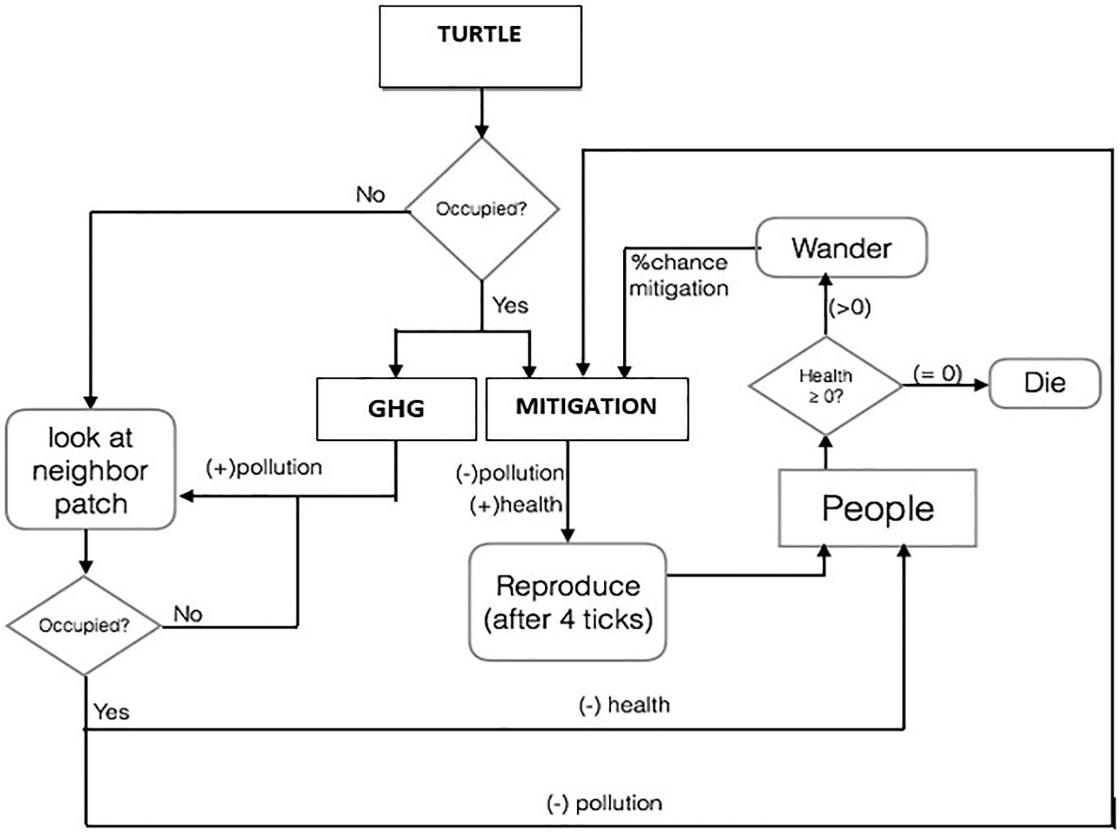

Figure 1. Logical flowchart of agent-based model simulation

the population is adversely affected by this pollution and those who create children is governed by the 'Growth-rate'. This factor also gives an idea on the cloning rate for natural deaths.

The population can think of ways to alleviate pollution generation and was represented in the work of Felsen and Wilensky by 'Planting-rate'. In this work, this mitigation activity is now represented by 'Mitigation-rate' and signifies the budget allocation in percent for the implementation of pollution mitigation activities or researches. Stability of the ecosystem is achieved if neither the people population nor the pollutants overrun the environment. The number of ticks represent the number of years that a certain can be livable. Livability is defined as the period of time that a certain area (e.g. city) could sustain good quality of air to human inhabitants. The following rules were adopted from Felsen and Wilensky (2007):

1. GHG emission sources are grid cells with a very high fixed pollution value (determined by the GHG emission rate).

2. All grid cells have some GHG emission which is a major indicator value for pollution, although it may be 0. Pollution diffuses throughout the grid, so each grid shares part of its pollution value with its neighboring cells. Since the GHG emission is fixed at a high amount at GHG emission sources, this has the effect that pollution emanates out from the GHG emission sources.

3. Mitigation programs by the government (determined by mitigation rate), however, clean up pollution in the cell they are placed, and the neighboring cells. Thus, they block the spread of pollution, by emanating low-pollution values. Mitigation programs are implemented in a set period of time.

Table 1. Preliminary data for agent-based pollution model simulation as of year 2010.

Area	Parameter				
	Initial Population	**Ave. Population Growth Rate (in%)**	**Annual Mitigation Rate(in%)**	**Annual GHG emission source**	**Annual GHG emission source**
Metro Manila	11, 855,975 (a)	1.78 (a)	9.50(b)	6,641,181ⓒ	14,022,070ⓒ
New York City	8,175,133(d)	1.30(d)	6.00	1,972,127(f)	54,300,00(g)

Notes:
(a) – (NSO-NCR, 2012)
(b) – (DENR-NCR, 2016); estimated
(c) – (EMB, 2012)
(d) – (NYC, Planning 2014)
(e) – (Page, 2015); estimated
(f) – (Charles-Guzman, 2012)
(g) – (Dickinson and Tenorio, 2011

4. Each time step (tick) of the model, people agents
    a) move randomly to an adjacent cell
    b) with some probability, they may plant a landscape element
    c) if they are healthy enough, with some probability, they may reproduce (clone)
    d) if their health has dropped to 0, they die.

The logical process on how the agent-based model simulation works is shown on Figure 1.

Input. Preliminary data were gathered to provide input on the pollution model, shown in Table 1. These are the data sets that will be used to run the model.

Results and Discussion

Process Output. After running the model for 500 runs, starting from year 2010, and calculating the average livability in years for each mega city, it was found out that Metro Manila has higher livability compared to New York City by 6.11% with an average livability of 57 and 54 years, respectively. This means that Metro Manila and New York City can be livable until year 2067, and 2064, respectively. This may be due to higher initial population, growth rate, and GHG mitigation measures observed in Metro Manila than in New York City. Furthermore, higher growth rate may have improved the chance of involvement of human factor in the area in mitigating air pollution which could increase the livability of a city.

The snapshot of the process output shown by NETLOGO version 5.2.1 is shown on Figures 2 and 3 for Metro Manila and New York City, respectively.

Sensitivity Analysis. To enable to determine which factor plays an important role on the livability expectancy of the two mega cities, sensitivity analysis for each was conducted by increasing a single criteria by 60 percent for each run. Results were consistent for both mega cities that the variance under Population Growth Criteria has the highest variance among others indicating that this criteria is the most sensitive among others. It must also be noted that the simulation process assumes that all human inhabitants that comprise the population growth are all participating in the GHG intervention programs.

It can be implied that the population growth of a city plays a vital role in increasing the livability of a city considering the chance of their involvement in mitigating air pollution. Provided however, that that chance of involvement of the population will not go beyond the carrying capacity of a certain ecosystem

Validation. The result of the simulation for each city was validated to determine the degree of reliability of the simulation results

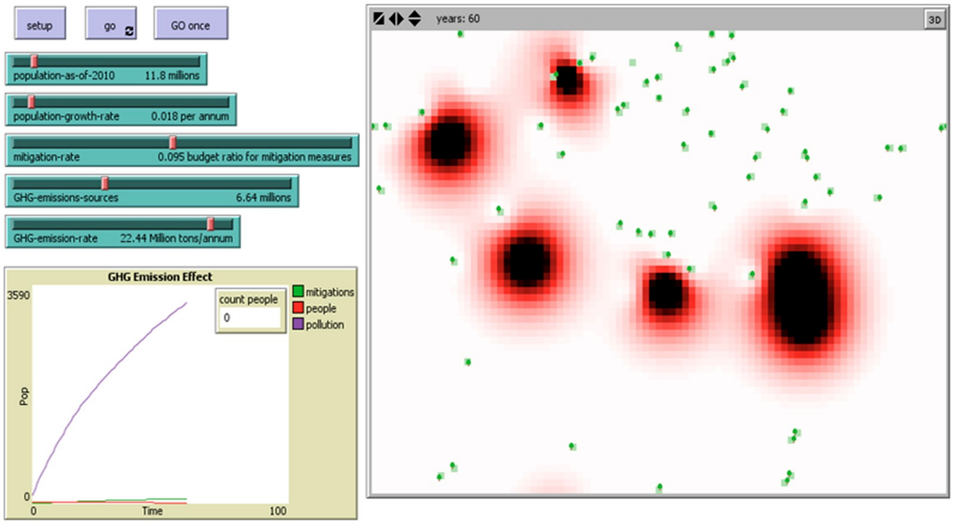

Figure 2. Process output of agent-based model simulation for Metro Manila.

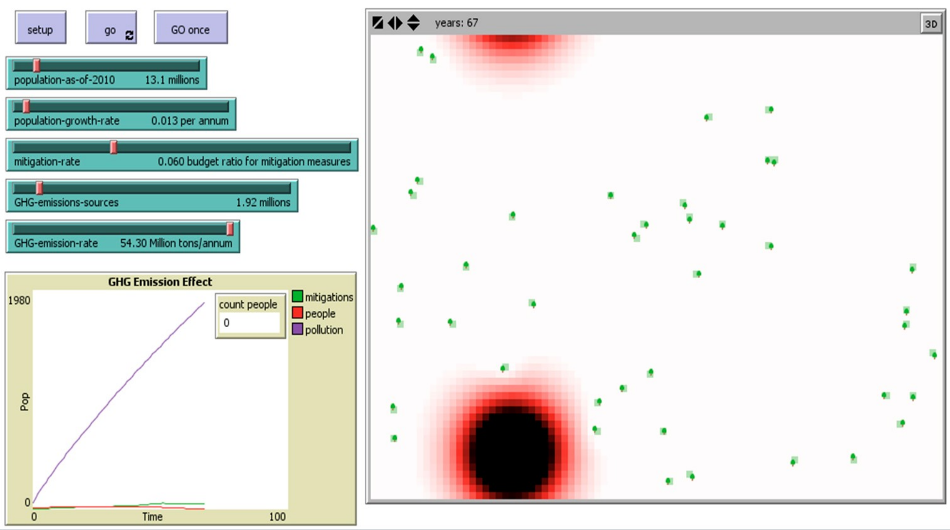

Figure 3. Process output of agent-based model simulation for New York City..

using the population growth for Metro Manila and New York City in the year 2013. Since there is no census conducted yet for 2013 in the Philippines, the growth rate of Metro Manila is assumed constant from 2010 to 2013 equivalent to 1.78% (NSO-NCR, 2012). This is used thereafter to estimate the population of Metro Manila for 2013 which is 12.01 million. When this estimated value is compared to the value obtained after ten (10) simulations using NETLOGO version 5.2.1, it was found out that the mean is equivalent to 11.6 million. The simulated value came out to have a margin of error of $\pm$6.54% relative to the estimated value at 95 percent confidence level.

Similar method was done in estimating the population of New York City by year 2013 which came to be 8.31 million (NYC Planning, 2014). Simulated mean value came out to be equal to 8.48 million. The simulated value for New York City came out to have a margin of error of $\pm$4.82% relative to the estimated value at 95 percent confidence level.

Hence, it can be said that the simulated values are reliable when a margin of error of $\pm$7% is considered as acceptable.

Conclusion

The model was found out to be reliable in projecting the livability of the two mega cities with a margin of error of approximately $\pm$7%. Metro Manila has higher livability expectancy than New York City by approximately 6% when simulated from year 2010 onwards considering socio-environmental system of each city. The result showed to be quite alarming for the livability of both cities. It was also found out that the livability of both cities is mainly dictated by the population growth rate which may be due to the possible involvement of human inhabitants to the GHG mitigation programs provided that chance of involvement of the population will not go beyond the carrying capacity of a certain ecosystem.

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