People VS Pollution analyses using Urban Suite – Pollution

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Abstract—**Air pollution and population health is one of the most pressing environmental and public health issue contemporarily. Economic development, fossil fuels, transportation/motorization, urbanization, energy consumption and rapid population growth are major driving forces of air pollution in large cities, especially in megacities. Air pollution levels have been decreasing dramatically in developed countries in recent decades. However, in countries in transition and developing countries, levels of air pollution are still relatively high, though the levels have been gradually decreasing or have remained stable during rapid economic development. Several hundred epidemiological studies have emerged in recent years showing adverse health effects associated with short-term and long-term exposure to air pollutants. In this work, we have presented the agent based modeling system to explore the temporal behavior of the population to ambient air pollution. The computed results are processed and visualized using the NetLogo modeling environment. The results shows the variation of the population density over time with the corresponding pollution exposure.**

I. Introduction

The model "Urban Suite – pollution" is simulating the effect of pollution on people's population over time. We are analyzing the fragile equilibrium between the people, air-borne pollutant agents and other landscape elements like trees interacting dynamically and competing for resources with in enclosed environment. Basically, the model has 3 main components people, pollution, and trees. People have the ability to reproduce offspring as per the defined birth rate. They can wander around the 2d grid space and also have chance to plant the trees based on defined plantation probability. Trees can curb the pollution (spreading throughout the grid cells at certain rate) from grid cells.

Regular oscillations (cycles) in size of population amid pollution indicates balance and stability in the eco-system where, despite fluctuations, populations maintain themselves over time. The phenomenon is also called Homeostasis. In contrast, irregular oscillations indicate instability leading toward potential extinction of respective population. The model establishes a kind of feedback regulation: predators(pollution) inhibit the density of prey(people), and prey also have chance of reducing the density of predators by planting the trees.

Below are the control parameters of model:

INITIAL POPULATION - controls the number of people created at the start of the model

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BIRTH-RATE controls the chance each person has of producing offspring. The chance of producing offspring depends upon the health of parents. For each year(tick), people's health is decreasing by constant number resembles aging effect. Pollution is also effecting the health adversely.

PLANTING-RATE controls the chance a person has of planting a tree each year. The presence of trees helps curb the pollution diffusing through the grid cells.

POWER-PLANTS controls how many power plants are created. Power plants create pollution into the environment which is adversely affecting the health of people thereby reducing chances for reproduction.

II. Related work

In order to support health risk assessment and management, numerous pollution exposure models have been developed.. Dimitroulopoulou et al.[1] have evaluated personal NO2 exposure by using a deterministic model. Their model can distinguish three types of exposures: indoor air exposure resulting from penetration of outdoor air, outdoor air exposure and outdoor air exposure. The outdoor NO2 concentrations were assessed based on the measurement data from urban background sites. The adjunct research on traffic-specific particle exposures improves estimates of the actual concentrations experienced while commuting in urban areas[2]. Particle samples were drawn from locations specific to commuting bus, metro, train or footpaths. Introductory conclusions reveal significant differences between traffic specific locations and urban background in terms of particle size and exposure concentration. To include a fairly simple exposure model, AirQUIS (air quality management system) has been expanded. [3] The exposure modelling part of the system utilised a geographical information system (GIS) by associating a number of persons with each individual building, and collate this information with the computed ambient air concentrations. [4] The modelling system developed has been utilised to evaluate environmental impacts of traffic planning and land use scenarios in the area. Preliminary potential NO2 exposures, NO2 concentrations and emissions have been assessed in the transportation system plan for the Helsinki Metropolitan Area (Helsinki Metropolitan Area Board, 1999). [5]A mathematical model is presented for the quantification of ambient air pollution vs human exposure in an urban area. The main aim was to calculate the temporal and spatial alteration of average exposure of the urban population to ambient air pollution.

III. METHODOLOGY

Approaches used to perform 3 sets of experiments are as follows.

1st Experiment:

In this experiment, we have located the 8 power plants at the bottom end of the grid while the population is wandering through out the grid. Settings of control parameters are as follow:

Initial population = 50
Plantation rate = 0.05
Birth rate = 0.01 - 0.20
Pollution-rate = 2

Birth rate is variable. It ranges from 0.01 to 0.20. Pollution rate is the rate at which power plants emit pollution. Each power plant has the same pollution rate.

We are analyzing the relationship between the birth rate(variable) and pollution(constant) when power plants are grouped together at one corner.

2nd Experiment:

In this experiment, we have confined the population within one quadrant instead of entire grid. Other configurations regarding power plants, pollution rate, plantation rate etc. are same as the first experiment. One change is that for the birth rate > 0.10, we are testing the results by making the pollution rate dependent on number of people.

We are analyzing the effect of pollution when population is inhabited far away from power plants.

3rd Experiment:

Now, we have located the power plants along the grid boundary ,unlike experiment 1 & 2, while the population is confined within a quadrant. Configurations of control parameters are same as experiment 1 except when birth rate >0.1. We have made the pollution dependent on number of people. In addition, we also have maintained the neighbor count. If a person has 8 neighbors then the person dies.

In this, we are analyzing effect of pollution when power plants are distributed along grid boundaries as compare to grouped together at bottom.

IV. EXPERIMENT

The results from the 3 experiments are as follows. Each experiment shows 3 behaviors, categorized by birth-rate.

1st Experiment:

<u>Self-organization</u> –

People which are at the top end of grid or far from the power plants remain heathier for long time and have high reproduction rate. This increases good amount of count in overall population. In the meanwhile, people which are near by the power plants are helping in reducing the diffusion of pollution throughout the cells by planting the trees. However, their production rate is less than people residing at the top as they are exposed to the pollution generated by power plants. The generations or predecessors of the population located far from power plants also find their way nearby power plants. Then they help in reducing the pollution by planting the trees even if the previously located population nearby power plants dies by exposure. This again give good amount of time to population at top end to reproduce. Thus, the cycle goes on repeating over the years when birth rate = 0.1, thereby maintaining the population balance.

a) 0 < Birth rate < 0.1

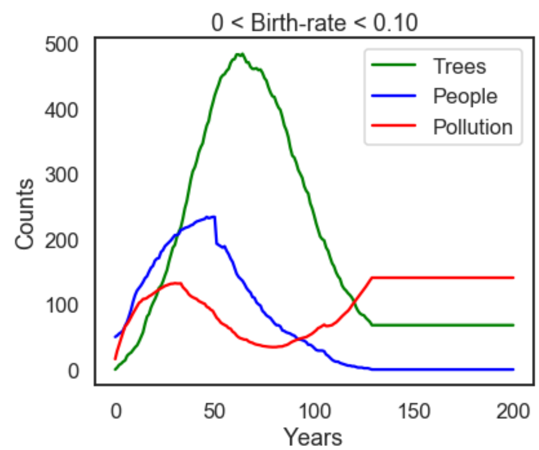

Fig.1a. With in above range of birth rate, system is showing fixed point behaviour as population eventually results to 0 in very short time.

b) Birth rate = 0.10

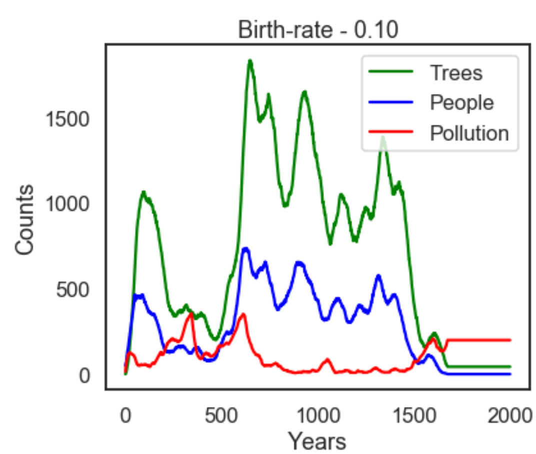

Fig.1b. The above graph shows that the system has the tendency to resort to stable behavior by maintaining the population balance. This is also known as Homeostasis.

c) Birth rate > 0.10

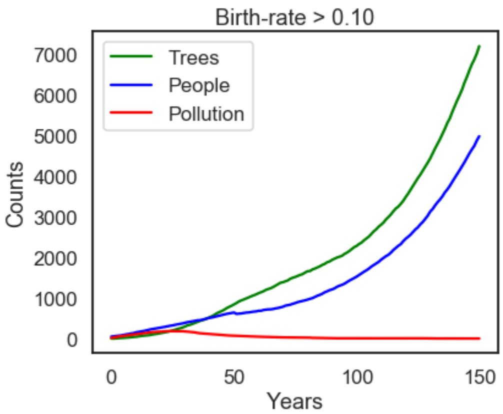

Fig.1c. For the birth-rate greater than 0.10, system leads to chaotic behavior attractor aka strange attractors. Similar behavior in exp 2 and 3 with these parameter settings.

2nd Experiment:

<u>Self-organization –</u>

When we run the model with this setting, initially population may have good chance to reproduce as nobody is directly exposed to power plants/pollution but at the same time the pollution emanates out from power plants also increase in linear like trend with time. The reason for this constant increase is that there is no plantation present in the neighborhood or near the power plants as the population is situated far away. After some time, pollution will become so dominant that it will conquer the majority part of grid and harm the population with high intensity, but population still have chances to remain unexposed from at least 2 sides. This factor helps the unexposed people to reproduce and to plant the trees as depicted in Fig. 2b when Birth-rate = 0.1. When birth-rate is 0.16 (Fig. 2c), system is resorting to kind of stable trend for years. As pollution is dependent on the number of people(when birth rate >0.1), this condition stopping the healthy(unexposed) population for high reproduction(Chaos). Thus, maintaining balance.

a) *Birth rate = 0.1*

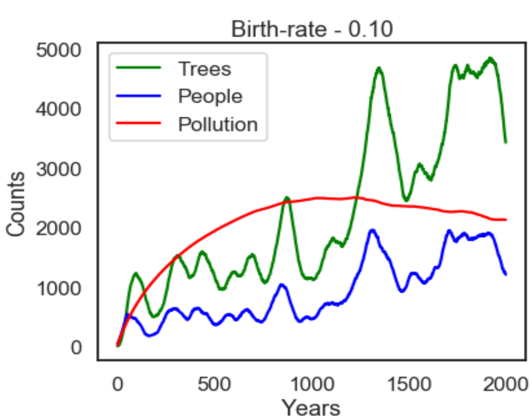

Fig. 2b. Here after some time (1000 years) pollution decreases, as plantation increase due healthy(unexposed) people and birth rate.

b) *Birth rate > 0.1*

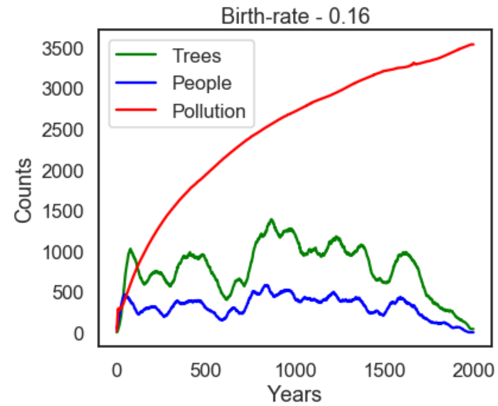

Fig. 2c. When the birth rate is 0.16 and pollution is dependent on number of people. For birth rate >0.16, model shows similar chaotic behavior as in Fig. 1c. Similar behavior sustained in experiment 3 with these parameter settings.

3rd Experiment:

<u>Self-organization –</u>

In this scenario, we have located the power plants along the grid boundary while the population is situated within a quadrant. After we run the model with these settings, the pollution starts diffusing from all the sides. After some time, the population will be completely surrounded by the pollution unlike in second experiment where population have chances to remain unexposed from at least 2 sides. When population extend or try to expand, the exposure makes an impact on their health or may die there by restricting the rate of reproduction and also plantation. For birth-rate >0.1, population has direct impact on pollution rate and also the neighborhood. The result of this case shown in Fig. 3c.

a) *Birth rate = 0.1*

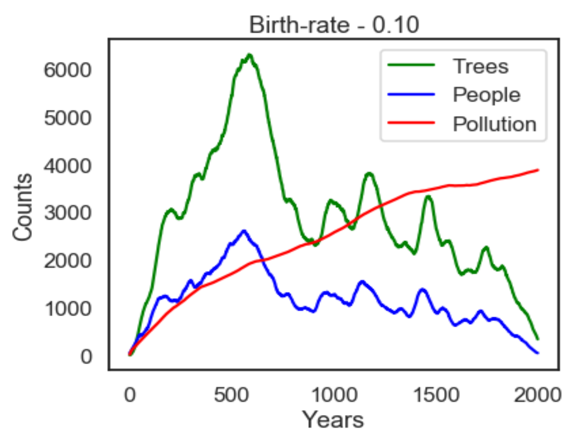

Fig. 3b. The system is able to maintain the homeostasis between population and pollution with this birth-rate.

b) Birth rate > 0.1

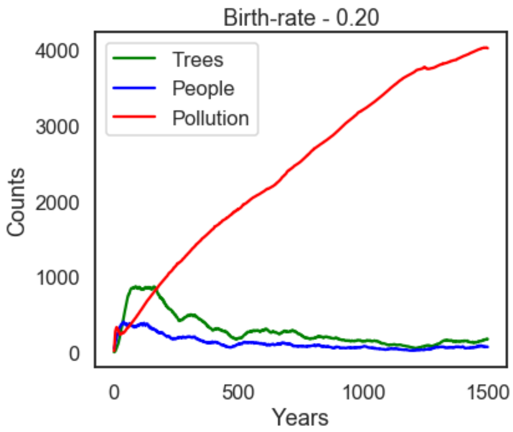

Fig. 3c. The model is able to maintain the people's population within count of 200 despite the highest birth rate of 0.20. This indicates the balance and stability with the respective adjustments.

V. Discussion

1st Experiment:

When the birth rate is between 0 and 0.1, the population dies out within 200 years because the people are reproducing less within given time. This is also affecting the plantation rate in a negative way there by increase in diffusion of pollution. Also, increase in pollution deteriorates the population's health resulting in less reproduction. With birth rate value greater than 0.10, population goes on increasing with a reproduction rate higher than death rate. Also, increase in plantation is posing as factor in curbing pollution there by increase in population indefinitely.

2nd Experiment:

When birth rate is 0.10, there are low chances for stable behavior and high chances for chaotic behavior. It depends on population exposure to pollution. If the population is partially exposed to pollution by extending towards power plants, then there may be stable/balance behavior otherwise it will go into strange attractor. In fig. 2c, pollution goes on increasing as population and power plants are at far distance. Number of people and trees are maintained with in certain range despite high birth rate. Thus, giving rise to regular oscillations for people and trees.

3rd Experiment:

When birth rate is 0.1 (Fig.3a), the model shows stable behavior. The reason behind this stability is that the population is somehow exposed to pollution from all the sides. This helps in preventing the over-reproduction of offspring. The location where the population dwells, plantation of trees helps in curbing the pollution from the cells there by maintaining the population within inhabit circle. There are less chances that model is showing chaotic behavior for the birth rate 0.1. When birth rate >0.1, specially when it is 0.2, the system is not leading to chaos (unlike Fig. 1c.) because the population is controlled by neighborhood people plus dependence on pollution rate. Thus, maintaining stability within area of inhabitance.

VI. Conclusion

In **1st experiment**, for the birth rate<0.1 (Fig.1a), model shows clear fixed-point behavior as people dies within 200 years. This is because the birth rate is low against pollution rate. The similar behavior follows for 2nd and 3rd experiment (birth rate<0.1) with these parameter settings. For the birth rate 0.1 (Fig.1b) system has chances of leading to regular oscillations (cycles, indicate stability and balances) as some part of population is nearby the power plants curbing the pollution by plantation and some people situated far away. When birth rate > 0.1(Fig .1c), system is leading to chaos because birth rate is higher against pollution rate. In **2nd Experiment**, when birth rate is 0.1(Fig. 2b), model shows stable fluctuating behavior among the populations but sometimes this fluctuating trend as shown leads to chaos. This is because the part of population ,not exposed to power plants(pollution), remains healthy and sometimes gets the room to reproduce large number of offspring which leads to strange attractor. When birth rate(0.16) > 0.1(Fig. 2c), system able to maintain stability of people count even pollution is increasing in linear like trend. This is because the population is dependent on pollution which confines people within range of oscillation. The similar behavior follows for 3rd experiment (birth rate>0.1) with these parameter settings. In **3rd Experiment**, when the birth rate is 0.1(Fig. 3b), system has high tendency of maintaining the equilibrium between people, trees and pollution because the population circle and surrounding pollution works in regulated manner of curbing(pollution) and polluting(environment). When birth rate(0.20) > 0.1(Fig. 3c), model exhibit the potential to keep the people's population count stable, though within small range, for years against linear increase of pollution. The reason for this is the highest birth rate. This birth rate is also controlled by neighborhood count plus dependence on pollution which thwart its way towards chaos aka strange attractor.

References

[1] Dimitroulopoulou C, Ashmore MR, Byrne MA, Kinnersley RP. Modelling of indoor exposure to nitrogen dioxide in the UK. Atmospheric Environment. 2001 Jan 1;35(2):269-79.

[2] Aarnio P, Kousa A, Yli-Tuomi T, Jantunen M, Koskentalo T, Hillamo R. Composition of and exposure to PM2. 5 while commuting in the metro and on the street. Strategies for Clean Air and Health. 2003 Nov 5.

[3] Bohler T, Riise A. Using the air quality assessment system AirQUIS in modelling the population's exposure to traffic induced air pollution. InFourth International Scientific Symposium on Transport and Air Pollution 1997 Jun (pp. 9-13)

[4] Kousa A, Kukkonen J, Karppinen A, Aarnio P, Koskentalo T. A model for evaluating the population exposure to ambient air pollution in an urban area. Atmospheric Environment. 2002 May 1;36(13):2109-19

[5] Karppinen A, Kukkonen J, Elolähde T, Konttinen M, Koskentalo T, Rantakrans E. A modelling system for predicting urban air pollution: model description and applications in the Helsinki metropolitan area. Atmospheric Environment. 2000 Jan 1;34(22):3723-33.