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A Dynamic Model of Air Pollution, Health, and Population Growth Using System Dynamics: A Study on Tehran-Iran (With Computer Simulation by the Software Vensim)

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Abstract**—**The significance of environmental protection is well-known in today's world. The execution of any program depends on sufficient knowledge and required familiarity with environment and its pollutants. Taking advantage of a systematic method, as a new science, in environmental planning can solve many problems. In this article, air pollution in Tehran and its relationship with health and population growth have been analyzed using dynamic systems. Firstly, by using casual loops, the relationship between the parameters effective on air pollution in Tehran were taken into consideration, then these casual loops were turned into flow diagrams [6], and finally, they were simulated using the software Vensim [16]in order to conclude what the effect of each parameter will be on air pollution in Tehran in the next 10 years, how changing of one or more parameters influences other parameters, and which parameter among all other parameters requires to be controlled more.

Keywords**—**Air pollutions, Simulation, System Dynamics, Tehran, Vensim.

I. INTRODUCTION

CITY dwellers have, in actuality, turned into the plenipotentiary owners of the Earth. In 21st century, 80% of people will live in cities, and metropolises will destroy natural environment. In such a civilization, some elements including wind, water, and temperature will change drastically, and pollution will seriously increase accordingly. Meanwhile, culture and traditions of nations can sometimes cause a change in climate conditions [5].

Development of Tehran is considerably significant from the perspective of population because while taking more space, this population has never stopped growing. Such a development has imposed a change on environment, and pieces of land which were one day covered moderately with greenery have now become inundated by a large mass of polluted materials. High buildings, cars, heating systems, and factories located in cities have increased the amount of dust and suspended solids in the air, and in consequence, they have influenced solar radiation, temperature, moisture, downfall, wind, etc. Air pollution in Tehran has now reached the level that it is considered as a serious threat to the health of the residents of this metropolis [6].

Thus, population growth in Tehran is regarded as one of the main parameters of pollution increase in this city. This key parameter has many other parameters of air pollution as its subdivisions. Here we have taken into account some of these parameters and their relationship and interaction with each other. The effect of these parameters on pollution and people's health has been studied based on a cause and effect relation so that, using computer simulation, we can conclude which of the parameters will have the greatest effect on pollution in the next ten years. This way, we will be able to reduce air pollution, or at least, avoid its increase in future by controlling those specified parameters [6].

II. Definition of Pollution

Pollution is any kind of changes in the features of the components of the environment in such a way that those components cannot be used as consistently they could be previously and that the change endangers the life of the living creatures of that environment [3].

Pollutants are usually produced as a result of human activities, and they have been constantly present in developed human societies in which modern technology dominates. On the other side, growth of population, per capita income, development of technology, and rise of living standards are considered as critical factors of pollution increase [3].

III. Polluted Air

Addition of any material changes chemical and physical characteristics of air to some extent. Thus, such materials are considered as pollutants of air [3].

Pollutants are usually classified based on the effects they cause on humans, animals, plants, or materials. Nearly any natural or artificial material which can be taken out from air is classified in a group of pollutants. Such pollutants can take the form of suspended solids, liquids, gases, or a mixture of all. Most of the time, the problems of air pollution are due to the presence of a diversity of pollutants in different forms [8].

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IV. Types of Pollutants

Five types of materials have been known as the major pollutants of air which constitute more than 90% of the factors of air pollution. These five types are [3]:

- Carbon Monoxide (CO)
- Nitrogen Oxides (NO_x)
- Hydro Carbon (HC)
- Sulphur Oxides (SO_x)
- Suspended Solids

Lead (PB) might be also included in the above list. Three questions are repeatedly asked about air pollution:

- Which source constitutes the major part of air pollution?
- Which single-element pollutant can be found in greater amount than others?
- With what speed does the density of pollutants in air increase?

Answering these important questions provides us with a comprehensive picture of air and its compositions inside, and taking advantage of dynamic modeling is a consistent way to get to the answers to these questions.

V. Modeling Air Pollution in Tehran

A. Statement of Problem

An increase in one or more types of the mentioned pollutants will raise the general air pollution index.

5.1.1. The Variables of the Model:

The main variables in this model are:

1. Pollution index

This is under the effect of

2. The rate of pollution.

An increase in this rate is dependent on different types of pollutants, such as

3. Suspended solids,
4. The numerous industrial and domestic pollutants,
5. Temperature inversion,
6. Greenhouse effect,

And many other factors, On the other hand, some variables cause a decrease in air pollution, such as

7. Wind,
8. Downfall,
9. Regulating automobile engines,
10. Using lead free petrol,
11. Setting some traffic limits for cities,
12. Getting rid of old automobiles and relocating factories to outside of cities
13. Using various filters to reduce the amount of pollutants produced in factories.

There are many more variables which can be listed here.

However, the one which can cover most of the above variables is:

14. Population of Tehran.

An increase in population naturally increases all industrial and domestic pollutants. This is why this variable can be considered as the key variable. Population of Tehran affects five other variables:

15. The rate of population growth
16. The rate of death
17. The proportion of the rate of birth
18. The proportion of the rate of death
19. The rate of immigration to Tehran

On the other hand, as air pollution increases, public health will be endangered, so the following variables will be also influenced:

20. The rate of infection with diseases due to air pollution
21. The number of the sick
22. The rate of medical treatment
23. The number of the treated people
24. The number of people who breathe the polluted air
25. The number of people who get infected with a disease related to air pollution.

The mentioned variables are the ones taken into account in this modeling and discussed in terms of their relationships with each other in a single model. This model discusses air pollution, population, and health [5].

B. Dynamic Hypothesis

5.2.1. Dynamic Hypothesis: Reduce in air pollution and in diseases related to air pollution in Tehran from 2005 to 2015

5.2.2. Model Boundary Diagram: In this diagram, all the variables which can affect the model are shown. In general, these variables can be divided into three groups (Table 1):

5.2.2.1. Endogenous Variables: They are the variables originated from the model itself.

5.2.2.2. Exogenous Variables: They are the variables imported from outside to the model.

5.2.2.3. Excluded Variables: They are the variables ignored in the model, and they can be named errors of the model.

C. Casual Loops Diagram (CLD)

In the process of modeling, after determining the influential variables in the model of the diagram, we show the casual relationship between two or more variables and their effects on one another. Drawing some loops to show the relationship between the variables, we indicate which relationship is positive and which one negative. Then, what we will have is a series of loops (showing the relationships) being either positive(R) or negative (B) [6].

The casual loop diagram of the model of air pollution in Tehran is shown in fig.1. In this model, we see seven casual loops: three positive and four negative loops. The positive loops indicate an exponential growth, while negative loops suggest a balanced and purposeful decrease or negative growth.

Getting more precise in the figures, we realize that there is a positive loop between air pollution index and suspended solids, meaning that an increase in air pollution is accompanied with an increase in the amount of suspended solids and that these strengthen each other and raise the air pollution index.

The next loop is the general negative loop between the air pollution index from one side and the rate of diseases, population, the number of pollutants, and the amount of the suspended solids from the other side. This loop indicates a balance with a consistent growth for air pollution index.

There is also a positive loop between the rate of diseases related to air pollution and the number of the sick, which indicates that the higher the rate of diseases, the greater the number of the sick.

There is another negative loop between the number of the sick, the price of treatment, the number of the treated people, and the population of Tehran, which indicates that the rate of the diseases related to air pollution increases as the population grows, and accordingly, the price of treatment falls.

TABLE I
MODEL BOUNDARY DIAGRAM

Endogenous Variables	**Exogenous Variables**	**Excluded Variables**
Air Pollution Index	Temperature Inversion	Economical Conditions
The Rate of Pollution	Greenhouse Effect	Political Conditions
Suspended Solids	Wind	Developing Green Areas
The Number of Industrial and Domestic Pollutants	Downfall	Urban Expansion
Regulating Automobile Engines		Subway Expansion
Using Lead-Free Petrol		Increasing Public Transport Vehicles
Setting Traffic Limits based on the License Plates of Automobiles		Gathering of Governmental Administrations and Ministries in Tehran
Using Different Filters for Pollutants Produced in Factories		Intensity of Population in Different Districts of the City
Getting Rid of Old Automobiles and Relocating Factories to Outside of Cities		Not Taking Advantage of Modern Technologies in Automobile Production
Population of Tehran		
The Rate of Population Growth		
The Rate of Death		
The Proportion of Birth		
The Proportion of Death		
The Rate of Immigration to Tehran		
The Rate of Infection with Diseases due to the Air Pollution		
The Number of the Sick		
The Rate of Medical Treatment		
Treatment Period		
The Number of the Treated People		
The Number of People Who Breathe the Polluted Air		
The Number of the People Who Get Infected with a Disease Related to Air Pollution		

There is another negative loop between the rate of diseases due to air pollution, the number of the sick, the rate of death, population, and the number of the people who breathe the polluted air. As population grows, the number of people who breathe the polluted air increases, and the rate of diseases goes up, then the number of the sick increases, which means a higher rate of death, and this negative loop ends in a decrease of population. This means that the population of Tehran increases but with a lower rate.

There is also a negative loop between the rate of death and the population. The higher the rate of death, the smaller the population, but since the population has also a specific rate of growth; the population will grow as long as the rate of death does not exceed the rate of population growth. However, we know that the population in such a case will grow with a lower speed.

The last loop is a positive loop between the rate of birth and the population. It is quite obvious that as the rate of birth increases, the population also grows, and on the other hand, with a growth in the population, we will witness a rise in the number of births. This signifies an exponential growth, and as long as the rate of death is lower than the rate of birth, the population will continue its growth although with a lower speed. Thus the negative loop of death functions as a balancer in population growth.

The model works dynamically in a general interaction with these seven loops. The diagrams of each of these variables and an explanation of the performance of each after being simulated by Vensim have been included in this paper.

D.The Flow Diagram of the Model

After drawing the casual loops of the model, we have used flow diagrams to be able to present a better analysis of the model. In fact, flow diagrams are the casual loops which can be formulized. The flow diagram of the model is shown in fig. 2. [6].

The flow diagram visualizes the variables of the model in such a way that the processes of focusing and flowing of information and materials are made clear. The flow diagram also embeds the main structure and physical basis of the model. The size of population (Person), the amount of pollutions (Gr/m^3), pollution index (PSI), etc in the flow diagram are given a number or a numerical and logical formula. In the flow diagram of the model of the air pollution, the parameters and variables are divisible into the following categories:

5.4.1. Level Variable: pollution index, the number of the sick, the number of the treated people, and the population of Tehran.

5.4.2. Rate Variable: The rate of pollution, the rate of the diseases due to air pollution, the rate of treatment, the rate of death, and the rate of birth.

5.4.3. Auxiliary Variable: The suspended solids, the number of the industrial and domestic pollutants, dust, BP, HC, CO, SO_2, NO_2, and NO.

5.4.4. Constants: Treatment period, the number of the

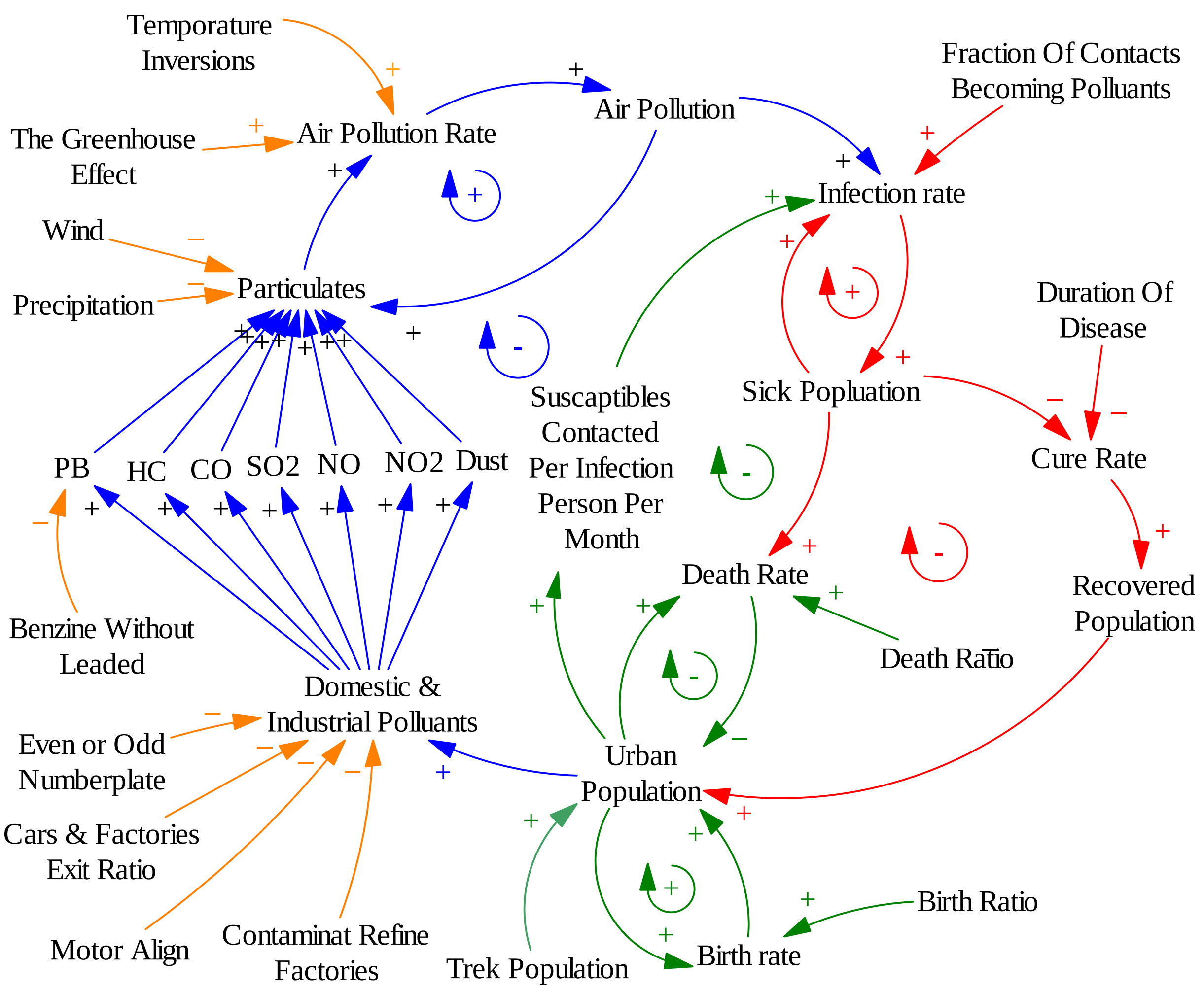

Fig. 1 Casual loops diagrams

people who breathe the polluted air and get infected with a disease due to that, the proportion of the rate of death, the proportion of the rate of birth, immigration to Tehran, temperature inversion, the greenhouse effect, wind, downfall, using lead-free petrol, setting traffic limits based on the number of automobiles, getting rid of old automobiles, and transferring factories to outside of the city, using various filters to reduce the amount of pollutants produced in factories, regulating automobile engines, and the number of people who breathe the polluted air.

5.4.5. Table Function: After drawing the flow diagram of the model, using Vensim, we insert the numbers and formulae for each of our level, rate, and auxiliary variables as well as constants and table function. Now we have a complete model, so we run it.

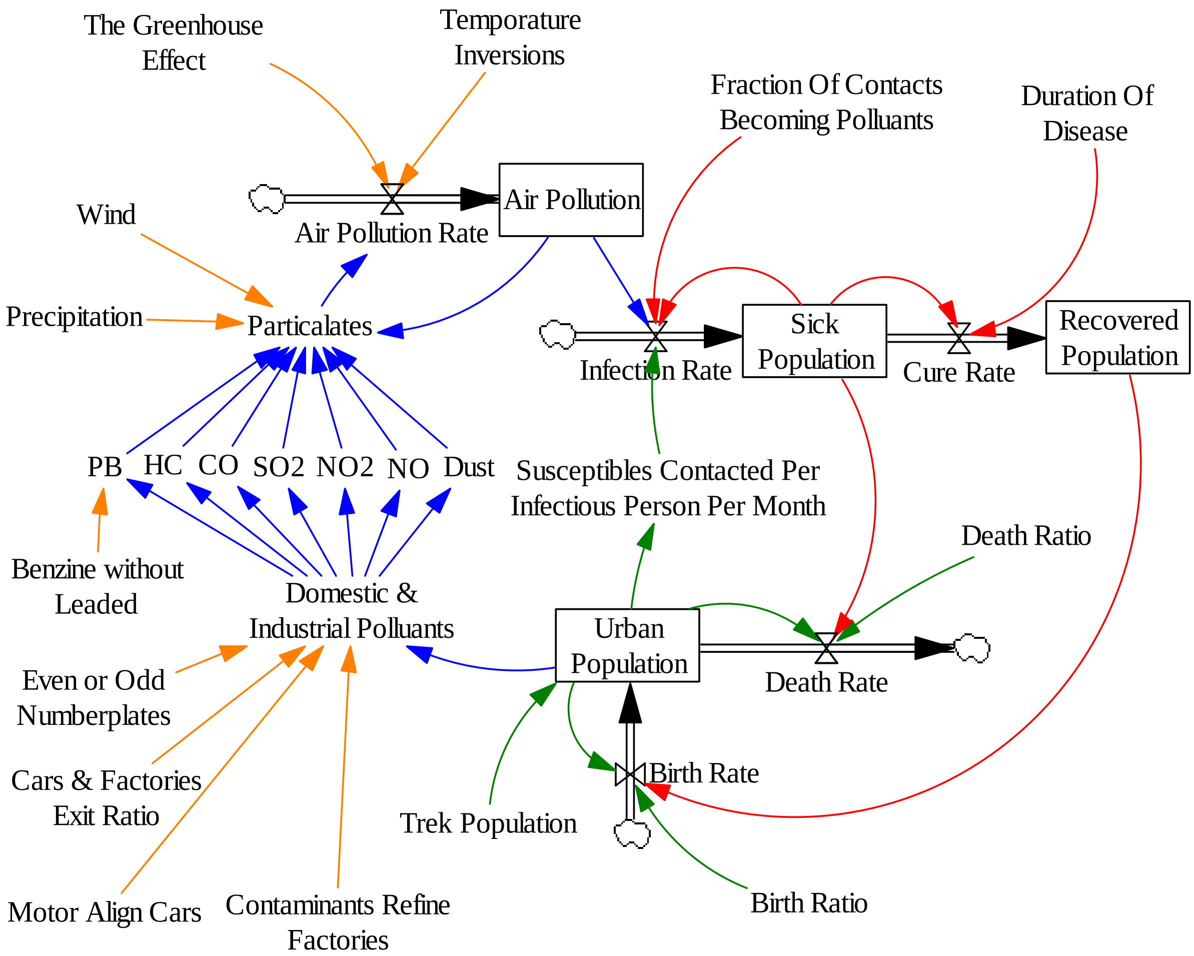

Fig. 2 Flow diagrams

VI. Simulation with the Software Vensim

By inserting the numerical amounts of each of the parameters of the model and running this software, we can have the whole process and course of changes of the parameters. Through the option of Automatically Simulate on Change of Vensim, we change the amounts of input constants, and then we observe the changes of other parameters in consequence. Parameters which we have in the model are divided into two groups:

6.1. There are a number of parameters which we cannot make any changes in, such as wind, downfall, temperature inversion, and greenhouse effect. However, their amounts change naturally. As an example, in this model, the range of wind blow has been set between 0 to 10 m/s. This means that based on the speed of wind, we can simulate its effect on air pollution index and other parameters or predict the results. We do the same for the parameter of the amount of downfall. The range of downfall has been set between 0 to 20 ml. The same procedure has been taken for the parameters of temperature inversion and greenhouse effect.

6.2. There are also a number of parameters in which we can make changes in short or long term periods, such as regulating automobile engines, getting rid of old automobiles, relocating factories to outside of the city, setting traffic limits based on license plates, using lead free petrol, immigration to Tehran, the rate of birth, the rate of death, using different filters to reduce the amount of pollutants produced in factories, the number of people who get infected with a disease due to air pollution, and treatment period. As an example, a range of 1 to 2 has been set regarding the parameter of regulating automobile engines. This means that by running the model through Vensim, we can change the amount of this parameter from 1 to 2 times and observe clearly its effect on air pollution index and other parameters. For instance, if we set a traffic limit in a way that those automobiles with even license plates are permitted to go out on 3 days a week and those with odd license plates on the other 3 days (excluding Saturdays), then the traffic will be reduced to half, and so will the pollutants produced by automobiles.

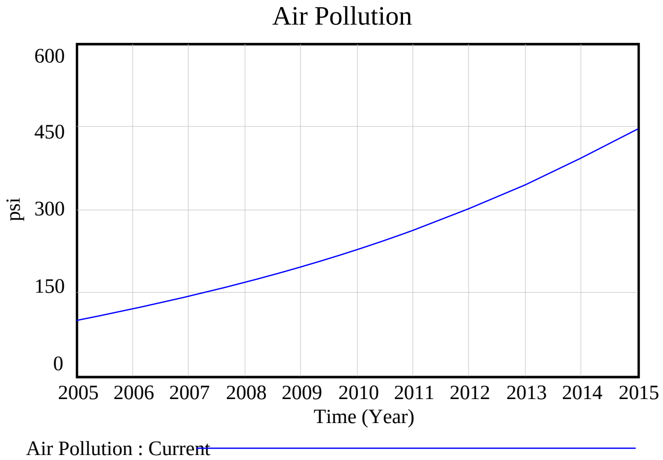

Fig. 3 Level of Air pollution from 2005 to 2015

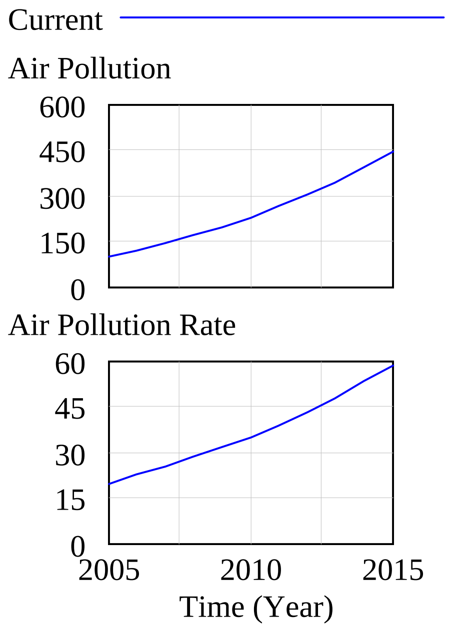

Fig. 4 Level of air Pollution and air pollution rate from 2005 to 2015

TABLE II
THE CONNECTION OF AIR POLLUTION AND URBAN POPULATION

Time (Year)	Air Pollution	Urban Population
2005	Current 100	Current 1.2e+007
2006	119.738	1.288e+007
2007	142.165	1.35958e+007
2008	167.416	1.41975e+007
2009	195.682	1.47217e+007
2010	227.201	1.51953e+007
2011	262.257	1.56388e+007
2012	301.178	1.60689e+007
2013	344.342	1.65001e+007
2014	392.172	1.69461e+007
2015	445.149	1.74216e+007

TABLE III
THE CONNECTION OF AIR POLLUTION AND SICK POPULATION

Time (Year)	Air Pollution	Sick Population
2005	Current 100	Current 2e+006
2006	119.738	2.025e+006
2007	142.165	2.07529e+006
2008	167.416	2.15592e+006
2009	195.682	2.27371e+006
2010	227.201	2.43811e+006
2011	262.257	2.66241e+006
2012	301.178	2.96569e+006
2013	344.342	3.37566e+006
2014	392.172	3.93336e+006
2015	445.149	4.70079e+006

TABLE IV
THE CONNECTION OF AIR POLLUTION AND SICK POPULATION AND URBAN POPULATION

Time (Year)	Air Pollution	Urban Population	Sick Population
2005	Current 100	Current 2e+006	Current 1.2e+007
2006	119.738	2.025e+006	1.288e+007
2007	142.165	2.07529e+006	1.35958e+007
2008	167.416	2.15592e+006	1.41975e+007
2009	195.682	2.27371e+006	1.47217e+007
2010	227.201	2.43811e+006	1.51953e+007
2011	262.257	2.66241e+006	1.56388e+007
2012	301.178	2.96569e+006	1.60689e+007
2013	344.342	3.37566e+006	1.65001e+007
2014	392.172	3.93336e+006	1.69461e+007
2015	445.149	4.70079e+006	1.74216e+007

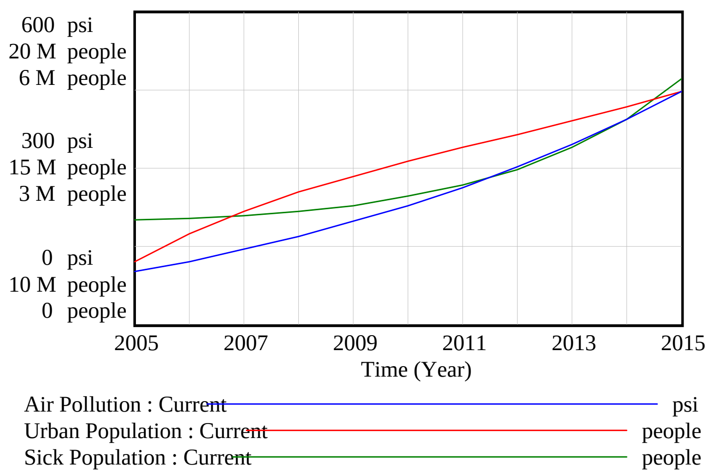

Fig. 5 The diagram of the connection between air pollution and urban population and sick population

VII. CONCLUSION

As mentioned earlier, by making changes in any of the parameters of the two groups, we can easily observe the consequences and the interaction between the parameters. After running this model of air pollution in Tehran, we can infer the following results as the conclusion (fig. 3, 4 and 5) (table 2, 3 and 4):

- An increase in wind blowing, as a general parameter which is not under our control, plays a crucial role in weakening temperature inversion and reducing air pollution because it spreads out pollutants in the air.
- An increase in downfall, which is also a significant parameter and is not under our control, has a quite great effect on decreasing air pollution.
- Regulating automobile engines, if done continuously and permanently, can also be effective in decreasing air pollution.
- A decrease in the rate of immigration to Tehran, as a long term program and policy, which prevents an immoderate population growth and stops domestic and industrial pollutants from increasing, can result in a considerable decrease in air pollution.
- Using more filters for pollutants produced in factories in a long term program has quite a great effect on decreasing air pollution.
- An increase in use of lead-free petrol also decreases air pollution to a good extent. PB is among the pollutants which greatly endangers people's health.
- By getting rid of more old automobiles and by transferring factories to outside of cities, we can witness a decrease in air pollution.
- Setting traffic limits based on the license plates of automobiles, as an emergency program, has a huge effect on decreasing air pollution.
- An increase in the rate of birth results in a population growth, and consequently, the number of domestic and industrial pollutants goes up, so controlling this long term parameter can bring about a considerable decrease in air pollution.
- An increase in the rate of death, on the other hand, results in population reduction; however, the rate of birth also directly influences population balance. Thus, as long as the rate of birth is higher than the rate of death, population keeps growing, and consequently, the number of domestic and industrial pollutants goes up, so this long term parameter can bring about only a minor decrease in air pollution.
- Greenhouse effect increases because of an increase in the density of carbon dioxide in atmosphere. An increase in CO_2 due to human activities causes some changes in weather conditions by affecting the temperature of the Earth. CO_2 is not considered to be a serious pollutant of the air because it is naturally one of the components of the air. As human beings burn fossil fuels, cut trees, or turn limestone into cement, they cause a breakdown in carbon cycle. In general, greenhouse effect is the result of the interaction between CO_2 of atmosphere and the rays which leave the Earth. Greenhouse effect deeply influences air pollution in a rather long term period.
- Temperature inversion is a serious factor of air pollution not only because it is a source of pollution, but also because it entraps other pollutants in the lower atmosphere (and does not let them scatter throughout the air). This occurs when a cold layer of air remains under a warmer layer. This inversion impedes the vertical movement of the atmosphere because the cold layer cannot go up passing through the warmer layer. As a result, pollutants get entrapped in the lower cold layer, and the pollution increases gradually until a wind blows and moves the layers. This phenomenon, which mostly occurs in winters, has quite a great effect on increasing air pollution in this season.
- Finally, an increase in the parameters of treatment period of the diseases related to air pollution and the number of people who breathe the polluted air has only a minor effect on decreasing air pollution because these two parameters slightly influence the variable of population, and this variable affects air pollution index through a number of processes.

In this model, the interaction between air pollution in Tehran, public health, and population growth was shown dynamically, and the influential parameters and variables of the model were discussed in detail. What can be mentioned as our conclusion is that the diagram of air pollution index of Tehran generally indicates an exponential growth. Although there are parameters which affect this growth by strengthening or weakening it, no real change takes place in this general exponential growth. Thus, by manipulating the parameters of the model, we can only try to keep the air pollution index in the normal range, i.e. between 0 to 100 PSI (100 to 200 PSI: warning range, 200 to 300 PSI: emergency range, and above 300: critical range).

In the above modeling, a number of parameters and variables have not been taken into consideration, which can serve as the basis for further research in this regard.

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