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Hiep Xuan Huynh
Can Tho Univeristy, Vietnam
hxhiep@ctu.edu.vn

Phuoc Thanh Luu
Can Tho Univeristy, Vietnam
luuthanhphuoc@gmail.com

Huong Hoang Luong
FPT University, Vietnam
huonglh3@fe.edu.vn

Nghia Duong-Trung
Can Tho University of Technology
FPT University, Vietnam
duong-trung@ismll.de

Minh Thai Truong
Can Tho Univeristy, Vietnam
tmthai@ctu.edu.vn

Nga Quynh Thi Tang
National Taiwan University of Science and Technology
Taipei, Taiwan
tangnga2695@gmail.com

Tu Cam Thi Tran
Vinh Long University of Technology Education
Vietnam
tuttc@vlute.edu.vn

ABSTRACT
Urban environmental problems are contributed by numerous factors, such as greenhouse gas emissions and air quality. Material combustion from vehicles, manufacturing plants, fossil fuel consumption, and many other industrial activities are the primary sources of atmospheric pollution. These noxious implications cause thousands of premature deaths, million years of life lost, and a contributor to climate change, primarily in developing countries. Therefore, pollution forecast and simulation before happening are the main focus of this paper. It helps address pollution levels, infrastructure installation of cities and underpins a range of environmental policies. Awareness of the characteristics of the atmospheric quality, including the mathematical basis for assessing pollution, allows building the pollution assessment models required to understand air quality and controls. In this paper, an effective model for simulating and analyzing atmospheric quality using cellular automata is proposed. Our model employs three novel underlying rules, e.g. rules of gravity, diffusion, and wind. Four experimental scenarios have been conducted to demonstrate the applicability of update rules necessitated to apprehend air pollution.

CCS Concepts
• Theory of computation→Formal languages and automata theory • Theory of computation→Automata over infinite objects • Computer systems organization→Cellular architectures • Human-centered computing→Geographic visualization • Computing methodologies→Simulation evaluation

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Keywords
Cellular automata; Atmospheric quality; Simulation; Air pollution indicators

1. INTRODUCTION
The downside of rapidly developing industries has caused numerous irreversible environmental damages with complex negative effects on human being and its enduring socio-economic sustainability. There is no doubt that atmospheric pollution is an increasingly demanding challenge. Recent statistics made by the World Health Organization (WHO) reveals that more than 60 000 deaths from heart disease, stroke, lung cancer, chronic obstructive pulmonary disease and pneumonia in Viet Nam in 2016 were linked to air pollution [27]. The complex of the problem is that air pollution is not caused by a single source but the association of factors. Hence, understanding air pollution assessment and simulation process strongly depends on the comprehension of several environmental factors such as wind, diffusion, and gravity. However, little research has been conducted to exploit the underlying rules of these phenomena.

There is a mass of pollutant gas from a discharge source that predicts the degree of influence of the pollutant mass in space to predict human activity[1], [5, 6]. In a thousand cubic meter space, when there is a mass of contaminated air, it is almost impossible to perform an air test to analyze the dispersion of pollutants in the air. Based on factors affecting the air: gravity, diffusion, wind. Automata air-based simulators have become almost indispensable for understanding and preventing some processes of water and air pollution, among other things. In this paper, the use of the cell automata model [13], [15- 16], [21-24] predicts the specific atmospheric pollution level of Co gas based on the AQI air quality rating [1-3], [5]. It helps people make better decisions to prevent or reduce the impact of air pollution on health. In this paper, an application of cellular automata (CA) [13], [15-16] to analyze the dispersion of pollutants in the air is presented. It includes a quick review of the mathematical background [17-18], practical modeling [14], [19-20], and four simulation scenarios, showing the applicability of the software being developed.

The rest of this paper is organized as follows. Some related works are introduced in Section 2. Section 3 is our main contribution where we present the simulation design. Section 4 describes Visualworks Air Cell Automata Simulation tool and the Netgen platform. The authors present experiments in Section 5. The last section summarizes our contributions and suggests some research in the future.

2. RELATED WORKS

A wide number of research works regarding air pollution have been carried out [1-4]. Some of them have been focused to the analysis of pollutants [1][6], at the molecular level, and their combinations with the natural atmosphere elements and compounds. On the other hand, there are some others focused at the dispersion phenomena, but at the microscopic level. In both cases, though, these studies allow to predict the pollutants behavior based upon mathematical models describing the phenomena, and their simulations [1-4]. Clearly, because of the complexity of the models, these have to be solved numerically.

In this work, CA are the mathematical models for computer simulations trying to model Nature's behavior. The concept of CA was first introduced by Von Neumann [11], [13], [15-16] for a particular task, namely, to prove the existence of a universal computer capable of self-reproduction within a defined space. This concept has evolved into a theory leading to different types of CA [13], [15-16], [21-24], which in turn, and based upon their features, have been applied to a variety of physical phenomena, as well as biological and chemical.

Here are several areas where CA have been successfully deployed to simulate and evaluate physical phenomena. The first application can be considered is the simulation of fire propagation. A good simulation of the extent of burnt-out areas and of the speed of wildfire propagation under different environmental conditions is important for fire control and prevention. Traditional models assumed uniformly distributed fuel bed and elliptical fire shapes, while in the real cases fuel beds are often discrete or even patchy, and this affects the speed of fire spread and the extent of area interested, beyond its shape. An interesting simulation based on a 2D CA [13] of fire diffusion in patchy fuel-bed environments, due to direct contact and heat accumulation under different wind speeds has been presented in [7].

3. SIMULATION DESIGN

3.1 Cellular Automata Background

Cellular automata (CA) are a system that includes a regular network of cells, e.g. a square grid of cells where each cell is called automaton. A cell has a finite state at a time. The state of a specific cell depends on the states of its adjacent cells. The effect of the adjacent cells' states to the state of examined cell is defined by an update rule. Automata in the network change their states simultaneously under the governing of the identical underlying rule. The state is updated at discrete time steps. This characteristics makes cellular automata the perfect solution for simulation modeling and massively parallel computation.

To explain CA in more details, the authors introduce some notation. Let define d as a positive dimension. Then a d-dimensional cellular space is Q^d. We denote S as states. Then a CA's configuration of that cellular automata with predefined states S is a mapping function as follows:

$$g: Q^d \rightarrow S \qquad (1)$$

The state of cell $\vec{b} \in Q^d$ is denoted as $g(\vec{b})$. A snapshot of the entire system's states at a of time is a CA's configuration. Let define m as the number of a cell's neighbors. Then a d-dimensional vector of m neighbors is described as follows:

$$B = (\overrightarrow{b_1}, \overrightarrow{b_2}, \dots, \overrightarrow{b_m}) \qquad (2)$$

Where $\overrightarrow{b_u} \neq \overrightarrow{b_v}, \forall u \neq v$. Each cell $\overrightarrow{b_u} \in Q^d$. Each cell $\vec{b}$ has $\vec{b} + \overrightarrow{b_u}$ for $u = 1, 2, \dots, m$ neighbors. Let define f as the update rule of a CA. Let also denote $s_1, s_2, \dots, s_m$ as the states of m neighbors of a cell. Then the new state of that cell is controlled by $f(s_1, s_2, \dots, s_m)$. The local update rule can be written as follows:

$$f: S^m \rightarrow S \qquad (3)$$

Remember to note that the local update rule is applied simultaneously at all cells. In this paper, we apply six adjacent cells for a central cell in hexagon form, or honeycomb [26].

3.2 Cellular Automata Model and His Nest Structure

The cellular cell model [13], [15-16] for updating the trapping state of the regions consists of a set of cell plots, each cell representing a real out-of-area region. We have a set of cells. The set denotes the state of each cell is called a configuration. This configuration will change in time steps. On the rules of cellular automata, we have:

- Each cell will have a value in the state set S = 0, 1, 2, 3, 4, 5, 6. State 0 corresponds to the position being considered without a light trap and state 1 corresponds to the location in which the light trap is being considered.
- Each cell has six different cells directly adjacent to it called six neighboring cells. The state of a cell at time t+1 will be determined based on the state of the neighboring 6 cells and its state at time t.
- The change of cells will follow a principle defined in the cellular code set, which applies equally to each cell and does not change over time.

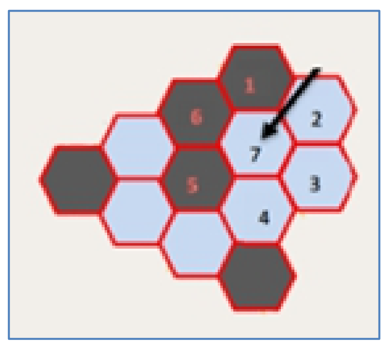

Figure 1. Splitting geographic space into multiple cells

In figure 1, the area under consideration (zone 7) has zero pollution status (0), there are 6 neighboring cells, of which 3 are zero pollution and 0 are contaminated. (first). Over time, the state of the area under consideration will change, the change of state of the regions follows a rule defined in the law of cooled-cell cars.

3.3 The Rules of the Cellular Model

A rule that defines how a cell changes states based on neighbors is called a law with the $f: S^7 \rightarrow S$ mapping function.

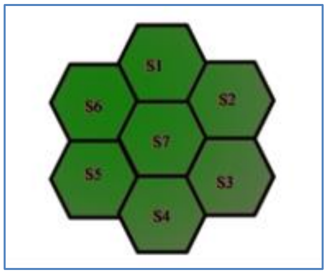

Figure 2. Order of cells when inserted into law

A law in the rulebook shows the rules of cell change in the middle based on neighboring cells, each having two states of 0, 1, 2, 3, 4, 5, 6. We have all 7^7different patterns for a set of 7 cells. As such, each sample will map to 0, 1, 2, 3, 4, 5, 6, for the state of the middle cell, i.e we have $7^7 = 823543$ rules for a set of rules. So the input of a 7 bits rule is the state of the cell in question and neighbors are arranged in the order shown in figure 2 and 3.

For f is a function mapped as mentioned above or also referred to as a law to update the 7^{th} bit, i.e the state of the cell in the middle. Each rule in the rulebook will take the form:

$$\mathrm{f}\,(S1, S2, S3, S4, S5, S6, S7) \rightarrow 0$$

or

$$\mathrm{f}\,(S1, S2, S3, S4, S5, S6, S7) \rightarrow 1$$

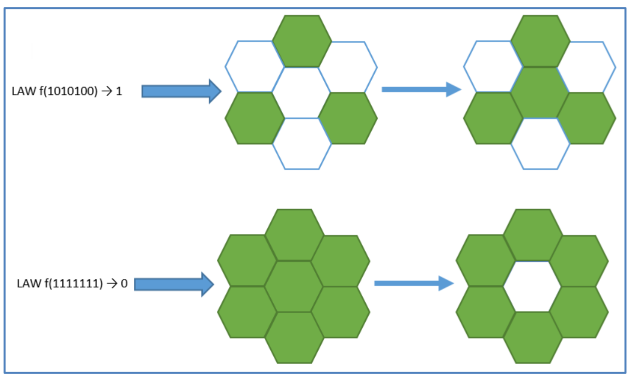

Figure 3. Order of cells when inserted into law

3.4 Indicators of Air Pollution

The pollutants are emitted by human activities and natural sources. Hundreds of toxic pollutants in our environment have identified. However, six of these pollutants are well-studied and commonplace in our daily lives, including carbon monoxide (CO) [7], nitrogen dioxide (NO2) [8], ozone (O3) [9], sulfur dioxide (SO2) [10], particle matter (PM) and lead (Pb) [6][12]. Health effects and environmental effects caused by contaminants can be found in [7][9][11].

Governments and organizations have set limits on pollutants to reduce risk. The United States Environmental Protection Agency (EPA), the World Health Organization (WHO), the European Commission (EC), Vietnam has released: National technical regulation on ambient air quality for pollutants To help people understand the current air quality easily, the government and organization agencies recommend an index called the Air Quality Index (AQI). The AQI measures the condition or condition of each of which involves the requirements of one or more species. AQI tells us how good air quality is today. AQI is provided in the table 1.The AQI system provides a better understanding of health risks. Heal the public and show detailed preventive actions for each AQI level. The color codes according to the AQI values and their levels of health concern are illustrated in figure 4.

Air Quality Index (AQI) Values	Levels of Health Concern	Colors
0 to 50	Good	Green
51 to 100	Moderate	Yellow
101 to 150	Unhealthy for Sensitive Groups	Orange
151 to 200	Unhealthy	Red
201 to 300	Very Unhealthy	Purple
301 to 500	Hazardous	Maroon

Figure 4. AQI rating

Table 1. Effect of pollutants on health

Pollutant	Health Effects
Carbon Monoxide (CO)	Reducing oxygen capacity of the blood cells leads to reduced oxygen delivery to the body's organs, and tissues. An extremely high level can cause death.
Nitrogen Dioxide (NO2)	The high-risk factor of emphysema, asthma and bronchitis diseases. Aggravate existing heart disease and increase premature death.
Ozone (O3)	Trigger chest pain, coughing, throat irritation, and congestion. Worsen bronchitis, emphysema, and asthma.
Sulfur Dioxide (SO2)	The high-risk factor of bronchoconstriction, and increased asthma symptoms.
Particulate Matter (PM2.5 & PM10)	Cause premature death in people with heart and, lung diseases. Aggravate asthma, decrease lung, function and increase respiratory symptoms, like coughing and difficulty breathing.
Lead (Pb)	Accumulate in bones and affect the nervous system, kidney function, immune system, reproductive, systems, developmental systems and cardiovascular, system. Affect the oxygen capacity of blood cells.

3.5 Proposed Group of Rules

3.5.1 The rule of gravity

Cells that are polluting at levels 1 and neighbors above levels 1 level will not change the level of pollution. Cells that are contaminated with levels 1 and the neighbors above have a level of pollution of one, will reduce the level of pollution one level. See figure 5.

Next, it will get some similar proportions from neighboring nodes near it, and prepare for the next step (t + 1). And so over time, the propagation will be simulated.

Rule 1: The rule of gravity	
Data: The concentration of pollutant cells, the location of pollutant cells	
Transition rule: At each time step t, to achieve a new state at time t + 1, each cell performs a sequential task	
begin	
	Cells are contaminated with 1 and the neighbors above are contaminated with 1, the cell is polluting with 1.
1,	Cells are considered to have pollution levels of 1 and neighbors above the level of pollution is greater than the cell is considered to have a pollution level of 2.
equal	Cells are considered to have zero pollution levels and the neighbors above have pollution levels greater than one, then the cell is considering levels of pollution to 2.
end	

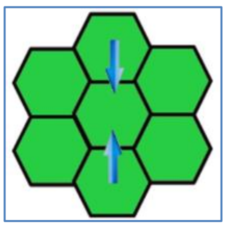

Figure 5. Cells affect the central cell with gravity

3.5.2 The rule of diffusion

Rule 2: The rule of Diffusion	
Data: The concentration of pollutant cells, the location of pollutant cells	
Transition rule: At each time step t, to achieve a new state at time t + 1, each cell performs a sequential task	
begin	
	Cells are contaminated with 1 and the neighbors above are contaminated with 1, the cell is polluting with 1.
1,	Cells are considered to have pollution levels of 1 and neighbors above the level of pollution is greater than the cell is considered to have a pollution level of 2.
equal	Cells are considered to have zero pollution levels and the neighbors above have pollution levels greater than one, then the cell is considering levels of pollution to 2.
end	

Cells that are polluting at levels 1 and neighbors above levels 1 level will not change the level of pollution. Cells that are contaminated with levels 1 and the neighbors above have a level of pollution of one, will reduce the level of pollution one level. Next, it will get some similar proportions from neighboring nodes near it, and prepare for the next step (t + 1). And so over time, the propagation will be simulated.

3.5.3 The rule of wind

Rule 3: The rule of wind	
Data: The concentration of pollutant cells, the location of pollutant cells	
Transition rule: At each time step t, to achieve a new state at time t + 1, each cell performs a sequential task	
begin	
have have	Cells are polluted with 1 and neighbors on the left pollution levels equal to 1, cells are considered to pollution levels of 1.
cells	Cells are considered to have pollution levels of 1 and left neighbors have pollution levels greater than 1, are considered to have pollution levels of 2.
pollution	Cells are considered zero pollution levels and the neighbors on the left have more than one level of pollution, the cell is considering a level of A of 2.
neighbors change the level	Cells are contaminated with levels 1 and left pollution levels 1, then the cell will not of pollution.
neighbors decrease	Cells are contaminated with levels 1 and left have pollution levels by one, the cells will pollution levels one level.
end	

Next, it will get some similar proportions from neighboring nodes near it and prepare for the next step (t + 1). And so over time, the propagation will be simulated.

4. THE VACAS TOOL

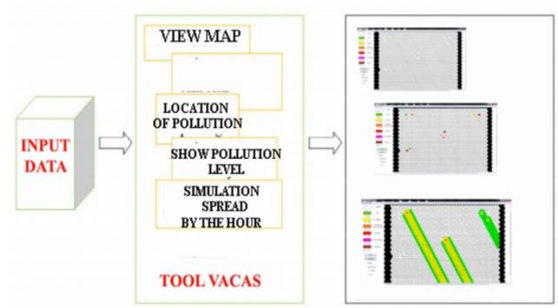

Figure 6. The functions of tools VACAS

The VACAS (VisualWorks Air Cell Automata Simulation) tool is based on the Netgen platform - a multilingual support platform: Smalltalk, Occam, Cuda, developed in collaboration with the Brest University of France [25], see figure 6. Main functions of the VACAS tool are:

- Show simulation map.
- Receive input data and locate the contamination by input data on the map.
- Display the information of the cells on the map (color according to the level of infection and the location of pollution).
- Build and simulate the cell (cell) according to the degree of infection by gravity, diffusion, wind on the map by hour.
- Statistics the number of contaminated cells.

5. EXPERIMENTS

5.1 Dataset

The authors deploy 11 sets of sensors in several areas of Can Tho city in the south of Vietnam. For several weeks, the information of gravity, wind, and diffusion is collected. One thing to note is that the sensors' locations are selected randomly to ensure obtaining only environmental factors without any invervention of industry sources. The location of 11 sets of sensors is presented in figure 7. The Input data is a data file in the text format contains the level of pollution, gravity, wind, and diffusion at the taken times from all 11 locations.

	A	B
1	P1,10.161110238851,105.64461708069	
2	P2,10.163306827881,105.64294338226	
3	P3,10.165524522646,105.64122676849	
4	P4,10.16769996065,105.63951015472	
5	P5,10.169558575561,105.63755750656	
6	P6,10.173550336933,105.6450676918	
7	P7,10.171733986093,105.64744949341	
8	P8,10.169178405209,105.6493806839	
9	P9,10.166242630032,105.65109729767	
10	P10,10.164046061179,105.65453052521	
11	P11,10.166665045388,105.65603256226	

Figure 7. Input data

5.2 Scenario 1: Cells are Affected by Gravity

Input data including room size data, pollution quantity file and pollution level in contaminated sites. This scenario simulates data input on 1-7-2017 with gravity Direction: from cell 304 to cell 1245. Results are shown in figure 8.

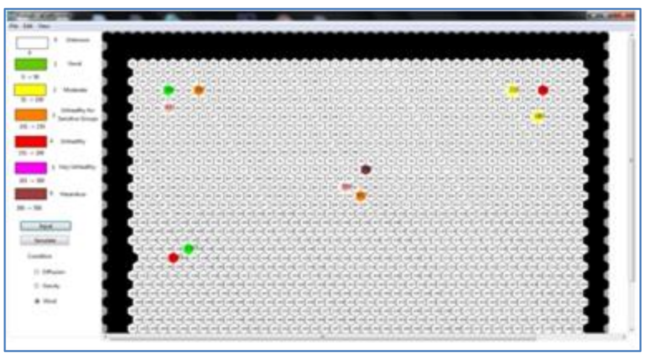

Figure 8. Cells are affected by gravity. Input date 1-7-2017

After the simulation time t = 1 hour the polluted cells spread in the direction of the gravity direction. With the level of pollution down led from the pollution source down to the ground. The number of pollutants is greater than 1 at present: 393 occurrences, 28.2%. See figure 9.

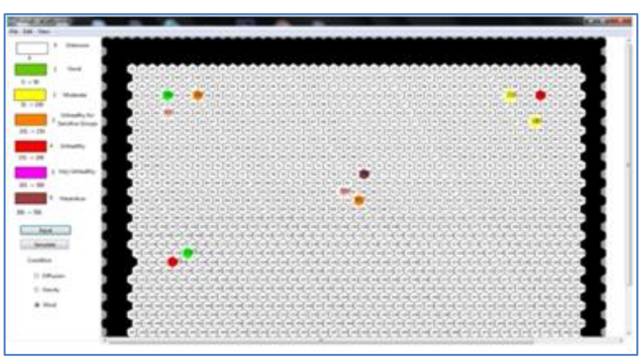

Figure 9. Cells are affected by gravity. Data output after 1-hour simulation

5.3 Scenario 2: Cells are Affected by the Wind

This scenario simulates data input on 1-7-2017 with Wind Direction: from cell 355 to cell 455 (in figure 10). Result: After a period of t = 1 hour the polluted cells spread in the direction of the wind direction. With the same level of pollution. The number of pollutants is greater than 1 at present: 279 occurrences, 14.1%. The number of pollutants is greater than 1 today: 279 occurrences: 14.1%. Spreading in the wind direction the polluted cells are lower than those spread by gravity by 14.1%.

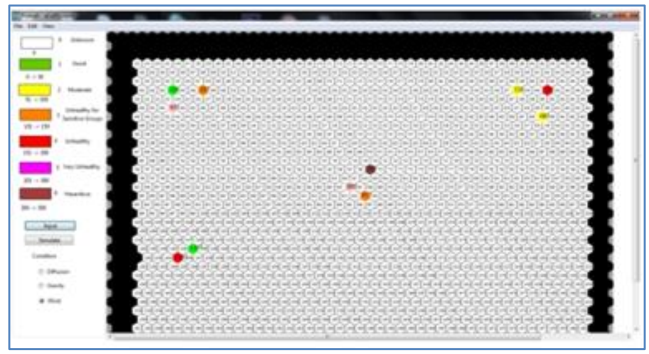

Figure 10. Cells are affected by wind. Input date 1-7-2017

The result after 1-hour simulation is shown in figure 11.

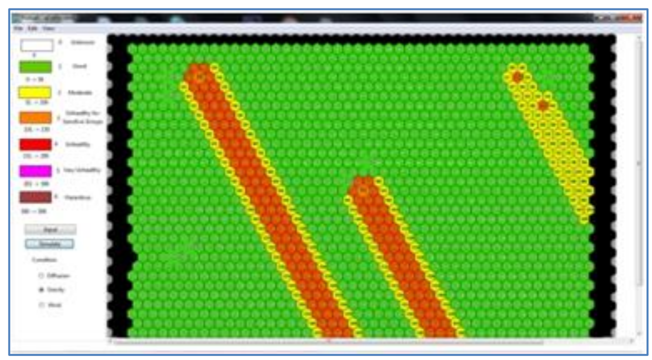

Figure 11. The cells are affected by the wind. Data output after 1-hour simulation

5.4 Scenario 3: Cells are affected by diffusion

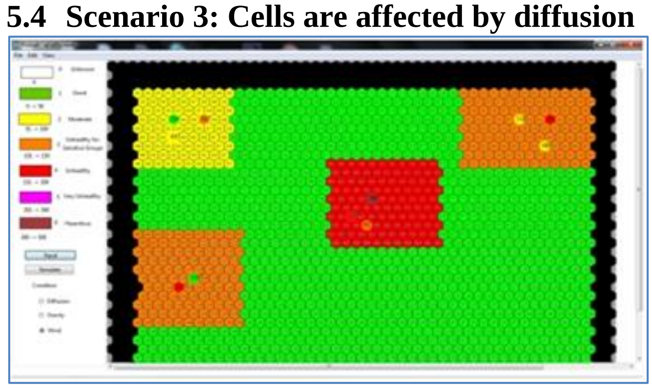

Figure 12. Cells are affected by diffusion. Data output after 1-hour simulation

This scenario simulates data entered on July 1, 2017 with the effect of diffusion. Results: After a period of t = 1 hour, polluted cells spread in all directions. The central cell has the highest level of pollution. The number of polluted cells is greater than 1 at present: 438 occurences: 31.4%. Diffusion propagation has a higher number of pollutants spreading by 7.2% gravity. And the number of pollutants is higher than the wind: 17.2%. Diffusion is the most polluting factor in air diffusion, diffusion, gravity. Results are shown figure 12.

5.5 Scenario 4: Cells are Affected by Gravity, Wind, Diffusion

This scenario simulates the data entered on July 1, 2017 with the influence of three factors: gravity in the direction from top to bottom, wind in the direction: from cell 355 to cell 455, dispersion in all directions Number of pollutants after 1 hour, greater than 1 today: 1329 occurances: 95%. With the above 4 results: The pollution is affected by the three factors, wind, gravity, diffusion, which have the highest percentage of contaminated plots. Results are shown in figure 13.

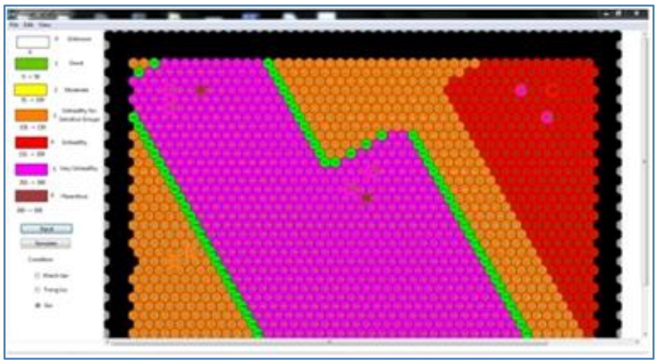

Figure 13. Cells are affected by gravity, wind, diffusion - Data output after 1-hour simulation

6. CONCLUSION

We have described a simulation system for forecasting air pollution using real input data. The proposed model developed based on CA and honeycomb structure can determine an analysis of atmospheric pollution. The choice of CA-based technique has been motivated by its characteristics that make CA the perfect solution for simulation modeling and massively parallel computation. Our model employs three novel underlying rules, e.g. rules of gravity, diffusion, and wind. Four experimental scenarios have been conducted to demonstrate the applicability of update rules necessitated to apprehend air pollution. The intended scenarios help users predict the future implications of numerous environmental factors that contribute to the atmospheric pollution of a regular region.

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