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Multi-agent modelling of impacts from the blue-green algae event in taihu lake on employees' income levels in Wuxi city

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ABSTRACT

This paper develops a multi-agent model that aims to recognise the interaction between an event and people's income levels and to simulate the impact of the blue-green algae bloom event in Taihu Lake on people's income levels in Wuxi City. This research lays a foundation for a further monetary measurement of the social influence of the blue-green algae bloom event in Taihu Lake. To explore the model, the JAVA programming language is used to take advantage of the Repast Simphony toolkit. The results show that the model is capable of reflecting the impacts of this event on people's income levels. More specifically, people's total income levels in the city first decreased due to the effects of the event. Then, incomes returned gradually to normal levels, benefiting from the implementation of governmental measures for Green Industry Development and re-employment. Next, using a Cosine Similarity analysis, it is found that the simulation results are in accordance with the outcomes of our field surveys, which indicates that the agent-based modelling approach is appropriate for studying the impacts of sudden water pollution events on people's income.

KEYWORDS

Blue-green algae; Sudden environmental events; Taihu lake; Income levels; Social impacts; Multi-agent modeling.

INTRODUCTION

The algae bloom in Taihu Lake began to be a significant pollution issue in the region in the 1990s. The water supply in Wuxi was suspended for half a month in the early summer of 1990 because of the blue-green algae bloom pollution, which caused direct losses of over 2 billion Yuan[1]. Since that time, blue-green algae in the Lake has been increasing in its blooming scale and frequency. The event in 2007 was of unprecedented severity. The bloom occurred two months earlier than ever, affected by the extremely warm weather and the local wind conditions, which favoured bloom growth[2]. The algae bloom together with the wind direction caused the toxic bloom to accumulate around the water treatment plant intakes for the two million people of Wuxi city[2], which resulted in a crisis in the water supply in Wuxi city and thus negative impacts on the social wellbeing of the city.

The blue-green algae bloom event in Taihu Lake is typical and poses some urgent questions to not only the region but also the entire country about development and environmental protection. Since this typical water pollution event, many studies have been conducted to assess its impact not only on the environmental systems but also on the socio-economic systems. For instance, Sun et al. (2011)[3] used an agent-based approach to simulate the impact of the Taihu blue-green algae bloom event on the price of bottled water. Xu et al. (2011)[4] concentrated their research on the impacts of the Taihu blue-green algae bloom event on the environmental consciousness of urban residents. However, there is still a dearth of studies on the impacts of such environmental events on residents' incomes.

We would like to concentrate our research on the income changes of the local residents triggered by the Taihu Lake blue-green algae bloom event on the grounds that these income changes, for one thing, are one of the primary negative and indirect social impacts of this event and are ignored by governments and researchers. People's income is the most important prerequisite for their lives. Our study examines the changes to residents' income levels and how these changes resulted from this blue-green algae bloom pollution event. To achieve this goal, we make use of an agent-based approach combined with field investigation. This study is the preliminary work for the National Social Science project: Quantitative Research on the Social Impacts of the Blue-Green Algae Pollution Event in Taihu Lake in 2007 for the cities Suzhou, Wuxi and Changzhou. The study provides an important step towards further monetary measuring of the social influence of this event. The remainder of this paper consists of six sections.

LITERATURE REVIEW

It has been decades since scholars began to study residents' income, and these studies predominantly focus on the relationship between income and consumption[5-8], the relationship between income distributions and economic development[9,10], and the influence factors of people's income[11]. In addition, some studies have been made of the dynamics between environmental change and household income. The primary perspective used for research on environmental change and economic income is an Environmental Kuznets Curve (EKC) analysis. However, some research has shown that the EKC is not applicable to all regions in terms of different pollution indices[12,13].

Although research on the relationships between incomes and environmental quality is available, many studies are dominated by EKC analysis and not many studies have concentrated on the impact of environmental change on people's income. There is still a lack of interdisciplinary studies, which are important for capturing the relationship between people and nature as a foundation for building resilience and sustainability for social-ecological systems in the changing world. This paper attempts to establish an agent-based model to simulate the impact of environmental incidents on people's income levels to recognise the relationship between environmental change and people's income.

THE MODEL AND DATA

It has been proved that the agent-based simulation approach is one of the useful techniques in analysing complex adaptive systems as its powerful function to simulate behaviour in the real world by representing agents and their interactions with each other[14]. The multi-agent simulation model of this paper is developed in the following chapters.

Model Assumptions

(1) Agent assumption

Suppose that the government-agent (AG) can be used to represent all of the government departments involved in the blue-green algae event, including the water conservancy, the industry and the business department, and the Administration for Commodity Prices. Similarly, we use the enterprise-agent (AE) to represent the "five small enterprises" involved after the outbreak of the blue-green algae event and the staff-agent (AS) to represent the workers unemployed because of the reorganisation of the "five small enterprises".

(2) Wages are the only income source of the unemployed workers, which means that their incomes exclude property income, transfer income, and operating income.

(3) The unemployed workers (AS) who have paid their unemployment insurance benefits can finish all the procedures of claiming unemployment insurance a month after they lost the job.

(4) Prior to the close or reform of the AE, the AS left their job only in rare situations. The AS have a status of unemployed after the Taihu Lake event.

Agents and attributes

The attributes of each agent are identified as follows:

(1)AG: the AG represents the government's functions, which not only include solving the water crisis, controlling the price of drinking water and improving the water quality in Taihu Lake, but also rectifying the polluting enterprises, constructing plants for sewage treatment and improving the wastewater treatment capacity of the city.

(2)AE: The "five small enterprises" become involved in various enterprises and begin to be rectified after the blue-green algae event in Taihu Lake. Because those enterprises and plants are numerous, it is difficult to map them onto each agent. Therefore, the enterprises and plants in Wuxi are categorised and defined as one enterprise agent. The generalised AE has all of the attributes of those five small enterprises. In addition, the behaviour of the generalised AE can represent the behaviour of those rectified enterprises. Meanwhile, the output of the generalised enterprises' behaviour is also generally equal to the output of the rectified five small enterprises under the effects of the national policies.

(3)AS: The gender ratio is set up according to the proportion of male and female workers in Wuxi city. The age, educational attainment, and wage rates of the AS before the event are determined by the "Labour Laws of China" and the researched data for Wuxi city. The health state of the AS is unified at a good level.

Simulation Rules and Behaviour Mechanism

Simulation Rules Expressed by Non-Determinate Finite Automata (NFA)

According to the aforementioned assumptions for the AG, AE, and AS, the NFA set can be given by (1):

$$M = \{Q, \Sigma, \delta, Q_1, F\} \quad \textbf{(1)}$$

where Q represents all of the states of the Agents. Suppose that the states of the Agent are AG= {rectify, do not rectify}, AE= {open, closed}, and AS= {employment, unemployment}. According to the investigated information, there are four real states. Thus, Q_1= (do not rectify, open, employment), Q_2= (rectify, open, employment), Q_3= (rectify, closed, unemployment), and Q_4= (rectify, closed, employment). Q_1 represents the initial state, while Q_3 and Q_4 represent the final states. Note that these states imply an assumption that workers would not lose their jobs if the plants that they are working in are not forced to shut down. Σ represents the set of possible actions of the Agents. In this study, the effective actions include (1) the government does nothing to the plants in response to the event, which is represented by A'(G); (2) the government attempts to rectify the plants, which is represented by A (G, E); (3) the workers were unemployed and were compensated by the government for their unemployment, which is represented by B (G, S); or (4) the workers obtained their salary after their re-employment from plants, which is represented by C (E, S). δ is the state-transition set of Agents. Equation $\delta = Q * \Sigma$ means that the state Q changes to another state under the effect of action set Σ. F is the state collection, which includes states Q_3 and Q_4.

State transition rules and decisions

According to the definition of the workers' income, with the changes in the tick (time), the income of the workers (S_E) consists of S_n, which is the monthly income, and S_s, which represents the accumulated income of workers from the start time to the current time. These two income variables can then be provided by a binary group (2).

$$S_E = (S_n, S_s) \quad \textbf{(2)}$$

The set for the attributes of the Agents, which could affect the changes in the workers' wages after their re-employment, is given by (3).

$$S_a = (g, a, e, j_c) \quad \textbf{(3)}$$

where g, a, e, j_c, respectively, represent gender, age, educational attainment, and whether or not the workers' job changed. Hence, the state transition rules of the Agents can be interpreted as follows:

(1) $Q_1 \rightarrow$A'(G) represents whether the government rectifies the enterprises. As time passes, the probability of the enterprises being rectified by the government increases with the adoption of regulations and can be given by (4).

$$I\{rdm(0,1) > 1/t\} \quad \textbf{(4)}$$

where $rdm(0,1)$ represents a random number between 0 and 1 and t is the time. The function means that when the random number $> 1/t$, the output of the discrimination number of the state is 1, in which case A'(G) will occur. Or, A (G, E) will occur. In this case, the income statistical decision of the workers is that no change occurs to the current income of the workers during this period while their accumulated income grows with the increase of the "tick" and can be given by function (5).

$$S_E(S_n\ ,\ Ss_{t+1} = Ss_t + S_n) \quad \textbf{(5)}$$

where S_n can be valued according to the researched data about the income levels of workers in the "five small enterprises" in the Wuxi area.

(2) Q_1→A (G, E) represents the decision on whether the enterprises need to be closed when the governmental regulations are applied to the "five small enterprises". The decision rule is given by equation (6).

$$I\{rdm(0,1) > p\} \quad \textbf{(6)}$$

where p is the probability of the workers becoming unemployed when the plants or enterprises are regulated by the government. This function means that when the random number $> p$, the output of the discrimination number of the state is 1 and the NFA will then change to Q_2; when the model output is 0, the NFA will change to Q_3. In this case, the income levels of the workers are not affected before the NFA changes into Q_2 and Q_3, at which point their accumulated income is given by (5).

(3) Q_2→B (G, S) represents the degree to which the government can help the unemployed workers gain re-employment by offering re-employment training and unemployment compensation. Note that the re-employment probability of workers increases with time, and the state changes are determined by equation (7).

$$I\{rdm(0,1) > \gamma / (t - td)\} \quad \textbf{(7)}$$

where t is the current time and td is the point of time at which the Agent changes to state Q_2. This function means that when the random number $> \gamma / (t - td)$, the output of the discrimination number of the state is 1; then, the NFA will change to the final state Q_4. If not, the NFA will change to state Q_2 and then keep trying again. γ is an index that affects the state of the Agents. The value of γ is different between each AS and is influenced by several factors, such as gender, age, and educational attainment. The value of γ can be calculated by formula (8):

$$\gamma = 1 - g * u_1 - e * u_2 \quad \textbf{(8)}$$

where g represents the gender, which is valued by 0 for female and 1 for male. e is the educational attainment, with a range from 1 to 4 (from low to high). u_1 and u_2 are the weights that indicate the influence of different genders and levels of educational attainment to the re-employment rate of the unemployed workers. The value of u_1 and u_2 can be evaluated using existing studies and our investigation. In this case, the income levels of workers change in state Q_2 because they have become unemployed and their current source of income is only the compensation from the government. The unemployment compensation is represented by a constant S_u. Thus, the income of the workers at this period is given by equation (9).

$$S_E(S_n = S_u\ ,\ Ss_{t+1} = Ss_t + S_n) \quad \textbf{(9)}$$

where the constant S_u is determined by the investigated data, including the income levels of workers in the "five small enterprises" in the Wuxi area and the proportion of the workers who have paid for the Social Insurance and Housing Fund.

(4) Q_4→C (E, S) represents the final state of the unemployed, namely the state of re-employment. At this stage, the workers obtain a salary from their new job and no longer obtain compensation from the government. Their income levels can then be given by (10).

$$I\{1 = 1\} \quad \textbf{(10)}$$

In this case, the income levels of the workers are determined by the duration of the state of unemployment, i.e., the duration of Q_2, because the duration of unemployment has a significant negative effect on the re-employment income levels. More specifically, if the duration of the unemployment increases by 10%, the re-employment income levels will decrease by 0.46%-0.55% (Du and Cheng 2006). However, the duration of unemployment is impacted by the duration of government compensation, the education levels of the workers, the status of the workers' physical health, and a worker's gender. The re-

employment income of the workers is identified as the period starting at the moment when they become re-employed (when they enter the final state). Thus, S_n in the equation (9) is given by formula (11).

$$S_n = S'_n\left[1-\left|\frac{t-td}{0.1t}\right| * rdm(0.0046, 0.0055)\right] \quad \textbf{(11)}$$

Therefore, the accumulated income is

$$Ss_{k+1} = Ss_k + S_n \quad \textbf{(12)}$$

(5) Q_3→C (E, S) is another possible final state, in which the plants and enterprises were not forced to shut down, and it can be described as the states' transition rules (4) and the current income and accumulated income of workers can be calculated by equation (1).

Accordingly, the state and transition rules expressed by the NFA are shown in Figure 1 below.

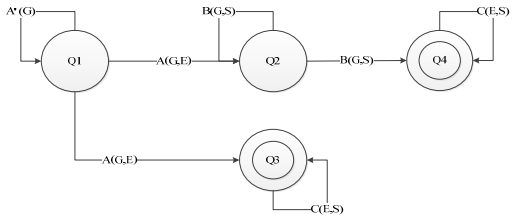


Figure 1 : The state and transition rules of the NFA

Data collection

Two types of datasets are used in our research. One dataset is to identify what factors affect the re-employment of unemployed workers and how they affect it. Another dataset covers the personal details and the changes in the salaries of the affected workers after the Taihu blue-green algae event. The former dataset is gathered through a literature review, while the latter is collected through investigations and statistical analysis. Thus, we conducted a face-to-face questionnaire survey in Wuxi city in August of 2010.

The questionnaire covers a variety of related questions, including the satisfaction of the workers with their jobs at the time of the blue-green algae outbreak in Taihu Lake, whether the workers suffered pressure from unemployment, whether the workers considered changing their job during the event, whether it was easy for them to obtain a new job, the impact of the event on the workers' salary and Social Insurance and Housing Fund, and the approaches that the unemployed workers used to find a new job after the event. In addition, we also conducted interviews with the relevant officials in the government departments that took charge of regulating the "five small enterprises" and with the managers in those "five small enterprises" regarding the re-employment training, compensation, and government settlements for the unemployed workers during and after the Taihu Lake algae event.

The personal details include gender, age, income and educational attainment. Questionnaires were distributed to individuals in the areas around Wuxi city, including residential communities, the polluting plants, and the relevant authorities. The questionnaire was targeted to the unemployed workers in the "five small enterprises" that were rectified by the government and to the residents who are familiar with these unemployed workers. To avoid deviation as much as possible, we attempted to keep a balance in gender and the age of participants during the investigation.

The sampling method of this study is similar to that used in Xu et al (2013)[15]. However, because of the different target groups, the distribution of the sample is a little bit different from these authors'. A total of 900 questionnaires were distributed, and 751 were completed with valid and useful information (the valid rate is 83.44%).

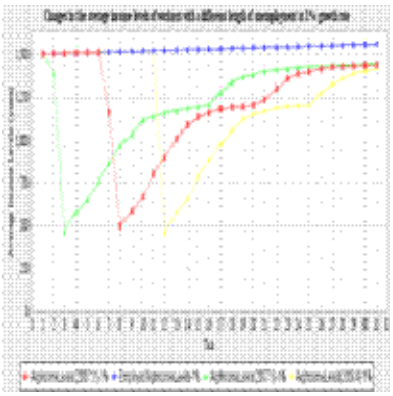
RESULTS AND DISCUSSION

Robert Tobias and Carole Hofmann compared four multi-agent simulation tools and concluded that REPAST has the highest composite scores in almost all of the projects; in particular, REPAST has the highest scores in terms of its modelling and simulation capacity and its ease of use[16]. Consequently, REPAST is an important implementation tool and Repast Simphony Toolkit 1.2.0 is used to run the simulation. Given the limitation in the long time series data, the simulation period of this study spans from May 29th of 2007 to December 31st of 2009, with 31 ticks in total (a tick is one month).

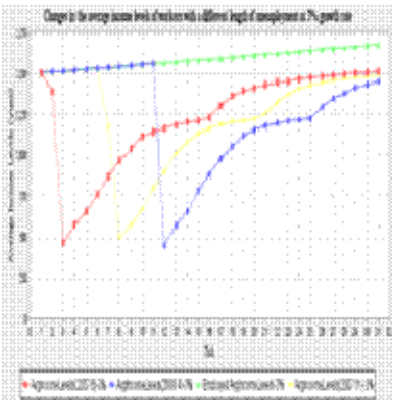
In this study, the average growth rate for the annual income of workers in private plants, according to our investigation, compared with the national level, is set to three levels at 1%, 3%, and 5%. Then, three specific periods of time (June of 2007, November of 2007, and April of 2008) are set for simulating the effects of the different unemployment time on the laid-off workers' average and accumulated income levels.

Changes in average income levels

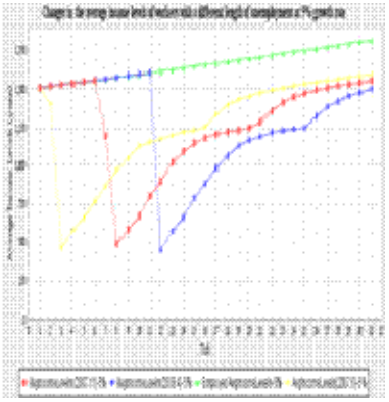
The simulation outputs for changes to the average income levels of unemployment for workers during different periods of time at different income growth rates are shown in Figure 2.



(a)



(b)



(c)

Figure 2 : Simulation of the average income levels of unemployed workers compared with employed workers in different scenarios

It can be concluded according to Figure 6 that 1) the trajectories of changes for the laid-off workers' average income levels are in accordance with the actual situation reflected in our investigation. That is, the changes of the laid-off workers' average income decreased at the beginning of the event and gradually returned to normal levels after the event; and 2) different average annual income growth rates have different degrees of impact on the income levels of the re-employed workers, and the higher the growth rate is, the faster the re-employment income increases. The re-employment average wage levels for the unemployed people are all lower than the average income of the employed people at any point in time, whether the income growth rate and unemployment time are changed or not.

A different unemployment time has a different impact on the income levels of the re-employed workers. Specifically, the shorter the duration of the unemployment is, the higher the re-employment average income level is. This difference is more apparent with an increase in the growth rate of the workers' income.

The fit test between the simulation results and the questionnaire data

This study employs the Cosine Similarity and Euclidean Distance to test the degree of fit between the simulation and the questionnaire results so as to ensure the reliability of the simulation results. According to the investigation, only 33.4% of the workers' income increased, while more workers saw their income decrease. Approximately 13.3% of the workers' income decreased after re-employment by 20% compared to their original income.

However, the model was run 500 times using the Repast toolkit in the three scenarios. By using equations (13) and (14), the results show that the Cosine Similarity is 0.92 and the Euclidean Distance is 21.63, which suggests that the model is feasible to simulate this issue.

CONCLUSIONS

This paper establishes a multi-agent model to analyse and simulate the impacts of the blue-green algae event in Taihu Lake on people's income levels in Wuxi city. The primary findings are as follows.

(1) The blue-green algae bloom event in Taihu Lake had a negative impact on residents' income levels. Specifically, in the early periods of the event, workers lost their jobs due to governmental regulations that affected the so-called "five small enterprises", which resulted in the reduction of their income levels. In addition, even if they were re-employed, their income levels were lower than in their former jobs. However, the income levels of residents increase gradually, even beyond their income level before the event, as the economy develops.

(2)The income levels of residents are influenced by many factors, such as educational attainment, physical health, gender, duration of unemployment, and the time when the government start to compensate for them. Specifically, the longer the unemployment time is, the higher the average re-employment income level is at the same income growth rate. However, the time when unemployment happened to workers has little impact on the accumulated income level at re-employment. In addition, economic factors also affect the workers' income levels, and the higher the workers' income growth rate is, the faster the rate of increase for both the re-employment average and the accumulated income.

(3) The actions of the government and enterprises have a great influence on residents' income level. For example, when the government issues regulations or measures, the effectiveness of the regulations, the amount of unemployment compensation, and the settlement methods for unemployed workers from the government and the plants could change the impacts on the residents' income levels to different degrees.

(4) A multi-agent modelling approach is feasible for analysing the interplay between complex systems, such as simulating the impact of sudden water pollution events on socio-economic systems. This approach is appropriate because the social impacts of those environmental incidents are complicated and many of them are often ignored and unnoticeable, although they are important to social wellbeing. It is important to focus on their social impacts; because it is difficult to gather or observe information about the social impacts of environmental incidents, a computer-based modelling approach, such as agent-based modelling, can be used to determine the interactions between environmental changes and socio-economic wellbeing.

This paper primarily emphasised analysing and simulating the influences of the residents' income in response to the blue-green algae events in Taihu Lake. However, there is still a need to move beyond simulating the interaction between the environment and humans so as to better adapt to the changing environment. For example, valuing the impacts of the increasing number of sudden environmental pollution incidents and extreme weather events on social systems is of great significance for integrated adaptive management and the creation of resilient social-ecological systems for a sustainable future.

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