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Changes in public environmental awareness

in response to the Taihu blue-green algae bloom incident in China

1. Introduction

In the late spring of 2007, blue-green algae bloomed and spread quickly into large areas of Taihu Lake, the third largest freshwater lake in China. The prevailing wind direction caused the toxic bloom to accumulate around the water treatment plant intakes for the two million people living in the adjacent Wuxi city (Qin et al. 2010). The algae bloom led to massive and rapid fish deaths. The efforts of the Ministry of Water Resources and Jiangsu Province to divert water from the Yangtze River to flush the bloom from the lake were ineffective and “diversion helped create a stable water current which transported the concentrated cyanobacterial agglomerates to the Wuxi city drinking water plant intake” (Qin et al. 2010:108). On the morning of 29 May 2007, many Wuxi residents discovered that an intolerable odour was coming from their water taps. The water supply to Wuxi city was forced to be suspended for several days. During this period, the availability of drinking water was restricted, which resulted in increased prices for fresh water, and created chaos, rumours and panic (China Daily 2007; Anonymous 2007). Local residents did not use tap water until 5 June 2007 when the mayor of Wuxi made an announcement on television news and drank boiled city water to demonstrate that the water was safe for drinking and daily use (Qin et al. 2010).

Although cyanobacterial blooms have been recurring summertime events in Taihu Lake since the mid-1980s, the event that happened in 2007 was of unprecedented severity. It occurred two months earlier than previously, affected by the extremely warm weather and local wind conditions which favoured bloom growth (Qin et al. 2010). The local government claimed that "the water quality problem is in no way caused by manufacturing or any other human activity" (Jun 2007:n.p.) and called residents (including through websites) to join their forces to fight the crisis. There is however ample evidence that this was not a natural disaster for the lake, whose hydrology is characterised by shallowness (Qin et al. 2007). Many commentators link it to the serious eutrophication of the freshwater basin as a result from environmental human-created pollution associated with industry, agriculture and household activities (Jun 2007; Qin et al. 2010).

Environmental problems are becoming increasingly severe in China (China Environmental Protection Bureau, 2009). The water quality of most main lakes and catchments has been deteriorating since the 1970s. Large areas of the water in the Huai, Hai and Liao rivers – China's three main rivers, as well as in the Taihu, Caohu and Dianchi lakes, were of poor quality, below the worst category V in 2009 – 17.4%, 42.2%, 36.1% 19.3%, 62.5% and 41.7%, respectively (China Environmental Protection Bureau 2009). Degraded water quality, increasing pollution and consequently serious eutrophication affect 85% of the lakes in China (Qin et al. 2007) and an increasing number of water-related environmental incidents are happening in many areas of the country. The blue-green algae bloom incident in Taihu Lake in 2007 was one such example.

The degradation of water quality in China derives from industrial discharges, household sewages and agricultural non-point source pollution (Hays 2008). Every year, non-point source pollution (that is pollution from diffuse sources, such as run-offs from agricultural areas and wind-borne debris) accounts for approximately 50% of the total pollutants in the lakes of eastern China (Qin et al. 2007) and about two-thirds of the total industrial wastewater discharge into the country’s rivers, lakes and the sea (Wang et al. 2008). The situation is similar in the Taihu basin (Qin et al. 2007), where more than 60% of the total phosphorus of the lake comes from household sewage and 44% of the Chemical Oxygen Demand (COD) is from industrial discharge (Chinese Academy for Environmental Planning 2001).

While industrial and agricultural pollution can be treated to a certain degree through new and improved technologies and is increasingly controlled through environmental regulations, the task of decreasing household sewage relies mainly upon the residents themselves. According to Yang (2002), improving public environmental awareness (PEA) is a key measure for success in environmental protection. People with developed appreciation and knowledge of the ecology are in a position to exert pressure not only on policy makers and legislators but also lead by example and condemn polluting behaviour by others. Many studies, such as that conducted by Palmer et al. (1998), show that negative environmental experiences, including pollution and ecological disasters, rank highly in the influence they have on developing personal concerns about the environment. Although research on PEA has been carried out for over 40 years, very few quantitative studies have been conducted to examine awareness development, particularly in response to major environmental incidents. In this paper, a mathematical model is used to quantitatively assess PEA and changes of PEA in Wuxi after the Taihu Lake algae bloom incident.

Owing to the complexity of the issues involved, most of the research conducted to assess PEA is based on subjective criteria and many indicators exist. The first series of systematic

PEA indicators is the Ecological Attitudes and Knowledge Scale which was established in 1975 by Maloney et al. (1975). It involves four different sub-scales and 45 items related to ecological knowledge, sensitivity, oral promises and real behaviours. Later on, the Environmental Concern Scale (Russel and Weigel 1978) and New Environmental Paradigm Scale (Dunlap and Van Liere 1978) were developed and had been used until Schwartz (1992) established the Value Scale.

Specifically, Schwartz (1992) suggested that 53 sub-class values indicators derived from 10 types of human values should be considered to assess PEA. In 1994, he further classified the contents of the Value Scale into self-transcendence, self-enhancement, openness and tradition (Schwartz 1994). Based on the individual value scale, Stern et al. (1995) centred their research on the primary motivation behind individual environmental awareness and behaviours. They argued that the motivation for PEA and behaviours is predominantly influenced by the degree of people's environmental values in relation to environmental protection, thus their environmental awareness and behaviours are dominantly influenced by biospheric values, social-altruistic values and egoistic values (Dunlap et al. 2000). Remarkably, the New Ecological Paradigm (NEP), put forward by Dunlap et al. (2000) following their New Environmental Paradigm Scale, is now a widely used indicator system. It includes five multi-faceted issues around the contested concepts of: limits to growth, objection to anthropocentrism, fragility of the natural balance, and humankind and any other species confined to natural ecosystems. In China, many studies assessing PEA use the indicators published in the National City Public Awareness Survey Report conducted by the Ministry of Environmental Protection of China (Wang and Reisner 2010). It includes sections on environmental knowledge, environmental significance, importance of the environment and environmental protection behaviour.

Many of the existing PEA assessment studies focus on comparisons between geographic areas, particular types of locations or sectors, or on a specific aspect of PEA during a period of time (Kessel 1985; Stabler et al. 1997; Huang et al. 2006; Liu et al. 2009; Dimitrakopoulos et al. 2010). Other studies examine in particular, PEA reaction to some slow changes in the ecosystems, such as the physical and biological transformations of a lake environment caused by climate change (Várkuti et al. 2008). In order to improve the robustness of the mathematical assessment of changes in PEA in response to environmental pollution incidents, the present paper applies a fuzzy matter-element analysis method (Cai et al. 1997) to quantitatively assess PEA based on the 2007 algae bloom incident in Taihu Lake.

In response to the need for a new assessment methodology, section 2 describes an indicators system and a mathematical model developed for a quantitative assessment of PEA. The selected study area for which the model is applied is described in section 3. Some policy recommendations from the analysis together with concluding remarks are presented in section 4.

2. Indicators system and modelling

Public awareness plays an important role in igniting community enthusiasm and knowledge to achieve a particular goal, such as more sustainable societies (UNEP 2008). Environmental awareness is associated with desires to protect the planet's ecosystems, including freshwater resources. According to North (1997:175), it represents the development of understanding and consciousness towards the biophysical environment and its problems, including the ones resulting from human interactions. In this paper, PEA refers to people's thinking pattern in relation to environmental problems in the place they live, including their degree of knowledge about the environmental situation, basic understanding of common environmental phenomena and understanding of environmental protection. This type of thinking pattern is imperceptibly generated and rooted in people's minds in the process of socio-economic development and material wealth creation. In general, it includes how a person treats and understands the relationships between human activities and the natural environment, as well as the extent of the accordance of this thinking with their actual behaviours. From this point of view, PEA is not only influenced by individual differences such as educational background, age and income, but also by social factors such as level of social activity, cultural characteristics, natural environment status and government policies. The assessment indicators system we will establish is based on the above definition and incorporates existing widely used indicators.

2.1. Indicators system

Depending on their level and type of education, work and life experiences, all residents have a certain degree of familiarity with the issues related to the natural environment, physical laws and environmental functions as well as law, regulations and other mechanisms put in place to protect the ecosystems. The degree of environmental familiarity is also impacted by government and mass media campaigns and information. For this type of passive familiarity to translate into environmental awareness, it requires the adoption of attitudes and values, which direct behaviour. From a philosophic perspective, the human cognitive process about nature is a gradual progression which can be viewed as an advancement from perceptual learning to rational knowledge. Perceptual learning is a kind of subjective reflection in the human mind of outer objective matters people encounter in nature through their physical senses such as sight, hearing, taste, touch and smell (China Digital Science and Technology

Museum n.d.). Perception is accompanied with imagination and remembering. Rational knowledge on the other hand, is related to the systematic understanding of, learning and thinking about the world within the western scientific tradition. When related to ecological problems, environmental awareness becomes a subjective reflection in sensuous forms, such as feelings and images, or rational forms, such as judgements and reasoning about environmental phenomena (Liu 1993). In our opinion, perceptual learning about the environment can be regarded as the initial perception about environmental problems and the first stage of people's environmental awareness. It includes people's concerns about environmental issues and protection policies, personal evaluation of the quality of the surrounding environment, identification of pollution sources and attitudes towards behaviour of environmental contamination or destruction by other people (Wang 2000).

On the other hand, people's rational knowledge reflects their thinking about the relationship between their behaviour and the natural environment, which can form a rational thinking pattern and remain rooted in their mind shaping their thoughts, judgements and behaviours. This kind of rational thinking is usually used as a major indicator for assessing PEA and is also a key factor that can influence people's behaviours. It is unlikely that people will treat the natural environment with respect and desire for protection unless they have rationalised its importance and this has become part of their personal beliefs and values. Research has shown that people's willingness to conserve the environment tends to be stronger when the level of their rational knowledge is higher, as they are likely to pay more attention to environmentally related issues (Ajzen 1991; Aiken 2002).

It is not an easy task to develop indicators that reflect the various aspects of environmental awareness without avoiding overlap between what individuals know, think, experience and how they behave. Any such an attempt involves arbitrary judgements and assumptions made in order to progress further the research agenda on a topic that is of vital importance to human survival. In fact, when it comes to human behaviour, it is impossible to find any mutually exclusive indicators. Accordingly, the indicators system presented in Table 1, which comprises two assessment levels with 3 and 14 items respectively, is one possible way to analyse public environmental awareness. The first layer of indicators represents the evolution of environmental awareness from the passive degree of familiarity (B_1) through the more practical perceptual learning (B_2) to the active rationalised knowledge (B_3) about the environment.

In order to describe the degree of familiarity with the environment, four second layer indicators are used, that represent the degree of familiarity with the main environmental problems in the area, environmental protection through regulation and reporting mechanisms as well as familiarity with basic environmental knowledge, such as energy flows, nutrient cycling, interactions and interdependence, relationships between species and human impacts (Hungerford et al. 2005). Similarly, four second layer indicators are used to represent perceptual knowledge, namely attitudes to pollution, awareness of water recycling, attitudes to rubbish and attitudes covered by the New Ecological Paradigm (NEP) scale (Dunlap et al. 2000) as represented through the level of (dis)agreement with statements, such as “humans are severely abusing the environment”, “the earth is like a spaceship with very limited room and resources” and “humans are meant to rule over the rest of nature”. The level of rational knowledge is linked to individual ethics and moral judgements represented by six second layer indicators which cover willingness to pay for environmental protection, views about water recycling, environmental degradation, environmental protection as well as willingness to participate in green consumerism and consider environmental consequences in any human actions. The higher the values for each indicator, the higher the overall PEA becomes.

Table 1 Indicators for the assessment of public awareness of environmental protection

	First Layer Indicators	Second Layer Indicators
PEA	Degree of familiarity with the environment (B_1)	Degree of familiarity with the main surrounding environmental problems (C_1)
		Degree of familiarity with laws and regulations referring to environmental protection (C_2)
		Degree of familiarity with ways of reporting environmental concerns, e.g. phone number (C_3)
		Degree of familiarity with basic environmental knowledge (C_4)
	Perceptual knowledge about the environment (B_2)	Attitudes to pollution behaviour by industry plants and other people (C_5)
		Awareness of water recycling (C_6)
		Attitudes to views in the NEP scale (C_7)
		Attitudes to garbage sorting (C_8)
	Rational knowledge about the environment (B_3)	Willingness to pay for environmental protection (C_9)
		Views about reasons for recycling water (C_{10})
		Views about reasons for environmental degradation (C_{11})
		Views about environmental protection responsibility (C_{12})
		Willingness to participate in green consumption (C_{13})
		Willingness to think about environmental consequences

		before acting (C_{14})

It is impossible to reflect all aspects of the way people perceive and engage with the environment. Public environmental awareness cannot be truly understood without input from, for example, sociologists and psychologists. It is a very personal and subjective thing that translates into real individual and social behaviour which, ultimately, affects the health of other people and species on the planet. Longitudinal studies can also help with overcoming some of the current knowledge limitations. On the other hand, when major environmental disasters occur, people and policy makers need quick answers that can avoid future mistakes. The Taihu algae bloom provided such an opportunity to investigate people's environmental attitudes and the indicators system described above is capable of capturing some valuable information from Wuxi residents.

2.2. Quantitative assessment model

As PEA is a very subjective matter, many of the indicators are unclear, indistinct and difficult to express and assess. The quantitative assessment of PEA can be treated as a process of decision-making affected by multi-factors and a process of coping with contradictory problems by quantifying qualitative indicators. The matter-element analysis method, a mathematical model developed by Cai in the 1980s, can therefore be introduced for assessing PEA. This method aims to establish a multi-factor assessment model by using a ternary combination set $R = (N, C, X)$ which synthesizes qualitative and quantitative indicators (in this case used to assess PEA) and consists of the assessment object N (namely PEA), its characteristics C (in this case the 14 second layer indicators) and the corresponding values of each characteristic X so as to achieve the purpose of a quantitative assessment (Cai 1994; Cai et al. 1997). If an object *N* is described by n (14 in this case) characteristics [c_1, c_2, …, c_n] with corresponding measures [x_1, x_2, …, x_n] (the values for each awareness indicator), then the n-dimensional mixed-element *R* can be described in a matrix as shown in equation (1):

$$R = (N, C, X) = \begin{bmatrix} N & c_1 & x_1 \\ & c_2 & x_2 \\ & \vdots & \vdots \\ & c_n & x_n \end{bmatrix} \qquad (1)$$

This mathematical modelling method is applied for the PEA assessment according to the following steps:

(1) Assessment matter-elements

The first step for assessing PEA using the matter-element method is to build up an *n*-dimensional matrix to describe the assessment object, including ranks and criterion of the assessment, on the basis of its characteristics and corresponding value of measures. In this study, there are 14 indicators for the selected characteristics (Table 1), i.e. in equation (1) n = 14 and i=1,2,…, 14. As all indicators are of qualitative nature, the values used are numbers on a relative scale between 1 and 3 (see Section 3).

(2) Classical and nodal field

The classical field represents a ternary combination that categorises different levels of PEA, e.g. bad, medium, good and excellent (see Section 3). A matrix for the classical field is established using the following equation:

$$R_0 = \begin{bmatrix} N_0 & C_1 & \langle a_{01}, b_{01} \rangle \\ & C_2 & \langle a_{02}, b_{02} \rangle \\ & \vdots & \vdots \\ & C_n & \langle a_{0n}, b_{0n} \rangle \end{bmatrix} \qquad (2)$$

where N_0 represents the condition of PEA within the particular assessment category (bad, medium, good and excellent). C_i is the *ith* assessment indicator and $x_{0i}=<a_{0i},b_{0i}>$ is the value range for the measure of C_i; namely, x_{0i} is the value range (score space) of C_i for the particular assessment level. As there are four PEA assessment levels in this case, there are also four classical fields.

The nodal field represents a ternary combination that describes the overall PEA as a combination of all classical fields. Hence, the nodal field matrix for the evaluation of PEA is described as follows:

$$R_P = \begin{bmatrix} N_P & C_1 & \langle a_{p1}, b_{p1} \rangle \\ & C_2 & \langle a_{p2}, b_{p2} \rangle \\ & \vdots & \vdots \\ & C_n & \langle a_{pn}, b_{pn} \rangle \end{bmatrix} \quad (3)$$

where N_p indicates the collection of all ranks for the assessment criteria, $x_{pi}=<a_{pi},b_{pi}>$（$i=1,2,\ldots,14$）is the value range for all assessment indicators c_i, and $x_{0i} \subset x_{pi}$ ($i = 1, 2,\ldots,14$).

(3) Correlation function

The correlation function $K_j(x_i)$ in the model is used to describe the extent of each assessment indicator belonging to assessment category j, where j describes the PEA four levels (namely bad**,** medium, good and excellent). It enables quantitative assessments of the range of indicators allowing the assessment to be more precise than with other methods. The function is used to calculate the distances from the points (the values for the measures of C_i) to the classical fields and the nodal field. Describing different positions and status of points in the fields by the correlation function can not only determine the classifications and ranks but also reflect the degrees of variation for the assessment object. This correlation function is presented by equation (4):

$$K_j(x_i)=\begin{cases}\dfrac{\rho(x_i,x_{0i})}{\rho(x_i,x_{pi})-\rho(x_i,x_{0i})}, & x_i\notin x_{0i}\\ -\dfrac{\rho(x_i,x_{0i})}{|x_{0i}|}, & x_i\in x_{0i}\end{cases} \quad (4)$$

where x_i is the value of indicator i in the matter-element matrix being assessed while $\rho(x_i,x_{0i})$ and $\rho(x_i,x_{pi})$ are the distances between point x_i and classical field x_{0i} and nodal field x_{pi} respectively with the distance of the field $|x|=|b-a|$, and

$$\rho(x_i,x_{0i})=\left|x_i-(a_{0i}+b_{0i})/2\right|-(b_{0i}-a_{0i})/2 \quad (4a)$$

$$\rho(x_i,x_{pi})=\left|x_i-(a_{pi}+b_{pi})/2\right|-(b_{pi}-a_{pi})/2 \quad (4b)$$

(4) Correlation degree

According to the correlation function (4), the calculation for the integral correlation degree of object N being assessed at category j is given by equation (5):

$$K_j(N)=\sum_{i=1}^{n}w_iK_j(x_i),\ (i,j=1,2,\ldots) \quad (5)$$

where w_i indicates the standardised weight for indicator C_i of the assessed object, n is the number of indicators (14 in this study) and the number of j categories is m (4 in this study).

If $$K_{j0}(N)=\max_{j\in\{1,2,\cdots,m\}}K_j(N) \quad (6),$$

the conclusion could be made that the assessed object N belongs to rank j_0. This equation is used here to qualify the extent to which the state of PEA complies with the criteria for category j for indicator x_i and not as a statistical significance test.

3. Assessment of PEA in Wuxi city in response to the Taihu Lake incident

3.1. Study area

Taihu Lake is the third largest freshwater lake in China and its basin supports approximately 40 million people (Qin et al. 2010), including Wuxi city in the Jiangsu Province, located in the Yangtze River Delta and adjacent to Taihu Lake (Fig. 1). The Taihu basin is situated in one of the most developed regions in China which generates more than 10% of the country's GDP (Sun and Huang 1993; Li et al. 2009). The development of intensive industries which discharge various chemicals combined with pollution from residents is making the Yellow River Delta become more fragile and susceptible to natural hazards (Deng and Jin 2000; Lin et al. 2001; Huang and Fan 2004; Fan et al. 2006; Wang 2006; Jiang 2009). For example, the water quality of Taihu declined from level 2-3 in 1990 to 4-5 in 2000 (World Bank 2001) with water eutrophication and algae bloom becoming serious environmental problems.

In 2007, between the end of May and the beginning of June the algae bloomed in the lake and polluted 70% of the local water supply in Wuxi, affecting 2 million people (Jiang 2009; Qin et al. 2010). This environmental incident caused a crisis in the water supply to Wuxi, impacted the local community and drew a lot of attention from the rest of the country. The degradation of the water quality in Taihu mainly stems from the growing industrial discharge and non-point source pollution, in particular agricultural pollution and domestic sewage. It is a consequence from the inadequate treatment and prevention measures associated with the existing low level of environmental awareness (Lin 2002). Agricultural non-point source pollution in the Taihu basin attributed respectively 59% and 30% of the total nitrogen and total phosphorus in Taihu Lake while domestic sewage accounted for respectively 25% and 60% (Qin et al. 2007; Wang et al. 2010). In order to find effective ways to raise PEA, it is important to examine what impact such an environmental incident has had.

Fig. 1 Map of the location of Taihu Lake and Wuxi City

(edited from Wang et al., 2004)

3.2. Assessment object and indicators ranking criterion

According to the indicators presented in Table 1, the assessment object can be described as a 14×3-dimensional matrix, x_i is the score for C_i. The matter-element matrixes for the different levels of PEA before, during and after the Taihu blue-green algae incident can be described as follows:

$$R_{before} = \begin{bmatrix} N_x & c_1 & x_1 \\ & c_2 & x_2 \\ & \vdots & \vdots \\ & c_{14} & x_{14} \end{bmatrix}, R_{during} = \begin{bmatrix} N_x & c_1 & x_1 \\ & c_2 & x_2 \\ & \vdots & \vdots \\ & c_{14} & x_{14} \end{bmatrix}, R_{after} = \begin{bmatrix} N_x & c_1 & x_1 \\ & c_2 & x_2 \\ & \vdots & \vdots \\ & c_{14} & x_{14} \end{bmatrix}$$

Four categories are introduced to rank all the indicators: class I (bad), class II (medium), class III (good) and class IV (excellent). Correspondingly, the evaluation results are also divided into four classes: I (bad), II (medium), III (good) and IV (excellent). Scores in the ranges of [1, 1.5], [1.5, 2], [2, 2.5] and [2.5, 3] are respectively assigned to these four classes using the criteria outlined in Table 2. These four score ranges are the classical fields for the assessment indicators, and the nodal field is [1, 3]. Then, the classical matrixes can be given as:

$$R_{0_1} = \begin{bmatrix} N_{bad} & C_1 & \langle 1, 1.5 \rangle \\ & C_2 & \langle 1, 1.5 \rangle \\ & \vdots & \vdots \\ & C_n & \langle 1, 1.5 \rangle \end{bmatrix}, R_{0_2} = \begin{bmatrix} N_{medium} & C_1 & \langle 1.5, 2 \rangle \\ & C_2 & \langle 1.5, 2 \rangle \\ & \vdots & \vdots \\ & C_n & \langle 1.5, 2 \rangle \end{bmatrix}$$

$$R_{0_3} = \begin{bmatrix} N_{good} & C_1 & \langle 2, 2.5 \rangle \\ & C_2 & \langle 2, 2.5 \rangle \\ & \vdots & \vdots \\ & C_n & \langle 2, 2.5 \rangle \end{bmatrix}, R_{0_4} = \begin{bmatrix} N_{excellent} & C_1 & \langle 2.5, 3 \rangle \\ & C_2 & \langle 2.5, 3 \rangle \\ & \vdots & \vdots \\ & C_n & \langle 2.5, 3 \rangle \end{bmatrix}$$

while the nodal field matrix is described as:

$$R_p = \begin{bmatrix} \mathrm{N}_p & c_1 & [1,3] \\ & c_2 & [1,3] \\ & \vdots & \vdots \\ & c_{14} & [1,3] \end{bmatrix}$$

Table 2 Assessment criteria and description

Indicators	Criteria and descriptions			
	Bad (I) [1,1.5]	Medium (II) [1.5,2]	Good (III) [2,2.5]	Excellent (IV) [2.5,3]
C_1	Indifference	Aware of the basic environmental problems around, but ranking large parts of these problems incorrectly	Knowing the main environmental problems around and ranking parts of these problems correctly	Knowing the main environmental problems around and ranking problems correctly
C_2	Indifference	Knowing very little about environmental	Aware of about half of the existing environmental laws	Familiar with explicit parts of the environmental

		regulation	and regulations	regulations
C_3	Indifference	Aware about the environmental phone line but not using it	Aware about the environmental phone line but using it infrequently	Knowing the environmental phone line and reporting as soon as becoming aware of an offence
C_4	Indifference	Knowing well the importance of the environment for human physical health	Understanding basic environmental knowledge and how it applies in daily routine	Familiar with many aspects of environmental protection
C_5	Indifference/ Acceptance	Condemning without any action	Condemning and often informing the administration office	Condemning and always informing the administration office
C_6	Disagreement	Agreement and doing it occasionally	Agreement and doing it most of the time	Agreement and doing it every day
C_7	Degree of the agreement/ disagreement =	Degree of the agreement/ disagreement = 2	Degree of the agreement/ disagreement –	Degree of the agreement/ disagreement = 5

	1		between 3 and 4	
C_8	Indifference/ Being unnecessary	Being necessary, and this should be done by cleaners	Being necessary but can do that from time to time	Being necessary, and can do this as a matter of habit every day
C_9	Willingness (＜￥1)	Willingness (￥1–￥3)	Willingness (￥3–￥5)	Willingness (＞￥5)
C_{10}	Indifference	Saving expenses	Saving water	Saving water and reducing wastewater discharge
C_{11}	Indifference	People’s low level of environmental awareness is a small part of the reason	People’s low level of environmental awareness is mainly the reason	People’s low level of environmental awareness is the main reason
C_{12}	Indifference	Governments and companies have the main obligation	The public has a some obligation	The public is largely responsible
C_{13}	Never buy	Might buy	Buying and recommending	Buying and strongly recommending

C_{14}	Indifference	Occasionally thinking about environmental consequences	Thinking about environmental consequences most of the time	Thinking about environmental consequences all the time

3.3. Weight system

The 14 indicators used to describe PEA (see Table 1) can have different relative importance in the overall assessment. A way to represent this is through assigning different weights to them. The Analytical Hierarchy Process (AHP) analysis is applied in this case as the qualitative characteristics of these indicators are hierarchically structured (first and second layer in Table 1). As a method, AHP can be used to create measures in both, the physical domain with tangible criteria and the social domain with intangible criteria. The important starting step is to establish paired comparisons between each pair of indicators about which judgements of importance are made using numerical values taken from the AHP absolute fundamental scale of 1 to 9 (Saaty 1987 & 1990). We used 10 university experts in this case, each populating a matrix of paired comparisons. The next step is to normalise these paired comparisons. After that, the AHP models can be used to calculate the weight for each indicator. The weights are reflecting the relative importance and relevance of each indicator, and the total weight at each equals 1, i.e. $\sum_{i=1}^{3} w_{B_i} = 1\ (i = 1, 2, 3)$ and $\sum_{i=1}^{14} w_{C_i} = 1\ \ (i = 1, 2, \cdots, 14)$. In addition, AHP provides a way to test the consistence of the values assigned to the indicators making the weights system as reasonable as possible. The weights obtained for the PEA indicators are listed in Table 3 and they all pass the consistence test[1].

[1] The details of the weighting process (paired comparisons, experts' scoring, normalized matrixes and consistence test) are available from the author(s).

Table 3 Weights and consistence test for the PEA assessment indicators system

Indicators	B_1					B_2					B_3			
Weights	0.251					0.159					0.589			
Consistence Test			λ_{max}=3.053, *C.I.*=0.026, *C.R.*=0.045<0.10											
Indicators	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}	C_{11}	C_{12}	C_{13}	C_{14}
Weights	0.029	0.018	0.018	0.036	0.023	0.041	0.055	0.047	0.119	0.081	0.101	0.137	0.138	0.156
Consistence Test			λ_{max}=14.645, *C.I.*=0.050,*C.R.*=0.031<0.10											

3.4. Data collection

Any public awareness research benefits from time series data which can be used to describe past and current states as well as shifts that have happened or are expected to occur. There are however no other PEA studies conducted previously in this specific area and hence no reliable data exist. Being the first study of this kind, it was important to collect as much information as possible despite some obvious difficulties.

With the questionnaire, individuals were asked to respond to 30 specific questions concerning their levels of familiarity with environmental problems, perceptual and rational knowledge. Each question had five possible answers for self-assessment on a scale of 1 to 5, where 1 was poor (or awareness value score of 1), 2 – low (score of 1.5), 3 – medium (score of 2), 4 – good (score of 2.5) and 5 – excellent (score of 3). The interviewees were asked to give their responses to every question for three time periods: before, during and after the algae bloom incident[2]. Taking people's attitudes towards "garbage sorting" (indicator C_8) as an example, the participants were asked: "To what extent did/do you agree about the need for garbage sorting in the following periods: before, during and after the blue-green algae bloom incident in Taihu Lake?" Thus the answers provided information about three time periods which allowed assessing the changes in PEA in response to the incident.

It is acknowledged that this method of collecting earlier data is obviously not exceptionally reliable. The incident was a shock to the normal daily life in Wuxi with long-lasting memories but as time goes on, there is also the possibility that people could exaggerate or dismiss its importance. The method used can generate some impreciseness, inaccuracies or errors in the assessment as people might not be able to remember clearly things that have happened 2-3 years earlier, but this was a way to compensate for the lack of time series data. We were also not in a position to separate any "natural" increase in environmental awareness in the area as time progresses from the changes triggered solely by the incident. Despite this, what is important is that we were able to establish a stepping stone for any policy measures and further research.

Based on the explained assumptions and the designed questionnaire, face-to-face surveys were conducted to collect data in Wuxi in August 2010 (two years after the algal bloom incident) by eight research trained postgraduate students under the supervision of two university professors. The simple random sampling method was used to determine the sample size according to the total population of Wuxi city in 2009. The required sample size was calculated using the following equation:

[2] A copy of questionnaires is available from the authors upon request.

$$S = \frac{H \cdot t^2 \cdot p(1-p)}{\Delta p^2 + t^2 p(1-p)} \quad (7)$$

where S is the required sample size of the total population (H) of Wuxi city, t is the value of the given confidence coefficient, p is the sample ratio, Δp^2 is the average deviation of sampling (Hu and Sun 2000). In this study, *H* is 6,195,700 according to the 2009 Year Book of Wuxi city, the confidence coefficient is given as 95%, thus t=1.96, p and Δp are 0.5 and 5%, respectively. Accordingly, the calculated required sample size for the survey was 384, but to increase its effectiveness for the research the final sample size was augmented to 800. The sample was not normalised according to age, education, income and gender to be representative of the Wuxi population as this would have been impossible to achieve with face-to-face interviews.

3.5. Research results

The 800 questionnaires were administered by the researchers to local residents and 630 were completed with valid and useful information. This high response rate, namely 78.75%, was obtained by opting to have the questionnaires administered by researchers as opposed to being self-administered. The opportunity to collect valuable first-hand information for an unexplored yet significant issue for Wuxi justified the extra resources that were put in collecting the data.

The categorisation of the participants according to gender, average income, age and educational attainment are shown in Fig. 2. They are not representative of the total Wuxi population. There were relatively more women in the sample than the Wuxi City's share of 48% (Statistical Bureau of Wuxi City 2010). The sample also has higher educational level than the statistical averages. For example, the share of people with university and higher education in Wuxi is only 12.9% compared to the 40% in the sample. Overall, the participants in the study are relatively well educated with at least 66% having studied further than high school level. This means that it can be expected the awareness of the sample to be higher than the average for Wuxi residents.

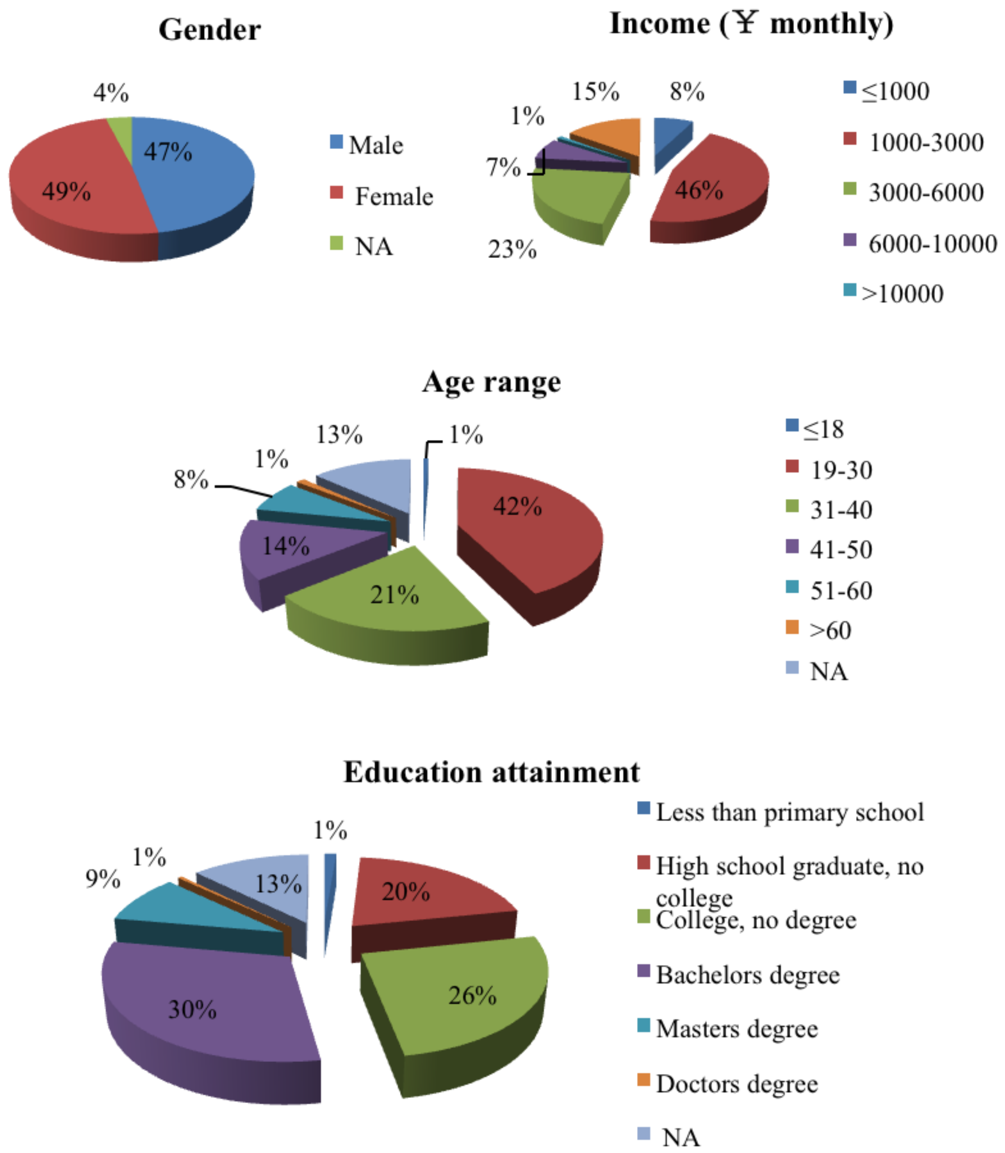


Fig. 2 Demographic overview of the survey participants

The average awareness scores, according to the survey of residents in Wuxi city for the 14 indicators of PEA assessment in the three different periods are shown in Table 4.

Using the assessment criteria and corresponding descriptions (see Table 2) combined with the weights and average scores for each indicator, Table 5 presents the results from the values of the correlation function K (see equations 4 and 5). It shows that the degree of PEA in Wuxi has grown between 2007 and 2010. The PEA was at a low level prior to the algae bloom incident but increased in 2007 and in 2010 reached a medium to good level. Specifically, the maximum correlation function value of the indicators is -0.146 in the period prior to the algal incident which belongs to Class I (bad) and is at a 0.129 distance from the smaller correlation function value of -0.275 which can be ranked as Class II (medium).

Table 4 Average value scores of residents for 14 indicators of PEA assessment

	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}	C_{11}	C_{12}	C_{13}	C_{14}
x_{before}	1.748	1.765	1.110	1.990	1.780	2.087	1.267	1.107	1.310	1.395	1.805	2.045	2.135	1.092
x_{during}	2.303	1.851	1.095	2.005	2.084	2.024	1.511	1.146	1.442	1.435	1.675	2.245	2.290	1.259
x_{after}	2.298	2.013	1.946	2.079	2.121	2.263	1.662	1.761	1.421	1.295	2.210	1.974	2.304	1.569

Table 5 Correlation values and assessment results of PEA in Wuxi

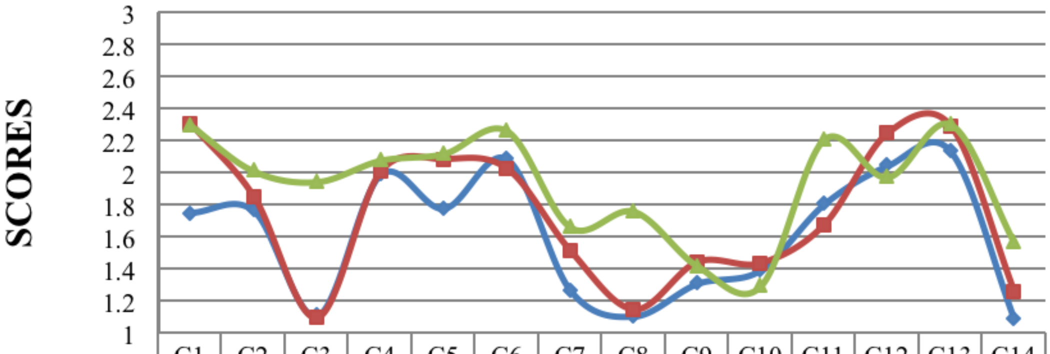
Correlation Function Values $K_j(N_x)$	Classifications/ Ranks (*j*)				j_0
	Bad (Class I)	Medium (Class II)	Good (Class III)	Excellent (Class IV)	
K_{before}	**-0.146**	-0.275	-0.393	-0.595	Class I
K_{during}	**-0.190**	-0.222	-0.310	-0.534	Class I
K_{after}	-0.265	**-0.123**	-0.193	-0.468	Class II

Note: The maximum values are presented in bold (equation 6).

During the period of the algal incident, the maximum correlation function value for the assessment indicators for the level of PEA is -0.190 which belongs to Class I. However the level of PEA at this stage was higher than that in the period before the incident and the gap between Class I and Class II has narrowed from 0.129 to 0.032 which means that the degree of PEA during the incident went up by 0.097. After the algal incident, at the time of the survey, the rank of PEA in Wuxi has increased from Class I to Class II, and the correlation function value of rank is -0.123. In addition, the rank of PEA in this period is closer to Class III (good), and the gap between Class II and Class III is only 0.070.

The results for the 14 individual indicators are presented in Fig. 3. With the exception of three indicators (C_6, C_{11} and C_{12}), all values prior to the algae bloom incident were not higher than during and afterwards. The most significant increases in awareness after the incident showed in relation to familiarity with reporting environmental concerns (C_3) and attitudes to garbage sorting (C_8). The highest level of awareness was recorded during and after the incident in relation to general familiarity with surrounding environmental problems (C_1) and willingness to participate in green consumerism (C_{13}). People's views about water recycling (C_{10}) and environmental protection responsibility (C_{12}) are the only indicators whose values have diminished compared to the time prior the algae bloom incident.

Being the first study of this nature, the aim was to record changes in public awareness. At this stage it is difficult to extrapolate the findings as significant across the entire Wuxi population. The main reasons for this are: (1) the sample's structure is not typical for Wuxi's population because of higher educational levels; (2) the methodology used is not a statistical analysis (aimed at testing distributions and significance) but a fuzzy mathematical model to quantify subjective attitudes; (3) the correlation function K used in the model indicates the “distance” from the current level of awareness to the next level up (or down). Nevertheless, the findings are important as they provide clear indication as to what changes occurred around the incident and how the selected sample of people reacted to them. This can inform policy-making. More explanation and discussion about the research findings are presented in the section to follow.



	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14
before	1.748	1.765	1.11	1.99	1.78	2.087	1.267	1.107	1.31	1.395	1.805	2.045	2.135	1.092
during	2.303	1.851	1.095	2.005	2.084	2.024	1.511	1.146	1.442	1.435	1.675	2.245	2.29	1.259
after	2.298	2.013	1.946	2.079	2.121	2.263	1.662	1.761	1.421	1.295	2.21	1.974	2.304	1.569

Fig. 3 Indicator scores

3.6. Discussion

Times of environmental accidents, including chemical and nuclear pollution, are not only highly complex and challenging to address, but they also have serious psychological effects on people (Becker 1997). Many reassess their value system, beliefs and actions in order to be better prepared or avoid the hardship caused by such events. The algae bloom incident was a serious water contamination situation that triggered such reassessment in people’s attitude towards the environment. It is interesting to examine what occurred during and after the incident.

• *During the incident*, ten of the 14 indicators went up. This is not an unexpected behaviour as people were experiencing first hand the consequences from the deterioration of the local ecosystem (Hannigan 2002), the freshwater basin in this case. The problem was real and not a possible scenario created by scientists, politicians or environmental activists. According to Grob (1995), the strongest effect on environmental behaviour comes from personal-philosophical emotions and values and the time of the incident generated ample opportunities for this. Two PEA indicators, namely degree of familiarity with ways of reporting environmental concerns (C_3) and basic environmental knowledge (C_4), remained almost unchanged during the algae bloom. The explanation about the lack of change is probably connected to the fact that the incident was so obvious that there was no need to learn anything more in order to comprehend what was happening or to report the perpetrators. Most importantly, however, the PEA associated with the reporting of environmental concerns (C_3) was the indicator which overall increased the most after the algae bloom incident. Finally, the two indicators which went down during the bloom, were awareness of water recycling (C_6), and views about environmental degradation (C_{11}). Confusion as to what people should do at the time of the water crisis explains the decrease in C_6 – they were short of water and there was also fear of using poor quality water. A major factor for C_{11} was the disagreement among policy makers and experts as to whether the incident was natural or whether it was the result of human activities. The mixed messages were also reinforced by the media making the situation even more complex (Becker 1997).

• Three of the PEA indicators (C_9, C_{10} and C_{12}) have *gone down compared to their pre-incident levels*. This may on the surface contradict the intuitive perception that people would become more environmentally aware after experiencing the inconvenience of water shortages. However these lower PEA levels can easily be understood within the context of who was responsible for the incident. According to Erikson (1994), human-made disasters are considered preventable and there is always a share of blame that goes to any stakeholders or people involved. It is not a surprise then that after the incident, the Wuxi participants perceived that government and companies should be more responsible about environmental performance (C_{12}). Personal behaviour, such as saving water and reducing wastewater discharge (C_{10}), or willingness to pay to avoid contamination (C_9), were also seen less important on the scale of the large contamination triggered by “other” people’s behaviour, including pollution from industry and agriculture.

• The majority of the PEA indicators, namely 11 have *gone up or remained about the same compared to the pre-incident levels* (8 and 3 respectively). This shows that people have become more willing to get involved in environmental protection and have started to be more concerned about the environment after the Taihu Lake incident. The mass media channels play a significant role in shaping public perception about environmental problems (McCombs and Shaw 1972; Mikami et al. 2000; Smith 2000; Hannigan 2002) and in this case the media were very active in portraying the event and its implications. By maintaining a focus on the importance of the ecology for human and planetary health, the media also play an educational role and have “a mammoth responsibility” (Chapman 2000:127). A Google search about environmental activities involving the community in Wuxi, conducted by us, shows that the volume of such news has steadily increased by 3% per annum between 2005 and 2010 (to reach 2.36 million in 2010). This has contributed in shaping people’s awareness. Despite this, the overall levels of PEA are still low and further education and motivation are required for the environment to become a way of thinking and acting for Wuxi residents. Exposure to better formal environmental education at school and university as well as industry training and the work of NGOs can all contribute for a better community engagement with the environmental agenda.

The above analysis shows that the overall degree of PEA in Wuxi after the environmental incident is higher and has significantly increased (by one level) during and after the incident. Nevertheless, there is still a lot of room for improvement and people's environmental awareness needs to continue to be encouraged. An area of further inquiry will be how to bridge the gap between this increased awareness and real behaviours.

3.7. Recommendations for PEA improvement

The assessment results in this study suggest that the 2007 algal incident in Taihu Lake brought significant positive impacts on PEA in Wuxi. This event acted as a wake-up call to many residents but a lot of confusion and uncertainty still remains. Despite the increase, the overall level of environmental awareness in Wuxi is still relatively low at a medium level (Class II), with a lot more work required for it to reach Class IV (excellent). As the sample used in this study had a considerably higher level of education than the statistical average for the Wuxi residents, the assessment we conducted may in fact had been biased towards higher PEA estimates. This makes the need for policy changes even more pronounced. To further raise and maintain a high PEA, more effective measures should be put in place for the short and in the long term.

Firstly, there is a need to increase environmental education in schools and across all university courses, including those offered by Jiangnan University, Wuxi University of Light Industry and Wuxi Nanyang Vocational and Technical College. For example, Jiangnan University currently offers several courses that are specifically related to environmental technologies and environmental engineering, but a sustainability approach (which integrates environmental, social and economic aspects) should permeate any of its courses. This should apply to business, engineering, communications as well as food related courses. With China's increasing role as a global player in the business world should also come an increasing responsibility in the environmental sphere.

Similarly, primary and secondary school education should contribute towards building a proper knowledge and understanding of the ecology together with the human-made world. The Taihu Lake incident can be used as an example of how things can go wrong. This study showed that the impact of the algae bloom on the freshwater supply affected public environmental awareness but similar results could be achieved through pedagogical means without the first-hand experience. The harmfulness of environmental incidents and their link with people's behaviour can be emphasised during educational activities allowing for public perceptual and rational knowledge about the environment to gradually be reinforced. Children and adolescents can also influence the attitudes and behaviour of their parents, other relatives and friends. The use of local examples and local evidence is a powerful way to make people engage with and care about their city and the ecological systems that allow for it to function as a human habitat.

Secondly, environmental non-government organisations (eNGOs) as well as other grassroots organisations can mobilise their efforts in igniting social intolerance towards such serious environmental incidents. Environmental NGOs have been very active in spreading environmental knowledge across China (Hong et al. 2006), but they should also be making greater efforts to propagandise the serious impacts of environmental incidents. They can command attention and alarm individuals through vivid scenes using pictures, photos and videos in the mass media and on the web. In addition to putting pressure on government and legislators, citizen participation in environmental decision-making (e.g. through citizens' juries) can be encouraged through their work. For example, it would be very interesting to see the outcomes from a citizens' jury about the Taihu incident, including responsibilities, role of the media, legislative and other changes.

Grassroots organisations in general are seen as a separate vehicle in environmental change that embraces the principles of environmental equity and demands environmental justice for everyone. They are less prepared to collaborate with industry and government (Silveira 2001) and are usually at the forefront of shaping the environmental agenda through voicing concerns, dissatisfaction, anger and a commitment to independent processes. In the past, many of these activists were seen as dissidents and political enemies but times have changed. With the opening of China's economy, there is a distinctive role for grassroots organisations to make industry and government accountable for serious accidents, such as the Taihu Lake's algae bloom and confirm the right of the public to know and have local input in the decision-making processes.

Thirdly, all levels of government should set up long-term incentive systems for improving PEA. A sound mechanism needs to be supported by efficient and effective policies, including an incentive policy to raise PEA and encourage people's pro-environmental behaviours. Four steps can facilitate such a process: (1) establish relevant regulations, including incentive measures and corresponding criteria for those who have pro-environmental behaviour; (2) establish a government incentives fund for environmental activists in particular areas; (3) establish a regular incentive timeframe; and (4) publicise the list of incentive holders via the mass media. The list of incentive holders is expected to be organisations and individuals who have significantly contributed towards a change in environmental awareness, behaviour and practices. They will also be potential case studies for further research, educational and publicising materials.

Fourthly, the authorities in China should allow for the public to participate in environmental activities, including grassroots organisations. Such public participation would lead to a decreasing number of people holding negative attitudes towards environmental protection. When people find that the external conditions encourage environmentally friendly behaviour, this is likely to have a psychological impact on them and they are more likely to adopt such attitudes (Ajzen 1991).

Accordingly, governments are responsible to provide the public more convenient ways and access to participate in environmental conservation. First of all, access to environmental information should be provided to the public quickly and accurately in the form of, for instance, reports, books or albums, through government agencies or other organisations. Providing the public with access to environmental information can encourage participation in environmental protection (Li et al. 2008). What is more, various means of participation in environmental protection need to be developed for individuals. For example, governments can build blogs linked to their official website where environmental information could be made available for the public, including facilities to make complaints and suggestions about environmental issues. In addition, the role of environmental NGOs and grassroots organisations should be facilitated through supporting policies and allocation of more funds.

4. Conclusions

Public environmental awareness is a powerful force in enabling work for ecological restoration and protection. The levels and influencing factors of PEA differ among the various regions of China. In this study, a mathematical model for assessing PEA was explored and used to quantitatively evaluate public environmental awareness in a typical urban area in China affected by a serious environmental problem. The main findings of our study are summarised below.

(1) The fuzzy matter-element method was introduced to establish a model for the assessment. It was found that the correlation function of the model is capable of resolving the fuzzy problems of ranking and classification for the subjectively assessed matter such as PEA.

(2) It was found that a major environmental incident, such as the blue-green algae bloom in Taihu Lake, had significant impacts on PEA, and the experience obtained from the incident can be a key factor for PEA improvement.

(3) Recommendations were made to raise PEA, including the use of such serious incidents as counter examples in all levels of education, the encouragement of grassroots involvement in setting up the environmental agenda, the establishment of long-term incentive government systems, and the offering of convenient and reliable access to information with opportunities for people to participate in environmental activities and decision-making.

Due to the complexity of the public awareness phenomenon, this study only provided a snapshot of Wuxi in relation to the algae bloom incident. The new methodology can allow for further research to be conducted using long-term observations, series data, representative samples and statistical correlations. It is clear that the better we understand the factors influencing PEA, the more likely are we able to formulate effective policy interventions.

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