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Research on Recognition Method of Algae Blooms Based on Complex Network

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Abstract: Based on the deep analysis of the formation process of algal blooms for the urban lakes and rivers, some key factors affecting the formation of algal blooms have been extracted. Furthermore, a recognition model of algae outbreak has been established based on the complex network to calculate the related parameters of the characters towards the complex network which is the way to achieve the recognition of the phenomenon mentioned above. By means of the experiment on the water quality in the urban lakes of Beijing, this method has been proved to be correct and efficient which provides the reference for the deeper research of the formation mechanism of algal blooms.

Key words: Complex network, algal blooms, blooms recognition

INTRODUCTION

With the rapid development of modern industrial process, the eutrophication of inland water bodies has become more and more serious. The water with eutrophication can easily outbreak under the suitable condition which brings a serious impact on ecological structure of water environment and the development of economy and society (Cui *et al*., 2009). Therefore, to analyze the formation mechanism of algal blooms is one of ways to provide reliable basis for the relevant departments to take timely and effective decision-making.

Water eutrophication models has achieved a large development both in theory and practice aspects through decades of development and a number of eutrophication models has been established on different levels (Pettersson *et al*., 2001). Among them, Jia HF etc has referenced the WASP model of water quality and the CAEDYM model of ecology and established algae ecological dynamics model (Jia *et al*., 2009) which described the dynamic relationship between four sub-systems that are phytoplankton, nitrogen, phosphorus and dissolved oxygen. And the model has been validated by the data of water quality monitoring of Beijing which shows that the model can well simulate the algal growth situation in urban river system. Chau has used the optimized PSO for training-perceptron model (Chau, 2005) which is based on several-input hydrodynamic parameters and water quality parameters that can forecast the red tide in Tolo Harbour in real time and the result is satisfying. Dong Shuoqi etc has proposed an idea that to build the model of blooms formation mechanism by means of intelligent simulation techniques based on Agent (Dong *et al*., 2012). The key factors which will result in the blooms outbreak have been confirmed via the experiment. And the relationship between key factors and algal changing has been analyzed which is an effective analysis towards algal growth trend, energy flow and the state of material flow.

The water with algal blooms is an opening complex system that the relationship between nutrients and between nutrients and the external environment and geological conditions during the algal blooms cannot be described accurately and more quantifiably by means of current research methods and techniques (Lee *et al*., 2003). The model in real life can be described into visible one by the complex network and the visible results can be obtained through the mathematical operation so that using complex networks to establish algal-blooms recognition model is becoming a research hotspot. The main influential factors of algal blooms have been used as a starting point in this article in order to establish a directed complex network model of algal blooms. The statistical characteristic function G has been established by calculating the statistical properties of complex networks and the semi-quantitative classification of G have been made to determine the degree of contamination of algal blooms.

COMPLEX NETWORK MODELING OF THE FORMATION OF RIVERS AND LAKES ALGAL BLOOMS

Complex networks built of algal bloom identified: The water bodies of the rivers and lakes can be seen as a complex network and the main factors of algal blooms

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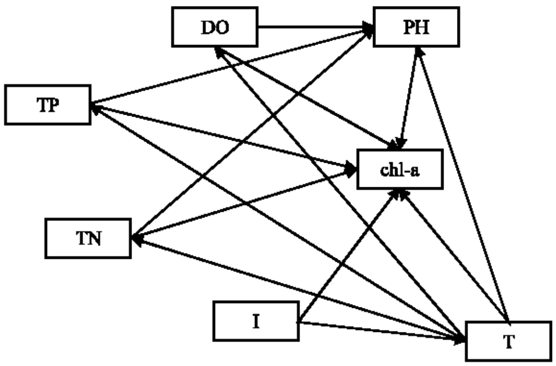

Fig. 1: The complex network structure of the recognition in the outbreak of lakes and rivers

could be acted as a point in the network which constitute a point set of the network namely V(V = $\{v_1, v_2,..., v_n\}$). The affective relationship between the key factors is a side forming a side set namely E(E = $\{e_1, e_2,..., e_n\}$). The algal blooms properties are shown by the diagram G = (V, E) composed of V and E. Where the number of nodes is denoted by n = |V|, the number of edges is denoted by m = |E| and all the sides of E have two nodes of V to correspond to at the same time (Zaiwen *et al*., 2008). According to the features of formation mechanism of city rivers, the factors including total nitrogen, total phosphorus, temperature, pH, dissolved oxygen, illumination and chl_a formed a point set V while the interactive relationship among the influencing factor formed the frontier set E,of which the node number n = 7 and the sides m = 14. The directed network model of algal-blooms outbreak based on complex network can be watched in Fig. 1.

The analysis in correlation among the influential factors and the calculation in node distance: The analysis in correlation is to analyze the related degree in various influential factors so that it is convenient to acquire the relationship between the factors and formation of algal blooms. In order to obtain the degree among the factors, the data in practical water have been analyzed in experimental environment. The results can be watched in Table 1.

The correlation index between temperature and chl_a is 0.867 indicating that the content of chl_a in the water is largely influenced by temperature compared to the illumination, so is the dissolved oxygen and pH while the content of chl_a in the water is largely influenced by them. At the same time, N, P and illumination have certain influence towards chl_a as well. But the impact by illumination is relatively weak which is completely conformed to the real situation.

Table 1: The analysis in correlation among the influential factors

	T	TP	PH	DO	I	TN	chl_a
T	1	0.302	0.733	0.749	0.163	0.445	0.867
TP		1	0.371	0	0	0	0.322
PH			1	0.909	0	0.781	0.765
DO				1	0	0	0.708
I					1	0	0.173
TN						1	0.592
chl_a							1

Table 2: The shortest distance of the complex network sides in recognition of algal-blooms outbreak

	T	TP	PH	DO	I	TN	chl_a
T	0	10.1701	5.8104	5.6862	11.6927	7.6015	4.9123
TP	10.1701	0	4.5633	∞	∞	∞	5.2578
PH	508104	4.5633	0	3.8009	∞	4.4238	4.5163
DO	5.6862	∞	3.8009	0	∞	∞	2.4124
I	11.6927	∞	∞	∞	0	∞	6.7803
TN	7.6015	∞	4.4238	∞	∞	0	2.6892
chl_a	4.9123	5.2578	4.5163	2.4124	6.7803	2.6892	0

Table 3: The shortest distance of the complex network nodes in recognition of bloom outbreak

	T	TP	PH	DO	I	TN	chl_a
T	1	2	3	4	-	6	7
TP	-	2	3	-	-	-	7
PH	-	-	3	-	-	-	7
DO	-	-	3	4	-	-	7
I	1	1	1	1	5	1	7
TN	-	-	3	-	-	6	7
chl_a	-	-	-	-	-	-	7

The correlation index obtained from Table 1 is r_{ij} while the distance between nodes and sides is w_{ij}(i, j = 1,2...7, n = 7). Then the shortest distance of the complex network sides can be calculated by Floyd-arithmetic namely (Tsai *et al*., 2004):

$$w_{ij} = \sum_{i,j=1}^{n} r_{ij} \Big/ r_{ij} \; (i, j = 1, 2.....7, n = 7) \qquad (1)$$

The results of the shortest distance of the complex network sides and nodes in Table 2 and 3.

The results indicate that the sides' distance between T and PH, T and chl_a, T and DO as well as pH and TN, DO is smaller than that among other influential factors showing that this complex network is easier to reach the shortest distance by means of the transfer way mentioned above. That is to say, the interaction among the elements mentioned above is easy to make the eutrophication induced. The "∞" and "0" in the complex network sides represent that there is no interaction between these two nodes.

Under the certain condition, the influential factors including T, TP, PH, DO, I, TN can reach the node 7(chl_a) without the help of other factors, that is to say, it could have the influence on the formation of algal blooms directly.

Table 4: Various parameters of complex network in the water outbreak

	Node degree					
Influential factors	λ_i^+	λ_i^-	sum	d_{min}	B_i	σ
T	5.00	1.00	6.00	4.9123	2.00	2.442848
TP	2.00	1.00	3.00	5.2578	2.00	1.141162
PH	1.00	4.00	5.00	4.5163	5.00	5.535505
DO	2.00	1.00	3.00	2.4124	2.00	2.48715
I	2.00	0.00	2.00	6.7803	1.00	0.294972
TN	2.00	1.00	3.00	2.6892	2.00	2.231147

The establishment of statistical characteristic parameters in the outbreak: In order to better reflect the effect of each node in complex network, the criticality model of the node is:

$$\sigma = \left(\lambda_i^+ + \lambda_i^-\right) \times B_i / d_{min} \quad (2)$$

where, d_{min} is the shortest distance between node v_i and chl_a; λ_i^+ and λ_i^-, respectively represent the in-degree and out-degree of related node where the node degree is the sum of the in-degree and out-degree. The larger the node degree is, the more important it is in the whole network; B_i shows the node betweenness of v_i indicating the impact and effect of related nodes in the whole network (Lin, 1965). The larger the node betweenness is, the more it is crossed showing its more powerful effect on outbreak of algal blooms.

To analyze the various parameters in complex network combined with the real data, the result can be watched in Table 4.

What we could get from Table 4 is that the extent by various influential factors in water outbreak is not the same. And the recognition model can be established:

$$G = 10 \times \exp((\sigma_1^{'} + \sigma_2^{'} + \sigma_3^{'} + \sigma_4^{'} + \sigma_5^{'} + \sigma_6^{'})/6) \quad (3)$$

where, G is the statistical characteristic function of algal-blooms outbreak; σ_i' represents the product of node v_i and its specific parameter value namely $\sigma_i' = c_i \times \sigma_i$.

THE VERIFICATION OF STATISTICAL CHARACTERISTIC PARAMETERS IN THE OUTBREAK

In order to verify the effectiveness of the parameters G, the data of lakes and rivers of Beijing are adopted to calculate which has been compared with chl_a. The result can be watched in Fig. 2.

What we could get from Fig. 2 is that the statistical characteristic parameter G has pronounced correlation with chl_a as its correlation index is 0.935. A conclusion can be made that the outbreak occurs when the density of chl_a is over 40ug L^{-1} according to the feature of Beijing water bodies and substantial experimental data (Wang *et al*., 2012). The corresponding G is 84.4579 when the density of chl_a is 40 ug L^{-1} according to the experimental result while the value of G fluctuates between 40 and 80 when the density of chl_a is between 20 ug L^{-1} and ug L^{-1}. Furthermore, the value of G is less than 40 when the density of chl_a is less than 20 ug L^{-1}. The conclusion can be made in Table 5.

Table 5: The statistical characteristic parameters G and the result about identification of algal-blooms outbreak

G value	Algae growth stage	Density of chl_a	recognition of bloom outbreak
≤40	adaptive phase	Less than 20 μg L^{-1}	Small possibility for outbreak
40~80	budding stage	20 μg L^{-1}~40 μg L^{-1}	The trend of the bloom outbreak
≥80	Eruption phase	More than 40 μg L^{-1}	Easy to outbreak

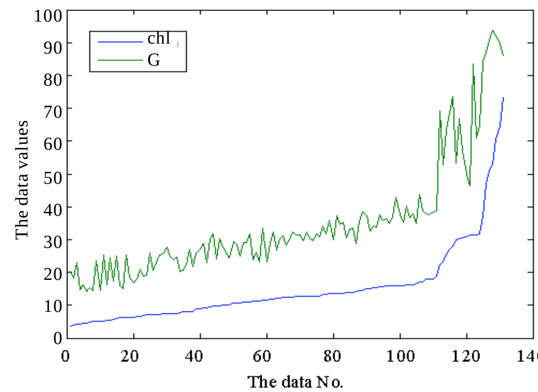

Fig. 2: The comparison between the statistical characteristic parameters G and chl_a

Therefore, we could effectively analyze the features of bloom outbreak by means of the statistical characteristic parameters G so that it could provide an effective reference basis for decisions.

CONCLUSION

On the basis of analyzing the water characteristic of the urban lakes and rivers, a recognition model of algal-blooms outbreak based on the complex network has been established. Combined with the feature of algal-blooms formation mechanism, the key parameters in the model have been analyzed and the data have been verified through the experimental means which indicates that the effective recognition can be reached by means of watching the statistical characteristic parameters G. Due to the complicated process of bloom outbreak, the conclusion in this article is just a preliminary and theoretical discussion which can provide an effective way for further research about the formation mechanism of algal blooms.

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