Early Warning and Source Identification System Design for Chemical Spill Incidents of Jinhua River

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Abstract. The key factor in solving frequent chemical spill accidents is how to identify the pollution source information such as discharge location, discharge time and discharge amount or discharge rate, that caused the accident as soon as possible. Furthermore, the diffusion process of pollution accidents is simulated and predicted. Based on the proposed warning model and source identification method, an early warning and identification system for river chemical spill incidences in Jinhua River was designed and developed after collecting the geographic scope of the rivers and the national and provincial monitoring sections of Jinhua River. The system is used to simulate and predict diffusion process of pollution mass, and identify the unknown pollution source information that occurred in the Jinhua River. The early warning and identification system has been applied to the Jinhua River. The results show that the system has higher reliability, and it can provide an intuitive and scientific basis for relevant departments to respond to water pollution accidents and help them to handle pollution accidents quickly, reasonably and economically.

1. Introduction

The sudden water pollution incidents are an important factor for the decline of water resources quality and availability. Statistical data show that there were 561 sudden water pollution incidents in China from 2012 to 2017, accounting for 94.8% of the total environmental pollution incidents. Therefore, for the prevention and control of incidents, the key problem is how to obtain the relevant information of pollution source causing accidents in the shortest time. Then by simulating and predicting the diffusion process of pollution mass, corresponding control measures can be taken. The early warning for chemical spill accident is usually to simulate and predict the influence of water quality downstream of the accident through the water quality-hydrodynamic model, so as to achieve the purpose of early warning [1]. In recent decades, many scholars at home and abroad have made some achievements in studying the source identification of unknown chemical spill events [2,3]. Most of these studies focus on the idea of deterministic and uncertain methods to discuss the source identification of sudden water pollution incidents in rivers. Deterministic theoretical methods include direct solution method and heuristic optimization method. Direct solution method refers to a method that takes parameters as dependent variables, uses derivative information in space and time domain, and applies backward calculation method based on water quality-hydrodynamic model to get pollution source information. For example, based on the fractional anomalous convection-diffusion equation of multi-point sources, Wei [4] uses the coupling method of optimal perturbation regulararization to trace the source of pollution. Stochastic method is often used in uncertainty theory. Stochastic methods use probability distribution function to describe the randomness of objective accidents, including statistical induction [5], Bayesian inference method [6-7] and minimum relative entropy (MRE) [8-10]. In this paper, an
early warning and source identification system for chemical spill incidents of Jinhua River is designed. The system can not only realize the early warning downstream of the chemical spill accident, but also identify the information of the unknown accident such as discharge location, discharge time and discharge amount. This study can provide decision-making basis for scientific and effective response to various water pollution accidents.

2. Design and Implementation of Early Warning System for Jinhua River

2.1. overall design of early warning system
The overall design idea of the early warning system is shown in Figure 1. Because the number of fixed monitoring stations in the national and provincial control sections is not enough to comprehensively monitor the real-time water quality and hydrological data, this system arranges a certain number of mobile monitoring points as supplements according to the characteristics of different water environments within the region. The mobile monitoring devices and the fixed monitoring stations can obtain the water quality and hydrological data in real time, and the data are transferred to the database of the cloud server by transmission chips provided by the equipment. When the early warning system needs to be run, the real-time hydrological data in the database is imported, and the background early warning calculation program can be called to simulate and predict the impact of chemical spill on water quality. The early warning system realizes the early warning function through the changing diffusion process diagram of pollutant concentration at the selected national and provincial control sections. The time and multiple of water quality exceeding the standard are counted at the same time. The early warning system applies the concepts of "static + dynamic" and "monitoring + early warning" to water quality monitoring, which can realize strict monitoring and scientific management of regional water environment.

2.2. Design of early warning system program module
Based on the two-dimensional convection-diffusion analytical model and the overall design idea of the early warning system, the input module and output module of the early warning system are divided to facilitate the program module design. The division of input and output of early warning system is shown in Figure 2.

2.2.1. input module
(1) input module of hydrological parameter. In the two-dimensional advection-diffusion model for instantaneous pollution source such as chemical spill incident, hydrological input parameters include \( u \) (longitudinal flow velocity (m/s)), \( v \) (lateral flow velocity (m/s)), \( k \) (the degradation coefficient (s\(^{-1}\))), \( C_0 \) (background concentration (mg/L)), \( D_x \) (longitudinal dispersion coefficients (m\(^2\)/s)), \( D_y \) (latitudinal dispersion coefficients (m\(^2\)/s)), \( h \) (water depth (m)). These hydrological parameters are actually measured by the fixed and mobile monitoring stations in the hardware system and are uploaded to the cloud database through sensors and network. Therefore, the hydrological input parameter module is designed to extract hydrological parameters from the database and import them into the early warning system for subsequent calculation.

(2) input module of pollutant information. The pollutant discharge amount \( M \) (instantaneous load of the pollutant source (t)), and the discharge time \( t \) are determined by the data input from the early warning system. The time step and the simulation duration of early warning determine the output of pollutant concentration information and the time range of the whole early warning every certain time. So, the pollutant information is input from the front end of the system and is transferred into the early warning system by the input module of pollutant information.
(3) calculation module of the distance \( x, y \). \( x \) is the distance along the channel (m). \( y \) is the distance along the cross-section (m). The distance \((x, y)\) from the calculation point to the pollution source should be obtained in two-dimensional convection-diffusion analytical model besides hydrological parameters. In reality, the Jinhua River is winding and accompanied by tributaries, and the river geographic information and section position are input as longitude and latitude format, which add a lot of difficulties to calculate the \( x \) and \( y \). To solve the above problem, ArcGIS software is used to obtain Jinhua River geographic information. Finally, 3014 geographical coordinate points (longitude and latitude format) are used to describe the whole river range. Every two geographical coordinate points are a pair, and their connecting line of each pair of geographical coordinate points is perpendicular to both banks of the river, forming 1507 self-divided sections. Therefore, a river is composed of many short sections based on self-dividing cross-section, and each section is approximately straight. In order
to calculate the pollutant concentration of the whole river more accurately, each self-dividing section is equally divided into 7 calculation points along the cross-section, totalling 10,549 river calculation points.

(4) input module of river section. In the early warning analysis, the system needs to realize the early warning function through the changing diffusion process diagram of pollutant concentration, the time and multiple of water quality exceeding the standard at the selected national and provincial control sections. Therefore, it is necessary to import the section location and target water quality information of Jinhua River into the early warning program in advance, so as to judge the time and multiple of pollutants exceeding the standard.

2.2.2. output module
(1) calculation module of \( C(x, y, t) \). \( C(x, y, t) \) is the pollutant concentration at the point \((x, y, t)\) (mg/L). The formula of \( C(x, y, t) \) is

\[
C(x, y, t) = \frac{M}{4\pi D t} \exp \left( \frac{-(x-vt)^2}{4Dt} \right) \exp \left( \frac{-(y-vt)^2}{4Dt} \right) \exp(-kt) + C_0
\]

The meaning of the variables in the formula is shown in 2.2.1.

(2) calculation module of time and multiples of pollutant concentration exceeding standard. In order to play an early warning role, the time and multiple of water quality exceeding the standard are counted at the selected national and provincial control sections.

2.2.3. Implementation steps of early warning system are as follows:
- Step 1: obtain the information of pollutant discharge amount, discharge position and discharge time from input module.
- Step 2: find the section and the river where the pollution source belongs according to the principle of shortest distance. And the information of pollutant flow direction is obtained through supporting documents.
- Step 3: after obtaining the information of pollutant flow direction, the sections located at the upstream of the pollution source are determined as a non-calculated section. Their pollutant concentration is equal to the background value. The sections located downstream of the pollution source are as the calculated sections.
- Step 4: the distance from the calculation point of each river to the pollution source is obtained by accumulating the distances from all the sections between the calculation points and the pollution source.
- Step 5: obtain the hydrological parameter information, the time step and the simulation duration from input module. The diffusion process of pollutant concentration within the simulation time range is calculated by two-dimensional instantaneous source early warning model.
- Step 6: According to the water quality standards of the selected national control and provincial control analysis sections, calculate the time and multiple of water quality exceeding the standard.
- Step 7: Feedback the above calculation results and display them as visual results.

3. Design of pollution source identification system of the Jinhua River

3.1. Overall design of pollution source identification system
The overall design idea of source identification system is shown in Figure 3. Based on the monitoring data from the fixed and mobile monitoring points and the geographic information of Jinhua River, the discharge location, discharge time, discharge amount of the pollution source are calculated by calling pollution source identification program. The pollution source identification system can provide scientific basis for quickly dealing with unknown chemical spill incidents.
The pollution source identification system includes hydrological parameter input module, $x$ and $y$ backward calculation module, pollutant monitoring data input module from emergency monitoring network, and output module of system identification results. Because the discharge position obtained by the source identification algorithm is initially a distance value in meters, the distance in meters needs to be transformed into distance in latitude and longitude by the $x$ and $y$ backward calculation module, and the transformed results needed to be transmitted to front end of the system. The principle of $x$, $y$ backward calculation module is as follows: in the early warning program module, Jinhua River has been divided into nearly straight rivers by 1507 self-dividing sections, and the distance calculation program between rivers has been designed.

3.2. Design of Program Module of Pollution Source Identification System for Instantaneous Incidents

Implementation steps of the source identification method of river chemical spill incidents based on the two-dimensional advection-diffusion-reaction equations are as follows.

- Once the pollutant concentration of a fixed monitoring point of the river exceeds the standard, the system issues alarm signal.
- The mobile monitoring points are arranged around the fixed monitoring points in time to form an emergency monitoring network, and the pollutant concentration is obtained from network by source identification steps.
- The monitoring data from the emergency monitoring network are imported into the two-dimensional pollution source identification algorithm, and the discharge location, discharge time, discharge amount or discharge rate are obtained.
- The distance between the fixed monitoring point and the pollution source is calculated by using $x$ and $y$ backward calculation module, and the converted location information of the pollution source is obtained.
- The above calculation results are fed back to front end of the system to visualize.

4. Conclusions

At present, China's water resources situation is grim, and chemical spill incidents and illegal sewage discharge often occur. This makes it increasingly urgent for relevant departments to grasp the information of pollution sources at the first time, and then to simulate and predict the diffusion process of pollution accidents. Under this background, this paper designs and develops an early warning and source identification system for sudden water pollution accidents in Jinhua River, which realizes early warning and rapid source identification of water quality for sudden water pollution accidents. The
system has been well applied in Jinhua River and has high reliability. It can provide intuitive and scientific basis for relevant departments to deal with water pollution accidents.

Acknowledgments
This research was supported by Zhejiang Provincial Natural Science Foundation of China under Grant No. LGF20E080014, Science and Technology Innovation Program of College Students in Zhejiang Province No.2020R409037.

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