Development of a Risk Rank Model for Environmental Risk Assessment of Abrupt Water Pollution Accidents – with the Case of Laoguan River Basin

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Abstract

In recent years, abrupt water pollution accidents have broken out frequently in watersheds and caused huge environmental and economic losses. These accidents have become one of the most serious environmental problems in China. Abrupt accidents in watersheds involve large scale, multiple sources, multiple stressors and complex risk spread relationships. An appropriate environmental risk assessment method that can solve these problems is needed to protect water quality and the safety of people and property. In this paper, we have adopted a risk rank method in ecological risk assessment and modify it to assess the risk of abrupt water pollution accidents in watersheds, and take a reach of Laoguan River in Xichuan County, Nanyang city as an example. After identifying risk factors and their relationships, the risk rank model is established accordingly, and then risk values are calculated. Finally, the assessment result is displayed and specific risk management decisions are provided.

Keywords: abrupt water pollution accidents, environment risk assessment, risk rank model, Xichuan County

Introduction

Abrupt water pollution accidents are caused by uncertain issues like natural disasters and human factors, which lead to sudden emission of pollutants from stationary or mobile sources into water by various ways. The migration of these pollutants is random and abrupt. In recent years, there have been several abrupt water pollution accidents in China. These accidents have become serious threats to the safety of aquatic environment, and done huge damage to people's health and properties.

Ranking factors is an effective method for describing, comparing and characterizing risks, which has been widely used in ecological risk assessment. In 1997, Landis and Wiegers used a ranking method called relative risk model to do an ecological risk assessment for the ballast water treatment plant for the tankers taking crude oil from the pipeline at Port Valdez (Wiegers et al., 1998). Ten years since then, this method has been used successfully for a variety of freshwater, marine, and terrestrial environments in North America, South America, Australia, and its whole assessing system got rapid development (Obery and Landis, 2002; Landis and Wiegers, 2007; Iannuzzi et al., 2010; Liu et al., 2010; Bartolo et al., 2012; Chen et al., 2012; Kilburn et al., 2012; O'Brien and Wepener, 2012). Risk rank models aim at assessing cases of multiple stressors from multiple sources affecting multiple endpoints in a heterogeneous environment, and are not limited by different units of factors. These distinguishing features make this type of methods a priority for solving problems of abrupt water pollution accidents risk assessment in large scale.

The Laoguan River is an important upstream tributary of Danjiangkou Reservoir system. The reach in Xichuan part is the entrance to Danjiangkou Reservoir, thus has direct and significant impact on the water quality and safety of Danjiangkou Reservoir. By doing risk assessment of abrupt pollution accidents in this reach, we can provide early warning and forecasting for the conveyance safety of Danjiangkou Reservoir, and reduce losses. Also, we can provide guidance for risk reduction means, risk zoning management, and region scale planning.

Method

Processes of the method

Risk rank model is based on a ranking scheme that characterizes the relative importance and impacts of each stressor on various landuse types and their related receptor/response endpoints. A simple depiction of the process is provided in Figure 1.

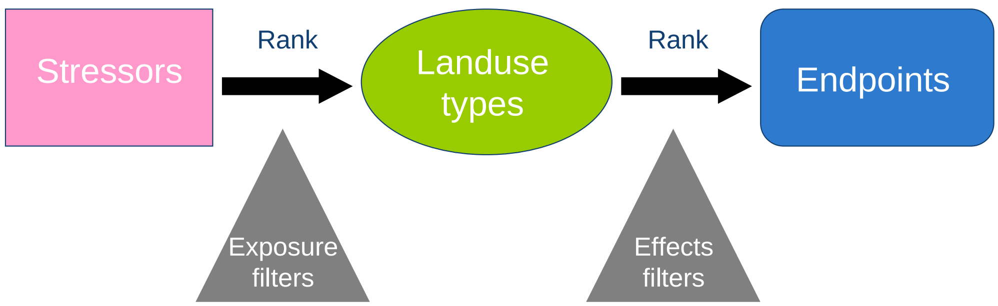

Figure 1. Risk rank model.

The risk impacts was calculated and ranked by quantitatively determining the interactions of the stressors and landuse types. Factors of stressors, related landuse types and endpoints are selected on the basis of the situation of study area and the management goals of decision makers. After analyzing the interactions among factors and determining filters, the preliminary risk rank model would be established. For results calculation, we have learned from the relative risk model. Ranks are assigned based on the characteristics of stressors and landuse types within a given geographic subarea. Filters determine the relationship between stressors, landuse types, and potential impact to assessment endpoints. Filters are numeric weighting criteria used to define the relationship among the risk components and identify how likely a landuse type and stressor are to co-occur (i.e., exposure filter) and how likely they are to cause a certain effect (i.e., effects filter). A filter is typically assigned a weighting factor of ‘‘0’’ or ‘‘1’’ indicating a low or a high probability, respectively. Both stressor and landuse type are assigned a relative rank and then filtered, first to examine the probability of exposure and then, to examine the probability of effect (Liu et al., 2010).

Ranks and weighting factors are combined through multiplication. The product is a relative estimate of risk in a given subarea. Final risk scores (*RS*) are calculated for each subarea by multiplying ranks by the appropriate weighting factor (W_{ij}) as follows (Landis, 2004),

$$RS = \sum S_{ij} \times H_{ik} \times W_{jk}$$

Where i = the subarea series; j = the stressor series; k = the landuse type series; S_{ij} = rank chosen for the stressors between subareas; H_{ik} = rank chosen for the habitats between subareas; and, W_{jk} = weighting factor established by the exposure or effect filter.

Study area

Laoguan River has its origins in Funiu Mountain of Luanchuan County, Henan Province, and enters Xichuan County, Henan Province at Ash swamp, finally joins the Dan River at Madeng Town of Xichuan County, with 1,340 m natural drop. The total river length is 255 km with watershed area of 4,219 km^2 , while the reach and watershed area belonging to Xichuan County is 68.7 km and 734.75 km^2 , which is also our main study area (Fig. 2).

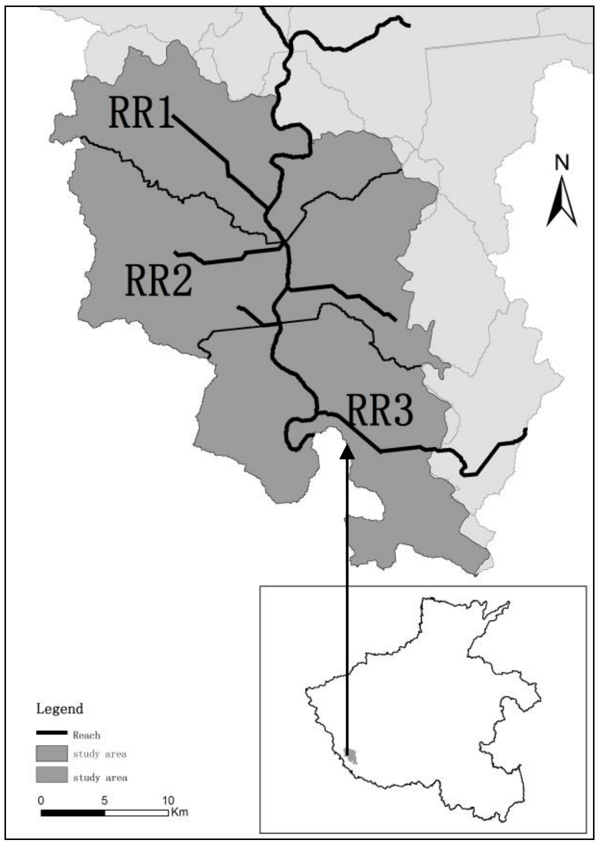

Figure 2. Study area of Laoguan River Basin.

Risk description

Risk region

The study area is broken into three risk regions (RR) based on geographic location, tributaries and the locations of sources, habitats and endpoints (Fig. 2). RR1 (195.5 km^2): Northern part of the study area with one tributary. RR2 (289.35 km^2): Central part of the study area with three tributaries. RR3 (249.9 km^2): Southern part of the study area with one tributary and the estuary of Danjiang River.

Sources

In order to describe the impact of abrupt water pollution accidents on water and society in Laoguan River basin, risk sources related to these factors are grouped into four major categories in this study, which are industry, municipal utility, agriculture and animal husbandry.

(1) Industry: Main industries along both sides of Laoguan River in the study area are mining and chemical industry, corresponding to 6 related companies and 4.63 km^2 mining area. This type of sources may bring pollution and security risks sometimes.

(2) Municipal utility: This type of sources mainly refers to sewage treatment plants and waste treatment plants in Xichuan County, which may cause chemical and biological pollution when accidents occur.

(3) Agriculture: Crop production is the main agriculture source in this study. The location and areas of it can be seen clearly in land use situation map as those 166.71 km^2 farmland. Agriculture source can bring non-point pollution and eutrophication caused by chemicals and manure application.

(4) Animal husbandry: There are 13 animal husbandry stations in the study area, most of which are along Laoguan River and its tributaries. A runoff burst may cause chemical or biological pollution in animal husbandry, from sources such as heavy metals in feedstuff, animal manure, sewage sludge and compost.

Landuse types

The landuse types related to assessment goals in the study area were reserve zones, residential area of towns and villages, woodland and garden, grassland, waters and facilities land.

Endpoints

The endpoints were chosen based on decision makers' concerns. In this study, the assessment focuses on the aquatic environment and the safety of people and properties nearby. Thus, water quality, safety of habitats, staffs, residents and properties were selected as the assessment endpoints.

Conceptual model

Once the risk components were identified, they were integrated into a conceptual model describing the possible relationships among stressors, exposure scenarios, and assessment endpoint responses (Landis, 2004; Phenrat et al., 2009). Fig. 3 is the conceptual model of this study.

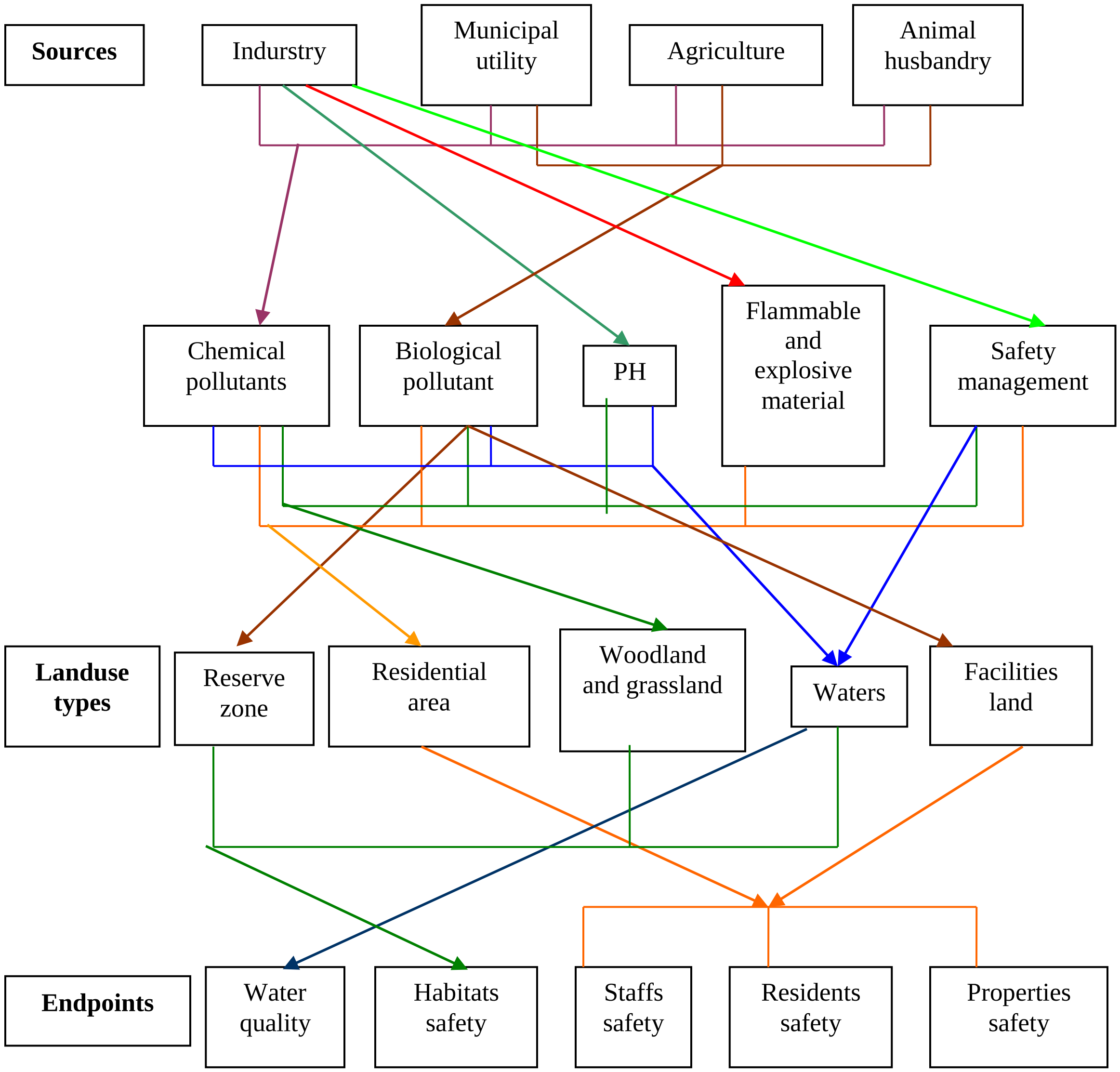

Figure 3. Conceptual model depicting potential and effects pathways from source to stressor to landuse type to endpoint.

Risk ranks and analysis

The source and landuse types are ranked baced on their areas, locations and other relevant conditions, shown in Table 1 and 2. Due to the limitation of article length, detail rank basis are omitted. Ranks of each risk region are listed in Table 3, assigned with 0, 2, 4, 6 rank values.

Table 1. Risk source areas, numbers or other conditions in each region

Source	RR1	RR2	RR3
Mining area (km^2)	1.61	2.35	0.67
Chemical industry numbers	2	4	0
Municipality numbers	0	1	1
Agriculture area (km^2)	43.89	72.83	49.99

Husbandry station distribution	H1,H3,H4,H10	H2,H5,H8-9,H11-13	H6-7

Table 2. Area (km^2) of each landuse type of each risk region

Landuse type	RR1	RR2	RR3
Reserve zones	0	22.38	102.38
Residents	7.4	20.92	9.63
Woodland and grassland	131.67	160.03	86.8
Waters	3.14	5.01	3.94
Facilities	0.13	0.49	0.42

Table 3. Source and landuse type ranks in each region

Risk factor	RR1	RR2	RR3
Source			
Mining	4	6	2
Chemical industry	4	6	0
Municipality	0	2	2
Agriculture	4	6	4
Husbandry	6	6	2
Landuse type			
Reserve zones	0	4	6
Residents	2	6	2
Woodland and Grassland	6	6	4
Waters	4	4	4
Facilities	2	4	4

Exposure and effects filters are weighting factors used to link risk components, which are briefly presented by those arrows in Fig 3. The spatial relationships between sources and landuse types, the possibility of a source releasing a stressor, the possibility of a stressor occurring in a type of land, and the potential effect a stressor may have on a endpoint, these elements decide the filter value altogether. Exposure filter values (W_{ex})of source-stressor-landuse are listed in Table 4. Effect filter values (W_{ef}) of stressor- landuse-endpoint are listed in Table 5.

Table 4. Risk source-stressor-landuse exposure filters

W_{ex}	Reserve zones	Residents	Woodland and grassland	Waters	Facilities
Mining	0	0.5	0.5	0.5	0.5
Chemical industry	0	0.5	0.5	1	0.5
Municipality	0	0.5	0	1	0
Agriculture	0.5	0	0.5	0.5	0.5
Husbandry	0.5	0.5	0.5	0.5	0.5

Table 5. Risk stressor-landuse-endpoint filters

W_{ef}	Reserve zones	Residents	Woodland and grassland	Waters	Facilities
Water quaility	0	0	0	1	0.5
Habitats safety	1	0	1	1	0
Staffs safety	0	0.5	0	0	0.5
Residents safety	0	0.5	0	0	0.5
Properties safety	0.5	0.5	0.5	0.5	0.5

Result and Discussion

Final risk scores are calculated by formula (1). The total scores of sources and landuse types of each risk region are: $RS_{RR1} = 248$, $RS_{RR2} = 500$, $RS_{RR3} = 152$, shown in Fig 3. Detailed scores for each source across all landuse types and each landuse type across all sources are listed in Table 6 (a), (b).

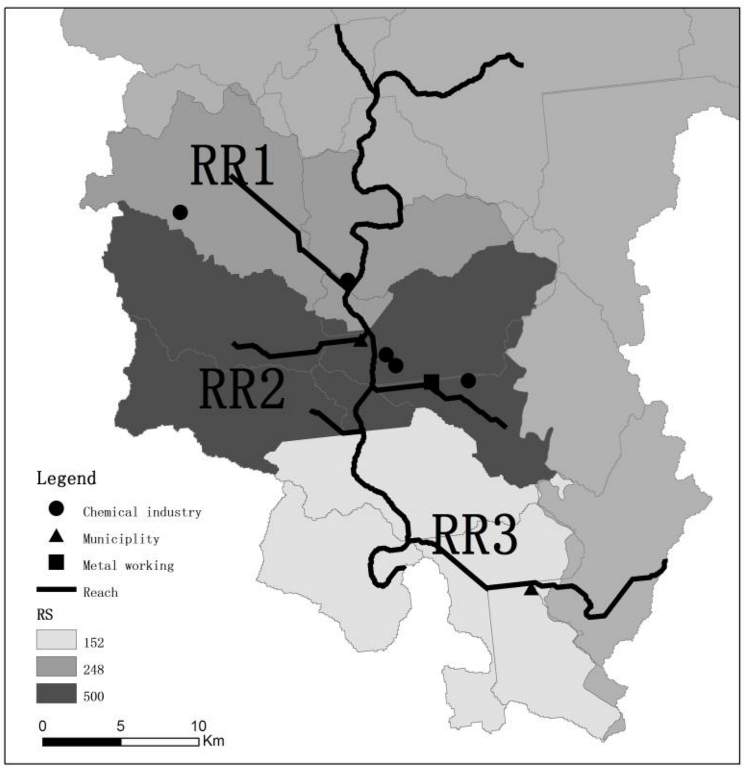

Figure 3. Risk rank results for the three risk regions.

Table 6 (a). Risk scores of each source across all landuse types in three risk regions

RS	Mining	Chemical industry	Municipality	Agriculture	Husbandry
RR1	52	72	0	46	78
RR2	108	138	29	99	126

RR3	27	0	23	56	36

Table (b). Risk scores of each landuse type across all soures in three risk regions

RS	Reserve zones	Residents	Woodland and grassland	Waters	Facilities
RR1	0	21	81	110	36
RR2	36	90	108	170	96
RR3	27	9	24	60	32

The highest risk region is RR2, followed by RR1, and the lowest is RR3. For RR2, the most threatening source is chemical industry, with risk score of 138. This is because 4 of the six chemical industry companies are located in RR2 (see Fig 3), and these companies are in or near resident area, woodland and grassland area, or facility area. What's more, pollutants of the companies are released into waters. Therefore, chemical industry bring direct impact on water quaility and habitat safety, and has potential hazards to the safety of staffs, residents and properties when abrupt pollution accidents occur, which is also confirmed in Fig 2. For RR1, the source with highest risk score is husbandry, for four husbandry stations with relatively high risk degree are located in this region (see Table 1, Fig 3), and they are either ecological sensitive landuse types or near Laoguan River. A runoff burst may cause chemical or biological pollution in animal husbandry and release these pollutants into surrounding environment. For RR3, risk scores of each source are all not very high. Among all sources, agriculture is relatively more threatening than others, which will bring chemical and biological pollution for waters and habitats under conditions like floods. As for landuse types, since waters are directly infected by most stressors with or without abrupt pollution, it has the highest risk score in all three risk regions.

Consequently, except for those regular management for the whole Xichuan County, the specific risk management measures of the three regions have different focuses: (1) Risk warning and management work should be paid full attention to the central part of the county. For existing industries, security check must be done periodically, contingency plans must be formulated and safety training should be implemented to every staff. Besides, environmental protection departments should inspect whether the discharging waster water of companies having hazardous materials is up to standards. (2) Management of husbandry, especially in northern Xichuan, should be more systematical. The treatment efficiency of husbandry waste water should be improved. Monitoring and checking of indexes such as BOD, COD, ammonia, TP, etc. should be done periodically. Protective measures for responding bursting runoff must be taken seriously. (3) As farming is a major economic source of Xichuan, the way of reducing potential risk of abrupt pollution for this part is to ensure the management and control of agricultural nonpoint source pollution and improving flood prevention and forecasting.

Conclusion

Aiming at the characteristics of large scale, multiple sources, multiple stressors and complex risk spread relationships of abrupt accidents in watersheds, this study has attempted to adopt a risk rank method in ecological risk assessment that is good at dealing with these problems and modified it to suitable for abrupt environment risk assessment. After the establishment of conceptual model and rank for all sources and landuse types, the final risk scores were obtained. In the assessing result, the most risky region is concentrated in the central part of Xichuan with industry pollution and security risks. The northern county has more potential risk in husbandry, and the environmental risk of the southern part mainly exists in agriculture. According to the results, specific risk management suggestions are provided at last.

However, due to the limitation of data resource and relative information, the risk rank model in this study is relatively simple that some factors of sources, landuses and endpoints were not taken into consideration. Therefore, the accuracy of the result may need enhancement. Besides, more effort of modifying this ecological risk assessment method to be more suitable for assessing risk of abrupt water pollution should be done in further research.

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