Probabilistic risk assessment for accidental environmental pollution at regional-scale.

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The chemical hazards occurred at large areas (e.g. watershed-scale), with the resulting exposures and hazard responses requiring environmental risk assessment at regional-scale. Risk assessment can be an effective tool to determine priority risk sources, produce coherent and comparable results, and simplify the decision-making process for developing management strategies at regional-scale.

Many watershed-scale risk assessments have addressed the cumulative pollution risks from pesticides, nitrogen and phosphorus, heavy metals, and multiple toxic chemicals. Others integrated the multiple risk sources of chemical, physical, and biological stressors that affect multiple endpoints within a watershed ecosystem. Recently a few researches have resolved regional-scale risk assessments for accidental pollution of heavy metals and hazardous/toxic chemicals towards human health and ecosystem safety. Regional-scale (e.g. watershed-scale) risk assessments involve multiple hazard sources, multiple exposures, multiple receptors, and complex interactions between these components. Unlike cumulative pollution risks, accidental pollution risks are obtained by estimating the probability and severity of hazardous pollutant spills at watershed-scale; each spill is abrupt, and involves large quantities of highly concentrated hazardous pollutants, which have acute and severe consequences to the receptors in a waterway.

A watershed-scale risk assessment deals with a complex environment wherein many "source-habitat-impact" risk routes co-exist in a network of multiple habitats with multiple sources of multiple stressors affecting multiple endpoints. Any single risk route potentially leads to a water pollution accident that is deemed to have occurred when an environmental pollution hazard is triggered (i.e. sudden release of toxic chemicals or heavy metals), highly concentrated hazardous pollutants pose a cascade of pollution hazards reaching receptors one-by-one in the downstream direction, and when its residual impact on a vulnerable risk receptor (e.g. a water intake) is sufficient to cause damage. Multiple sources that affect assessment endpoints are treated as additive at a spatial location. However, integration of these routes is best facilitated by the use of ranks, because of the incommensurable nature of the risks to the various entities and attributes in a watershed, along with the difficulty of quantifying numerous exposure-response relationships.

For large-scale areas, multi-criteria risk analyses have been performed using multi-criteria comprehensive assessment, experience and expert-judgment, and fuzzy aggregative risk assessment. Relative risk model (RRM) and its adaptive versions demonstrated more reasonable and reliable resultant risk maps at regional-scale. Because they can discriminate each single "source-habitat-impact" risk route where cascading and cumulative effects are embedded and so clarify and quantitatively measure the interrelationships between multiple sources and multiple receptors using pollutant transport and fate models which were both tangled within a single assessing region in the previous study.

However, many current environmental risk assessments are not truly assessments of risk in which variability and uncertainty (both resulting risk) are often dealt with by semi-quantitative precautionary practices. Conservative assumptions and safety factors have been assumed to provide sufficient safety to avoid the need for a formal probabilistic analysis. As the core concept in environmental risk assessment, probability never should be neglected or avoided. The good thing is the formal probabilistic analysis of uncertainty is increasingly used in many fields.

Recently, compared to traditional or frequentist statistical methods, Bayesian Networks have been increasingly applied to perform quantitative water resource management, ecological risk assessments, and accidental environmental pollution risk assessment at regional-scale. As a probabilistic mode, BNs use a directed acyclic graph (DAG) and conditional probability tables (CPTs) to describe relationships between a model's variables. BNs are well suited to solving problems with high levels of uncertainty, complexity, and variety. The BN-based models, which incorporates the quantitative interactions of the exposure pathway from stressors to endpoints, is designed to assess spatially combined risk by integrating multiple "sources/stressors-receptors-endpoints" routes. Potential synergistic effects between the stressor hazard and receptor vulnerability using CPTs were accounted for, which allowed complex risk routes to be quantitatively incorporated without increasing the model's complexity.

The key difference between BNs-based risk assessments and other classical statistical methods, such as potential ecological risk index, ecological response index, and risk ratios, is how the probability is utilized and introduced. As Bayesian

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statistics can give probabilities for both hypotheses and data, probability distributions of different states (Zero/Low/Medium/High) for both ecological and human health risks can be clearly expressed.

The regional-scale BNs-based model provides a foundation for later risk management schemes and can also be used in the adaptive management process to assess changes in risk due to management options in the future.

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