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Environment–accident index: validation of a model

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Abstract

Authorities and industry often have difficulties knowing what to focus on when it comes to risk assessment in the handling of chemicals. Hence, there is a requirement for a tool to facilitate this work. The Environment–Accident–Index (EAI) is proposed as such a tool. EAI is a simple model that gives guidance as to the identification and quick ranking of the kind of assessment to be performed. EAI is built on three parts: the first part contains information on the acute toxicity to aquatic organisms, the second part concerns the transported or stored amount of the chemical and the third part deals with chemical mobility. For example, the mobility part contains chemical–physical properties of the substance and those of the surrounding environment, such as the possibility of soil penetration and depth and mobility of the groundwater. The purpose of the EAI is to be an implement, to be used by authorities and industry, when planning for the storage and transportation of chemicals, amongst other uses. The model is intended to be simple to facilitate and increase the use of EAI. The results show that EAI is quite capable of becoming a useful tool for ranking different hazards and that EAI is a good basis for further development of the model. The results also show that there is a lack of environmental data available from chemical accidents and that a better system for environmental follow-up of chemical accidents would have facilitated and given a better foundation to the evaluation. The evaluation has been performed by Åsa Scott, Defence Research Establishment, by order of the Swedish Rescue Services Agency and the Swedish Environmental Protection Agency. An evaluation group has supported and guided the work. The evaluation group has, besides the Swedish Rescue Services Agency, the Swedish Environmental Protection Agency and Defence Research Establishment included experts from the National Chemicals Inspectorate in Sweden and the Association of Swedish Chemical Industries. The paper is an evaluation of EAI and discusses the present usefulness of the index and conceivable changes for the future. © 1998 Elsevier Science B.V. All rights reserved.

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1. Introduction

The increasing and complex flow of chemicals has resulted in harder demands for the authorities and industry that handle chemicals to estimate the risks involved. Authorities and industry often have difficulties knowing what areas to focus on when conducting risk assessment on the handling of chemicals and there is a need for a tool to facilitate this work. In the FOA report, 'Vådautsläpp av brandfarliga och giftiga gaser och vätskor. Metoder för bedömning av risker', Chapter 12, appendix 1 [1], a proposal for a so-called environment–accident – index (EAI), that can be used in this respect, is presented. The objective of this project is to validate the EAI including the usefulness of this index and possible changes that have to be made for future applications.

2. Description of EAI

EAI is a simple model that gives guidance for the identification and ranking of the kind of assessment to be performed in each case of dealing with chemicals. EAI consists of three parts: (i) the acute toxicity to water living organisms (Tox), (ii) the stored or transported amount of the chemical (Am), and (iii) factors controlling the spreading of a chemical. The latter part, the so called Spreading Part (consistency, solubility and properties of the surrounding environment), contains chemical–physical properties of the chemical, possibility of soil penetration and the depth and mobility of groundwater (Con, Sol and Sur).

EAI is calculated as follows:

$$\mathrm{EAI} = \mathrm{Tox} \times \mathrm{Am} \times (\mathrm{Con} + \mathrm{Sol} + \mathrm{Sur})$$

where **Tox** is the acute toxicity to water-living organisms; **Am** is the stored or transported amount of the chemical; **Con** is the consistency or viscosity/physical state of the chemical; and **Sol** is the water solubility of the chemical.

Sur is the properties of the surrounding environment such as:

1. distance, in meters, to nearest well, watercourse or lake
2. depth of groundwater, in meters
3. if the groundwater surface is leaning towards a well, lake or watercourse or if it is horizontal
4. the thickness, in meters, of the type of soil and the material it consists of, for example, gravel, sand, moraine, silt, clay, or if the ground is frosted.

Each four of the above surrounding parameters are assigned a numerical value according to Tables 1–4 and the sum is calculated. This sum gives a numerical value for the

Table 1
Distance to nearest well, lake or watercourse

	Points									
	9	8	7	6	5	4	3	2	1	0
Meters	0–10	10–20	20–35	35–50	50–75	75–150	150–300	300–1000	1000–2000	> 2000

Table 2
Depth to groundwater surface

	Points									
	9	8	7	6	5	4	3	2	1	0
Meters	0–0.2	0.2–1	1–3	3–5	5–7	7–12	12–20	20–30	30–60	> 60

Table 3
The leaning of the groundwater surface and the flow direction

Points		
5	1	0
The groundwater surface is leaning towards a well, lake or watercourse	The groundwater surface is horizontal	No well, lake or watercourse is laying within 1 km of the direction of the groundwater flow

Table 4
The permeability of the soil: choose the highest point in the interval if the rock beneath the soil is cracky. Choose the lowest point in the interval if the rock beneath the soil is massive

The thickness of the soil	Points					
	Gravel	Sand	Moraine	Silt	Clay	Frosted ground
> 30 m	9	8	6	4	0	0
25–30	9	7–8	5–6	3–5	0–1	0
20–25	9	7–8	5–6	3–5	0–2	0
15–20	9	7–8	5–7	3–6	0–3	0
10–15	9	7–9	5–8	3–7	0–4	0
3–10	9	7–9	6–8	4–8	1–6	0
< 3	9	7–9	6–9	4–8	2–8	0

parameter Sur according to Table 5. Each one of the four parameters Tox, Am, Con and Sol are assigned a point according to Tables 6–9.

All contributed values are then included the formula from which the EAI can be calculated. According to a classification scale (below), containing risk categories, further need of risk assessment can be identified.

Table 5
Points for the parameter Sur

Summarized point from Tables 1–4	Points (Sur)
> 25	10
20–25	7
15–20	5
10–15	3
< 10	1

Table 6
Points for the parameter Tox

Acute toxicity[a] (LC_{50} or EC_{50})	Points (Tox)
< 1[b] mg/l	10
1–6	8
6–30	6
30–200	4
200–1000	2
> 1000	1

[a]Use the lowest available LC_{50}-value or EC_{50}-value for fish, *Daphnia* or algae.
[b]Handling of extreme toxic chemicals should be investigated even if the calculated EAI-value will be low.

Table 7
Points for the parameter Con

Consistency viscosity[a] (cSt[b])/solid compound	Points (Con)
< 0.5	5
0.5–4.4	4
4.4–47	3
47–300	2
> 300	1
Solid compound	0
Unknown viscosity[a]	4

[a]If data about the viscosity is missing, use point 4 that correspond to the viscosity interval where most liquid chemicals can be found.
[b]If the viscosity only is available as cp (centipois), this value is first divided with the density of the chemical in g/cm^3.

2.1. Three graded classification scale for identification of further risk assessment

EAI 0–100: Hazard Analysis concerning the inherent properties of the chemical has to be performed
EAI 100–500: Introductory Risk Assessment has to be performed
EAI > 500: Advanced Risk Assessment has to be performed.

Table 8
Points for the parameter Am

Stored or transported amount of the chemical (tons)[a]	Points (Am)
> 500[b]	10
50–500	7
5–49	5
0.5–4.9	3
< 0.5	1

[a]The maximal amount of the chemical, converted into pure compound, that can be handled.
[b]Extreme large stocks should be investigated even if the calculated EAI-value will be low.

Table 9
Points for the parameter Sol

Water solubility (wt.%)	Points (Sol)
> 90%	5
25–90	4
5–25	3
1–5	2
< 1	1
Solved in water	5
Solved in organic solvent	a

a: The solubility point for the solvent.

2.2. EAI— limitations

EAI is limited to discharges to ground, water or groundwater and is not applicable on fires, explosions or accidents with release of gas into the air. EAI is only applicable to the acute phase of an accident and is accordingly not to be used in a long-term perspective. Further, EAI is not applicable on transport distance. In such an application other factors, statistics for example, must be considered. However, the EAI can be used for a certain position along a transport route as a particular location can be considered to have the same conditions as a permanent establishment, e.g., an industrial site.

The purpose of EAI is to serve as a quick and simple implement to guide the identification and ranking of the kind of further assessment to be performed. The EAI can be used by authorities and the chemical handling industry in their planning. The EAI is purposely formulated as a simple model to facilitate and increase its usage.

3. Method

The validation of EAI was performed in two parts.

Part one: EAI is tested on a number of chemical accidents by (a) calculation of the EAI value for each accident to study if it is possible, by using the EAI, to classify the accident into a risk category that matches the real consequences, (b) calculation of the remaining part, in percent, of the total amount of the released chemical and plotting this value against the sum of the Spreading Part in a diagram to determine wether a higher value of the spreading part correlated with the amount of chemical remaining in the ground- or water environment. A reasonable assumption should be that a higher point for the Spreading Part would lead to a larger amount of the chemical remaining in the ground- or water environment.

$$\text{Spreading Part} = \text{Con} + \text{Sol} + \text{Sur}$$

$$\%\text{chemical remaining in the environment} = \frac{\text{amount chemical remaining after decontamination}}{\text{amount released chemical}} \times 100$$

(c) performing a subjective judgement of the effects caused by accidents on vegetation, animals, technical equipment and the time of decontamination. The purpose with these judgements is to determine if a large effect, such as the elimination of a water supply plant or the death of a large number of organisms, correspond to a high value of EAI and vice versa. This leads to a better overview of the results and an indication as to whether the classification scale should be changed.

Part two: This part of the validation contains a theoretical sensitivity test where the different parameters in the formula are analysed to find their individual role in the EAI. This part has also included a calculation of EAI for 49 different chemicals to illustrate the distribution of the value of EAI to the different risk categories.

3.1. Material

The material used in the validation consists of reports, memoranda, articles in the press, personal interviews and available data for the used chemicals. The total material used in the validation is too voluminous to include in this paper and is therefore only listed in the original paper.

4. Results and discussion

The research work showed that there is a lack of environmental data from chemical accidents. When the EAI values are calculated for the accidents the result shows that 71% of the accidents are in the risk category 100–500, 24% in the risk category > 500 and 5% in the risk category 0–100.

The Spreading Part and the amount of chemical remaining in the ground- or water environment were calculated and plotted in a diagram (Fig. 1). As seen in Fig. 1, no

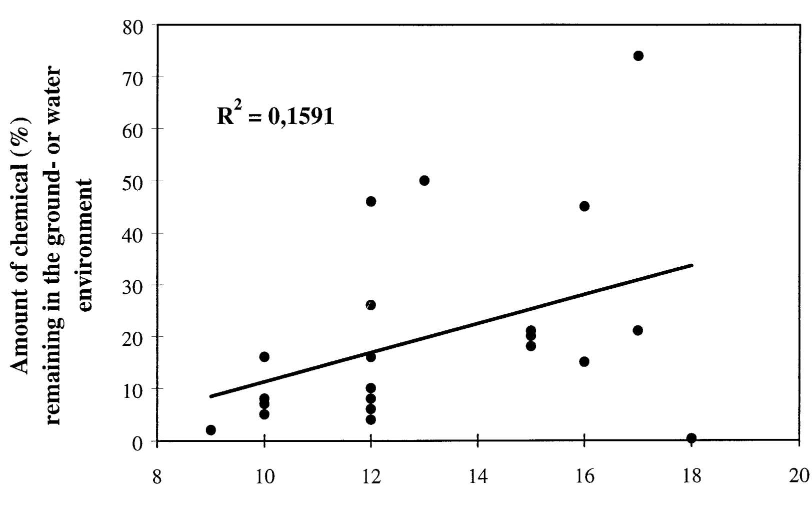

Fig. 1. Amount of chemical remaining in the ground or water environment—Spreading Part.

linear correlation was found. A high value of the calculated Spreading Part for each accident did not necessary correspond to a large amount (in %) of chemical remaining in the ground- or water environment. This means that the Spreading Part does not have the capacity to influence the magnitude of the risk for spreading of a chemical.

When studying the accidents used in the validation it was noticed that, for example, the factors reactivity, volatility, weather and density also influenced the amount of chemical that was decontaminated in each accident. These factors are not included in the EAI model. This shows that the spreading of a chemical is not only dependent on the parameters Con, Sol and Sur (in the EAI), but also on other factors as shown below.

The **season** (seasons in Scandinavia) has influence on the spreading of a chemical. In the summer, the warmer weather increases the evaporation. In autumn and spring there are often wet conditions that can more easily carry the chemical. In wintertime, there is often ground frost, without any ground frost crackers, that can effectively retain the discharged chemical. Some chemicals will become more or less viscous depending on the temperature. The **weather** is generally connected to the season. Precipitation can facilitate the spreading of a chemical. Strong winds also spread a chemical while low wind concentrates the chemical. High air temperature increases and low air temperature decreases evaporation. **Reactivity** can have a large influence on the spreading of a chemical. Some chemicals can react with water and form products that will be harder to decontaminate. Other chemicals will react and precipitate and the solid product might be easier to decontaminate. **Density** has a large influence on the distribution of a chemical in the environment. Chemicals lighter than water are more easily spread horizontally while chemicals heavier than water are spread vertically. **Volatility** influences the distribution of a chemical between ground, water and air. A chemical with high volatility evaporates and is then spread by air while a chemical with low volatility has a low or non-existent evaporation rate and the major part of the chemical will be spread to ground or water. **Explosive** or **inflammable** chemicals influence the spreading if the chemical explodes or burns. The area of distribution will increase because the chemical and/or the reaction products in a fire are spread by air. This can also have the effect that almost no chemical is spread to the ground- or water environment. When a chemical burns the spreading for the residual products can be hard to predict. The **decontamination** has a large effect on the amount of chemical remaining in the ground or water environment from/after a chemical accident. The result of the decontamination can vary depending on method of decontamination. Extinguisher foam, used by the rescue service to prevent fire or explosion, can affect chemicals making them easier to spread in water because of the increased water solubility. Extinguisher foam can be toxic to some water-living organisms. In case of a fire, the combustion products formed can spread in different directions depending on the amount of fire-fighting water and extinguisher foam used.

The above mentioned factors all influence the spreading of a chemical. The fact that EAI only includes some of these factors (Con, Sol and Sur) limits it to be a rough model.

In the subjective judgements the effects on vegetation, animals, technical equipment and time of decontamination, in each accident, were compared with the EAI-values. In its entirety the subjective judgement showed that there is a connection between effects and the calculated EAI-values. Although there were accidents where the effects and the EAI-values were not corresponding, most of the accidents did and the conclusion of the study is that the present risk categories work quite well and does not need to be changed.

The first part of the theoretical validation aimed to analyse the different parameters in the formula to find their individual role in the EAI. In summary, this test shows that the parameters within parenthesis (Con, Sol and Sur) have less influence on the magnitude of EAI than the parameters outside parenthesis.

In the test to illustrate the distribution of calculated EAI for 49 chemicals, the result shows that the distribution is quite even: 46% to risk category 100–500, 32% to risk category 0–100 and 22% to the risk category >500. The result shows no extreme predominance of any risk category but an even distribution and a change of the limits in the classification scale does not seem necessary at present.

5. Conclusions

After validation of the results and discussion of the above conditions the following conclusions on the EAI can be drawn.

(1) The EAI has, with future changes, the capacity to become a useful tool for the ranking and classification of the kind of further risk assessment to be performed.

(2) The changes to be made should strengthen the parameter Sur and perhaps add a parameter to the EAI that deals with volatility.

(3) The possibilities for development of the EAI model are good. One possibility is to introduce various parameters that influence the spreading of a chemical.

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