Spatial vulnerability assessment for road deicing salt on surface water using GIS

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Abstract— **Excessive salt concentrations in lakes have been proved to be directly related to the use of road deicing salt and to cause negative environmental impacts. The present paper presents a risk assessment and implementation in a GIS based management tool with emphasis on the validity of the method. In the risk assessment readily accessible data is used; estimated road deicing salt contribution to lakes and acceptance criteria. Estimated chloride concentrations have been compared to measured chloride concentrations and the results shows high correlation. The management tool is intended to be used by road authorities in relation to winter road maintenance contracts.**

Keywords-component; road de-icing, risk assessment, surface water, chloride

I. Introduction

The amount of de-icing salt applied annually on Norwegian roads has more than doubled since year 2000 and during the winter 2009/2010, 201 000 ton road deicing salt was spread [1]. Road de-icing salt is widely used to improve winter road conditions, but concerns have been raised regarding environmental impacts. Surface waters that are most sensitive to road deicing salt impacts are areas with low runoff, which is characterized by high evapotranspiration relative to precipitation, e.g. wetlands, small urban lakes and ponds with long residence times and small streams draining large urbanized areas [2]. Excessive salt concentrations in lakes have been proved to be directly related to the use of road deicing salt [e.g. 3, 4-8]. According to Ramakrishna and Viraraghavan (2005) the following impacts has been detected in surface waters due to road de-icing salt, 1) changes in density gradients, 2) increased chloride concentrations, 3) salt-induced stratification and 4) salt stimulation of algal growth. As a direct consequence of these effects there might be oxygen depletion in lakes adjacent to major [6].

The EU Water Framework Directive (WFD) was implemented by law in Norway 2006 [9]. It is expected that the Norwegian Public Roads Administration (NPRA) take part and make necessary action regarding the WFD implementation. This is in accordance to the general principle in the Norwegian governmental policy, that all ministries and operational departments have a sectorial environmental responsibility [10].

For winter road maintenance in vulnerable areas special requirements need to be considered to avoid environmental impacts. This could be reducing or banding the use of road deicing salt, making use of alternative de-icing chemicals or increased effort on mechanical snow and ice removal. Sampling of all Norwegian lakes is both time consuming and costly, and in this respect a GIS-based (Geographic Information System) web application has been developed to identify areas where road de-icing salt may have negative impact on lakes adjacent to roads. The web-application is intended to be used as a management tool for the road authorities and may be applied in winter road maintenance contracts. The present paper presents a brief summary of the use of existing knowledge in a risk assessment and implementation in a GIS based management tool with emphasis on the validity of the method.

II. Data and Methods

The data included in the web application was digital maps showing roads and road deicing salt consumption from the NPRA, lakes from Norwegian Institute for Water Research (NIVA), estimated concentrations of road deicing salt in lakes [11] and acceptance criteria [6]. The lakes were divided in relation to sea influence, above/below marine limit and calcium rich/calcium poor. The division is based on a subjective evaluation. Data was collected and gathered in a digital database. The data is raster-based on gridded information in the resolution 25 m x 25 m. The risk assessment for lakes vulnerable to road deicing salt was done by estimating the chloride concentrations in lakes close to roads and compared to acceptance criteria. The risk assessment was implemented in a GIS. To check and to verify the estimation, the results were compared with data obtained from a previous study of 59 lakes believed to be affected by road deicing salt [6].

A schematic description of the work to identify lakes vulnerable to road deicing salt is shown in Figure 1.

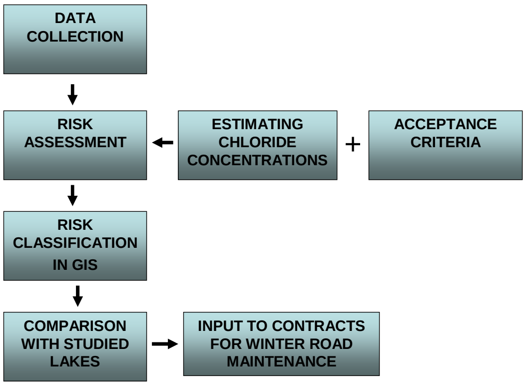

Figure 1. Schematic description of the approach to identify lakes vulnerable to road deicing salt.

A. *Risk assessment*

The risk of causing adverse environmental effects is expressed by the probability and consequences of an unwanted event to occur (Figure 2). Similarly, the present web application has focused on the potential pollution load and the acceptance criteria. Hence, the probability of the unwanted events to occur, e.g causing an adverse environmental effect on a lake, is expressed by the potential pollution load and the consequence is expressed by acceptance criteria.

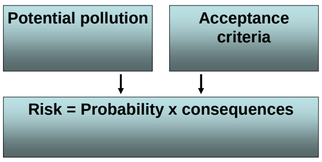

Figure 2. The risk of causing adverse environmental effects is expressed by the probability and consequences of the unwanted events to occur.

This risk assessment consists of two steps; 1) estimation of concentrations of road deicing salt in lakes by a model and 2) defining the acceptance criteria. To classify roads, the estimation of road deicing salt concentration in lakes, were compared with the acceptance criteria.

- Step 1: Estimation by model

For estimating concentrations of road deicing salts in lakes, a methodology for salt balance is developed by Kitterød, Turyumøygard et al [11]. The method is based on water balance, digital terrain maps and geographic information covering average consumption of road deicing salt for one year. The purpose of the method is to estimate stationary water balance, salt balance and salt concentration in any water body in Norway.

- Step 2: Acceptance criteria

The consequences of an unwanted event to occur, is considered in two ways by; 1) biological tolerance doses and by 2) chemical tolerance doses to salt-induced stratification.

In the present study, a biological tolerance test is used [12]. In brief, the tolerance of planktonic algae to road deicing salt was explored in two ways; 1) statistical analyses using algae and chemical data from Norwegian Institute for Water Research (357 lakes), and 2) laboratory tests. The statistical analyses revealed an effect of chloride concentrations on the algae community, especially in larger in lakes with low calcium concentration compared to lakes with high concentrations. In calcium-poor lakes, species of dinoflagellates and diatoms were not found at chloride concentrations exceeding 23-30 mg/L. In calcium-rich lakes however, chloride concentrations would need to be higher than 40 mg/L in order to observe dominance of the same two algae groups. In the laboratory tests the most sensitive species appeared to be the flagellate *Rhodomonas lacustris* with an EC50 value of 34 mg chloride/L. The results of both studies pointed in the same direction: lake algae communities in calcium-poor lakes become altered at chloride concentrations above 23–30 mg/L, whereas in calcium-rich lakes the chloride concentration has to exceed 40 mg/L in order to observe changes in the algae community.

According to Bækken (2006) formation of salt gradients depends mainly on the added road deicing salt quantity, road length in the catchments, lake morphology, run-off from the catchments and average annual daily traffic. Lakes with an area less than 200 decare, situated closer than 200 metres from the road and road deicing salt consumption of more than 25 tons / km, is at risk for salt-induced stratification.

B. *Risk classification in GIS*

To classify roads, the estimated road deicing salt concentration in lakes and the acceptance criteria were used. If the estimated concentration exceeds the acceptance criteria, the lake and the road in the catchments of the lake appears red (at risk) or yellow (possibly at risk) (Table 1).

TABLE 1. ACCEPTANCE CRITERIA USED IN THE PRESENT STUDY.

Acceptance criteria		
	Red	**Yellow**
Biological tolerance dose, mg/L	**Calcium poor: 25** **Calcium rich: 40**	
Chemical tolerance dose, ton road deicing salt/km	**25***	**10-25***

*If the lake area is less than 200 acres and closer than 200 metres from the road

C. *Statistics*

Correlation analyses were applied to test for any significant difference between estimated chloride concentrations [11] and measured chloride concentrations [6] in the lakes to verify the method used in the web-application. Due to skewed normality the data were transformed (Johnson transformation) prior to the statistical analysis. P<0.05 was set as criteria for significance. The statistics were conducted by using Minitab 15 software.

III. Results and Discussion

The spatial nature of diffuse sources, such as road deicing salt, make the estimation of such pollutants well suited to the integration in a GIS [e.g. 13, 14, 15]. Among the problems that are recognized are creation of the database, including both collection of data and the assurance of proper database quality. Errors and uncertainties can be managed by statistics in order to estimate the errors, but was not done in this study.

A. *Comparison with studied lakes*

The estimated chloride concentrations [11] and measured chloride concentrations [6] was highly correlated (r=0.93) (Figure 3). The results indicate high confidence for the estimated values. The correlation analyses were conducted on 40 lakes (out of 59 studied lakes).

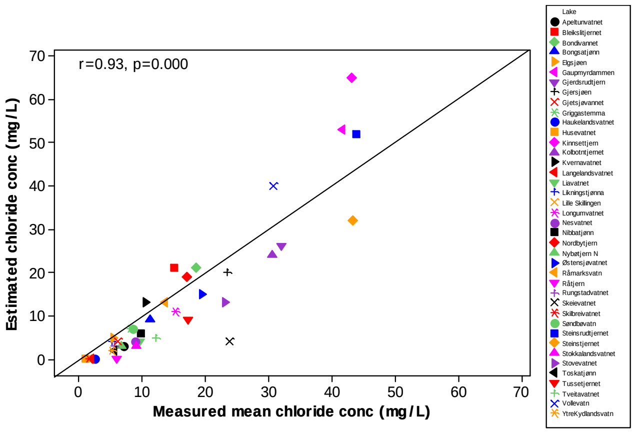

Figure 3. Estimated chloride concentrations and measured chloride concentrations was highly correlated (r=0.93). N= 40.

In most of the studied lakes the estimated chloride concentrations are below the measured chloride concentrations. High chloride concentrations can either origin from different anthropogenic sources, e.g. road deicing salt, or from natural deposits of salt, such as relict salt, atmospheric deposition, weathering of minerals and seawater intrusion [14]. In the mid south of Sweden, road salt application was estimated to contribute more than half of the total chloride load for a catchment area [16]. Most of the studied lakes are sea influenced, below marine limit and calcium poor (Figure 4), which indicates salt influence by natural sources.

A selection of sea influenced lakes (A) (r=0.95), lakes below marine limit (B) (r=0.94), lakes above marine limit (C) (r=0.97) and calcium poor lakes (D) (r=0.87) showed high correlation between estimated and measured chloride concentrations (Figure 4). Calcium rich lakes (D) (r=0.78, p=0.068) did not show any significant correlation between estimated and measured chloride concentration, which could possibly be explained by few lakes with these criteria (Figure 4). There were too few lakes not influenced by the sea to examine significance.

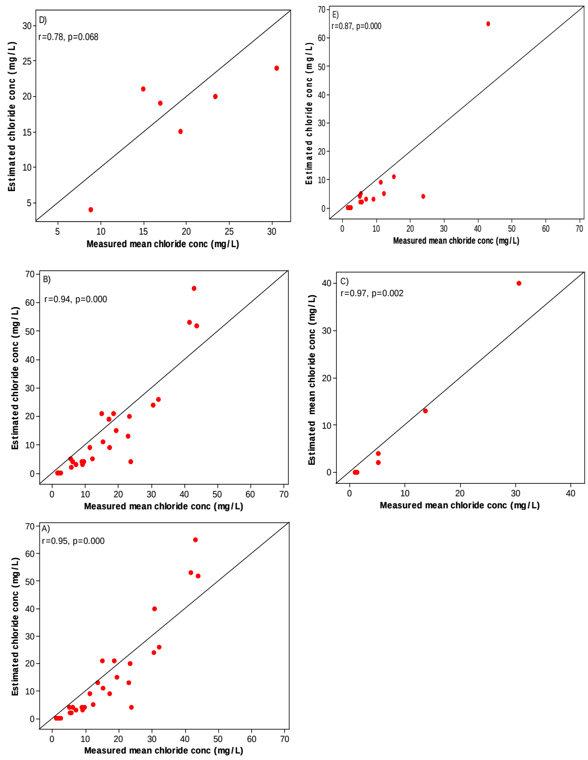

Figure 4. Most of the studied lakes are sea influenced, below marine limit and calcium poor. A selection of sea influenced lakes (A), lakes below marine limit (B), lakes above marine limit (C) and calcium poor lakes (F) showed high correlation between estimated and measured chloride concentrations. A selection of calcium rich lakes did not show significance or correlation (D).

B. *Output of the web application*

Through the web-application road deicing salt estimation in all Norwegian lakes closer than 10 kilometers from a salted road can be done. The risk assessment and the categorization of roads are based on a combination of estimated chloride concentrations and acceptance criteria. By selecting the desired lake, lake data, estimated road deicing salt concentration and acceptance criteria can be found (Figure 5). The red dotted line shows the lake catchment, while the green dotted line shows salted road in the lake catchment.

Lake data	
Name	Kolbotntjernet
Calcium rich/calcium poor	Calcium rich
Catchment area, km2	3,2
Run-off, m3/year	1551675
Contract no	203
Estimated road salt concentration in the lake	
NaCl, mg/L	35
Cl, mg/L	21
Total applied road salt in the lakes cathment, ton/year	55,7
Acceptance criteria	
Biological tolerance dose, mg Cl/L	Red: Calcium poor: 25 Calcium rich: 40
Chemical tolerance dose, ton/km	Red: 25* Yellow: 10-25*

*If the lake area is less than 200 acres and closer than 200 metres from the road

Figure 5. Mapping of roads vulnerable to road deicing salt.

The total road length in Norway is around 60 000 km, on which road deicing salt is spread on 8400 km during winter time. The calculations show that there are 133 km Norwegian roads located next to red lakes, while there are 639 km roads by yellow lakes (Table 2). 137 lakes are considered at risk, while 1030 lakes are considered as possibly at risk (Table 2).

TABLE 2. CALCULATED VULNERABLE ROADS AND LAKES IN NORWAY.

Norway	Kilometres road by red lakes	Kilometres road by yellow lakes	Amount of red lakes	Amount of yellow lakes
Total	133	639	137	1030

The web-application is designed as a management tool for road authorities and reports can be generated for special needs. One example of such a report is that for each winter road maintenance contract, information can be given on all lakes within the contract area, like percent exceeding the acceptance criteria for each lake, added road deicing salt and the amount of road deicing salt which must be used to get below the acceptance criteria.

CONCLUSIONS

An estimation of the chloride contribution from road deicing salt to lakes has been done and has been compared to measured chloride concentrations. The results from this study shows high correlation between estimated and measured chloride concentrations. Road deicing salt is the dominating source for observed sodium chloride in the observed lakes. Most of the studied lakes are sea influenced, below marine limit and calcium poor, which indicates salt influence by natural sources.

The generated maps provide a useful visual tool for assessing the potential impact of road deicing salt on surface water, and thereby provide valuable information to make management decisions in order to minimize environmental impacts.

The main challenge is to reduce the uncertainties related to spatial and temporal variation of the water balance. There is a need to estimate conditional uncertainty maps for the estimated values. Finally, there is also technical challenge to improve spatial and temporal monitoring of road salt application.

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