Salinization of private wells from de-icing chemicals - A pilot project in central Sweden

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Abstract

Road salt consisting of sodium chloride is a commonly used de-icer in Sweden. Many wells are situated close to major roads and thereby in risk of contamination. The area chosen for the present investigation is located in the central part of Sweden. Well records from eight counties were collected from the Geological Survey of Sweden (SGU) and, using GIS, wells located within a distance of 500 m from major roads were selected. Groundwater sampling and analysing was carried out in 93 wells located within 300 m from major roads in the county of Västmanland. The correlation between the chloride content and various natural and technical variables, such as geology, topography, proximity to road and elevation related to the road, were statistically analysed through variance analysis (ANOVA). The project showed that almost 40 % of the collected water samples in the county of Västmanland had a raised content of chloride. A comparison between well records close to major roads in central Sweden and all well records from the same area stored at SGU, showed that wells close to roads had a harder (Ca+Mg) and more chloride rich water than the other wells. Increasing chloride content indicates the presence of NaCl, in this case probably road salt. The increased hardness is then a result of ion exchange processes due to addition of sodium to the soil. The amount of chloride is positive correlated to the depth of the wells. In the data from the county of Västmanland as well as in well records from SGU, wells with depths of 0-10 m show an increase of chloride that goes against the general trend, indicating an external salt source from the surface. The distance to the roads and the elevation of the well compared to the road surface were found as the primary risk factors for contamination. An increased amount of wells with an enhanced chloride content (>50 mg Cl/l) in the county of Västmanland were encountered among the wells situated close to major roads compared to all well records stored at SGU, within the same area. The project indicates that de-icing salts on roads may be an important source of chloride in groundwater, especially in shallow groundwater storages.

Introduction

Maintenance of roads and in particular de-icing chemicals may be one important cause to groundwater contamination. In the southern parts of Finland several municipal waterworks are believed to be contaminated by road salt (Soveri 1994). This has also been shown in Sweden (Bäckman 1980, Maxe et al. 1994) and in Canada (Howard & Haynes1993). However, the situation according to the private wells and their salinization due to road salt is of a unknown extension. This investigation is a first attempt to study the degree of salinization of private wells along major roads in Sweden at a regional scale. The aim was also to relate the salinization to the natural conditions of the wells such as geology, topography and hydrology. The investigation area is situated in the central part of Sweden.

In Sweden natural content of chloride in the groundwater is 1-20 mg/l (Aastrup 1979), depending on the geographical location. Waters with a chloride content exceeding 50 mg/l is in this investigation regarded as *salt affected* waters. Saline groundwater may have various sources e.g. marine (seawater intrusion, fossil seawater), geological (fluid inclusions, evaporites) or anthropogenic (leakage from waste deposits, road salt, sewers) which complicate the analysis of the origin of the saline water. Fossil seawater may be found below the highest marine shore level in Sweden where the land has been covered with salt or brackish water after the latest glaciation period. The occurrence and origin of salt water in Sweden is discussed by Olofsson (1994).

Well construction and sensitivity to contamination

The most common types of wells in the investigation area are drilled wells, dug wells and tube wells. The natural protection against contamination may not be enough if high permeable soils such as sand or gravel, or a highly fractured bedrock exists from the surface to the groundwater table. Unfortunately many old wells are situated in for groundwater contamination vulnerable areas. The vulnerability of the groundwater storage depends of its extension and capability, groundwater level, groundwater flow, geology, precipitation, the distance between the road and the aquifer and the amount of road salt used in the area (Bäckman 1980). The greatest risk is when the water storage has a high groundwater level, a plane topography and a slow groundwater flow (Bäckman 1994).

Runoff water from roads

The composition of Runoff water from roads depends on e.g. the intensity of traffic, the length of the dry periods and the intensity and duration of the precipitation (Lundberg & Lindmark 1994). The most important pollutants are suspended material, BOD and COD, nutrients (N,P), heavy metals (Pb, Cd, Zn, Cu, Fe, Ni), hydrocarbons (HC), micro-organisms, chemical de-icers, (Lundberg & Lindmark 1994). The runoff from a road section in a region with the mean precipitation of 700 mm/year in Sweden is estimated to 2.8×10^6 m^3 / m^2, year (Lundberg & Lindmark 1994).

The effect of road salt on soil and groundwater

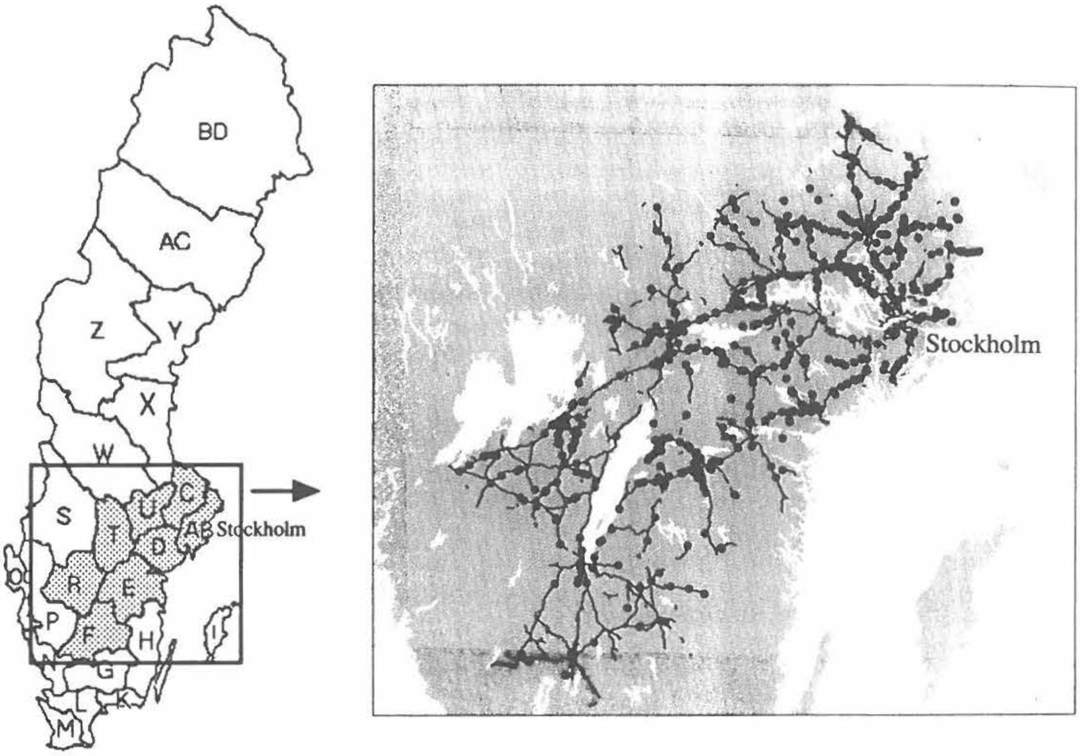
Road salt has generally been spread in Sweden since the nineteen-sixties. About 100 kg salt is spread per year and per vehicle (Falukuriren 1994). During the snow melting process the NaCl dissociates into Na^+ and Cl^-. Investigations have shown that NaCl effects the ground and the groundwater through an increased chloride content , sodium content, hardness, alkalinity and dissociated bound compounds (O'Brien & Majewski 1975). Chloride is a conservative ion, which does not react with the soil particles but instead leaches to the groundwater (Knutsson 1995). This characteristics makes it to an excellent tracer. The sodium ion tends to react with the soil e.g. through ion exchange:

$$2\,Na^{+}{}_{(aq)} + Ca_{(ad)} \rightarrow Ca^{2+}{}_{(aq)} + 2\,Na_{(ad)}$$

This ion exchange makes the water harder when the sodium ions change places with the calcium and magnesium ions which are adsorbed on the soil particles. Another effect of sodium ions is that it may disperse organic matters and clay minerals when the content of exchangeable sodium is high and the electrolytic concentration is low (Amhrein et al, 1992). This dispersion may release the heavy metals which are adsorbed on the organic matters or the clay minerals. I addition polyaromatic hydrocarbons (PAH), which are sorbed on the humus, may be released and thereby easily transported to the groundwater (Jacks et al. 1995).

Description of the investigation area

The county of Västmanland was chosen as the main field area due to its varying geological conditions and the presence of major roads parallel to or intersecting the many great eskers in the county. The bedrock in central Sweden consists mainly of hard crystalline rocks. The bedrock surface, which is slightly undulating, is covered by till and in topographical lower parts by glacial or postglacial clays. The eskers, which consist of glaciofluvial deposits of sand and gravel, are major groundwater reservoirs. The investigation area is located below the highest marine shore level.



AB= The county of Stockholm
C= The county of Uppsala
D= The county of Södermanland
E= The county of Östergötland
F= The county of Jönköping
R= The county of Skaraborg
T= The county of Örebro
U= The county of Västmanland

Figure 1 *Investigated area in central Sweden and the distribution of selected wells along major roads (data from SGU). A specific study was carried out in the county of Västmanland.*

Investigation methods

Specific study of the county of Västmanland

Water sampling was carried out in private wells situated within 300 m from major roads in Västmanland. In total 93 samples were collected, among which 45% were drilled wells in rock. The samples were collected directly from the water tap. In addition information regarding technical well parameters, the location of the well compared to the road as well as the geological environment close to and in the surrounding of the well, were collected.

The chemical analyses comprised content of chloride, sodium, magnesium and calcium, pH-value and electric conductivity. These analyses were made on wells which are presently in use.

Regional study in eight counties based on data from SGU

Chemical data from private wells in eight counties (see figure 1) were selected from the well record database at SGU using the GIS program MapInfo with the criteria that the wells should be located within a distance less than 500 m from roads which are at least 7 m wide. However, the accuracy regarding the exact position of the wells in relation to the roads were insufficient for detailed studies, hence the analysis can only give a rough picture of the chemical variations along the roads.

Statistical analysis
Statistical analyses were made based on results from the county of Västmanland in order to evaluate how various geological, topographical and hydrological factors influence on the chloride content. The statistical analyses comprised principal component analysis (PCA) and variance analysis (ANOVA). Primarily PCA was applied in order to gain a general view of the relationship between the components. ANOVA was used to investigate the influence on the chloride content by technical and natural, often non numerical, variables.

Results

Water chemical analyses
Median values for the chemical data of wells situated close to major roads in four counties, based on data from SGU, were chemically compared to the total amount of wells stored in the same database. For some of the counties, in which hydrogeological mapping has been carried out, the selected wells were compared with results from compilations made within the hydrogeological mappings. Although these two populations are not completely comparable since they represent different wells, the result may indicate the trend.

The compared parameters are chloride content and hardness. Soil and bedrock wells have been analysed separately in order not to mix the different water characteristics (see figure 2 and 3). The figures show that the hardness and chloride content for both soil and bedrock wells are usually higher in the wells located close to the road than the general values of the counties.

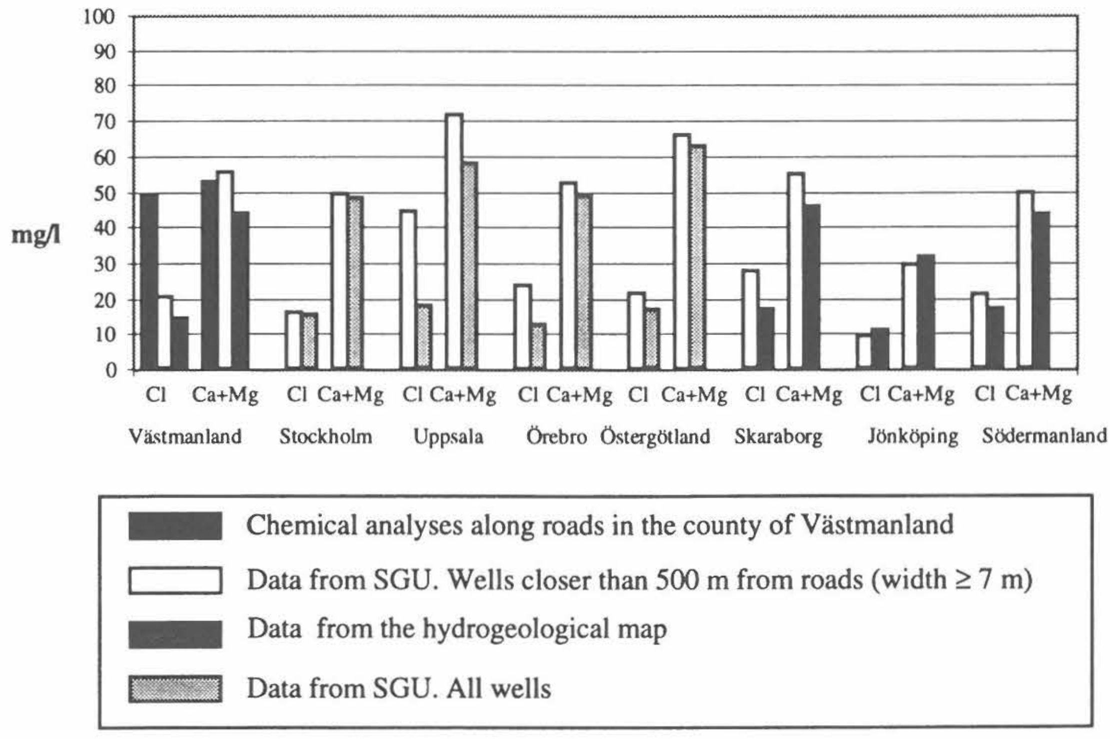


Figure 2 Median values of chloride content and hardness (Ca+Mg) comprising 8 counties, drilled wells

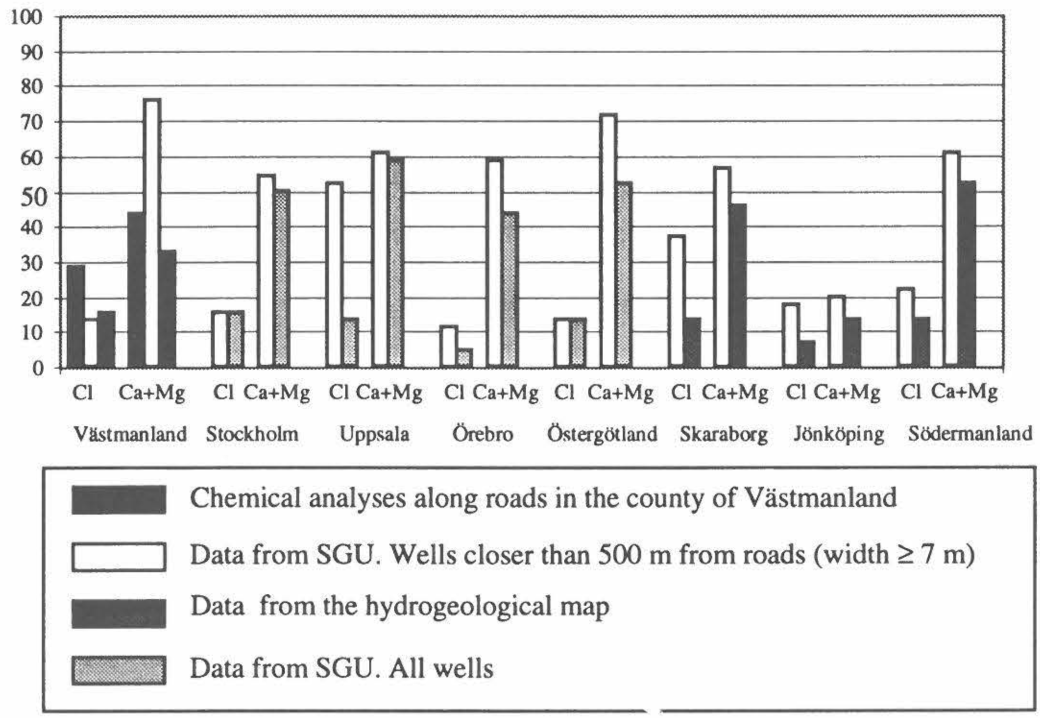


Figure 3 Median values of chloride content and hardness (Ca+Mg) comprising 8 counties, dug wells.

Statistical analyses

Principal component analysis gives a picture of the correlation between different parameters. If two parameters are running parallel they are highly correlated. The first two principal components are plotted in figure 4.

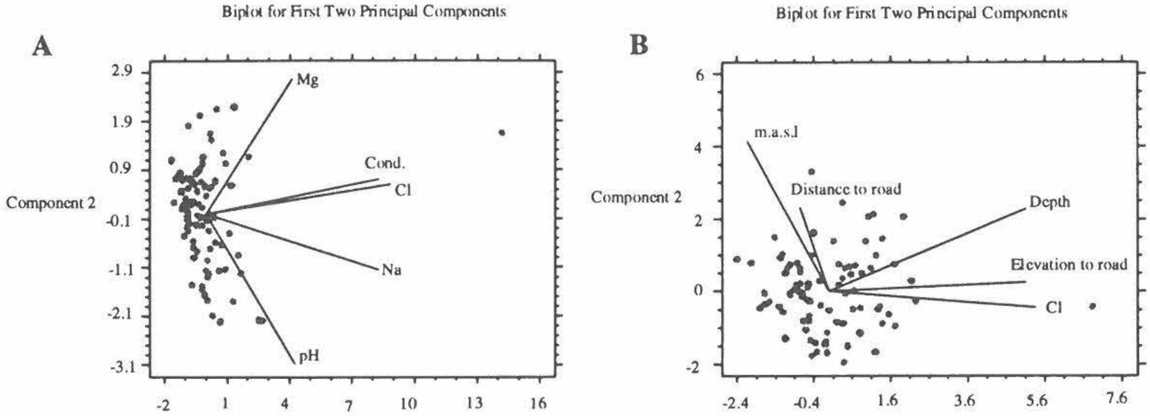
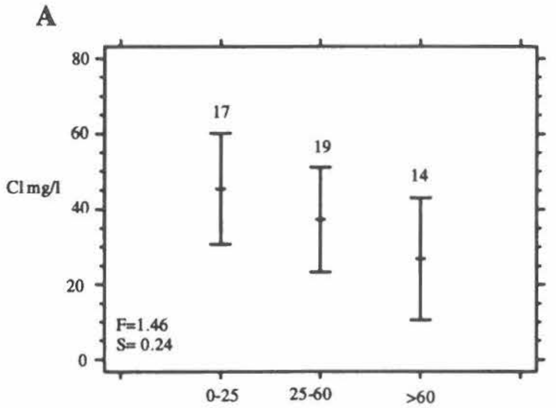


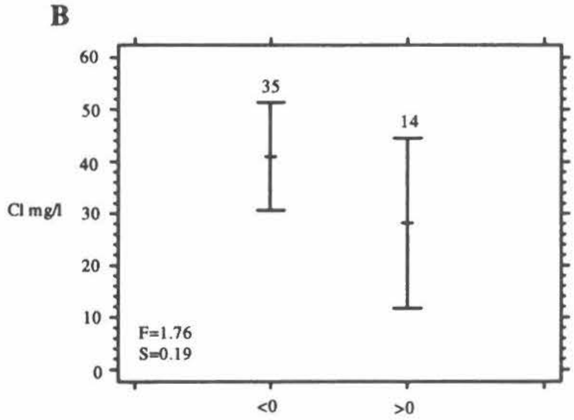
Figure 4 PCA - results from wells along roads in the county of Västmanland, 93 wells.

Figure 4A shows that the conductivity and the chloride content are highly correlated. In figure 4B, the depth and the elevation related to the road are relatively well correlated to the chloride content.

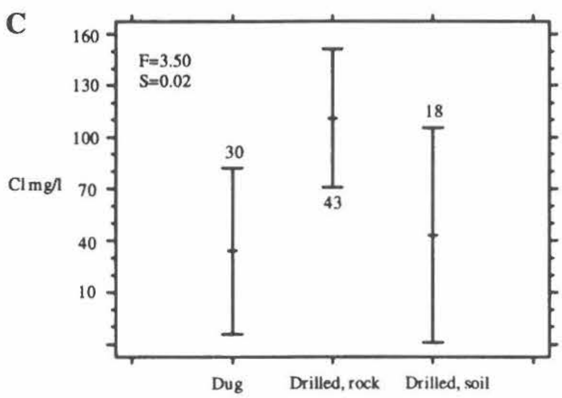
The results from the variance analysis (ANOVA) are presented in figure 5 A-F.



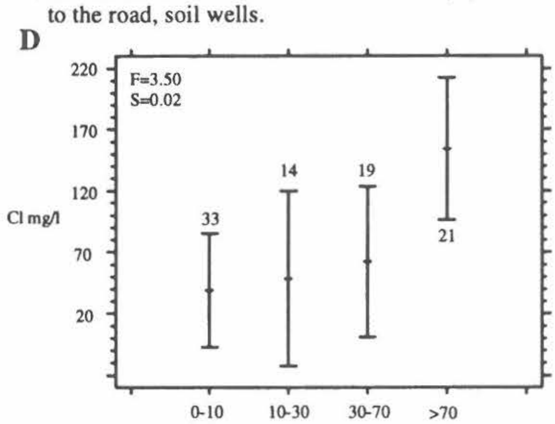
The chloride content versus the distance (m) to the road, soil wells.



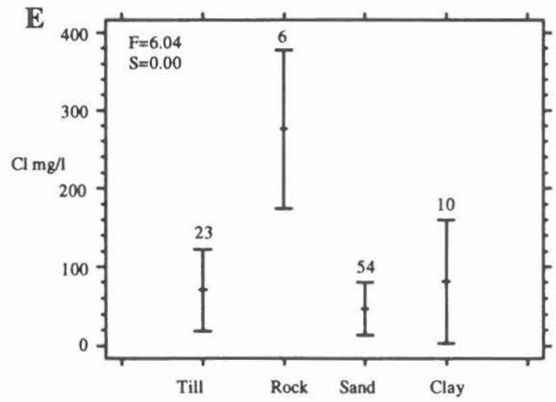
The chloride content versus the elevation (m) in relation to the road, soil wells.

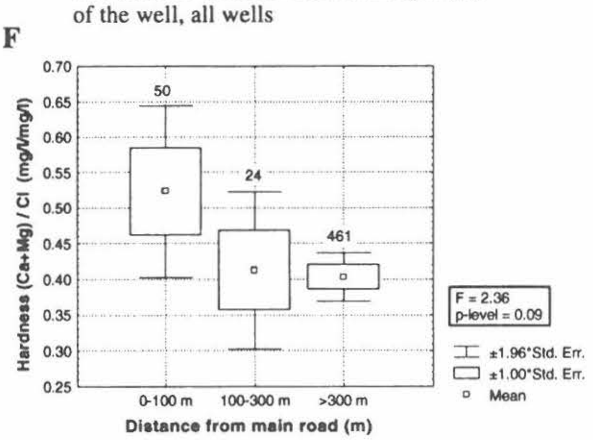


The chloride content versus type of well



The chloride content versus the depth (m) of the well, all wells





The chloride content versus the geology at the well, all wells. The Ca+Mg / Cl quota versus the vicinity to the road.

Figure 5 A-E Results from ANOVA carried out on wells along roads in the county of Västmanland (Median values are presented with 95 % confidence intervals). Figure. 5 F is based on data from SGU, comprising six counties.

The variance analysis showed that the chloride content decreases with increased distance to the road. Wells situated below the road surface have an enhanced chloride content compared to wells situated above the road surface. Figure 5 C shows that drilled rock wells have a higher chloride content than soil wells. Deep drilled wells have a significantly higher chloride content than superficial soil and rock wells. This is also shown in figure 5 E, in which wells situated in rock have a higher chloride content than the rest, due to that most rock wells are drilled to a relatively greater depth than wells in other geological settings. Figure 5 F shows that the hardness decreases with increased distance to the road, based on data from SGU comprising six counties in central Sweden.

The chloride content versus well depth

Wells sampled in the county of Västmanland and the well records from SGU have been analysed with regard to chloride content and depth (see figure 6 and 7). The chloride content is obviously higher in deep wells. The general trend in Sweden is an increased chloride content with increased depth (Engqvist et al. 1985). An increased chloride content in shallow wells contradicts this general trend.

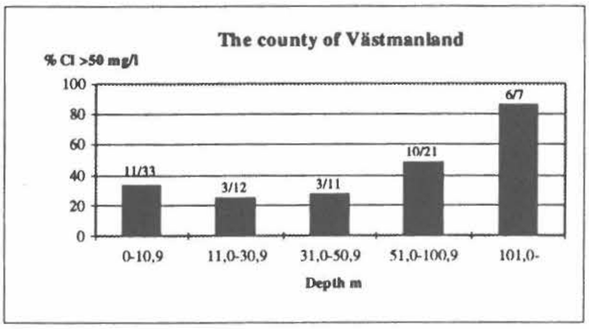


Figure 6 Enhanced chloride content versus. depths, county of Västmanland. (The figures above the bars show the number of wells with enhanced chloride content and the total number of wells).

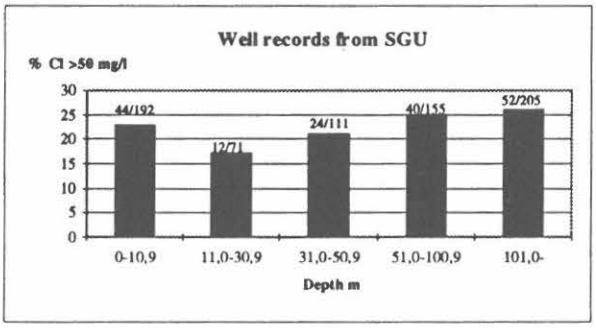


Figure 7 Enhanced chloride content versus. depths, well records from SGU, 8 counties. (The figures above the bars show the number of wells with enhanced chloride content and the total number of wells).

In total, 39% of the wells, presently in use along roads in the county of Västmanland, have a chloride content exceeding 50 mg/l. This figure can be compared to analyses of wells close to roads in the county of Västmanland selected from well records at SGU as well as to all well records from the county stored at SGU, which show an enhanced chloride content in 25% and 18% of the wells respectively, figure 8.

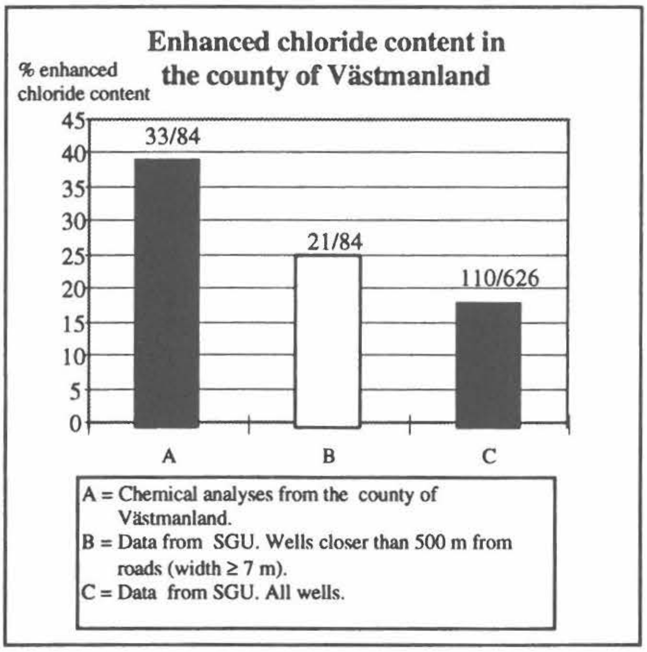


Figure 8 Enhanced chloride content of wells in the county of Västmanland. (The figures above the bars show the number of wells with enhanced chloride content and the total number of wells).

Discussion

A comparison between soil and rock wells shows that rock wells have a higher conductivity, pH-value, chloride content and usually a harder water. This is in agreement with for Sweden common situation. The conductivity and the pH-value increase with increasing depth of the well. When the chloride content raises the hardness (Ca+Mg), the pH-value and the conductivity tend to increase (Engqvist et al. 1985).

For the counties of Stockholm, Uppsala, Örebro and Östergötland (figure 2 and 3) it has been possible to compare a selected part of the well records with all well records stored at SGU. The results showed that wells close to roads had a higher hardness and in general a higher chloride content than the natural values. This is valuable for soil wells and for rock wells.

By ion exchange processes sodium may change place with adsorbed magnesium and calcium ions, which become released increasing the hardness of the groundwater. An increase of the chloride content in the groundwater close to roads is also obvious. The raised hardness in the groundwater as well as the increased chloride content can be explained by influence of road salt.

In the other investigated counties (figure 2 and 3) similar situation can be seen when wells close to roads are compared to well records compiled in connection to the hydrogeological mapping within these counties. However, the groups comprise two different populations which are not completely comparable. Also in this analysis an influence of road salt seems to have raised the hardness and the chloride content of the groundwater.

According to the results from the county of Västmanland, the vicinity and the elevation compared to the road are the major factors which influence on the vulnerability of the well for contamination of road salt. Wells situated at an altitude lower than the road surface and close to the road show a higher risk for contamination. This has previously been clarified by Canadian investigations (Howard & Beck 1993). De-icing salt on the road is transported to the surroundings as spray or as runoff water. Measurements have shown that 98 % of all the salt that is transported from the road surface is found within 50 m from the road borders (Demers & Sage 1989). Where the salt reaches the ground it may infiltrate to the groundwater, and hence contaminate wells situated close to the road.

Shallow wells (0-10 m) comprise a higher amount of salt affected wells than slightly deeper wells (10-50 m). The general trend ought to give an increasing chloride content with increasing depth (Engqvist et al. 1985). The superficial sources of salt, which can explain the high chloride content in shallow wells, include road salt, leaching sewers as well as leakage from waste deposits and industries.

Wells located close to roads in the county of Västmanland show an enhanced chloride content compared to the median content calculated from all wells in the county. The comparison between groundwater sampled along roads in the county of Västmanland and well record data from SGU as well as from well records compiled within the hydrogeological mapping are not completely comparable due to a higher amount of soil wells among the collected water samples. Soil wells have generally a higher risk for contamination. The significant difference regarding amount of salt affected wells in the county of Västmanland, between wells located close to roads (25-39%) and all wells in the same county (18%) can hardly be explained by other chloride sources than road salt. The minimum difference (7%) is probably underestimated because the selection of wells along major roads covers a distance of 500 m from the road, which probably is a much broader zone than can be affected by the road. A plausible assumption is that 10-20 % of the wells close to roads (within 100 m from the road) may be affected by road salt

Conclusions

The present investigation indicates that there is a general salinization of private wells along major roads in the central part of Sweden. As much as 40% of all the wells along major roads in the county of Västmanland showed an increased content of chloride. Wells located close to roads often show a higher median value of chloride and an increased hardness compared to the natural situation, which may be an effect of an external salt source, probably road salt.

The statistical analyses of wells in the county of Västmanland show that drilled rock wells generally have a higher chloride content than soil wells. The distance from the well to the road and the elevation of the well in relation to the road surface are the most important factors affecting the vulnerability to contamination. If the well is situated lower than, or close to the road, the risk for pollution increases significantly.

Acknowledgement

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