A COMPARISON OF SOIL- AND WATER CHEMISTRY IN A CATCHMENT IN CHINA WITH SITES IN POLAND AND NORWAY

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ABSTRACT

The results from a small catchment outside Guiyang in southwestern China are compared to results from catchments in Poland and Norway. Deposition, soil water, stream water and soils have been sampled and analyzed in all these catchments, using similar techniques.

The sulfur deposition is high in the Chinese catchment, as in some of the Polish catchments. Base cations, especially calcium, is an important part of the cations in deposition in Guiyang; in most of the Polish catchments ammonium is important together with calcium. At the Norwegian sites ions originating from sea salts are very important.

The concentration of monomeric inorganic aluminum complexes (Ali) in soil water is high in the Guiyang catchment, as in the Polish catchments. However, the high calcium concentrations keep the Ali/(Ca$^{2+}$+Mg$^{2+}$) ratio relatively low in the Guiyang catchment; only in one plot the molar ratio is commonly observed above one, which often is considered as potentially harmful. Surface waters in two of the Polish sites (Ratanica and Brenna) and in the lower part of the Guiyang catchment have high sulfate and calcium concentrations and almost neutral pH. At the Czerniawka catchment in western Poland, and at the Norwegian sites, the pH in surface water is generally low, indicating lack of neutralization of the soil water before it enters the stream.

1. INTRODUCTION

Acid deposition is an existing or potential problem in many parts of the world (Rodhe, 1989). During the 1970s extensive research concerning ecosystem effects of acid deposition was carried out in Europe and in North America. Later, in the early eighties,
Table 1. Characteristics of the different catchment involved in the comparison

<table>
<thead>
<tr>
<th>Catchment</th>
<th>Climate</th>
<th>Altitude m.a.s.l.</th>
<th>Precip. mm</th>
<th>Major soil type</th>
<th>Texture class</th>
<th>Bedrock/parent material</th>
</tr>
</thead>
<tbody>
<tr>
<td>Guiyang</td>
<td>Subtropical</td>
<td>1320–1400</td>
<td>1175</td>
<td>yellow, dystric Cambisol</td>
<td>Loams</td>
<td>Sandstone</td>
</tr>
<tr>
<td>Janow</td>
<td>Temperate</td>
<td>200</td>
<td>550</td>
<td>Podzol</td>
<td>Sand</td>
<td>Sand</td>
</tr>
<tr>
<td>Ratanica</td>
<td>Temperate</td>
<td>270–427</td>
<td>850</td>
<td>Podzol/Luvisol</td>
<td>Sand</td>
<td>Sandstone, shales</td>
</tr>
<tr>
<td>Czerniawka</td>
<td>Temperate / sub-alpine</td>
<td>650–1050</td>
<td>1200</td>
<td>Podzol</td>
<td>silty sand</td>
<td>Gneiss</td>
</tr>
<tr>
<td>Brenna</td>
<td>Temperate</td>
<td>640–730</td>
<td>1300</td>
<td>dystric Cambisol/Cambic podzol</td>
<td>Sandstone</td>
<td>Sandstone</td>
</tr>
<tr>
<td>Birkenes</td>
<td>Temperate</td>
<td>205–300</td>
<td>1500</td>
<td>Podzol</td>
<td>Granite</td>
<td></td>
</tr>
<tr>
<td>Ingabekken</td>
<td>Temperate</td>
<td>280–370</td>
<td>1300</td>
<td>Podzol</td>
<td>Granite</td>
<td></td>
</tr>
<tr>
<td>HUMEX</td>
<td>Temperate</td>
<td>150</td>
<td>2560</td>
<td>Histosol/Podzol</td>
<td>Sand</td>
<td>Granite</td>
</tr>
</tbody>
</table>

References:

Guiyang: Larsen, 1994
Poland: Vogt et al., 1994a
Birkenes and Ingabekken: Mulder et al., 1992 (soils); Aune, B., 1993 (temperatures); Seip et al., 1990 (precipitation and altitude)
HUMEX: Vogt et al., 1992 (soils); Aune, B., 1993 (temperatures); SFT, 1993 (precipitation).
the fast industrialization led to an increased interest and worry about acid rain in other parts of the world, for instance in China. Norway was among the first countries in the world to start acidification research (Overrein et al., 1980). Parts of Poland has been among the worst affected areas, with extensive forest damage. China, with its fast industrial growth, experiences today large emissions of acidifying pollutants; effects have already been observed some places. In contrast to Europe, the emissions and hence the deposition of acidifying pollutants are increasing fast and what will happen to ecosystems in the near future is uncertain.

In this paper we compare some results from a catchment near Guiyang in China with different catchments in Norway and Poland.

2. THE CATCHMENTS

A summary of important characteristics of the different catchments is given in table 1. Locations of the different catchments are shown in Fig. 1.

2.1 China

The Guiyang catchment in Southwestern China (See Fig. 1) is located about 10 km. north-east of the city center of Guiyang, the capital of the Guizhou province (26°34'N, 106°38'E) (Seip et al., 1995; Larssen, 1994; Larssen et al., 1996). This 7 ha. catchment was in 1992 equipped with instruments for integrated monitoring of deposition, soils, soil water and surface water; probably as the first catchment in China. The catchment is lo-
cated in the subtropical region at an altitude of 1320–1400 m. Monsoons result in high precipitation during summer and much less during winter although the humidity is often high most of the year. The soils are mainly dystric cambisols, the vegetation is Chinese fur (*Cunninghemia lanceolata*), pine (*Pinus massoniana*) and wild rose bushes. No forest damage is apparent.

Precipitation has been sampled just outside the catchment. Throughfall has been sampled at 5 plots in the catchment, and soils and soil water at 7 plots. Two small first order streams join to form a second order stream in the lower part of the catchment, ending up in a dam at the lower end of the catchment. Surface water has been collected from the two first order streams and from the dam. For details about the catchment see Larssen (1994) and Larssen et al. (1996); about the soils see Liao et al. (1994) and Liao et al. (1996).

### 2.2 Poland

The four Polish catchments are presented in Vogt et al. (1994a). In all catchments samples of deposition, soil water, stream water and soils have been collected. The four catchments are relatively different with respect to deposition, and to some extent also with respect to the soils.

The *Janow* site is located about 70 km south of Lublin in southeastern Poland in the Lasy Janowskie forest (50°42'N, 22°24'E). The vegetation is mainly pine (*Pinus sylvestris*) with sparse blueberry (*Vaccinium myrtillus*) undergrowth. Lysimeters have been installed in two plots.

The *Ratanica* catchment is located about 40 km south of Kraków at an altitude ranging from 270 to 427 m.a.s.l. (49°51'N, 20°02'E). The climate is typically temperate with an annual precipitation of 850 mm. The vegetation is mainly beech (*Fagus sylvatica*) and pine (*Pinus sylvestris*) with blackberry (*Rubus hirtus*) and blueberry (*Vaccinium myrtillus*) ground vegetation. The soils are mainly luvisols and podzols developed in sand or sandy loams. Throughfall and soil water are sampled in three transects in the catchment at 29 plots, in addition to deposition and surface water.

The *Czerniawka* site is located in south-west Poland near the boarder of the Czech republic (50°48'N, 15°35'E). The annual amount of precipitation is about 1200 mm; about half falls as snow. The dominating tree species is Norway spruce (*Picea abies*), with a sparse ground vegetation of mainly grass and moss (*Polytrichum formosum*). Forest damage is serious at the higher altitudes of the catchment. Podzolic soils dominate in the catchment, with some leptosols at the high altitudes and fluvisols and histosols along the stream banks (Skotte, 1995). In addition to deposition and stream water, soil water has been sampled from 11 plots in the catchment.

The *Brenna* catchment is located about 70 km. south of Katowice, close to the Czech and Slovakian republics (49°40'N, 19°56'E). The dominating tree species is Norway Spruce (*Picea abies*) and the dominating soils are dystric cambisols and cambic podzols. Throughfall and soil water have been sampled at 21 plots along two transects, precipitation at two plots and surface water at the outlet in the lower part of the catchment.

### 2.3 Norway

The Birkenes catchment is located in southernmost Norway (58°15'N, 08°15'E) and has been intensively studied since 1972 (Overrein et al., 1980). This catchment is situated in an area where the population of trout (*Salmo trutta*) experienced a serious dieback since
the 1950’s. Norway spruce (*Picea abies*) and pine (*Pinus sylvestris*) are the dominating tree species and blueberry (*Vaccinium myrtillus*) the main undergrowth vegetation in the catchment. The major soil type is podzol over a bedrock of granite. Soil water has been sampled from 8 plots, the deposition and stream water have been monitored in detail.

The *Ingabekken* site is located in mid Norway (64°38’N, 12°18’E), and was selected in the latter part of the 1980’s as a pristine catchment to study natural hydrogeochemical properties. The lower part of the catchment is mainly covered with pine forest, while the upper part has an alpine character with several small bogs and bare rock. The mineral soil is mainly shallow podzolic soils on a granite bedrock (Christophersen et al., 1990). The dominating middle part is covered by ombrogenic bogs.

The *HUMEX* catchment is located in the relatively pristine western part of Norway (61°26’N, 6°26’E). The two main vegetation species in this catchment are moss (*Sphagnum sp.*) and pine (*Pinus sylvestris*) (Røren, 1993). Podzols are the dominating mineral soil in the catchment, but a considerable part of the catchment is bogs (histosols) (Vogt et al., 1994b).

In this comparison study only the mineral soils in the catchments are discussed.

3. DEPOSITION

Volume-weighted average concentrations of the major ions in precipitation for the selected sites are shown in Fig. 2. The total concentration is highest in the Ratanica catchment, followed by Guiyang and the Polish catchments. In the Birkenes catchment the total ion concentration is similar to those in the Czerniawka and Brenna catchments. However, if we only look at the ions with possible anthropogenic origin, the concentrations in Birke-

![Bar chart showing volume-weighted annual precipitation chemistry in the catchments. Cations in left bar, anions in right bar.](image-url)

Figure 2. Volume weighted annual precipitation chemistry in the catchments. Cations in left bar, anions in right bar. (References: Guiyang: Larsen, 1994; Poland: Vogt et al., 1994a; Birkenes and Ingabekken: Seip et al., 1990; HUMEX (data from Nausta meteorological station): SFT, 1993).
nes are markedly lower, while concentrations of seasalts are high due to the vicinity to the sea. The sea-salt dominance is even more pronounced at the two other Norwegian catchments, which are located near the ocean, and further away from any large anthropogenic emission sources. These two catchments (Ingabekken and HUMEX) are classified as relatively pristine sites. In Guiyang the concentration of seasalt in the precipitation is negligible because of the very long distance from the ocean. In the Polish catchments, especially Ratanica, the concentrations of chloride and sodium are surprisingly high in spite of the long distance from the sea (see: Farrell, 1995). Because of relatively dry conditions during parts of the year, soil dust may contribute considerably to the deposition in Guiyang and some of the Polish catchments.

The ion concentrations in throughfall samples are compared in Fig. 3. The concentration in throughfall samples is very sensitive to the vegetation type and density above the sampler, hence several samplers are used giving an average for the catchment. The differences between the sampling plots are large in Guiyang, where the median sulfate concentration in one plot was 1440 μeq/L and in an other 315 μeq/L (Larssen, 1994). The average of all the medians in Guiyang is 640 μeq/L. This large variation within the same catchment is explained by differences in vegetation density at the sampling sites combined with a high dry deposition.

The dry deposition decreases relatively fast when moving away from the emission sources. The Guiyang catchment is located close to large emission sources, hence the dry deposition is large. In the Norwegian catchments, located very far from the main emission sources, dry deposition is generally about 15% of the total deposition.

The sulfur deposition, as shown in table 2, is calculated from the SO$_4^{2-}$ concentration in precipitation and the SO$_2$ concentration in air. The deposition velocity ($V_d$) used to calculate deposition from air SO$_2$ concentration varies with many factors, including vegetation type and density. We used $V_d = 0.6$ cm/s, as an estimate of annual average in southern Poland. In addition to the wet deposited SO$_4^{2-}$ and the dry deposited SO$_2$, dry

![Figure 3. Median concentrations of ions in throughfall in the Chinese and Polish catchments. Cations in left bar, anions in right bar. (References: Guiyang, Larssen, 1994; Poland: Vogt et al., 1994a; Birkenes and Ingabekken: Seip et al., 1990; HUMEX (data from Nausta meteorological station): SFT, 1993).](image-url)
Table 2. Total sulfur deposition for the different catchments

<table>
<thead>
<tr>
<th>Site</th>
<th>Wet deposition gSm(^{-2})yr(^{-1})</th>
<th>Throughfall deposition gSm(^{-2})yr(^{-1})</th>
<th>SO(_2) air conc. μgS/m(^3)</th>
<th>SO(_2) deposition(^a) gSm(^{-2})yr(^{-1})</th>
<th>Wet deposition + dry deposited SO(_2) gSm(^{-2})yr(^{-1})</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Guiyang</td>
<td>4.01</td>
<td>—</td>
<td>22</td>
<td>4.16</td>
<td>8.2</td>
<td>Larsen et al., 1996</td>
</tr>
<tr>
<td>Janow</td>
<td>0.97</td>
<td>2.71</td>
<td>5.5 (^b)</td>
<td>1.04</td>
<td>2.0 (^c)</td>
<td>Vogt et al., 1994c</td>
</tr>
<tr>
<td>Ratanica</td>
<td>3.33</td>
<td>2.45</td>
<td>10.5</td>
<td>1.99</td>
<td>5.3</td>
<td>Vogt et al., 1994b</td>
</tr>
<tr>
<td>Czerniawka</td>
<td>2.25</td>
<td>4.10</td>
<td>11.3</td>
<td>2.18</td>
<td>4.4</td>
<td>Vogt et al., 1994b</td>
</tr>
<tr>
<td>Brenna</td>
<td>1.94</td>
<td>4.44</td>
<td>13</td>
<td>2.46</td>
<td>4.4</td>
<td>Vogt et al., 1994b</td>
</tr>
<tr>
<td>Birkenes</td>
<td>1.47</td>
<td>—</td>
<td>—</td>
<td>0.18</td>
<td>1.64</td>
<td>SFT, 1992</td>
</tr>
<tr>
<td>Ingabekken</td>
<td>0.35</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>0.35</td>
<td>Seip et al., 1990</td>
</tr>
<tr>
<td>HUMEX</td>
<td>0.55</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>0.6</td>
<td>SFT, 1993</td>
</tr>
</tbody>
</table>

\(^{a}\) Assumed deposition velocity in Guiyang and the Polish sites is 0.6 cm/s (see: Iversen et al., 1991)

\(^{b}\) At Jarzow EMEF station, NE of Lublin, data from Schaug et al., 1994.

\(^{c}\) The total deposition is probably somewhat higher (as the figure for throughfall indicates) due to high deposition of sulfate in dust.

Deposited SO\(_4^{2-}\) from aerosols may contribute significantly to the total sulfur deposition in certain dry areas. Based on the concentration in throughfall it is likely that dry deposited sulfate is of special importance at Janow, which also would be reasonable because of the small amount of precipitation.

The total deposition is highest in the Guiyang catchment, followed by Ratanica, Czerniawka and Brenna. The Janow catchment receives considerably less sulfur, but still higher than the Birkenes catchment. In the two pristine Norwegian catchments, Ingabekken and HUMEX, a considerable part of the total sulfur originates from sulfate in seaspray.

4. SOILS

In Fig. 4, average mineral soil properties for the different catchments are shown. The upper, organic soil horizon in the Guiyang catchment has the lowest effective cation exchange capacity (CEC\(_E\)) compared to all the other catchments, while for the B horizon the Guiyang catchment has the highest. The CEC is generally strongly correlated to the amount of organic matter and a variable organic content is probably the main reason for the different CEC\(_E\) values in the OA horizons in these catchments. In the B horizons particle size is more important. The Norwegian catchments and Janow have more than 60% base cations and less than 20% aluminum on the ion exchange sites in the OA horizon, while at the Guiyang site aluminum and base cations account for 40% and 50%, respectively. In the B horizon the aluminum saturation (AIS) is between 80% and 90% in all the acidified catchments except Brenna, where it is 74%. The pristine Norwegian catchments have an average AIS of 75% and 65%.

5. SOIL WATER

Soil water concentrations for the different catchments are shown in Fig. 5. The concentrations presented are averages of the median values for the B-horizon from each plot.
Figure 4. Cation exchange capacity (CECg), base saturation (BS%) and aluminum saturation (AIS%) for the catchments. (References: Guiyang: Larsen et al., 1996; Poland: Vogt et al., 1994a; Birkenes and Ingabekken: Mulder et al., 1992; HUMEX: Vogt et al., 1992.)
The large spatial and temporal variability in the different catchments is not shown in the figure, but should be kept in mind.

The total concentration of ions in soil water is highest in the Guiyang catchment, though hardly significantly higher than in Ratanica and Janow. The two other Polish catchments, Czerniawka and Brenna have on the average lower total ion concentrations in soil water, but still higher than the Norwegian catchments (Brenna is not shown in Fig. 5 because aluminum data is lacking).

Among the anions, sulfate is dominating in the Guiyang catchment and at the Polish sites. In the Norwegian catchments chloride of marine origin is the dominating anion, even though the sulfate concentration is considerable at Birkenes.

For the cations we see the same trend with seasalts in the Norwegian catchments; Na⁺ is totally dominating in the “pristine” catchments, while in addition the aluminum concentration is considerable in the acidified Birkenes catchment. In all the Polish catchments and in Guiyang aluminum is very important. In addition calcium is high in some of them, giving rise to very different Ali/(Ca²⁺+Mg²⁺) ratios (see figure 6). Although the basis is weak, this ratio is commonly used in critical load studies as an indicator of possible harmful effects on vegetation when exceeding unity (Sverdrup and de Vries, 1994; Downing et al., 1993). Because of the high concentration of calcium in Guiyang, the ratio is considerably lower than in the Czerniawka catchment where serious forest decline is observed. This illustrates the importance of calcium at the Guiyang site. A considerable part of the calcium is supplied from the deposition. Therefore it is a cause of concern, in terms of acidification, what will happen if the emission of base cations is reduced much faster than the SO₂ emission, as is the case for present plans to limit air pollution in Guiyang (Xiong, 1995, pers. comm.).

![Ions in soil water B-horizon](image)

**Figure 5.** Concentration of ions in soil water collected from the B-horizons in the catchments. Cations in left bar, anions in right bar. (References: Guiyang: Larssen, 1994; Poland: Vogt et al., 1994a; Birkenes and Ingabekken: Mulder et al., 1995; HUMEX: Vogt et al., 1994b.)
Figure 6. The molar ratio of Al/(Ca$^{2+}$ + Mg$^{2+}$) for soil water from the Guiyang and Czerniawka catchments. Each bar corresponds to median values for one lysimeter.

6. SURFACE WATER

The chemistry of the surface waters is very different in the different catchments (Fig. 7). In Ratanica and Brenna, and to some extent in the Guiyang catchment, neutralizing soil processes are taking place in deeper soil layers (and bedrock) giving rise to surface water with approximately neutral pH together with high sulfate and calcium concentrations. Hence it seems unlikely that surface water acidification will become a serious problem in these catchments. To what extent the results for the Guiyang catchment are representative for this part of China is uncertain. However the conclusions of Zhao and Seip (1991) and Xue and Schnoor (1994) indicate the same.
In the Norwegian catchments and in Czerniawka the pH is low because the bedrock is of poorly weatherable gneiss or granite.

7. ALUMINUM CONTROL

The concentration of aluminum in soil- and surface water is of great importance when discussing effects on ecosystems by acidification. Hence it is of interest to find a model describing the aluminum chemistry in the catchment. A simple model involving a gibbsite (Al(OH)₃) mineral phase has been, and still is, widely used in acidification mod-
Figure 8. Saturation indices (SI = log $Q/K_{sp}$) for synthetic gibbsite for the Chinese and Polish catchments. (References: Guiyang: Larsen, 1994; Poland: Vogt et al., 1994a).

els. Several authors have pointed out that this model actually does not fit with the observed aluminum data (Neal et al., 1987; Seip et al., 1989; Vogt et al., 1994b). Here we illustrate that this is the case also for the Guiyang catchment and for the Polish catchments (Fig. 8). It is clear that better models should be found, further investigation is needed to develop such models.

8. CONCLUSIONS

Sulfur deposition in Guiyang is the highest among the selected catchments. In Guiyang the calcium deposition is high, while ammonium is more important in some of the Polish catchments.

Concentration of inorganic, monomeric aluminum in soil water is very high in Guiyang, as in the most acidified Polish catchments.

The ratio of $\text{Al}^3+/\text{Ca}^{2+}+\text{Mg}^{2+}$ is lower in Guiyang than in Czerniawka, where serious forest decline has occurred. However, in one plot in Guiyang the ratio exceeds unity.

Soil acidification is likely, and may become a major problem in China.

Water acidification is not likely to become a serious problem in SW China, but more studies should be carried out.

Future trends will depend on emission of base cations as well as of sulfur- and nitrogen oxides.
REFERENCES


