Time-dependent variations in groundwater chemistry: the Norwegian groundwater monitoring network

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Introduction

In 1977, the Geological Survey of Norway and the Norwegian Water Resources and Energy Administration initiated the Nation-Wide Groundwater Network project (LGN) to coordinate the rigorous and systematic collection of groundwater data in Norway. Presently, LGN consists of 38 monitoring stations distributed all over the country, where groundwater level, temperature and chemistry are determined at regular intervals. In 1980, four of these stations, Birkenes, Åmli, Evje and Langvassli, were transferred to the National Program for Monitoring Long-Range Transported Air Pollutants, administrated by the Norwegian State Pollution Control Authority. Discussed herein are decade-long groundwater trends with monthly resolution for these four stations, all placed in Quaternary superficial deposits overlying acidic bedrock.

Results

A summary of results is given in Table 1.

Discussion

Time-series for the various parameters were plotted and analysed. Additionally, between-year (long-term) and between-month (seasonal) variations were investigated using boxplot diagrams. Finally, covariations between measured parameters were examined visually and treated statistically.

At Birkenes (1980-1993), the groundwater pH displays a typical sawtooth pattern and has decreased overall (Figure 1*a*). The cumulative departure from mean pH (cdm-pH) curve for Birkenes groundwater (mean pH = 5.13) increases overall from 1980 to 1989, and decreases rapidly from 1990 to 1993 (Figure 1*b*). Yearly median pH has dropped from 5.25 in 1981 to 4.98 in 1993, with marked declines in 1981–1982 and especially in 1989–1990 (Figure 1*c*). There is no indication

TABLE 1. Summary of LGN results for Birkenes, Åmli, Evje and Langvassli stations

Var	units	Birkenes (1980-1993)			Åmli (1980-1993)			Evje (1982-1993)			Langvassli (1980-1993)		
		min	mean	max	min	mean	max	min	mean	max	min	mean	max
pH		4.92	5.13	5.37	4.59	5.36	5.95	5.05	5.25	5.69	4.89	5.18	5.76
Cond	mS/m	2.98	4.21	5.63	1.77	2.32	4.48	2.00	2.55	3.81	1.63	2.15	3.30
Ca	mg/l	0.51	1.30	3.04	0.43	0.94	1.31	0.45	0.58	1.00	0.52	1.05	1.62
Mg	mg/l	0.28	0.47	0.73	0.16	0.26	0.44	0.19	0.24	0.33	0.11	0.23	0.41
Na	mg/l	2.34	3.36	4.60	1.16	1.64	2.11	1.62	2.09	3.30	0.79	1.15	1.57
K	mg/l	0.13	0.37	0.47	0.16	0.32	0.56	0.05	0.14	0.44	0.02	0.41	1.14
Cl	mg/l	3.70	5.67	9.00	1.20	2.01	2.90	2.20	3.15	6.60	0.40	0.87	2.20
SO_4	mg/l	3.90	5.62	7.70	1.70	3.22	5.50	2.80	3.74	4.90	1.70	3.81	6.50
NO_3	mg/l	26.00	341.90	1450.00	40.00	225.45	570.00	13.00	27.72	101.00	1.00	125.64	1200.00
Alk	meq/l	0.00	6.22	38.80	0.00	24.14	61.90	0.00	12.12	31.40	0.00	12.16	49.30
SiO_2	mg/l	4.40	5.12	5.70	2.80	7.36	9.00	4.20	4.83	5.30	5.10	7.99	11.00
Al	mg/l	159.00	341.78	616.00	10.00	96.54	180.00	141.00	264.63	510.00	348.00	478.88	885.00
depth	cm	125.00	296.97	468.00	260.00	344.52	408.00	92.00	160.80	233.00	12.00	30.82	85.00

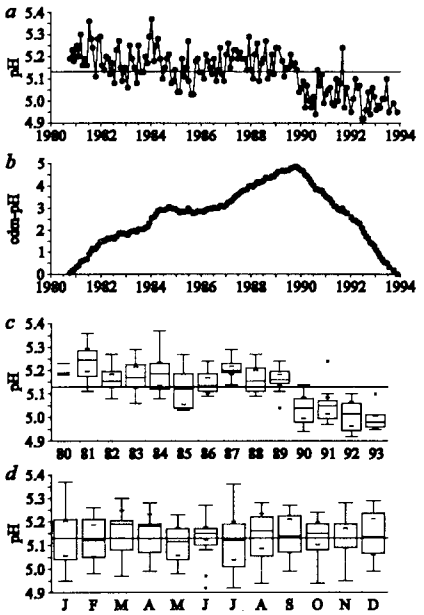

FIG. 1. LGN-Birkenes (1980–1993). Variation in pH as *a*: time-series (line is mean pH), *b*: cumulative departure from mean pH (5.13), *c*: between-year, and *d*: between-month boxplots.

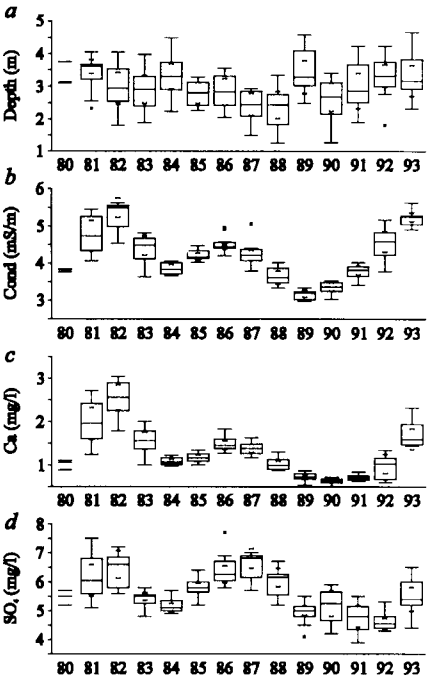

FIG. 2. LGN-Birkenes (1980–1993). Between-year boxplot diagrams showing long-term variations of *a*: depth to groundwater table, *b*: electrical conductivity, *c*: Ca, and *d*: SO_4.

of a significant seasonality in pH values (Figure 1*d*). Variations in depth to groundwater table and electrical conductivity at Birkenes are plotted in Figures 2*a*,*b*. Concentrations in Ca and SO_4 (Figures 2*c*,*d*) are positively correlated to conductivity. Groundwater level can not be correlated with any other parameter. The two strongest (positive) covariations are between Mg and conductivity, and Mg and Ca.

At Åmli (1980–1993), median pH shows a decrease from about 5.55 to 5.35, with the most rapid drop between 1981–1982 followed by relatively stable values. There is no indication of a significant seasonality in pH values.

At Evje (1982–1993), median pH oscillated between 5.2 and 5.3, showing no overall tendency to decrease. From 1990 to 1993, though, median pH has dropped from 5.3 to 5.2. There is no indication of a significant seasonality in pH values.

At Langvassli (1980–1993), interpretation of groundwater trends is complicated by the deforestation of the catchment area in 1986. Median pH first decreased from about 5.20–5.25 (in 1980–1982) to 5.05 (1986), then increased to about 5.26 (1993). Although there is a slight tendency for seasonality in pH values, it is not significant.

Conclusions

Time-series, boxplot, and correlation analyses are performed for four LGN stations with decade-long monitoring at a monthly resolution. At Birkenes and Åmli, the groundwater yearly median pH has decreased over the monitoring period. At Evje and Langvassli, it has fluctuated more irregularly. There is no indication of a significant seasonality in pH values at either station, whilst the groundwater level generally displays a seasonal variation. In general, there is no relationship between groundwater level and other measured parameters. The strongest noted covariations are for the pairs: Mg and Ca, Mg and conductivity, Na and Ca, Cl and K, NO_3 and Ca (all positive), and SO_4 and K (negative). Long-term trends in groundwater chemistry complement seasonality patterns revealed by short-term analysis, and, therefore, long-term monitoring is of paramount importance, alongside short-term investigations, for documenting and understanding the dynamics of groundwater resources.