

Vannkvalitet i to bekker fra jordbruksområder i Sørøst-Norge: Skuterud- og Mørdrebekken

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Sammendrag

I Norge har avrenning fra jordbruket vært viktig for vannkvaliteten i lang tid. Program for jord- og vannovervåking i landbruket ble satt i gang i 1992 og omfatter overvåking av jord- og næringsstofftap i 10 jordbruksdominerte nedbørfelt. Denne artikkelen tar sikte på å beskrive vannkvaliteten i to av de overvåkede bekkene (Skuterud- og Mørdrebekken). Vannføringsproporsjonale blandprøver fra bekkene ble tatt ut hver 14. dag i overvåkingsperioden. Prøvene ble analysert for 23 utvalgte vannkvalitetsparametere (pH, EC, SS, gløderest, DRP, TP, TN, $\text{NO}_3\text{-N}$, Na, K, Ca, Mg, Al, Fe, Zn, Cu, Mn, B, Mo, Si, Cl, HCO_3 , SO_4). For noen nedbørfelt blir også pesticidavrenning overvåket resultatene fra disse analyser er ikke tatt med her. Resultatene fra de 23 vannkvalitetsparametere viser at avrenning fra nedbørfeltene til Skuterud- og Mørdrebekken inneholder betydelige konsentrasjoner av flere stoffer.

Konsentrasjonen av jordpartikler og næringsstoffer er høyere om våren og høsten sammenlignet med vinter og sommer på grunn av jordbruksdriften og været. Ifølge klassegrenser definert under EUs RDV betyr konsentrasjonene av totalfosfor og totalnitrogen at bekkene har dårlig vannkvalitet. Konsentrasjonene for øvrig var stort sett under WHO/EU's grenser for drikkevann, unntatt Fe (0,75-2,8 mg L^{-1}) og Al (1,1-3,9 mg L^{-1}). Det er behov for nærmere undersøkelse av de høye konsentrasjonene av Fe og Al.

Summary

Water quality of two streams from agricultural watersheds in south-eastern Norway: Skuterud and Mørdre.

In Norway, the impact of agricultural runoff on water quality has been an important issue for long time. Since 1992, the National Agricultural Environmental Monitoring Program (JOVA) has been

monitoring sediment and nutrient losses from agricultural areas. The program comprises 10 agricultural watersheds across Norway. This paper attempts to describe the water quality of the Skuterud and Mørdre streams. Flow proportional composite water samples were collected at the outlets of Skuterud and Mørdre streams every two weeks during the monitoring period (1991/92-2009/10). The samples were analyzed for 23 selected water quality parameters (pH, EC, SS, suspended mineral, DRP, TP, TN, NO₃-N, Na, K, Ca, Mg, Al, Fe, Zn, Cu, Mn, B, Mo, Si, Cl, HCO₃, SO₄). Apart from this, pesticide concentrations are also monitored for some other streams which are not shown in this paper. In general, the concentrations of sediments and nutrients are higher during spring and autumn than summer and winter due to agricultural management practices and weather in Skuterud and Mørdre. According to the EU's WFD regarding concentrations of total phosphorus and total nitrogen the two streams are classified as having bad water quality. Furthermore, the chemical parameters showed concentrations below the WHO/EU limits and WFD standards for drinking water quality except for Fe (0.75-2.8 mg L⁻¹) and Al (1.1-3.9 mg L⁻¹). The high concentrations of Fe and Al (in both streams) are a concern that requires further investigation.

Introduction

The impact of soil and nutrient losses from agricultural land on water quality has been an important issue in Norway

since the early 1980s. In 1992, the Ministry of Agriculture and Food decided to set up a National Agricultural Environmental Monitoring Program (JOVA) to monitor soil and nutrient losses from small agricultural dominated watersheds. The program had two main goals: (1) to determine diffuse losses of suspended sediments and nutrients under different agricultural production systems in various parts of Norway and (2) to generate adequate data and knowledge for policy support and for the implementation of appropriate environmental measures. To achieve these goals, 10 watersheds representing important agricultural production systems, geo-hydrological settings, topographical, and climatological conditions were selected across the country, Figure 1. Skuterud and Mørdre



Figure 1. Location of the 10 monitoring sites including Skuterud & Mørdre, Norway.

watersheds were among the selected sites to document soil and nutrient losses from areas in the south-east of Norway.

Runoff from agricultural fields introduces soil, organic matter, manure, fertilizer, and pesticides into small streams and influences water quality (Cooper, 1993). The water quality of Skuterud and Mødre streams is adversely affected by runoff from nearby agricultural fields. The Skuterud and Mødre watersheds are roughly similar in land use but differ in soils, topography, climate, and hydrological processes. Hence, the quantity of runoff of nutrients, sediments, and water from these watersheds differs and so does the water quality of the streams. The hydrology, concentrations and losses of suspended sediments, nitrogen, and phosphorus in these streams have been described and evaluated in many reports and scientific papers (Øygarden et al., 2003; Bechmann et al., 2008; Deelstra et al., 2009; Rød et al., 2009) during the last two decades. Moreover, many other chemical parameters have also been analyzed but they have never been reported nor evaluated (in relation to water quality) so far. The aim of this study was therefore to describe and evaluate the water quality of Skuterud and Mødre streams in relation to chemical status.

Site description

Skuterud watershed

The Skuterud watershed covers an area of 449 ha and is located in the municipality of Ås in southeastern Norway. The geographical coordinates of the watershed are 59° 66' N and 10° 78' E. The

watershed area is relatively flat with small height differences. Average annual air temperature is +6.3°C ranging from monthly averages of -2.4°C in the winter to +16.5°C in the summer. Mean annual precipitation was 867 mm for the monitoring period with highest record (116 mm) in October (Rød et al., 2009). The dominant soils in the cultivated lands are silty clays with particle size distribution of 31% sand, 46% silt, and 23% clay. The agricultural land use constitutes about 60 % of the total area.

Mødre watershed

The Mødre watershed covers an area of 681 ha and is located in the municipality of Nes in southeastern Norway. The geographical coordinates of the watershed are 60° 06' N and 11° 24' E. The watershed is characterized by a typical inland climate with average annual rainfall of 721 mm in the monitoring period and annual temperature of +5.0°C (Rød et al., 2009). The topography of the watershed is dominantly flat with some ravines in between steep terrain against the main stream of Mødre. The highest elevation in the watershed is about 230 m a.s.l. The major soils types in the cultivated fields are silts with 77% silt, 8% sand, and 15% clay contents. More clay soils are found along the stream banks. The agricultural land use constitutes about 65 % of the total area.

Methods

Runoff measurements

Runoff measurements were carried out since 1993 in the Skuterud stream and

since 1991 in the Mørdre stream as part of the Agricultural Environmental Monitoring Program. Runoff are measured using a crump-weir where water levels are recorded automatically using a Campbell data logger in combination with a pressure transducer. The runoff is calculated on the basis of the existing head-discharge relation using the following equation:

$$Q = C \times B_c \times h_1^a$$

where, Q is discharge ($\text{m}^3 \text{T}^{-1}$) C is a coefficient, B_c is width of the crest (m), and h_1 is water level (m) measured at control section. The coefficient corrects the friction losses, possible flow curvature and non-uniform velocity distribution by neglecting the velocity heads at the measuring station (Deelstra et al., 2005). The watershed boundaries are evaluated based on both surface and subsurface water assuming that all the excess water from precipitation (in Skuterud and Mørdre watersheds) will flow as runoff into the streams. Thus, the discharge in the streams ($\text{m}^3 \text{T}^{-1}$) was converted into mm so as to relate with the precipitation rate.

Sampling and chemical analysis

Composite water samples were collected automatically (on a volume proportional basis) at the monitoring stations of Skuterud and Mørdre streams. The water sampling is controlled by a data logger. When a preset volume of water has passed the measuring station, a small water sample from the stream is taken and

added into a glass container (20 liter capacity). By default, composite water samples are collected from Skuterud (1993-2009) as well as Mørdre (1991-2009) streams every 14 days throughout the hydrological year (i.e. 15 October to 15 October of the following year). However, since sampling is flow-proportional, samples are collected more frequently during periods of high runoff.

The Jordforsk/Bioforsk laboratory was used for running water analysis until May 2007. Thereafter, the analyses were done by Eurofins laboratory until 2009. Since then, the Toslab is carrying out the water analysis. Sampling, preservation, and transportation of the water samples to laboratories were performed as per standard methods. The water samples were analyzed for a range of parameters including pH, Electrical Conductivity (EC), suspended sediments, sediments minerals, Dissolved Reactive Phosphorus (DRP), total P, total N, $\text{NO}_3\text{-N}$, sodium, potassium, calcium, magnesium, zinc, copper, manganese, aluminum, iron, silicon, boron, molybdenum, chlorine, sulphate, and bicarbonate. All the water quality parameters are expressed in mg L^{-1} except for pH and EC ($\mu\text{S cm}^{-1}$). Chemical analyses for the 23 water quality parameters were carried out by the aforementioned laboratories following their standard protocols. Although the Skuterud and Mørdre streams are not used for drinking water, the drinking water quality standards of WHO (1992) and EU (1998) and classification defined in Water Framework Directives (WFD) by Direktoratgruppen Vanndirektivet (2009)

were used to evaluate the streams water quality in relation to chemical status.

Statistics

The data on chemical water quality parameters are presented as mean concentrations analyzed for all water samples that were collected during four seasons. These seasons are spring (March-May), summer (June-August), autumn (September-November) and winter (December-February). The mean values are not flow-weighted concentrations. The runoff data in studied streams are also mean

values for each season over the monitoring period (1991/92-2009/10).

Results and discussion

Runoff variability

Figure 2 depicts the quantity of runoff in Skuterud and Mørdre streams in winter, spring, summer and autumn during the monitoring period (1991/92-2009/10). In general, the maximum runoff (in each year) was registered during spring and autumn in Skuterud as well as in Mørdre streams. This is attributed to the higher precipitation rate in autumn coupled

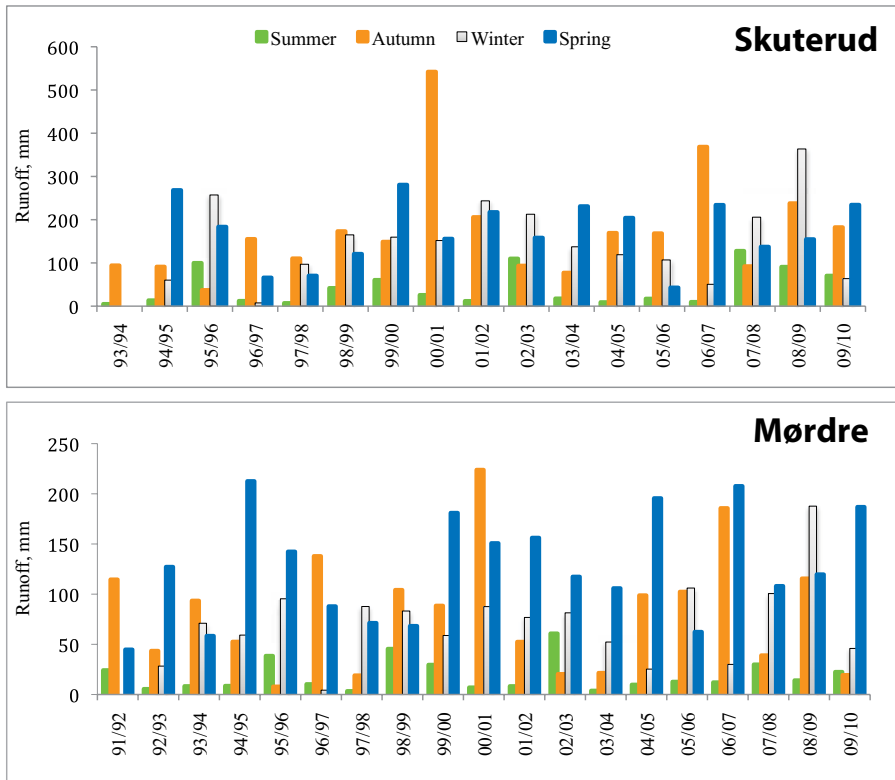


Figure 2. Runoff in Skuterud and Mørdre streams during spring, summer, autumn and winter, (1991/92-2009/10).

with low evaporation during cold season and furthermore snow accumulation during winter and followed by snow melting in spring. The minimum seasonal runoff (3.5 mm per 3 months) was recorded in summer in Mørdre 1997/98 and the maximum seasonal runoff (542 mm per 3 months) was recorded in Skuterud in autumn 2000/01 over the last two decades.

The mean annual runoff in Mørdre stream (294 mm) was almost 1.9 times lower than Skuterud stream. Mean seasonal runoff ranged from 43 to 174 mm in Skuterud stream. While in Mørdre stream, mean runoff varied widely from 18 to 127 mm during the four seasons. Mean annual runoff coefficient was 0.41

in Mørdre and 0.63 in Skuterud streams on measured data basis.

Water quality

For the sake of simplicity and clarity, the results of chemical analysis from Skuterud and Mørdre streams are categorised into four subsections. These are 1) acidity/alkalinity related parameters, 2) sediments and nutrients, 3) metals and 4) trace elements/anions. The results are presented in tables and/or figures which show mean concentrations of chemicals in the streams during winter, spring, summer and autumn from 1991/92 to 2009/10. Each chemical parameter was compared against the drinking water

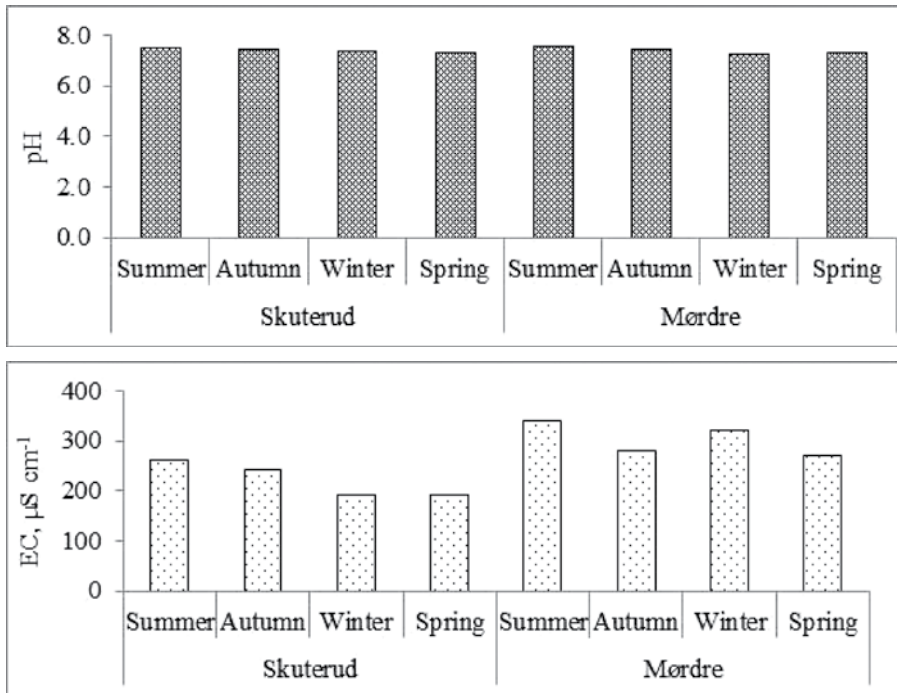


Figure 3. Seasonal mean pH and EC values in Skuterud and Mørdre streams.

quality standards of WHO/EU and some available data from WFD.

Acidity/alkalinity

pH & EC: Figure 3 shows the seasonal mean pH and EC values in Skuterud and Mørdre streams. Mean pH in the studied streams ranged from 7.2 to 7.5 during the whole seasons which could be classified as nearly neutral and non alkaline water.

Mean conductivity of the streams water ranged from 190 to 340 $\mu\text{S cm}^{-1}$ which are considered as non-saline water. The mean concentrations of EC in Mørdre stream were greater than Skuterud

stream in all seasons. The pH and EC concentrations in both streams were within the normal range ($\text{pH} = 6.5\text{-}8.5$ and $\text{EC} = 1000 \mu\text{S cm}^{-1}$) according to the drinking water standards of WHO (1992) and EU (1998).

Sediments and nutrients

Suspended sediments: Highest concentrations of Suspended Sediments (SS) were measured in Mørdre stream during spring, Figure 4. This is attributed to the high erosion risk of these areas and to snow-melt and runoff from agricultural fields following the cold winter. On the other hand, the lowest concentrations of

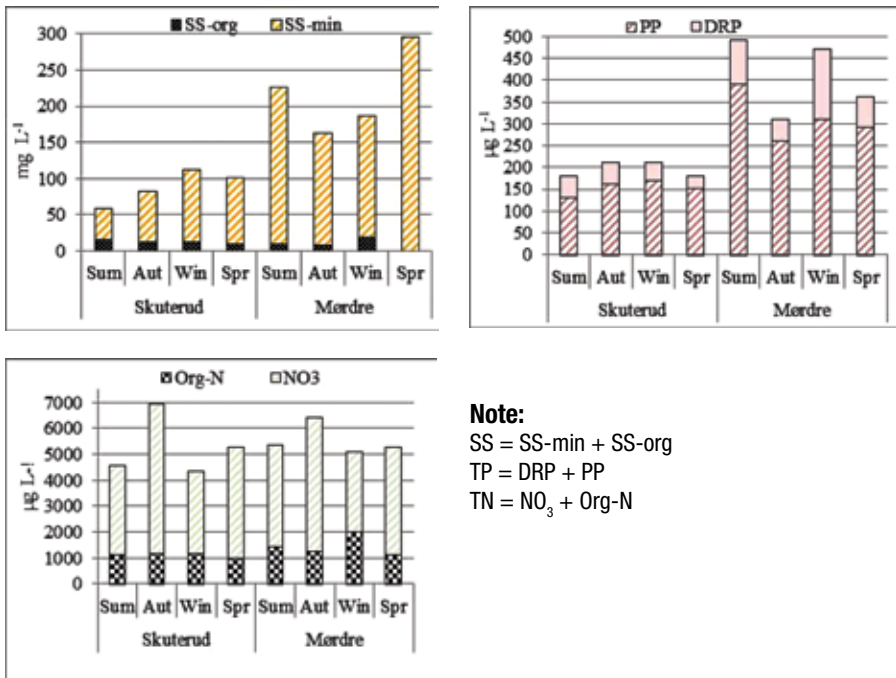


Figure 4. Seasonal mean concentrations of sediments, phosphorus, and nitrogen in Skuterud and Mørdre streams (1991/92-2009/10). Sum: summer, Aut: Autumn, Win: winter, Spr: spring.

sediments were measured in Skuterud stream during summer, probably due to good soil cover. The concentrations of SS ranged from 59 to 112 mg l⁻¹ in Skuterud and 163 to 296 mg L⁻¹ in Mørdre streams. These mean concentrations are almost 5 to 20 times greater than the WFD limit (10 mg L⁻¹) which are classified as bad water quality. The mineral part of the suspended sediments was on average 85% in Skuterud and 94% in Mørdre streams. In other words, the organic portion of the SS was 5% and 6% in Skuterud and Mørdre streams, respectively.

DRP and total P: Mean concentrations of dissolved reactive phosphorus (DRP) varied from 30-60 µg L⁻¹ and total P from 180 to 490 µg L⁻¹. The concentrations of phosphorus were higher in the Mørdre stream than in the Skuterud stream. On average year in the Skuterud and in the Mørdre streams, DRP constitutes 22% and 25% of the total P concentrations, respectively. The remaining 78% and 75% of the total P consists of particulate phosphorus (PP). The total P and DRP concentrations were >40-60 µg L⁻¹ and 10 µg L⁻¹, respectively which are

not acceptable according to WFD limits, Figure 4. According to WFD characterization, both the DRP and total P concentrations correspond to bad water quality (Direktoratsgruppa Vanddirektivet, 2009). On average 72 to 83% and 66 to 84% of the total P was in the form of PP in Skuterud and Mørdre streams, respectively.

NO₃-N and total N: Mean nitrate concentrations in the streams ranged from 3000 to 6000 µg L⁻¹ and total N from 4300 to 6900 mg L⁻¹ during spring to winter seasons. The NO₃-N and total N concentrations in Skuterud stream were greater than Mørdre stream in most of the seasons, Figure 4. In both streams, the total N concentrations were higher during autumn probably due to tillage of agricultural fields that triggers higher runoff. The seasonal NO₃-N and total N concentrations in both streams were six to seven folds greater than WFD's standard of 500-1000 µg L⁻¹ which are considered as bad water quality.

Na and K: The Na contents in both streams ranged from a minimum of 8 mg L⁻¹ to a maximum of 21 mg L⁻¹ which is

Parameter	Skuterud				Mørdre				WHO limits
	Sum	Aut	Win	Spr	Sum	Aut	Win	Spr	
Na	11.27	8.03	8.73	8.27	20.72	10.34	19.20	15.76	200
K	6.39	5.77	4.42	4.29	9.90	8.66	7.23	7.81	12
Ca	27.40	24.06	17.81	18.72	29.10	26.99	17.23	20.52	100
Mg	6.33	6.63	5.07	5.22	10.39	10.09	7.64	8.40	50
Si	6.82	9.75	8.07	6.61	10.45	15.11	8.90	10.74	100

Table 1. Seasonal mean values of Na, k, Ca, Mg and Si (mg L⁻¹) in Skuterud and Mørdre streams (1991/92-2009/10) and corresponding WHO limits.

much below the WHO/EU's 200 mg L⁻¹ guide value. Mean concentrations of K in the streams varied from 4 to 10 mg L⁻¹ which are below the WHO's 12 mg L⁻¹ limit. Almost all of the analyzed water samples for K from Mørdre stream measured above the concentrations of K in Skuterud stream, Table 1.

Ca and Mg: Mean concentration of Ca and Mg in both streams were in the range of 17 to 29 mg L⁻¹ and 5 to 10 mg L⁻¹, respectively. These concentrations were lower than the critical limits of WHO/EU for Ca (100 mg L⁻¹) and Mg (50 mg L⁻¹) in all the tested samples, Table 1.

Si: The mean Si content of the streams ranged from a minimum of 6.6 to a maximum of 15.1 mg L⁻¹. The maximum concentration of Si was measured in Mørdre stream during autumn. However, all concentrations of Si were below the critical limit of 100 mg Si L⁻¹ (Table 1).

Metals

Fe and Al: Mean Fe varied widely from 0.75 to 1.59 mg L⁻¹ in Skuterud and 2.23

to 2.82 mg L⁻¹ in Mørdre stream. The mean concentrations of Fe in Skuterud as well as in Mørdre stream were 3 times higher than the desirable limit (0.3-0.6 mg L⁻¹) of WFD. Mean Al varied from 1.07 to 2.58 mg L⁻¹ in Skuterud and 3.12 to 3.91 mg L⁻¹ in Mørdre stream. The Al concentrations in both streams exhibited also above the desirable limit of WFD, i.e. 0.2 mg L⁻¹ as shown in the Figure 5.

The highest concentrations of Fe and Al were measured in Skuterud during autumn and in Mørdre stream during spring. The Fe and Al concentrations in both streams could be classified as bad water quality according to the classification of WFD.

Trace elements and anions

Cu, Zn, and Mn: In Skuterud and Mørdre streams, the mean Cu concentrations were in the range of 0.01 to 0.04 mg L⁻¹. Zn concentrations varied from 0.01 to 0.16 mg L⁻¹ and Mn concentrations from 0.02 to 0.12 mg L⁻¹. Cu and Mn concentrations were below the critical value of 2.0 and 0.1 mg L⁻¹, respectively. However, the Zn concentrations in Mørdre streams

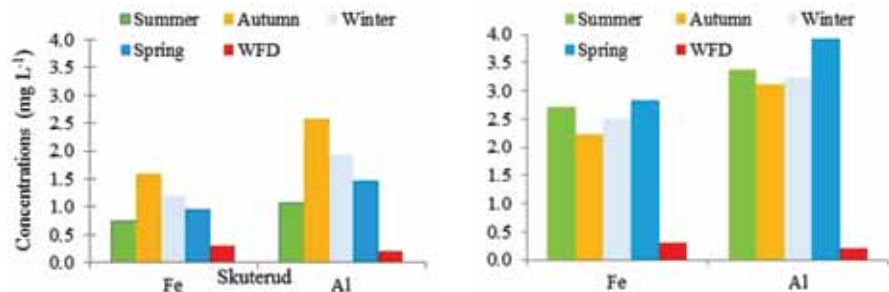


Figure 5. Seasonal mean concentrations of Fe and Al in Skuterud and Mørdre streams and WFD limits.

Trace element/anions	Skuterud				Mørdre				WHO/EU limits
	Sum	Aut	Win	Spr	Sum	Aut	Win	Spr	
Cu	0.01	0.01	0.01	0.01	0.04	0.03	0.02	0.03	2
Zn	0.01	0.01	0.02	0.02	0.16	0.07	0.10	0.14	0.01
Mn	0.02	0.02	0.02	0.02	0.04	0.03	0.12	0.05	0.1
Mo	0.11	0.02	0.02	0.02	0.01	0.01	0.02	0.04	0.07
B	0.05	0.05	0.04	0.06	0.08	0.07	0.08	0.05	0.3
Cl ⁻	20.11	18.17	15.24	14.94	28.64	22.98	21.51	25.39	250
HCO ₃ ⁻	63.86	48.66	41.24	167.71	93.99	54.00	65.73	55.56	400
SO ₄ ²⁻	8.15	6.03	5.06	5.15	8.12	9.97	11.75	8.23	200

Table 2. Seasonal mean values of some trace elements and anions (mg L⁻¹) in Skuterud and Mørdre streams (1991/92-2009/10) and corresponding WHO/EU limits.

were above the desirable limits of 0.01 mg L⁻¹ in all seasons but only during winter and spring in Skuterud stream, Table 2.

Mo and B: Mean concentrations of Mo and B in the studied streams ranged from 0.01 to 0.04 and 0.04 to 0.08 mg L⁻¹, respectively. The concentrations of Mo (in both streams) were three times lower than the critical limit (0.07 mg L⁻¹). Most of the analyzed samples for B were also lower than 0.3 mg L⁻¹ (the critical limit for drinking water).

Cl, HCO₃⁻ and SO₄²⁻: Mean Cl content of the streams was in the range of 15 to 28 mg L⁻¹ which was much below 250 mg L⁻¹ (a critical limit). Mean concentrations of HCO₃⁻ varied widely from 41 to 168 mg L⁻¹. The concentrations of HCO₃⁻ in Mørdre stream were greater than Skuterud stream except in spring when the HCO₃⁻ concentrations were three times lower. All HCO₃⁻ concentrations in both streams were below 400 mg l⁻¹ which ex-

hibited low alkalinity as the pH values of the two streams water also revealed (Figure 3). The HCO₃⁻ concentrations in both streams are as per the drinking water quality standards of WHO and EU. Mean sulphate concentrations in the streams ranged from 5 to 12 mg L⁻¹. All concentrations of SO₄²⁻ were much below the critical limit of 200 mg L⁻¹ (Table 2).

Concluding remarks

Mørdre stream contains higher suspended sediments and nutrient concentrations than Skuterud stream. The mean suspended sediments concentrations in Mørdre stream were 2.5 to 3 times greater than Skuterud stream in all seasons probably due to higher erosion risks of the Mørdre soils. The mean runoff in Mørdre stream was 1.5 to 2.5 times lower than Skuterud stream

The water quality of Skuterud and Mørdre streams are highly variable over time. By and large, the Skuterud and

Mørdre streams constituted higher concentrations of sediments, nutrients (particularly N and P) and metals (like Al, Fe) during autumn & spring compared to summer and winter. These differences may be explained by tillage of agricultural fields during autumn & spring on one hand. On the other hand, good soil cover plus nutrient uptake during summer and snow cover during winter might have contributed to low concentrations of sediments and chemicals in the streams.

The mean total P and total N concentrations in Skuterud and Mørdre streams is almost 4-8 folds greater than the WFD limits for good chemical status of water quality.

The minimum and maximum concentrations of Fe ($0.75\text{-}2.8\text{ mg L}^{-1}$) and Al ($1.1\text{-}3.9\text{ mg L}^{-1}$) in Skuterud and Mørdre streams were nearly 3-10 fold greater than WFD standards. The elevated concentrations of Al and Fe in both streams are a concern.

There is need for a comprehensive water quality assessment of Skuterud and Mørdre streams that takes into account the physical and biological constituents of water that affect the life of aquatic organisms in the streams.

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