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Urban geochemistry in Kristiansand, Norway

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ABSTRACT

Kristiansand is one of the participating cities in the European URGE project (URban GEOchemistry) that aims to map potentially toxic elements (PTEs) in the soil of European cities, identify sources of contamination, use health-based criteria for classification and cooperate with the local health authorities. For more than a century a metallurgical industry, including a large nickel smelter, was in operation in Kristiansand City. Despite the long industrial history of the Ni smelter, elevated Ni values (contaminated 200–<1200 mg/kg) in the surface soil (0–10 cm) are only found in a radius of < 1.5 km from the smelter and no samples within this zone are classified as extremely contaminated (120–<2500 mg/kg). Moderately elevated Ni-values (60–<135 mg/kg) are interpreted as natural elevated concentrations, and are ascribed to the local sulphide-bearing bands occurring within the banded gneiss that dominates the bedrock of Kristiansand. The general scarcity of easily accessible moraine and gravel in the Agder province and Kristiansand municipality has traditionally resulted in extensive reuse of urban soil, which might be reflected in some of the hot spots of PTEs in the suburban areas. None of the 300 samples collected in the area are above the Norwegian uncontaminated to moderately contaminated classification regarding Hg (1–<2 mg/kg) and Cd (1.5–<10 mg/kg). In general, the urban soil quality in Kristiansand is good and represents no hazard to human health. An exception is the residential areas close to the Ni smelter that are characterised by elevated values of As, Cu, Ni and Pb. Precaution has to be taken when old wooden houses are renovated to avoid the generation of new contamination of local soil and discharge to the Kristiansand fjord of PTEs that are in house paint.

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1. Introduction

Kristiansand is one of the participating cities of the 'Urban Geochemistry' (URGE) project, initiated by the EuroGeoSurveys Geochemistry Expert Group. This project aims to map chemical elements and other parameters defining soil quality in European cities, to identify sources of contamination, and to use health based criteria to classify the health risk from the most toxic elements in cooperation with the local health authorities.

In Norway, the 'Pollution Control Act' of 1981 regulates protection against pollution and concerning waste.¹ It is based on the polluter pays principle; for soil pollution, the present landowner can be held liable for investigation and remediation costs. The Geological Survey of Norway (NGU) started a geochemical mapping programme of urban

soil in Norwegian cities in close cooperation with the local authorities at the beginning of the 1990s. The soil quality criteria were then based on guidelines proposed by Hauge and Breedveld (1991). Ten years later, a large survey for characterising soil in child-care centres and public playgrounds was initiated (Ottesen et al., 2008, 2011). This survey followed a new set of soil quality criteria given by the Norwegian Institute of Public Health in 2007 (Hansen and Danielsberg, 2009), which are based on the work of Hauge and Breedveld (1991), Vik and Breedveld (1999), Ottesen et al. (2007). At present, the soil quality of almost all larger cities in Norway has been mapped and some cities as, for example, Trondheim have even been mapped repeatedly (Andersson et al., 2010; Moe, 2015).

In the present study, the concentration levels of inorganic elements of topsoil in Kristiansand has been analysed and evaluated regarding health based soil criteria given by the Norwegian authorities. Kristiansand city has been the home of a metallurgical industry, including a nickel smelter, for >100 years, and special attention on the impact from this industry will be given in the interpretation of the data and in the discussion of the element distribution in the topsoil of Kristiansand.

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1.1. Study area

Kristiansand is the fifth largest city in Norway with 87,446 inhabitants per January 2015.² It is also a municipality and the administrative centre of the Vest-Agder County, which is the southernmost county in Norway, bordering Rogaland to the west, Aust-Agder to the east and north, and the Skagerrak Sea to the south (Fig. 1). The landscape in the Kristiansand municipality is characterised by rounded hills with exposed bedrock or with thin humus or peat cover. In depressions and valleys, between the hills, till material or other superficial deposits occur (Follestad et al., 2013). There is little documentation of the predominant wind direction in the survey area, but a technical review of an area close to the city centre indicates a north to north-west predominant wind direction in the summer, whereas a south-east direction dominates from autumn to spring (Rieck, 2007). The wind speed is rarely greater than 'strong breeze'.

The bedrock is dominated by various felsic magmatic and sedimentary rocks of Mesoproterozoic age (1600–1000 Ma) that were metamorphosed at amphibolite facies conditions during the 1140–900 Ma Sveconorwegian orogeny (Starmer, 1991; Bingen et al., 2008; Engvik et al., 2016). The topographic depression defined by the Topdal fjord represents the brittle tectonic contact between the Telemark lithotectonic block to the north-west and the Bamble lithotectonic block to the south-east (Fig. 1; Henderson and Ihlen, 2004; Mulch et al., 2005). Most of Kristiansand city is situated on the western side of the fjord and is dominated by banded and granitic gneiss (locally porphyritic: 'augen') with minor amphibolite and marble (Fig. 1). The areas east of the Topdal fjord comprise primarily migmatite, banded gneiss and amphibolite (Fig. 1). The banded gneiss on both sides of the fjord are primarily of sedimentary and felsic volcanic origin (Falkum, 1966). Biotite-garnet-sillimanite schist (interpreted as metamorphosed shale) occurs within the banded gneiss <10 km north of Kristiansand, on the western side of the Topdal fjord, contain generally low amounts of trace elements (e.g., 30–49 mg/kg Ni and 73–130 mg/kg Cr; N = 9; Falkum and Grundvig, 2006). During construction of the new Highway E18 to the east of the Topdal fjord the sulphide and trace metal content of rusty bands within the gneiss was investigated (Bjerkgård and Nordgulen, 2002). Samples of these rusty bands contain relatively minor amounts of sulphides and trace elements (e.g., 0.58–1.28% S; 20–25 mg/kg Ni; 26–38 mg/kg Cu; 57–102 mg/kg Cr; N = 5), and it was inferred that these could not have an impact on the environment (Bjerkgård and Nordgulen, 2002). However, the concentrations of trace elements in stream water draining the three construction sites increased by a factor of 25 to 400 (highest for Ni and Co, lowest for Cu) compared to pre-construction levels (Hindar and Nordstrom, 2015). However, the concentrations of As, Cr and Fe remained unchanged. Rapid weathering of minute amounts of sphalerite and pyrite is interpreted to be the reason for the elevated element concentrations in stream water (Hindar and Nordstrom, 2015).

Historically, Kristiansand has held a strategically important trading and defence position ever since it was founded on the west side of the river Otra by King Christian IV on the 5th of July 1641. In the 18th century, one third of the inhabitants were economically linked to the nine shipyards in the town and at the beginning of the 19th century, the town of Kristiansand housed one of the world's largest fleets of sailing ships. Kristiansand has been regarded for several centuries as an important seaport and is still a busy international shipping port. The last shipyard was closed down in 1990 after 145 years of naval construction. It was located south of Kristiansand's railway station (location 1; Fig. 1). Along the outlet of the river Otra there were several industrial activities during the 18th century (Sødal et al., 2011). In modern times, there has been a gas plant at Tangen (abandoned in 1957; location 4) and a wood impregnation plant at Kjøita (abandoned in 1986; location 5; Fig. 1).

Marvika naval base was established in 1899 with boat slips and workshops (location 6; Fig. 1). The base was continuously in use by the navy until 2002.

Today, there still exist several active industrial areas in Kristiansand. At Fiskå, approximately 8 km from the city centre (location 2; Fig. 1), a metallurgical company is producing electrode paste and other specialised carbon products for the steel industry. Since 2009, the business has expanded to produce solar grade silicon. Historically, there was also a long period of ferrosilicon production at this site, which was terminated in 1979. Less than 2 km south-west from Kristiansand's city hall, at Hannevika (location 3; Fig. 1), another metallurgical company is located. Here a nickel smelting plant has been in production since 1910 under different owners. At present, high quality nickel and cobalt, in addition to copper, platinum group elements and sulphuric acid, is produced.

1.2. The Norwegian pollution control act (N-PCA)

The Norwegian Environment Agency together with NGU, Norconsult, Norwegian Institute for Public Health, Bioforsk and Aquateam produced guidelines for the classification of contaminated soil (TA2553/2009; Hansen and Danielsberg, 2009). This is a supplement to the Norwegian 'Pollution Control Act' (Act of 13 March 1981 No.6 Concerning Protection Against Pollution and Concerning Waste). Soil is classified into five classes from uncontaminated to extremely contaminated (Table 1). Only the most common toxic elements proven to influence the inhabitants' health are included in the legislation (Table 1). Soil with element concentrations above class 5 is defined as hazardous waste.

1.3. Facilities in Kristiansand with an exception to the pollution control act (N-PCA)

The Norwegian Environment Agency may on application issue a permit for activity that could lead to pollution. In Kristiansand, only two companies have permission to release inorganic elements to air. These are the two metallurgical companies in the Industrial area west of Kristiansand city centre (locations 2 and 3; Fig. 1). The company at Fiskå (location 2; Fig. 1), producing electrode paste and solar grade silicon, has permission to release Hg (10 kg/year), As (400 kg/year), Cd (20 kg/year), Pb (300 kg/year) and Ni (200 kg/year). The nickel smelter at Hannevika (location 3; Fig. 1) can release in total to air Ni (1700 kg/year), Cu (1900 kg/year), Co (260 kg/year). The smelter is also permitted to discharge As, Cd, Fe, Pb and Zn to the sea.³ However, some of these elements are also discharged to the air. The company is, therefore, decreed through the N-PCA and its supplements and guidelines to perform emission control of diffuse emissions to air for these elements ("The Pollution Regulation") ("Forurensningsforeskriften"⁴).

1.4. Remedial work

The first systematic mapping of contaminated soil and waste disposal sites for special category waste in Vest-Agder County, including Kristiansand municipality, was carried out by Misund and Tvedt (1990). It was then concluded that there were several sites in the Kristiansand area that needed further investigation. The driving force for the majority of the remediation work done in Kristiansand has been to reduce the contamination of the Kristiansand and Topdal fjord through the project 'Pilotprosjektet Kristiansandsfjorden'.⁵ Berge et al. (2007) summarises the remedial work done in the area between 2004 and 2007 to prevent run-off of toxic elements to the harbour area and the sea from contaminated soil situated on land. Projects where contaminated soil has been

³ <http://www.norskeutslipp.no/en/Lists/Virksomheter-med-utslippstillatelse/>.

⁴ <https://lovdata.no/dokument/SF/forskrift/2004-06-01-931>.

⁵ <http://www2.fylkesmannen.no/Vest-Agder/Miljo-og-klima/Kristiansandsfjorden/>.

² <http://ssb.no/befolkning/statistikker/folkendrv/kvartal/2014-02-20>.

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