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The inorganic drinking water quality of some groundwaterworks and regulated wells in Norway.

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REPORT

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Summary:

A selection of 351 wells and/or springs serving public waterworks registered at Nasjonalt folkehelseinstitutt (Norwegian Institute of Public Health) and 302 wells and/or springs registered at Mattilsynet (Norwegian Food Safety Authority) were analysed at NGU Lab for anions, cations, and a long range of trace elements as well as pH, alkalinity, turbidity, colour, and electrical conductivity.

Groundwater samples from bedrock boreholes are generally more mature than samples from wells in Quaternary unconsolidated sediments. This is shown by higher pH, alkalinity, and electrical conductivity as well as higher concentrations of most elements (except nitrate, aluminium and copper). The bedrock groundwater samples comprised generally the following water types based on dominating ions: Ca-HCO_3 type waters 77% ; Na-HCO_3 type waters 15% ; Na-Cl type waters 6% ; others 2%. The groundwater samples from unconsolidated sediments included the following water types: Ca-HCO_3 type waters 68% ; Na-Cl type waters 13% ; Na-HCO_3 type waters 9% ; Ca-Cl type waters 6% ; Ca-SO_4 type waters 4%.

In total, 51.5% of the water samples do not meet all the requirements in the current drinking water quality regulations. Elevated levels of manganese and/or iron are a common problem both in groundwater from bedrock wells (28% and 10.2%, respectively) and from unconsolidated Quaternary sediments (21.4% and 10.8%, respectively). A few samples breach the drinking water limits for arsenic and molybdenum (0.9% and 0.6% in bedrock wells, respectively), while the levels of cadmium, chromium, nitrate, and antimony are lower than the limits for all samples. Elevated copper, lead, and nickel concentrations seem to be due to leaching from water pipes and fittings as the levels are higher in water samples from private wells than from waterworks. In Norway, no limits are defined for uranium in drinking water. 7.2% of bedrock boreholes have uranium concentrations above the WHO guideline of 30 μg/L.

The dataset cannot be used to make a hydrogeochemical map of Norway. A few anomalies can however be found, such as elevated yttrium and rare earth element concentrations in groundwater from Quaternary aquifers in southernmost Norway.

Keywords: Geokjemi	Hydrogeologi	Borebrønn
Grunnvann	Berggrunn	Helse
Kartlegging	ICP-MS	Sporstoffer

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1 Introduction

Natural unpolluted groundwaters are far from pure H_2O. The soil and the rocks consist of a broad range of chemical compounds and water is an effective solvent. It is now well known that the groundwater of the alluvial plains in Southern Bangladesh contain elevated levels of arsenic, and more than 20 million people are at risk of developing skin cancer due to chronic arsenic poisoning. When aid organisations during the 1970s drilled thousands of tube wells to provide hygienic safe drinking water, no one thought about checking the trace chemistry of the water and the aquifer. Also in Norway, knowledge of the distribution of trace elements in groundwaters was almost absent until the first surveys were carried out in the 1980s and 1990s (Flaten 1986, Hongve et al. 1994, Banks et al. 1995a,b, Morland et al. 1997, Sæther et al. 1995, Reimann et al. 1996, Banks et al. 1998 a,b, Frengstad et al. 2000).

The national groundwater database in Norway "GRANADA" is run by NGU. NGU wanted to ensure that GRANADA contains a minimum of information about the most important wells in Norway, namely those which serves the public with potable water. The EU Water Framework Directive requires knowledge about the chemical status of groundwater bodies, and NGU wanted to improve the knowledge about the variation in inorganic chemical composition of groundwater on a national level.

In 2003 NGU thus sent letters to all waterworks based on groundwater in the Waterworks Register (VREG) of the Norwegian Institute of Public Health (Nasjonalt folkehelseinstitutt). The waterworks were requested to provide data and coordinates for their wells and were offered a free analysis of a broad range of inorganic chemical parameters. This work was organised under NGU project 324320 Well database (Brønndatabasen) and the following staff were involved: Malin Anderson, Jan Cramer, Sylvi Gaut, Pål Gundersen, Renata Viola and Pia Sunde. 205 waterworks of 569 (36%) accepted the offer of water analyses for 381 wells and/or springs. 161 of the samples were derived from bedrock aquifers, while 216 were derived from unconsolidated Quaternary aquifers. Lithologies were unknown for 4 samples. The samples were analysed at NGU lab for 32 cations by ICP-AES technique, 7 anions by ion chromatography in addition to pH, alkalinity, colour, turbidity and electrical conductivity. Peder Eide Helgason (2004) presented most of this material in his Master thesis. Due to problems with the ICP-MS instrument at NGU-Lab, analyses for a broad range of trace elements were not available before the thesis had to be submitted.

In 2005 the project was expanded to include also the groundwater wells registered at the Norwegian Food Safety Authority (Mattilsynet). These encompass wells serving schools and village halls as well as hot-dog stands and dairies. Also waterworks in VREG which had not answered in the first round were invited once more. 1098 invitation letters were sent in June 2005 and 241 well owners and waterworks responded (22%). Due to the modest response, new invitations were sent both in June 2006 and July 2007. By the end of November 2007, 579 well owners and waterworks had sent information about 679 wells or springs. Of these, 226 waterworks wanted water analysis for 273 wells and springs. In addition, 29 samples of waterworks and private wells from the three northernmost counties sampled during NGU project 304700 (Technical quality of bedrock wells) were included in order to make the dataset more geographically representative. In total, 302 groundwater samples were analysed in the second phase of the project. 185 of the samples were

derived from bedrock aquifers, 98 were derived from unconsolidated Quaternary aquifers and 27 samples had unknown aquifer lithology.
Tomm Berg took care of the incoming water samples and the information and sample lists, blanks and standards. An overview of batches and laboratory reports is given in Appendix 1.

2 Background

Norway occupies the western margin of the Pre-Cambrian FennoScandian shield and has the Caledonian orogenic belt as a NE-SW trending backbone. The Oslo region has experienced extensional rifting and volcanism during Perm and Carbon. With very few exceptions the country comprises crystalline, hard rock aquifers, which may be overlain by relatively thin Quaternary deposits. In upland areas the deposits are dominated by till and peat, while in the valleys and the lower-lying areas glaciofluvial sands and gravels and fluvial sediments dominate. Due to post-glacial isostatic rebound, marine silts and clays are found along the coast up to 200 m above the present sea level.

The majority of Norway's population live near the coast, mainly where rivers meet fjords. The valleys are also populated while the mountain plains are almost uninhabited. Arable land makes up around 3% of the total land area and farms are widely spaced. In rural areas, individual drilled wells in crystalline bedrock are often the only viable solution for water supply and it is estimated that around 300,000 people are supplied from at least 140,000 bedrock boreholes.

Previous investigations (Banks et al. 1998a,b, Frengstad 2002) has shown that groundwaters from crystalline bedrock aquifers are generally more hydrogeochemically mature than their counterparts in Quaternary drift deposits and displays a median pH around one pH unit higher. Potential drinking water quality problems in bedrock boreholes include radon, fluoride and uranium and elements of practical or aesthetical interest, such as manganese, iron, hydrogen sulphide and hardness. Wells in Quaternary drift deposits are less prone to water quality problems except for iron and manganese.

According to figures from the Norwegian Institute of Public Health (Folkehelseinstituttet) (Myrstad et al 2011) there are 1547 waterworks, each serving more than 20 households/50 persons. In total they supply 4,26 million people or around 90% of the Norwegian population. 62 % of the waterworks draw their water from lakes or rivers, while 38% are groundwaterworks. Around 10 % of the population are connected to public groundwaterworks. Groundwaterworks based on hard rock aquifers seldom serves more than 1000 people, while some towns (e.g. Lillehammer, Hønefoss, Elverum, Alta) have groundwaterworks based on aquifers in Quaternary sediments enhanced by river bank infiltration. The majority of larger towns and cities have their potable water from surface waters which supply 80% of the population. It should be noted that around 10% of the population have individual water supplies or are connected to waterworks supplying less than 20 households. Most of these water sources are deemed to be bedrock boreholes or springs/dug wells.

3 Why does groundwater contain solutes?

Remark: This chapter is mainly derived from Banks et al 2000 and Frengstad 2002.

Groundwater is not only water. It contains small concentrations of solutes of different origin. Normally, groundwater is derived from precipitation which percolates through the soil and fills pores and fractures in unconsolidated sediments and rocks. The chemical composition of groundwater thus often reflects precipitation, soil processes, pollution, marine salts and reactions with minerals in the ground. In addition, the water may also react in the well or the distribution network.

3.1 Precipitation

Precipitation is not pure distilled water, but often contains soluble constituents from windblown dust and sea salts (mainly sodium chloride - Na^+Cl^-), dependent on the climate and the distance to the coast. Precipitation will also equilibrate with natural atmospheric gases like CO_2 and industrial pollutants like NO_x and SO_2, most of them decreasing the pH of the water to a sub-neutral value. The amount of sea salts in groundwater normally decreases with the distance to the coast. Sulphate concentrations in groundwater may be somewhat higher in southern Norway than in northern Norway due to deposition of sulphur compounds in acid rain. The acid of acid rain is usually effectively neutralized in the ground, and acid rain seldom causes acid groundwater.

When rain or snow falls on the ground or on vegetation a significant amount will evaporate directly or be transpired by the plants. This will increase the concentrations of dissolved elements in the soil water, though their relative proportions will often be approximately conserved.

3.2 Soil processes

When the water percolates through the soil cover, the chemistry may change significantly. Plant roots will take up macro-nutrients like nitrate and potassium, but also a range of micro-nutrients like boron, copper, manganese and silver from the pore water (Epstein 1972, Reimann et al. 2001). Respiration of plant roots and micro-organisms consumes oxygen and produces carbon dioxide. The partial pressure of CO_2 in soil gas may well be 10 to 100 times higher than in the atmosphere (Brook et al. 1983). CO_2 dissolves in the groundwater, forming carbonic acid and thus strongly enhances the potential for rock weathering by acid hydrolysis.

Organic (humic) acids may be washed out of the soil. This gives the characteristic brown-yellow colour which surface waters and shallow groundwaters in Norway seasonally display.

3.3 Pollution

Anthropogenic pollution may influence the groundwater quality. Most groundwaterworks in Norway are situated in rural settings and the waters analysed in the present study are expected to be uncontaminated of urban and industrial activities. Possible sources of pollution might i.a. be

(i) agriculture - especially use of fertilizers and/or release of nutrients by ploughing of grazing land
(ii) Leakage from a septic tank or sewerage system
(iii) road salt
(iv) leakage of oil and oil derivates from storage tanks

In the two first cases, nitrate is a good indicator of possible contamination, although faecal bacteria or specific indicator bacteria are better proves of these contaminations.

3.4 Marin salts

Sea salts may enter groundwater in low concentration via precipitation. Larger concentrations of sea salts may occur in coastal areas due to:

(i) intrusion of water from the ocean. This may happen if the well is drilled too close to the coast and heavy pumping draw sea water into the well.
(ii) intrusion of fossil sea water, which may be found at depth as a result of sea water capture in fractures and pores during isostatic uplift after the last ice age.
(iii) leaching of salts from marin deposits (e.g. marin clay) which cover areas previously lying below sea level. These have emerged as a result of isostatic uplift in post-glacial time.

3.5 Reactions with minerals in the ground

Newly recharged soil water contains CO_2 and O_2 and is therefore acidic and oxidising. The common rock-forming minerals are basic (carbonate, silicate) and reducing (sulphide). For this reason groundwater will inevitably react with the bedrock via acid-base and redox reactions, and release quantities of dissolved material dependent i.a. on the mineralogical composition of the rock (Strömberg & Banwart 1994, Albu et al. 1997). These solutes are natural components of the groundwater and occur in varying amounts.

Utilised groundwaters from Quaternary drift aquifers in Norway are generally relatively soft, slightly acidic and clearly influenced by the chemistry of the precipitation (Banks et al. 1998b) This indicates that any soluble minerals possibly originally present in the permeable sediments have already been weathered and/or leached and also reflects the fact that the groundwater wells often draw on infiltrating surface water from adjacent rivers and lakes. In contrast, the mineral assemblage of glacial and post-glacial marine clays is normally illite, chlorite, quartz and feldspar with some amphibole and carbonate, and the extent of weathering is generally low (Hilmo 1989). Groundwater and pore water in these clays still carry remnants of seawater chemistry, including some high F^--concentrations. Na-HCO_3 type water is the norm and the pH values are mainly alkaline (up to 9.2) (Hilmo 1989).

The bedrock in Norway is relatively fresh and unweathered due to numerous events of glacial erosion and scouring during Quaternary time. Reactive minerals are thus available along the flowpath of the groundwater, either as gouge material, as precipitated minerals on fracture walls or as the rock-building minerals themselves. True chemical equilibrium between the flowing groundwater and the different mineral phases and common silicate components in the bedrock is seldom reached (Allard 1995). As weathering, redox reactions, complexation, dissolution and precipitation continuously occur along the pathway and water from different fracture systems and sources become mixed, the water chemistry at any sampling point is unique in terms of dissolved constituents.

In the following an introduction to the most important geochemical processes at the water-rock interface is given. More thorough descriptions are found in most textbooks on groundwater chemistry (e.g. Appelo & Postma 1994, Albu et al. 1997, Langmuir 1997, Saether & de Caritat 1997, Merkel & Planer-Friedrich 2008).

3.6 Dissolution

Minerals with ionic bonding, like halite (NaCl) dissolve in pure water, independently of pH. Most minerals have a far lower solubility than halite and a long reaction time. For example, dissolution of the mineral fluorite (CaF_2) releases calcium ions and fluoride ions:

$$CaF_2 \leftrightarrow Ca^{2+} + 2F^-$$

3.7 Hydrolysis

Water has the ability to dissociate by the reaction

$$H_2O \leftrightarrow H^+ + OH^-$$

with an equilibrium constant

$$K_w = \frac{[H^+][OH^-]}{[H_2O]}$$

The concentration of hydrogen ions are commonly described by pH, defined as pH = -log[H^+]. For pure water at normal pressure and temperature

$[H_2O] = 1$ and $K_w = 1.0 \cdot 10^{-14}$

Then $[H^+] = [OH^-] = 1.0 \cdot 10^{-7}$ and pH = 7.

During hydrolysis, the water reacts chemically with another reactant (e.g. a mineral). For example H^+ ions replace the cations of the mineral and OH^- ions accumulate in solution, thus raising pH. This process can be illustrated with weathering of forsterite (Mg_2SiO_4)

$Mg_2SiO_4 + 4H_2O \leftrightarrow 2Mg^{2+} + 4OH^- + H_4SiO_4$

If the water is acid, the hydrolysis process goes considerably faster. Conversely, hydrolysis of ferric sulphate ($Fe_2(SO_4)_3$) may result in an acid solution.

$Fe_2(SO_4)_3 + 6H_2O \rightarrow 2Fe(OH)_3 + 6H^+ + 3SO_4^{2-}$

Dissolved CO_2 in groundwater is distributed amongst the weak acids of the carbonate system:

$H_2O + CO_2 \leftrightarrow H_2CO_3 \leftrightarrow H^+ + HCO_3^- \leftrightarrow 2H^+ + CO_3^{2-}$

HCO_3^- is typically the most abundant anion in shallow groundwaters, indicating that the dissociated carbonate species in water are the most important H^+-supplier to weathering reactions. The weak acids react with bases (i.e. carbonate, silicate and aluminosilicate minerals) e.g. calcite

$CaCO_3 + H_2O + CO_2 \leftrightarrow Ca^{2+} + 2HCO_3^-$

This reaction is ubiquitous in groundwater. The reaction releases calcium and bicarbonate (i.e. alkalinity) to the water and groundwater in limestone aquifers is therefore often hard and alkaline. Through weathering of carbonate minerals about half of the resulting alkalinity is derived from the dissolved CO_2 in the water and the other half is derived from the carbonates.

If the rock contains only small amounts of calcite, also hydrolysis of silicate minerals like albite (sodium feldspar)may have a significant effect on groundwater chemistry.

$2NaAlSi_3O_8 + 2CO_2 + 3H_2O \leftrightarrow 2Na^+ + 2HCO_3^- + Al_2Si_2O_5(OH)_4 + 4SiO_2$

This reaction release sodium ions, alkalinity and silica, and a clay mineral (such as kaolinite) is produced. In this case all the resulting alkalinity is derived from the dissolved CO_2 in the water.

3.8 Redox reactions

Redox reactions involve the transfer of electrons from one species to another. The redox potential of a solution is a measure of its reducing or oxidising capacity, i.e. the ability to provide electrons to an oxidising agent or the ability to receive electrons from a reducing agent, respectively.

Solved oxygen in water may react with reducing minerals, such as pyrite:

$2FeS_2 + 2H_2O + 7O_2 \leftrightarrow 2Fe^{2+} + 4SO_4^{2-} + 4H^+$

and solved iron, sulphate and acid are released to the water.

The opposite reaction may occur in anoxic groundwater, where sulphate is reduced by organic matter to hydrogen sulphide. This solved gas gives the characteristic smell of «rotten eggs» that may be found in some boreholes:

$2CH_2O + SO_4^{2-} \leftrightarrow H_2S + 2HCO_3^-$

Many redox reactions also involve transfer of protons, i.e. H^+ ions, and the pH of the solution will thus often influence or be influenced by the reaction. In the geochemical environment, it is often the case that reduction reactions provide alkalinity to the water while oxidation reactions make the water more acidic.

Infiltrating rainwater is oxidising and groundwater will normally become gradually more reduced along a flow path as it loses contact with the atmosphere and reacts with decaying organic matter and reducing minerals in the subsurface. Redox reactions follow sequences with decreasing energy due to equilibrium and kinetic/microbial reasons. A typical sequence involves the disappearance of O_2, NO_3^- and SO_4^{2-} and the appearance of Mn^{2+}, Fe^{2+}, H_2S and CH_4.

Many redox reactions are mediated or enhanced by bacteria e.g. Fe^{2+}oxidation where the activity of *Thiobacillus ferrooxidans* increases the reaction rate by up to five orders of magnitude. To a large extent, redox reactions control the speciation of Fe and Mn, as well as C, N and S.

3.9 Sorption processes and ion exchange

Some minerals, like zeolites and clay minerals may have a negative charge due to substitutions of metals in the crystal structure, e.g. Al^{III} for Si^{IV}. Cations in groundwater may be sorbed to the solid surfaces in order to compensate the deficit of positive charge. Humic substances and amorphous Fe-, Mn-, and Al-compounds may also act similarly.

The amount of exchangeable cations that may be adsorbed to a material is measured as milliequivalents/100 g sample and is termed the cation exchange capacity, C.E.C. The cation exchange capacity is dependent on specific surface area, i.e. grain size, and the content of clay minerals, organic matter and oxides/hydroxides. The C.E.C. of organic matter is highly pH-dependent and increases with increasing pH. A typical ion exchange reaction can be written as:

$(Na)_2$ - clay mineral + $Ca^{2+} \leftrightarrow$ Ca – clay mineral + $2Na^{+}$

All cations in solution will compete for the exchange sites and this should be taken into account during calculations of ion exchange. The result is dependent on pH, ionic strength of solution, and concentrations of the individual ions. Divalent ions tend to displace monovalent ions and ions with a smaller hydrated radius replace ions with a larger hydrated radius, i.e. the affinity is dependent on charge density. Based on these criteria the following series may be defined (the cations most strongly adsorbed to the left):

$Ba^{2+} > Sr^{2+} > Ca^{2+} > Mg^{2+}$

$Cs^{+} > Rb^{+} > K^{+} > Na^{+} > NH_4^{+} > Li^{+}$

In coastal aquifers in contact with sea-water, the available exchange sites will mostly be occupied by Na ions. During postglacial isostatic uplift of the landmasses, fresh $Ca\text{-}HCO_3$ type groundwater may enter the aquifer and Ca-ions displace the Na-ions on the exchange sites as shown in the preceding equation. The resulting groundwater chemistry will typically be of $Na\text{-}HCO_3$ type. As long as the Ca^{2+}-concentrations in the groundwater can be kept low by ion exchange and calcite is still available in the aquifer, calcite dissolution is likely to occur and pH and alkalinity may increase according to the following equation

$CaCO_3 + CO_2 + H_2O \leftrightarrow Ca^{2+} + 2HCO_3^{-}$

or

$CaCO_3 + H_2O \leftrightarrow Ca^{2+} + OH^{-} + HCO_3^{-}$ (in the absence of CO_2).

When an aquifer in a coastal area containing fresh water is over-pumped, the reverse process may take place, with a Ca-Cl type groundwater as a result. Calcite precipitation is likely to occur, consuming alkalinity and driving the pH downwards according to the equation

$Ca^{2+} + HCO_3 \leftrightarrow CaCO_3 + H^{+}$

The water chemistry can thus give an indication on how the saline/fresh groundwater interface is moving. Cation exchange of Na for Ca is used in water conditioning equipment to soften hard water.

There are also minerals that act as ion exchangers for anions, like fluoride. Mica, apatite and amphiboles probably act as anion exchangers in contact with alkaline water:

mica-F + $OH^{-} \leftrightarrow$ mica-OH + F^{-}

This reaction implies that the hydroxyl ions are adsorbed on the mica grain and replace the fluoride ions which in turn are released to the water.

3.10 Kinetics

Only reactions that are reversible and fast compared to the residence time of the water can truly be regarded as equilibrium-controlled. Chemical equilibrium is not necessarily reached in a system if the chemical composition is constant with time. A steady-state situation may have occurred. For interpretation of irreversible, heterogeneous and very slow reactions, it is necessary to use the concept of chemical kinetics. The time required for different geochemical processes to occur is highly variable and a groundwater system will typically be in partial equilibrium.

It should be noted that the reaction rates may be dependent on factors like the chemical and crystalline properties of the aquifer minerals, on surface defects and on the presence of catalytic and retardation factors, including the activity of micro-organisms. Redox reactions including the species Fe, S, N and C and silicate weathering may be orders of magnitudes faster if biological activity is involved. Reaction rates are also temperature-dependent.

3.11 Transport and mixing

As groundwater moves along its flowpath, congruent and incongruent dissolution of carbonate and silicate minerals will increase pH, alkalinity and the amount of ions in solution. The groundwater becomes gradually more reduced (O_2, Mn^{IV}, NO_3^-, Fe^{III}, S^{VI}, and C become progressively reduced) due to oxidation of e.g. sulphides and organic matter. pH continues to increase, which in turn may lead to precipitation of secondary minerals like calcite or adsorption of trace metals. There is also a range of processes connected to transport, like mixing with old deeper groundwater (brines) or seawater. The hydrochemistry of the resulting groundwater is usually not a sole addition of the ions from the mixed waters as precipitation and/or dissolution of minerals are likely to occur. Hydrodynamic dispersion, diffusion and even reverse osmosis are of importance for water with long residence time in fissures of extremely low permeability (Pačes 1984).

3.12 Reactions in borehole and distribution net

Most of the groundwater samples in this study are not taken directly in the borehole, but usually at a tap somewhere on the net. The water chemistry may have been affected by reactions in the borehole or during transport from the borehole to the tap. Possible reactions include:

- Surface water may intrude the well
- Minerals may precipitate in the borehole or the distribution net.
- Elements like Cu, Pb and Zn may be dissolved from the armature
- There is a possibility that the water has been treated, though information about eventual water treatment has been requested from the well-owners.

4 Groundwater quality and health

This chapter summarizes the potential connections between health and the chemical composition of drinking water. For some elements the recommended concentrations and the maximum admissible concentrations (MAC) defined by national authorities differ significantly between different countries. For this reason not only Norwegian drinking water standards (Sosial- og helsedepartementet, 1995) and (Mattilsynet, 2005)) are given, but also standards from the European Union (EU, 1998), the USA (USEPA, 2009), Canada (Health Canada, 1996), Russia (Kirjuhin et al. 1993) and the World Health Organisation (WHO, 2008).

The following chapter is an updated version from the thesis "Groundwater quality of crystalline bedrock aquifers in Norway" (Frengstad, Groundwater quality of crystalline bedrock aquifers in Norway, 2002).

4.1 Physical and chemical parameters

4.1.1 pH

The pH of natural waters has no direct impact on human health, but many undesirable heavy metal elements are more soluble at lower pH. Low pH may also promote increased corrosion of the water supply net. Other elements of health concern, such as As and F, occur at higher concentrations at high pH (Frengstad et al. 2001). In Norway and the EU, the recommended pH-interval for drinking water is between 7.5 and 8.5, while the lowest admissible pH value is set at 6.5 and the highest at 9.5.

4.1.2 Alkalinity

Alkalinity is determined by titration with strong acid to a pH of around 4.5 and is thus also a measure of the acid buffering capacity of the water sample. In most water samples alkalinity is equal to $[HCO_3^-] + [CO_3^{2-}]$ where [ ] = concentrations in meq/L or $(HCO_3^-) + 2(CO_3^{2-})$ where ( ) = concentrations in mmol/l. For water of very high pH the concentration of OH^- should also be added when the alkalinity is calculated. High alkalinity in water has indirectly a positive effect on health due to reduced solubility of many heavy metals. In Norway there is no longer defined a limit for drinking water. The former recommended interval was 0.6-1.0 meq/L (36-60 mg/L HCO_3^-) to avoid corrosive water. The upper limit is probably set with regard to water hardness as high HCO_3^- concentrations often indicate high Ca^{2+} and Mg^{2+} concentrations.

4.1.3 Colour

The colour of water is classified according to the platinum-cobalt scale. A high value is usually caused by a high concentration of aquatic humic substances. Metals like iron and manganese associated with humus enhance the colour. Chlorination of water with high concentration of humus may lead to formation of chlororganic compounds like chloroform, which is suspected to causing cancer. Besides, humus can bind heavy metals and organic contaminants and change their mobility and bioavailability. In addition, colour can reduce the effectiveness of UV-disinfection.

Norwegian health authorities have defined a maximum admissible value for colour of 20 mg/L Pt.

4.1.4 Turbidity

Turbidity is a measure of the cloudiness of water and results of the scattering and absorption of light by suspended solids like clay or suspended iron. Turbidity of drinking water is always an aesthetic concern, but high levels of turbidity can also be associated with high levels of disease-causing microorganisms (USEPA 2009). High turbidity can lead to sludge formation in water pipes, which can cause odour and taste problems. Additionally, a large amount of fine particles can reduce the effectiveness of disinfection.

Norway operates a maximum admissible value of 0.4 FTU.

4.1.5 Conductivity

The electrical conductivity of a solution is a measure of its ability to conduct electricity. Pure water that, in the ideal case, contains only H_2O without any salts or minerals has a very low conductivity. Because the electrical current is transported by the ions in solution, the conductivity increases with increasing concentration of ions.

Measuring electrical conductivity is a routine procedure in groundwater sampling and gives a first indication about the chemical composition of the sample (Brattli 1999).

Norway operates a maximum admissible conductivity of 250 mS/m at 25°C.

4.2 Elements and anions

4.2.1 Silver (Ag)

The World Health Organisation does not regard silver as particularly toxic. Silver may be absorbed in the human body, but when bound to sulphur components in food, the absorption efficiency increases. Silver may accumulate in tissue, especially in the skin.

No limit is set for silver in drinking water in Norway. The former maximum admissible concentration (MAC) of silver in water was 10 μg/L. The United States Environmental Protection Agency has proposed a MAC of 100 μg/L in USA. No MAC is set in the EU.

4.2.2 Aluminium (Al)

Aluminium is the third most common element in the earth's crust after oxygen and silicon and is contained in most rock types. Virtually all natural water contains some aluminium, but the solubility is strongly dependent on pH and is very low unless the water is acid (pH<5.5) or extremely alkaline. Aluminium sulphate is widely used as a coagulant for water treatment to entrain suspended and colloidal matter and may also contribute to aluminium concentrations in treated drinking waters.

Comparisons of maps and correlation and regression analysis have indicated a geographical association between aluminium in drinking water and Alzheimer's disease in Norway, but there are some major uncertainties due to possible differences in diagnosis and registration on death certificates (Flaten 1986). Despite major research effort, the cause (or causes) of Alzheimer’s disease remains unknown and ordinary environmental exposure to aluminium is considered to be safe (Epstein 1988).

Norwegian health authorities (SIFF 1987) recommend Al concentrations below 0.01 mg/L (10 μg/L) in water used as dialysis fluids. The MAC of aluminium in drinking water in Norway and the EU is set to 0.2 mg/L (200 μg/L).

4.2.3 Arsenic (As)

Arsenic is an essential element in very small amounts. Arsenic is also carcinogenic and some trivalent As-compounds are highly toxic. Arsenic is a problem parameter in groundwater many places on earth (e.g. Southwest USA, Taiwan, South America, Mexico, India, Ghana, and Thailand), and chronic poisoning inducing keratotic lesions of palms and soles and skin cancer are documented (Edmunds & Smedley 1996). In the large river deltas of southern Bangladesh, 50 % of wells pump groundwater with As concentrations above the WHO Guideline Value of 10 μg/L. The arsenic is released to the groundwater from sedimentary Fe-oxyhydroxides under reducing conditions (Burgess et al. 2000). In Norway, in the EU, the USA and in Canada there is a MAC of 10 μg/L arsenic in drinking water in accordance with the recommendations from WHO. In Russia the MAC is set to 50 μg/L.

4.2.4 Boron (B)

Digestion of large amounts of boron may affect the central nervous system (SIFF 1987). The MAC in Norway and in the EU is 1000 μg/L. Russia has a MAC of 500 μg/L in accordance with the recommendation from WHO. Canada operates a MAC of 5000 μg/L.

4.2.5 Barium (Ba)

Barium may have negative health effects on heart, blood vessels and nerves (SIFF 1987). Barium sulphate (barite) has low solubility and elevated barium concentrations are thus likely to appear in groundwater with low sulphate content (e.g. under reducing conditions where sulphate is reduced to sulphide). Like in the EU there is no MAC in Norway. The former guidance level in Norway was 100 μg/L barium in drinking water. MAC is 2000 μg/L in the USA, 1000 μg/L in Canada and 100 μg/L in Russia. WHO recommends a limit of 700 μg/L.

4.2.6 Beryllium (Be)

No limits for beryllium concentrations in drinking water have been set in Norway. USEPA (2009) notes that long-term exposure to beryllium in drinking water above the MAC may cause intestinal lesions. The MAC in the USA is set to 4 μg/L beryllium. Beryllium is more likely to be found in acidic than in alkaline groundwaters and tends to be associated with feldspars and pegmatite bodies. Due to the insolubility of the oxides and hydroxides at the normal pH range, beryllium is seldom present in natural water at concentrations above 1 μg/L. The geochemistry of Be follows that of Mg due to the same valence and similar chemistry and Be may thus be preferentially taken up by organisms (Edmunds & Trafford 1993). WHO do not regard the available data to be adequate to recommend any limit. In Russia, the MAC is set to 0.2 μg/L.

4.2.7 Bismuth (Bi)

Bismuth is regarded as a non-essential element. Bismuth usually forms insoluble compounds and its mobility is low under oxidising and very low under reducing conditions (Reimann et al. 1998). In Russia, the MAC for bismuth in drinking water is set to 100 μg/L. No MAC values are set in western countries.

4.2.8 Bromine (Br)

Bromine is essential for some organisms, but is also regarded as toxic, particularly in some organic compounds (bromacil, bromadiolon, bromchloridfluormethane, bromomethane). Bromides have been used as sedatives for a long time (Crounse et al. 1983). Bromine is deemed undesirable in connection with water treatment, involving ozonation or chlorination due to possible formation of bromated and bromorganic compounds (Edmunds 1996). In natural waters, bromine normally occurs as the anion bromide (Br^-). Mobility and solubility is high under most environmental conditions. In Norway, no MAC for bromine is set. In Russia, the MAC for bromine in drinking water is set to 200 μg/L.

4.2.9 Calcium (Ca)

Calcium in groundwater is mainly derived from weathering of carbonates, plagioclase and mafic silicates. The sum of Ca and Mg ions in water is referred to as hardness, which may cause technical problems due to precipitation of carbonates in kettles and water heaters. Hardness also reduces the washing effect of soap. Some studies have indicated that hardness in water has a prophylactic effect against some cardiovascular diseases, but there is disagreement as to whether the effect is causal or due to secondary factors like reduced solubility of heavy metals. There is no MAC in Norway, but a former recommended span of Ca concentrations in drinking water was between 15 and 25 mg/L.

4.2.10 Cadmium (Cd)

Cadmium accumulates in the body and has a toxic effect on several organs. The element is known to induce bone and renal disease in populations exposed to contaminated drinking water (Crounse et al. 1983) and is also suspected to be carcinogenic (SIFF 1987). Cadmium may be derived from older fittings in pipework and on some occasions from cadmium mineralisations in the ground. Cadmium is particularly soluble in soft and acidic water. The MAC of cadmium in drinking water in Norway, the EU, the USA and Canada is 5 μg/L, while the MAC in Russia is set to1 μg/L. WHO recommends a limit of 3 μg/L.

4.2.11 Chloride (Cl^-)

The chloride content in shallow groundwater is normally determined by the salt content of the rocks and sediments and the supply from precipitation. Near the coast the rainwater resembles highly diluted seawater and the concentration of ocean-derived ions in rainwater and hence in groundwater decreases with increasing distance from the coast. Elevated levels of Cl occur in wells situated under the former marine limit where salts are washed out from marine deposits and where seawater may have been trapped in fissures and cavities in the bedrock. Wells drilled near the coast and with high abstraction rates may extract groundwater with a component of direct seawater intrusion. Use of $CaCl_2$ for de-icing of roads can also contaminate groundwater.

The chloride ion has no known negative impact on human health, but concentrations above 200 mg/L may add an unpleasant taste to the water. High concentrations of Cl^- will also accelerate corrosion of the distribution net, especially if the alkalinity of the water is low.

Norwegian health authorities have set a guidance level for Cl^- in drinking water of 25 mg/L and a MAC of 200 mg/L. WHO recommends an MAC of 250 mg/L. Canada and the EU operate a MAC of 250 mg/L.

4.2.12 Cobalt (Co)

Cobalt is essential and an important element in vitamin B 12. Larger doses of cobalt are toxic and deemed to be carcinogenic. Its solubility is highest under acidic and oxidising conditions. WHO and Norwegian regulations have not set any norm for cobalt in drinking water. In Russia there is set a limit of cobalt in drinking water of 1000 μg/L.

4.2.13 Chromium (Cr)

Chromium occurs in water both in trivalent and hexavalent form (Cr^{III} and Cr^{VI}). In natural groundwater Cr^{III} is expected to be the dominating species. Under oxic conditions and alkaline pH Cr^{VI} will dominate at equilibrium as a chromate anion (Allard 1995). Cr^{VI} may cause damage to the liver and kidneys and is registered as carcinogenic. The MAC for chromium in Norway, Canada and in the EU is set to 50 μg/L in accordance with recommendations from WHO. In the USA, the MAC is 100 μg/L. In Russia, the water directive distinguishes between Cr^{III} and Cr^{VI}. 100 μg/L is the MAC for Cr^{VI}, while up to 500 μg/L Cr^{III} is allowed. Cr^{III} is relatively insoluble under all conditions, but Cr^{VI} is more mobile (Reimann et al. 1998).

4.2.14 Caesium (Cs)

Caesium is regarded as a non-essential element. Caesium is most frequently associated with potassium in silicate rocks (Reimann and de Caritat 1998). 30 artificial produced isotopes are known but only the stable isotope Cs-133 occurs naturally. In large quantities it is mildly toxic as it resembles essential macrocations like potassium and can be built in accidentally (Kabata-Pendias & Pendias 1984). No drinking water limits are set.

It is emphasized that this report refers to the natural occurring caesium and not the radioactive caesium which is often associated with nuclear incidents.

4.2.15 Copper (Cu)

Trace amounts of copper are essential. Short-term exposure to higher doses may cause gastrointestinal stress, while long-term exposure may cause damage to the liver or kidneys (USEPA 2009). Fatal poisoning of small children from drinking water has been reported (Reimann et al.1998). Persons suffering from Wilson's disease may be particularly vulnerable to the negative effects of copper. There is inadequate evidence to state whether or not copper has the potential to cause cancer from a lifetime exposure in drinking water. Copper occurs in drinking water primarily due to its use in plumbing materials and its high solubility at low pH. Minor amounts may also be derived from the bedrock. Russia and Canada operate a MAC of 1000 μg/L. In the USA, the MAC is 1300 μg/L, while the MAC in the EU is 2 mg/L (2000 μg/L) as recommended by WHO. The Norwegian MAC is set to 100 μg/L.

4.2.16 Fluoride (F^-)

Fluorine is ubiquitous in nature, in one form or another. Dissolved in water it is found as the negatively charged fluoride ion. The minerals fluorite (CaF_2) and apatite ($Ca_5(PO_4)_3(F,Cl,OH)$) are rich in fluorine while smaller quantities occur in silicates such as micas (biotite) and amphiboles. Fluoride is released to groundwater by weathering or anion exchange at high pH levels.

Fluorine is an essential element, and has - at the right concentrations - a positive effect on human health, especially on our teeth and bones. Drinking water with a fluoride content of up to c. 1.0 mg/L is favourable and impedes the development of dental caries. Fluoride is therefore added to drinking water in certain countries. On the other hand, excessive fluoride concentrations in drinking water can harm tooth enamel when it is being formed (dental fluorosis). Drinking water given to children should not, for this reason, contain more than 1.5 mg/L and the use of additional fluoride-toothpaste or tablets should be avoided even at lower concentrations. Long-term exposure to very high fluoride concentrations in drinking water can cause skeletal fluorosis (deformed bones and even lameness (Edmunds & Smedley 1996). Neither dental nor skeletal fluorosis can be treated. Ca^{2+} in the water seems to suppress harmful effects due to complexing with the free fluoride ion (Krajnov & Shvets 1987). Consumption of high-pH, Na-HCO_3^- type waters with low Ca content may thus lead to fluorosis at lower F^- concentrations (Mwende & Dietrich 1999). In EU, Canada and Norway, MAC for F^- in drinking water is set at 1.5 mg/L as recommended by WHO. In the USA, MAC is 4.0 mg/L.

4.2.17 Iron (Fe)

Iron is an essential element to all organisms. Digestion of iron in normal concentrations from drinking water has no negative health effects (only toxic at concentrations above 200 mg/L (Reimann et al. 1998). On the other hand, in treatment plants using ultra-violet irradiation, iron (and manganese) colloids precipitated in the water might obstruct the UV light and thus reduce the disinfection effect. Water with a high content of iron may be brown-coloured and precipitation of rusty residues in the well or the distribution system may cause unattractive taste and appearance. The USA operates a guidance value of 0.3 mg/L (300 μg/L) which is in accordance with the Canadian MAC. The MAC in Norway and in the EU is set at 0.2 mg/L (200 μg/L), while Norway operates an additional guidance level of 0.05 mg/L (50 μg/L). Water with iron concentrations above this limit may cause yellow-brown staining on laundry and sanitary installations (SIFF 1987). Iron is commonly present in anoxic groundwater in the mobile ferrous form. The main sources are the dissolution of iron-bearing minerals such as magnetite, ilmenite, pyrite, siderite, ankerite, and the mafic silicates and the reduction of Fe-oxy-hydroxides such as goethite/limonite (Appelo & Postma 1994). In the normal pH range of groundwater (pH = 5-8) iron is dissolved as Fe^{2+}. Once the water becomes aerated, Fe^{2+} oxidises to Fe^{3+} and Fe-oxyhydroxides are precipitated.

4.2.18 Gallium (Ga)

Gallium is not known to play a decisive role in the biological cycle. It is moderately toxic but there is no MAC for gallium in drinking water.

4.2.19 Germanium (Ge)

Germanium is not known to play a decisive role in the biological cycle. It is of low toxicity and there is no drinking water limit set.

4.2.20 Iodine (I)

Iodine is an essential element. A daily intake of 0.15-0.2 mg is recommended. At lower intake levels, goitre can develop. Allergic reactions against iodine are not uncommon. The mobility of iodine is very high under all environmental conditions (Reimann & de Caritat 1998). Iodine is normally associated with evaporites, but the most important source in Norway is marine salts in precipitation. Testing of nuclear bombs and accidents at nuclear power plants may release health-threatening radioactive iodine isotopes.

4.2.21 Indium (In)

Indium is regarded as essential element in small amounts, though larger amounts can be toxic. Indium is most frequently associated with zinc materials like zinc blende (Reimann and de Caritat 1998). No drinking water limits are set.

4.2.22 Potassium (K)

There is no known relationship between potassium in drinking water and human health except the possible protective effect of increased dietary potassium on sodium-induced hypertension (Crounse et al. 1983). K is an essential nutrient for plants and is thus often removed from infiltrating water by vegetation. K is usually derived from weathering of mica and feldspar while high concentrations may indicate contamination from fertilizers. Norway does not longer have drinking water limits for potassium. The former guidance level was 10 mg/L and the former MAC 12 mg/L.

4.2.23 Lithium (Li)

Lithium is regarded as an essential element and a correlation between low lithium concentrations in drinking water and increased incidence of mental disorders is documented (Reimann et al. 1998). It is used in the treatment of manic-depressive disorders (Crounse et al. 1983), but with overdose many toxic effects can occur. No drinking water limits are applied in the Western countries; although Russia operates a MAC of 0.03 mg/L or 30 µg/L. Lithium is a soluble element and is often associated with sodium due to similar chemical properties.

4.2.24 Magnesium (Mg)

Mg together with SO_4^{2-} (Epsom salts) may have a laxative effect at concentrations above 300 mg/L $MgSO_4$ (SIFF 1987) corresponding to about 50 mg/L Mg and about 250 mg/L SO_4^{2-}. Diarrhoea may occur at lower concentrations among babies and sensitive persons. Mg also provides water hardness. Norway does not longer have a MAC for Mg. The former MAC for Norwegian drinking water was 20 mg/.

4.2.25 Manganese (Mn)

Manganese is essential to all organisms and deficiency in humans and animals occur (Reimann et al. 1998). Manganese in drinking water has no known direct health effects, but particles of precipitated manganese in the water may reduce the disinfection effect of UV irradiation and cause similar aesthetic problems to iron (see above). Precipitated manganese is usually dark brown to black. The MAC in domestic water in Norway, Canada and the EU is 0.05 mg/L (50 µg/L) while the guideline value in Norway is 0.02 mg/L (20 µg/L). WHO recommends a provisional guide value of 0.4 mg/L (400 µg/L).

4.2.26 Molybdenum (Mo)

Molybdenum is an essential element for most organisms, but is also regarded as potentially toxic at elevated concentrations. WHO has recommended a limit of 0.07 mg/L (70 µg/L), while Russia operates a MAC of 0.25 mg/L (250 µg/L). No limit is set for molybdenum in drinking water in Norway.

4.2.27 Sodium (Na)

Na, as Cl^- is a major component of marine salts. In addition, Na is derived from weathering of Na-rich rocks such as granite and gneiss. Hydrochemically "mature" groundwater samples will thus usually have higher Na than Cl^- concentrations.

Clinical and epidemiological studies have shown that sodium intake influences blood pressure. Higher blood pressure is believed to predispose individuals to strokes, and heart attacks as well as compounding renal disease and diabetes (Crounse et al. 1983). People who are on particularly low-sodium diets should not drink water with Na contents in excess of 20 mg/L. For those with a recommended daily sodium intake below 2 g, the drinking water should not contain more than 100 mg/L (SIFF 1987). In Norway there is a guidance level of 20 mg/L Na in drinking water and a maximum admissible concentration (MAC) of 200 mg/L. MAC in EU is set at 200 mg/L as recommended by WHO.

4.2.28 Niobium (Nb)

Niobium is regarded as non-essential and its toxicity is deemed to be relatively low. No limit is set for niobium in drinking water in the western countries, but Russia operates a MAC of 0.01 mg/L or 10 µg/L.

4.2.29 Nickel (Ni)

Nickel is an essential element. Bivalent nickel compounds are of relatively low toxicity, while other compounds such as nickel carbonyl may be toxic and/or carcinogenic (Reimann et al. 1998). The MAC in Norway and in the EU is 0.02 mg/L or 20 µg/L. The WHO has set a guidance value of 0.07 mg/L or 70 µg/L. In Russia MAC is 0.1 mg/L or 100 µg/L. USEPA (2009) reports no short-term health effects at concentrations above the MAC, but long-term intake of water with high nickel concentrations may cause reduced body weight, damage to heart and liver and irritation of the skin.

4.2.30 Nitrate (NO_3^-) and nitrite (NO_2^-)

Elevated concentrations of nitrate in drinking water are normally derived from sewage and livestock manure or from the use of artificial or natural fertilisers. It is thus recommended to analyse the water for bacteria content if NO_3^- is found in high concentrations in the drinking water. A part of ingested NO_3^- is transformed to NO_2^- in the intestinal tract and may cause infant methaemoglobinaemia or "blue baby syndrome" due to oxidation of the haemoglobin and thus reduced ability to transport oxygen with the blood (SIFF 1987). The disease may be fatal. NO_2^- can also undergo transformation in the stomach, colon and bladder to form N-nitroso compounds, known to cause cancer in a variety of organs in more than 40 animal species, including higher primates. A study of about 22,000 women in Iowa showed an increased risk for bladder cancer even at moderately elevated levels of nitrate in the drinking water (Weyer et al. 2001). The level of NO_3^- in groundwater has been increasing in many agricultural areas of the world, mainly due to extensive use of fertilizers and inappropriate farming practices (Van der Hoek et al. 1998). In Norway, MAC of NO_3^- is set at 10 mg/L expressed as NO_3^- – N or 44 mg/L expressed as NO_3^-. In EU, the corresponding numbers are 11.3 and 50 mg/L, respectively.

For nitrite, the Norwegian drinking water directive has defined a MAC of 0.05 mg/L expressed as NO_2^- -N or 0.16 mg/L expressed as NO_2^-.

4.2.31 Phosphate (PO_4^{3-})

High concentrations of phosphate in drinking water usually have the same sources as nitrate and may thus be an indication of contamination by sewage or fertilizers. Phosphate has no known negative impact on human health. Norway no longer has a MAC for PO_4^{3-}. The former guidance level was 0.4 mg/L (400 µg/L) and the MAC was 5 mg/L (5000 µg/L) of phosphorus expressed as P_2O_5. Measured as PO_4^{3-}, this corresponds to 0.27 mg/L and 3.35 mg/L, respectively.

4.2.32 Lead (Pb)

Lead accumulates in the body and may cause damage to the nervous system, blood and kidneys, particularly in small children (SIFF 1987). Delays in physical or mental development, including deficits in attention span and learning abilities are other potential health effects (USEPA 2009). Lead may be derived from the distribution system, but lead pipes are not widespread in Norway. In some cases, lead may be derived from mineralisation in the bedrock. Lead is particularly soluble in soft, acid water. The MAC in Norway, Canada and the EU are 0.01 mg/L or 10 µg/L and are in accordance to the recommendations of the WHO. Other drinking water limits are 0.015 mg/L (15 µg/L) in the USA and 0.03 mg/L (30 µg/L) in Russia.

4.2.33 Rubidium (Rb)

Rubidium is regarded as neither essential nor toxic element. It occurs as substitute for potassium in silicates and salts (Reimann et al. 1998). No drinking water limit is set for Rubidium.

4.2.34 Sulphate (SO_4^{2-})

SO_4^{2-} has a laxative effect and the Norwegian MAC for SO_4^{2-} in drinking water is thus set at 100 mg/L. Water with higher concentrations may have an unpleasant taste, but no serious health effects are known. Many mineral waters have SO_4^{2-}-concentrations well in excess of the drinking water standards (Albu et al. 1987, Misund et al. 1999). SO_4^{2-} may be an indicator of influence from acid rain, but is also one of the main components of marine salts. Oxidation of sulphides releases SO_4^{2-} to groundwater. A high sulphate content increases the risk of corrosion of the water distribution net, particularly when alkalinity is low (SIFF 1987). In addition to the MAC, a guidance level of 25 mg/L is set in Norway. In EU, MAC for SO_4^{2-} in drinking water is set at 250 mg/L as recommended by WHO.

4.2.35 Antimony (Sb)

Antimony is a non-essential element. The MAC in Norway and the EU is 0.005 mg/L (5 µg/L). In the USA and Canada, the MAC is set to 0.006 mg/L (6 µg/L). The WHO recommends concentrations below 0.02 mg/L or 20 µg/L. High concentrations of antimony will in the short-term cause nausea, vomiting and diarrhoea. In the long-term, a carcinogenic effect of antimony is suspected (USEPA 2009).

4.2.36 Scandium (Sc)

Scandium is regarded as a non-essential element and knowledge of potential health effects is relatively scarce. There are no drinking water limits for scandium.

4.2.37 Selenium (Se)

Selenium is an essential element to many organisms, but is also toxic in higher concentrations. The former MAC in Norway was 0.01 mg/L (10 µg/L). Both Canada and the EU operate a MAC of 0.01 mg/L (10 µg/L) which is in accordance to the guidance value of the WHO. In the USA, MAC is 0.05 mg/L (50 µg/L). The more restrictive Russian limit is set to 0.001 mg/L (1 µg/L). Elevated concentrations of selenium in drinking water may cause loss of hair and nails, numbness in fingers or toes and circulatory problems (USEPA 2009).

4.2.38 Strontium (Sr)

Strontium is deemed to be non-essential to most organisms. No limit is set for strontium in drinking water in Norway, but Russia operates a MAC of 7 mg/L. The radioactive isotope ^{90}Sr, which forms as a result of nuclear bomb testing and accidents in nuclear power plants, is highly toxic because it may replace calcium in the human body. Russia has set a limit of $4x10^{-10}$ mg/L for ^{90}Sr. However, the analyses in this report are concerned with the natural stable strontium isotopes (mainly ^{88}Sr).

4.2.39 Tantalum (Ta)

Tantalum is deemed to have no function in the biological cycle and is of very low toxicity. In nature the element is always associated with niobium and the mobility is low under all conditions (Reimann and de Caritat 1998). No MAC is set.

4.2.40 Thorium (Th)

Thorium is a naturally occurring radioactive trace element with chemical properties similar to those of rare earth elements (REE). Thorium is generally associated with potassium and uranium. As distinct from uranium, the mobility is very low under all environmental conditions. Of the common rock types, granites, granodiorites, shales and schists contain the highest Th concentrations. Thorium is considered non-essential. The health effects of thorium in drinking water are poorly known and drinking water limits are not defined.

4.2.41 Titanium (Ti)

Titanium is not known to be essential to any organism. The element seems to be of low toxicity and no drinking water limits are set.

4.2.42 Thallium (Tl)

Thallium is a metal that is associated with ores of copper, zinc, cadmium and gold. It is to a lesser extent present in other rocks, mainly connected to minerals rich in potassium and rubidium. The mobility of Tl is limited by incorporation into clays and sheet silicates and by adsorption. Typical concentrations in natural groundwaters range between 0.0001 and 0.01 μg/L and may reach a few μg/L where oxidation of sulphide minerals occurs (Shand et al. 1998). Thallium in drinking water may cause intestinal irritation in the short term and damage to nerves, blood, liver, kidney and testicles, as well as hair loss. USEPA has defined a guideline value of 0.5 μg/L and a MAC of 2 μg/L in the USA. In Russia, the MAC is set to 0.1 μg/L. Thallium sulphate has been used as rat poison, and the acute lethal dose for adult humans is about 1 g.

4.2.43 Uranium (U)

Uranium is a natural element, typically found in granites, granodiorites, black shales and schists. The solubility is low under reducing conditions, but is high in oxidising water, especially at low pH. Formation of complexes with other elements may further increase the solubility. Natural uranium has, as distinct from artificially enriched uranium, relatively low radioactivity. The chemotoxicity probably exceeds the radiotoxicity (Milvy & Cothern 1990). A drinking water limit of 30 μg/L is defined in Norway. This is in accordance to the MAC defined by the USEPA (2009). In Canada, the MAC is 20 μg/L (Health Canada 1996). It may be of interest that the Russian MAC for uranium is set to 1700 μg/L or 1.7 mg/L. WHO (2011) has finally set a guideline value of 30 μg/L for uranium after first been giving a provisional guideline value of 2 μg/L (0.002 mg/L) and then a updated provisional guideline value of 15 μg/L (0.015 mg/L) for uranium

4.2.44 Vanadium (V)

Vanadium is essential to some organisms, but is also regarded as potentially toxic. Vanadium is listed under undesired substances in the Norwegian drinking water directive, but no MAC is defined. In Russia, the MAC is 0.1 mg/L or 100 μg/L. Many natural crude oils contain significant amounts of vanadium.

4.2.45 Tungsten (W)

Tungsten is deemed to be a non-essential element, and knowledge about its toxicity is scarce. No limit for tungsten in drinking water in Norway is defined. In Russia, the MAC for tungsten in drinking water is 0.05 mg/L or 50 μg/L.

4.2.46 Yttrium (Y)

Yttrium is regarded as a non-essential element of low toxicity. There are no drinking water limits set.

4.2.47 Zinc (Zn)

Small amounts of zinc are essential for the human metabolism. According to SIFF (1987), no negative health effects of zinc in drinking water are known. Very high zinc concentrations may cause an acrid taste in the water. Norway does not longer have drinking water standards for zinc. The former guideline value was 0.1 mg/L (100 µg/L) and the former MAC was 0.3 mg/L (300 µg/L). Canada operates a MAC of 5 mg/L (5000 µg/L), which is consistent to the guideline value of WHO. In Russia the MAC is set at 1 mg/L (1000 µg/L).

4.2.48 Zirconium (Zr)

Zirconium is regarded as a non-essential element of low toxicity. There are no drinking water limits set.

4.2.49 Rare earth elements (REE)

"Rare earth elements" is a common name for the elements scandium (Sc), yttrium (Y), lanthanum (La), cerium (Ce), praseodymium (Pr), neodymium (Nd), promethium (Pm), samarium (Sm), europium (Eu), gadolinium (Gd), terbium (Tb), dysprosium (Dy), holmium (Ho), erbium (Er), thulium (Tm), ytterbium (Yb), and lutetium (Lu). They have similar chemical properties and are not deemed to be essential to any organisms. Rare earths which are digested via drinking water accumulate in skeleton, teeth, lungs, liver and kidneys. Knowledge of potential health effects of REE is relatively scarce, but generally they seem to be of low toxicity. The elements with higher atomic numbers seem to be less toxic than those having a lower atomic number. No drinking water limit is set for the elements belonging to this group. The solubility of the REEs is commonly regarded as low under all environmental conditions, despite the fact that many studies have indicated significant mobilisation of REEs during weathering, alteration, and diagenesis (Smedley 1991 and references herein).

5 Methods

5.1 Sampling

One 500 ml polyethylene bottle for each borehole or spring was sent to all the groundwater-works which had agreed to participate in the survey. The bottles were pre-marked with the name of the waterworks and a unique sample number, and the sampler was asked to note the sampling date and, if more than one sampling point, a numbering of the points with reference to coordinates. The following sampling protocol was given:

- Let the water run for at least five minutes before sampling in order to obtain fresh groundwater
- Rinse the bottle and the bottle cap three times with the sampled water before the final sample is taken
- Avoid getting into touch with the inside of the bottle or cap.
- Fill the bottles to the top to avoid air and tighten the cap firmly

The water samples were then put in a fibre envelope and returned to NGU by ordinary mail.

5.2 Analysis

Upon arrival at NGU laboratory the samples were registered and any content of particles or other deviations were described. Half of the content in the 500 ml bottle was decanted into a 250 ml polyethylene bottle intended for anion analysis by ion chromatography and for determination of pH, alkalinity, electrical conductivity, colour and turbidity. 250 µl suprapure HNO_3 (65%) was added to the remaining 250 ml water in the 500 ml bottle in order to dissolve metals that had been adsorbed or precipitated since sampling. The bottles were then stored in a cooling room at 4.5^{o}C.

The water samples were by intention not filtered prior to analysis. The reason for this was to analyse the mineral content of the water 'as consumed'. This choice has also been made for earlier drinking water survey performed by NGU, and the results of the present study will thus be more comparable to previous results.

5.2.1 pH

pH was measured at NGU lab with a glass electrode pHC 2701-8 ”Red Rod”.

5.2.2 Alkalinity

Total and partial alkalinity was measured at NGU lab with the use of a Radiometer Titralab 94 instrument with a lower detection limit of 0.04 mol/l.

5.2.3 Colour

Colour was determined at NGU lab using a Shimadzu UV-1201 Spectrophotometer. The sample is filtered through a membrane with pore size 0.45 µm. Absorbance is measured at 410 nm and the result is given as the concentration of platinum (mg/L Pt) in a reference solution with a similar absorbance. Analytical uncertainty is ±7.5 % (relatively) and the lower detection limit is 1.4.

5.2.4 Turbidity

Turbidity was determined at NGU lab using a Hach 2100 A Turbidity-meter. Determination of turbidity is based on nefelometry (measurement of light dispersion) due to the ability of the suspended material to disperse light. The degree of light dispersion is compared to a standard solution and the result is given in FTU (Formazin Turbidity Unit), which is a widely used reference. Analytical uncertainty is ±0.04 FTU in the 0.05 – 1.0 FTU range, ±0.4 FTU in the 1.0 – 10 FTU range, and ±4 FTU in the 10 – 100 FTU range. Lower detection limit is 0.05 FTU.

5.2.5 Conductivity

Electrical conductivity was measured at NGU lab with the use of a Radiometer Titralab 94/CDM 210 conductivity meter with a lower detection limit of 0.07 mS/m.

5.2.6 Concentration measurements (IC, ICP-AES, ICP-MS)

All groundwater samples were analysed for seven anions (Cl^-, Br^-, NO_3^-, NO_2^-, SO_4^{2-}, F^- and PO_4^{3-}) at NGU lab using a Dionex Ion Chromatograph 2120i instrument. As nitrite (NO_2^-) requires determination immediately after sampling, results are not regarded as valid and are not discussed further in this work. Analytical uncertainty is 10 % relatively for all ions and detection limits for each ion are given in Appendix 1.

Major, minor and trace elemental concentrations were determined by ICP-MS using a Finnigan Mat Element instrument. The samples were also analyzed by ICP-AES using a Perkin Elmer Optima 4300 Dual View apparatus. Accordingly, 32 elements were determined by both ICP-MS and ICP-AES. Lower detection limits and analytical uncertainty of the methods are given in Appendix 2.

5.3 Data handling

A spreadsheet containing information about the location of the well, sample-code, aquifer type, analytical results etc was established. All in all, the dataset contains information about 691 groundwater samples. 346 of these originate from bedrock boreholes and 314 were taken from unconsolidated sediment wells. For 31 samples the aquifer type was not reported. By mistake, one water sample had been reported as taken from unconsolidated sediment groundwaters, instead of bedrock. Accordingly, all maps were created based on a dataset of 345 bedrock waters and 315 waters from unconsolidated sediments. However, all individual element descriptions and summarizing table are based on the corrected dataset.

All samples were assigned with an individual identification number.
All coordinates were transformed to EU89-UTM zone 32.

When the concentration was lower than the detection limit, the value was set to half the detection limit. The detection limits for the different elements are summarized in Appendix 2 and Appendix 3. In some cases, two different detection limits are given. In these cases, the older (and higher) value was chosen. This applies to the following elements: Ag, Cd, I, Mo, P, Sb, Ti, and Zr.

Some elements were analyzed by both ICP-AES and ICP-MS. Generally spoken, the ICP-MS values were used. In some cases, the element concentrations were too high to be analyzed reliable with ICP-MS. Instead of leaving gaps in the dataset, ICP-AES data were used for these samples.

Afterwards the data were analyzed with the statistic software R. The geographical distribution was investigated using ArcMap.

5.4 Sources of Error

Some hydrochemical variables should ideally be measured in the field. This is particularly important for pH values of groundwaters with a low content of solutes. Groundwater may contain high concentrations of solved carbon dioxide CO_2, as a result of, i.a. respiration of organisms in the soil. Carbonic acid will then be produced according to the following equilibrium

$H_2O + CO_2 = H_2CO_3$

and pH of the groundwater will be lowered. If the CO_2 gas is given the opportunity to escape from the water sample, the pH value will raise. The solubility of CO_2 in water is temperature-dependent, and decreases with increasing temperature.

If the concentrations of calcium and bicarbonate (alkalinity) are high enough in the water sample, calcite may precipitate according to the following equation:

$Ca^{2+} + HCO_3^- = CaCO_3 + H^+$

An H^+-ion is released and thus pH will decrease. This applies to samples with pH above 8.2 – 8.3 which is the buffer pH for calcium carbonate at atmospheric CO_2 pressure.

Even if a large amount of bottles were distributed at the same time, it often took several weeks from the first groundwater samples were returned until an adequate number of samples had arrived to set up a laboratory batch.

The pH was therefore measured as a routine immediately after arrival at NGU. A comparison of pH values measured at arrival and after some weeks displays some large deviations (Figure 1). In addition, one might expect that pH has changed during transport from the sample was taken until it arrived at NGU. Some spot tests showed that when pH had changed (e.g. due to CO_2 degassing), the pH-value could be very stable during further storage of the water sample.

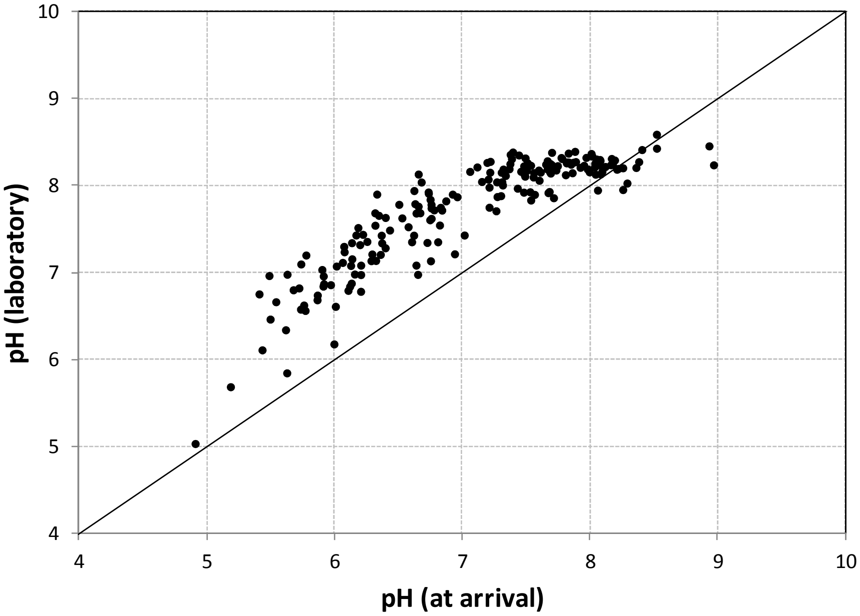

Figure 1: pH measurements of 193 groundwater samples after arrival at NGU compared to pH measurements several weeks later. The bisecting line is given for comparison.

5.5 Quality control

5.5.1 Ion balance

The first step of the water analysis was an assessment of the quality of the data, which was accomplished by calculating the balance of positive and negative ions. Water fulfils the principle of electroneutrality and is therefore always uncharged. The level of error in the data was calculated using the following equation (Appelo & Postma, 1994):

$$Error\ of\ ion\ balance\ (\%) = \frac{\sum Cations - \sum Anions}{\sum Cations + \sum Anions} * 100$$

The sum of cations was calculated using following equation:

$$\sum Cations = \frac{meq(Ca^{2+})}{l} + \frac{meq(Mg^{2+})}{l} + \frac{meq(Na^{+})}{l} + \frac{meq(K^{+})}{l} + \frac{meq(Fe^{2+})}{l} + 1000 * 10^{(-pH)}$$

The sum of anions was calculated using following equation:

$$\sum Anions = Alkalinity + \frac{meq(Cl^{-})}{l} + \frac{meq({SO_4}^{2-})}{l} + \frac{meq(F^{-})}{l} + \frac{meq({NO_3}^{-})}{l}$$

Figure 2 shows the error of ion balance for all 691 groundwater samples plus 13 standard samples that were analyzed for controlling reasons.

70 % of all samples had an error of ion balance within ± 5 % and 89 % had an error of ion balance within ± 10 %. 76 % of groundwater samples from bedrock boreholes and 64 % from unconsolidated sediment wells had an error of ion balance within ± 5 %. 92 % of groundwater samples from bedrock boreholes and 86 % from unconsolidated sediment wells had an error of ion balance within ± 10 %. The errors of ion balance range from alarming -87 % to 51 %.

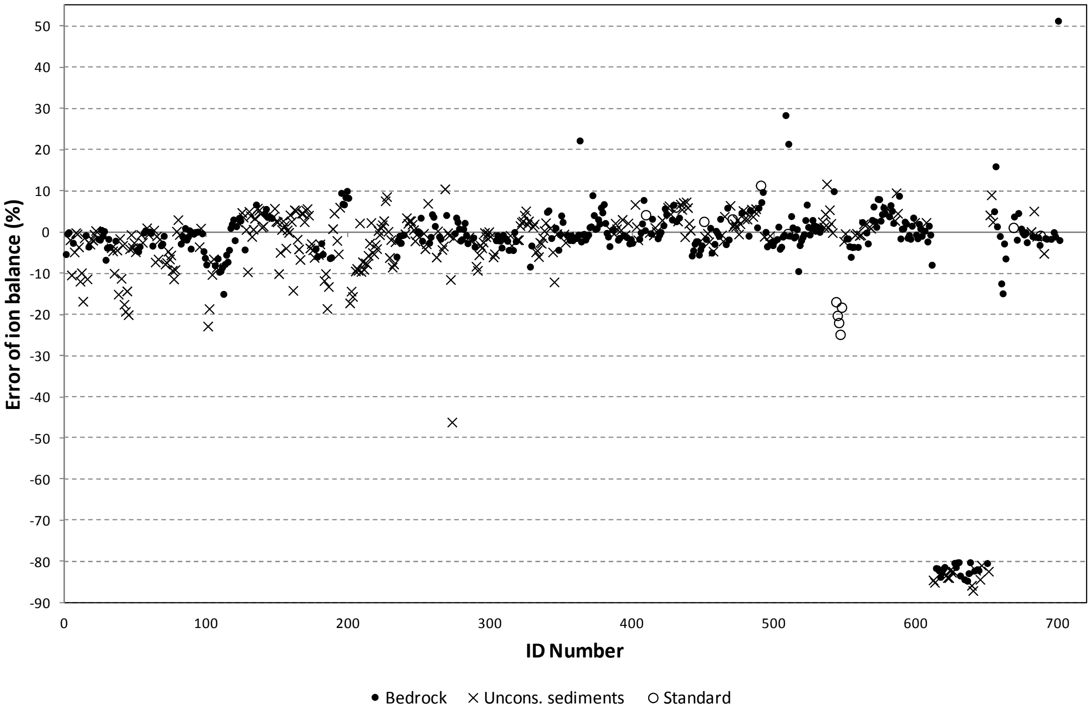

Figure 2: The error of ion balance in 345 groundwater samples from bedrock boreholes, 315 groundwater samples from unconsolidated sediment wells and 13 standard samples.

This indicates that around 10 % of the samples have serious measuring or sampling errors. Samples with low ionic strength are more susceptible to errors in the ion balance, which can be seen in the overweight of unbalanced analyses from unconsolidated sediment aquifers. This phenomenon also applies to the group of blank samples (open circles around ID number 550). The group of samples between ID number 600 and 650 with too high anion values in the ion balance are assumed to be affected by incorrect alkalinity measurements. Interpretation of data has to be done with care.

After the water analyses for the current project were completed, it was discovered that there had been a leakage in the instrument for alkalinity determination. This problem cannot explain all of the deviations from ion balance, but are at least the probable reason for the most extreme deviations towards the negative side, e.g. the samples between ID number 610 and 650, see Figure 2 above.

5.5.2 ICP-MS and ICP-AES

Several elements that were analyzed with ICP-MS were also analyzed with ICP-AES. All analytical results that are lower than the analytical detection limit were set to a number half the detection limit. In Figure 4 and Figure 4 the results from the ICP-MS analysis were plotted against the results from the ICP-AES analysis. Most of the results from the different analytical methods confirm each other. For the elements arsenic, cadmium, cerium, chromium, lithium, lead and vanadium there were several samples with strongly differing results. It seems that the accuracy of the ICP-AES method is weaker when the concentrations come close to the lower detection limit

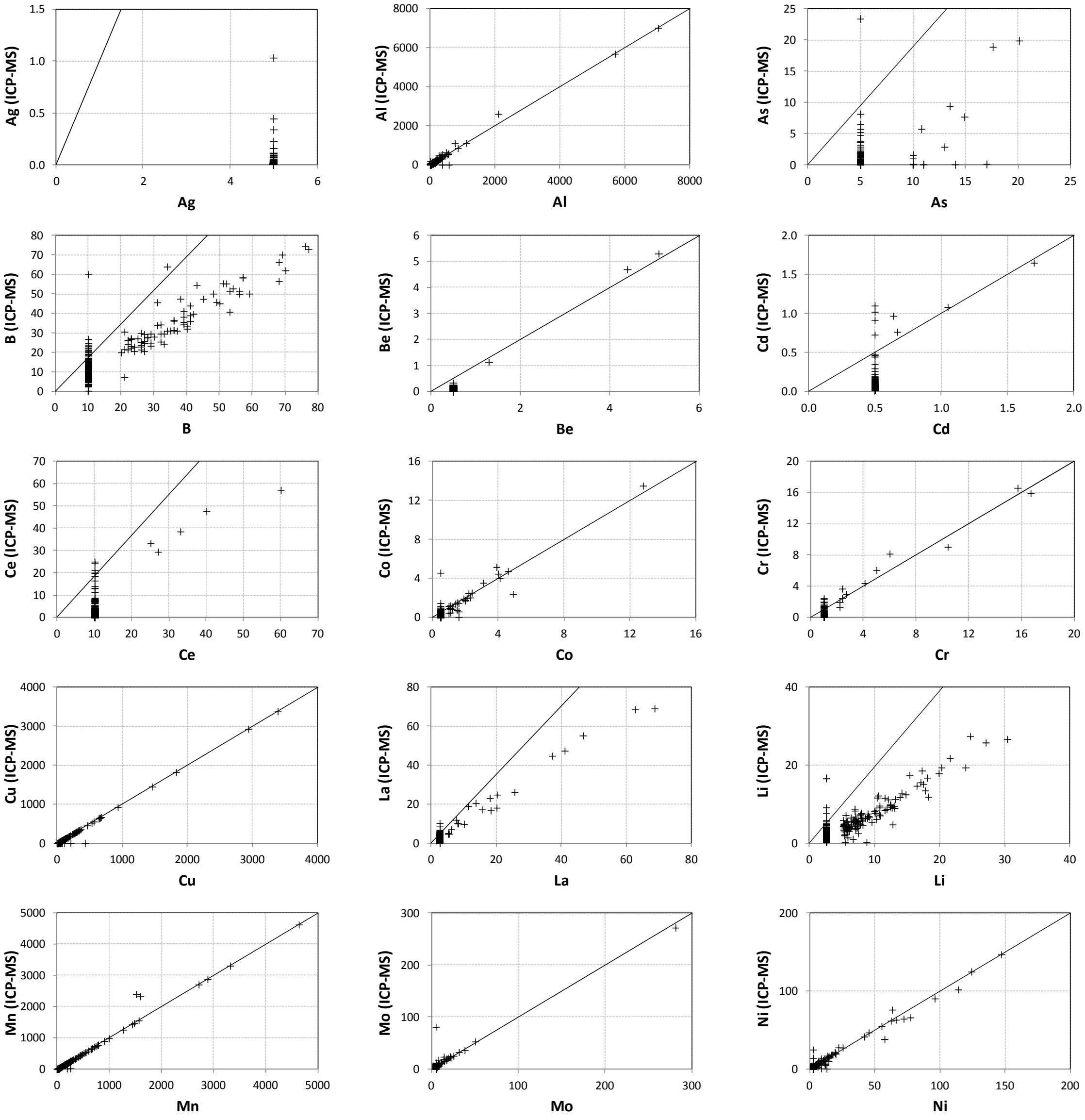

Figure 3: xy-plots showing analytical results of ICP-AES (x-axis) versus ICP-MS (y-axis) analysis for several elements. All concentrations are given in µg/L. The bisecting line is given as comparison.

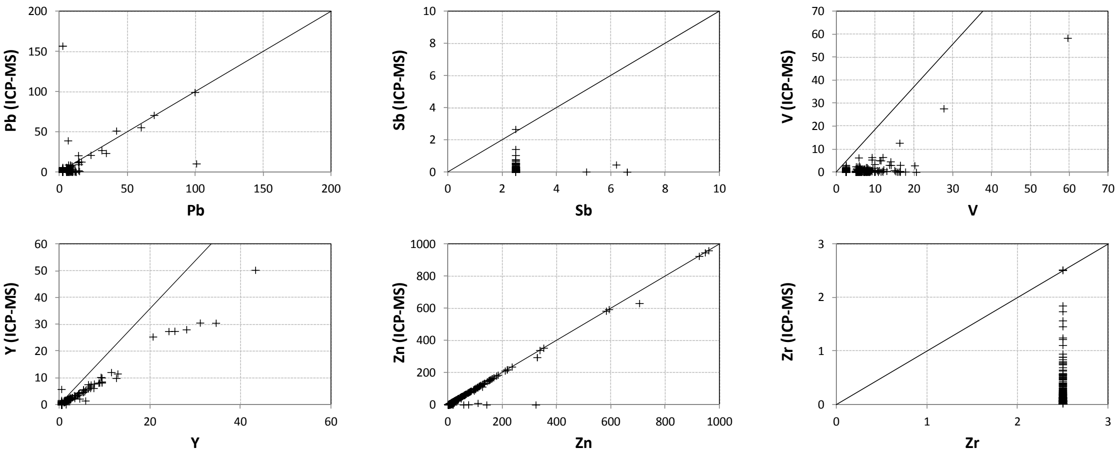

Figure 4: xy-plots showing analytical results of ICP-AES (x-axis) versus ICP-MS (y-axis) analysis for several elements. All concentrations are given in µg/L. The bisecting line is given as comparison.

5.5.3 Standard samples

In order to control whether the water analyses were stable over time and in different batches, standard samples were evenly distributed in the dataset, one for each twenty regular samples. A number of sampling bottles were taken of the local drinking water (Jonsvatnet waterworks, Trondheim) at the tap before the project started. As the project first was aimed at waterworks and later was expanded to also include wells registered at the Norwegian Food Safety Authority, the standard samples had to be replenished midway in the project. There is thus a slight shift in the water quality between samples 17 and 18 which is most pronounced in the measurement of colour and manganese. As the standard samples are from a lake, many of the trace elements have concentrations below detection limit. A groundwater sample would therefore have been a better choice as a standard. Figure 5 - Figure 7 show some selected parameters sorted chronologically. There was a considerably time span of almost four years from the first to the last sample was analysed. Although there are some variations in the precision, no time-dependent trend in the analytical values is detected.

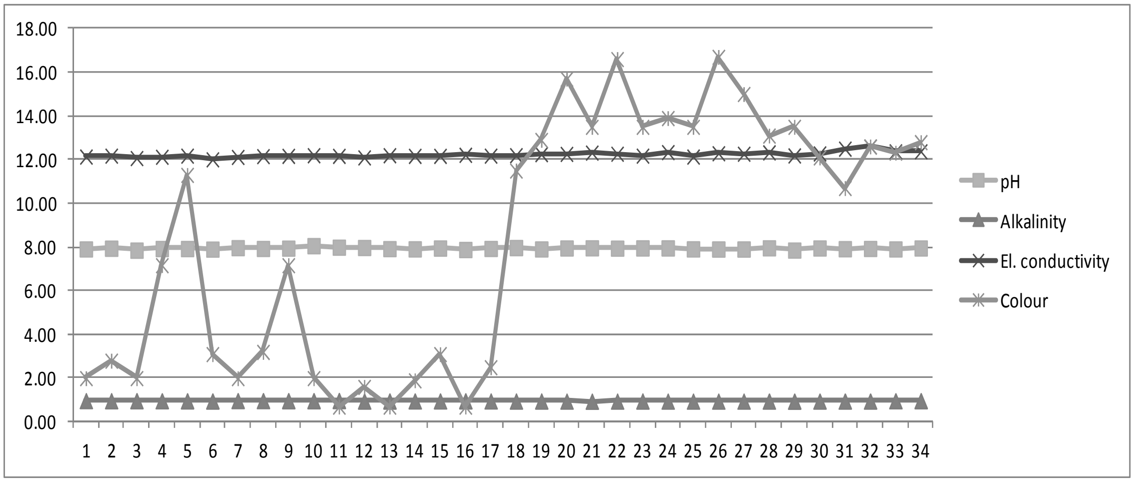

Figure 5: Line diagram showing variations in the analysis of standard samples over time for pH, alkalinity [mmol/l], electrical conductivity [mS/m) and colour.

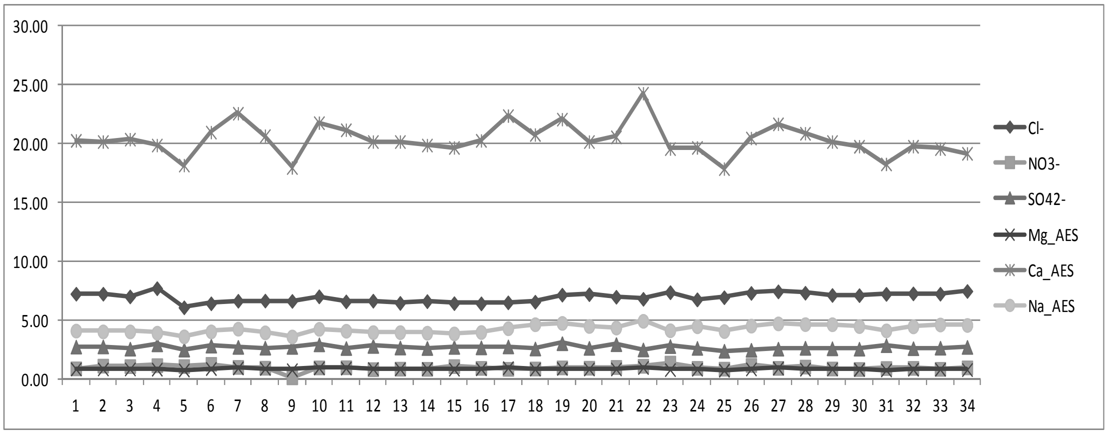

Figure 6: Line diagram showing variations in the analysis of standard samples over time for chloride, nitrate, sulphate, magnesium, calcium and sodium, all values in [mg/L].

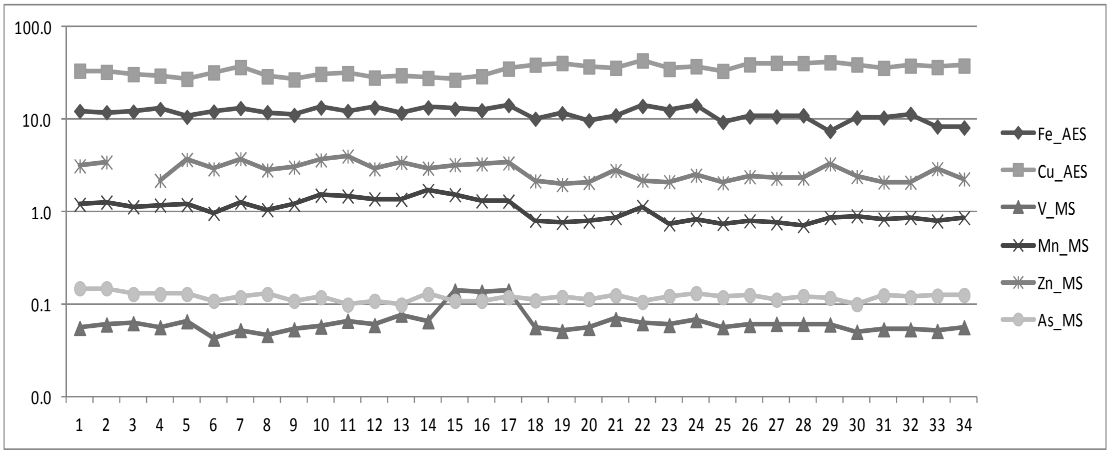

Figure 7: Line diagram showing variations in the analysis of standard samples over time for iron (Fe), copper (Cu), vanadium (V), manganese (Mn), Zinc (Zn) and arsenic (As), all values in [µg/L]. Note the log scale.

5.5.4 Blanks

Five samples of deionised ultrapure water (Milli-Q) were given the same treatment as the ordinary samples (except from being sent by mail) and were analysed in the same way. The laboratory returned values below the given detection limits for most of the parameters. The analysis of tungsten, copper and aluminium gave some values more than three times higher than the detection limits, but the absolute values are small and far below any drinking water limit. In addition, there are some values slightly above the given detection limits for fluoride, bromide, sulphate, zink , uranium and colour, see Table 1.

Table 1: Analytical results of blank samples for the parameters where values above the given detection limit occurred.

	pH_lab	EC_lab	Colour	Turbidity	F	Br	SO4	W	Cu	Zn	Al	U
Detection limit		*0.07*	*1.4*	*0.05*	*0.05*	*0.1*	*0.1*	*0.05*	*0.05*	*0.1*	*2*	*0.0005*
Blank 1	5.46	0.13	3.1	0.09	< 0.05	< 0.1	< 0.2	<0.05	<0.05	<0.1	<2	<0.0005
Blank 2	5.46	0.13	< 1.4	0.09	< 0.05	< 0.1	0.22	<0.05	0.318	0.31	<2	0.0010
Blank 3	5.41	0.13	1.6	0.07	0.07	< 0.1	< 0.2	<0.05	<0.05	<0.1	<2	<0.0005
Blank 4	5.41	0.13	1.6	0.07	0.05	0.13	0.26	<0.05	<0.05	0.12	<2	<0.0005
Blank 5	5.39	0.13	< 1.4	0.09	0.05	< 0.1	< 0.2	0.241	0.122	0.16	7.6	<0.0005

6 Results

6.1 Frequency distribution of parameters and presentation of boxplots

A total of 691 groundwater samples from bedrock boreholes and unconsolidated sediments (Quaternary) in Norway have been analyzed.

To give a first impression of the water chemistry, all parameters and element concentrations were plotted in cumulative distribution frequency (CDF) diagrams (Figure 8 - Figure 11). Vertical lines in the plots indicate drinking water limits in Norway and can therefore be a help to evaluate drinking water quality. Furthermore, the number of log-cycles shown on the x-axis displays the variance of the dataset. Comparison of curves for the bedrock aquifer subset and the unconsolidated aquifer subset gives a clear picture of relative enrichment or depletion of groundwater parameters between the two. No assumptions on data distribution or any transformations of the datasets are made.

Afterwards, boxplots comparing aquifer and well type are presented (Figure 12 - Figure 14). The boxplot is a useful presentation technique for comparison of different data subsets, because location, spread, skewness, tail length and outlying data points appear at a glance (Reimann et al. 1998). The box itself contains the mid 50 % of all data where the median value is marked with a line that divides the box. The left and right end of the box (called "hinges") represent the 75 % quartile and the 25 % quartile, respectively. Lines (called "whiskers") are drawn from the ends of the box towards the maximum and minimum values, respectively, each containing about 25 % of all data. The whiskers extend up to 1.5 times the length of the box and outlying data points (outliers) are plotted as dots.

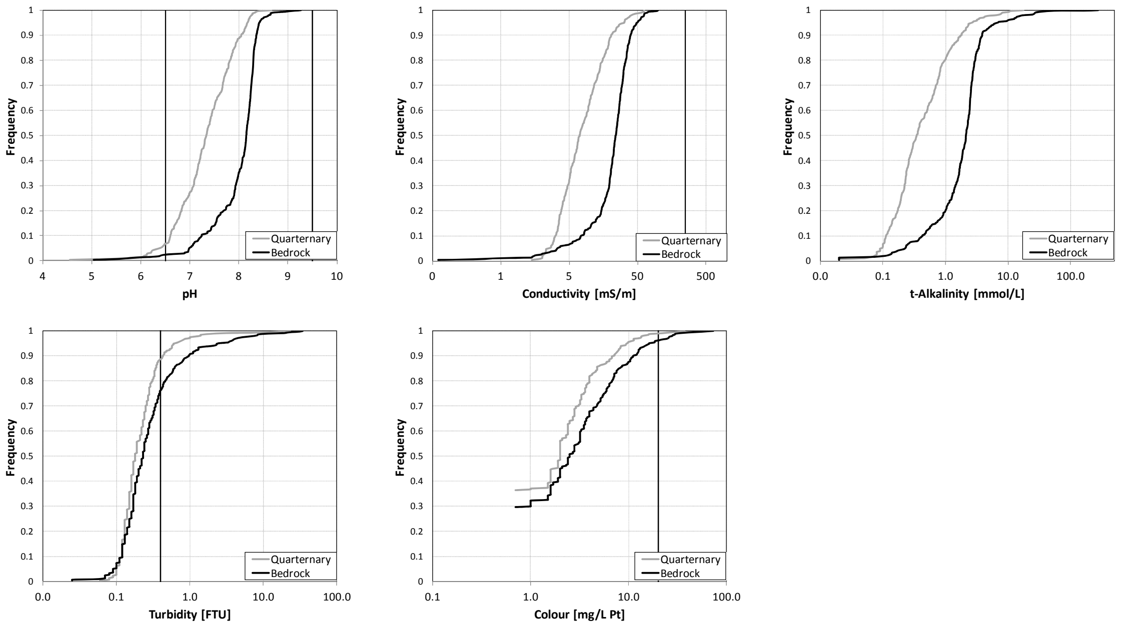

Figure 8: Cumulative distribution frequency plots for pH, conductivity, alkalinity, turbidity, and colour of both bedrock groundwaters (n=346) and unconsolidated sediment groundwaters (n=314). Vertical lines mark the minimum / maximum admissible values for drinking water in Norway.

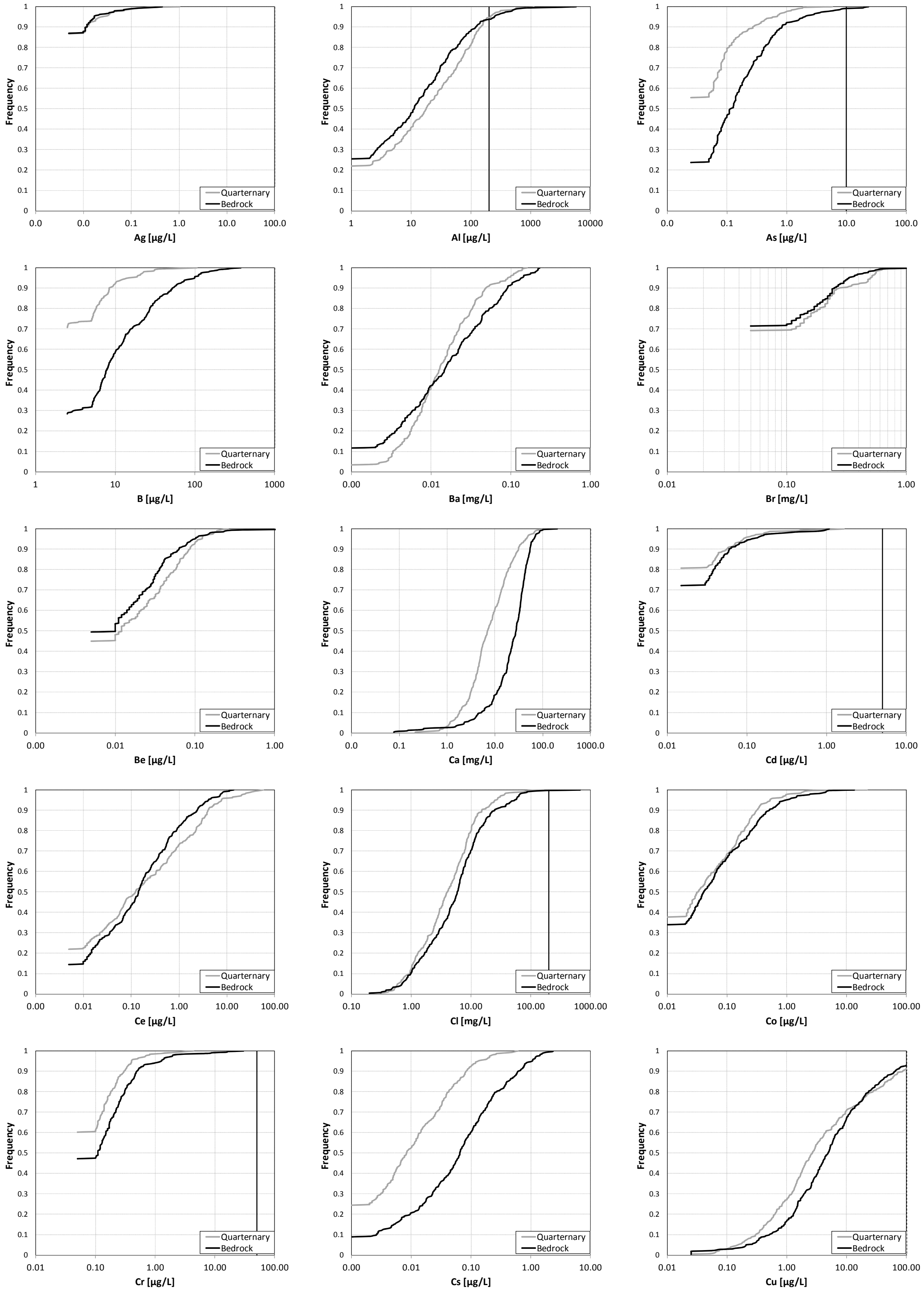

Figure 9: Cumulative distribution frequency plots for the elements Ag till Cu of both bedrock groundwaters (n=346) and unconsolidated sediment groundwaters (n=314). Vertical lines mark the maximum admissible concentrations (MAC) for drinking water in Norway.

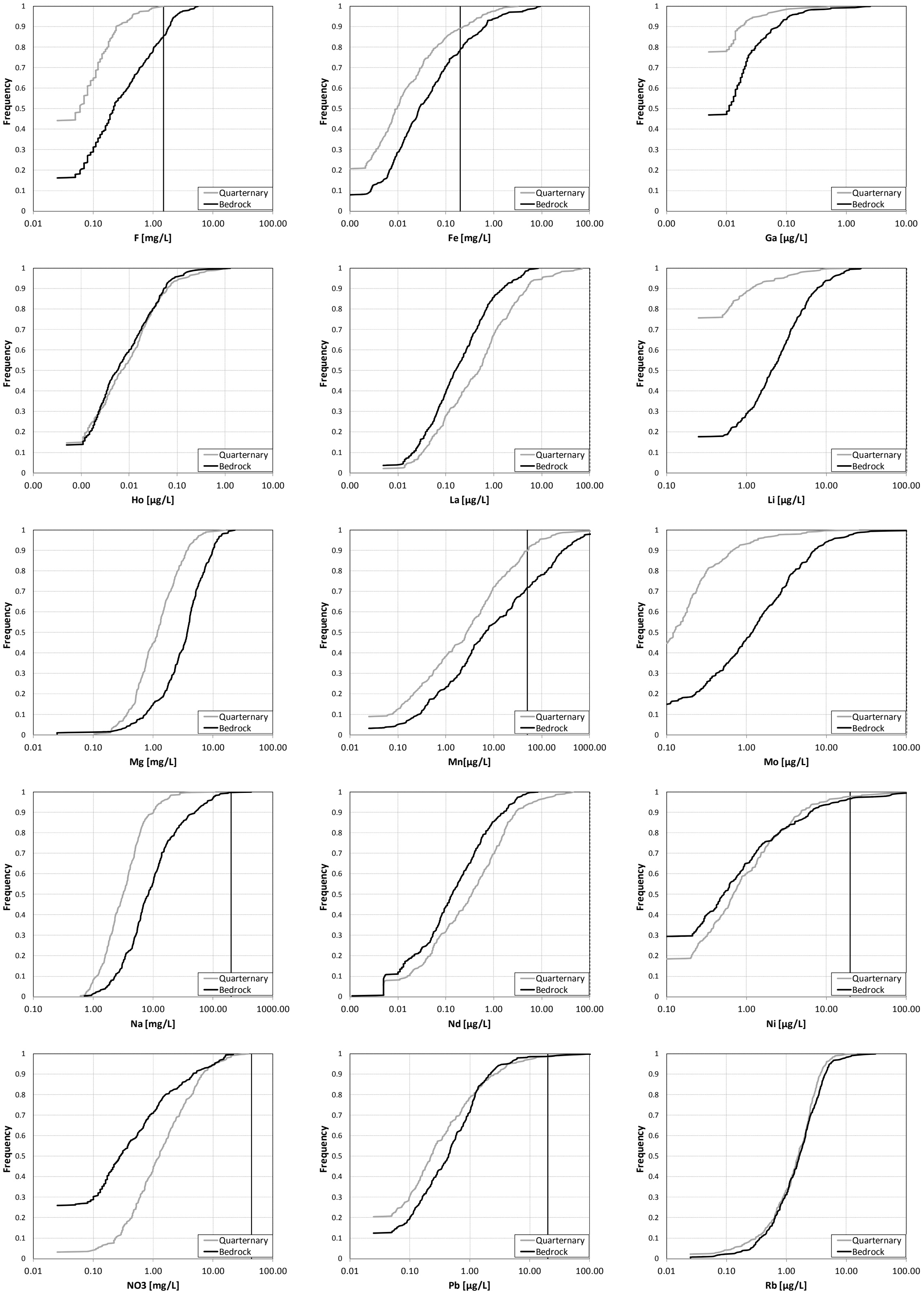

Figure 10: Cumulative distribution frequency plots for the elements F till Rb of both bedrock groundwaters (n=346) and unconsolidated sediment groundwaters (n=314). Vertical lines mark the maximum admissible concentrations (MAC) for drinking water in Norway.

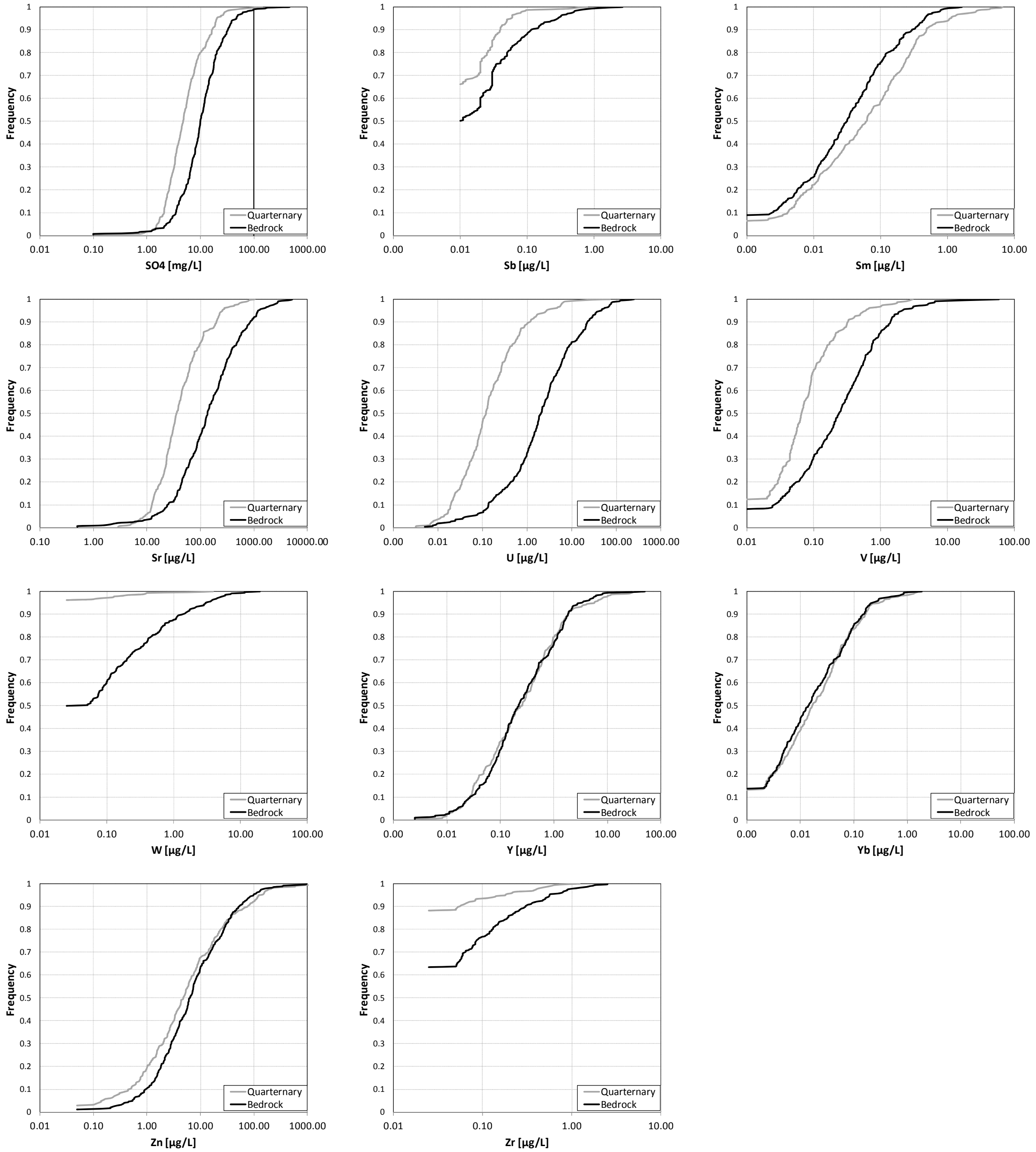

Figure 11: Cumulative distribution frequency plots for the elements SO_4 till Zr of both bedrock groundwaters (n=346) and unconsolidated sediment groundwaters (n=314). Vertical lines mark the maximum admissible concentrations (MAC) for drinking water in Norway.

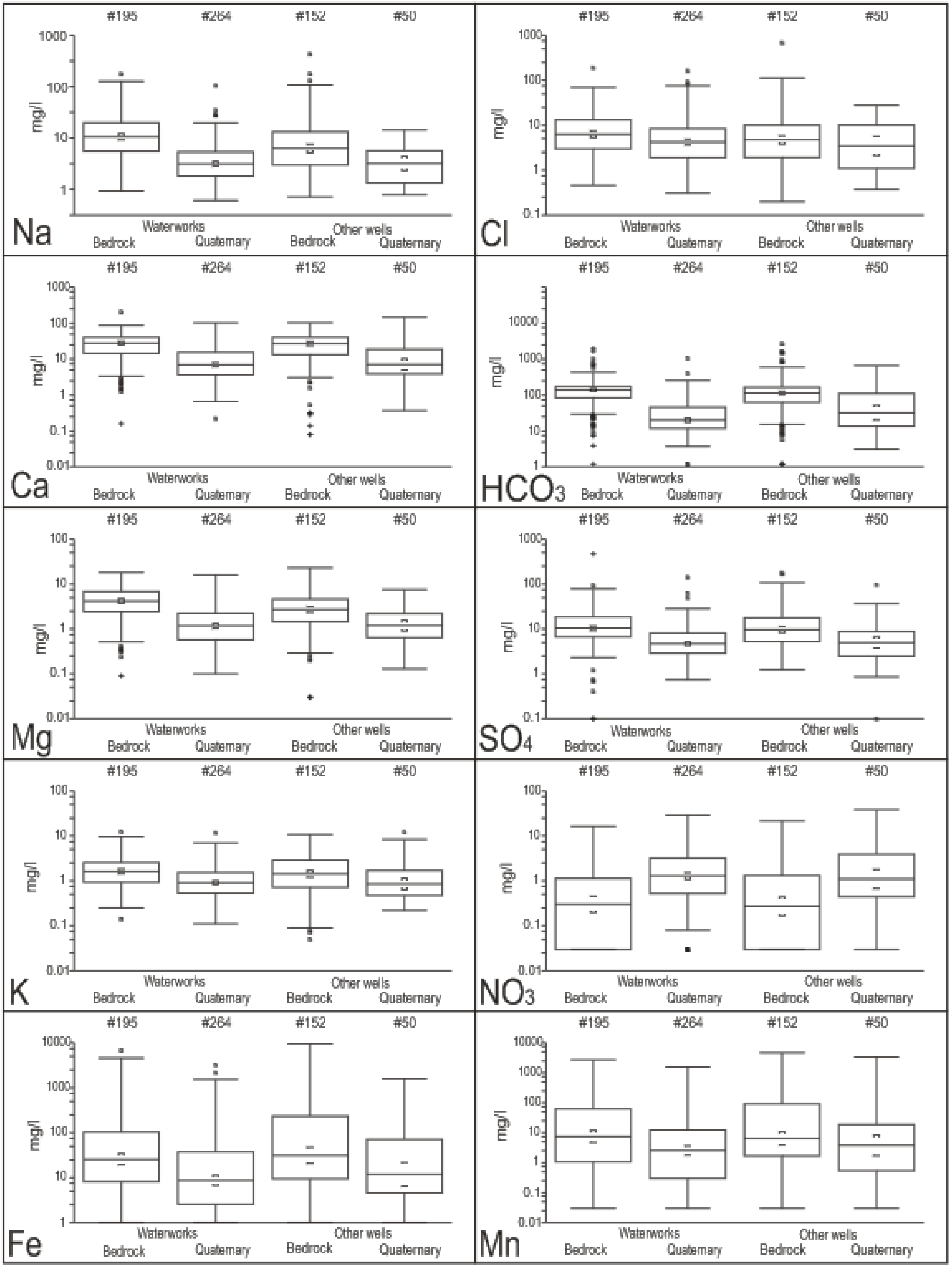

Figure 12: Comparison of elemental concentrations in waterworks and other wells with respect to different aquifer types (# no. = number of samples).

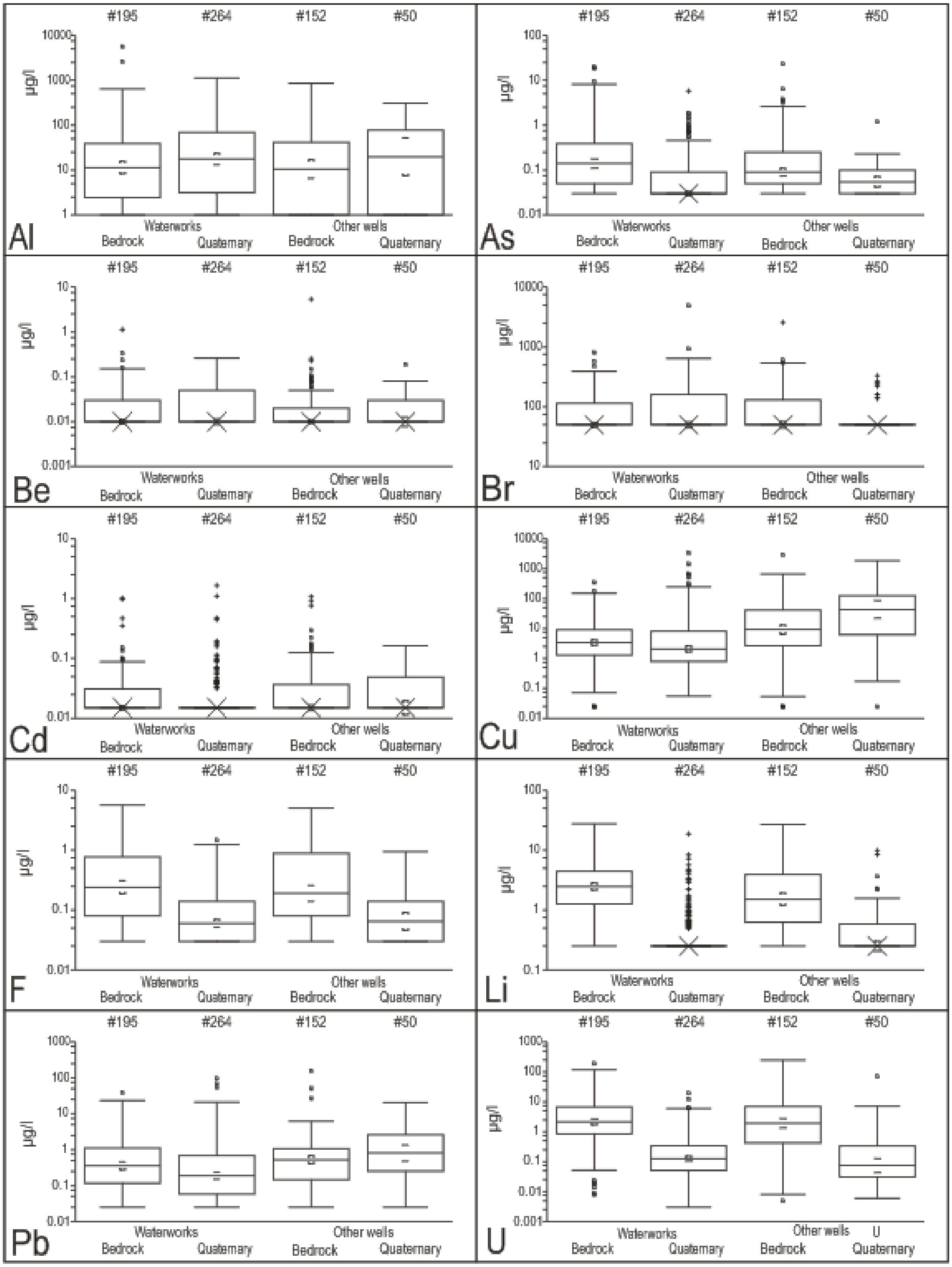

Figure 13: Comparison of trace elemental concentrations in waterworks and other wells with respect to different aquifer types (# no. = number of samples).

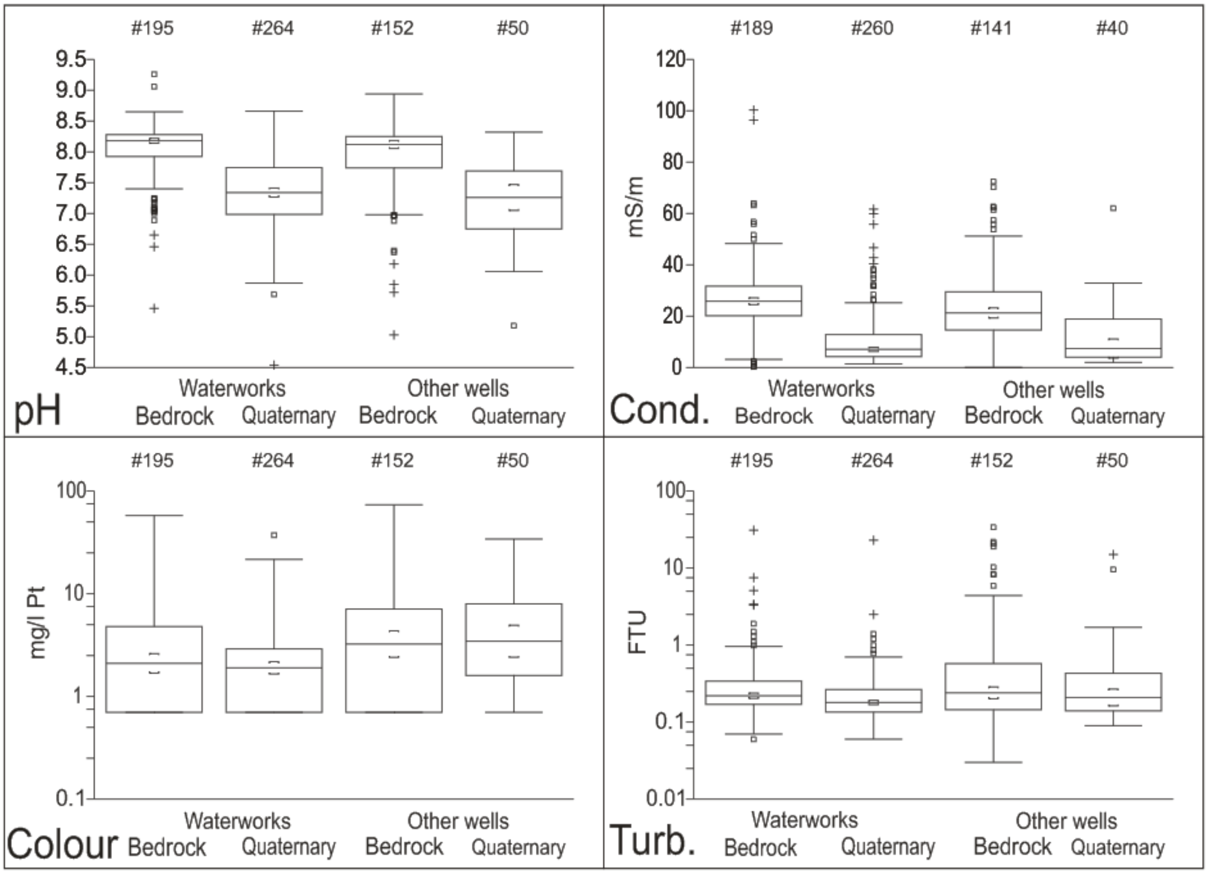

Figure 14: Comparison of general parameters in waterworks and other wells with respect to different aquifer types (# no. = number of samples).

6.2 Geographical distribution of wells

The analyzed 691 groundwater samples were collected from all over Norway. Even though there are generally more samples from the south of the country than from the north, the geographical distribution of wells is relatively even. 346 samples were taken from bedrock groundwaters whereas 314 samples came from unconsolidated sediment groundwaters.

Figure 15 shows the geographical distribution of the wells with regard to aquifer type. As described in chapter *Data manipulation*, by mistake one water sample had been assigned to the wrong group. Accordingly, the maps were created are based on a dataset of 345 bedrock waters and 315 waters from Quaternary aquifers (unconsolidated sediments). Individual element descriptions and summarizing tables are based on the corrected dataset.

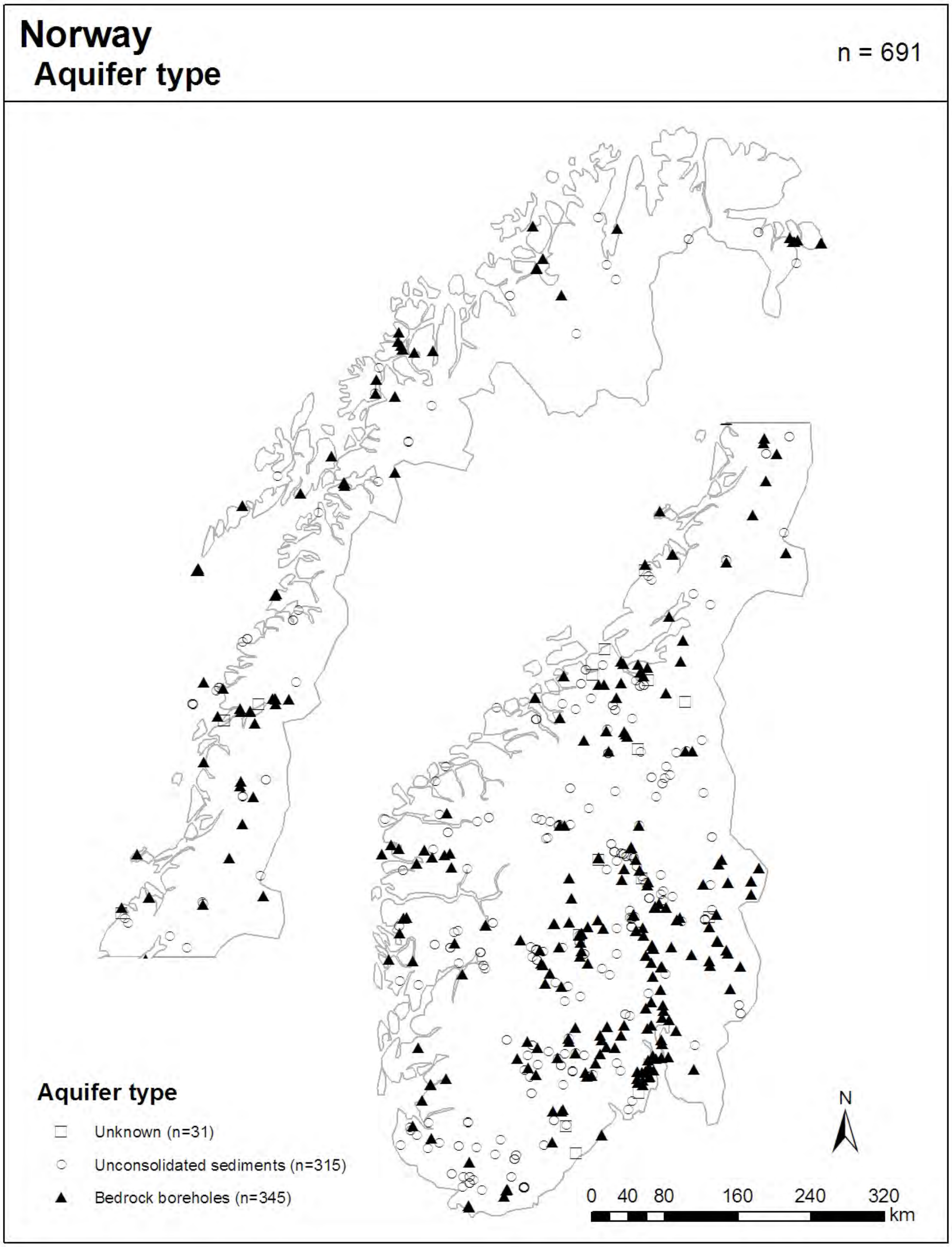

Figure 15: Geographical distribution of the wells with regard to aquifer type.

6.3 pH

The median pH value of the whole dataset was found to be 7.8, but a distinct difference between water samples from bedrock boreholes and unconsolidated sediments could be detected. Water samples from bedrock boreholes showed a median value of 8.2 with a range from 5.0 to 9.3. With a median value of 7.3, a minimum of 4.5 and a maximum of 8.7, water samples from unconsolidated sediments generally had slightly lower pH values.

The portion of wells with high pH values is lowest in the central and western part of South Norway (Figure 16 and Figure 17). The rest of the country generally shows higher pH values – although there is a certain variation.

31 of 691 samples (4.5 %) were lie below the minimum admissible pH of 6.5. None of the sample was above the maximum admissible pH of 9.5.

6.4 Alkalinity

The alkalinity shows a similar trend as the pH values. The median value of the whole dataset is 1.07 meq/L with a considerable difference between bedrock boreholes and unconsolidated sediments. While groundwater samples from unconsolidated sediments have a median value of 0.35 meq/L and a maximum of 17.5 meq/L, waters from bedrock boreholes have much higher values. Waters from bedrock boreholes are found to have a median value of 2.12 meq/L and a maximum value of 271.6 meq/L. The minimum alkalinity of both aquifer types is 0.02 meq/L.

The geographical distribution (Figure 18 and Figure 19) of alkalinity shows clear differences between groundwater samples from bedrock boreholes and unconsolidated sediments. When looking at samples from bedrock boreholes, the portion of wells with low alkalinity values is highest in the central parts of South Norway. For samples from unconsolidated sediments the area with a high portion of samples with low alkalinity also include Sørlandet and Sørvestlandet.

Norwegian health authorities have not set a maximum admissible value, but a previous guideline (Sosial- og helsedepartementet, 1995) suggested a range of 0.6 – 1.9 meq/L. If this guideline was applied, 358 samples (51.8 %) would lay above and 256 samples (37 %) below the recommendations. Almost 80 % of the bedrock boreholes show alkalinities above 1.0 meq/L and about 60 % of the samples from unconsolidated sediments fall below 0.6 meq/L.

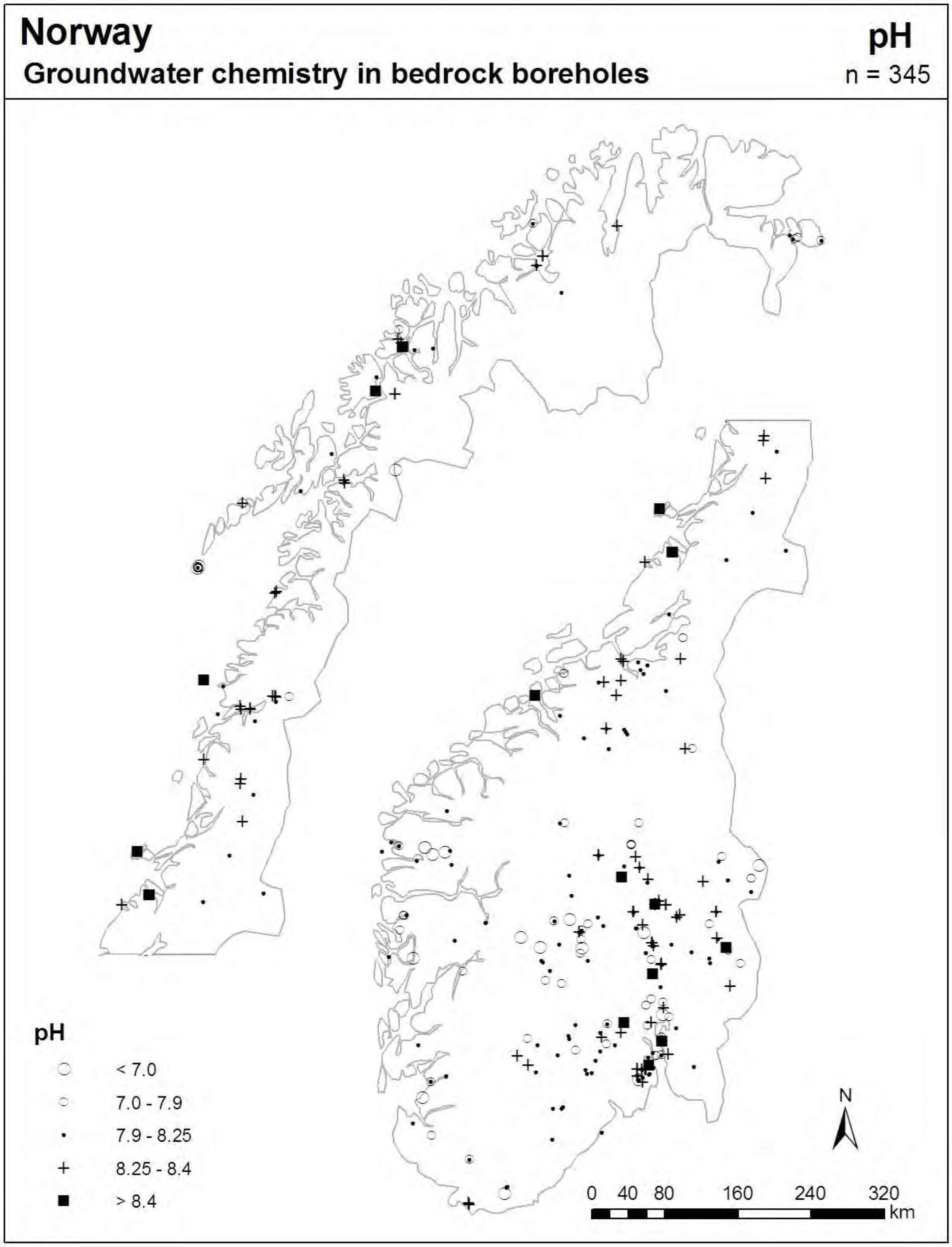

Figure 16: Map of Norway showing the pH in groundwater samples from bedrock boreholes.

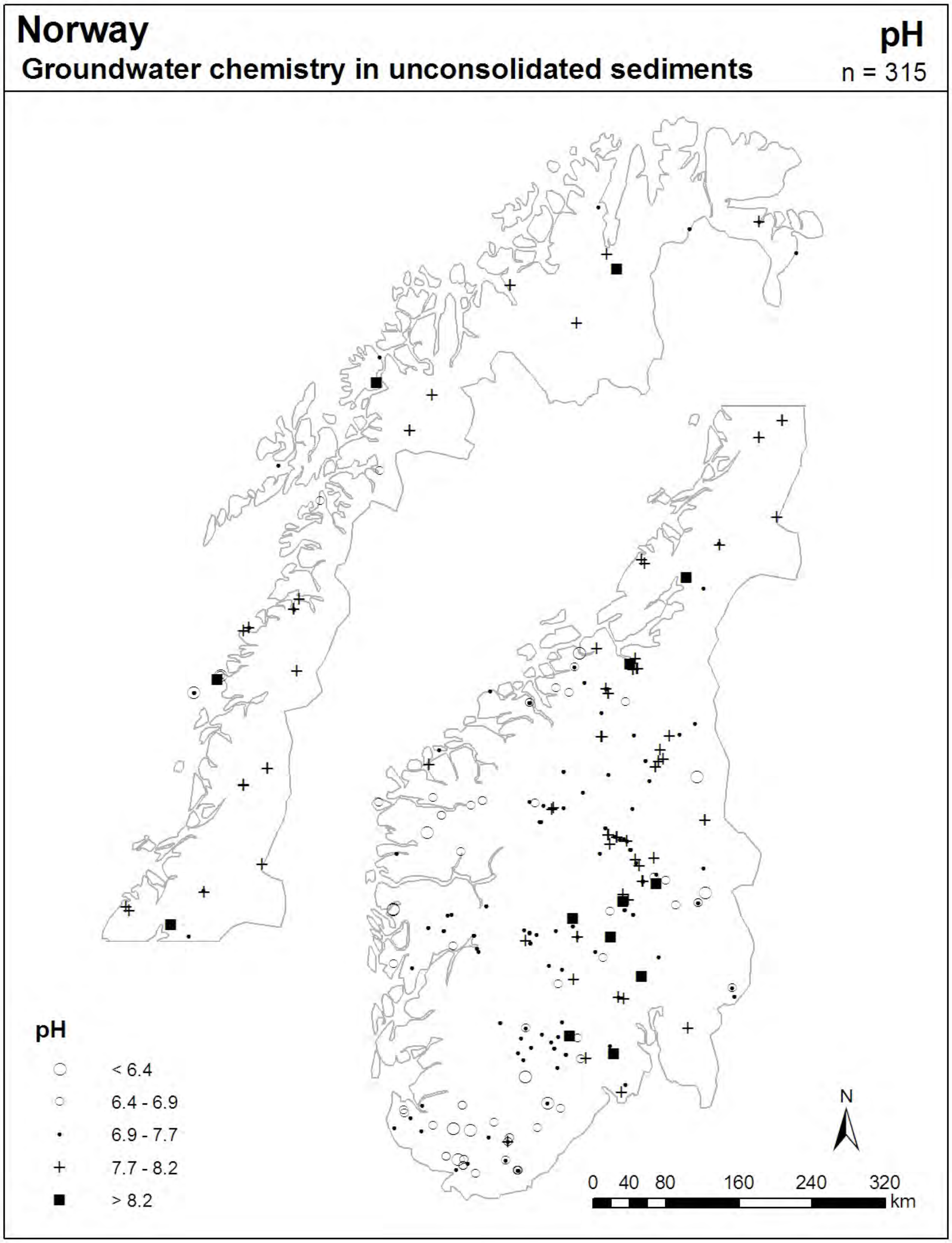

Figure 17: Map of Norway showing the pH in groundwater samples from unconsolidated sediments.

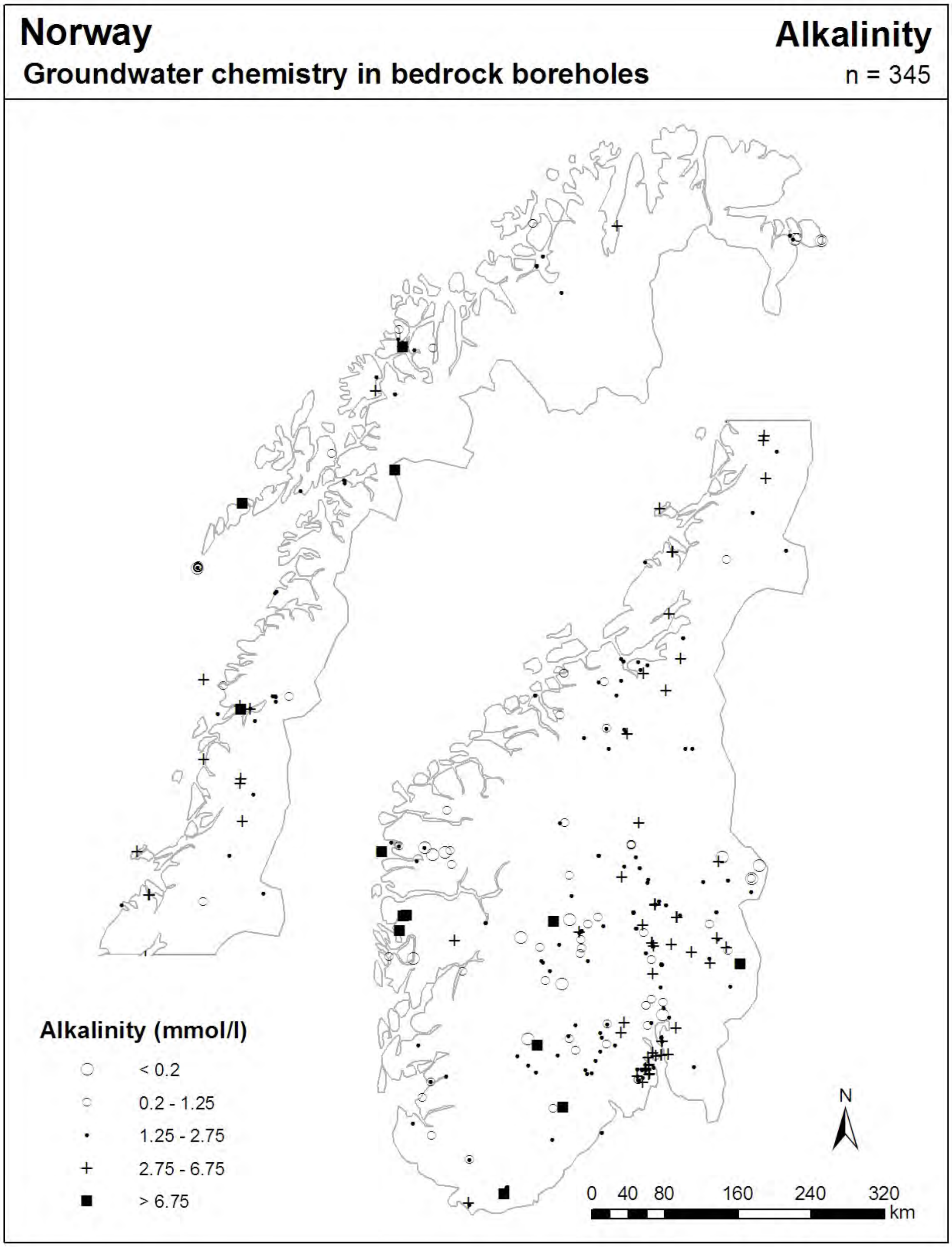

Figure 18: Map of Norway showing the alkalinity in groundwater samples from bedrock boreholes.

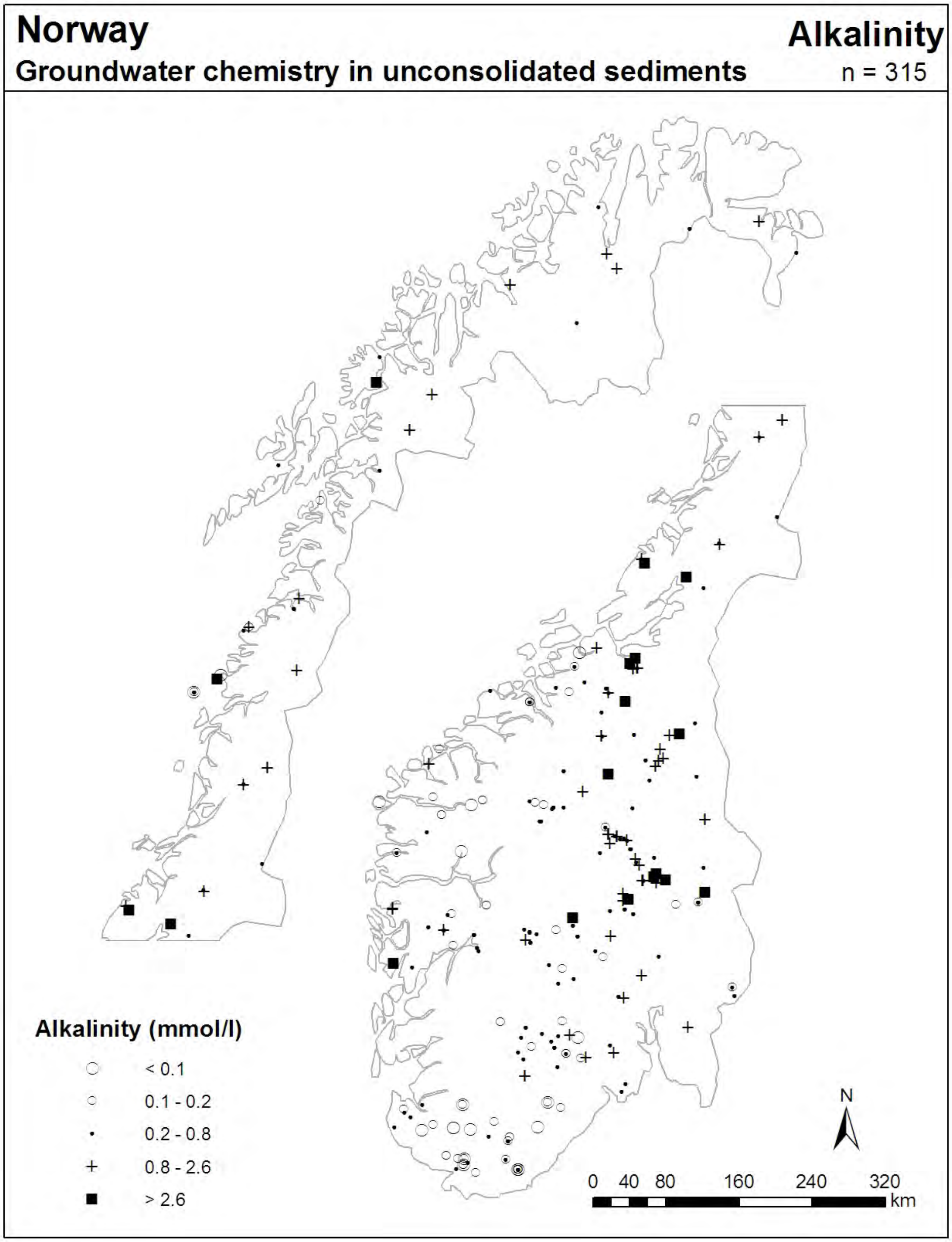

Figure 19: Map of Norway showing the alkalinity in groundwater samples from unconsolidated sediments.

6.5 Colour

The median value for colour in the whole dataset was found to be 2.0 mg/L Pt-Co. Groundwater samples from bedrock boreholes show a minimum value of 0.7 mg/L Pt-Co, a median value of 2.5 mg/L Pt-Co and a maximum of 73.5 mg/L Pt-Co. Water samples from unconsolidated sediments show slightly lower values. The minimum value is 0.7 mg/L Pt-Co, the median value 2.0 mg/L Pt-Co and the highest value 37.2 mg/L Pt-Co.

No geographical trend could be identified.

The maximum admissible value for the colour of drinking water in Norway is 20 mg/L Pt-Co. 20 samples out of 691 lie above this line.

6.6 Turbidity

The turbidity-measurements of the whole dataset showed a median value of 0.21 FTU, a minimum of 0.03 FTU (from bedrock borehole) and a maximum of 34 FTU (from bedrock borehole). Samples from unconsolidated sediments showed a median value of 0.18 FTU, while bedrock boreholes have a median value of 0.23 FTU.

For samples from bedrock boreholes no geographical trend could be identified. For samples from unconsolidated sediments, Trøndelag and North-Norway generally showed low turbidity values.

Norwegian health authorities have defined a maximum admissible value of 0.4 FTU. 135 of 691 samples have a higher turbidity, which corresponds to 15.5 % of the dataset. Almost 24 % bedrock borehole samples and 11 % of groundwater samples from unconsolidated sediments exceed the norm.

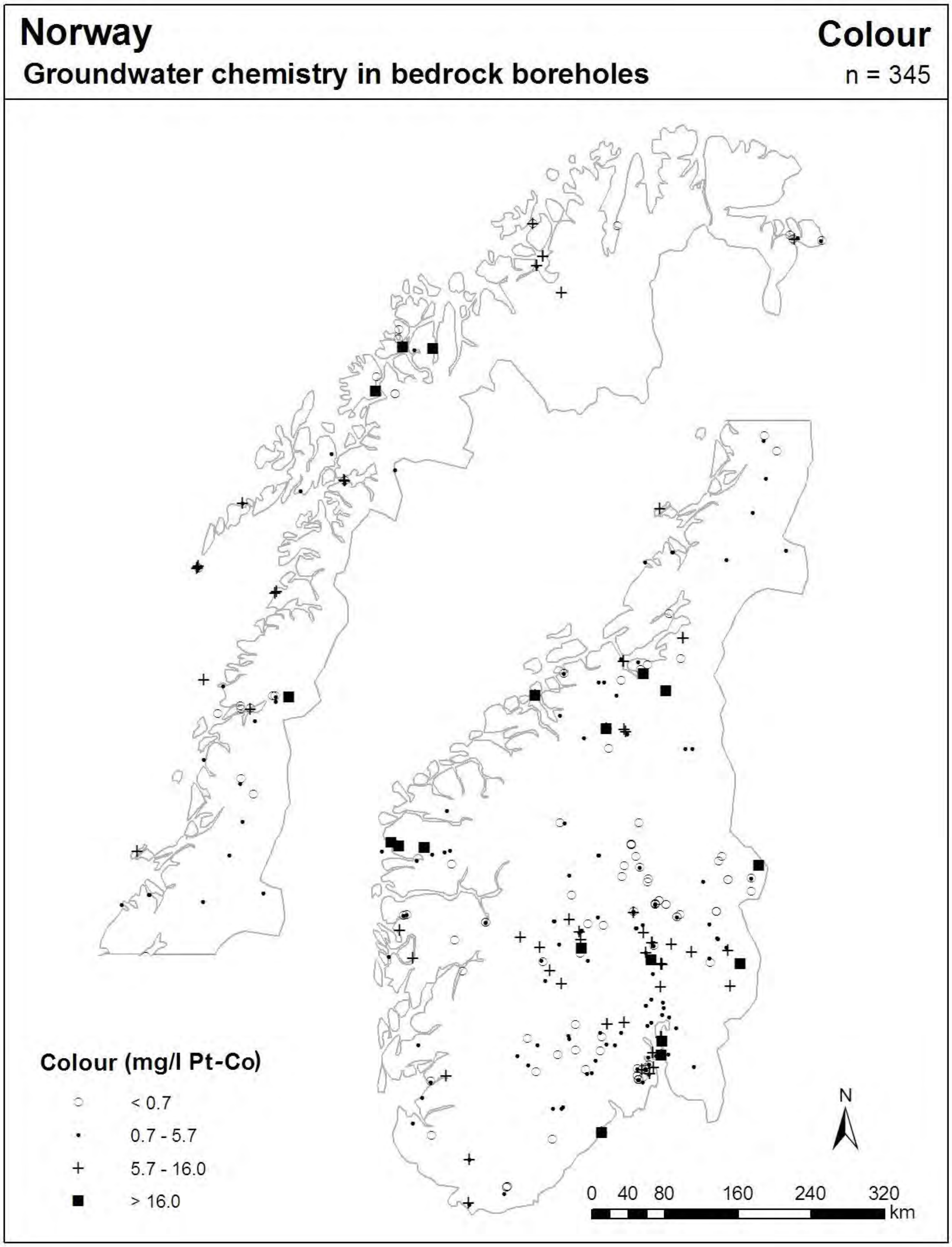

Figure 20: Map of Norway showing the colour of groundwater samples from bedrock boreholes.

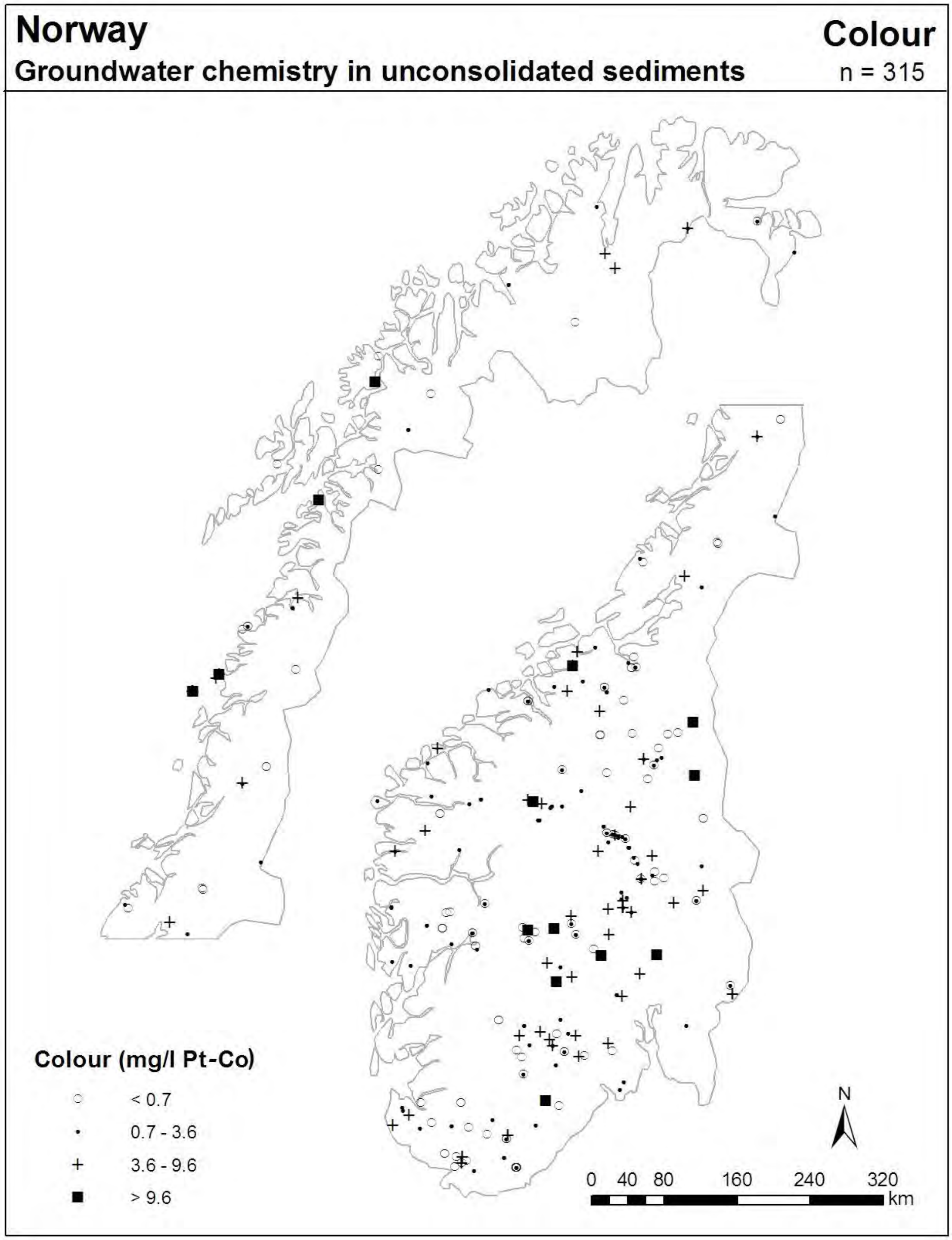

Figure 21: Map of Norway showing the colour of groundwater samples from unconsolidated sediments.

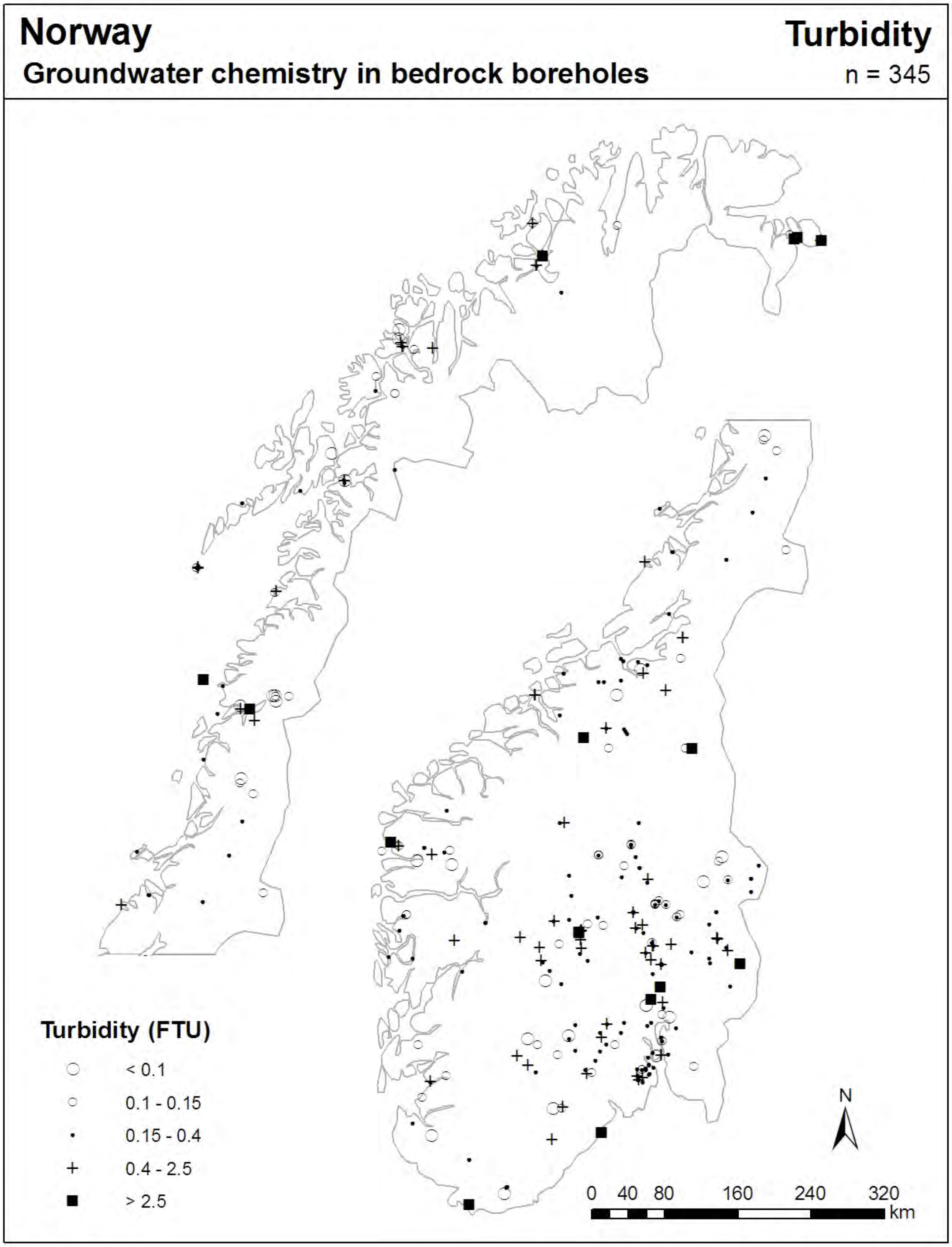

Figure 22: Map of Norway showing the turbidity in groundwater samples from bedrock boreholes.

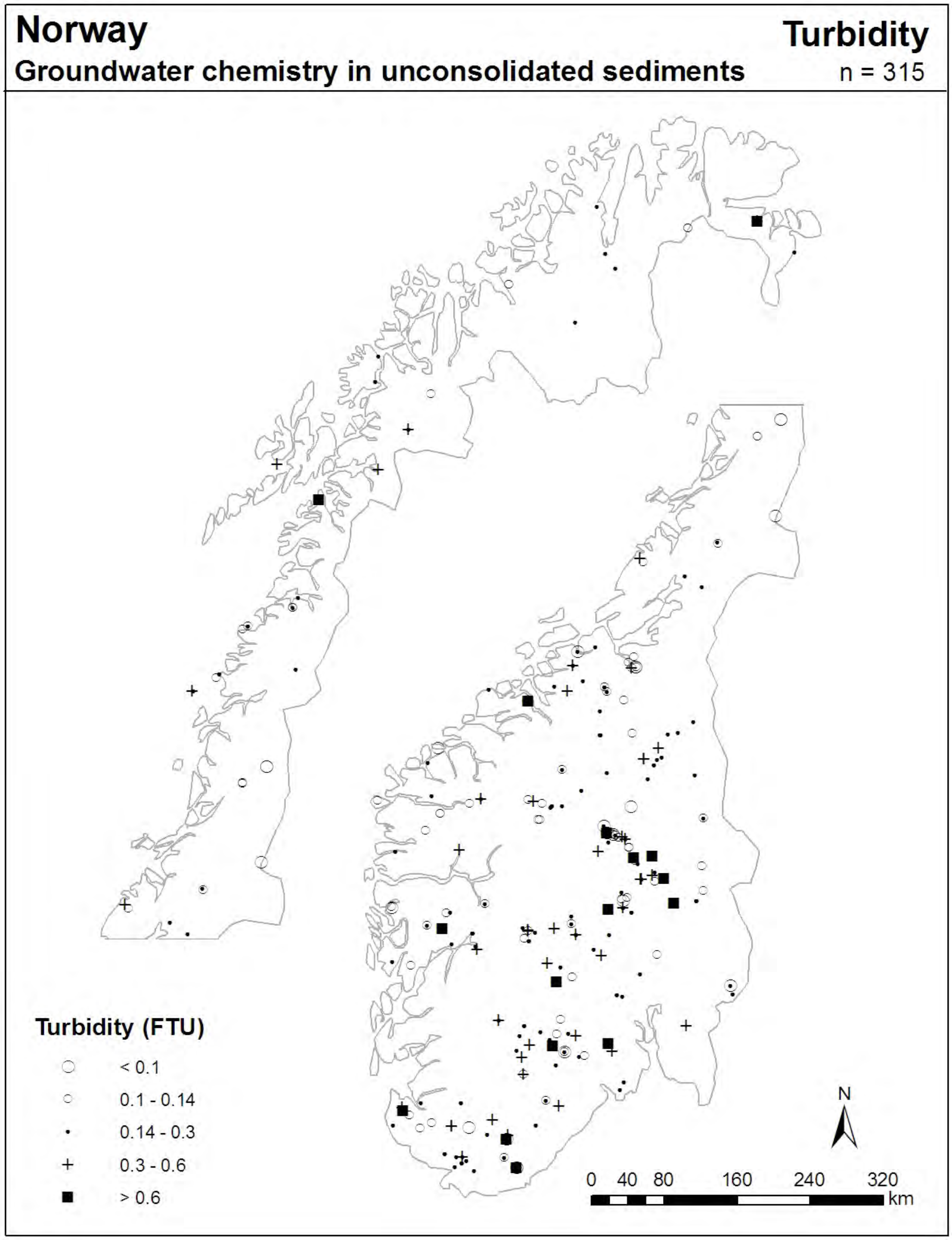

Figure 23: Map of Norway showing the turbidity in groundwater samples from unconsolidated sediments.

6.7 Conductivity

With a minimum value of 0.06 mS/m (from bedrock borehole) and an extreme value of 912 mS/m (unknown aquifer type), the groundwater samples showed a wide range of conductivity. The median value of the whole dataset was 15.91 mS/m, the median value of samples from bedrock boreholes was 24.26 mS/m, and the median value of samples from unconsolidated sediments was 7.1 mS/m. Groundwater samples from bedrock boreholes and unconsolidated sediments showed a maximum of 100.3 ms/m and 62.1 mS/m respectively. Both maxima lie below the maximum admissible value (250 mS/m at 25°C) for drinking water. The only sample that exceeds that norm, is the sample from an unknown aquifer (912 mS/m), mentioned above.

Water samples from bedrock boreholes (Figure 24) taken in central parts of South Norway and Vestlandet had generally lower conductivity values than other parts of the country. Water samples that were taken from unconsolidated sediment wells (Figure 25) showed the lowest values in Sørlandet and Vestlandet.

6.8 Silver (Ag)

605 (88 %) of all 691 groundwater samples showed silver concentrations below the detection limit of 0.01 µg/L (measured with ICP-MS). The groundwater samples from both aquifer types had median concentrations below the detection limit. The highest concentration (1.03 µg/L) was measured in groundwater samples from unconsolidated sediments. Due to the low number of reliable data, it is difficult to interpret them.

When looking at the geographical distribution of silver concentrations in groundwaters from bedrock boreholes (Figure 26), samples from Østlandet showed more samples with high silver concentrations than the rest of the country. A similar distribution can be seen in Figure 27, where silver concentrations in groundwater samples from unconsolidated sediments are depicted. Additionally, samples from Sørlandet show higher silver concentration.

No maximum admissible concentration (MAC) is defined in Norway. A former MAC in Norway was set to 10 µg/L (Sosial- og helsedepartementet, 1995). None of the samples exceeds this MAC.

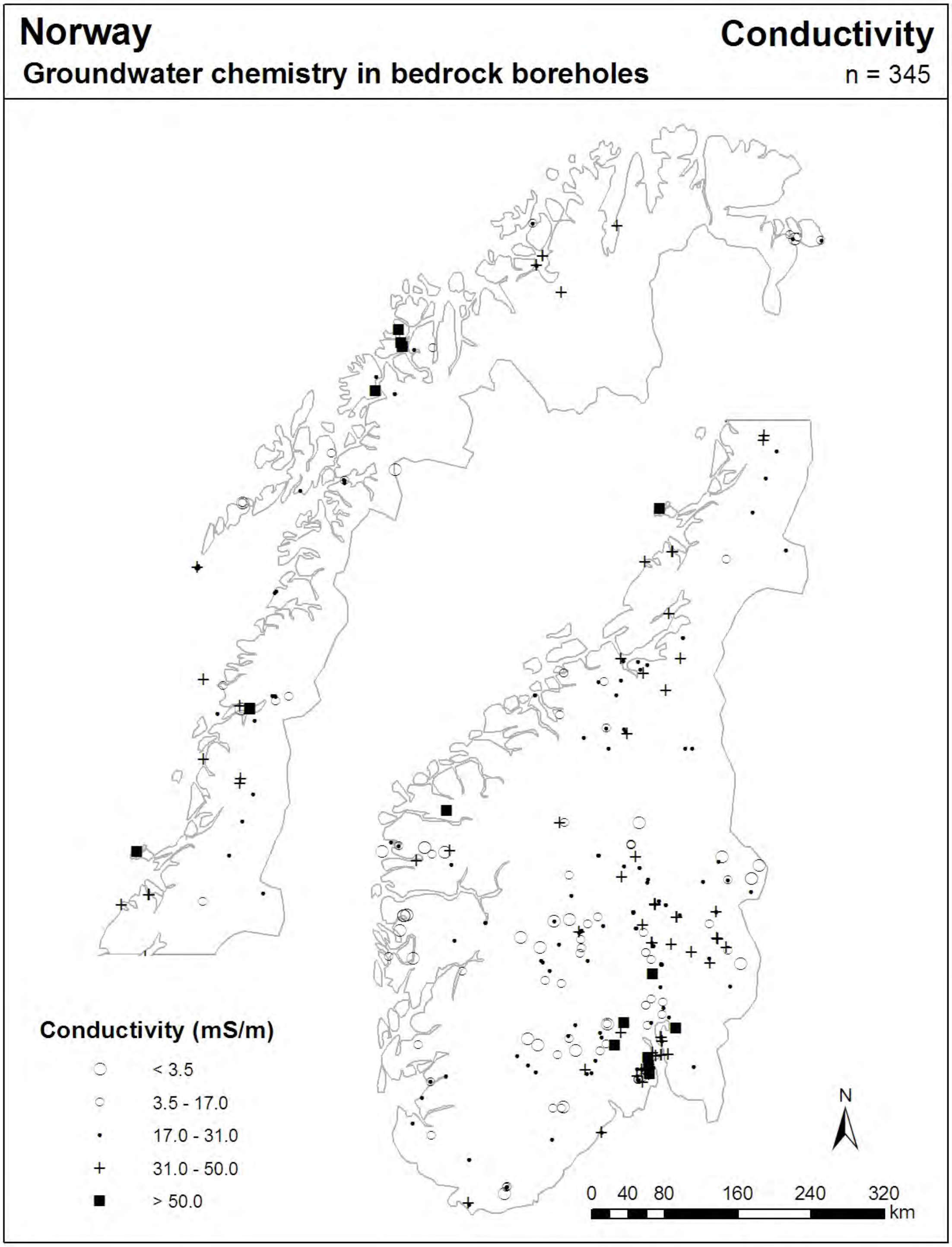

Figure 24: Map of Norway showing the conductivity in groundwater samples from bedrock boreholes.

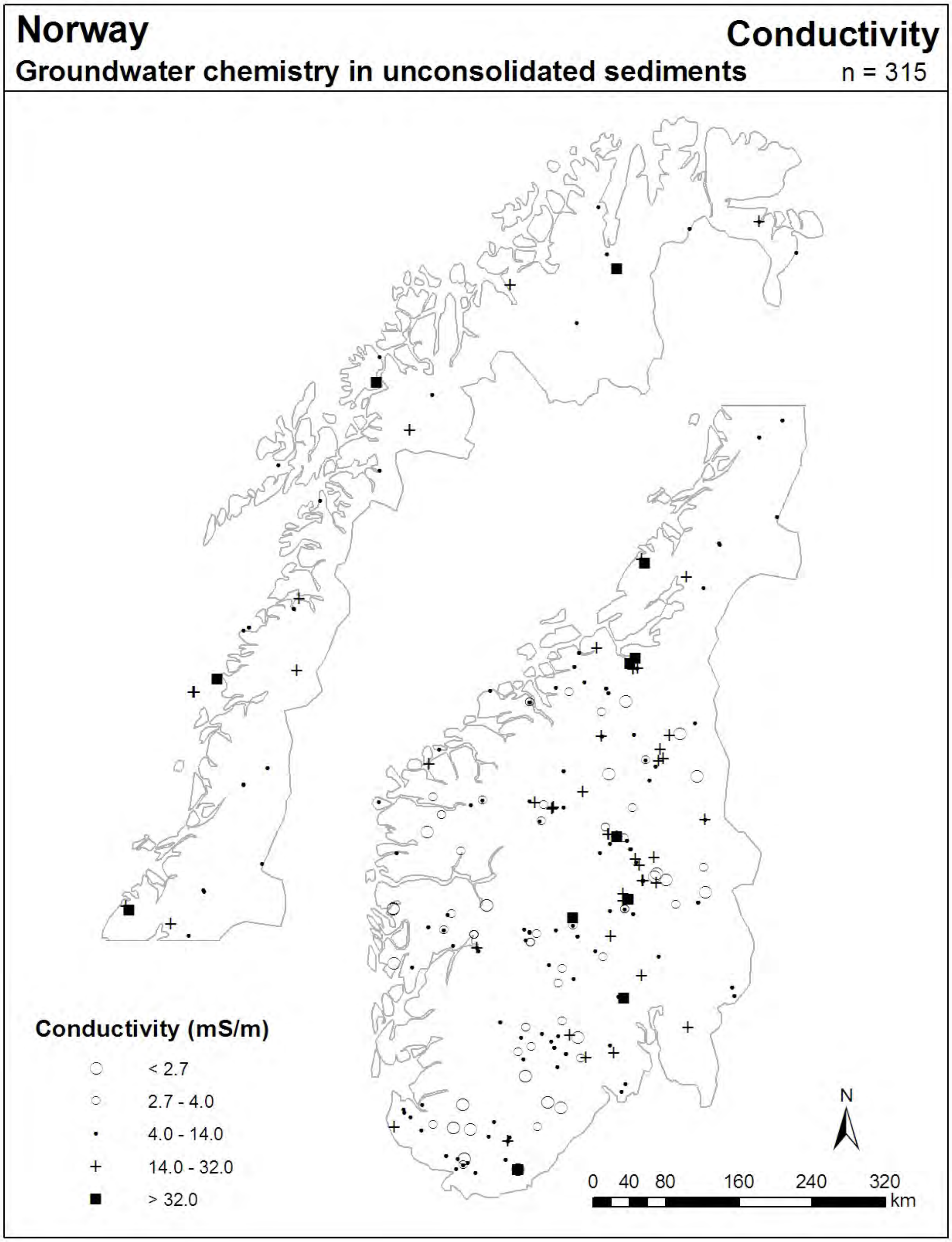

Figure 25: Map of Norway showing the conductivity in groundwater samples from unconsolidated sediments.

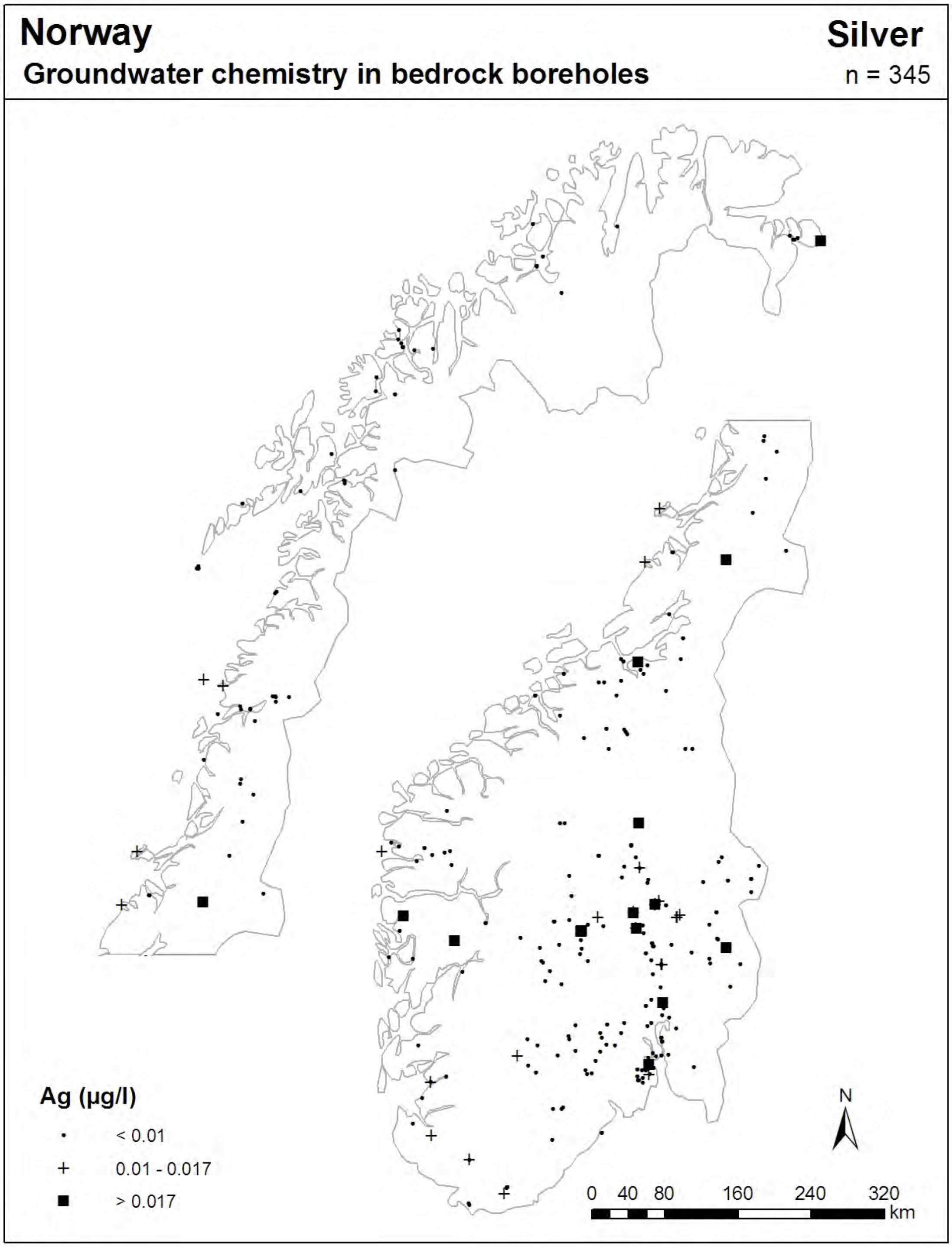

Figure 26: Map of Norway showing silver concentrations in groundwater samples from bedrock boreholes.

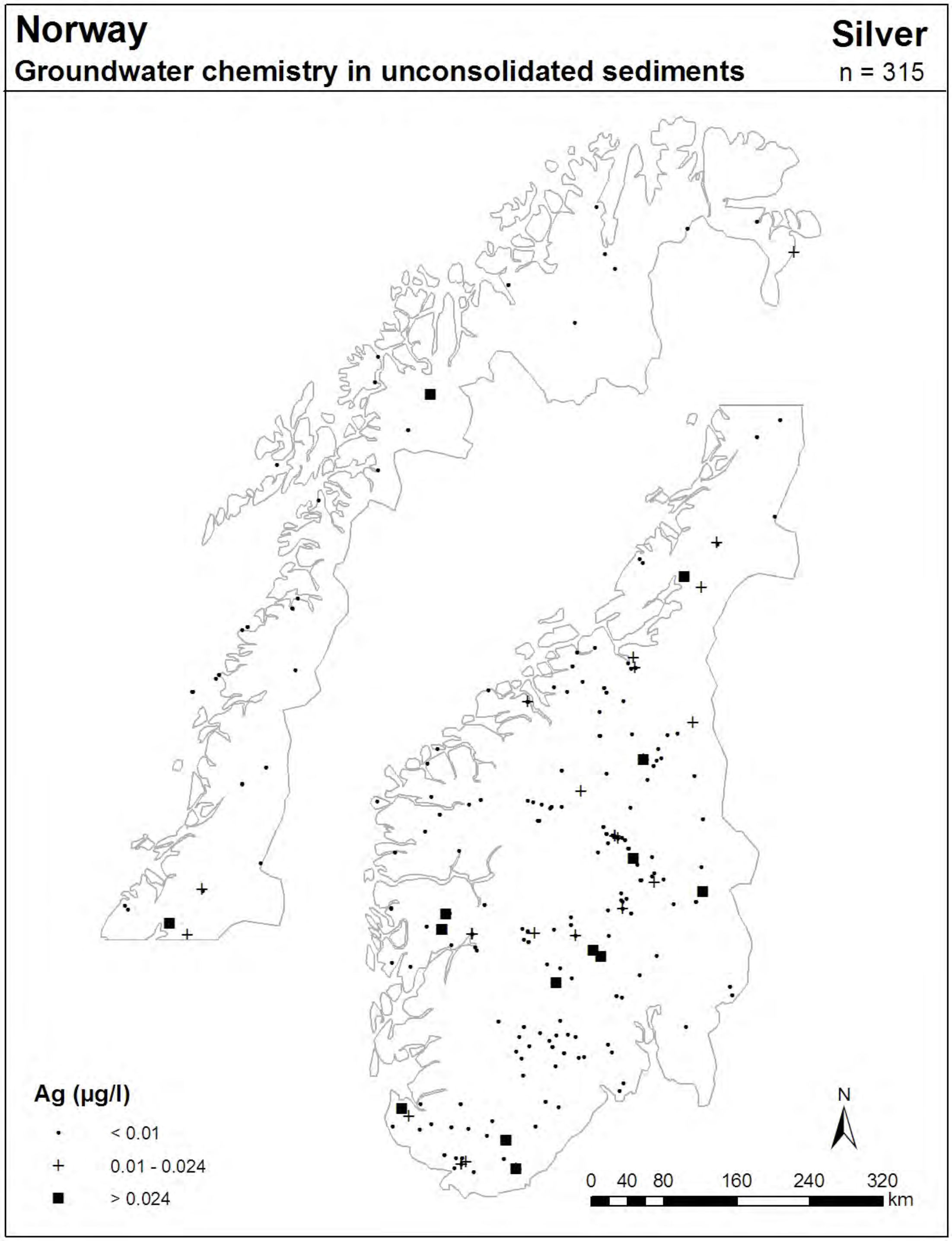

Figure 27: Map of Norway showing silver concentrations in groundwater samples from unconsolidated sediments.

6.9 Aluminium (Al)

The aluminium concentration of the whole dataset was found to be 13.3 µg/L. 24 % of the samples had concentrations below the detection limit of 2 µg/L (ICP-MS). Groundwaters from bedrock boreholes and unconsolidated sediments showed a median value of 11.2 µg/L and 17.7 µg/L respectively. The maximum concentrations of the water samples from different aquifer types were 7020 µg/L (unknown aquifer type), 5690 µg/L (bedrock boreholes) and 1120 µg/L (unconsolidated sediments).

The geographical distribution of aluminium concentration in groundwater samples from bedrock boreholes (Figure 28) is very different to the elemental concentration distributions analyzed so far. The highest measured concentrations are found in samples taken from North-Norway, while the central part of South-Norway, Sørlandet and the area around Oslo show rather low aluminium concentrations. The distribution patterns for aluminium concentrations in water samples from unconsolidated sediment wells (Figure 29) look different. Samples from Østlandet and Trøndelag generally show low aluminium concentrations, while many samples from Sørlandet have high aluminium concentrations.

Norway operates a MAC of 200 µg/L aluminium. 42 (6 %) of 691 groundwater samples were above this norm. 6.4 % of bedrock boreholes and 5.4 % of samples from unconsolidated sediments are affected.

6.10 Arsenic (As)

40 % (278 of 691) of the arsenic concentrations were below the detection limit of 0.05 µg/L. The median concentration of the whole dataset was 0.07 µg/L. Groundwater samples from bedrock boreholes had considerably higher arsenic concentrations than samples from unconsolidated sediments. While the median concentration from the latter aquifer was below detection limit, the median concentration from bedrock boreholes was found to be 0.12 µg/L. The 95% percentile (0.6 µg/L) of samples from unconsolidated sediments still lies below this median concentration. The maximum arsenic concentration measured (23.4 µg/L) was found in a sample from a bedrock borehole. The highest measured concentration in samples from unconsolidated sediments was 5.73 µg/L.

The geographical distribution of arsenic concentration in groundwater samples from bedrock boreholes (Figure 30) shows a few “hot-spots”, where arsenic concentrations are elevated. These are located in the counties of Sogn og Fjordane, Sør-Trøndelag and Vestfold. No general pattern could be observed. The different arsenic concentrations in water samples from unconsolidated sediment wells (Figure 31) seem to be relatively evenly distributed over the country. Samples from Sørlandet generally showed low arsenic concentrations.

The MAC for arsenic in Norwegian drinking water is 10 µg/L. 3 out of 691 samples exceed this MAC – all three of them come from bedrock boreholes. The water samples that fail the standard have arsenic concentrations of 18.9 µg/L, 19.9 µg/L and 23.4 µg/L. This is around twice as much as the MAC and could have health implications.

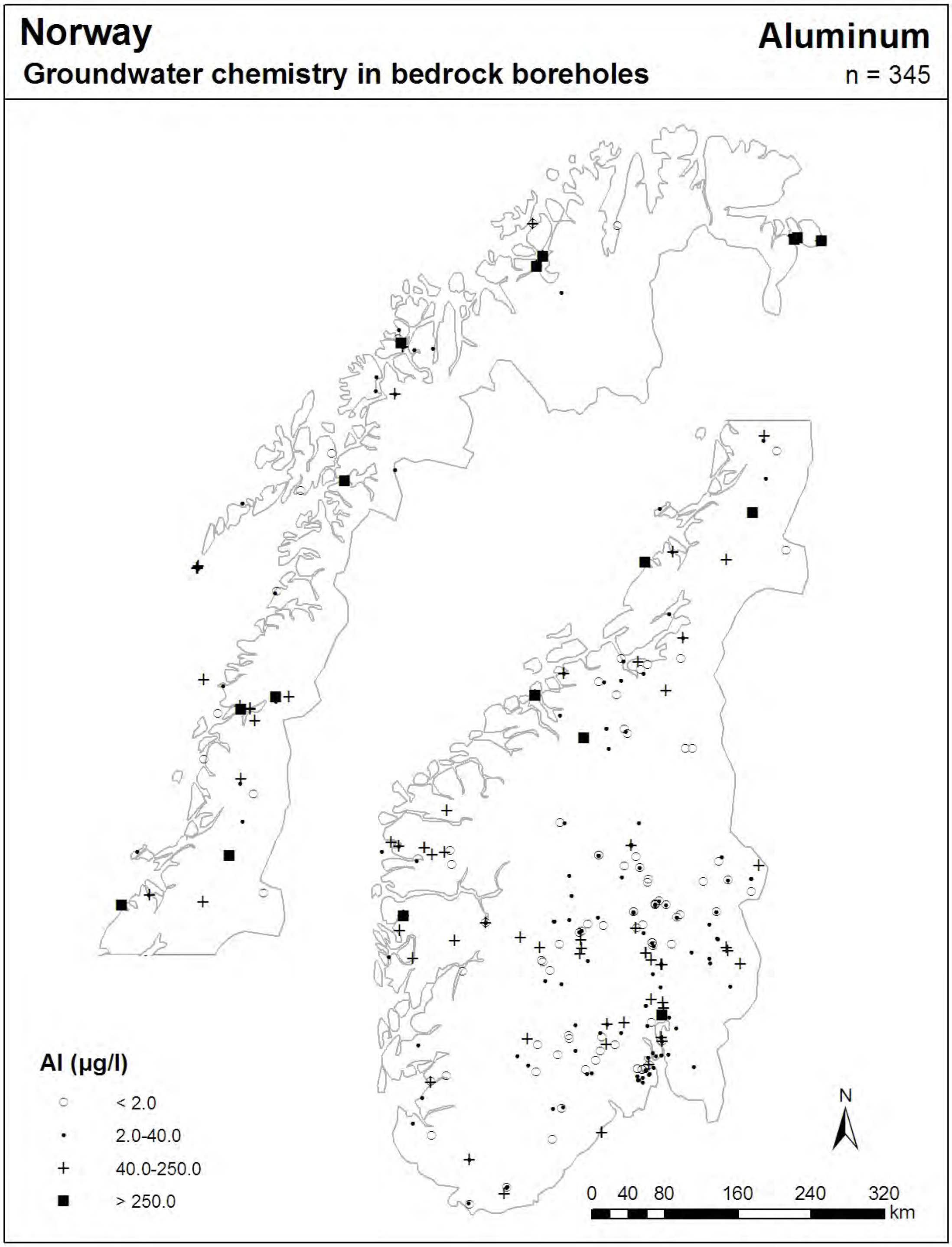

Figure 28: Map of Norway showing aluminium concentrations in groundwater samples from bedrock boreholes.

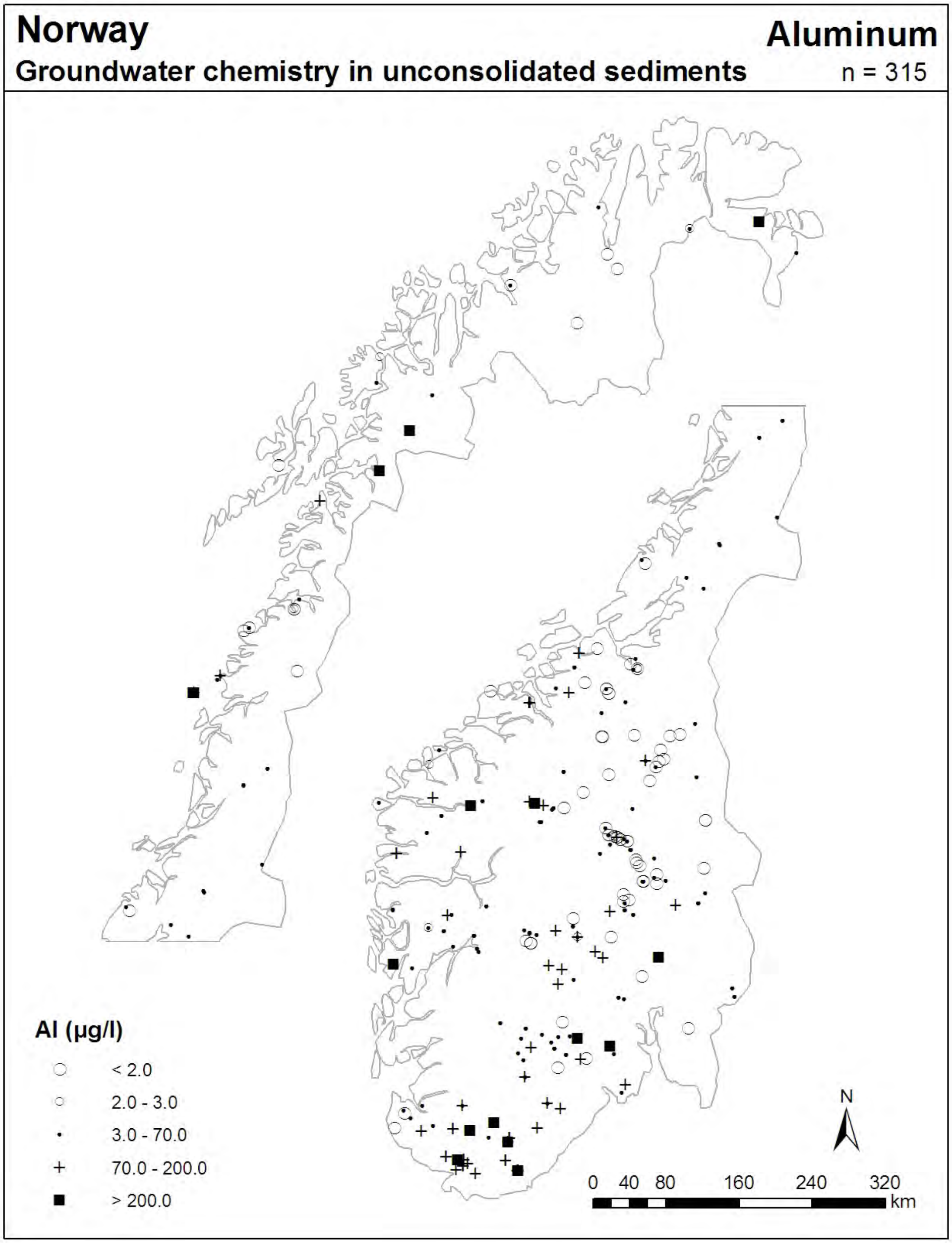

Figure 29: Map of Norway showing aluminium concentrations in groundwater samples from unconsolidated sediments.

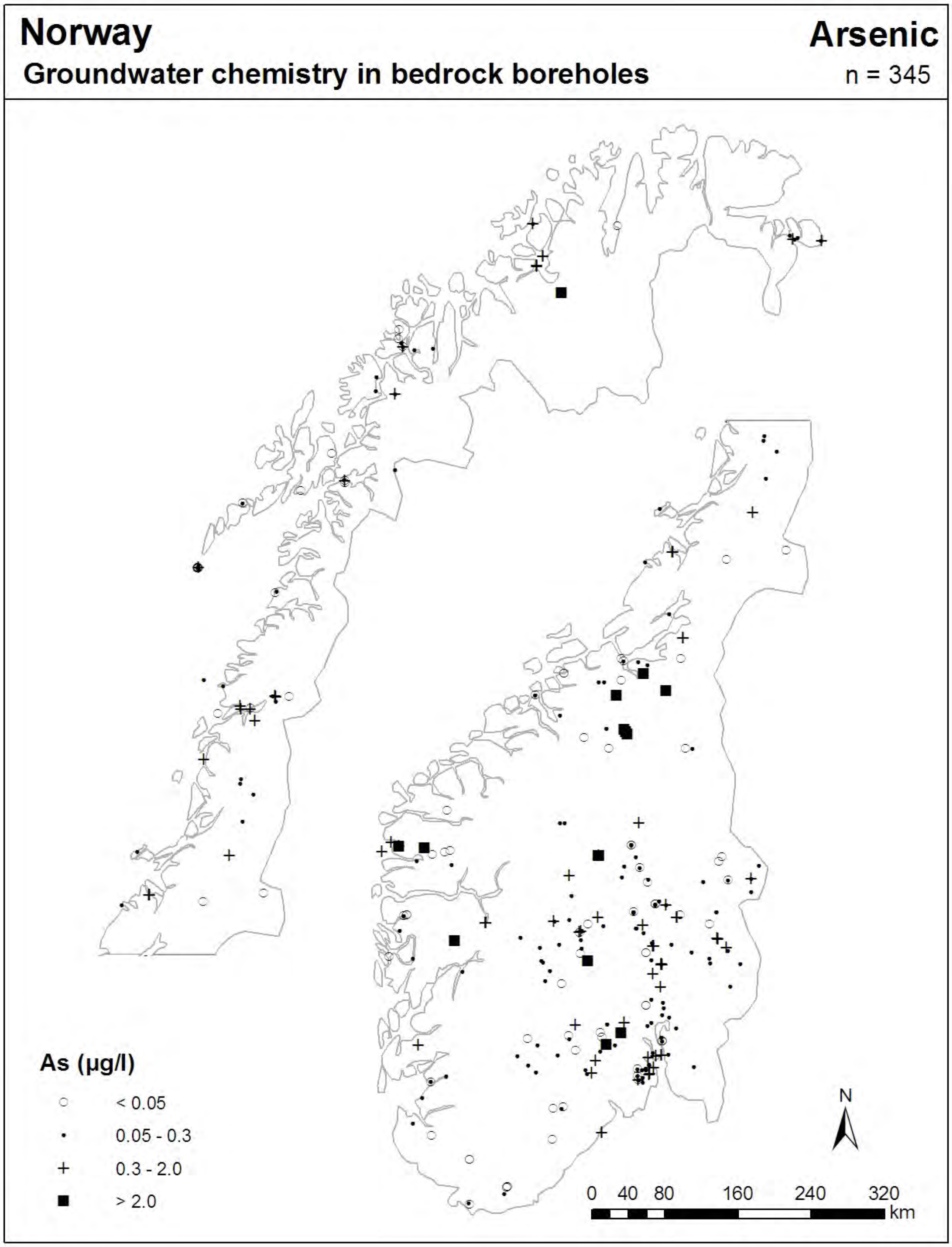

Figure 30: Map of Norway showing arsenic concentrations in groundwater samples from bedrock boreholes.

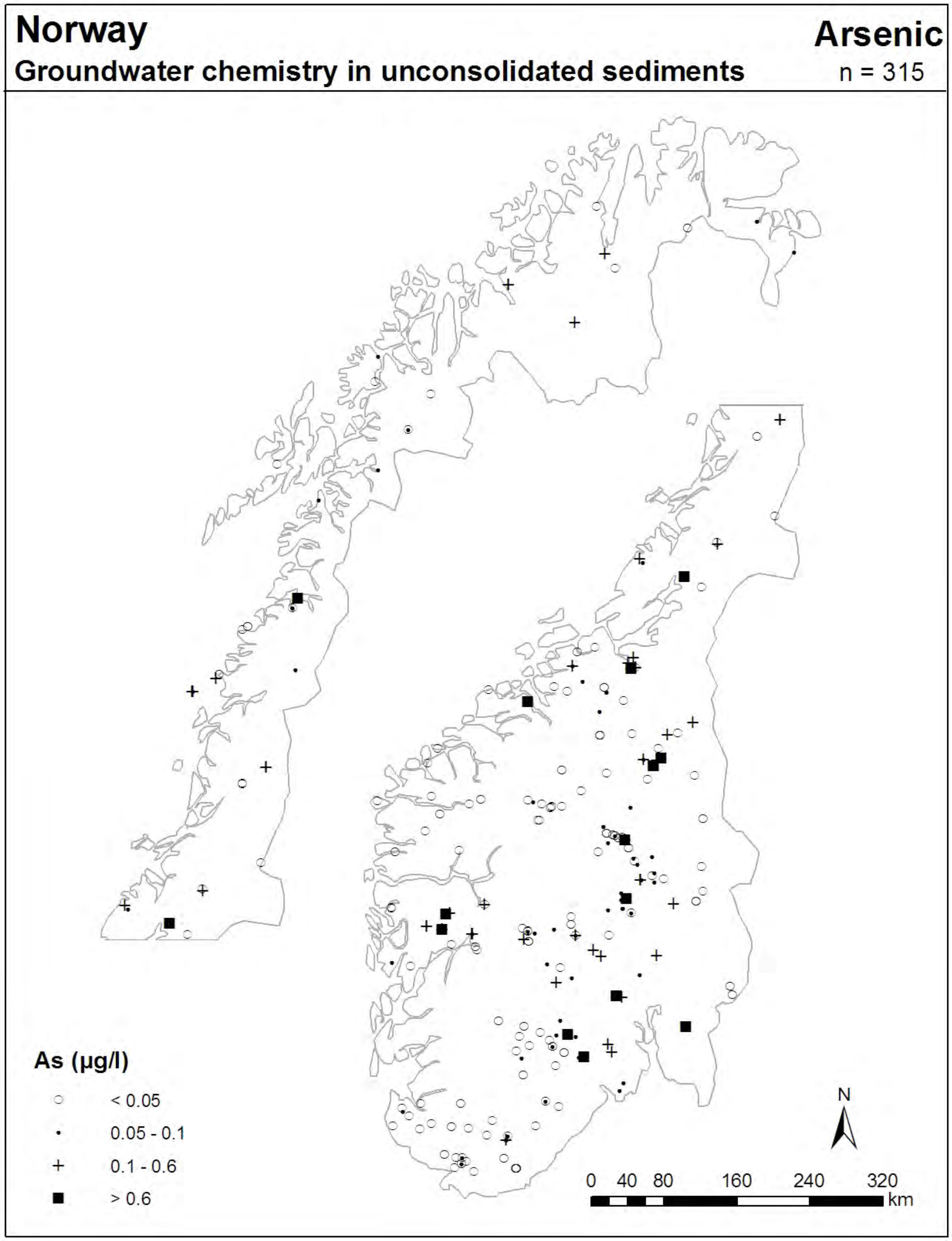

Figure 31: Map of Norway showing arsenic concentrations in groundwater samples from unconsolidated sediments.

6.11 Boron (B)

359 of 691 (52 %) groundwater samples showed boron concentrations below the detection limit of 5 µg/L. Accordingly, the median value of the complete dataset lies below the detection limit. The same applies to the median value of groundwater samples from unconsolidated sediments. The median value from bedrock groundwaters is found to be 7.9 µg/L. Bedrock groundwaters generally showed higher boron concentrations. This is not only reflected by the median value, but also by other percentiles. While samples from sediment groundwaters showed a 75th percentile concentration of 5.15 µg/L and a 95th percentile concentration of 14.6 µg/L, bedrock groundwaters revealed concentrations of 23.3 µg/L and 98.8 µg/L, respectively. Bedrock groundwaters had a maximum concentration of 376 µg/L and unconsolidated sediment groundwaters showed a maximum of 106 µg/L. Yet the highest concentration measured (512 µg/L) comes from a sample of unknown aquifer type.

Groundwater samples from bedrock boreholes (Figure 32) in Østlandet, Vestfold and the coastal areas of North-Norway had higher boron concentrations than in the rest of the country. For samples from unconsolidated sediment wells (Figure 33), no pattern could be observed.

Norway operates a MAC of 1 mg/L. None of the samples lies above this limit. The WHO recommends a limit of 0.5 mg/L. According to these recommendations, one of the samples would exceed the limit.

6.12 Barium (Ba)

58 of 691 (8.4 %) groundwater samples lie below the detection limit of 0.002 mg/L (ICP-AES). The median concentration of the complete dataset is 0.01 mg/L, which is the same as the one from unconsolidated sediment groundwaters and from bedrock groundwaters. The maximum concentration of the whole dataset is 0.232 mg/L (bedrock borehole) and the maximum concentration of unconsolidated sediment samples is 0.159 mg/L.

When looking at the geographical distribution of barium concentrations in groundwaters from bedrock boreholes (Figure 34), Hedmark showed more samples with barium concentrations above 0.1 mg/L than the rest of the country. Many groundwater samples with barium concentrations above 0.09 mg/L that originated from Quaternary aquifers (Figure 35), were taken in Oppland county.

Norwegian health authorities have not defined a MAC for barium. A former guideline value was 0.1 mg/L (Sosial- og helsedepartementet, 1995). 43 of 691 samples (6.2 %) would exceed these recommendations. The guideline value of the WHO (0.7 mg/L) is not as strict as this value. None of the samples exceeds the recommendations of the WHO.

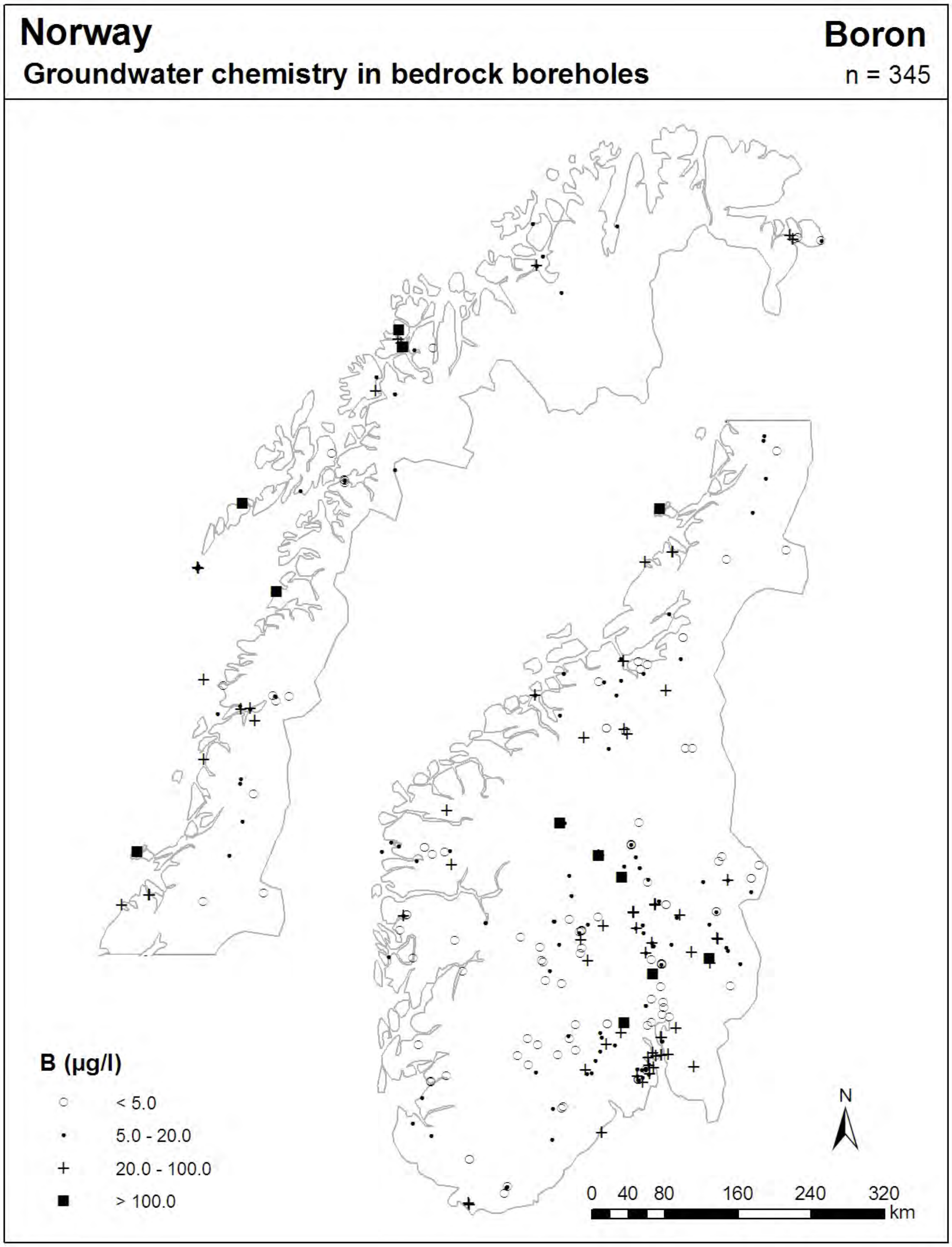

Figure 32: Map of Norway showing boron concentrations in groundwater samples from bedrock boreholes.

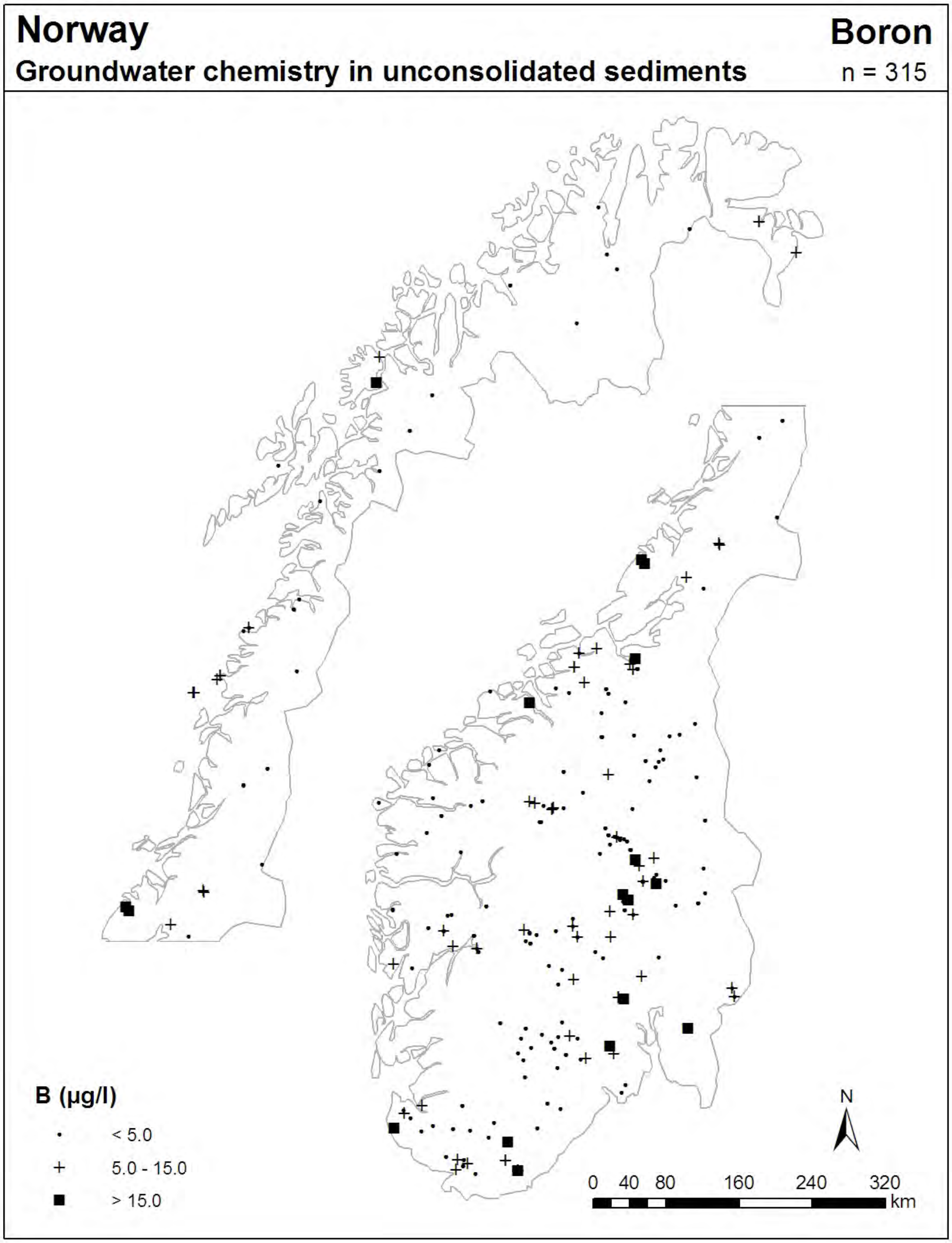

Figure 33: Map of Norway showing boron concentrations in groundwater samples from unconsolidated sediments.

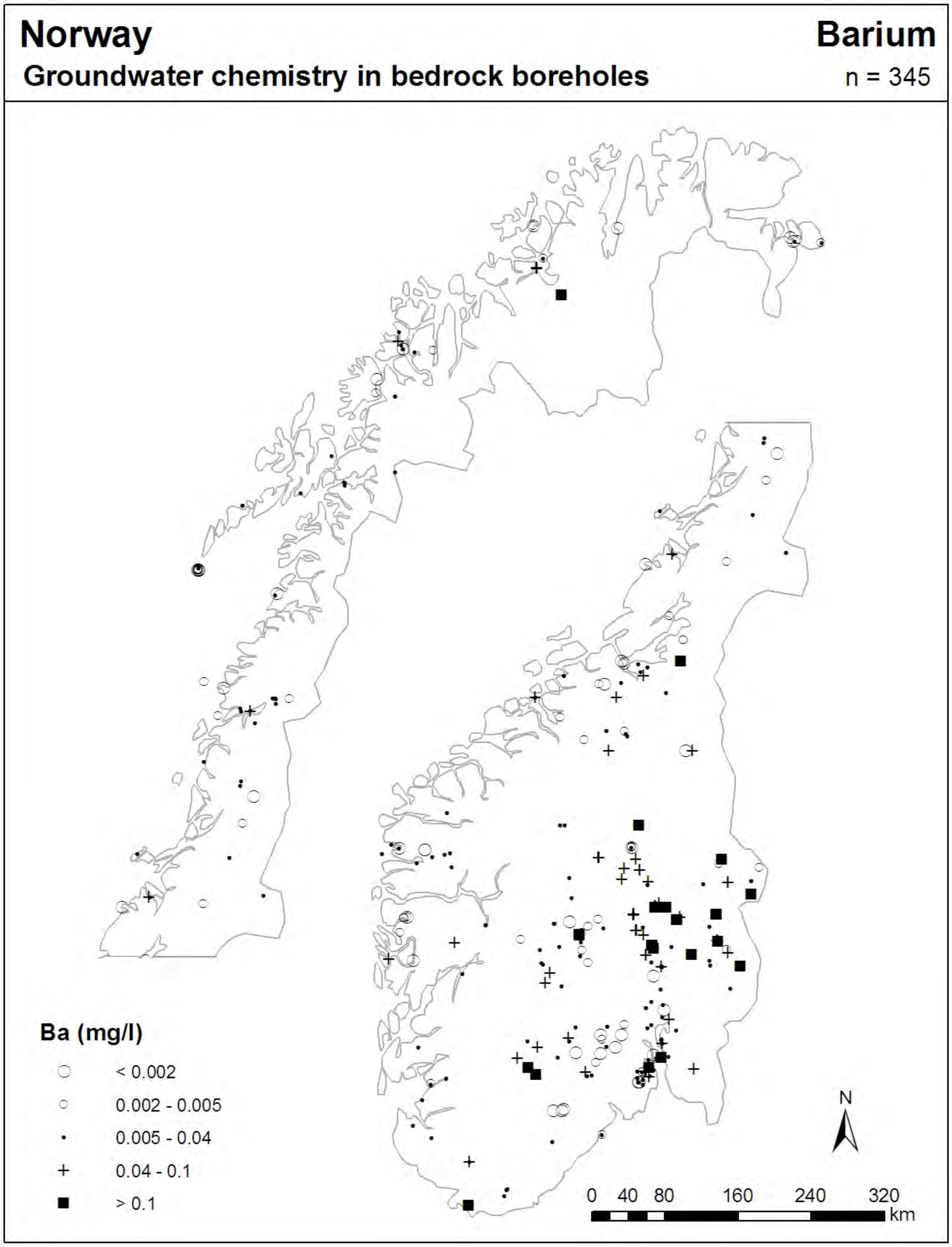

Figure 34: Map of Norway showing barium concentrations in groundwater samples from bedrock boreholes.

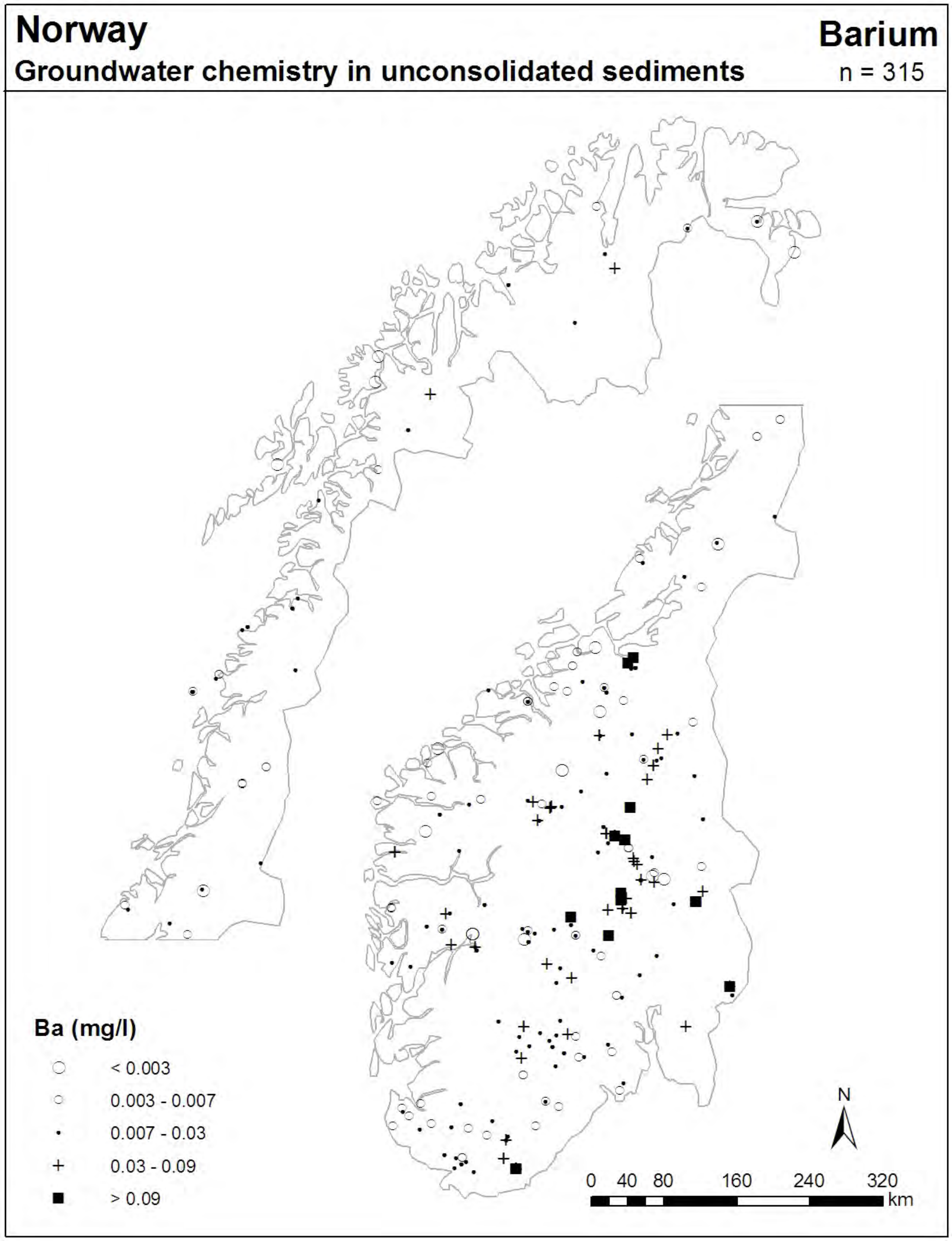

Figure 35: Map of Norway showing barium concentrations in groundwater samples from unconsolidated sediments.

6.13 Beryllium (Be)

356 out of 691 (52 %) groundwater samples lie below the detection limit of 0.01 µg/L. The median concentration of the whole dataset, as well as the median concentrations of water samples from both aquifer types, lies below this limit. The highest measured concentration (5.3 µg/L) was found in a bedrock water sample (n=346). The maximum concentration found in water samples from unconsolidated sediments was 0.3 µg/L.

When looking at the geographical distribution of beryllium concentrations in samples from bedrock boreholes (Figure 36), no special pattern can be observed. Yet the groundwater samples taken from unconsolidated sediment wells (Figure 37), that show high beryllium concentrations, seem to be clustered in Sørlandet.

Even though beryllium is listed under harmful substances in the Norwegian Directive on drinking water, no limit has been set so far. The MAC in the USA is set to 4 µg/L beryllium. According to this limit two samples would exceed the limit.

6.14 Bismuth (Bi)

685 of 691 (99 %) groundwater samples showed bismuth concentrations below the detection limit of 0.01 µg/L. The maximum concentration was found to be 0.132 µg/L (bedrock borehole). Only a few samples showed bismuth concentrations above detection limit. Yet, these were so close to the detection limit, that no reliable statistical analysis could be expected. Thus, no further analysis was carried out.

No MAC values are set in western countries.

6.15 Bromine (Br^-)

490 out of 691 (71 %) groundwater samples had bromine concentrations below the detection limit of 0.1 mg/L (ion chromatography). The maximum concentration was found to be 9.04 mg/L (unknown aquifer type). Bedrock groundwaters revealed a maximum of 2.56 mg/L and the maximum found in samples from unconsolidated sediments was 4.93 mg/L.

No geographical pattern could be identified.

In Norway, no MAC for bromine is defined.

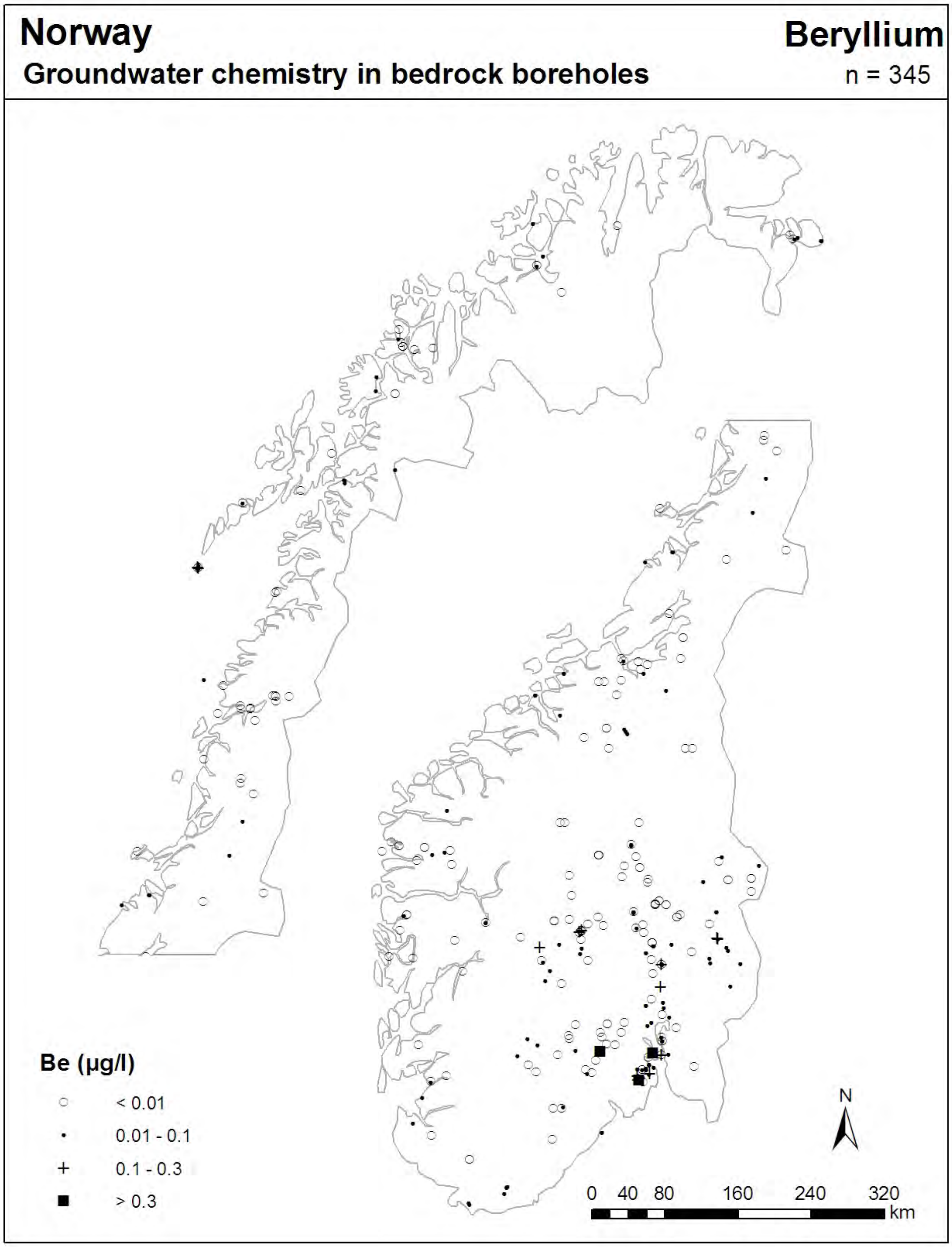

Figure 36: Map of Norway showing beryllium concentrations in groundwater samples from bedrock boreholes.

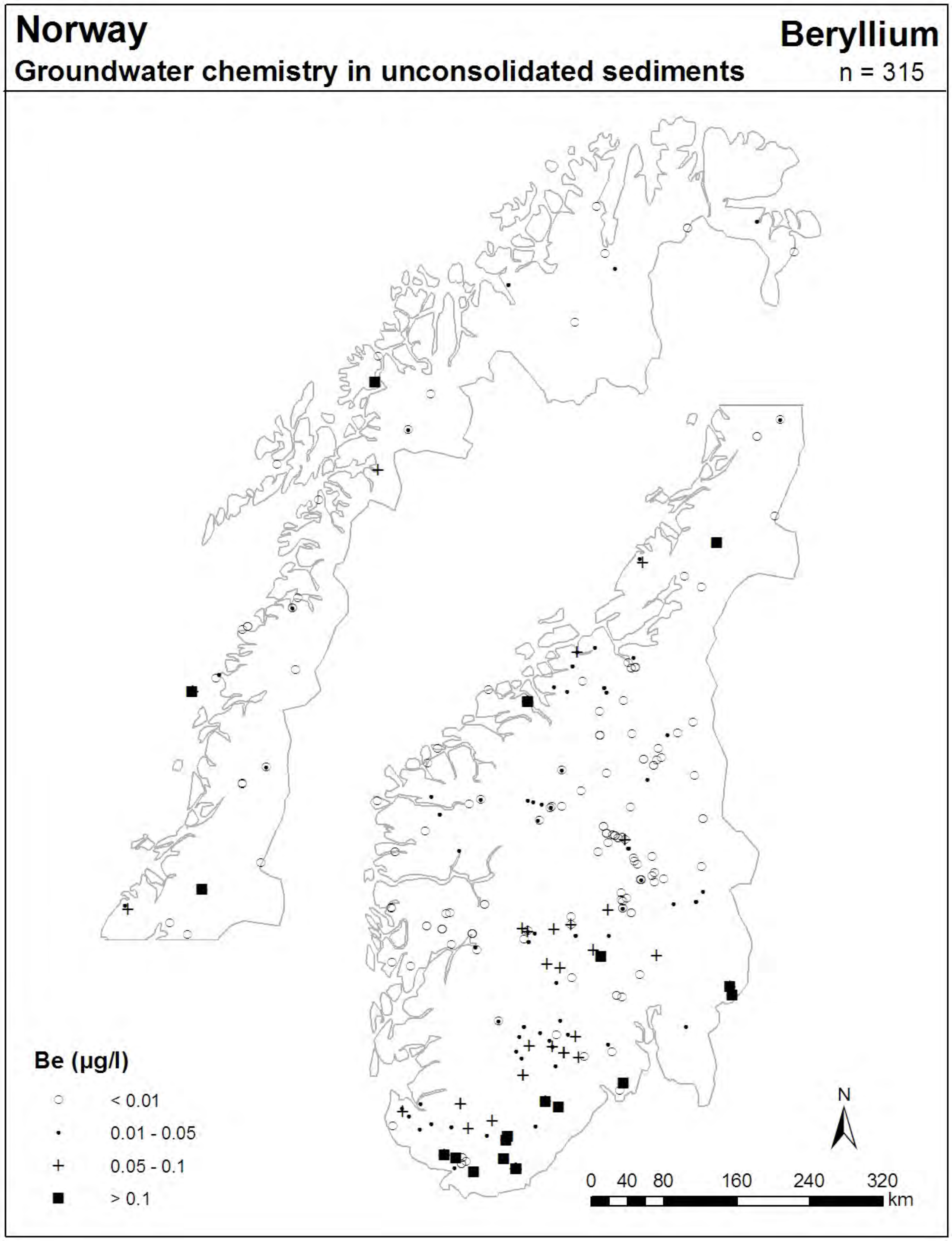

Figure 37: Map of Norway showing beryllium concentrations in groundwater samples from unconsolidated sediments.

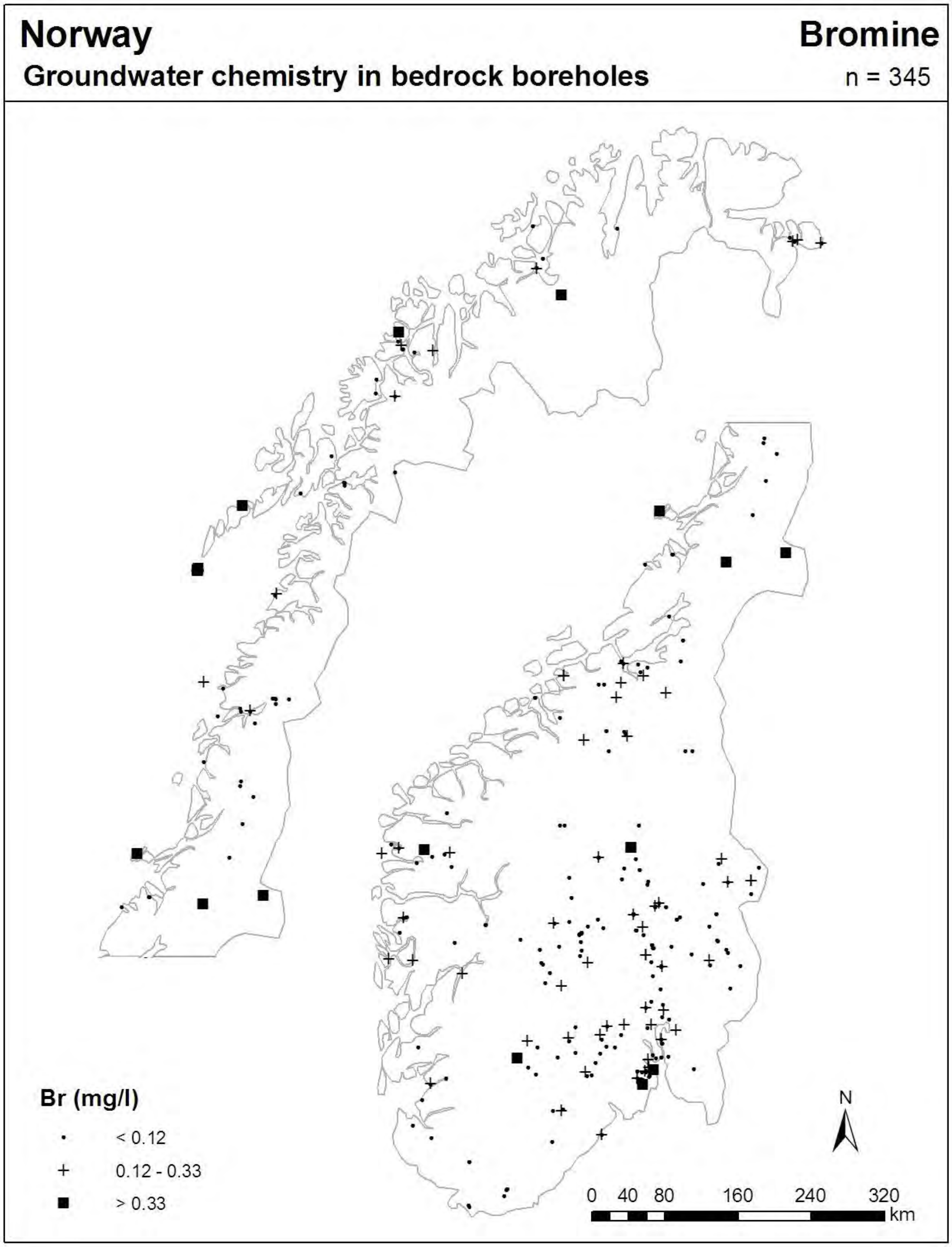

Figure 38: Map of Norway showing bromine concentrations in groundwater samples from bedrock boreholes.

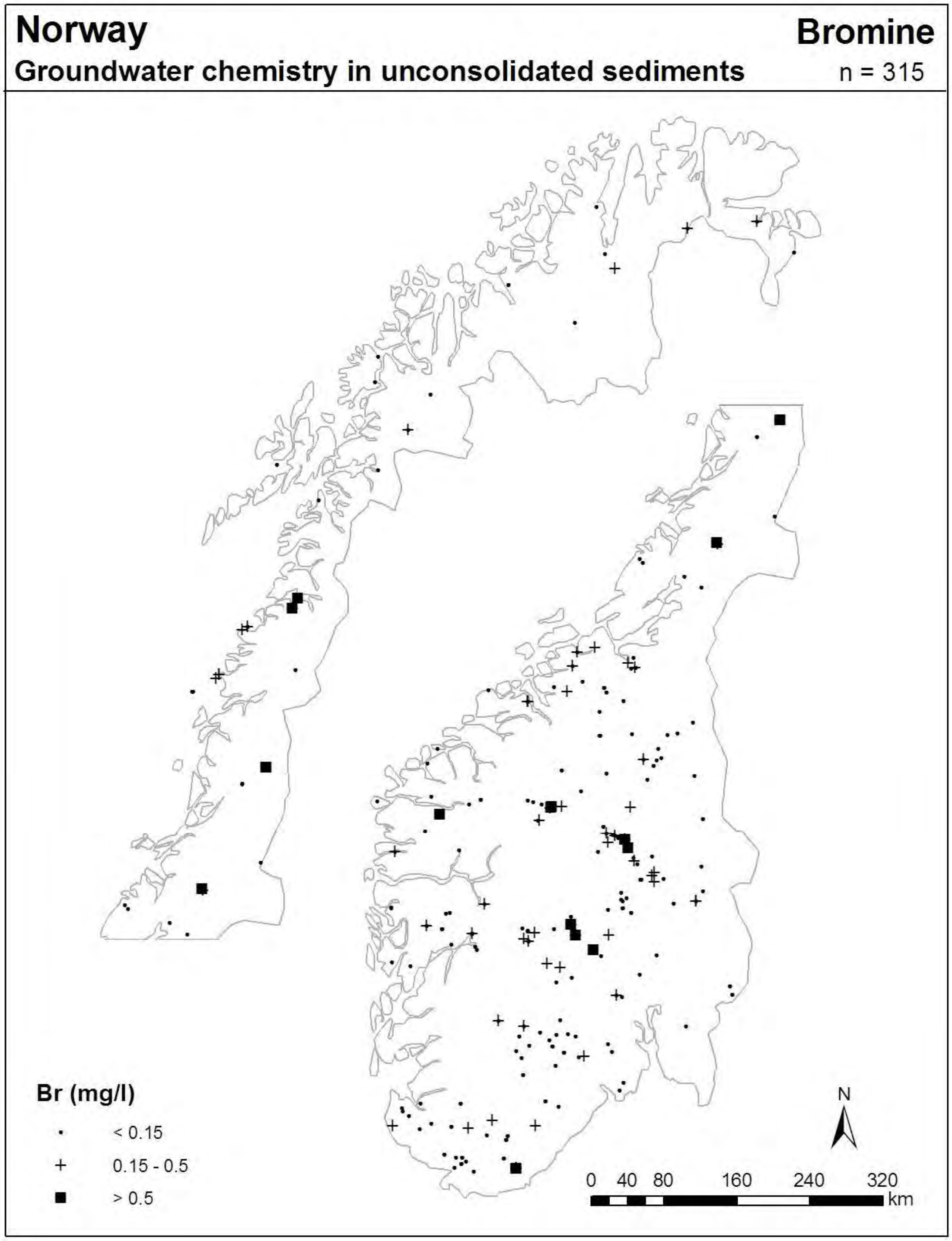

Figure 39: Map of Norway showing bromine concentrations in groundwater samples from unconsolidated sediments.

6.16 Calcium (Ca)

None of the 691 groundwater samples was below the detection limit of 0.02 mg/L (ICP-AES). The median value of the whole dataset is given by 16.1 mg/L with a range from 0.08 mg/L (bedrock borehole) to 201 mg/L (bedrock borehole). Bedrock groundwaters generally showed higher calcium concentrations than groundwaters from sediments (n=314). The median concentrations for bedrock boreholes and unconsolidated sediment groundwaters are 27.8 mg/L and 7.0 mg/L, respectively. The highest measured concentration in the unconsolidated sediment samples was 145 mg/L.

For the bedrock boreholes, elevated calcium concentrations seem to follow the Cambro-Silurian sediments in the Oslo graben. For unconsolidated sediments a higher portion of low calcium concentrations is observed in the southern and western parts of South Norway.

Norwegian health authorities have not defined a MAC for calcium. A previous guideline range recommended concentrations from 15-25 mg/L (Sosial- og helsedepartementet, 1995). According to these recommendations, 247 out of 691 (35.7 %) samples would have concentrations below the recommended range. 54 % of bedrock groundwaters showed concentrations below 15 mg/L. 332 of 691 (48 %) samples showed concentrations above the recommended 25 mg/L. 72 % of the samples from unconsolidated sediments were found to have concentrations above the recommended range.

6.17 Cadmium (Cd)

532 of 691 (77 %) groundwater samples showed cadmium concentrations below the detection limit of 0.03 μg/L. 73 % of samples from bedrock boreholes and 80.6 % from unconsolidated sediments were below this limit. The maximum value (1.65 μg/L) was measured in sediment groundwaters. The highest measured cadmium concentration from bedrock boreholes was 1.08 μg/L.

For water samples from unconsolidated sediment wells (Figure 42), no geographical distribution pattern could be identified. For bedrock groundwaters (Figure 43), the southern part of Østlandet seemed to have the biggest portion of samples with elevated cadmium concentrations.

Norwegian health authorities have set a MAC of 5 μg/L cadmium. None of the samples exceeds this limit.

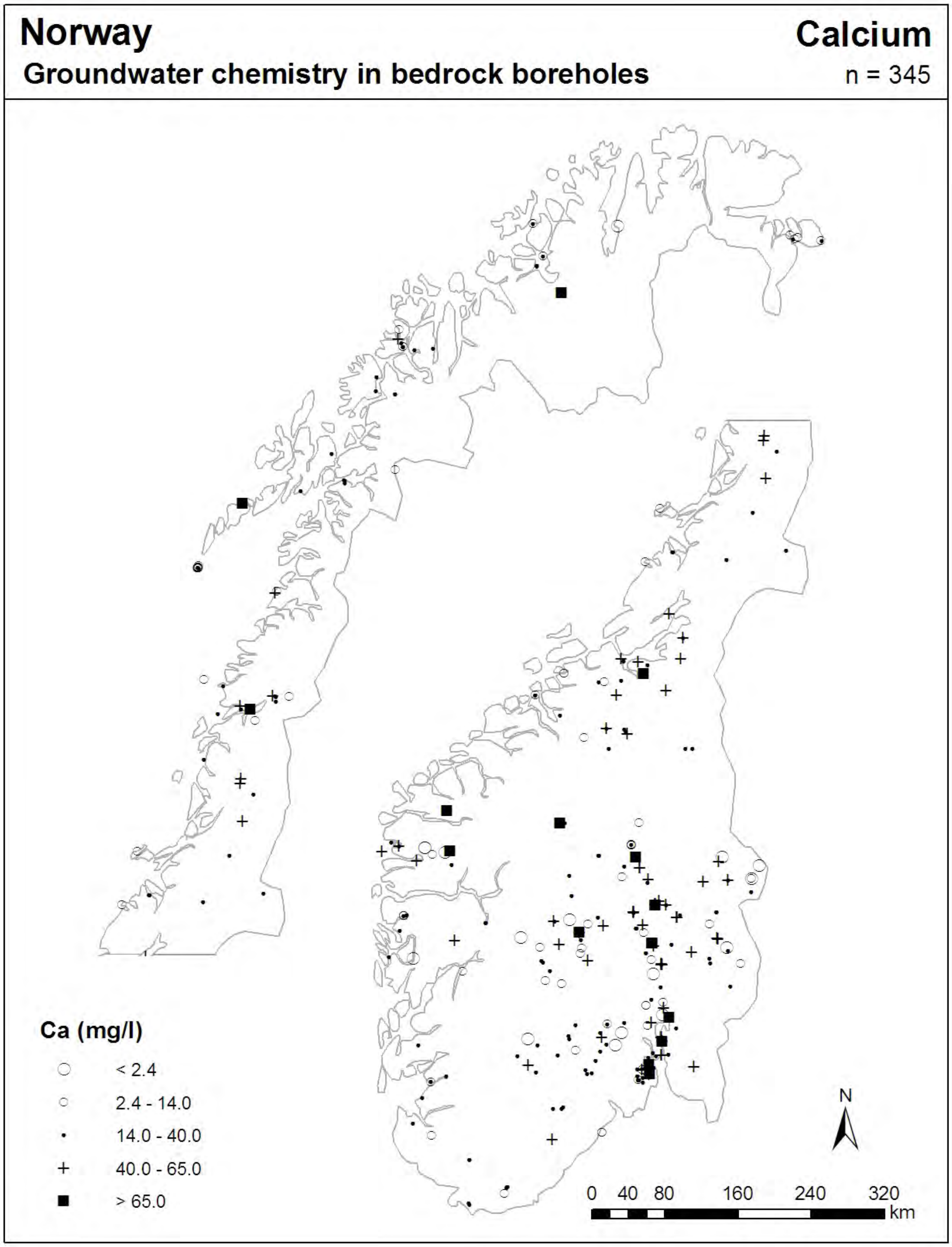

Figure 40: Map of Norway showing calcium concentrations in groundwater samples from bedrock boreholes.

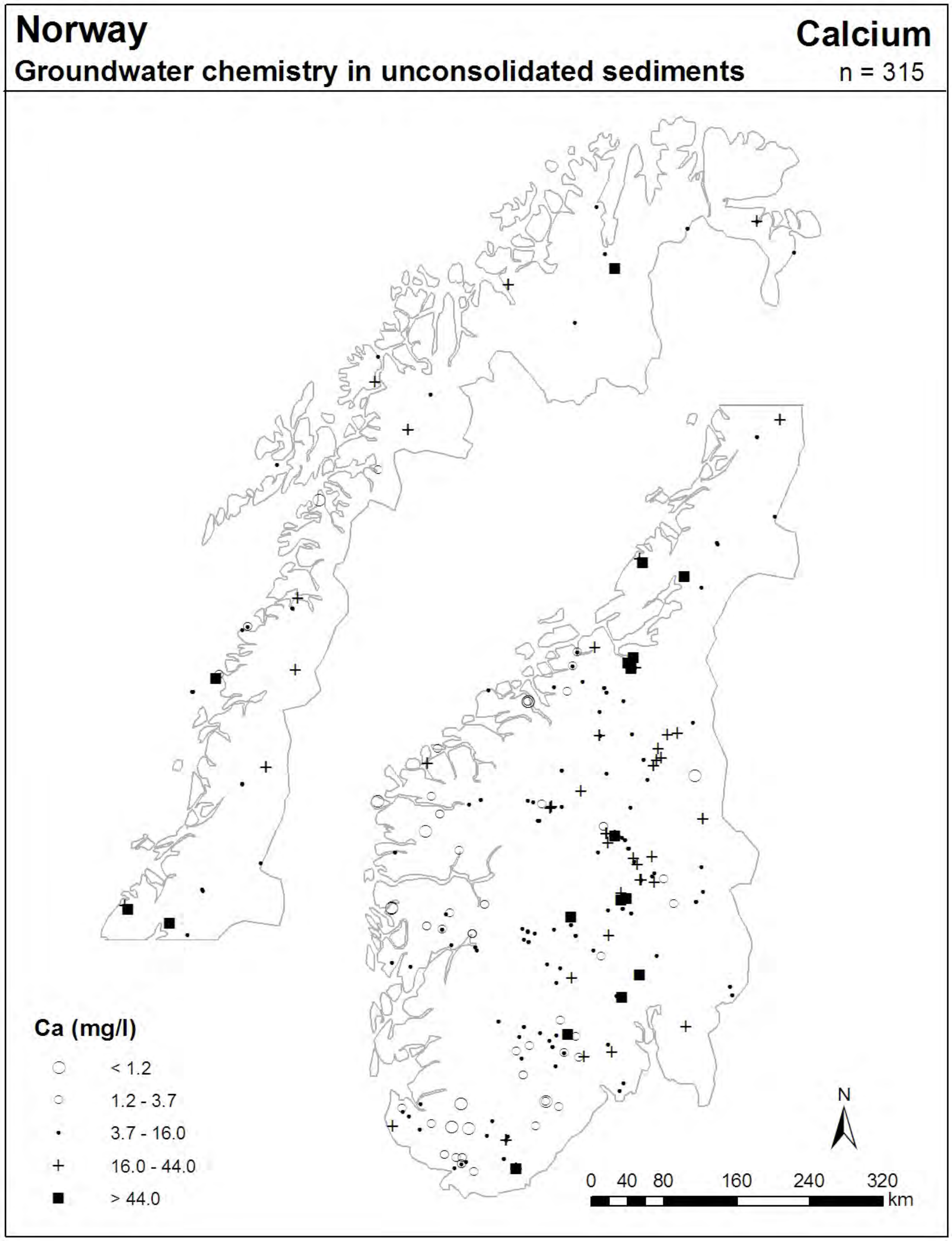

Figure 41: Map of Norway showing calcium concentrations in groundwater samples from unconsolidated sediments.

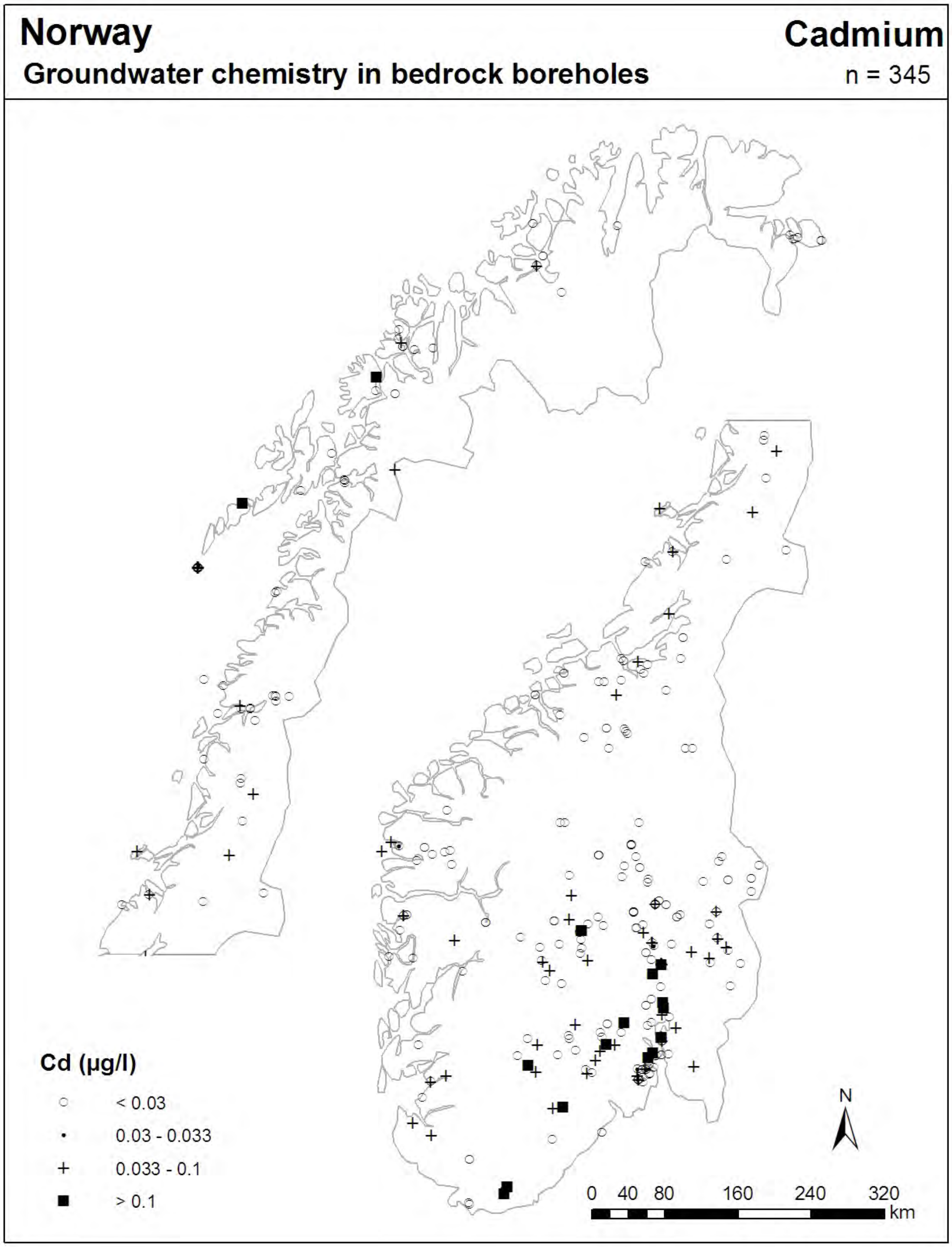

Figure 42: Map of Norway showing cadmium concentrations in groundwater samples from bedrock boreholes.

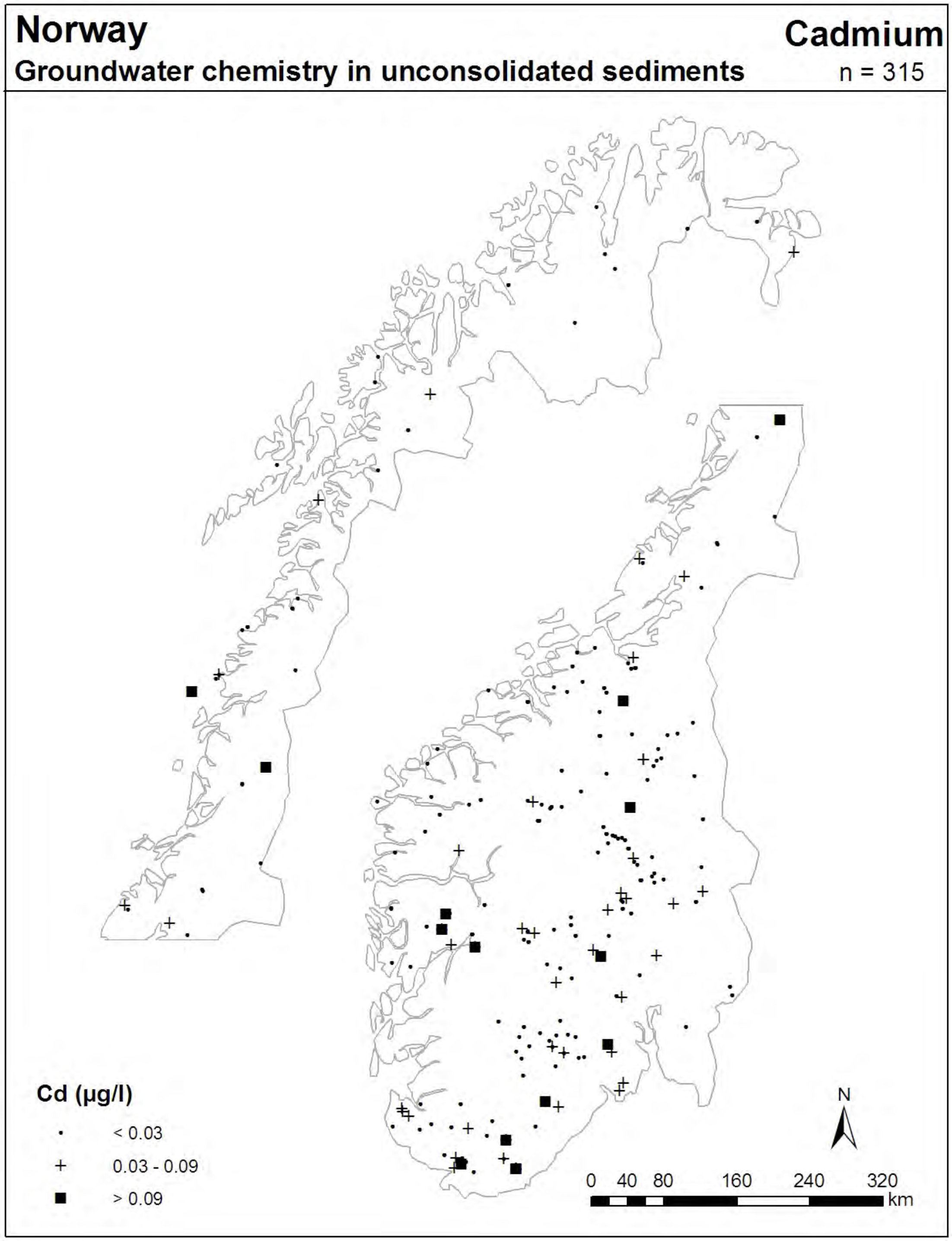

Figure 43: Map of Norway showing cadmium concentrations in groundwater samples from unconsolidated sediments.

6.18 Chloride (Cl^-)

None of the 691 groundwater samples was below the detection limit of 0.1 mg/L (ion chromatography). The median chloride concentration of the whole dataset was 5.2 mg/L. The median value of the analysed bedrock groundwaters was slightly above (6.0 mg/L) and the median value of the analyzed sediment groundwaters slightly below (4.1 mg/L). The highest measured concentration (3050 mg/L) was found in a sample of unknown aquifer type. In bedrock groundwaters, the highest measured concentration was 677 mg/L, and, respectively, 162 mg/L in unconsolidated sediment groundwater samples.

Samples with high chloride concentrations were mainly found close to the coast or below the upper marin limit (Figure 44 and Figure 45). Elevated chloride concentrations further inland may be derived from application of salt on the roads.

Norwegian health authorities have set a guidance level for Cl^- in drinking water of 25 mg/L and a MAC of 200 mg/L. 55 of 691 (8 %) exceed the guidance level. Two samples exceed the MAC – one of them comes from a private well in Agdenes and the other one from Lofoten. Both wells are located very close to the coast and were presumably intruded by seawater. For comparisons, seawater has a chloride concentration of 19000 mg/L (Izbicki, 2005).

6.19 Cobalt (Co)

246 of 691 (35.6 %) groundwater samples showed cobalt concentration below the detection limit of 0.02 µg/L (ICP-MS).The median concentration of the complete dataset is 0.04 µg/L; the maximum concentration is 127 µg/L (unknown aquifer type). Bedrock groundwaters were found to have a median concentration, which is 0.04 µg/L; samples from unconsolidated sediment groundwaters had a median concentration of 0.03 µg/L. In bedrock groundwaters, the highest measured concentration was 13.5 µg/L and the highest measured concentration in unconsolidated sediment groundwater samples was 22 µg/L.

No geographical patterns for cobalt concentrations could be observed.

The Norwegian health authorities have not specified a MAC for cobalt.

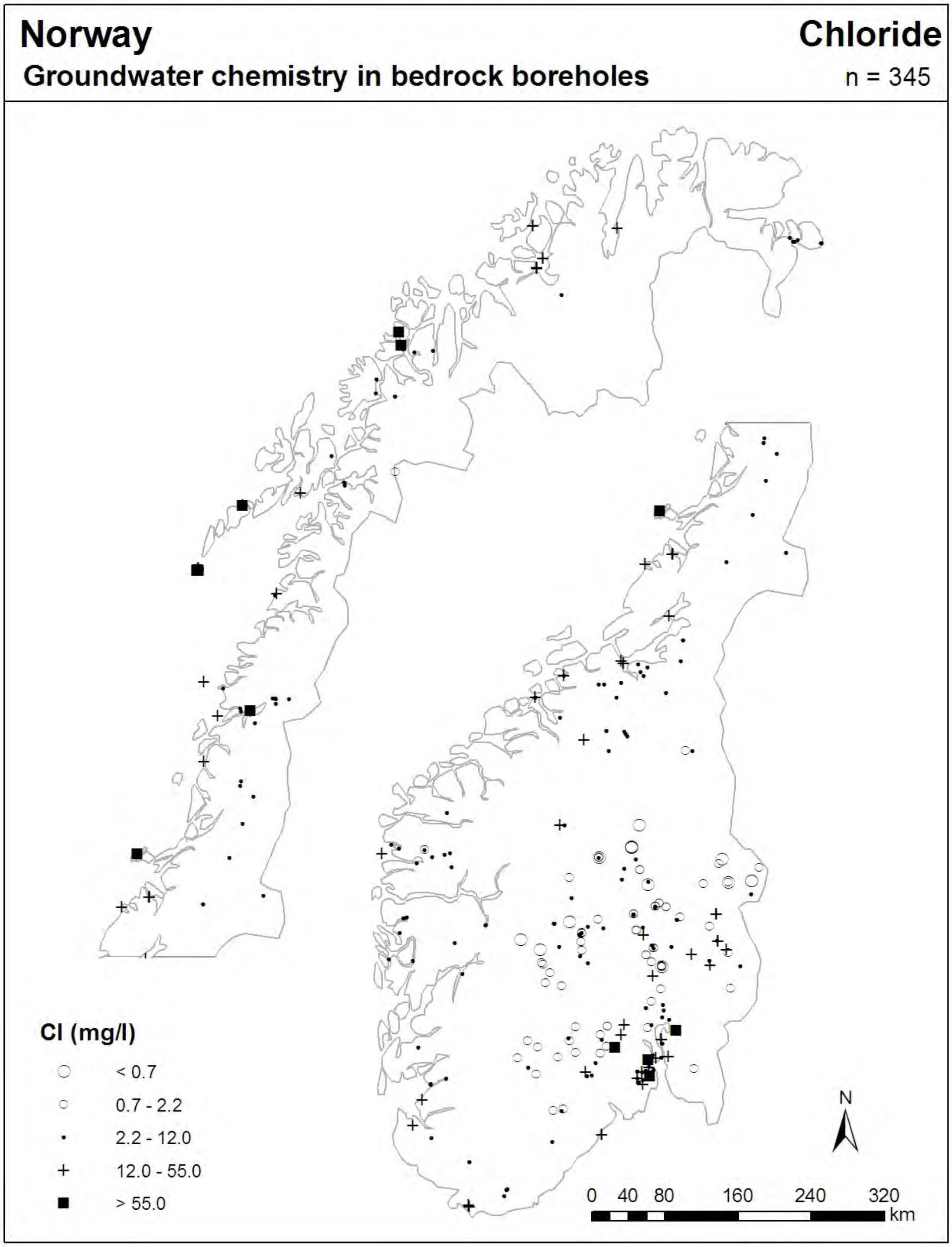

Figure 44: Map of Norway showing chloride concentrations in groundwater samples from bedrock boreholes.

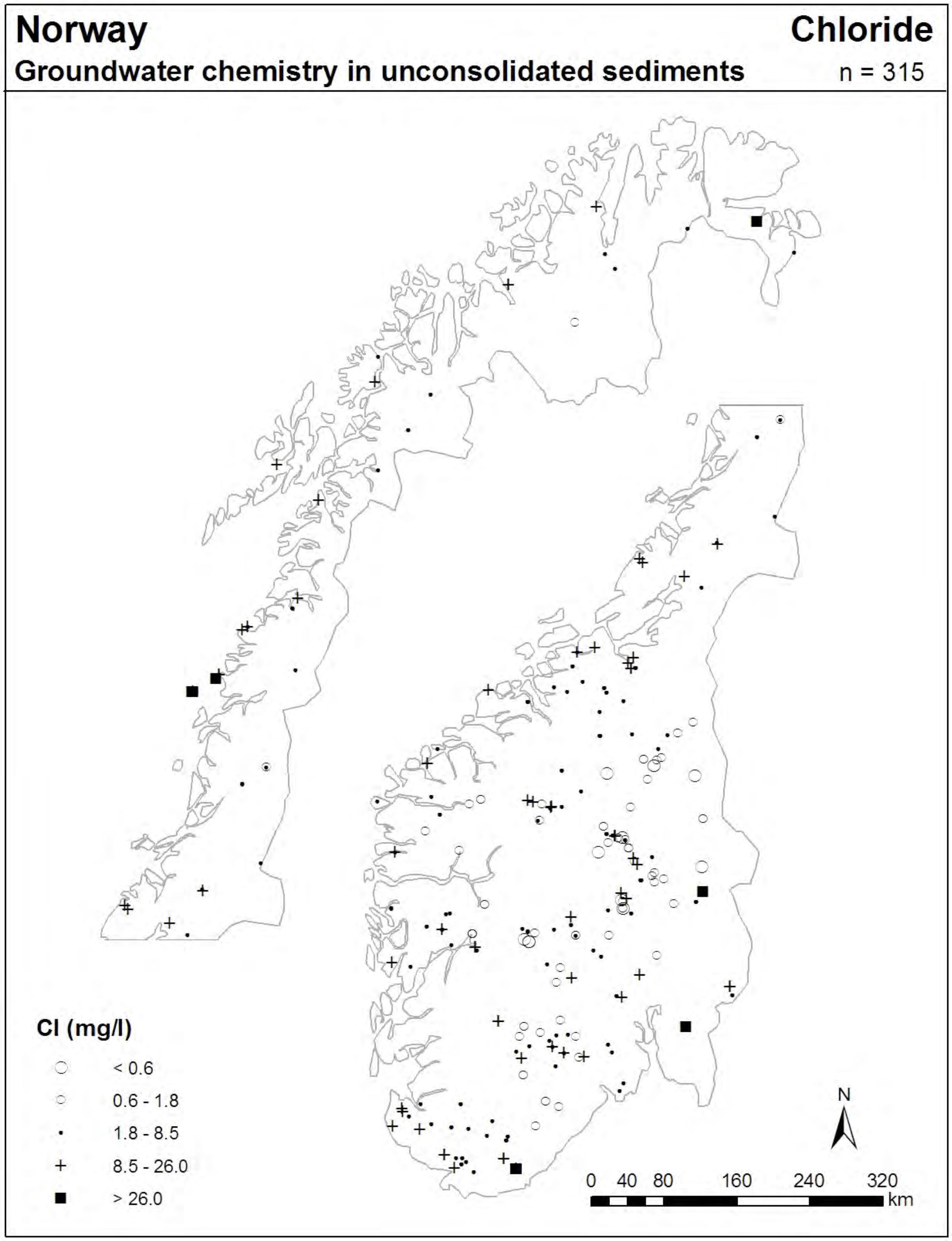

Figure 45: Map of Norway showing chloride concentrations in groundwater samples from unconsolidated sediments.

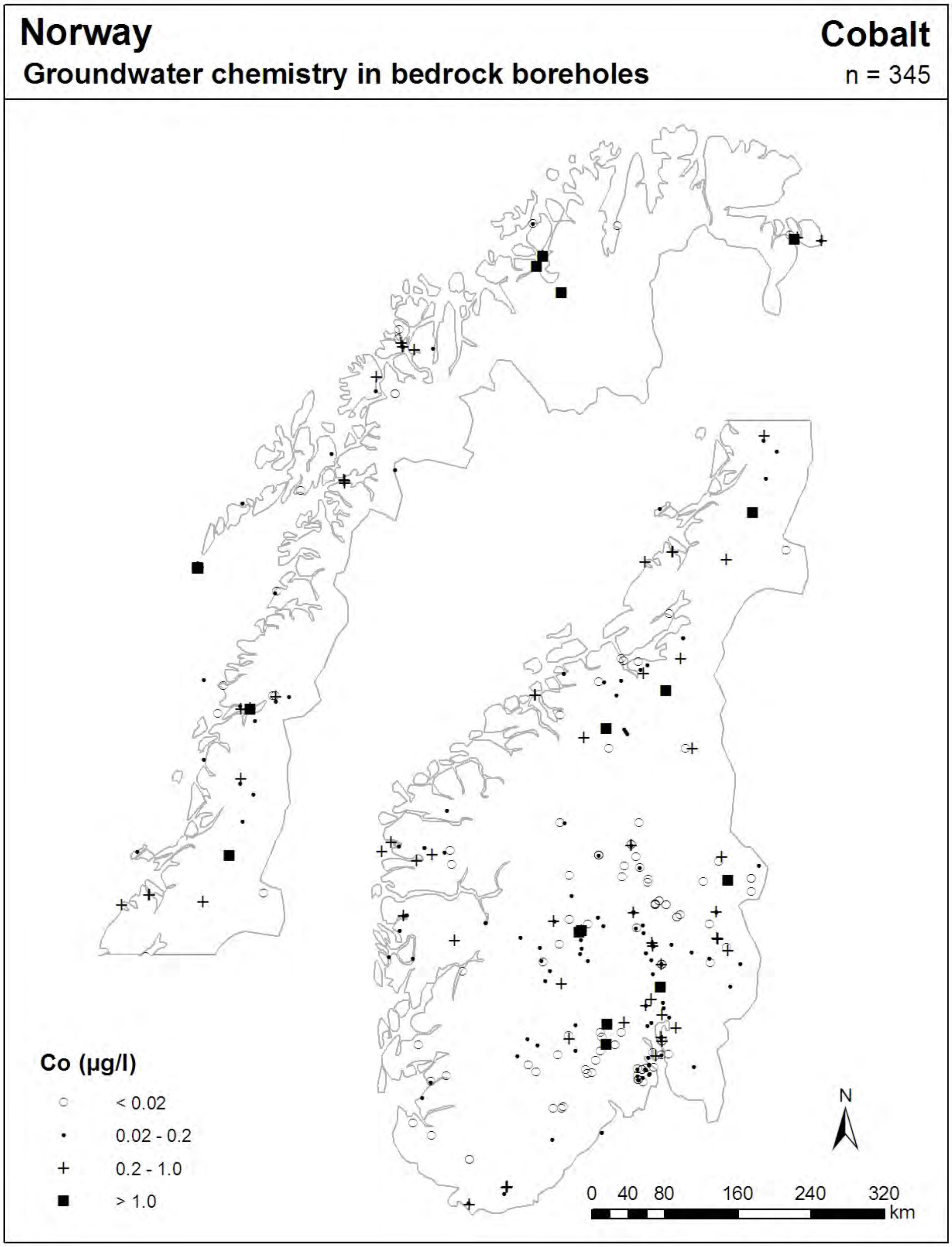

Figure 46: Map of Norway showing cobalt concentrations in groundwater samples from bedrock boreholes.

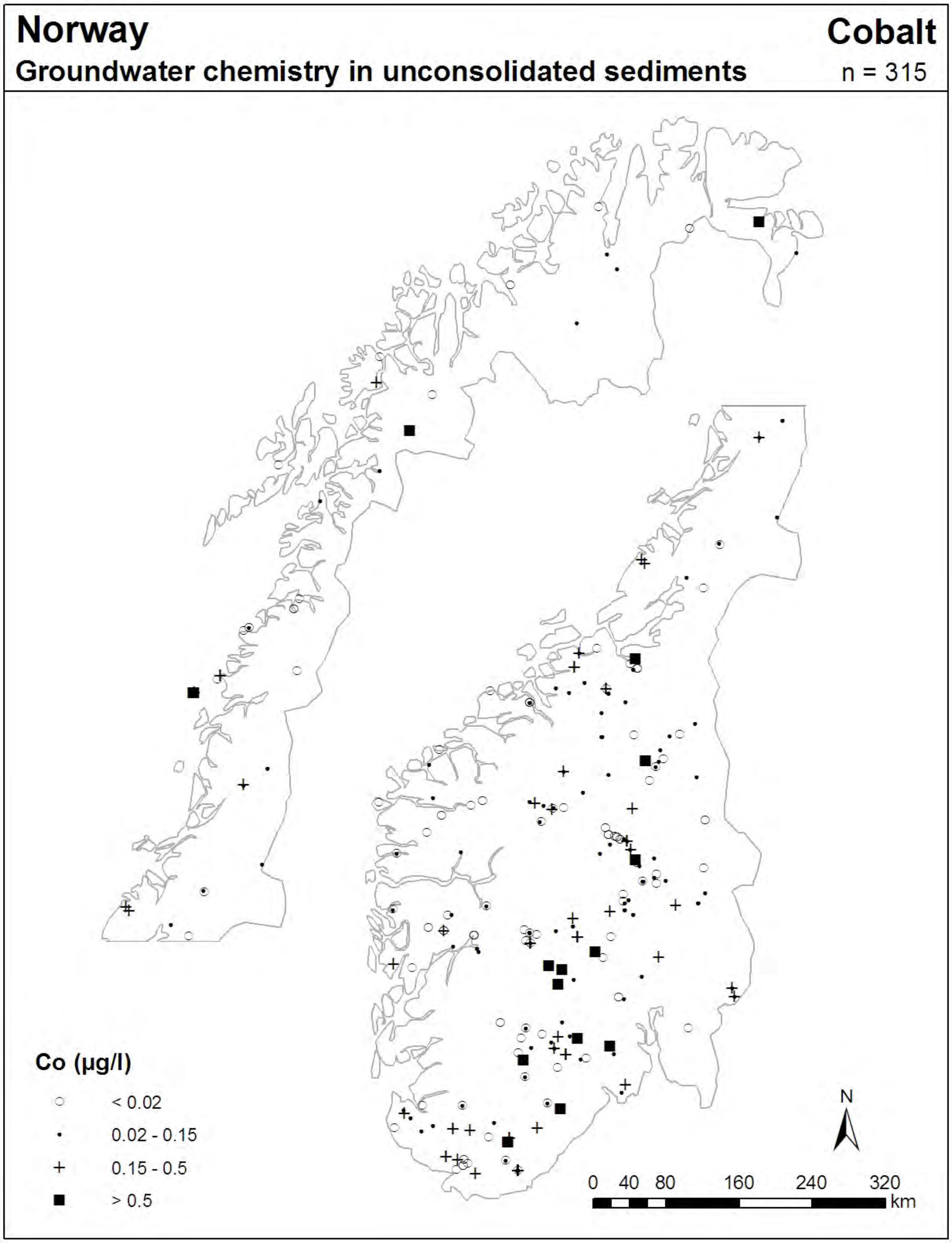

Figure 47: Map of Norway showing cobalt concentrations in groundwater samples from unconsolidated sediments.

6.20 Chromium (Cr)

371 of 691 (53.7 %) groundwater samples were found to have chromium concentrations below the detection limit of 0.1 µg/L (ICP-MS). Accordingly, the median concentration of the whole dataset lies below detection limit. The same applies to the median concentration of unconsolidated sediment groundwaters. The median concentration of bedrock groundwaters was just slightly above. The highest measured concentration was 30.2 µg/L (bedrock borehole). The highest measured concentration in unconsolidated sediment groundwaters was 4.38 µg/L.

When looking at the geographical distribution (Figure 48 and Figure 49) of chromium concentration in Norwegian groundwaters, most of the samples with slightly elevated concentrations were found in the northern part of Norway.

None of the groundwater samples exceeds the MAC of 50 µg/L chromium (Mattilsynet, 2005).

6.21 Caesium (Cs)

114 of 691 (16.6 %) groundwater samples had caesium concentration below the detection limit of 0.002 µg/L (ICP-MS). The median concentration of the whole dataset was 0.03 µg/L and the maximum concentration was found to be 2.37 µg/L. Generally it can be said, that caesium concentrations found in bedrock groundwaters were higher than concentrations in samples from unconsolidated sediment groundwaters (n=314). Water samples from bedrock boreholes showed a median concentration of 0.07 µg/L, a 95th percentile of 1.05 µg/L and a highest measured concentration of 2.37 µg/L. Water samples from unconsolidated sediment aquifers showed a median concentration of 0.01 µg/L, a 95th percentile of 0.14 µg/L and a maximum value of 0.611 µg/L.

No geographical pattern can be seen for caesium in bedrock boreholes. For groundwater in unconsolidated sediments one may speculate whether the belt of elevated caesium concentrations east of the mountain range reflects areas of precipitation after the Chernobyl accident. Unfortunately, the density of sampled wells is low in the county of Nord-Trøndelag which received the highest amount of radioactive caesium. The upper part of Gudbrandsdalen which normally lays in the rain shadow between two mountain massifs, show only caesium concentrations below the detection limit.

No drinking water limits are set for caesium.

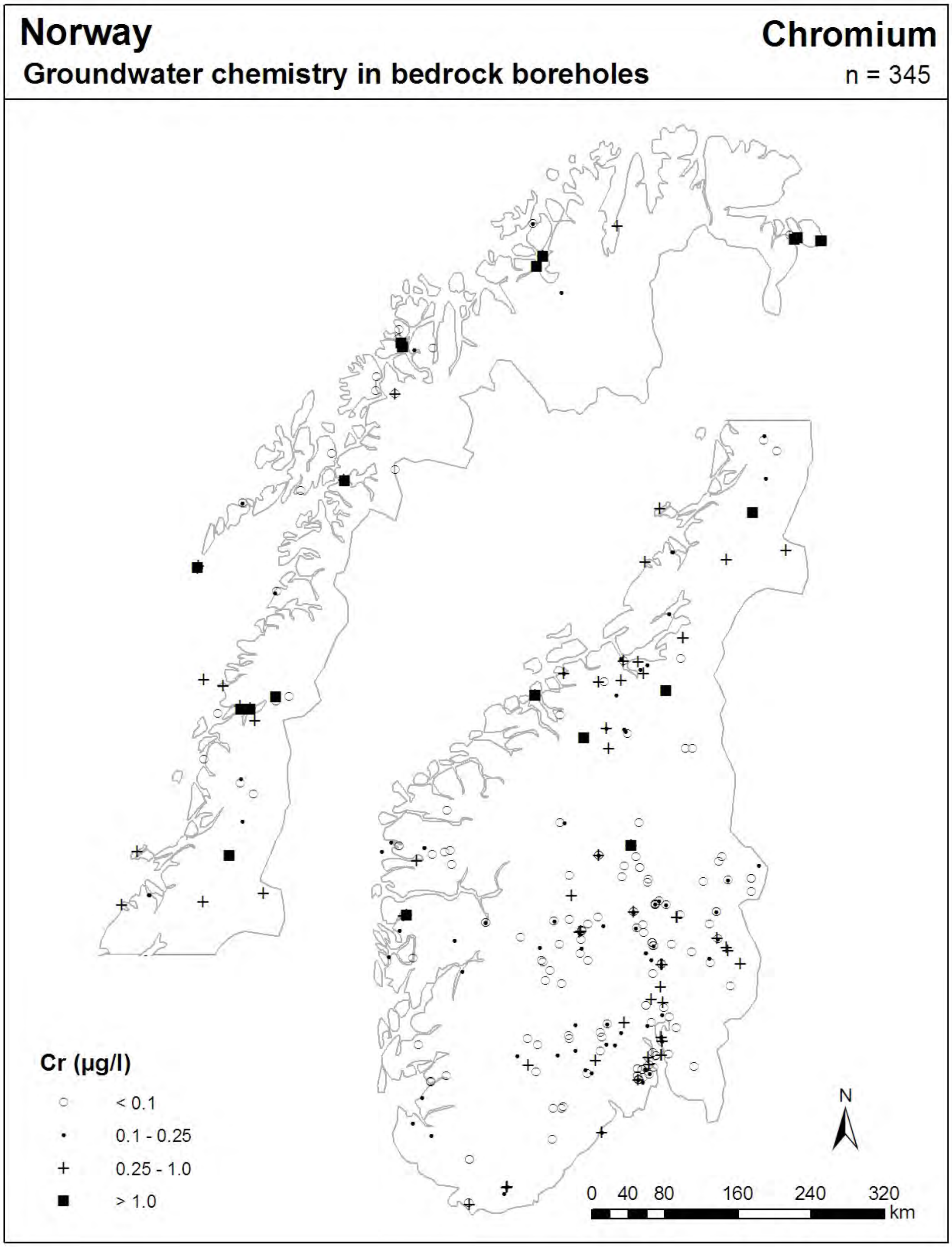

Figure 48: Map of Norway showing chromium concentrations in groundwater samples from bedrock boreholes.

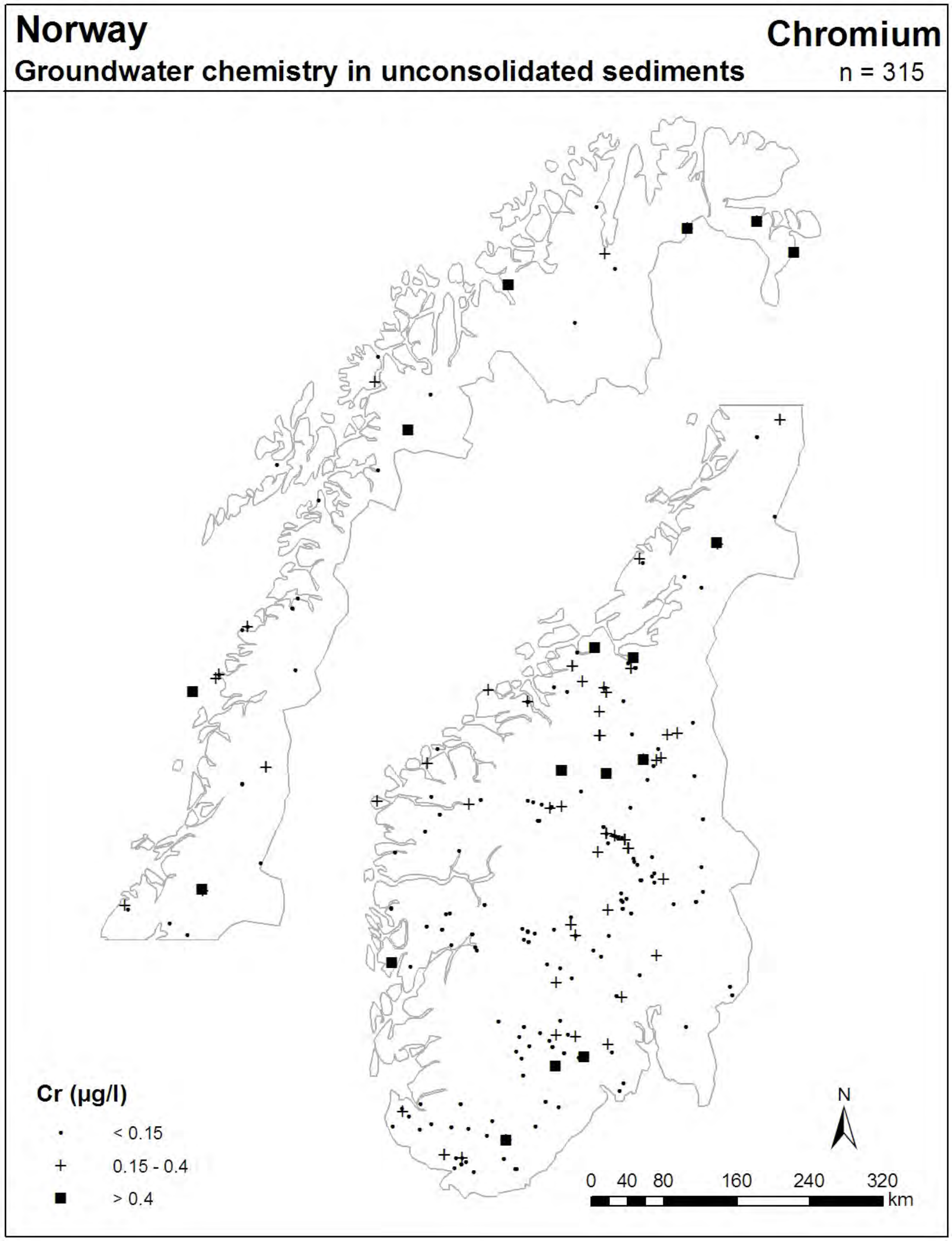

Figure 49: Map of Norway showing chromium concentrations in groundwater samples from unconsolidated sediments.

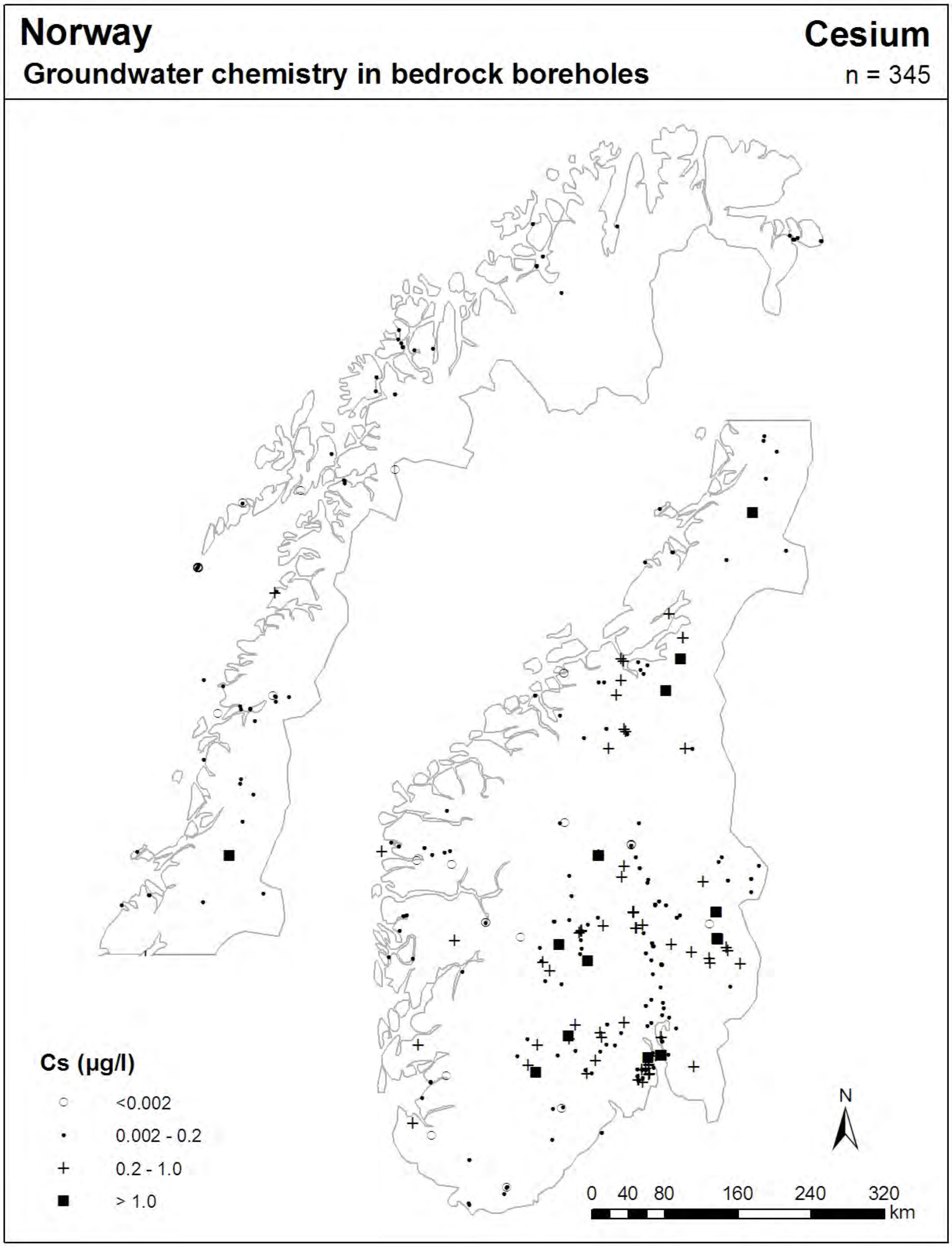

Figure 50: Map of Norway showing caesium concentrations in groundwater samples from bedrock boreholes.

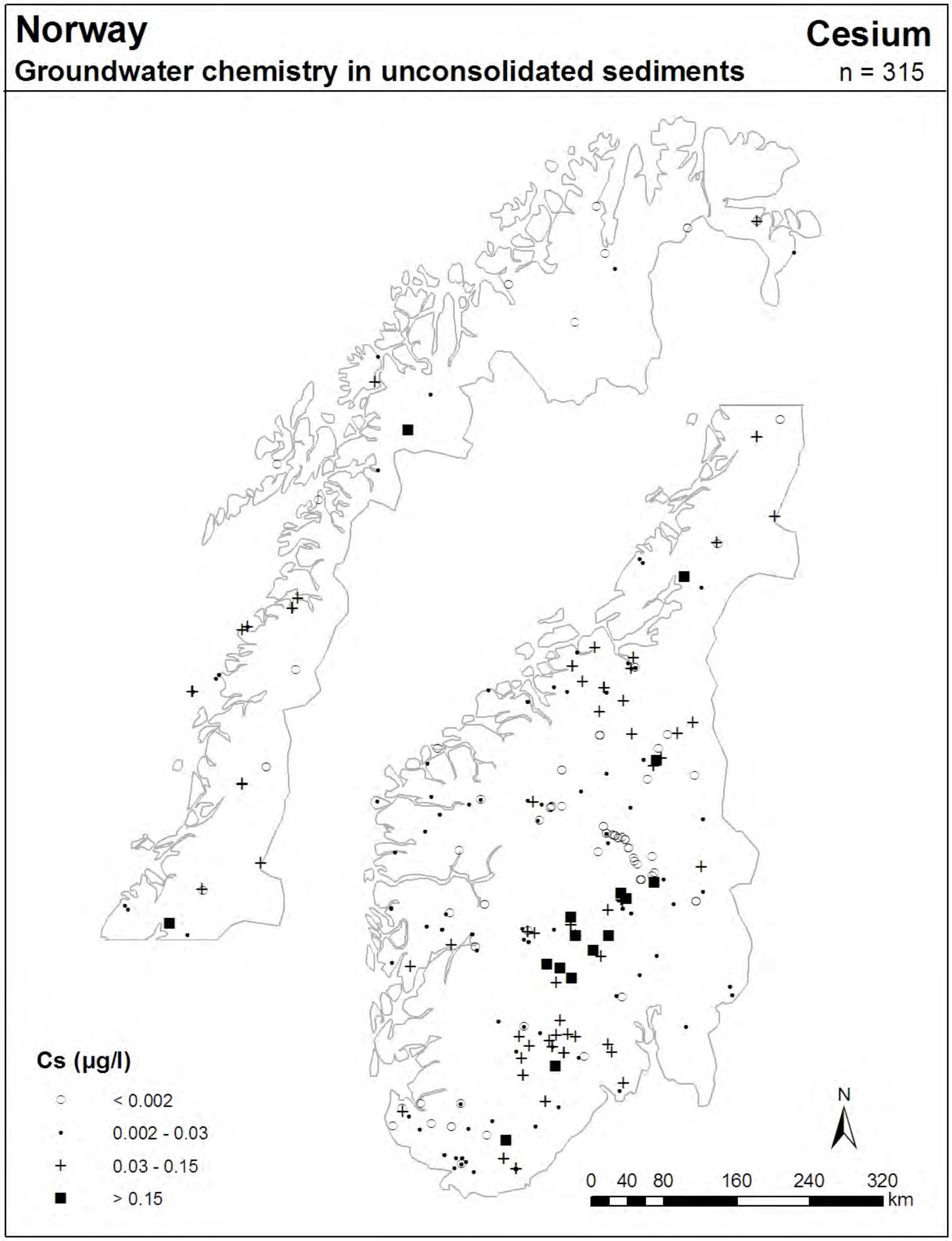

Figure 51: Map of Norway showing caesium concentrations in groundwater samples from unconsolidated sediments.

6.22 Copper (Cu)

13 of 691 (ca 2 %) groundwater samples showed copper concentrations below the detection limit of 0.05 µg/L (ICP-MS). The median concentration of the complete dataset was found to be 3.59 µg/L. The median concentrations of bedrock groundwaters and samples from unconsolidated sediment wells are 5.0 µg/L and 2.7 µg/L, respectively. The 75th percentiles are with 17.0 µg/L (bedrock aquifer) and 17.2 µg/L (unconsolidated sediment aquifer) basically the same. The maximum concentrations of bedrock groundwaters and waters from sedimentary aquifers are 2930 µg/L and 3380 µg/L, respectively.

Samples with copper concentrations above 100 µg/L that were measured in bedrock groundwaters seem to be evenly distributed over the country (Figure 52). Samples with copper concentrations above 200 µg/L that were measured in groundwaters from sedimentary aquifers seemed to be concentrated in the central part of Østlandet and the very South of the country (Figure 53).

The rather strict MAC for copper in Norwegian drinking waters (100 µg/L) is exceeded by 53 out of 691 (7.7 %) samples. Around 7 % of bedrock aquifers and 8.9 % of sediment aquifers were above this MAC. The MAC in the EU is 2 mg/L, which is in accordance to the recommendations of WHO. Only two samples lie above this MAC.

6.23 Fluoride (F^-)

223 of 691 (32.2 %) groundwater samples showed fluoride concentration below the detection limit of 0.05 mg/L (ion chromatography). The concentrations varied from < 0.05 mg/L to a maximum of 5.67 mg/L (bedrock aquifer) and the median concentration was found to be 0.11 mg/L.

Bedrock groundwaters generally showed higher fluoride concentrations. The median concentration was found to be 0.22 mg/L, while waters from sedimentary aquifers had a median fluoride concentration of 0.06 mg/L and a maximum value of 1.48 mg/L.

No special geographical pattern could be observed.

In EU, Canada and Norway, MAC for F^- in drinking water is set at 1.5 mg/L as recommended by WHO. This MAC is exceeded by 54 of 691 (7.7 %) samples. All of these originate from bedrock groundwaters.

In the USA, the MAC is 4.0 mg/L. According to this MAC, 7 (ca 1 %) bedrock groundwater samples would exceed the limit.

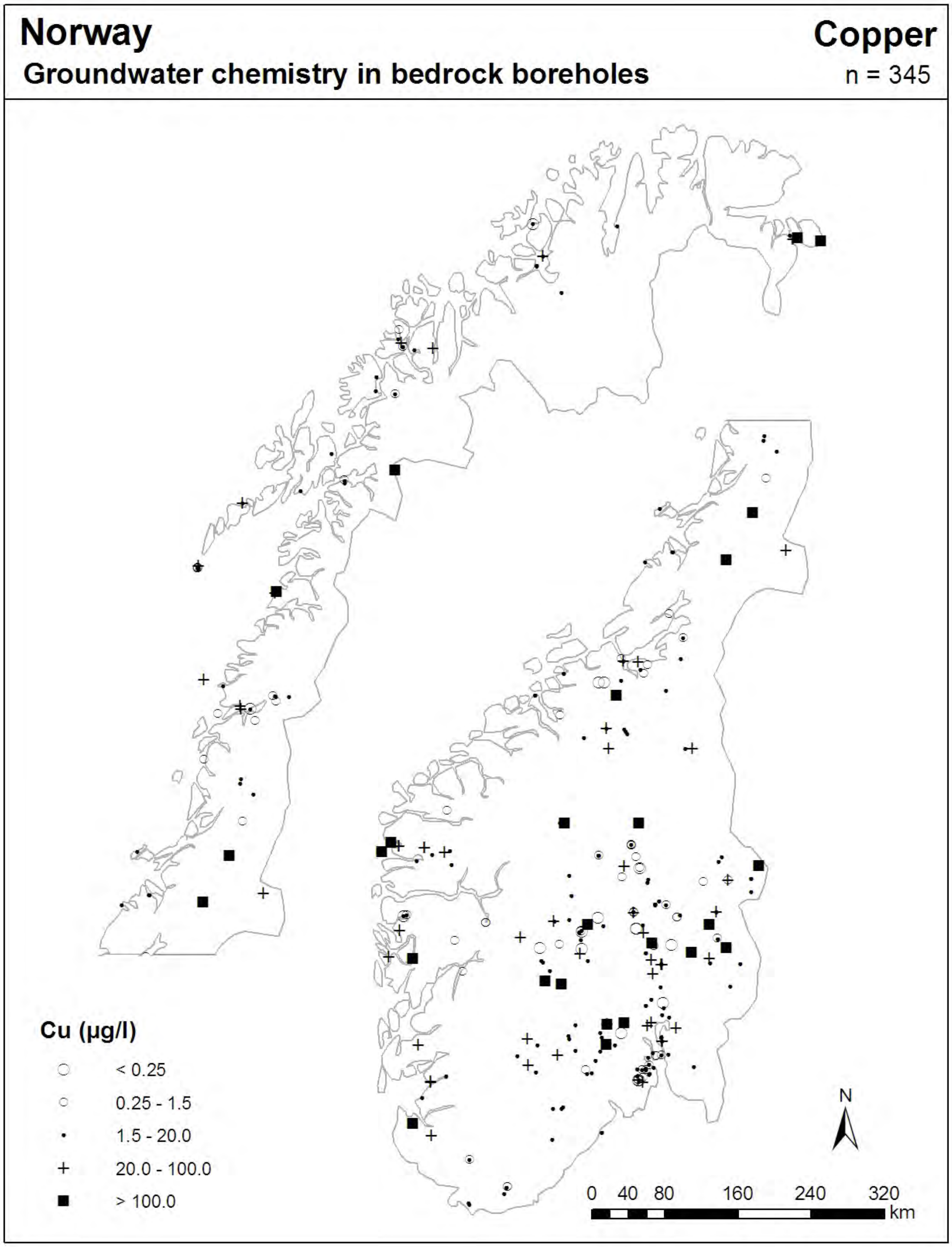

Figure 52: Map of Norway showing copper concentrations in groundwater samples from bedrock boreholes.

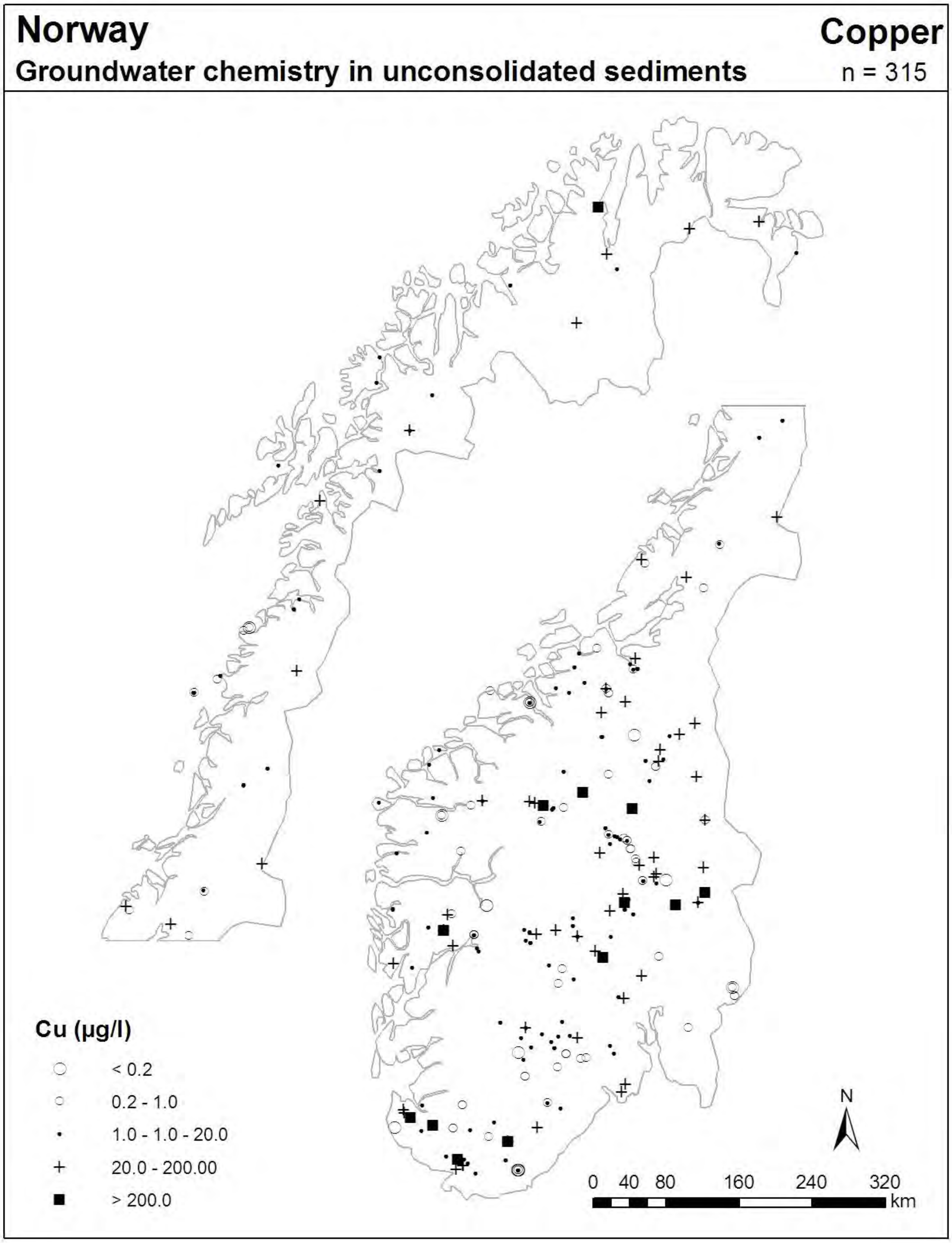

Figure 53: Map of Norway showing copper concentrations in groundwater samples from unconsolidated sediments.

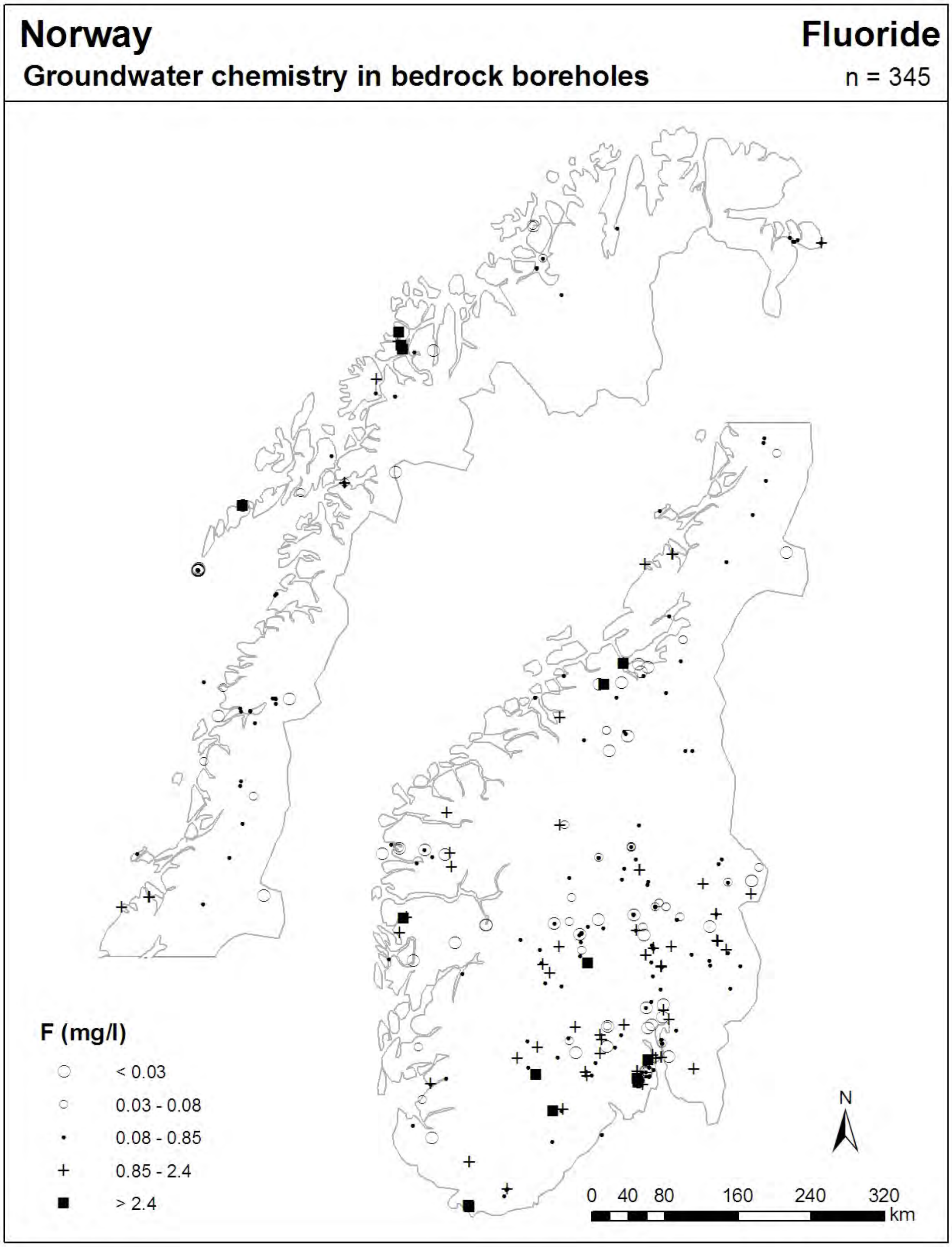

Figure 54: Map of Norway showing fluoride concentrations in groundwater samples from bedrock boreholes.

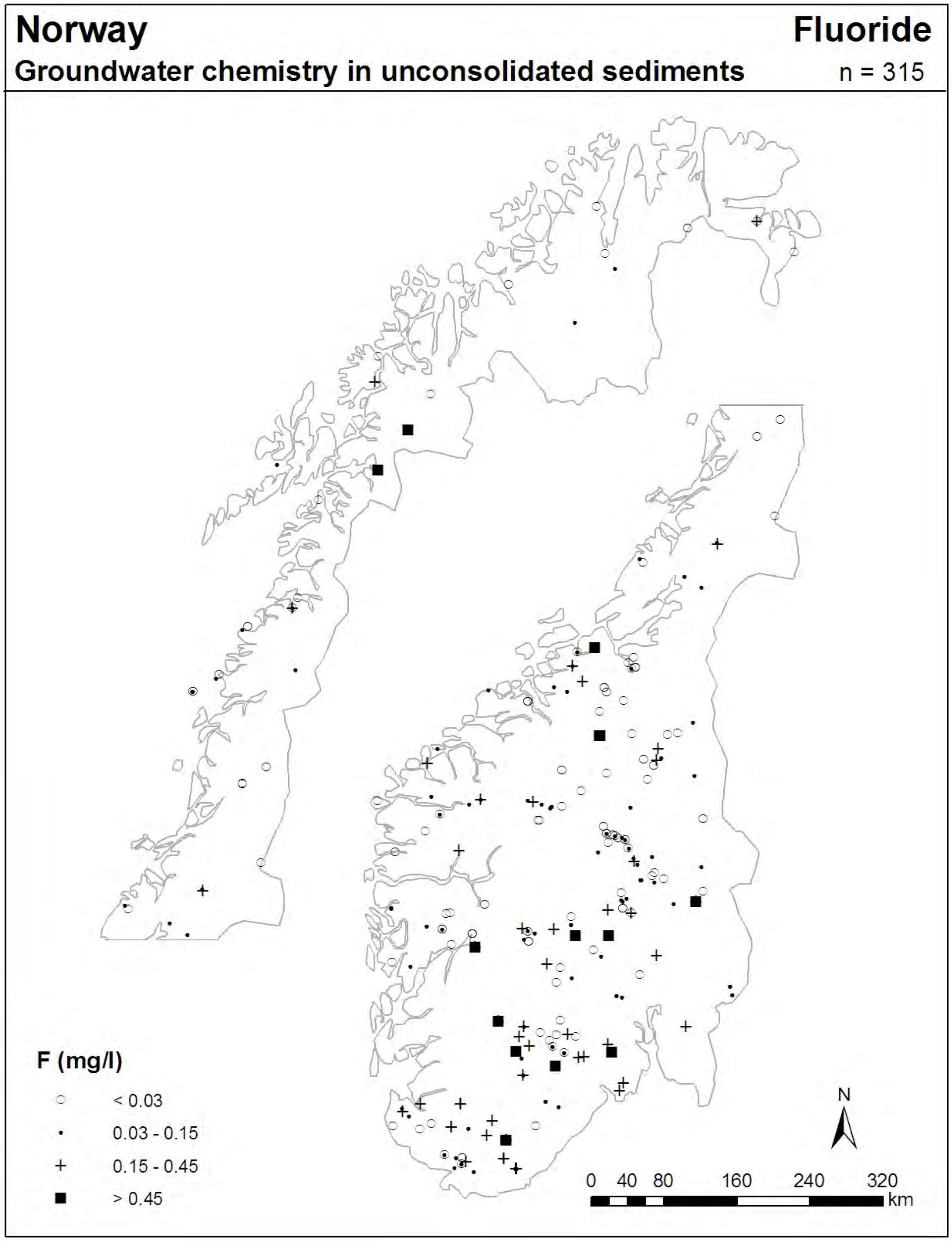

Figure 55: Map of Norway showing fluoride concentrations in groundwater samples from unconsolidated sediments.

6.24 Iron (Fe)

The iron concentrations in the 691 groundwater samples varied from < 0.002 mg/L (94 of 691; 13.6 %) to a maximum of 9.46 mg/L (bedrock aquifer). The median concentrations of the whole dataset, bedrock groundwaters and samples from unconsolidated sediments were 0.02 mg/L, 0.03 mg/L and 0.01 mg/L, respectively. The highest measured concentration in samples from unconsolidated sediment aquifers was found to be 3.21 mg/L.

No general geographical trend can be observed. The local variations in iron concentration can be high (Figure 56 and Figure 57).

The MAC in Norway and in the EU is set at 0.2 mg/L, while Norway operates an additional guidance level of 0.05 mg/L.

115 of 691 (16.6 %) groundwater samples exceed the MAC for iron in drinking water. 21.4 % of bedrock groundwaters and 10.8 % of samples from unconsolidated sediments lie above the operated MAC. 231 out of 691 (33.4 %) samples lie above the guidance level for iron.

6.25 Gallium (Ga)

430 of 691 (62 %) groundwaters showed gallium concentrations below the detection limit of 0.01 μg/L. Accordingly, the median concentration of the dataset is < 0.01 μg/L. Bedrock groundwaters were found to have a median concentration of 0.011 μg/L and a maximum value of 2.5 μg/L. 78 % of groundwater samples from unconsolidated sediments had gallium concentrations below detection limit. The maximum gallium concentration in water samples from unconsolidated sediment wells was found to be 0.517 μg/L.

No geographical trend can be observed.

There is no MAC for gallium in drinking water.

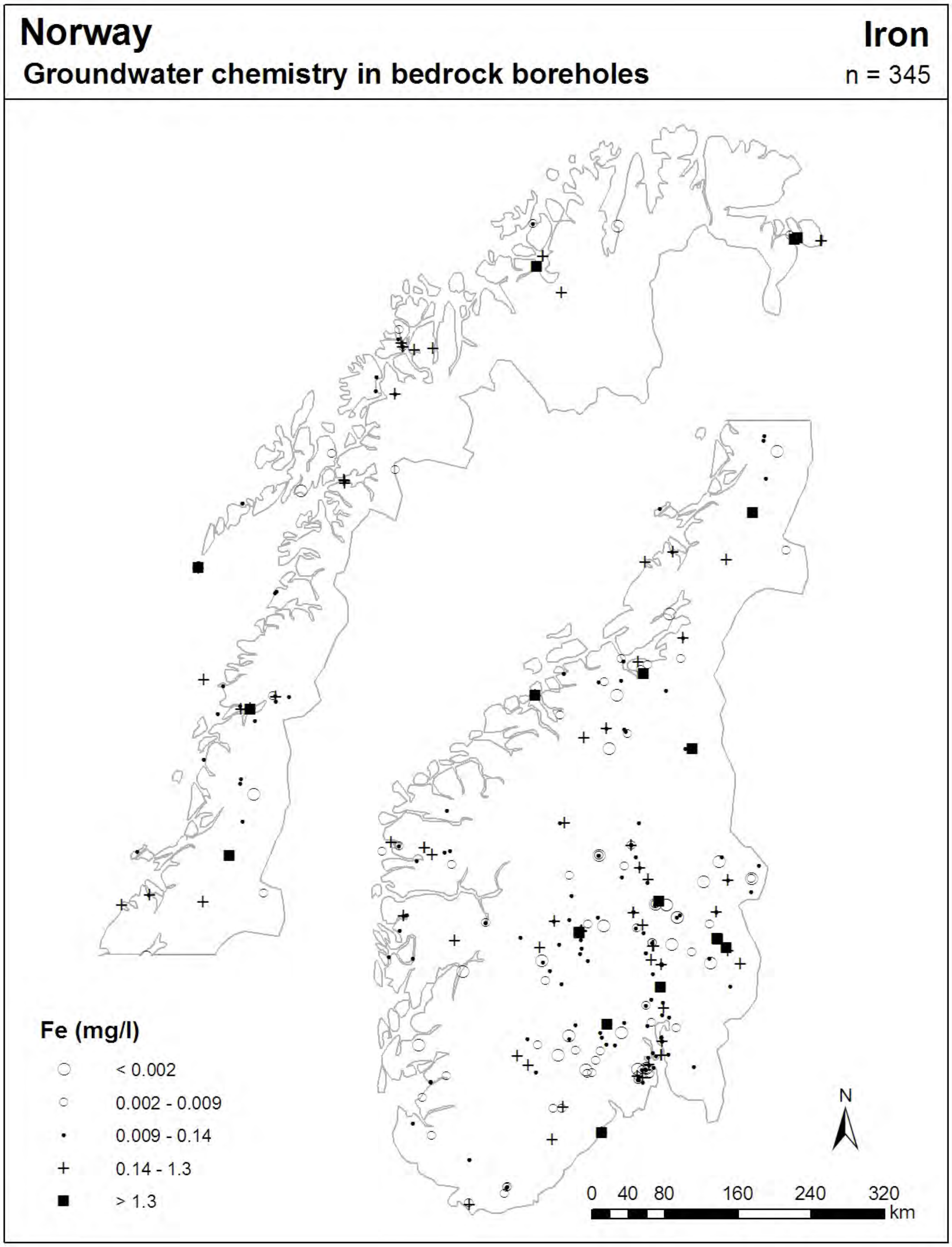

Figure 56: Map of Norway showing iron concentrations in groundwater samples from bedrock boreholes.

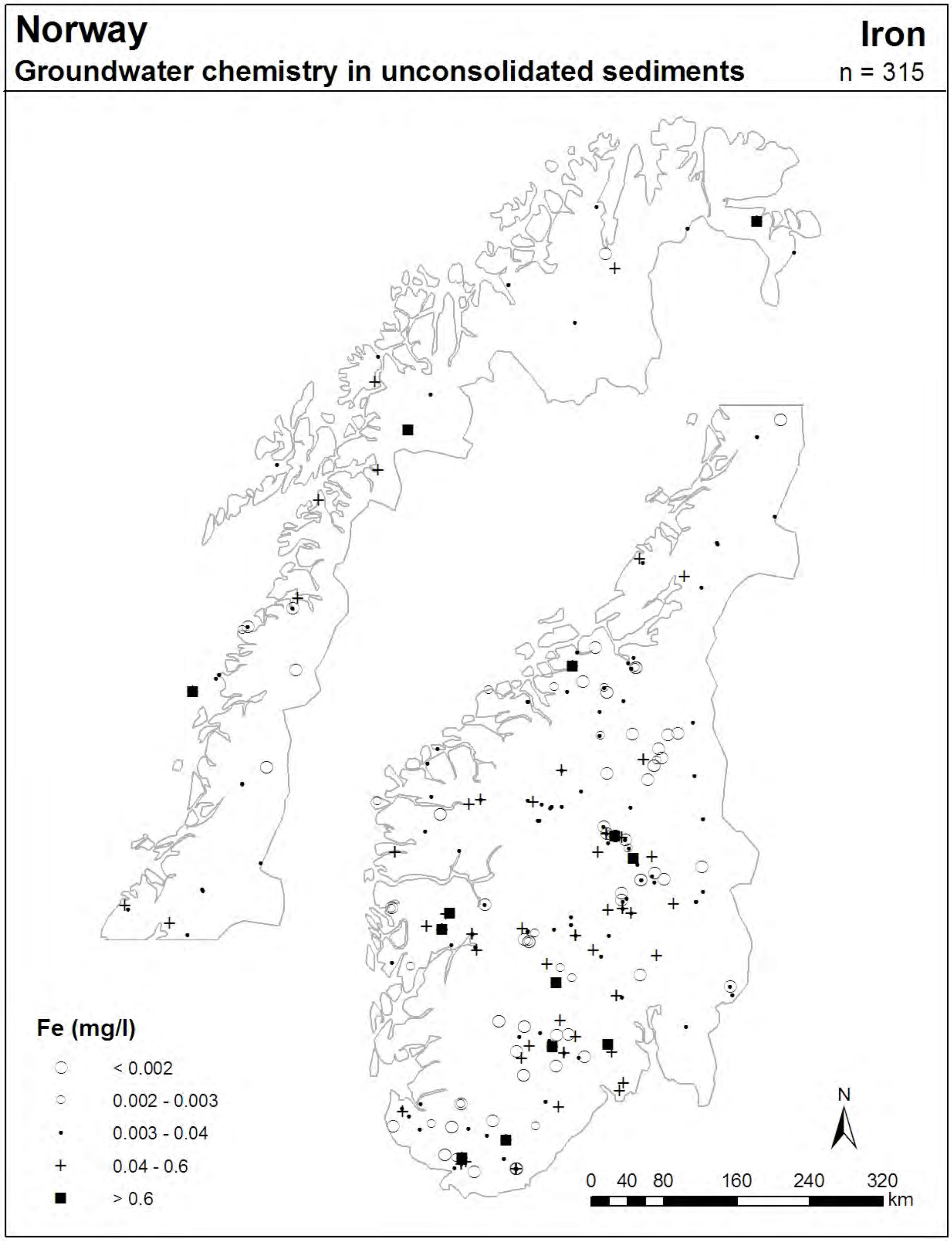

Figure 57: Map of Norway showing iron concentrations in groundwater samples from unconsolidated sediments.

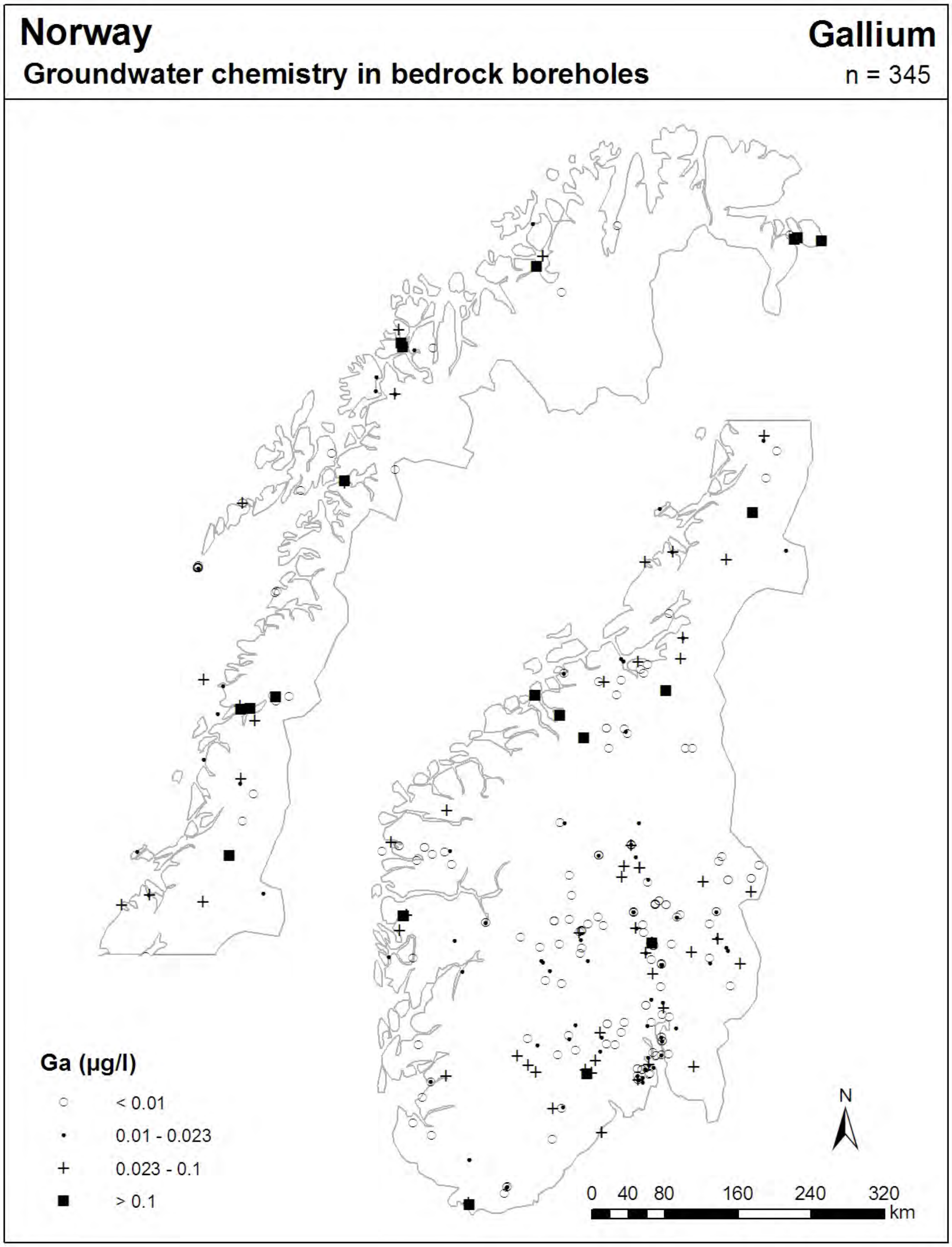

Figure 58: Map of Norway showing gallium concentrations in groundwater samples from bedrock boreholes.

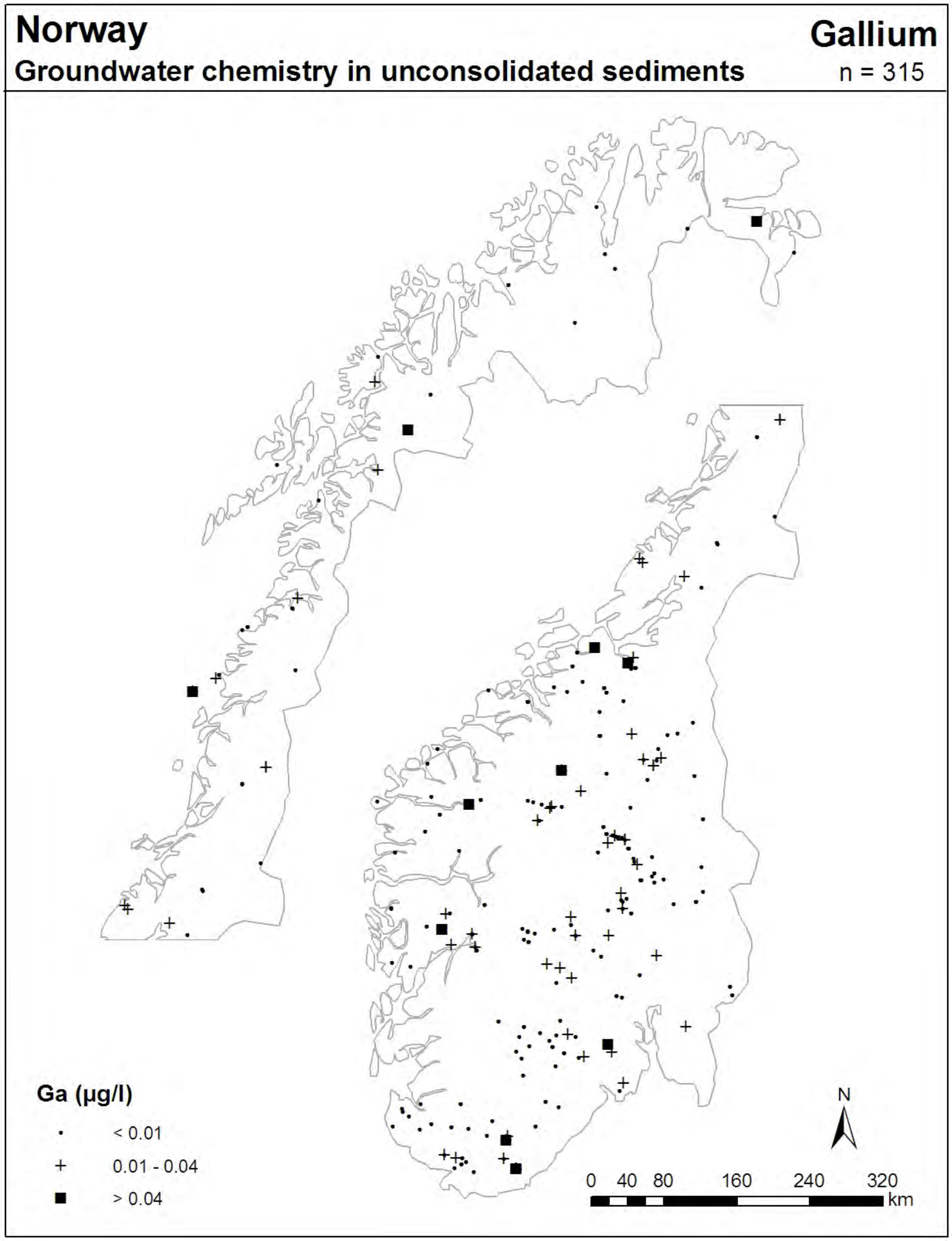

Figure 59: Map of Norway showing gallium concentrations in groundwater samples from unconsolidated sediments.

6.26 Germanium (Ge)

605 of 691 (87.5 %) groundwater samples had germanium concentrations below the detection limit of 0.01 μg/L (ICP-MS). 78 % of all bedrock groundwaters and 98.4 % of all unconsolidated sediment groundwaters have concentrations below this limit. The maximum concentration found in bedrock groundwaters was 1.75 μg/L and 0.252 μg/L in groundwater samples from unconsolidated sediments.

As there are not enough reliable concentration values, no further statistical or geographical analysis were done.

There is no MAC for germanium in drinking water.

6.27 Iodine (I)

599 of 692 (87 %) groundwater samples showed iodine concentrations below the detection limit of 5 μg/L (ICP-MS). 82 % of bedrock groundwaters and 92 % of unconsolidated sediment groundwaters were found to have concentrations below this detection limit. The highest concentrations found from bedrock groundwaters and from unconsolidated sediment groundwaters were 53 μg/L and 41.3 μg/L, respectively.

As there are not enough reliable concentration values, no further statistical or geographical analysis were done.

No drinking water standard for iodine is set in Norway.

6.28 Indium (In)

680 of 691 (98.4 %) groundwater samples were found to have indium concentrations below the detection limit of 0.01 μg/L. The highest measured indium concentration in unconsolidated sediment groundwaters was 0.094 μg/L. The maximum concentration in samples from bedrock boreholes was 0.029 μg/L.

As there are not enough reliable concentration values, no further statistical or geographical analysis were done.

No drinking water limits for indium are set.

6.29 Potassium (K)

The evaluated potassium concentrations are a combination of ICP-AES and ICP-MS analysis. When available, ICP-MS data were taken. As not all potassium analyses were accomplished with ICP-MS, ICP-AES data filled the gaps. The lower detection limits for potassium are 0.5 mg/L (ICP-AES) and 0.025 mg/L (ICP-MS). None of the samples was below the ICP-MS detection limit.

The potassium concentrations ranged from 0.045 mg/L (bedrock aquifer) to 27.3 mg/L (unknown aquifer). The median concentration of the whole dataset was found to be 1.17 mg/L. Bedrock groundwaters showed slightly higher potassium concentrations than samples from unconsolidated sediment groundwaters (n=314). Bedrock groundwaters were found to have a minimum concentration of 0.045 mg/L, a median concentration of 1.58 mg/L and a maximum concentration of 12.4 mg/L. Groundwater samples from sedimentary aquifers had a minimum of 0.107 mg/L, a median concentration of 0.89 mg/L and a maximum of 12.2 mg/L.

Potassium concentrations do not show a clear geographical trend (Figure 60 and Figure 61), although for groundwater from unconsolidated sediments there is a tendency towards lower concentrations in inner parts of Sørlandet and Telemark.

Norway does not longer have drinking water limits for potassium. The former guidance level of 10 mg/L (Sosial- og helsedepartementet, 1995) is exceeded by 5 of 691 (0.7 %) samples. The former MAC of 12 mg/L (Sosial- og helsedepartementet, 1995) is exceeded by 3 samples.

6.30 Lithium (Li)

314 of 691 (45.6 %) groundwater samples have lithium concentrations below the detection limit of 0.5 µg/L (ICP-MS). The median concentration of the whole dataset was found to be 0.66 µg/L. Groundwater samples from bedrock aquifers and sedimentary aquifers showed considerable differences in lithium concentrations. While 77 % of all water samples from unconsolidated sediments had concentrations below detection limit, samples from bedrock aquifers were found to have a median concentration of 2.1 µg/L lithium. The maximum concentrations in samples from bedrock boreholes and sedimentary aquifers were 27.4 µg/L and 18.6 µg/L, respectively.

The biggest portion of bedrock groundwater samples with lithium concentrations above 10 µg/L seems to be located in Østlandet (Figure 62). Groundwaters from unconsolidated sediments do not follow a clear geographical distribution (Figure 63).

No drinking water limits are applied in the Western countries.

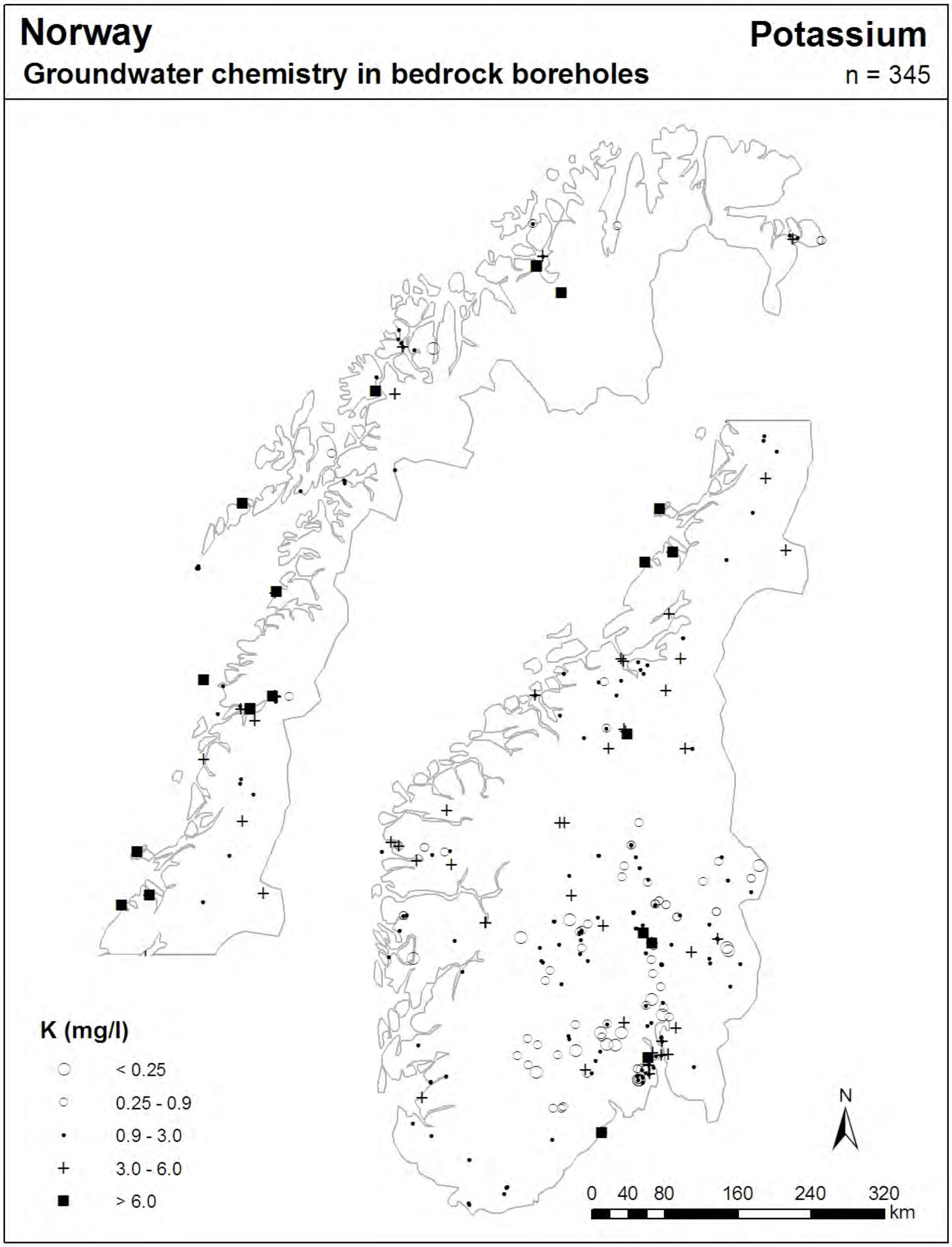

Figure 60: Map of Norway showing potassium concentrations in groundwater samples from bedrock boreholes.

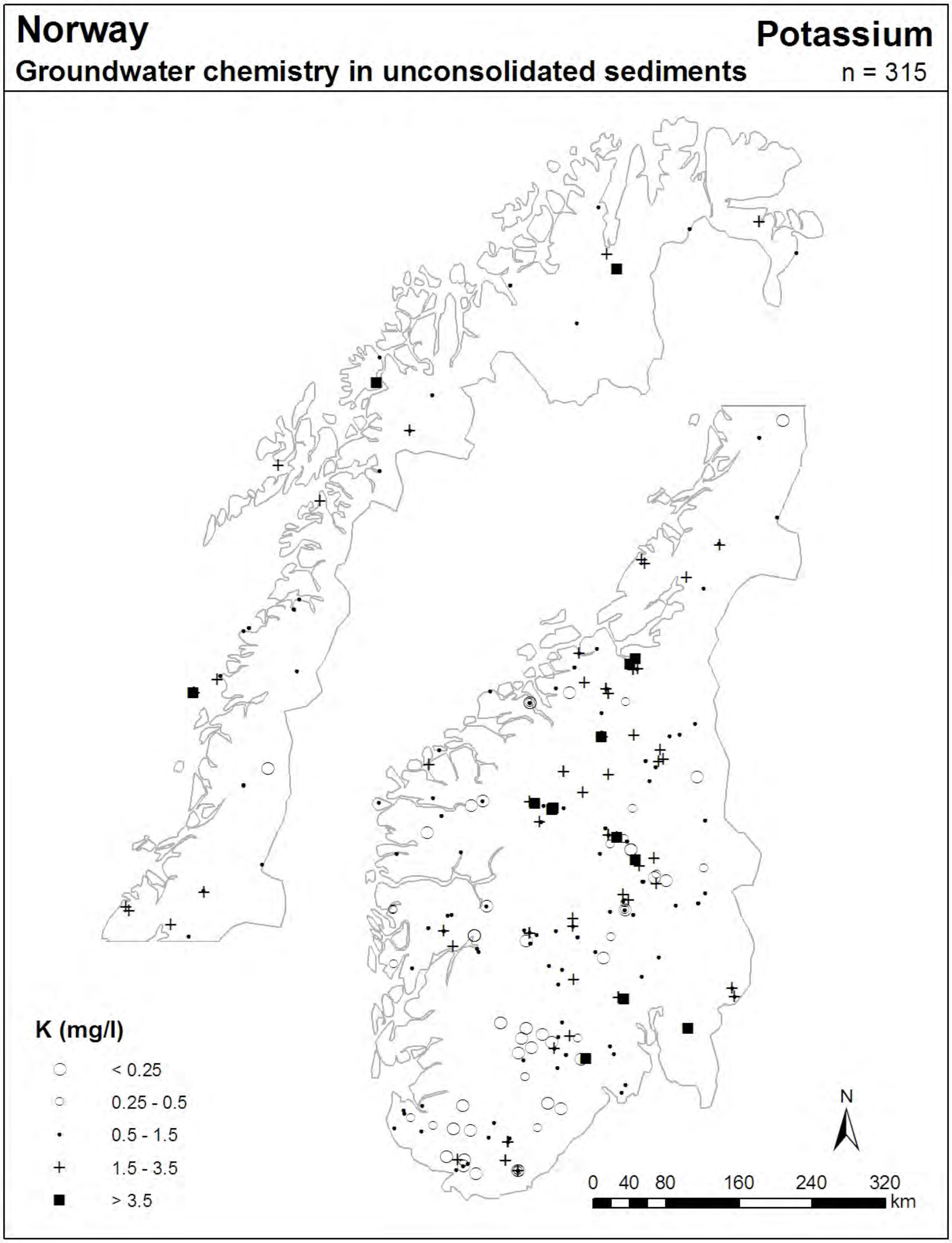

Figure 61: Map of Norway showing potassium concentrations in groundwater samples from unconsolidated sediments.

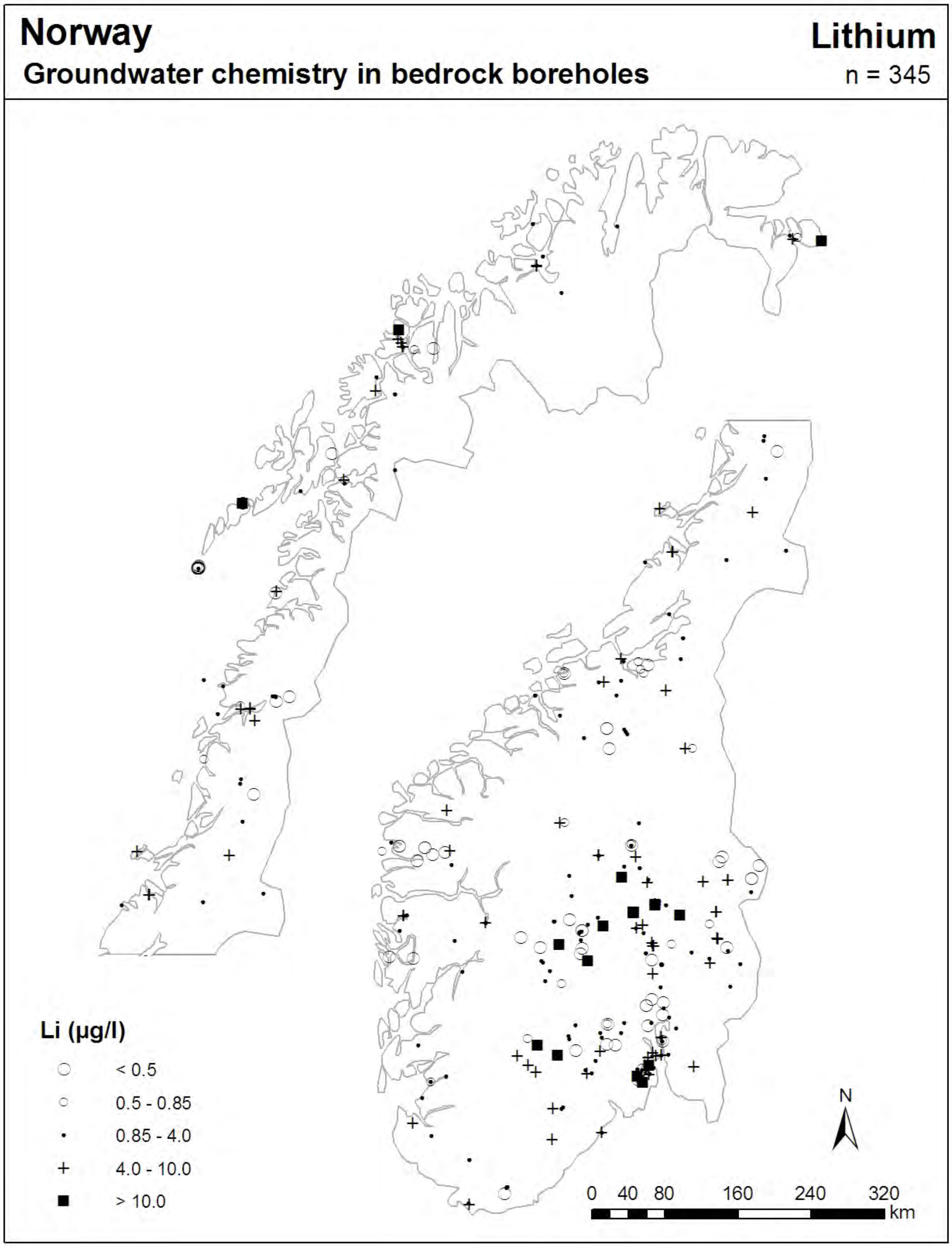

Figure 62: Map of Norway showing lithium concentrations in groundwater samples from bedrock boreholes.

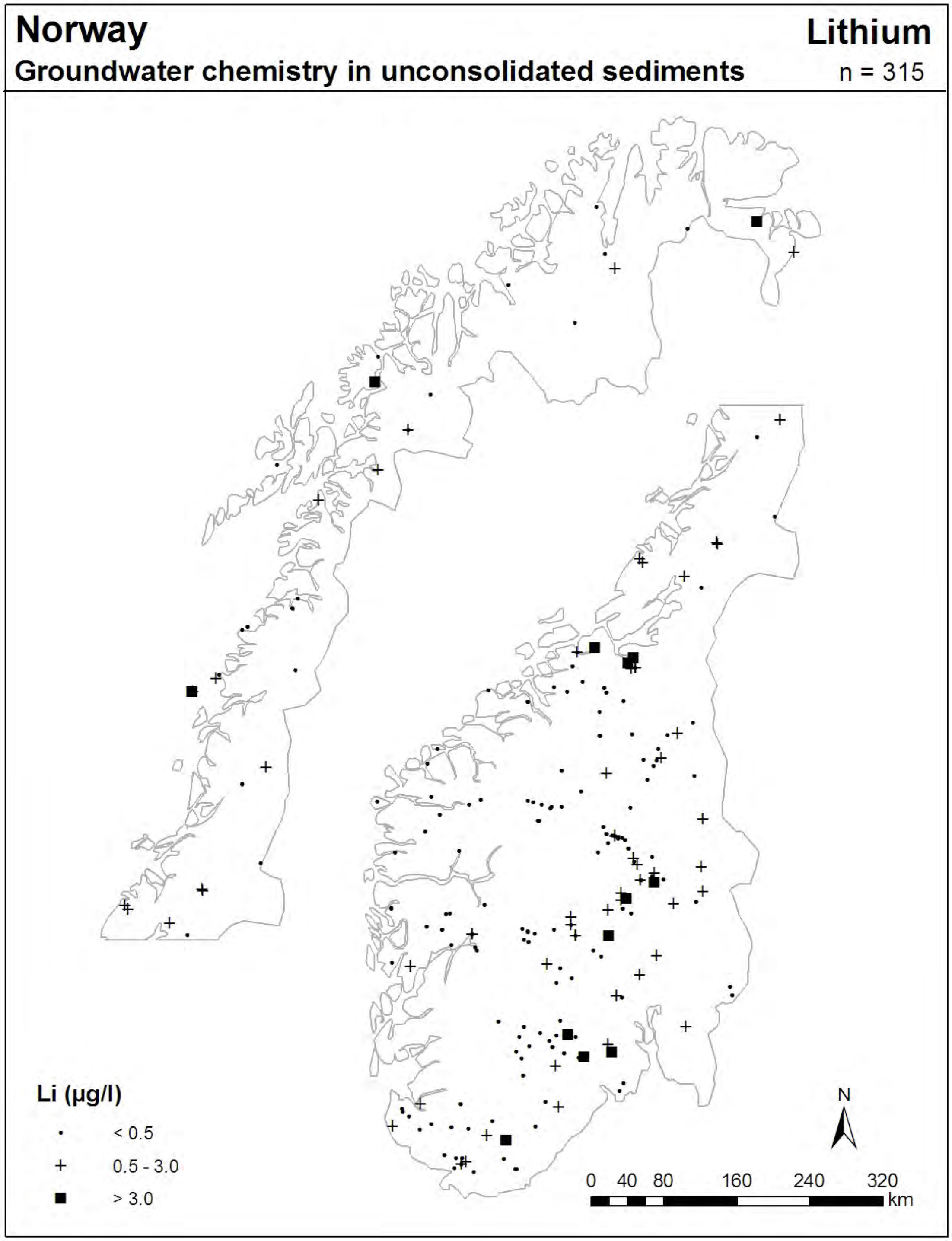

Figure 63: Map of Norway showing lithium concentrations in groundwater samples from unconsolidated sediments.

6.31 Magnesium (Mg)

3 out of 691 groundwater samples had magnesium concentrations below the detection limit of 0.05 mg/L Mg (ICP-AES). All three of these samples come from bedrock aquifers. The median concentration of the whole dataset was found to be 2.21 mg/L – the maximum concentration was 173 mg/L (unknown aquifer type). The median magnesium concentration in groundwaters from bedrock boreholes was 3.7 mg/L and the highest measured concentration was 23.1 mg/L. Magnesium concentrations in samples from sedimentary aquifers varied from a minimum of 0.1 mg/L to a maximum of 15.9 mg/L, with the median concentration being 1.2 mg/L.

No clear geographical trend could be identified (Figure 64 and Figure 65).

Norway does not longer operate a MAC for magnesium. The former MAC of 20 mg/L (Sosial- og helsedepartementet, 1995) is exceeded by 3 out of 691 (0.7 %) samples.

6.32 Manganese (Mn)

40 out of 691 (6 %) groundwater samples showed manganese concentrations below the detection limit of 0.05 µg/L (ICP-MS). The median concentration of the whole dataset was found to be 4.16 µg/L, the median of manganese concentrations in groundwaters from bedrock boreholes was 6.7 µg/L and the median of groundwater samples from sedimentary aquifers 2.8 µg/L. The highest value of 4630 µg/L was found in a bedrock groundwater. The second highest value was measured in a groundwater sample from unconsolidated sediments.

No clear geographical trend could be identified (Figure 66 and Figure 67).

The MAC in Norway and the EU is 50 µg/L. 139 samples (20 %) exceed this limit. 98 of these are from bedrock boreholes and 41 from unconsolidated sediments. 32 samples (5 %) exceed the WHO guideline value of 400 µg/L. 26 out of these come from samples from bedrock boreholes and 6 from sedimentary aquifers.

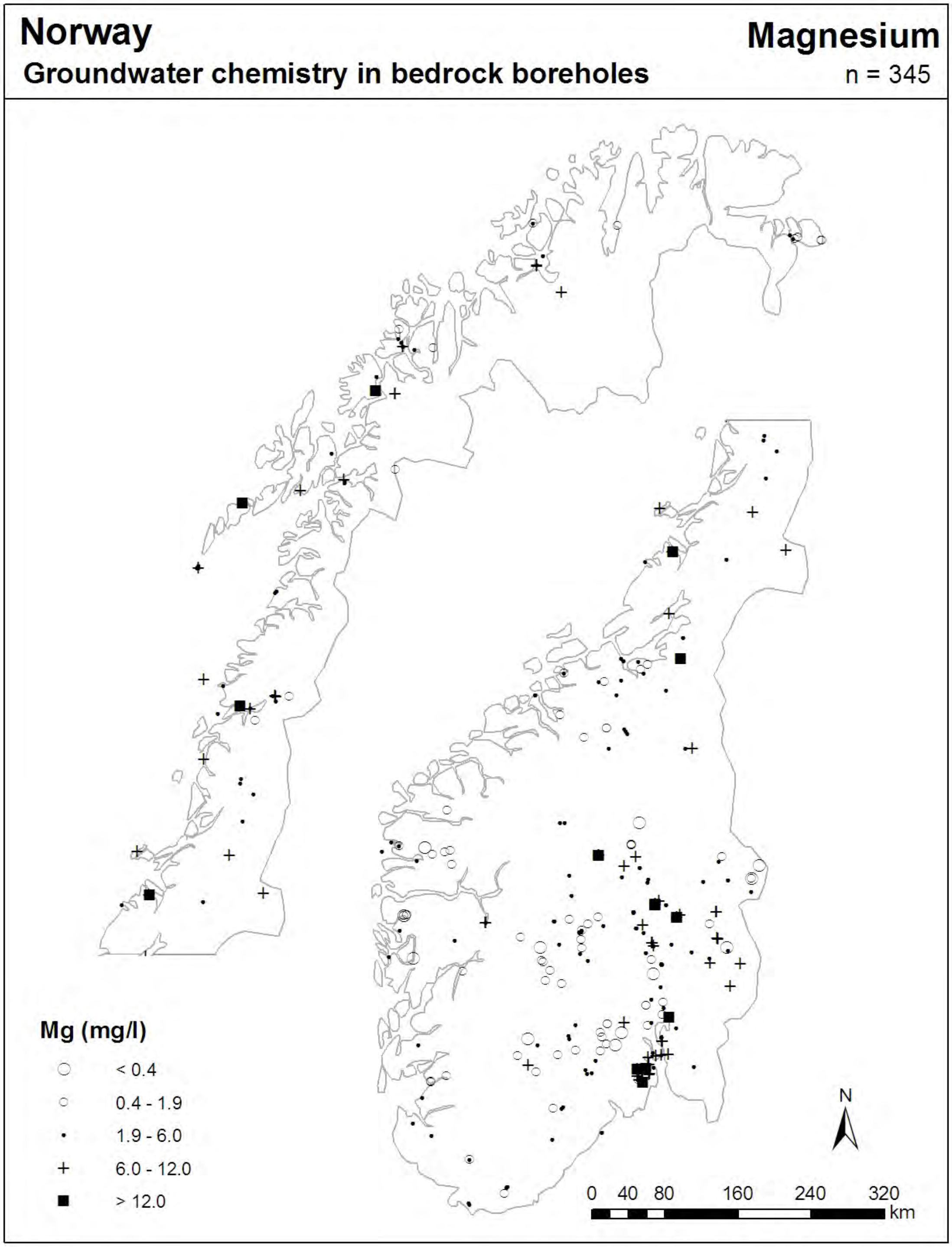

Figure 64: Map of Norway showing magnesium concentrations in groundwater samples from bedrock boreholes.

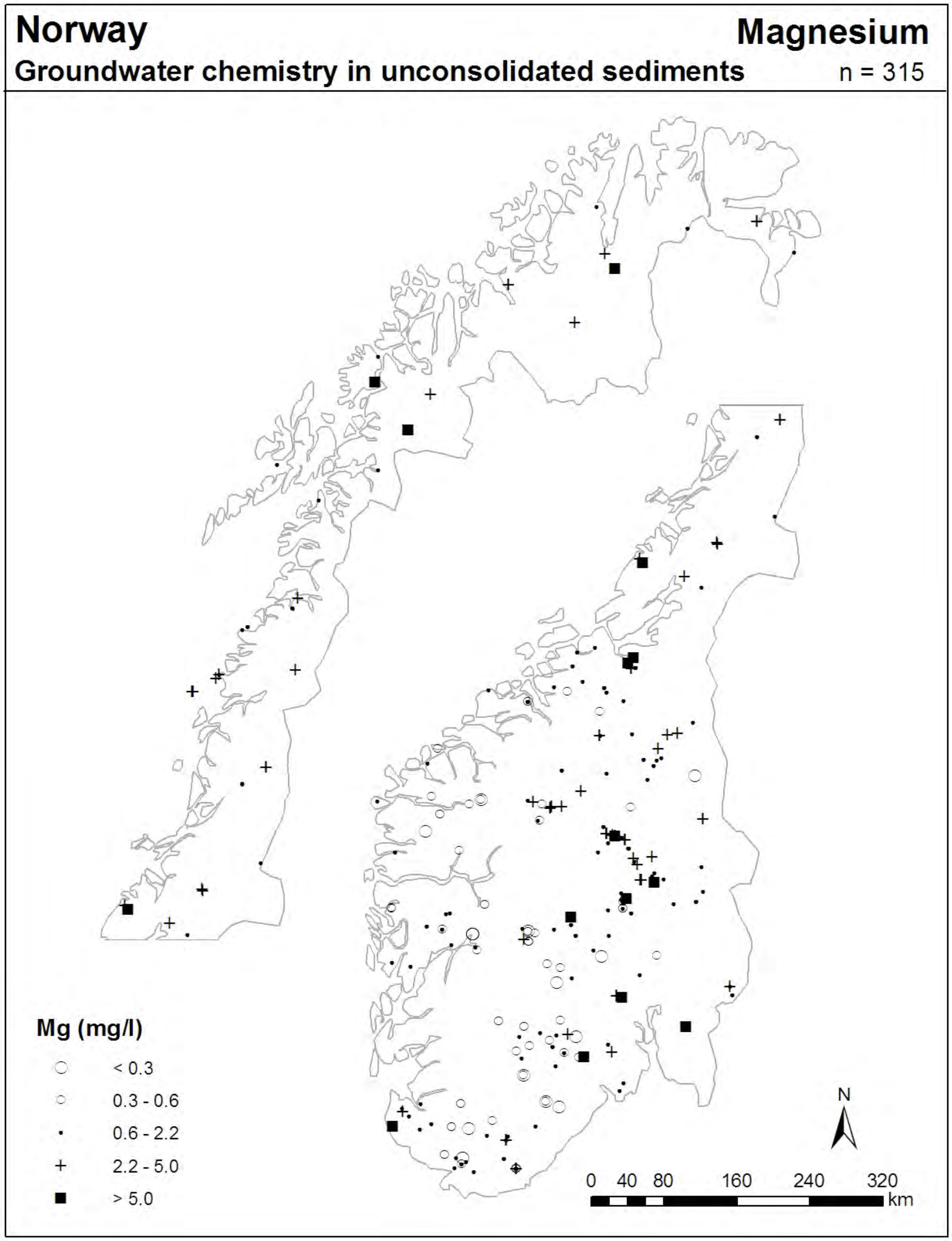

Figure 65: Map of Norway showing magnesium concentrations in groundwater samples from unconsolidated sediments.

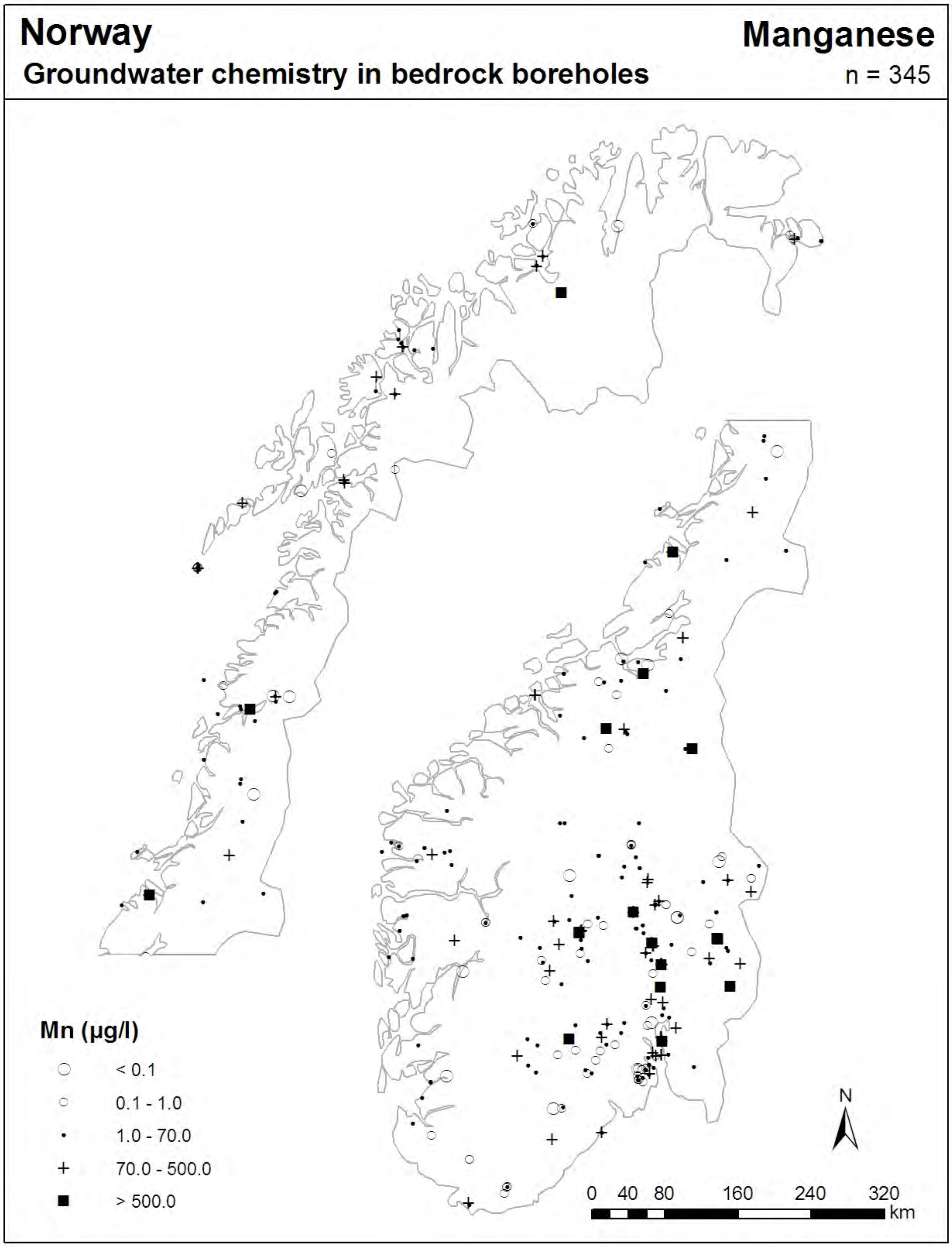

Figure 66: Map of Norway showing manganese concentrations in groundwater samples from bedrock boreholes.

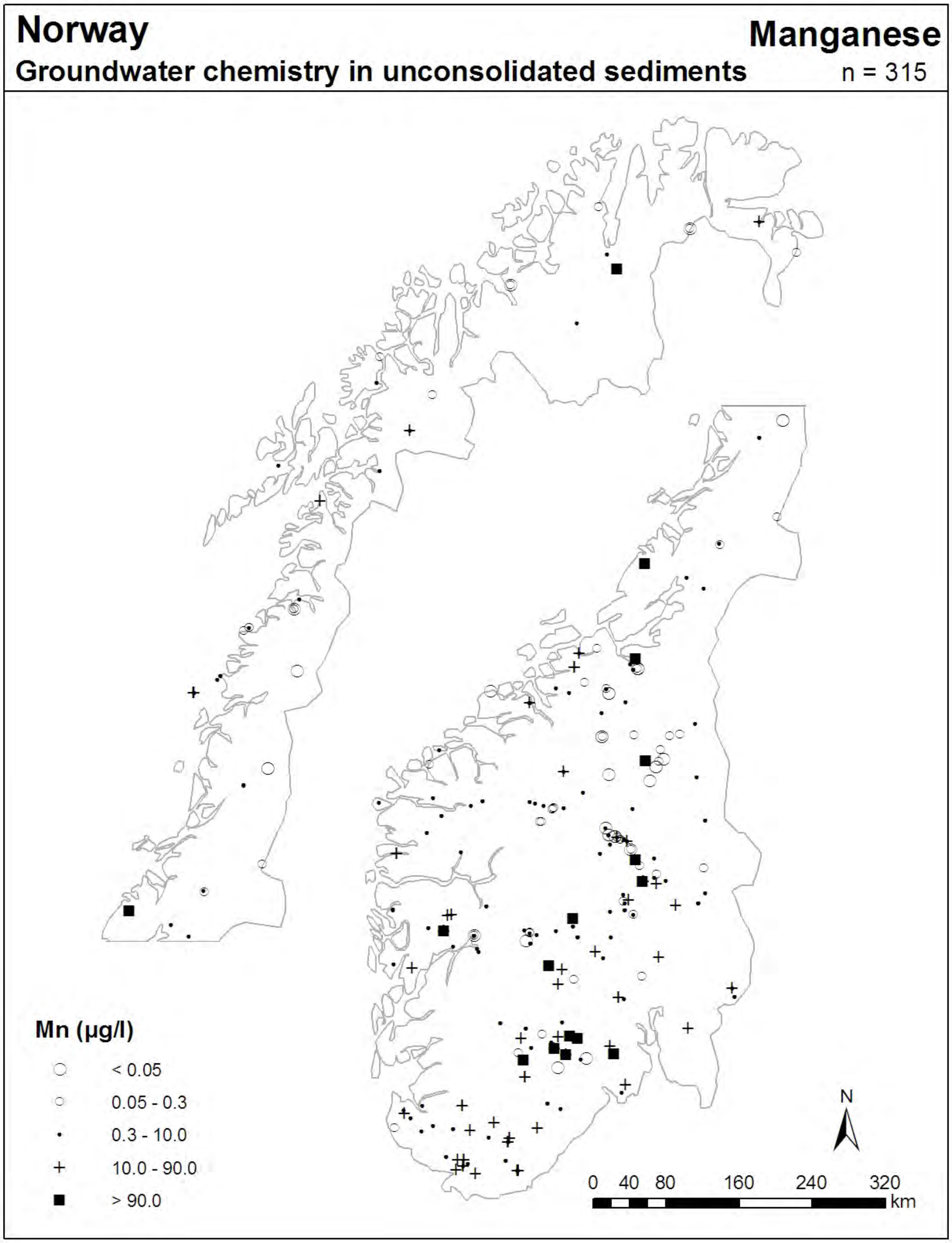

Figure 67: Map of Norway showing manganese concentrations in groundwater samples from unconsolidated sediments.

6.33 Molybdenum (Mo)

289 out of 691 (42 %) groundwater samples show molybdenum concentrations below the detection limit of 0.2 µg/L Mo (ICP-MS). The median concentration of the whole dataset was found to be 0.3 µg/L. While samples from bedrock boreholes showed a median concentration of 1.17 µg/L, the median concentration of groundwater samples from unconsolidated sediments was below detection limit. Groundwater samples from bedrock boreholes generally showed higher molybdenum concentrations. The highest found concentration (272 µg/L) was found in a sample taken from a bedrock borehole. The highest concentration in a sample from unconsolidated sediments was found to be 24.9 µg/L.

The biggest portion of bedrock groundwater samples with molybdenum concentrations above 10 µg/L seems to be located in the south-western part of Østlandet (Figure 68). Groundwaters from unconsolidated sediments do not follow a clear geographical distribution (Figure 69).

No water standard is defined in the EU and Norway, yet the WHO recommends a limit of 70 µg/L. According to this recommendation, 42 samples (35 from bedrock boreholes, 3 from unconsolidated sediment aquifers, 4 from unknown aquifer type) out of 691 samples do not meet the standard.

6.34 Sodium (Na)

The median sodium concentration of the whole dataset was found to be 5.13 mg/L. Groundwater samples from bedrock boreholes generally showed higher sodium concentrations than samples from sedimentary aquifers (n=314), such as a median concentration of 8.3 mg/L compared to 3.2 mg/L, and a maximum concentration of 431 mg/L compared to 105 mg/L. The highest concentration of all samples (1540 mg/L) comes from a well of unreported aquifer type.

Samples with high sodium concentrations were generally derived from wells close to the coast or below the upper marin limit. This is valid for groundwater samples from both aquifer types (Figure 70 and Figure 71).

In Norway there is a guidance level of 20 mg/L Na in drinking water and a MAC of 200 mg/L. This MAC is in accordance with the MAC in the EU and the recommendations of WHO. The drinking water standard of 200 mg/L sodium is exceeded by two samples (unknown aquifer type: 1540 mg/L, 431 g/L). The Norwegian guidance level is exceeded by 91 of 691 groundwater samples (13.1 %). 77 of these come from bedrock wells.

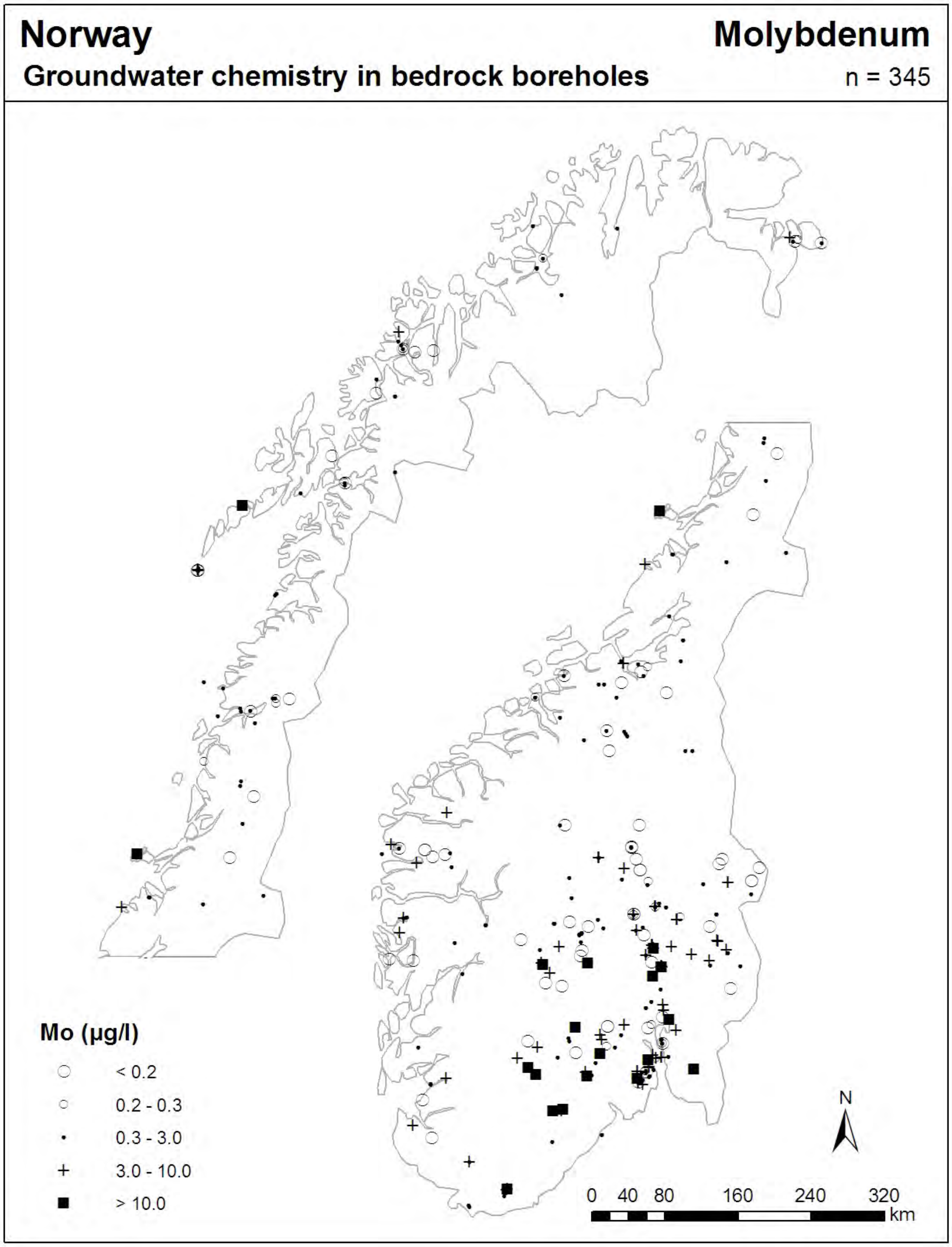

Figure 68: Map of Norway showing molybdenum concentrations in groundwater samples from bedrock boreholes.

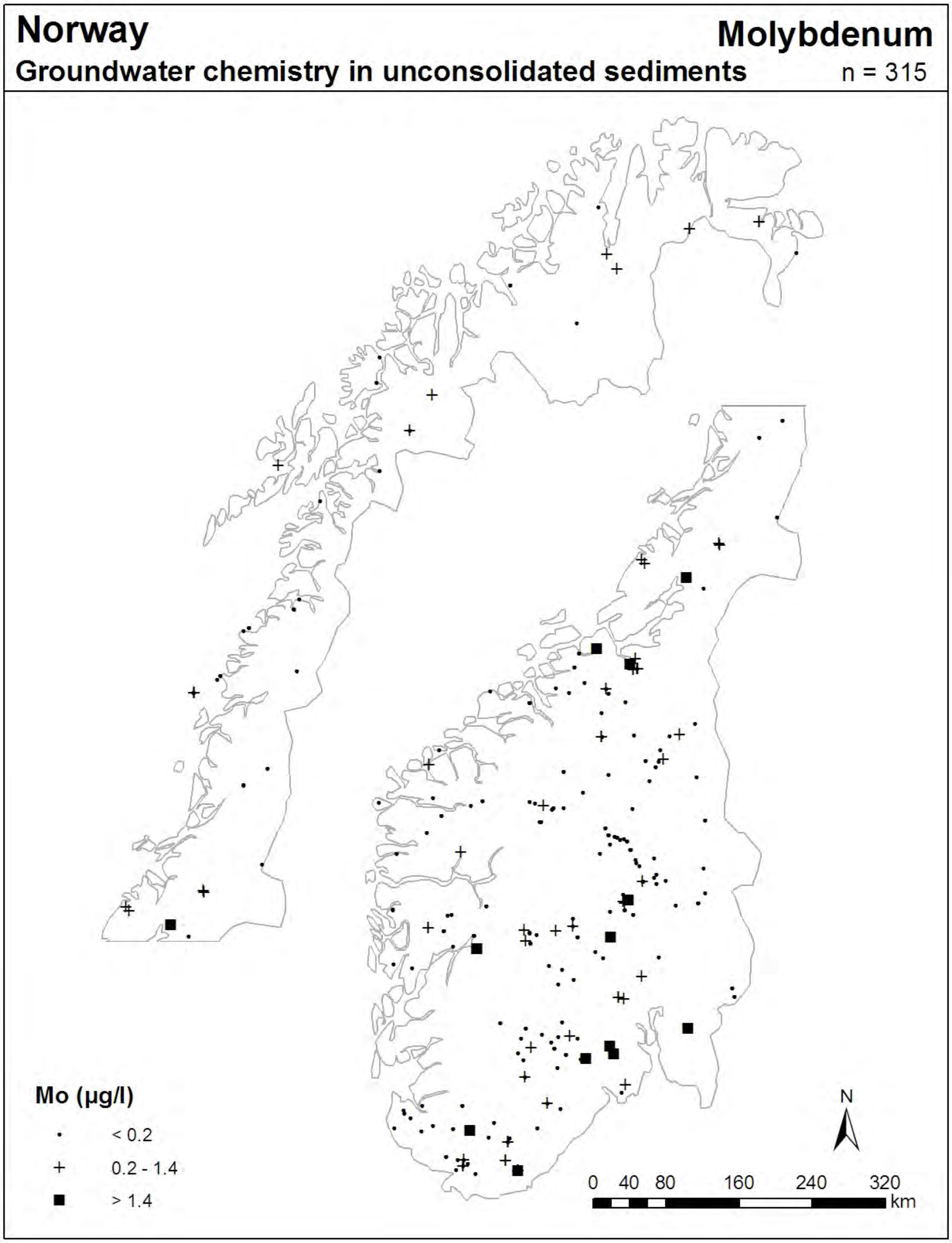

Figure 69: Map of Norway showing molybdenum concentrations in groundwater samples from unconsolidated sediments.

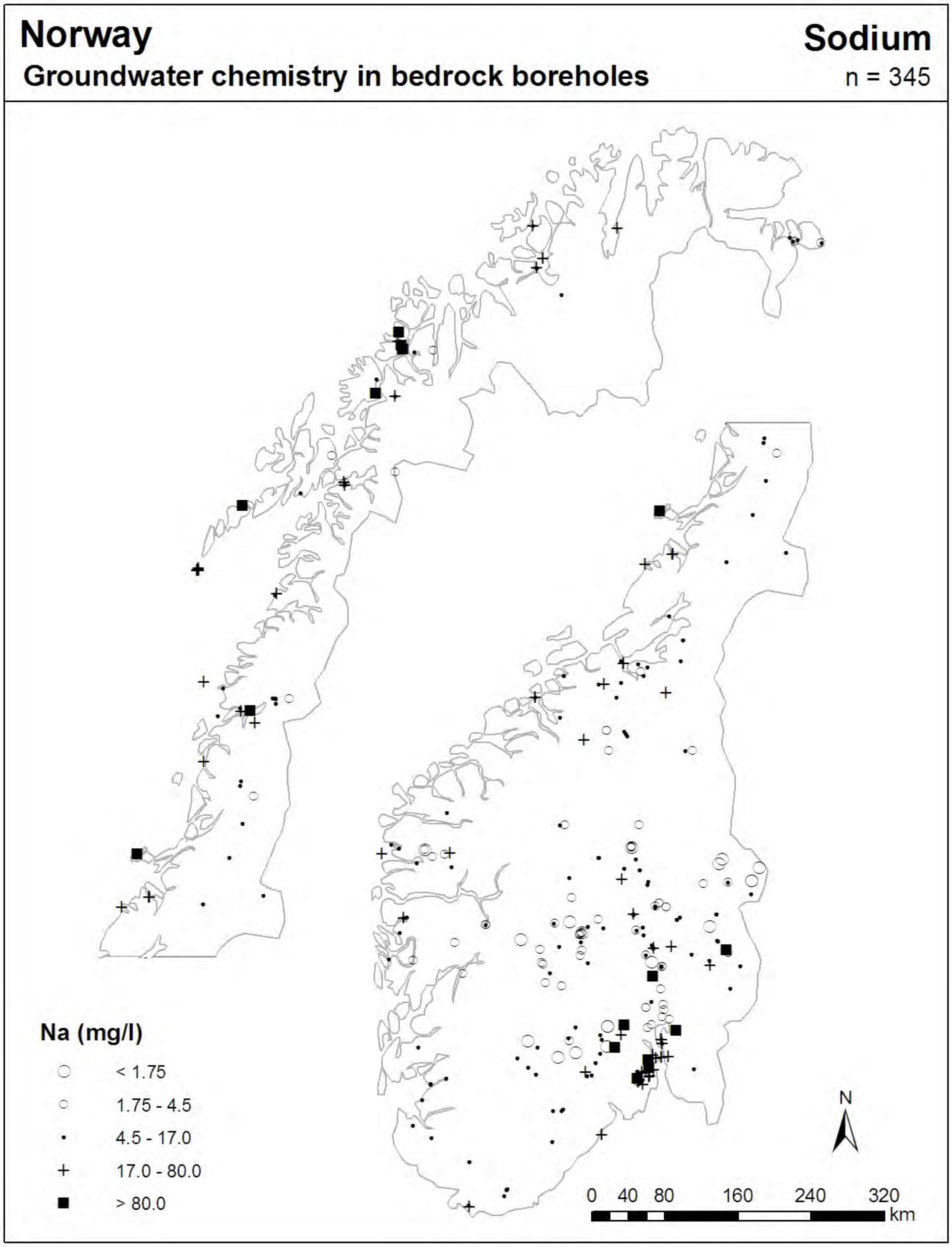

Figure 70: Map of Norway showing sodium concentrations in groundwater samples from bedrock boreholes.

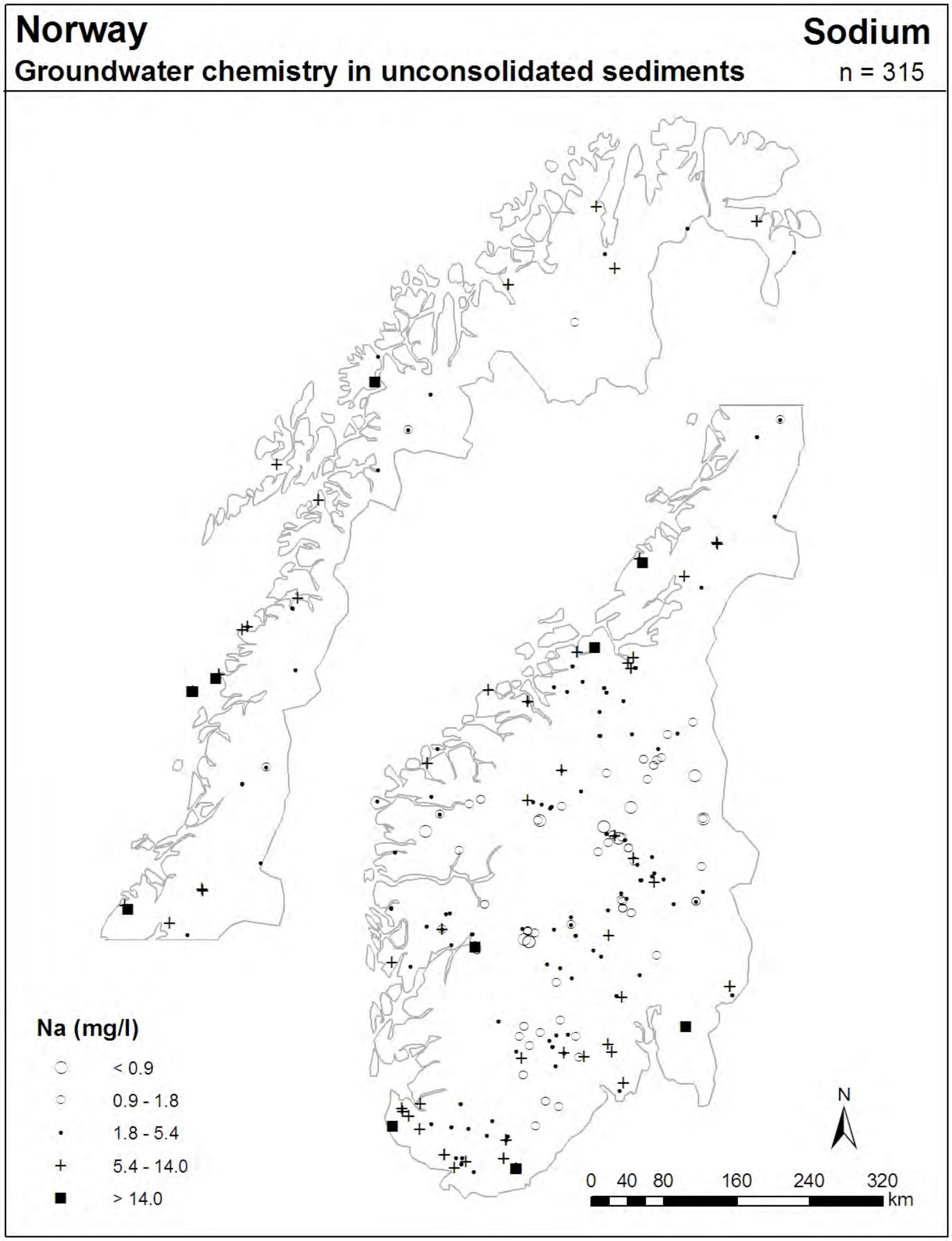

Figure 71: Map of Norway showing sodium concentrations in groundwater samples from unconsolidated sediments.

6.35 Niobium (Nb)

676 of 691 (98 %) groundwater samples have niobium concentrations below the detection limit of 0.05 µg/L. The highest found concentration (0.258 µg/L) was found in a sample from a bedrock borehole.

As there are not enough reliable concentration values, no further statistical or geographical analysis were done.

No limit is set for niobium in drinking water in the western countries.

6.36 Nickel (Ni)

169 out of 691 (25 %) groundwater samples had nickel concentrations below the detection limit of 0.2 µg/L. Groundwater samples from bedrock boreholes and from unconsolidated sediments showed very similar nickel concentrations. The median concentration of the whole dataset was 0.6 µg/L, that of bedrock boreholes 0.5 µg/L and that of groundwater samples from unconsolidated sediments 0.7 µg/L. Samples from bedrock boreholes showed a 95th percentile and a maximum concentration of 10.7 µg/L and 834 µg/L, respectively. In groundwater samples from sedimentary aquifers the 95th percentile of nickel concentration and the maximum concentration were found to be 8.6 µg/L and 125 µg/L, respectively.

Nickel concentrations in bedrock groundwaters do not follow a clear geographical trend (Figure 72). The largest portion of groundwaters from unconsolidated sediments with nickel concentrations below the detection limit seems to be located in Telemark. Water samples from Hordaland had comparably high nickel concentrations in water (Figure 73).

Norway operates a MAC of 20 µg nickel/l. This drinking water standard is exceeded by 20 samples. 12 of 346 groundwater samples from bedrock boreholes, 7 of 314 groundwater samples from unconsolidated sediments and one sample from an unknown aquifer type showed elevated concentrations.

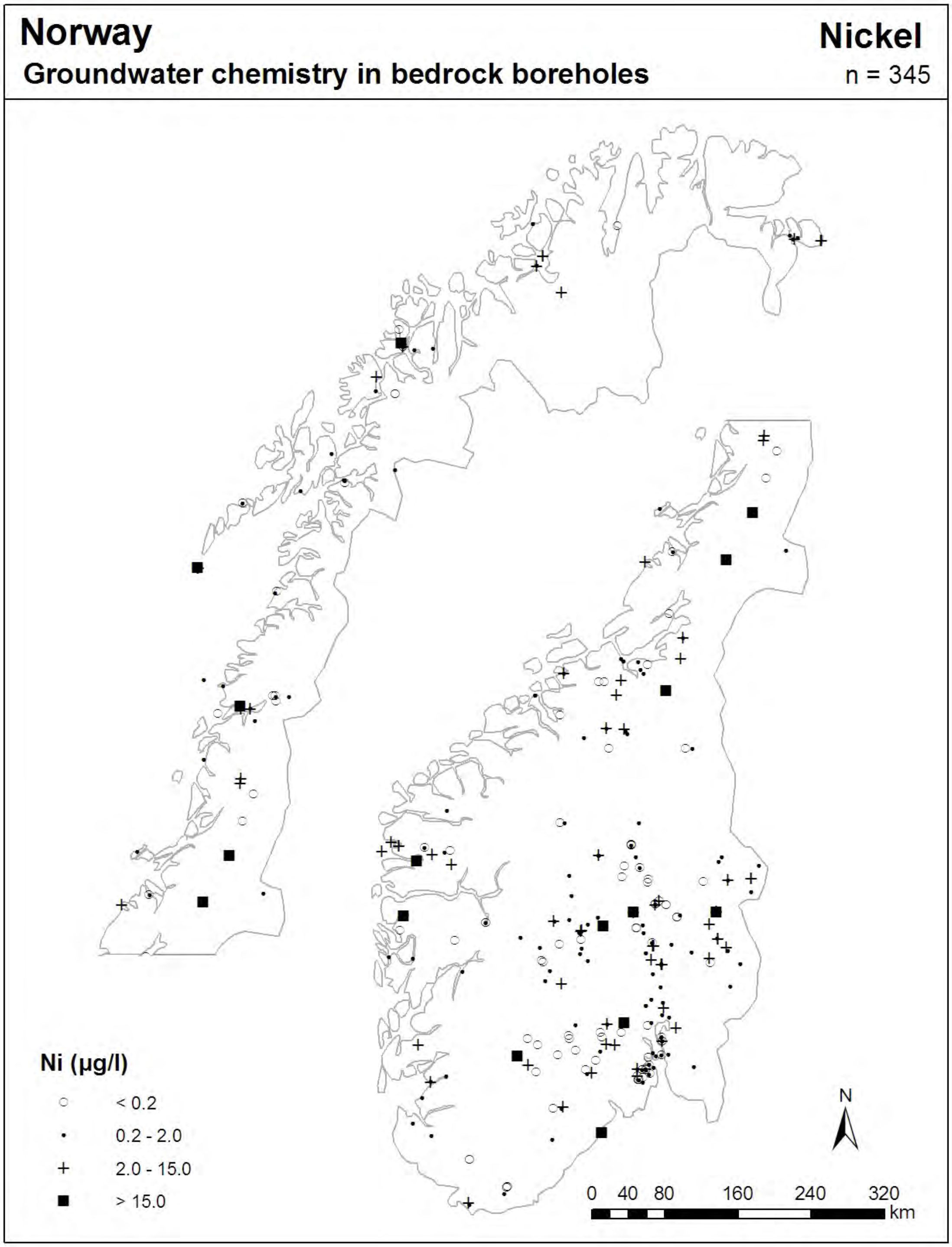

Figure 72: Map of Norway showing nickel concentrations in groundwater samples from bedrock boreholes.

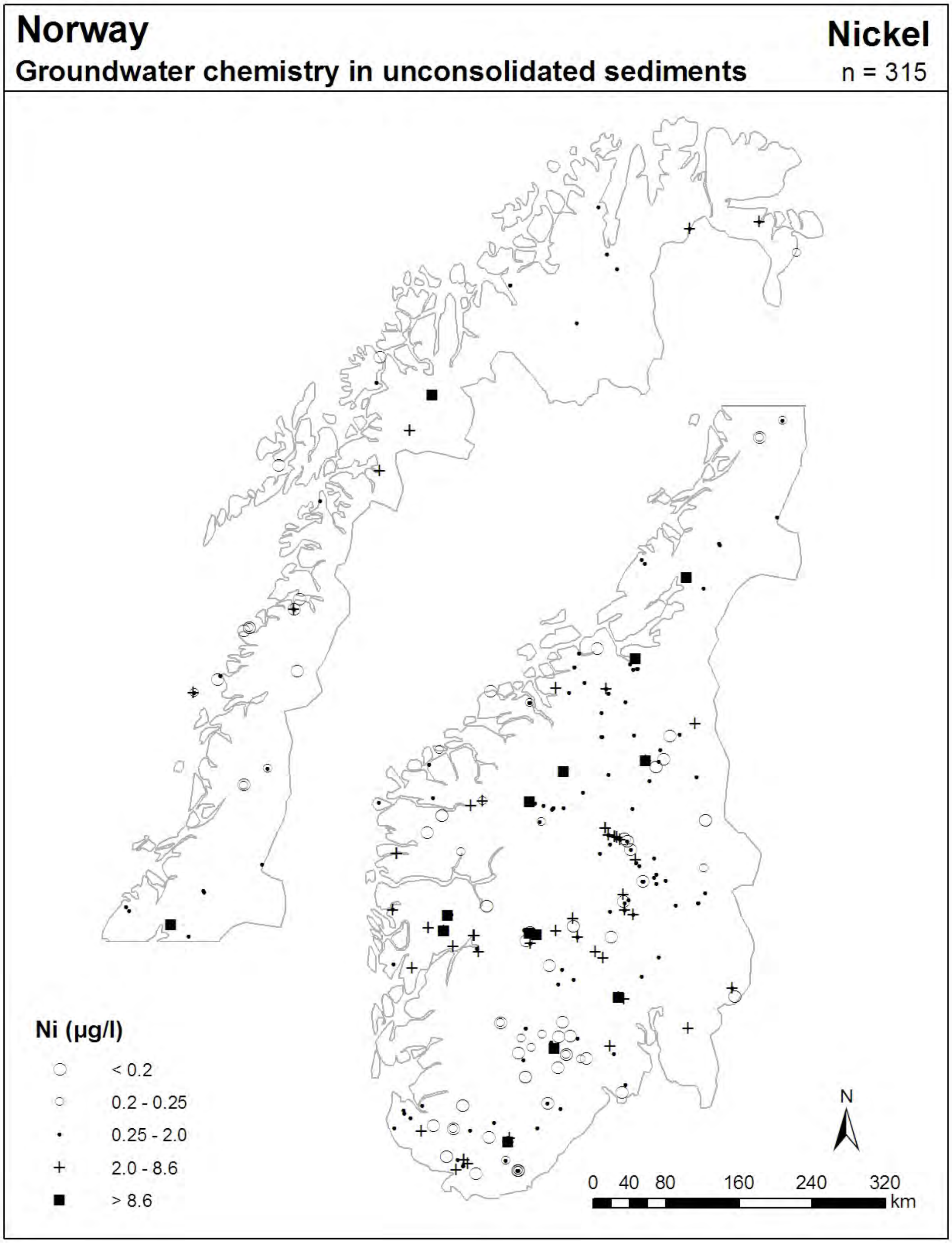

Figure 73: Map of Norway showing nickel concentrations in groundwater samples from unconsolidated sediments.

6.37 Nitrate (NO_3^-)

111 of 691 (16 %) groundwater samples showed nitrate concentrations below the detection limit of 0.05 mg/L NO_3. 92 out of these were bedrock groundwaters. Median nitrate concentration of the whole dataset was found to be 0.68 mg/L, median concentration of bedrock groundwaters and sedimentary aquifers groundwaters 0.28 mg/L and 1.27 mg/L, respectively. The highest measured concentration (38.4 mg/L) comes from a groundwater sample taken from a well in unconsolidated sediments. In bedrock groundwaters, the maximum value found was 21.7 mg/L.

The biggest portion of bedrock groundwater samples with nitrate concentrations above 11 mg/L seems to be located in the central part of Østlandet (Figure 74). Groundwaters from unconsolidated sediments seem to have the biggest portion of samples with nitrate concentrations above 11 mg/L in the western and northern part of Østlandet (Figure 75).

The Norwegian MAC of nitrate is set at 10 mg/L expressed as N. This corresponds to 44 mg/L expressed as NO_3^-. No sample exceeds this MAC.

6.38 Lead (Pb)

116 of 691 (17 %) groundwater samples showed lead concentrations below the detection limit of 0.5 µg/L. The concentrations vary from non-detectable concentrations, over a median value of 0.3 µg/L to a maximum value of 157 µg/L. Bedrock groundwaters were found to have a median lead concentration of 0.5 µg/L and a highest measured concentration of 157 µg/L. Groundwater samples from sedimentary aquifers showed a median concentration of 0.2 µg/L and a highest measured concentration of 99.3 µg/L.

Lead concentrations do not seem to follow a special geographical trend (Figure 76 and Figure 77).

Norway operates a MAC of 10 µg/L. 14 out of 691 samples show lead concentrations above this limit. Among these, 5 samples come from bedrock groundwater samples and 9 from groundwater samples from unconsolidated sediments. 4 samples exceed the limit only with a few µg/L, yet some of the others show rather extreme values. Some samples have around 20 µg/L, others have concentrations around 40 µg/L, 55 µg/L, 70 µg/L, 100 µg/L. The well with the highest measured lead concentration (157 µg/L) was a waterwork in Sogn and Fjordane County.

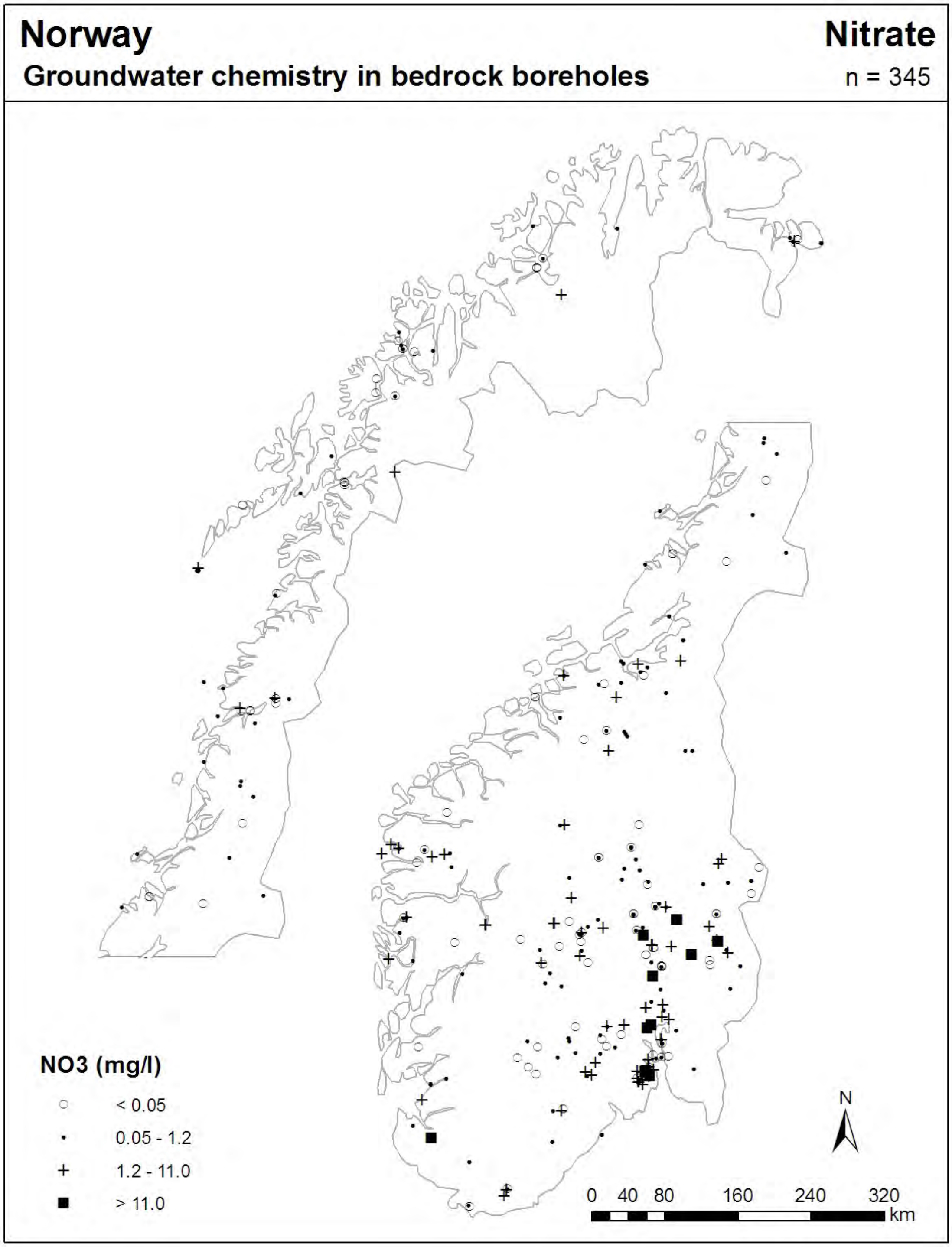

Figure 74: Map of Norway showing nitrate concentrations in groundwater samples from bedrock boreholes.

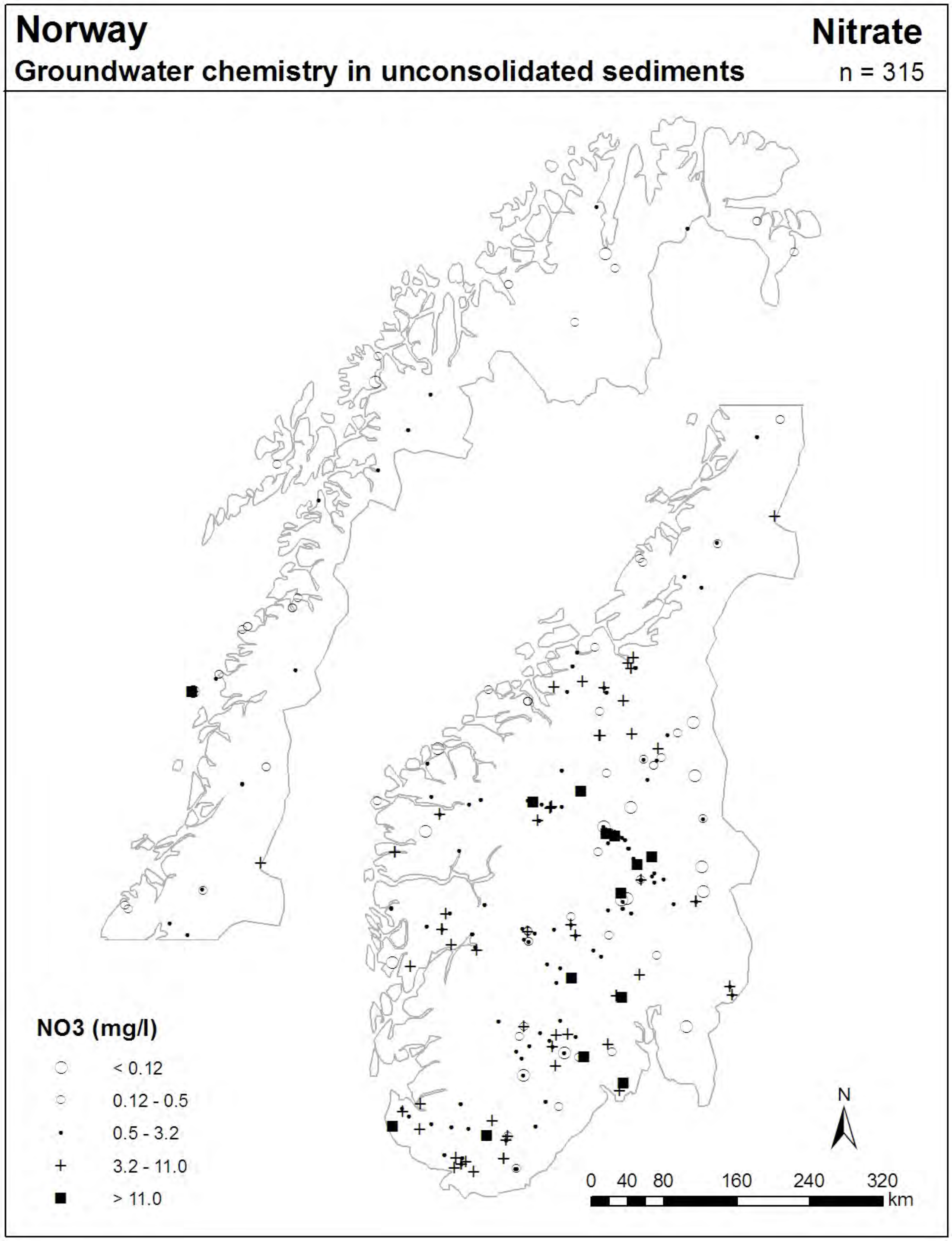

Figure 75: Map of Norway showing nitrate concentrations in groundwater samples from unconsolidated sediments.

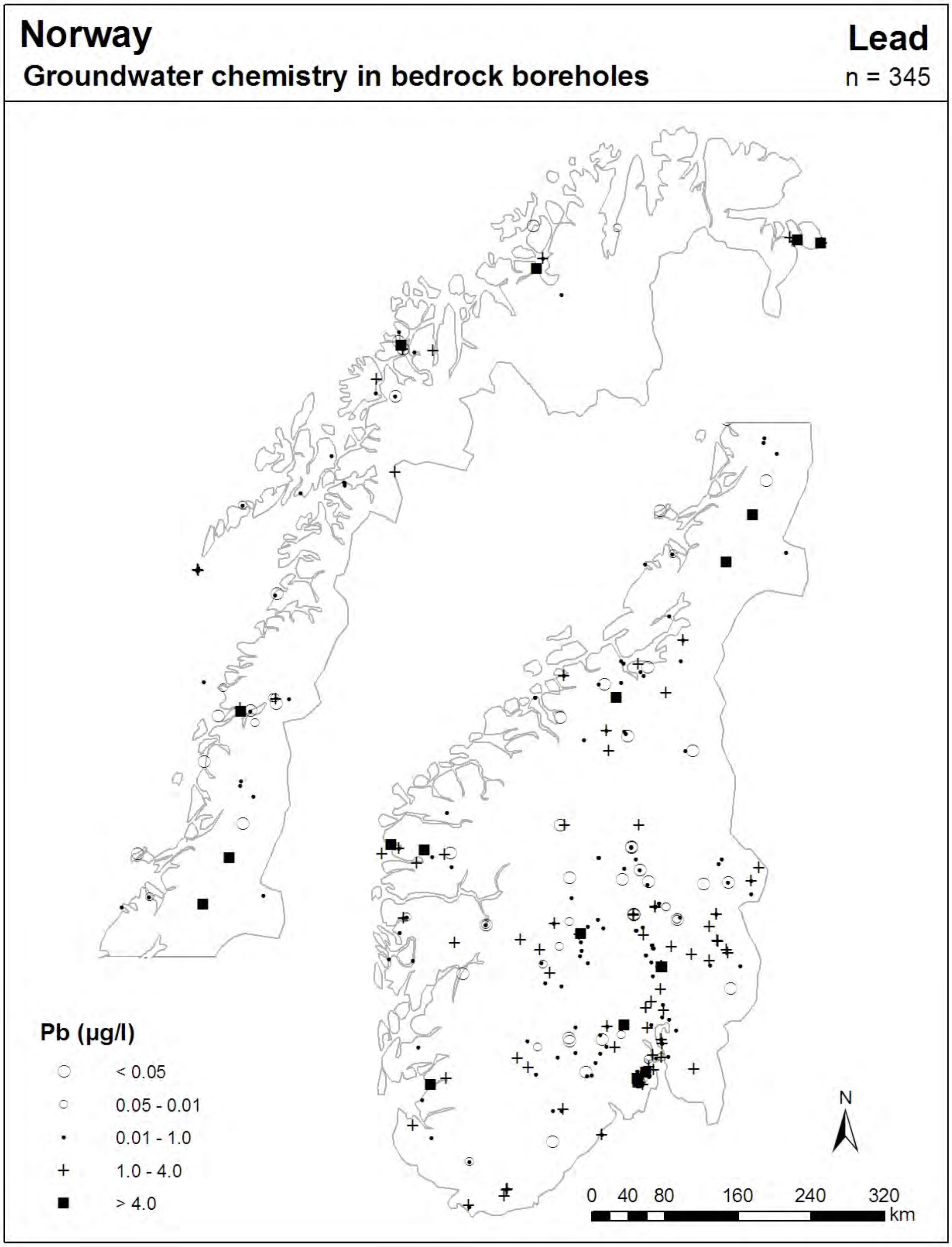

Figure 76: Map of Norway showing lead concentrations in groundwater samples from bedrock boreholes.

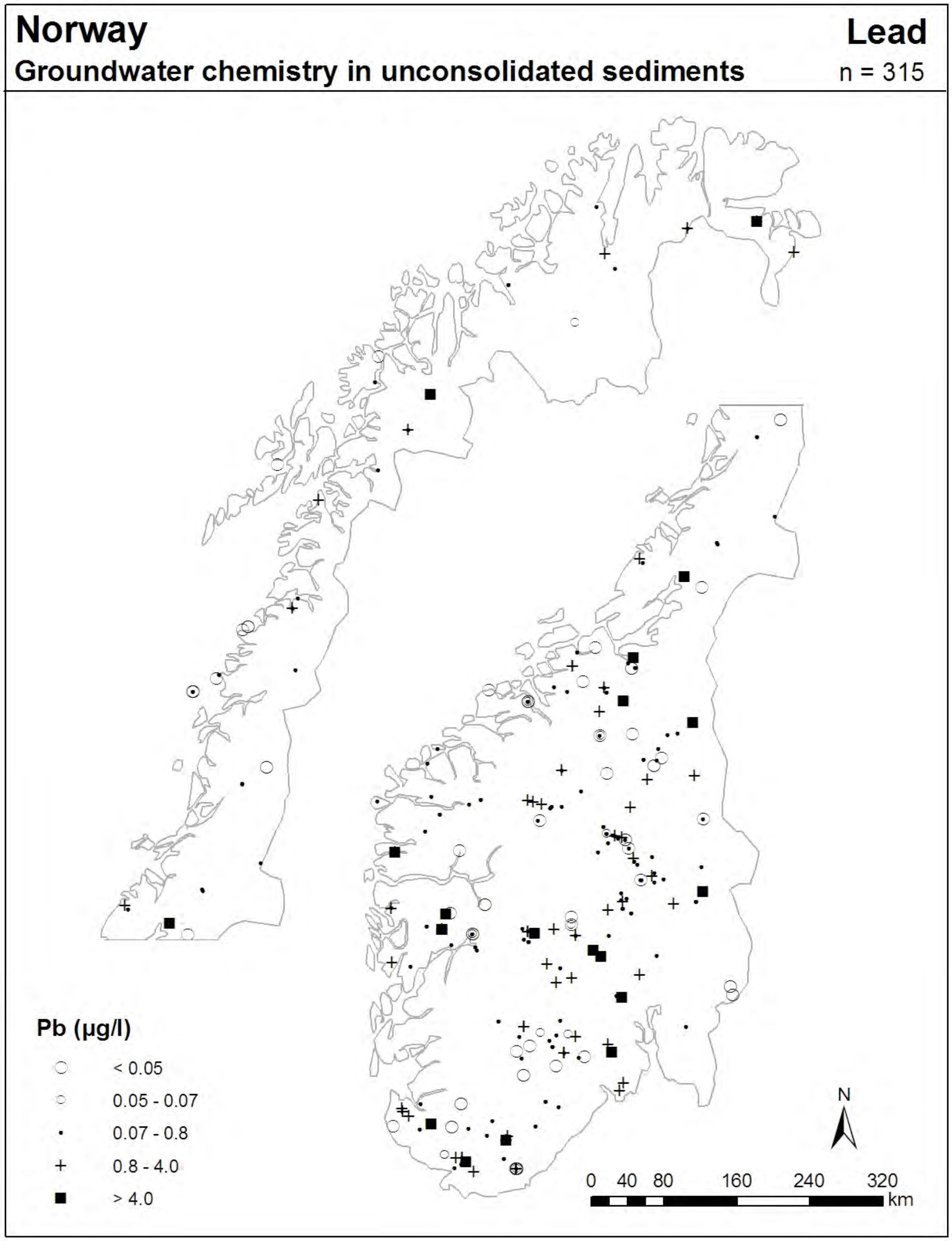

Figure 77: Map of Norway showing lead concentrations in groundwater samples from unconsolidated sediments.

5.39 Phosphate (PO_4^{3-})

650 of 691 (94 %) groundwater samples showed phosphate concentrations below the detection limit of 0.2 mg/L (ion chromatography). The highest measured concentration (7.72 mg/L) comes from a groundwater sample taken from an unconsolidated sediment well (n=314). Bedrock groundwaters showed a maximum value of 0.76 mg/L.

As there are not enough reliable concentration values, no further statistical or geographical analysis were done.

Norway no longer has a MAC for PO_4^{3-}. The former MAC was 3.35 mg/L of phosphorous expressed as PO_4^{3-}. According to this MAC, one sample exceeds the standard.

5.40 Rubidium (Rb)

Rubidium concentrations in the analyzed groundwater samples vary from concentrations below detection limit (0.05 µg/L) to a maximum value of 30.5 µg/L. This maximum value belongs to a sample from bedrock groundwaters. The median concentration of the whole dataset was found to be 1.6 µg/L. The median concentrations in groundwater samples from bedrock boreholes and unconsolidated sediments were very close to this value, too. In groundwaters from unconsolidated sediments, 14.5 µg/L was the highest rubidium concentration measured.

No geographical pattern could be identified (Figure 78 and Figure 79). No drinking water limit is set for rubidium.

5.41 Sulphate (SO_4^{2-})

Sulphate concentrations in the analyzed groundwater samples vary from concentrations below detection limit (0.2 mg/L) to a maximum value of 468 mg/L. This sulphate concentration was measured in a groundwater sample taken from a bedrock borehole. The median concentration of the whole dataset was found to be 7.3 mg/L. The median concentrations in groundwater samples from bedrock boreholes and unconsolidated sediments were 10.1 mg/L and 4.7 mg/L, respectively. In groundwaters from unconsolidated sediments, 141 mg/L was the highest sulphate concentration measured.

For bedrock groundwaters, no geographical trend could be observed (Figure 80). The biggest portion of groundwater samples from unconsolidated sediments with sulphate concentrations above 20 mg/L seems to be located in the central part of Østlandet (Figure 81).

Norwegian health authorities operate a MAC for SO_4^{2-} of 100 mg/L. This standard is exceeded by 9 of 691 groundwater samples. 76 samples showed concentration lying above the Norwegian guidance value. In EU, MAC for SO_4^{2-} in drinking water is set at 250 mg/L as recommended by WHO. This standard is exceeded by 3 groundwater samples.

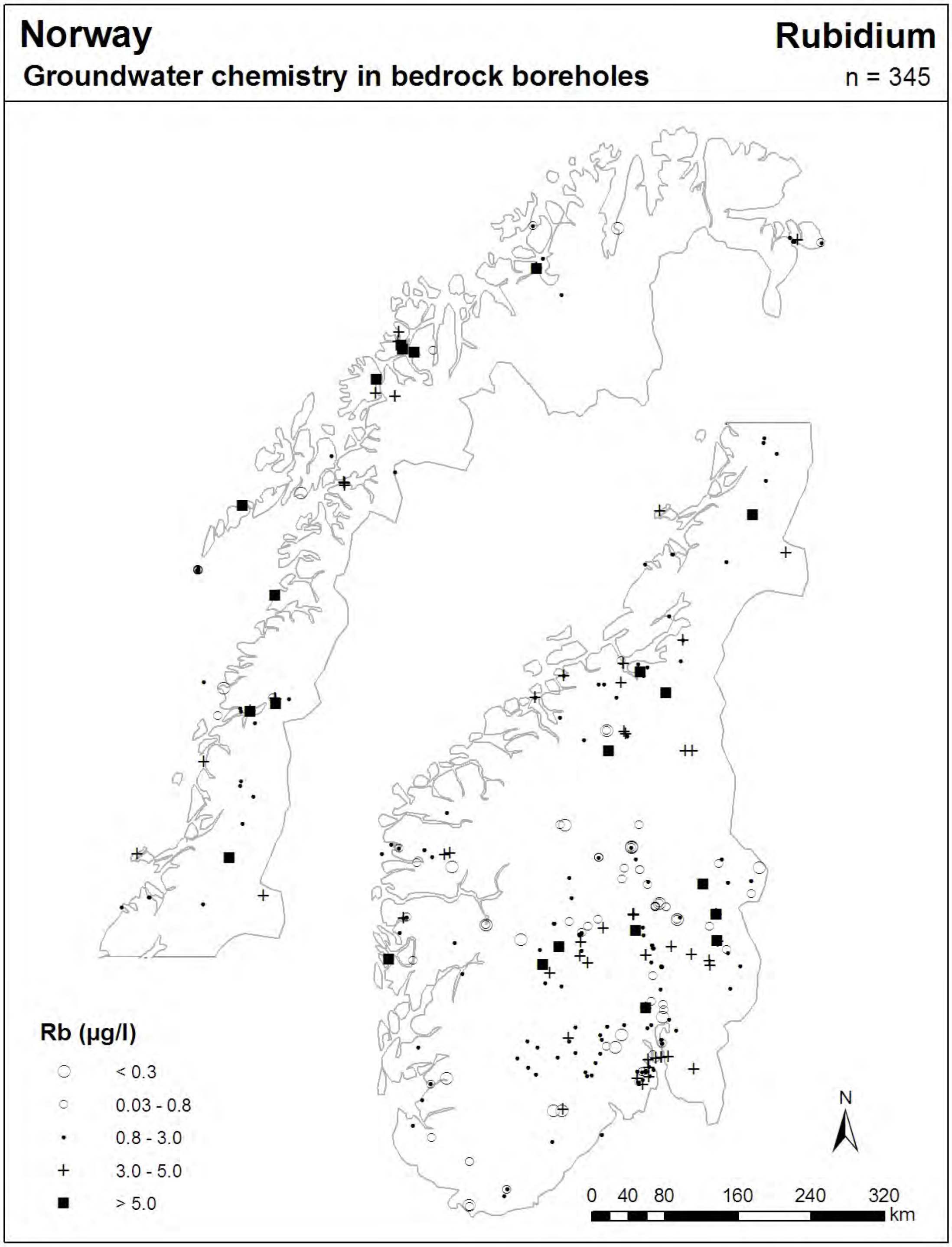

Figure 78: Map of Norway showing rubidium concentrations in groundwater samples from bedrock boreholes.

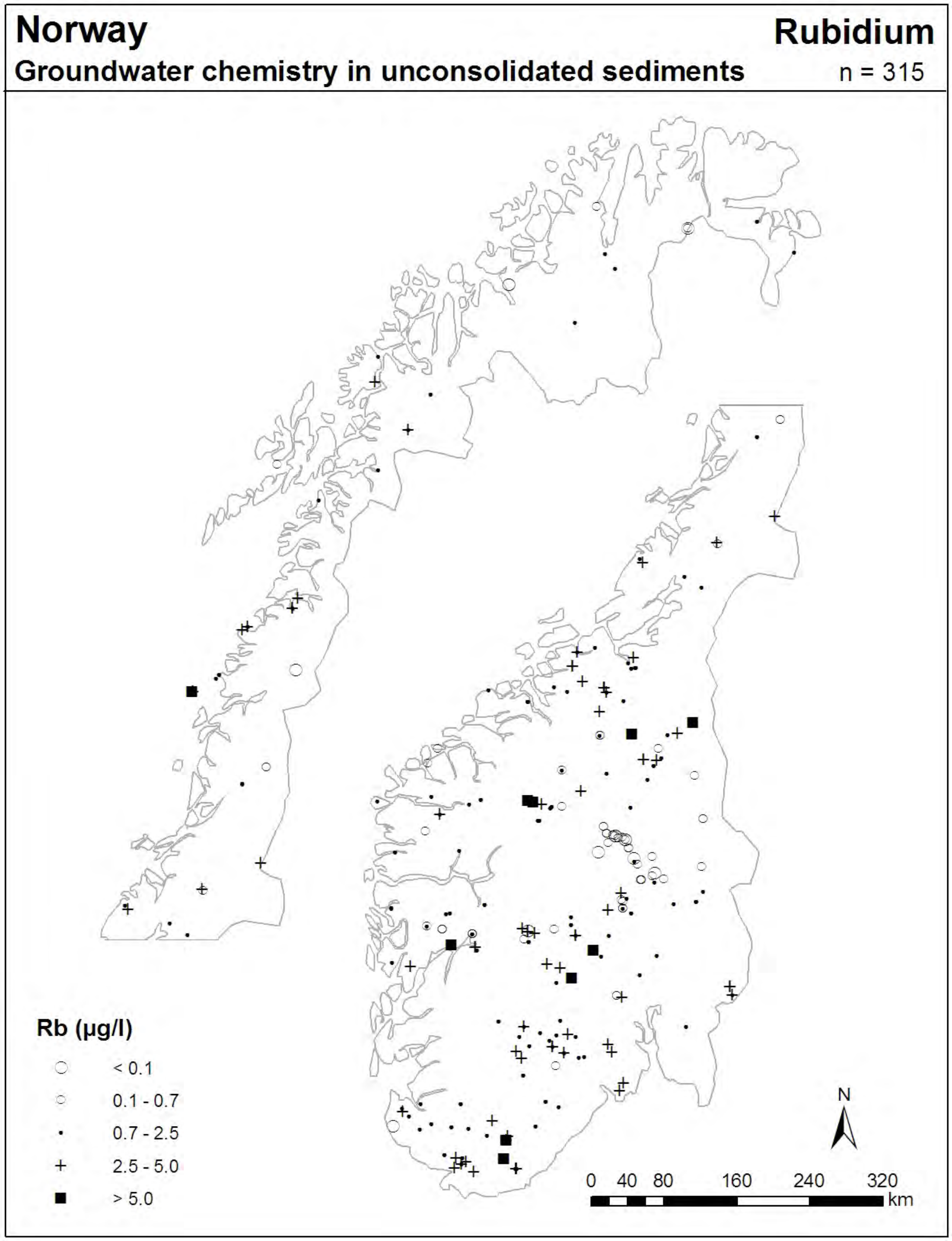

Figure 79: Map of Norway showing rubidium concentrations in groundwater samples from unconsolidated sediments.

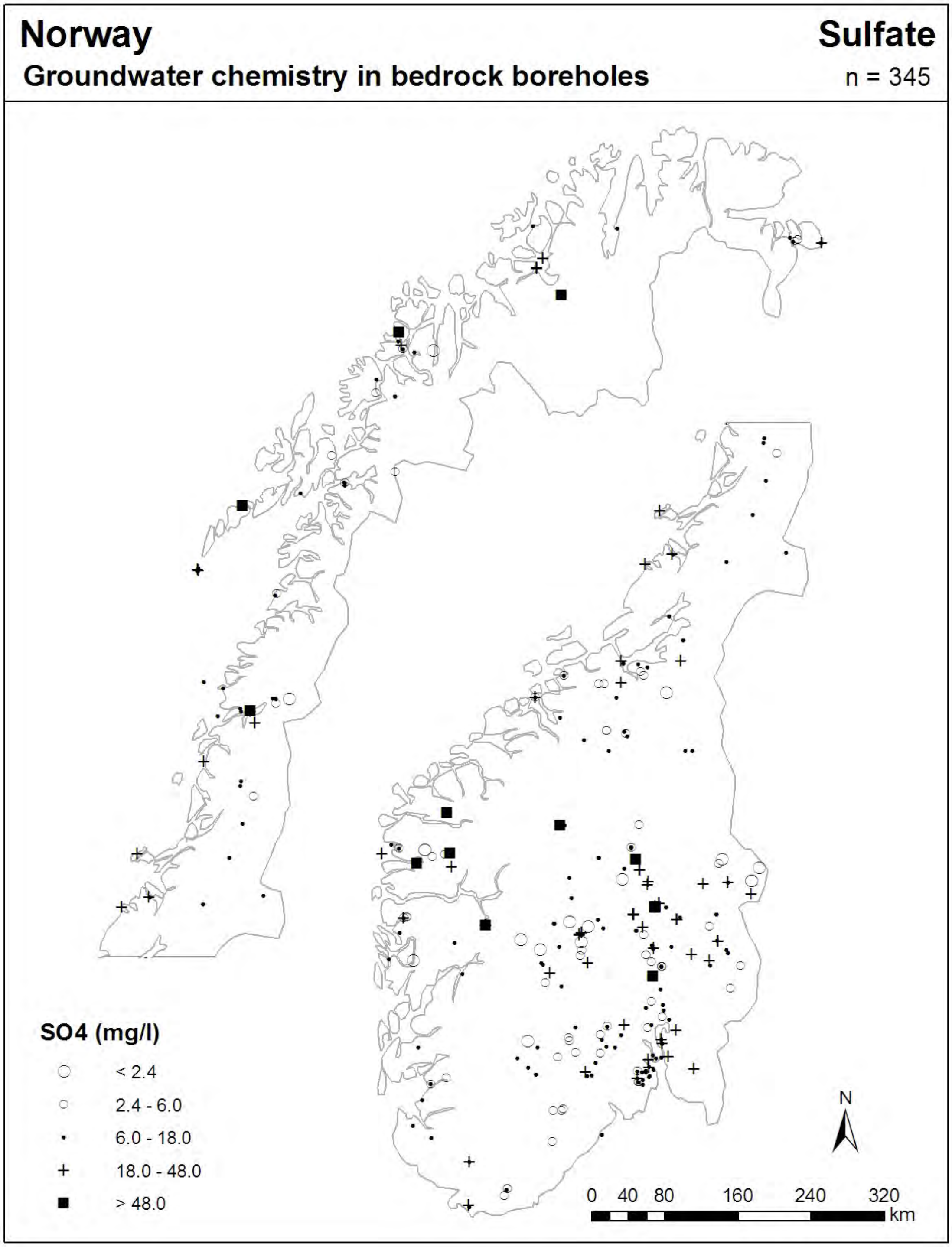

Figure 80: Map of Norway showing sulphate concentrations in groundwater samples from bedrock boreholes.

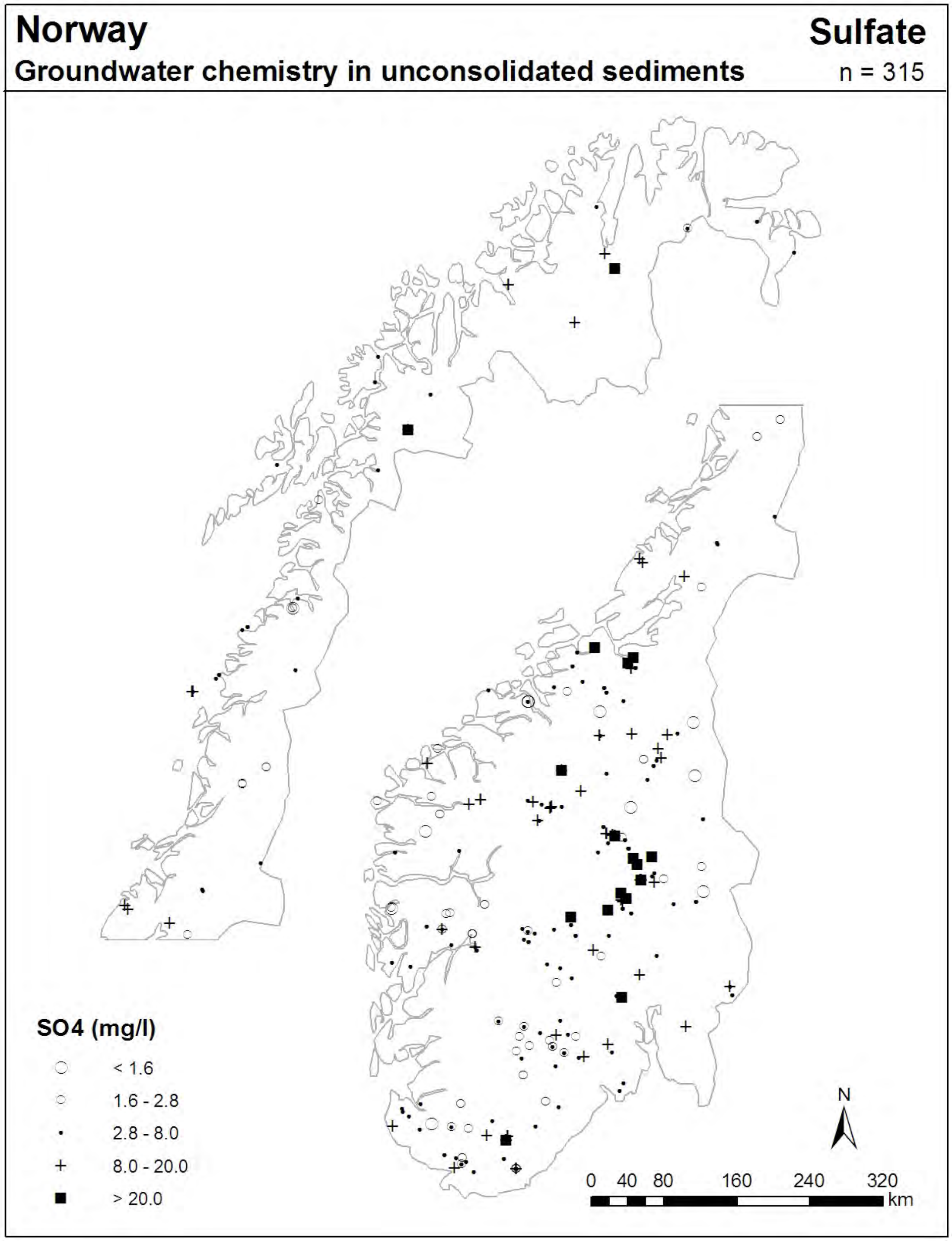

Figure 81: Map of Norway showing sulphate concentrations in groundwater samples from unconsolidated sediments.

6.42 Antimony (Sb)

466 of 691 (67 %) groundwater samples showed antimony concentrations below the detection limit of 0.2 µg/L. 60 % of analyzed bedrock groundwaters and 76 % of analyzed groundwaters from unconsolidated sediments showed antimony concentrations below detection limit. The highest measured concentration (2.67 µg/L) was found in a groundwater sample from a bedrock borehole. In samples from sedimentary aquifers, the highest measured concentration was 0.79 µg/L.

No geographical pattern could be identified (Figure 82 and Figure 83).

The MAC of 5 µg/L, which is operated in Norway and the EU is not exceeded.

6.43 Scandium (Sc)

In only 1 of 691 analyzed groundwater samples, scandium was detectable. No further statistical or geographical analysis was done.

There are no drinking water limits for scandium.

6.44 Selenium (Se)

Selenium was detectable in only 6 of 691 analyzed groundwater samples.. The highest measured concentration was 13.8 µg/L. This sample exceeds the former Norwegian MAC of 10 µg/L, which was in accordance with the MAC of Canada and the EU and the guidance value of the WHO. Today Norway does not operate a MAC for selenium.

As there are not enough reliable data, no further statistical or geographical analysis was done.

6.45 Strontium (Sr)

Strontium concentrations varied from concentrations below ICP-AES detection limits (0.001 mg/L) to a maximum value of 5.27 mg/L, which was measured in a bedrock groundwater sample. The median concentration of the whole dataset was found to be 0.07 mg/L. Groundwater samples from bedrock boreholes and unconsolidated sediments had median concentrations of 0.14 mg/L and 0.04 mg/L, respectively. The highest measured concentration in groundwaters from unconsolidated sediments was 1.04 mg/L.

No significant geographical pattern could be identified (Figure 84 and Figure 85). It seems like there is a bigger portion bedrock groundwater samples with slightly elevated strontium concentrations in central Østlandet.

No limit is set for strontium in drinking water in Norway.

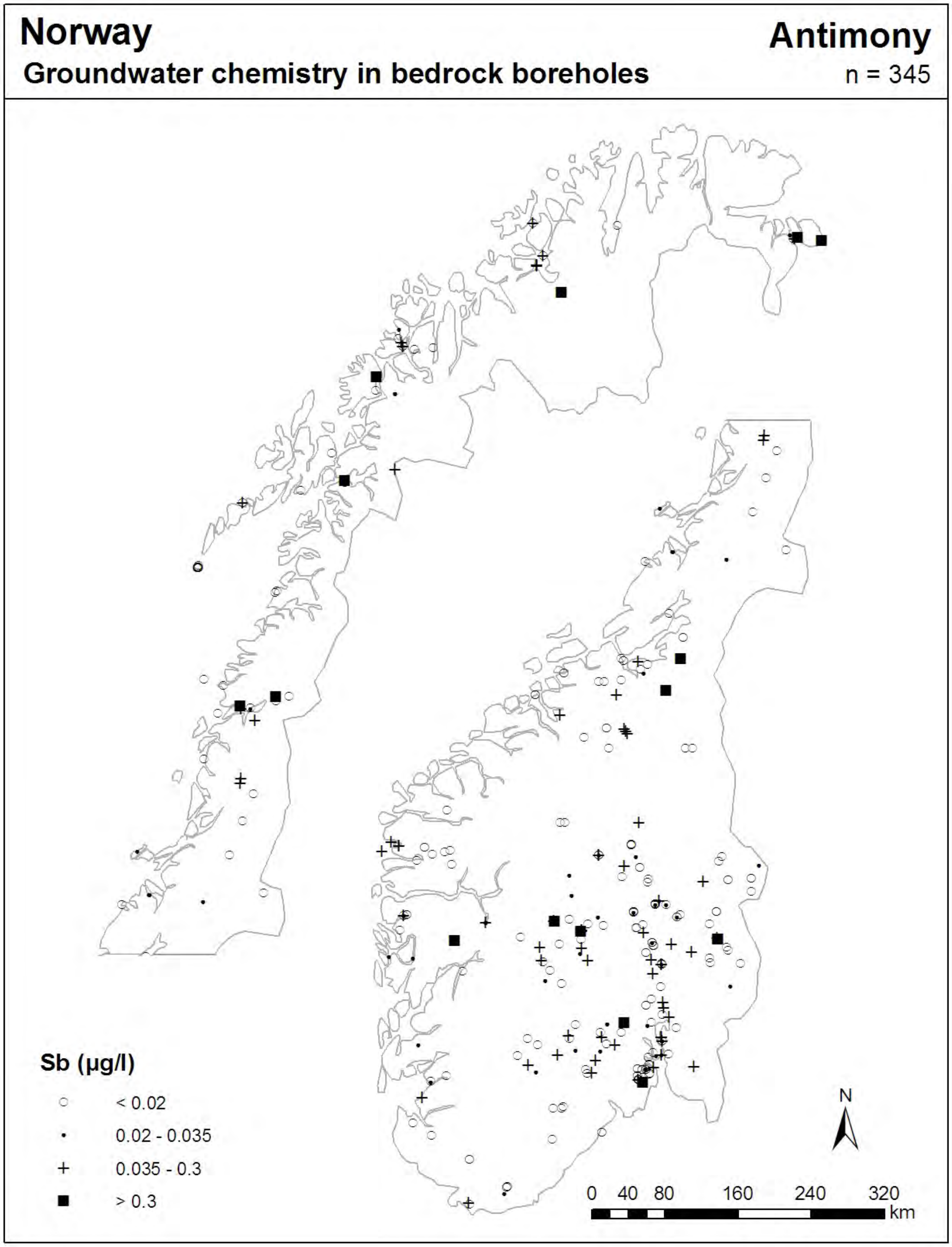

Figure 82: Map of Norway showing antimony concentrations in groundwater samples from bedrock boreholes.

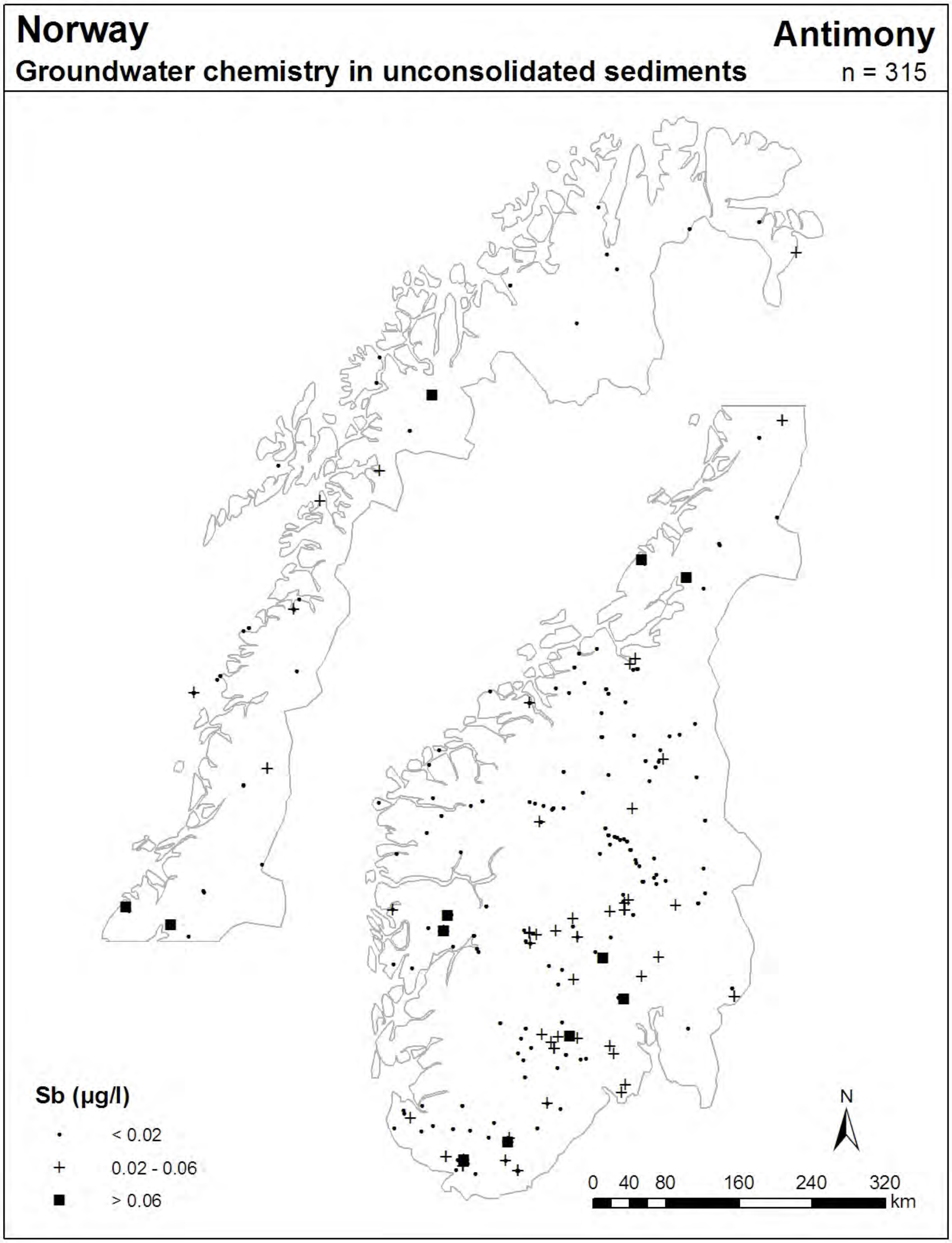

Figure 83: Map of Norway showing antimony concentrations in groundwater samples from unconsolidated sediments.

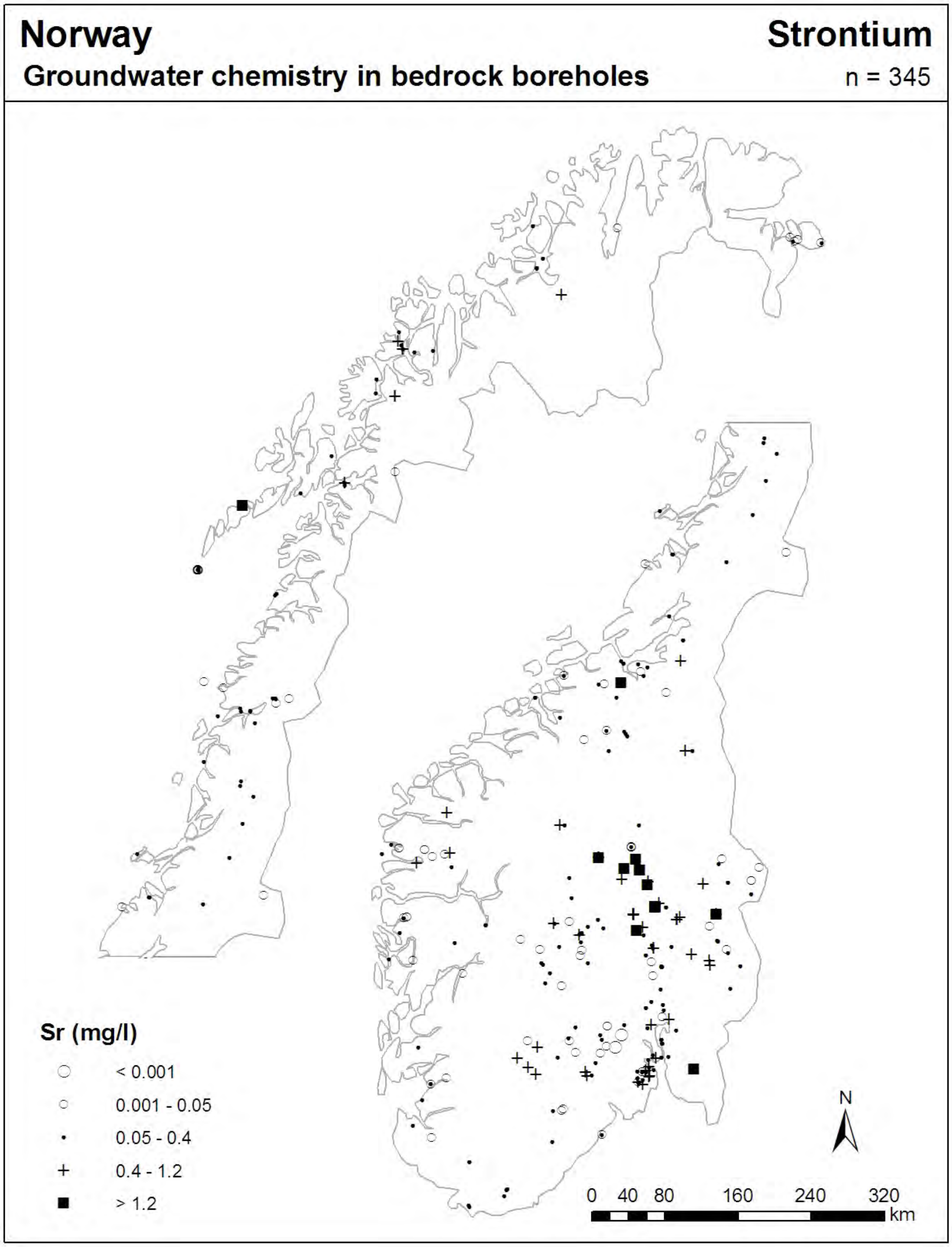

Figure 84: Map of Norway showing strontium concentrations in groundwater samples from bedrock boreholes.

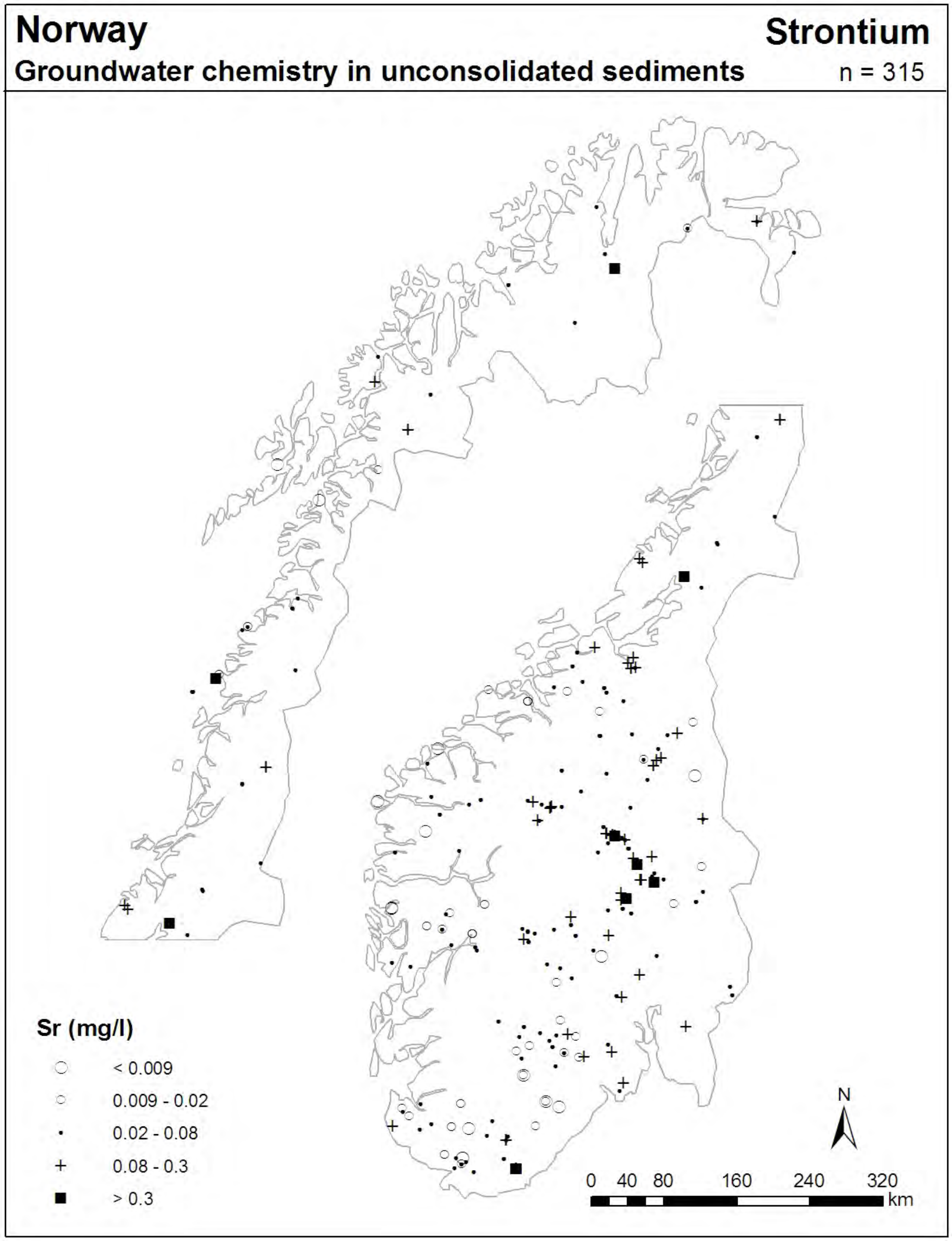

Figure 85: Map of Norway showing strontium concentrations in groundwater samples from unconsolidated sediments.

6.46 Tantalum (Ta)

Only 7 of 691 groundwater samples showed detectable tantalum concentrations. Thus, no further statistical or geographical analysis was done. No MAC for tantalum is set.

6.47 Thorium (Th)

520 of 691 (75 %) groundwater samples showed thorium concentrations below the detection limit of 0.02 μg/L. The highest measured concentration (4.76 μg/L) was found in a groundwater sample from a sedimentary aquifer. No MAC for thorium is set.

6.48 Titanium (Ti)

Only 46 of 691 (7 %) groundwater samples showed detectable titanium concentrations (ICP-AES). Thus, no further statistical or geographical analysis was done. No drinking water limits are set for titanium.

6.49 Thallium (Tl)

Only 9 of 691 groundwater samples showed thallium concentrations above detection limit (0.05 μg/L). The maximum concentration (0.204 μg/L) was measured in a sample from bedrock groundwaters. No MAC is defined in Norway. USEPA has defined a MAC of 2 μg/L in the USA. If this drinking water standard was applied, one sample would exceed the limit concentration. Yet, there are not enough reliable data to do any further statistical or geographical analysis.

6.50 Uranium (U)

Uranium concentrations in the analyzed groundwater samples range from concentrations below detection limit (0.0005 μg/L) to a maximum of 246 μg/L. The median concentration of the whole dataset was found to be 0.5 μg/L. Samples from bedrock groundwaters generally showed higher uranium concentrations than groundwater samples from unconsolidated sediments (n=314). Median concentration, 75th percentile and maximum value of bedrock groundwaters are 2.1 μg/L, 6.8 μg/L and 246 μg/L, respectively. Analogically, groundwater samples from unconsolidated sediments were found to have a median concentration of 0.1 μg/L, a 75th percentile of 0.3 μg/L and a maximum value of 77.1 μg/L.

The biggest portion of bedrock groundwater with uranium concentrations above 40 μg/L is located in the southern part of Østlandet (Figure 86). For groundwaters from unconsolidated sediments no geographical pattern could be observed (Figure 87).

No drinking water limit is defined in Norway, but in Canada a MAC of 20 μg/L is defined. USEPA has set a MAC at 30 μg/L in the USA. This value is consistent with the WHO guideline value for drinking water. 27 of 691 samples exceed this limit. Except for one sample from unconsolidated sediments and one sample of unknown origin, all these water samples were collected from bedrock groundwaters.

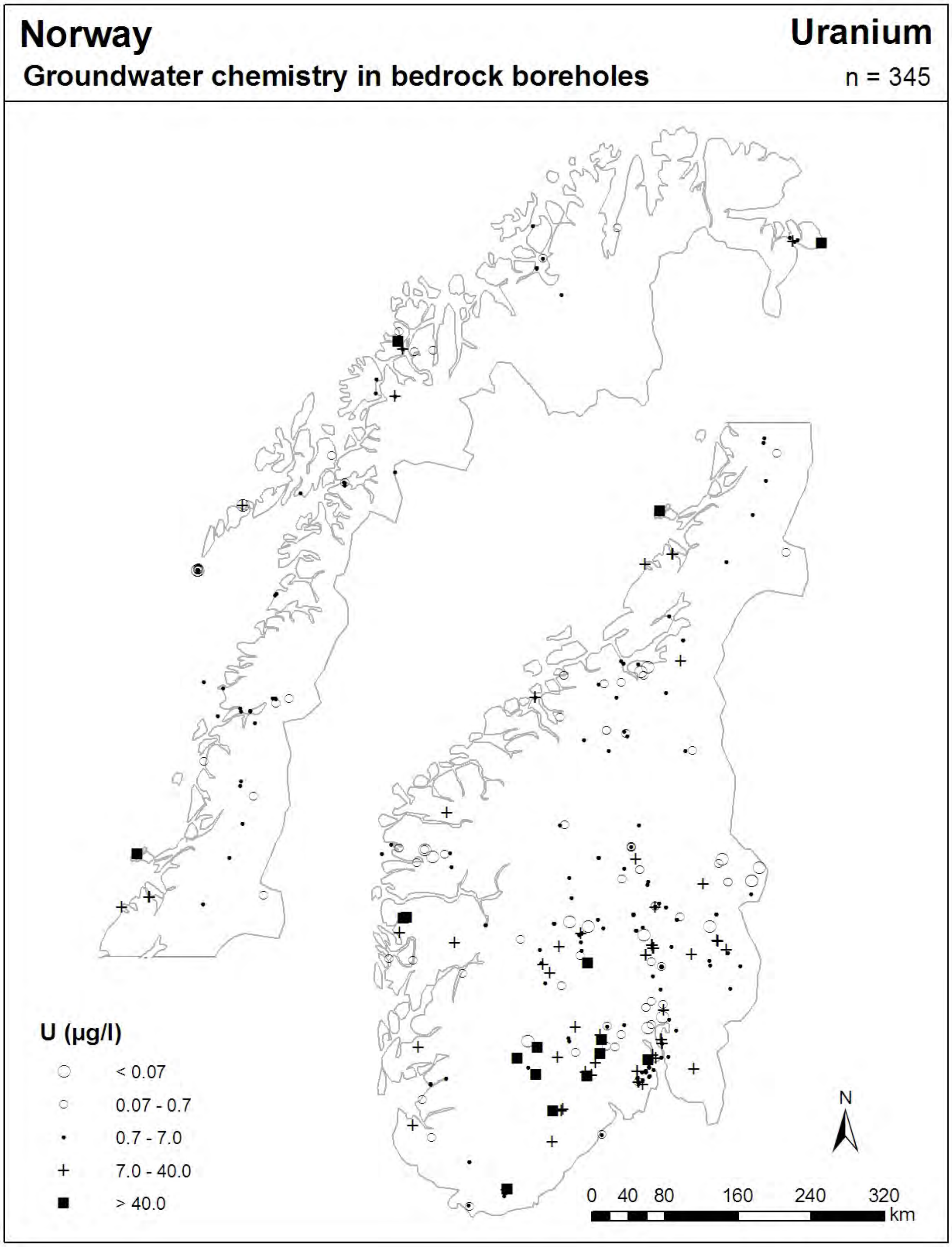

Figure 86: Map of Norway showing uranium concentrations in groundwater samples from bedrock boreholes.

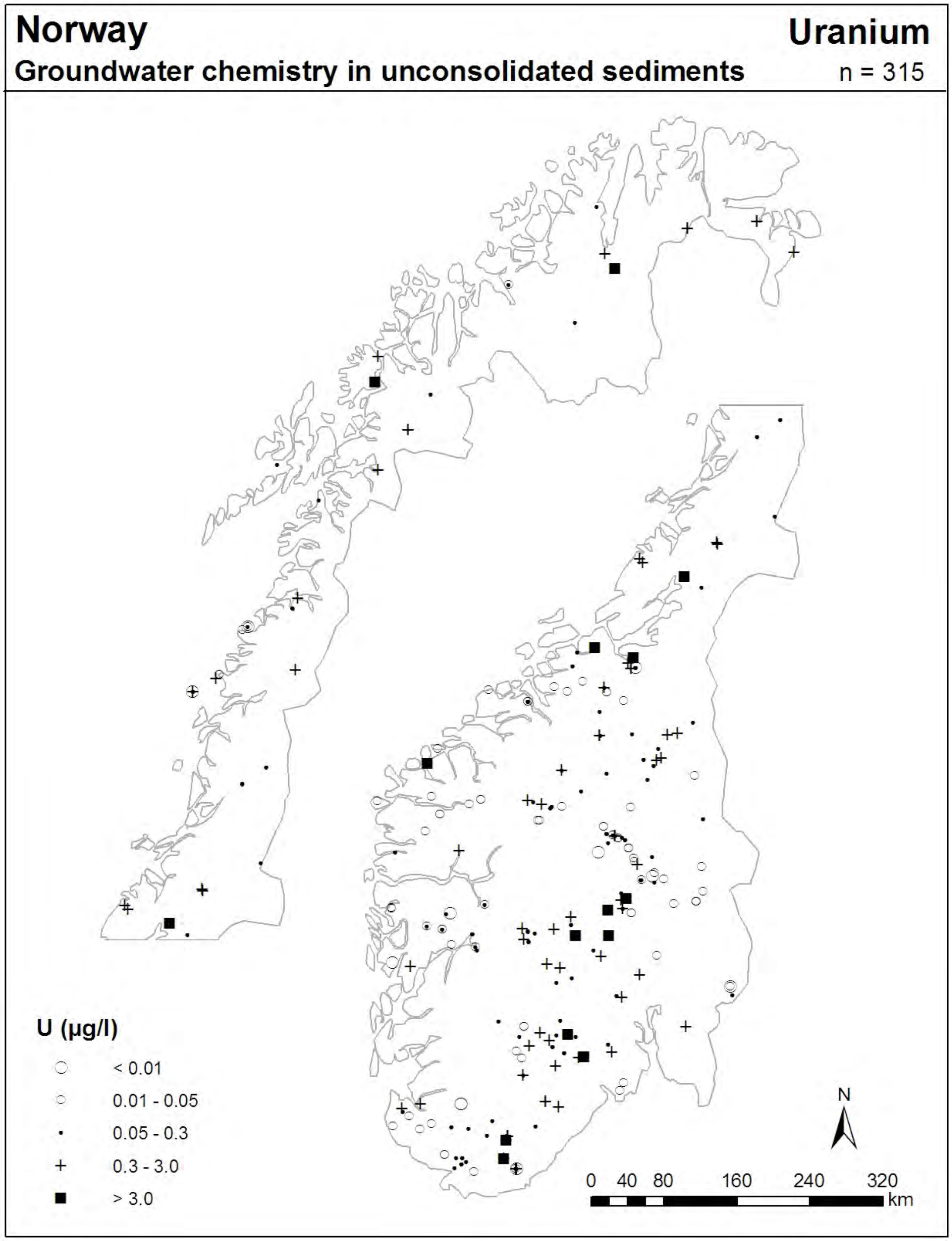

Figure 87: Map of Norway showing uranium concentrations in groundwater samples from unconsolidated sediments.

6.51 Vanadium (V)

Vanadium concentrations in the analyzed groundwater samples range from concentrations below detection limit (0.02 µg/L) to a maximum of 58.4 µg/L. The median concentrations of the whole dataset, groundwater samples from bedrock boreholes and groundwater samples from unconsolidated sediments are 0.1 µg/L, 0.2 µg/L and 0.1 µg/L, respectively. The highest measured concentrations were 58.4 µg/L in bedrock groundwaters and 3.04 µg/L in groundwater samples from sedimentary aquifers.

No geographical pattern could be observed (Figure 88 and Figure 89).

In the Norwegian drinking water directive, no MAC is defined for vanadium.

6.52 Tungsten (W)

493 of 691 (71 %) groundwater samples showed tungsten concentrations below detection limit (0.05 µg/L). 302 out of 314 (96 %) groundwater samples from unconsolidated sediment wells and 173 out of 346 (50 %) bedrock groundwaters were found to have concentrations below detection limit. The highest measured concentration in bedrock groundwaters was 19.6 µg/L and 3.88 µg/L in samples from wells in unconsolidated sediments.

As there are not enough reliable data from unconsolidated sediment groundwaters, only bedrock groundwaters are visualized on a map (Figure 90). No distinct geographical trend could be identified.

No limit for tungsten in drinking water in Norway is defined.

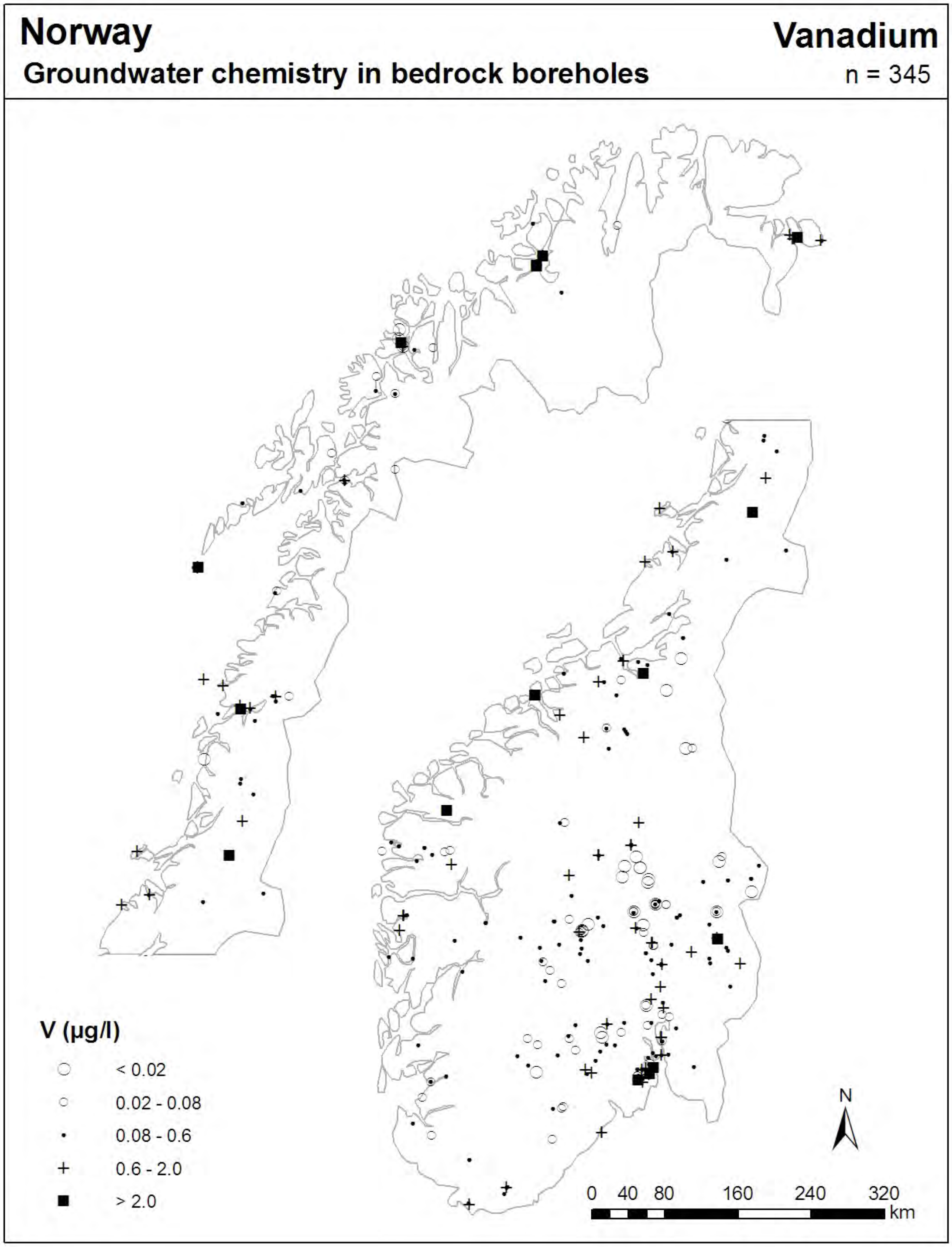

Figure 88: Map of Norway showing vanadium concentrations in groundwater samples from bedrock boreholes.

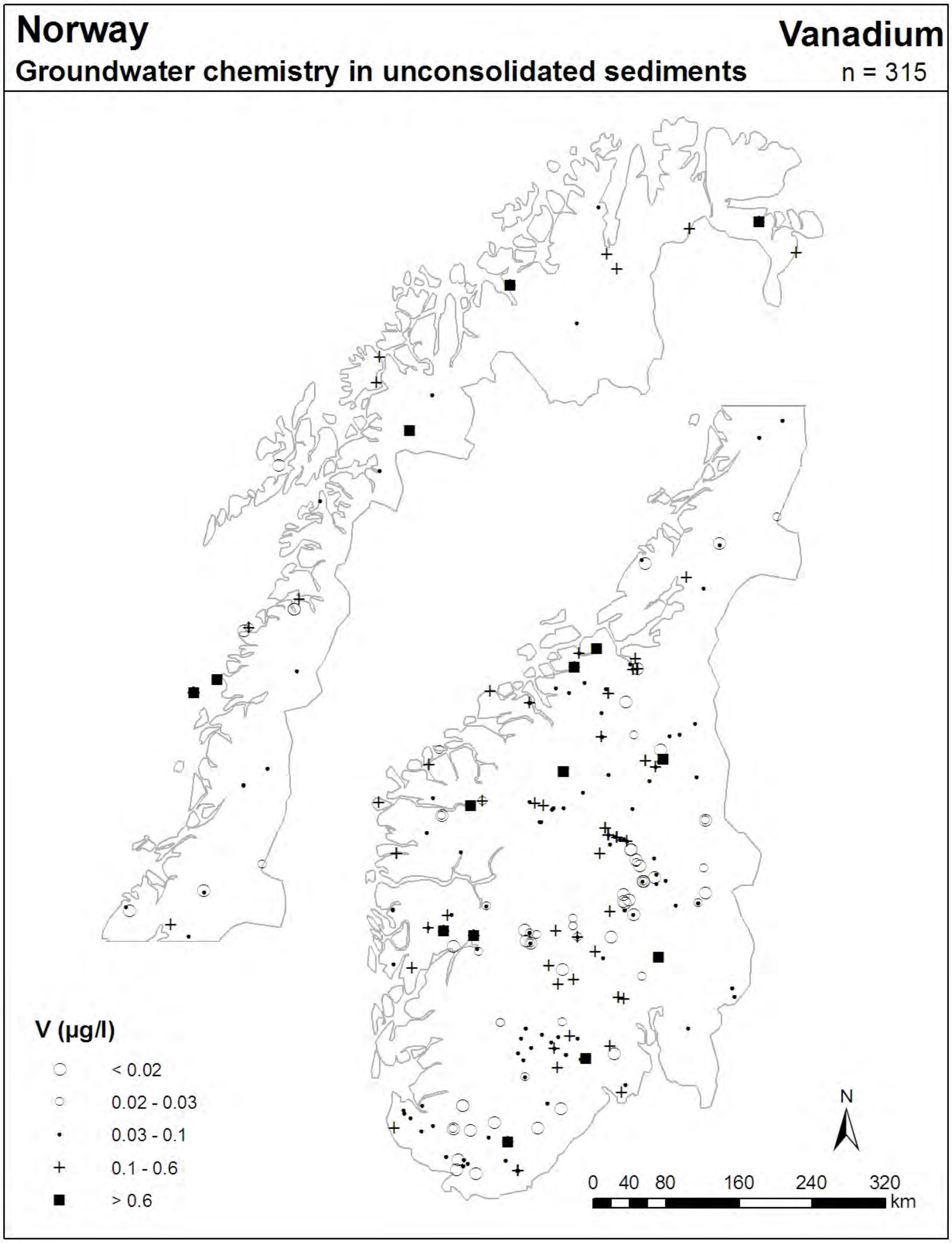

Figure 89: Map of Norway showing vanadium concentrations in groundwater samples from unconsolidated sediments.

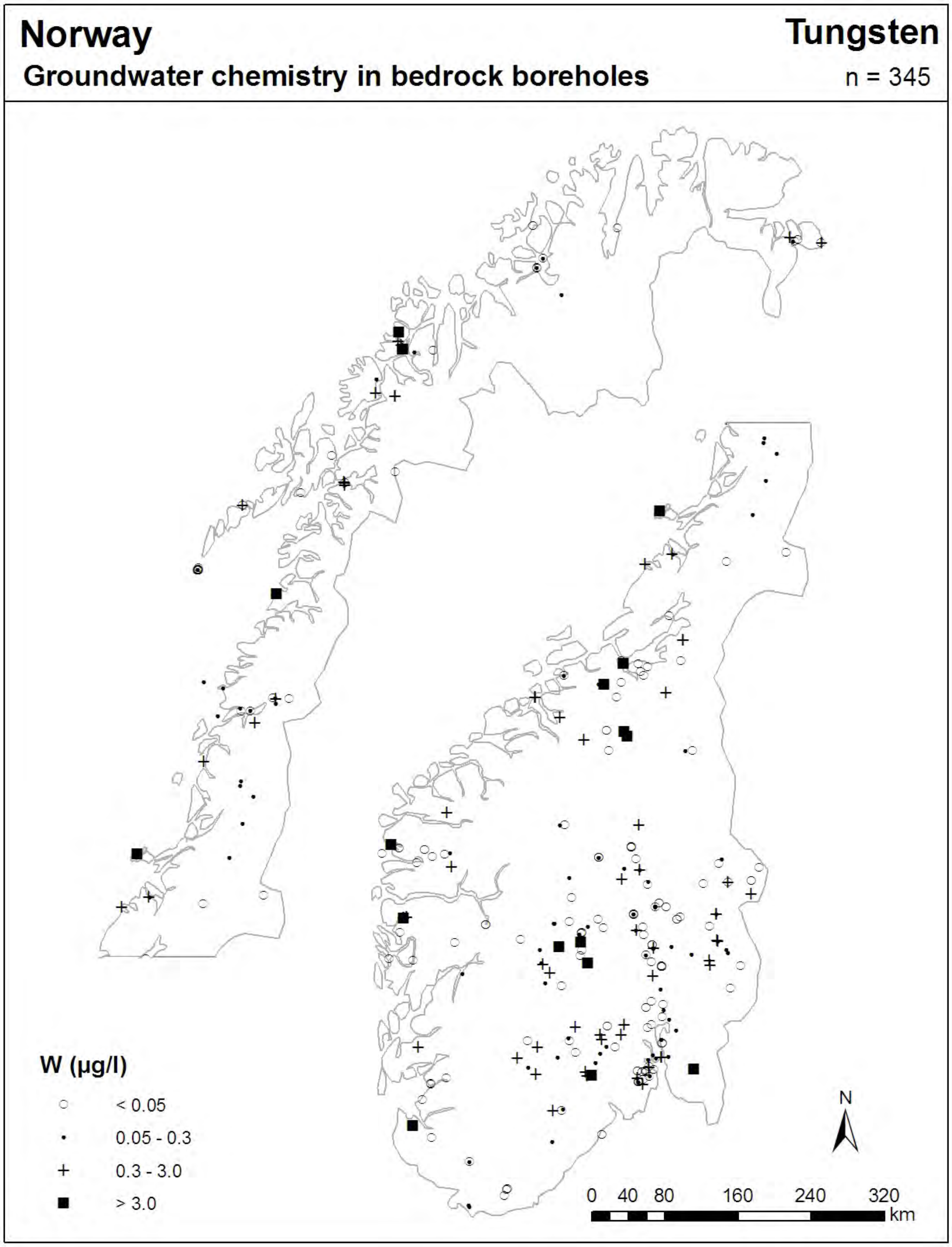

Figure 90: Map of Norway showing tungsten concentrations in groundwater samples from bedrock boreholes.

6.53 Yttrium (Y)

Yttrium concentrations in the analyzed groundwater samples ranged from concentrations below detection limit (0.005 μg/L) to a maximum of 50.3 μg/L. The median value of the whole dataset was found to be 0.22 μg/L. The median concentrations of samples from the different aquifer types were very similar. The highest measured concentrations in groundwater samples from bedrock boreholes and unconsolidated sediments were 50.3 μg/L and 30.6 μg/L, respectively.

No geographical pattern could be observed for yttrium concentrations in bedrock groundwaters (Figure 91). All groundwater samples from unconsolidated sediments with concentrations above 6 μg/L were located in the very south of the country, namely in the counties of Vest-Agder and Rogaland (Figure 92). Yttrium behaves more or less in the same way in the environment as the rare earth elements (REE). The elevated yttrium concentrations (as well as REE) might have been derived from the pegmatite dykes around Iveland, known for their rich variety of minerals, and have been distributed in southernmost Norway by glaciers and glaciofluvial processes.

There are no drinking water limits set for yttrium.

6.54 Zinc (Zn)

Zinc concentrations in the analyzed groundwater samples ranged from concentrations below detection limit (0.1 μg/L) to a maximum of 16600 μg/L. The median zinc concentration of the whole dataset was found to be 5.60 μg/L. This median concentration was similar to the median concentrations in groundwaters from bedrock boreholes and unconsolidated sediments (n=314). The highest measured concentrations in groundwater samples from bedrock boreholes and unconsolidated sediments were 960 μg/L and 16600 μg/L, respectively.

No geographical pattern could be observed (Figure 93 and Figure 94). Local variations of zinc concentrations were very high.

The former Norwegian guideline value of 100 μg/L is exceeded by a total of 41 (6 %) samples. The former MAC of 300 μg/L is exceeded by 10 samples.

6.55 Zirconium (Zr)

518 of 691 (75 %) groundwater samples showed zirconium concentrations below the detection limit of 0.05 μg/L. 63 % of bedrock groundwaters and 89 % of groundwater samples from unconsolidated sediments had zirconium concentrations below detection limit. Samples from unconsolidated sediment wells were not further interpreted. The maximum concentration found was 2.52 μg/L and comes from a bedrock groundwater sample. No geographical pattern could be observed (Figure 95 and Figure 96).

There are no drinking water limits set for zirconium.

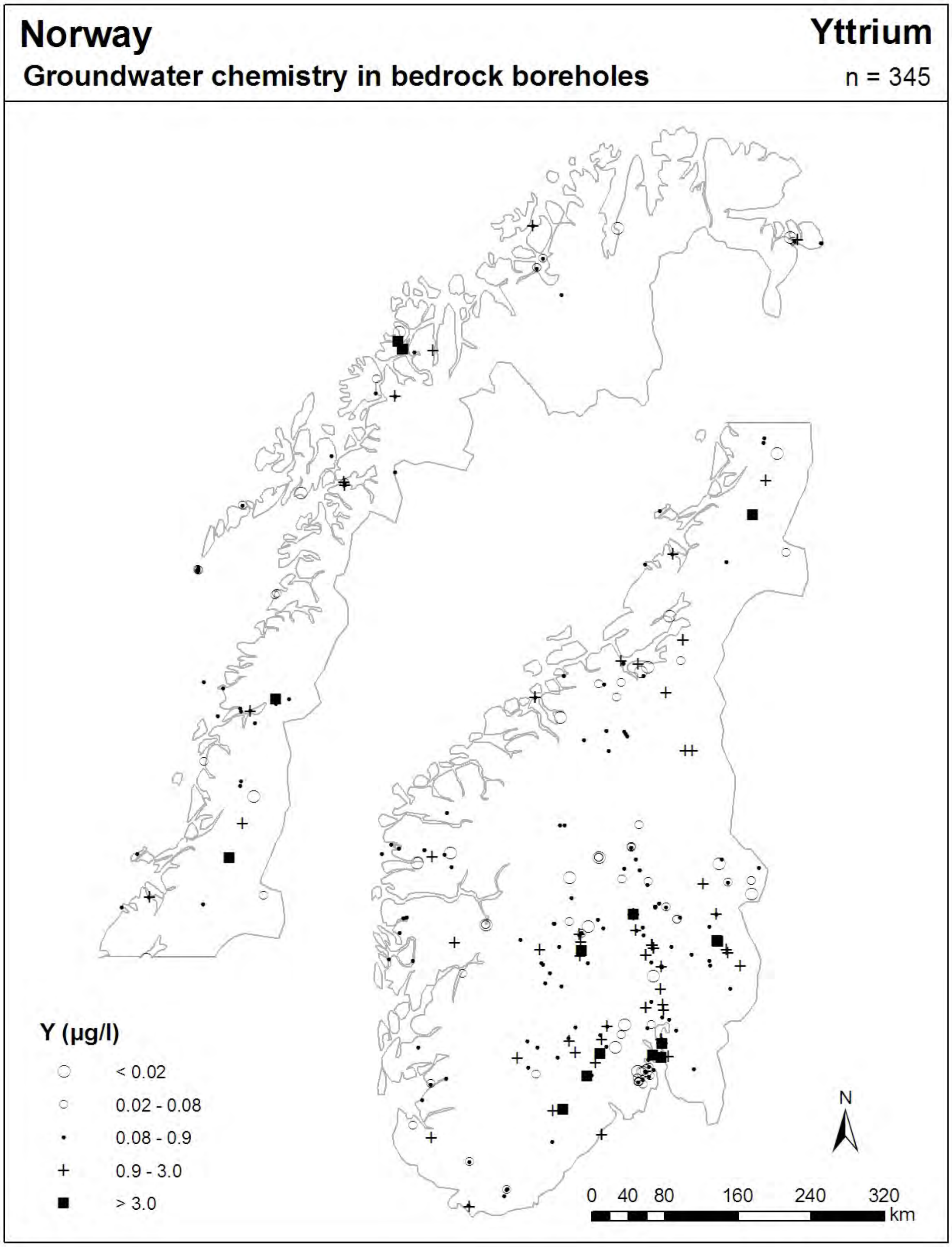

Figure 91: Map of Norway showing yttrium concentrations in groundwater samples from bedrock boreholes.

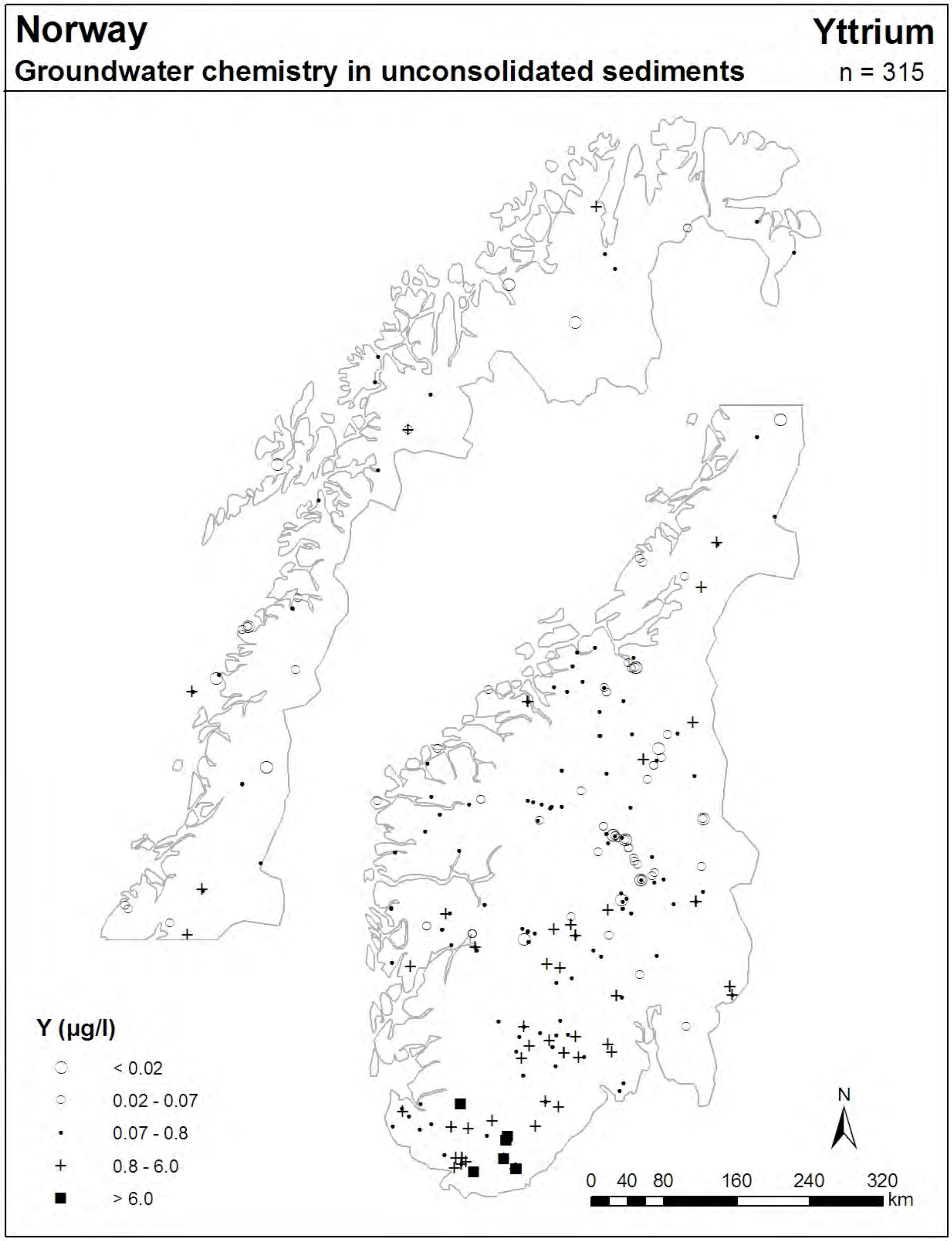

Figure 92: Map of Norway showing yttrium concentrations in groundwater samples from unconsolidated sediments.

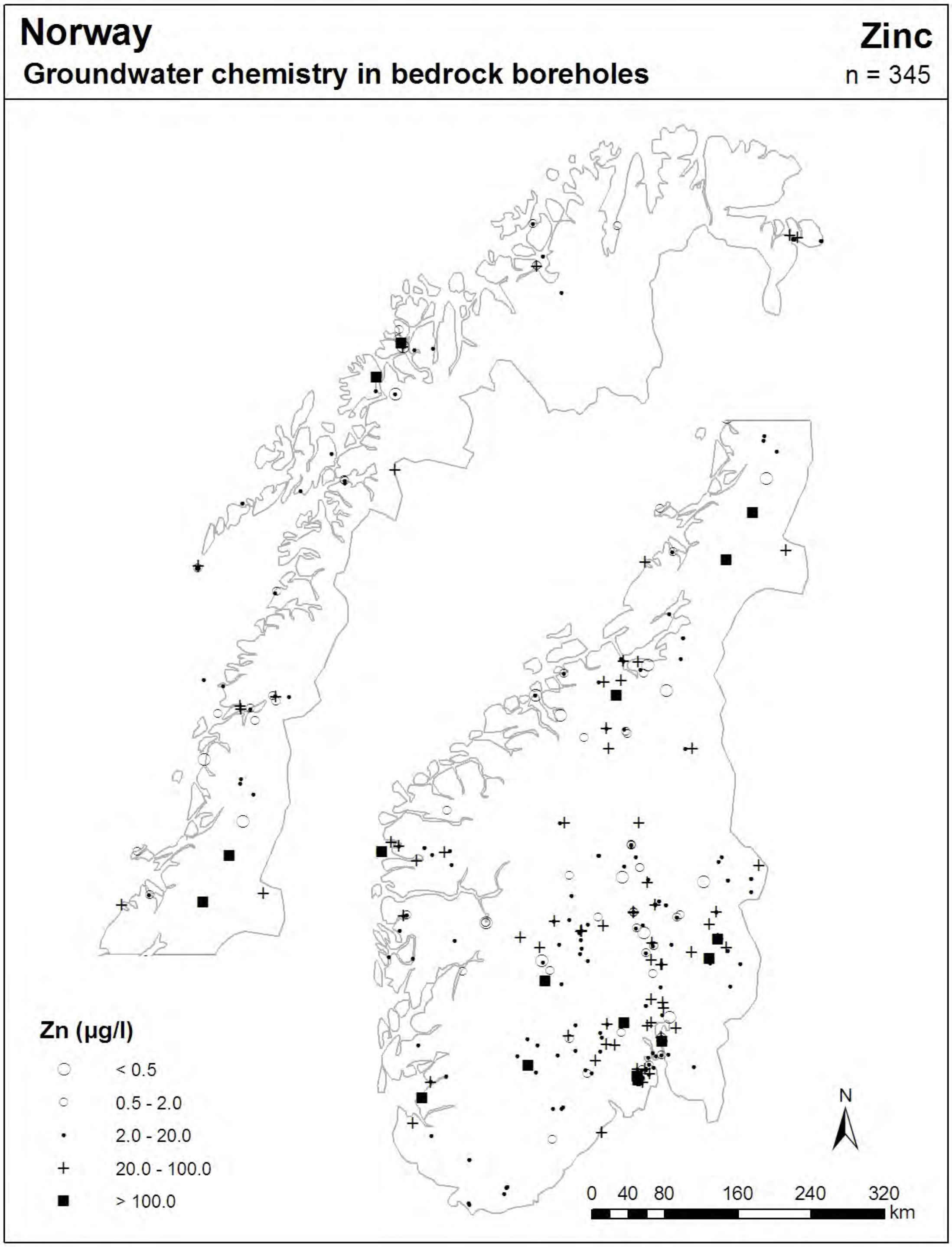

Figure 93: Map of Norway showing zinc concentrations in groundwater samples from bedrock boreholes.

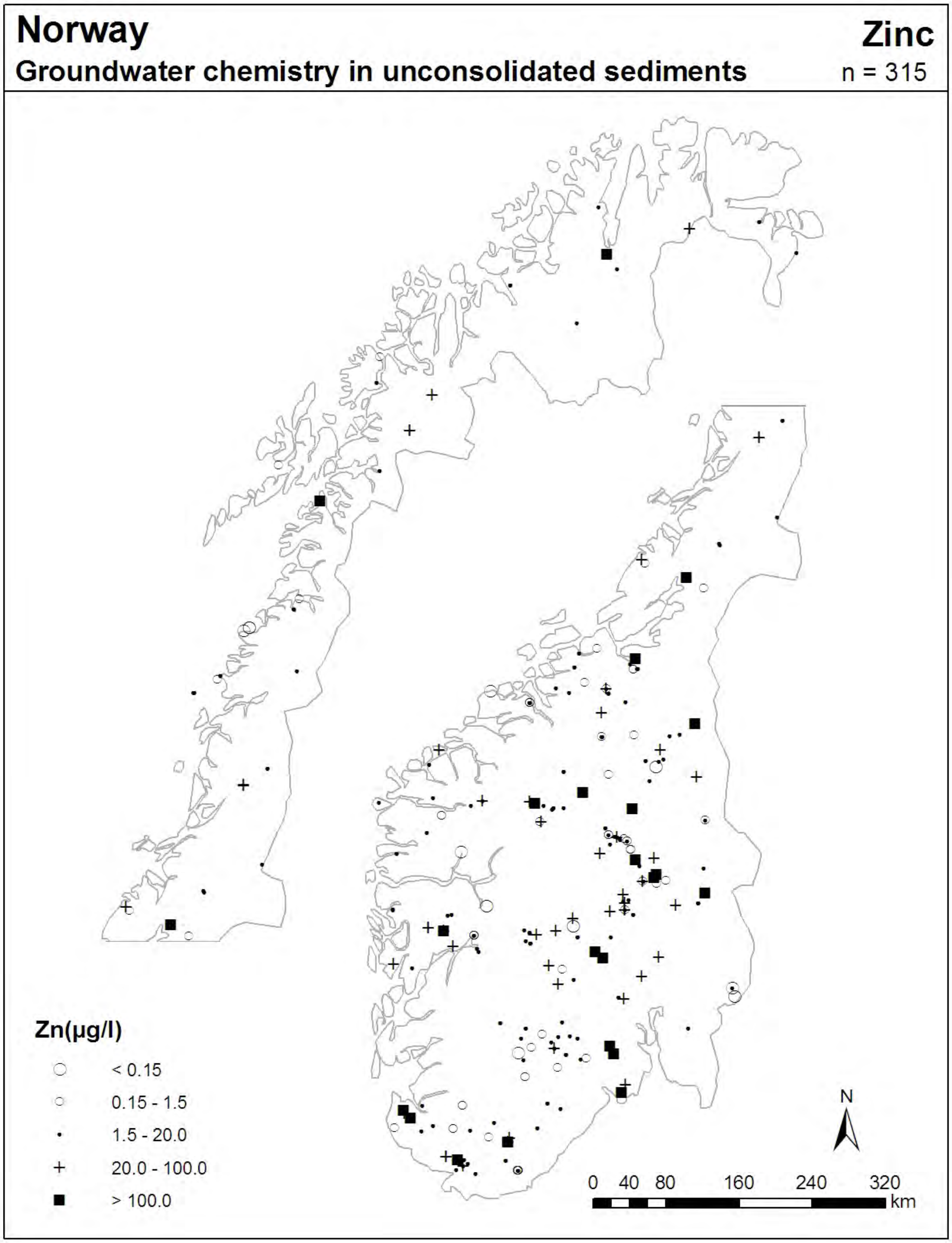

Figure 94: Map of Norway showing zinc concentrations in groundwater samples from unconsolidated sediments.

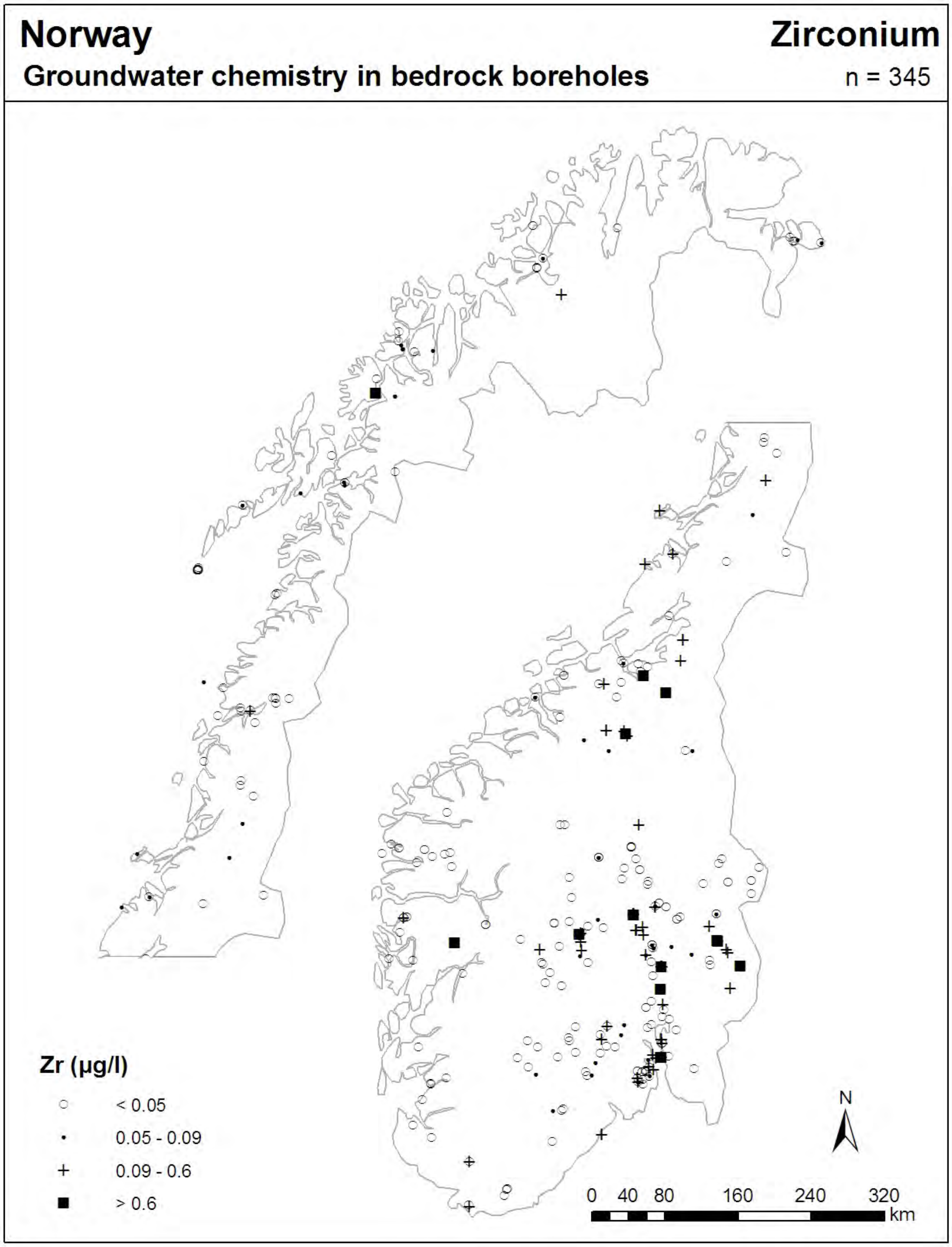

Figure 95: Map of Norway showing zirconium concentrations in groundwater samples from bedrock boreholes.

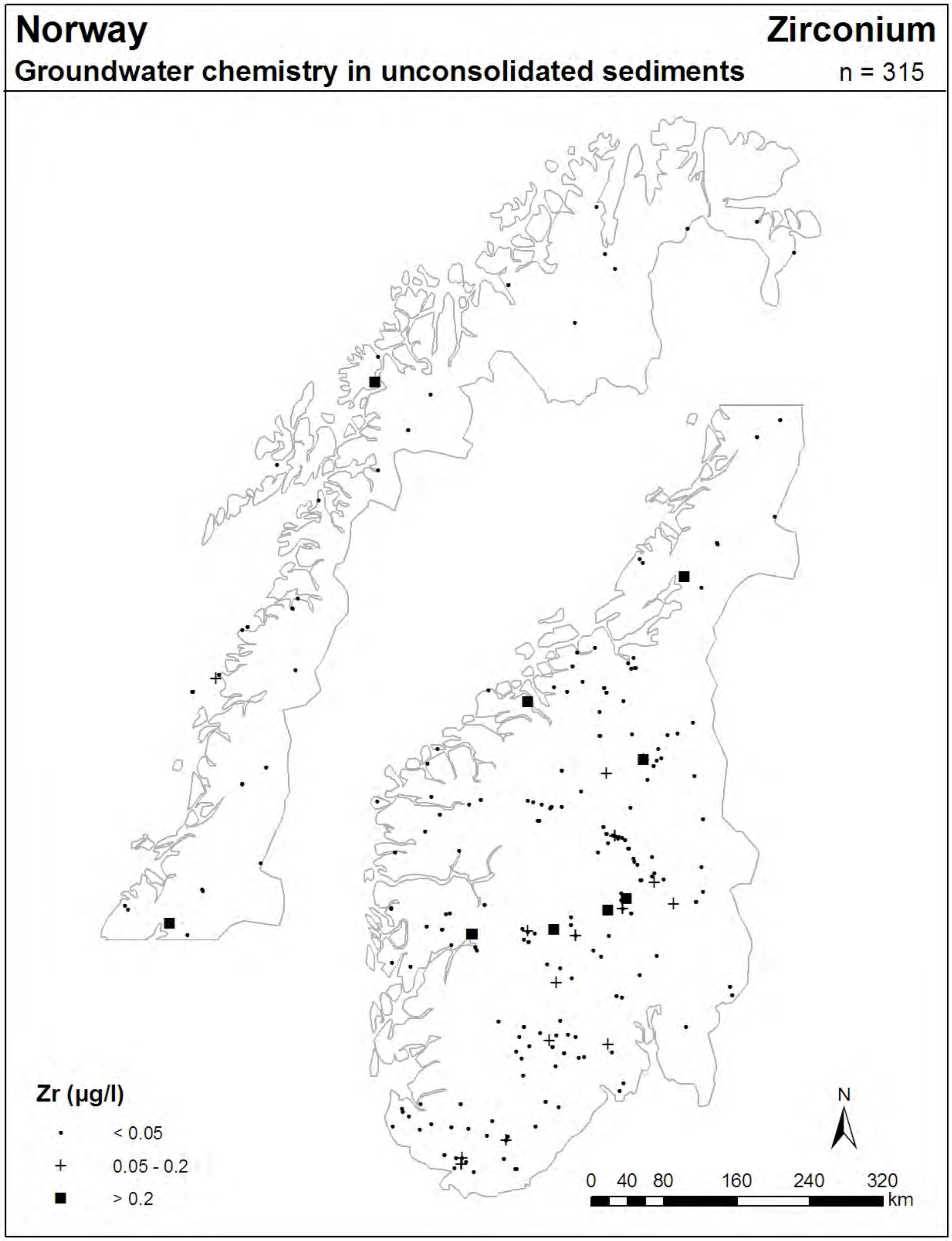

Figure 96: Map of Norway showing zirconium concentrations in groundwater samples from unconsolidated sediments.

6.56 Rare earth elements (REE)

6.56.1 Cerium (Ce)

Cerium concentrations in the analyzed groundwater samples showed a range from below detection limit (0.01 µg/L) to a maximum of 57.2 µg/L. The median concentration of the whole dataset was 0.14 µg/L. Samples from bedrock groundwaters and groundwater samples from unconsolidated sediments showed very similar concentrations. Both median concentrations were very close to the overall median concentration. The maxima were 14 µg/L (from bedrock borehole) and 57.2 µg/L (from unconsolidated sediment well).

Bedrock groundwaters do not show a specific distribution of cerium concentrations (Figure 97). All but one sample from unconsolidated sediments that have cerium concentrations above 8 µg/L, were from the county of Vest-Agder (Figure 98). Rare earth elements behave more or less in the same way in the environment. The elevated concentrations of cerium (and forthcoming REE) might have been derived from the pegmatite dykes around Iveland, known for their rich variety of minerals, and have been distributed in southernmost Norway by glaciers and glaciofluvial processes

There are no drinking water limits set for cerium.

6.56.2 Holmium (Ho)

Holmium concentrations in the analyzed groundwater samples showed a range from below detection limit (0.001 µg/L) to a maximum of 1.28 µg/L. The median concentration of the whole dataset was found to be 0.006 µg/L, which corresponds to the median values of both aquifer types. Yet, this value might be too close to the detection limit to make reliable statements.

Bedrock groundwaters seem to have the biggest portion of samples with slightly higher holmium concentrations in the southern part of Østlandet (Figure 99). For groundwater samples from unconsolidated sediments, the geographical distribution is basically like the one of cerium: All but one sample with holmium concentrations above 0.1 µg/L came from the county of Vest-Agder (Figure 100).

There are no drinking water limits set for holmium.

6.56.3 Lanthanum (La)

Lanthanum in the analyzed groundwater samples showed a concentration range from below detection limit (0.01 µg/L) to a highest measured concentration of 69.1 µg/L (from unconsolidated sediment well). The median concentration of the whole dataset was 0.24 µg/L. The median concentration of bedrock groundwaters was slightly below this value. The median concentration of groundwater samples from unconsolidated sediments was about 0.5 µg/L. In general, bedrock groundwaters provided lower lanthanum concentrations than groundwaters from unconsolidated sediments.

For lanthanum concentrations in bedrock groundwaters no specific distribution could be identified (Figure 101). All groundwater samples from unconsolidated sediments with lanthanum concentrations above 10 µg/L were from Vest-Adger County (Figure 102). The distribution is very similar to that of cerium and holmium.

There are no drinking water limits set.

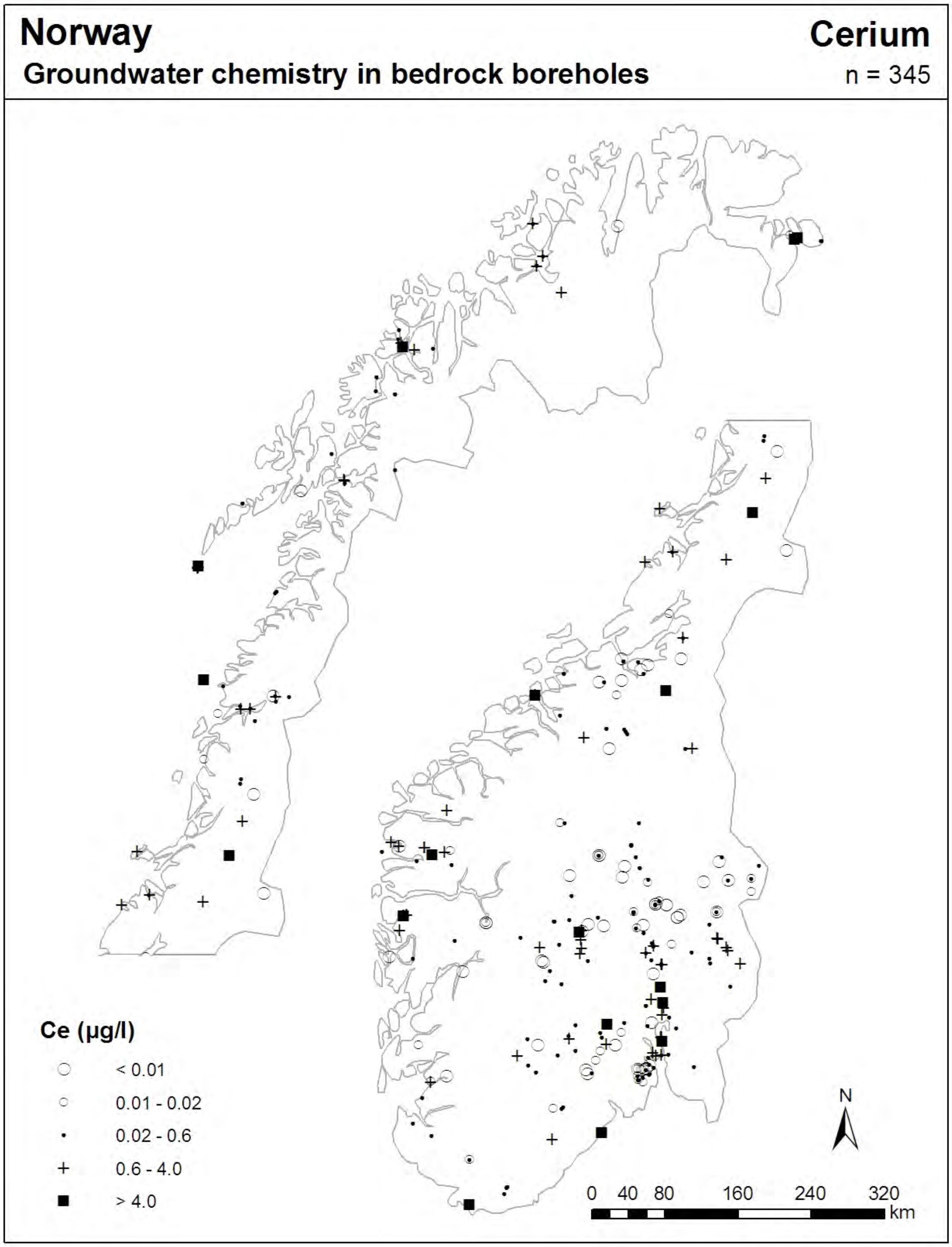

Figure 97: Map of Norway showing cerium concentrations in groundwater samples from bedrock boreholes.

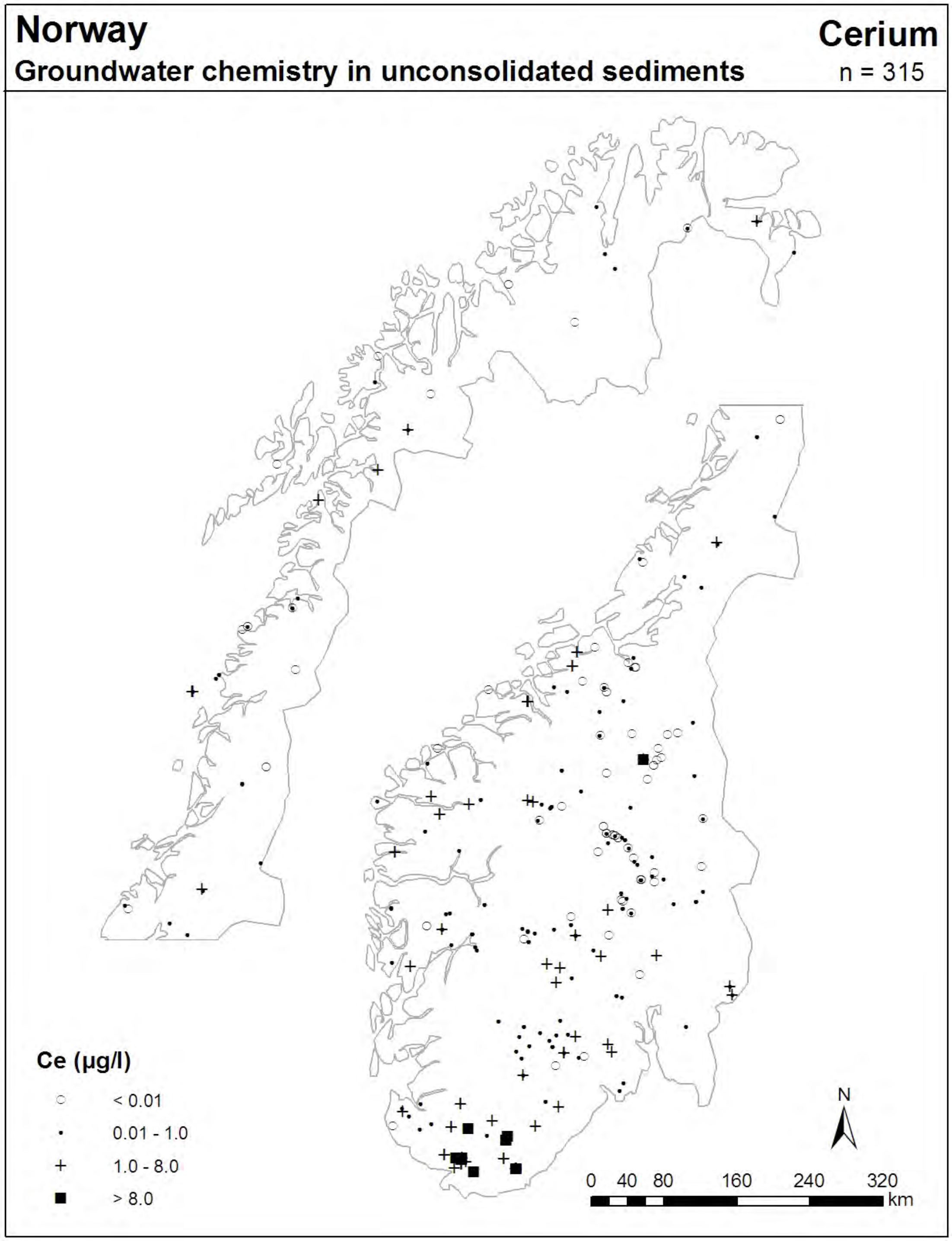

Figure 98: Map of Norway showing cerium concentrations in groundwater samples from unconsolidated sediments.

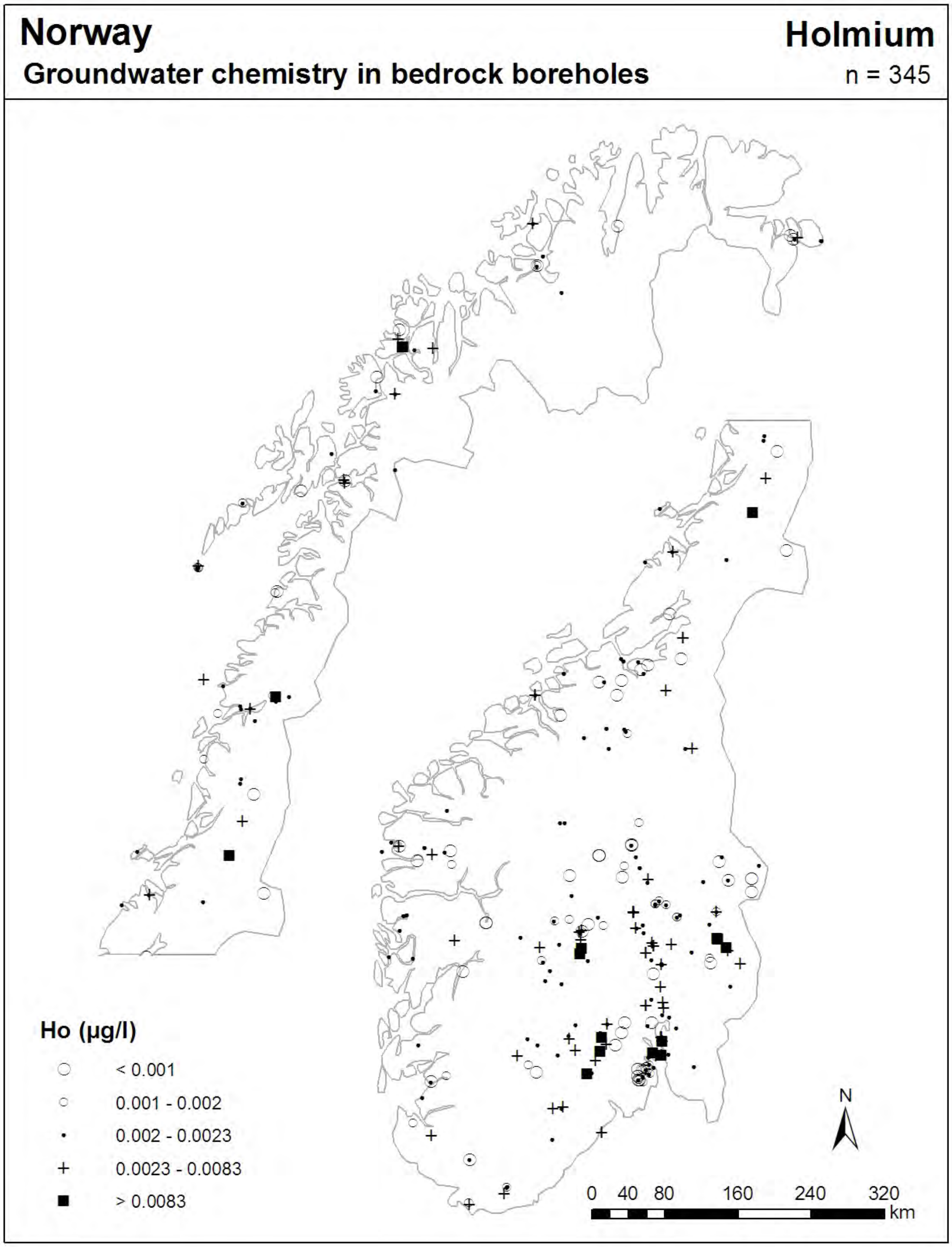

Figure 99: Map of Norway showing holmium concentrations in groundwater samples from bedrock boreholes.

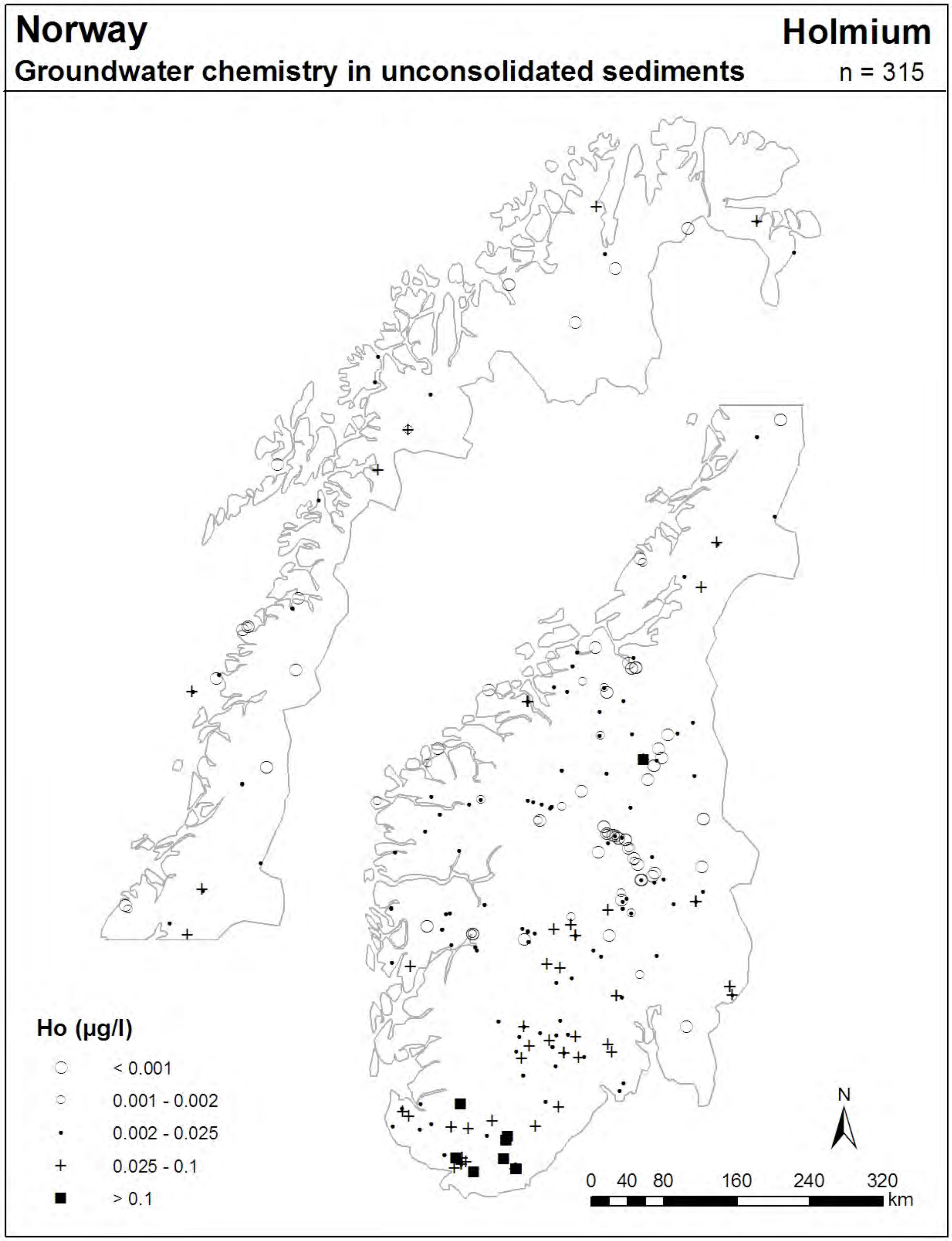

Figure 100: Map of Norway showing holmium concentrations in groundwater samples from unconsolidated sediments.

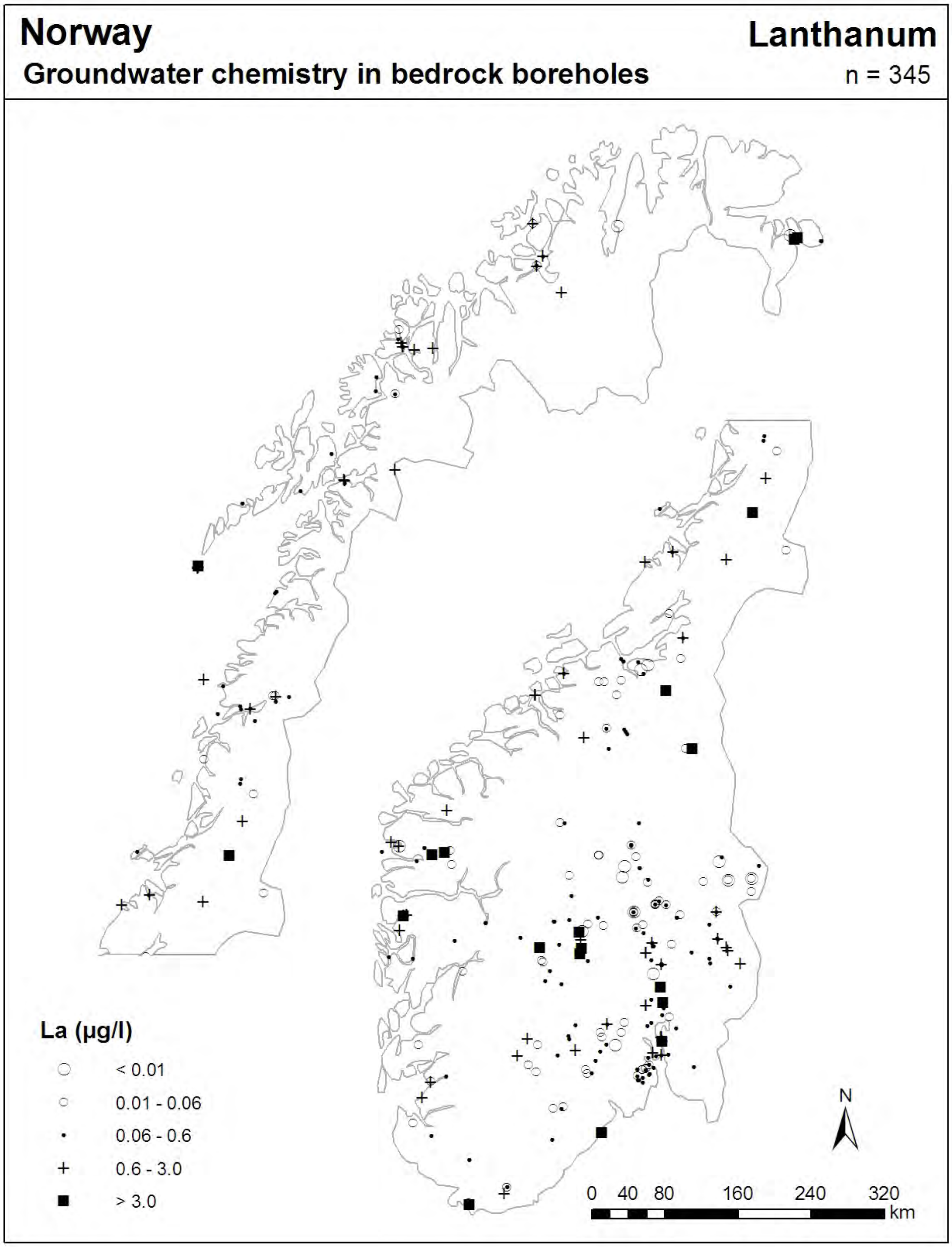

Figure 101: Map of Norway showing lanthanum concentrations in groundwater samples from bedrock boreholes.

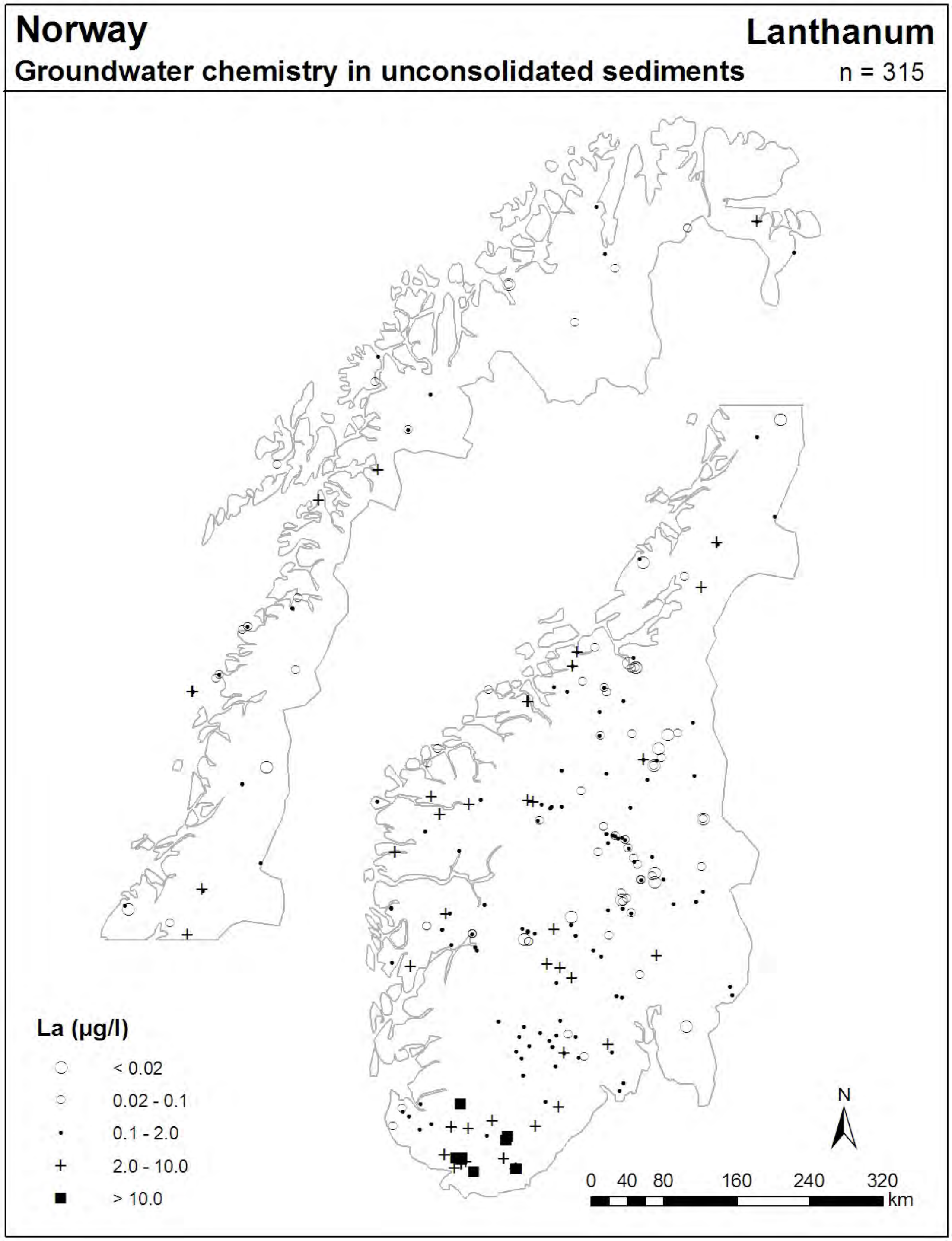

Figure 102: Map of Norway showing lanthanum concentrations in groundwater samples from unconsolidated sediments.

6.56.4 Neodymium (Nd)

Neodymium concentrations in the analyzed groundwater samples had a concentration range from below detection limit (0.01 µg/L) to a maximum of 45.5 µg/L (from unconsolidated sediment well). The median concentration of the whole dataset was found to be 0.2 µg/L – which is very close to the median concentrations of the two different groundwater types. Generally, water from unconsolidated sediment groundwaters showed higher neodymium concentrations than samples from bedrock groundwaters. In the latter the highest measured concentration was 8.27 µg/L.

No specific geographical distribution could be identified for bedrock groundwaters (Figure 103). The map for groundwater samples from unconsolidated sediments looks very similar to the corresponding map for lanthanum. All samples with neodymium concentrations above 7.0 µg/L came from Vest-Agder County (Figure 104).

There are no drinking water limits set for neodymium.

6.56.5 Samarium (Sm)

Samarium concentrations in the analyzed groundwater samples ranged from below detection limit (0.002 µg/L) to a maximum value of 6.58 µg/L (from unconsolidated sediment). The median concentration of the whole dataset was found to be 0.04 µg/L. The median concentrations in groundwaters from the two different aquifer types did not vary much from this median. Generally, groundwaters from unconsolidated sediment wells had slightly higher samarium concentrations than bedrock groundwaters. In the latter the maximum concentration was found to be 1.62 µg/L.

No specific geographical distribution could be identified for bedrock groundwaters (Figure 105).The map for groundwater samples from unconsolidated sediments looks very similar to the corresponding map for holmium and cerium. All but two samples with samarium concentrations above 1.0 µg/L were from Vest-Agder County (Figure 106).

There are no drinking water limits set for samarium.

6.56.6 Ytterbium (Yb)

Ytterbium concentrations in the analyzed groundwater samples ranged from below detection limit (0.002 µg/L) to a maximum of 1.88 µg/L (from bedrock borehole). The median ytterbium concentration of the whole dataset was found to be 0.015 µg/L. Bedrock groundwaters and groundwaters from unconsolidated sediments showed very similar concentrations.

The biggest portion of bedrock groundwaters that showed slightly elevated ytterbium concentrations was in the southern part of Østlandet (Figure 107). The map resembles the corresponding one of holmium. The map for groundwater samples from unconsolidated sediments looks very similar to the corresponding maps for holmium, cerium and samarium (Figure 108).

There are no drinking water limits set for ytterbium.

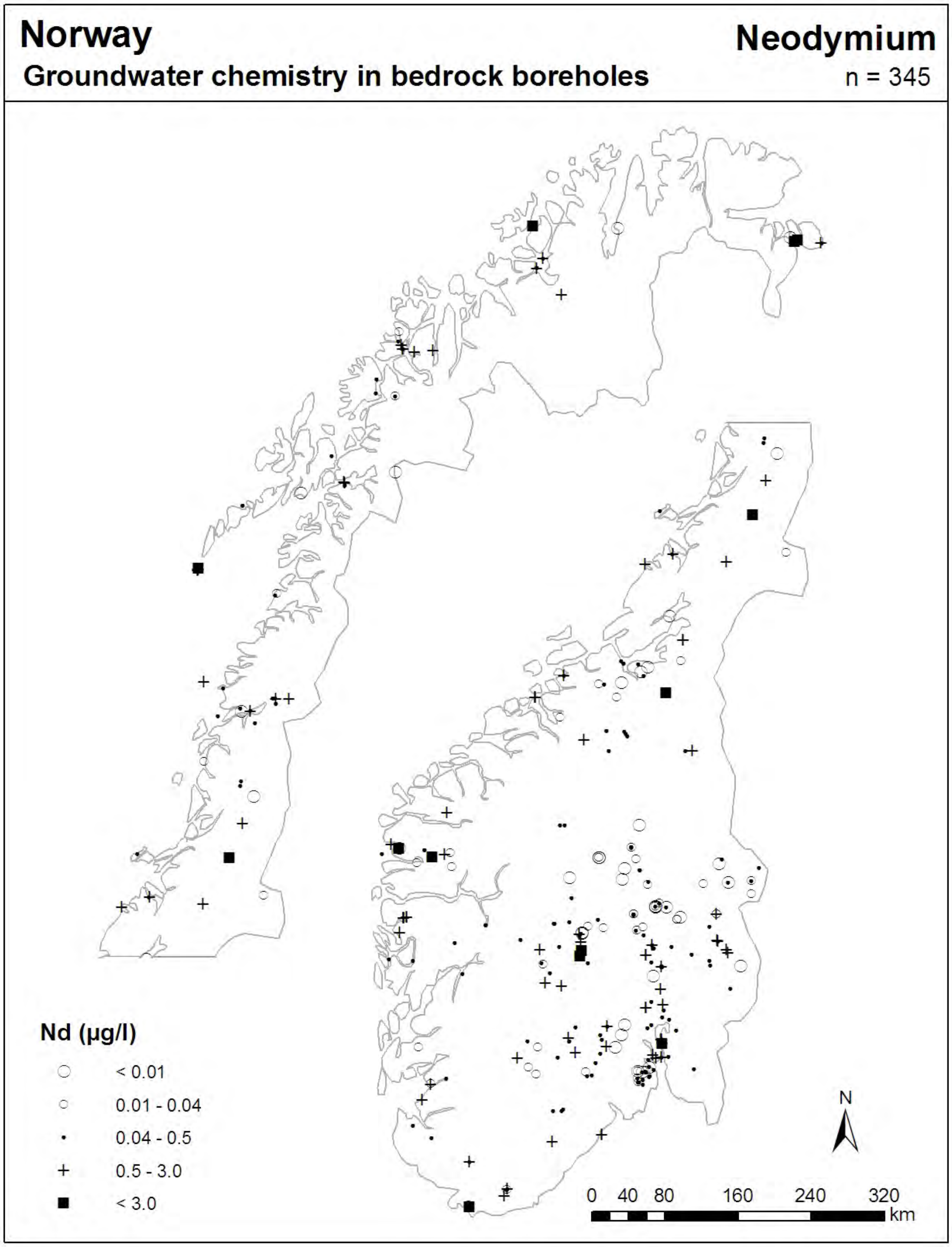

Figure 103: Map of Norway showing neodymium concentrations in groundwater samples from bedrock boreholes.

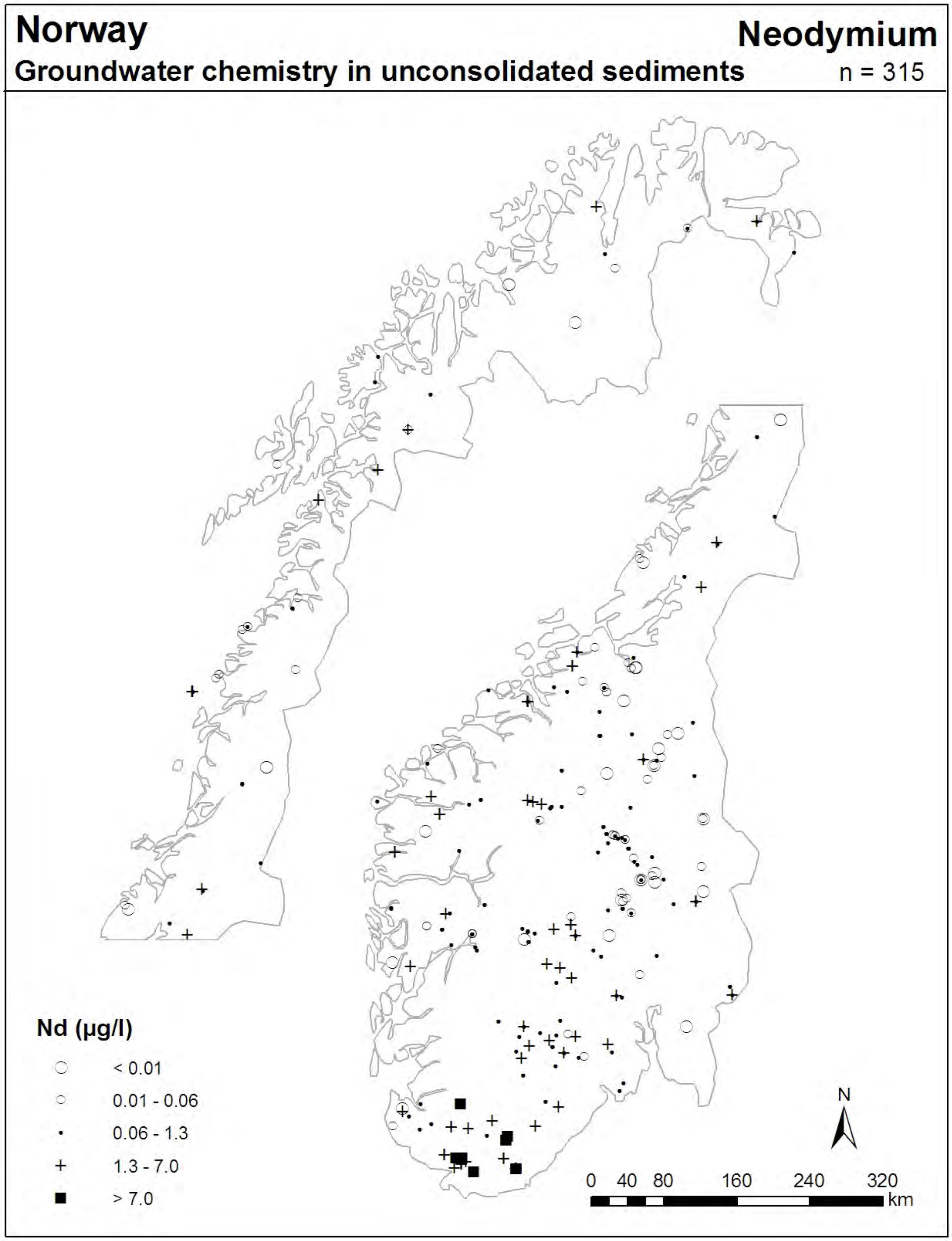

Figure 104: Map of Norway showing neodymium concentrations in groundwater samples from unconsolidated sediments.

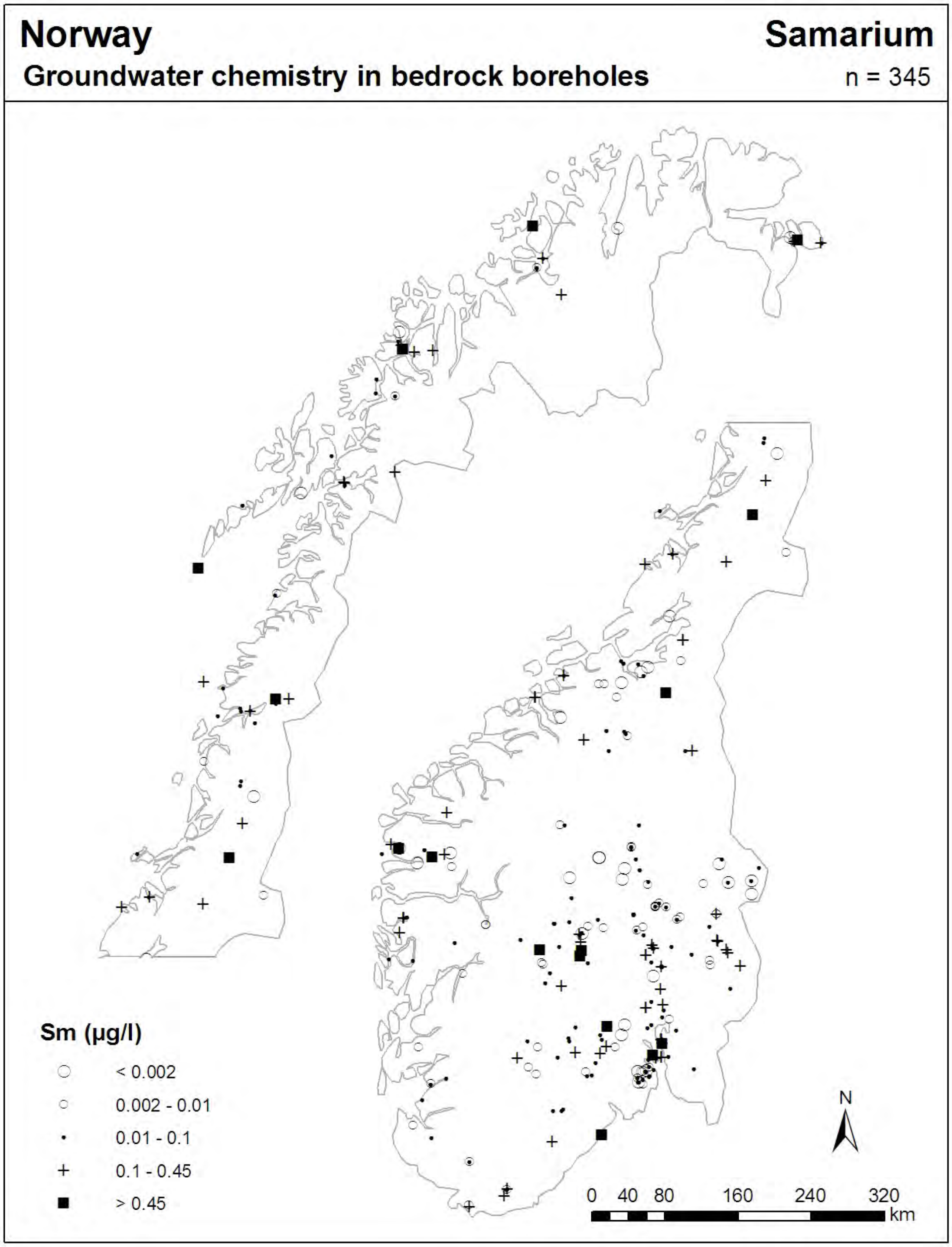

Figure 105: Map of Norway showing samarium concentrations in groundwater samples from bedrock boreholes.

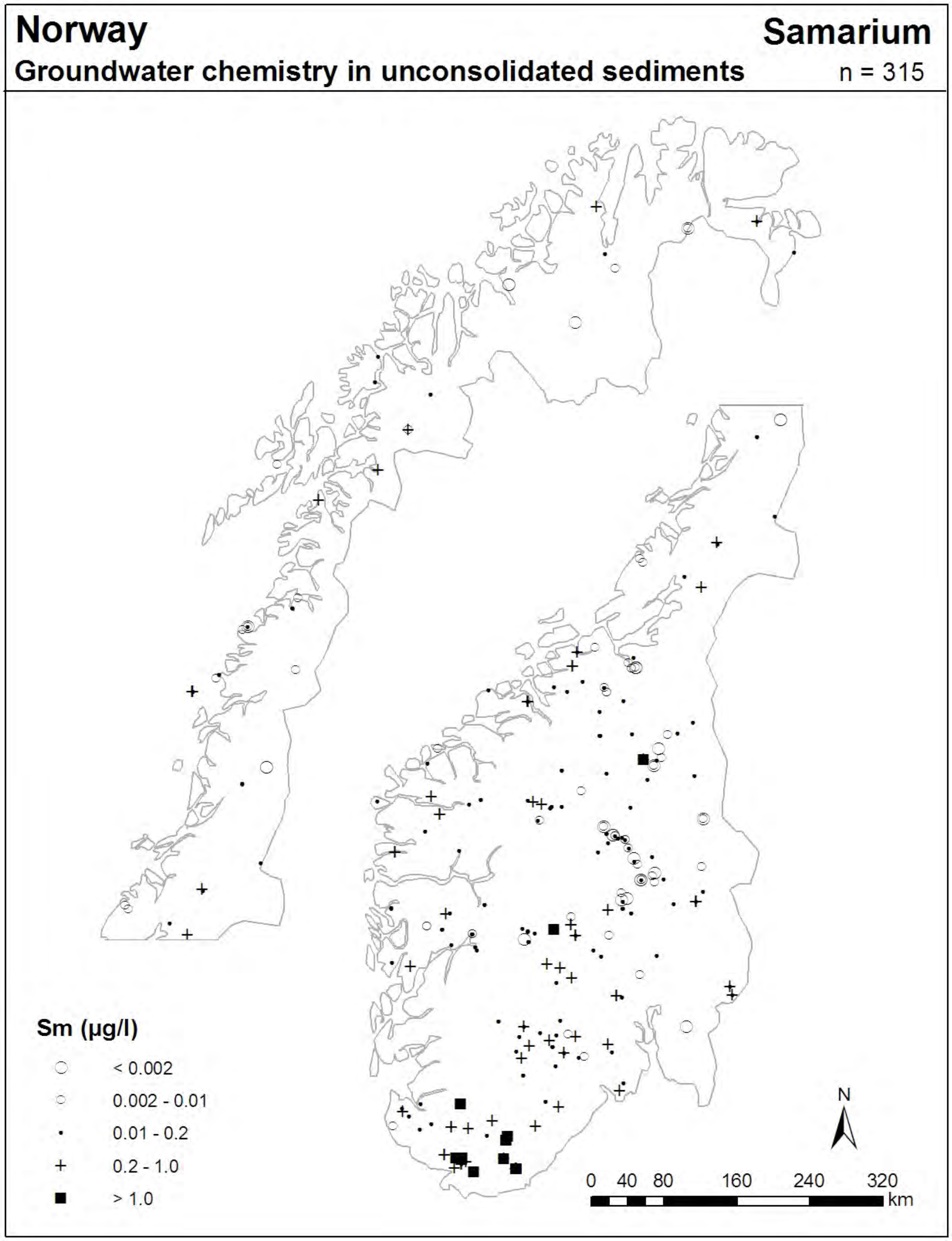

Figure 106: Map of Norway showing samarium concentrations in groundwater samples from unconsolidated sediments.

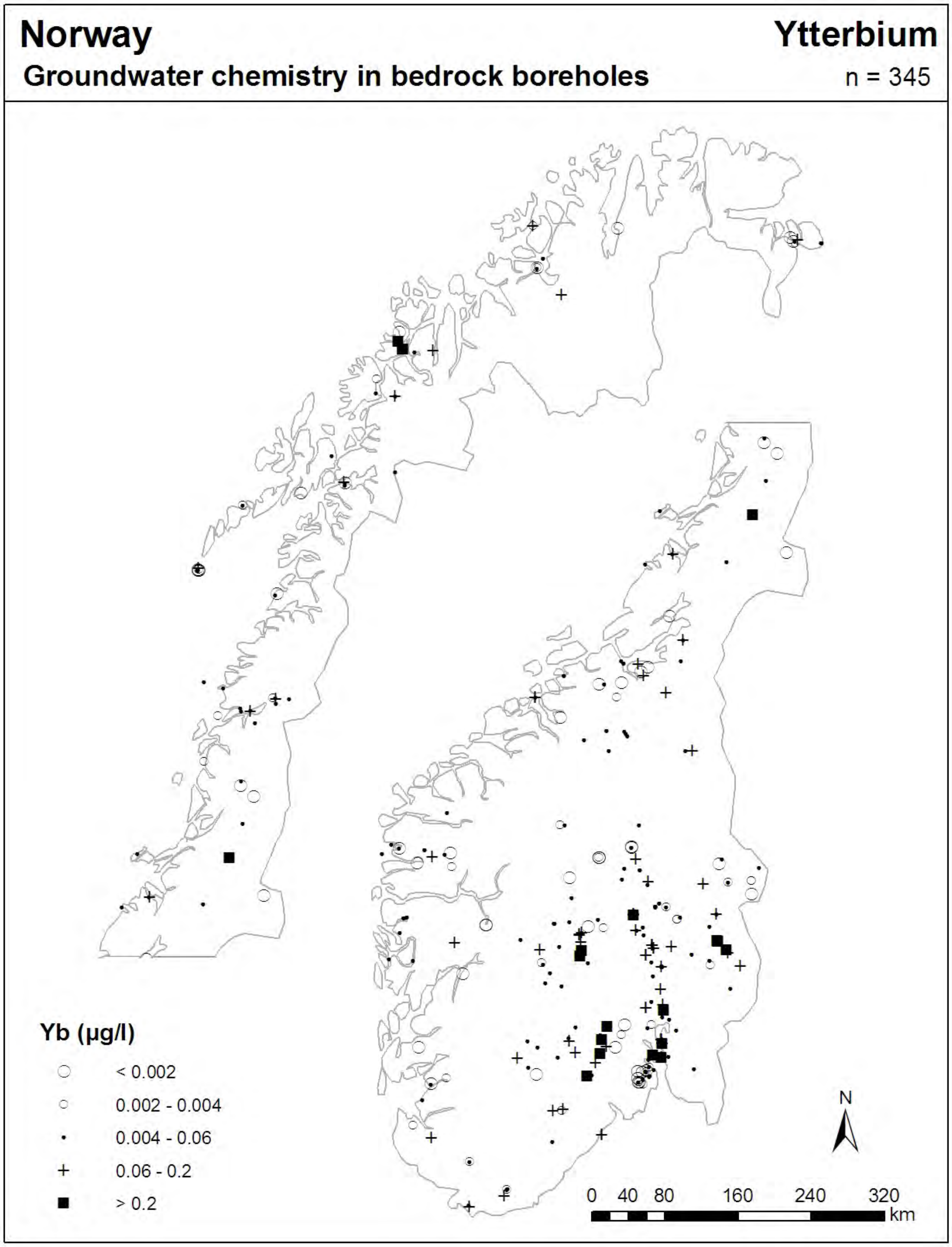

Figure 107: Map of Norway showing ytterbium concentrations in groundwater samples from bedrock boreholes.

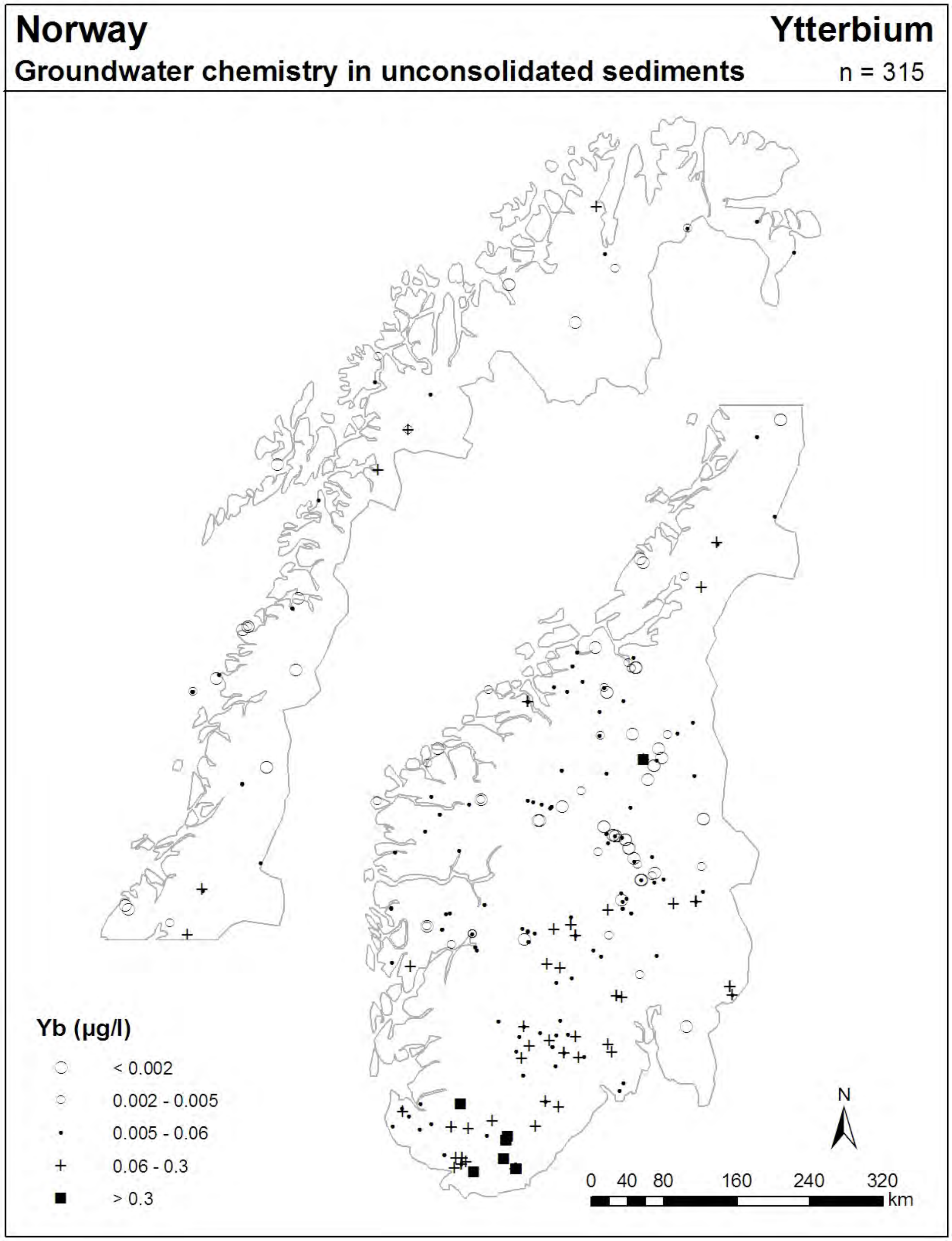

Figure 108: Map of Norway showing ytterbium concentrations in groundwater samples from unconsolidated sediments.

7 Discussion

7.1 Water-types

As each groundwater has a more-or-less unique hydrochemical composition, it is possible to plot the waters on a Piper diagram (Figure 109 and Figure 110). The Piper diagram plots the major cations and anions as percentages in meq/L in two separate triangles. The total cations and the total anions are set equal to 100 %. The major cations (Ca^{2+}, Mg^{2+}, Na^{+} + K^{+}) are plotted on the left triangle, while the major anions (SO_4^{2-}, Cl^{-}, and alkalinity or HCO_3^{-}) are plotted on the right triangle.

Then, the data points in the two triangles are projected onto a central diamond shaped grid. The main purpose of the Piper diagram is to show clustering of data points to indicate samples that have similar compositions.

Major ion chemistry of the 346 groundwater samples from bedrock boreholes is presented as a Piper plot in Figure 109. This figure indicates that most of the waters fall into the calcium-bicarbonate corner of the diagram. 266 out of 346 (77 %) groundwater samples are Ca-HCO_3 waters. Banks et al. (1998) presume, that this water type evolves due to weathering of (a) calcium carbonate-containing rocks, (b) calcite fracture mineralisation, or (c) calcic silicate rocks where calcite precipitation or ion exchange are insufficient to significantly deplete calcium.

In the following classification of water types only the dominant cation and the dominant anion are used, e.g. a Ca-Na—Mg-HCO_3-Cl type water will be classified as Ca-HCO_3 type water. Figure 109 and Figure 110 display the infinite possibilities of combinations between the six major ions.

52 of 346 (15 %) groundwater samples are Na-HCO_3 waters, which are probably more mature waters. 21 out of 346 (6 %) groundwater samples are Na-Cl waters, which are either coastal groundwaters or very immature waters that are still dominated by the sea salt content of precipitation (Banks et al. 1998). 7 groundwater samples were of other water types (Ca-SO_4, Mg-HCO_3, Na-SO_4). No Ca-Cl, Mg-Cl or Mg-SO_4 waters occurred. None of the samples was dominated by potassium.

Major ion chemistry of the 314 groundwater samples from unconsolidated sediments is presented as Piper plot in Figure 110. Also here, the dominating water type is the Ca-HCO_3 type. 217 of 314 (69 %) groundwater samples from sedimentary aquifers are of this type. 31 samples (10 %) are waters of Na-Cl composition, 28 samples (9 %) are Na-HCO_3 waters, 26 samples (8 %) are Ca-Cl waters and 13 samples (4 %) are Ca-SO_4 waters. When groundwaters are dominated by calcium and chloride, it might be due to contamination with $CaCl_2$ caused by the use of road salt. Ca-Cl waters may also be a result of ion exchange during infiltration of seawater (Na-Cl) in Ca-HCO_3 dominated groundwaters (Appelo & Postma, 1994). No Na-SO_4 waters occurred and none of the samples was dominated by potassium or magnesium.

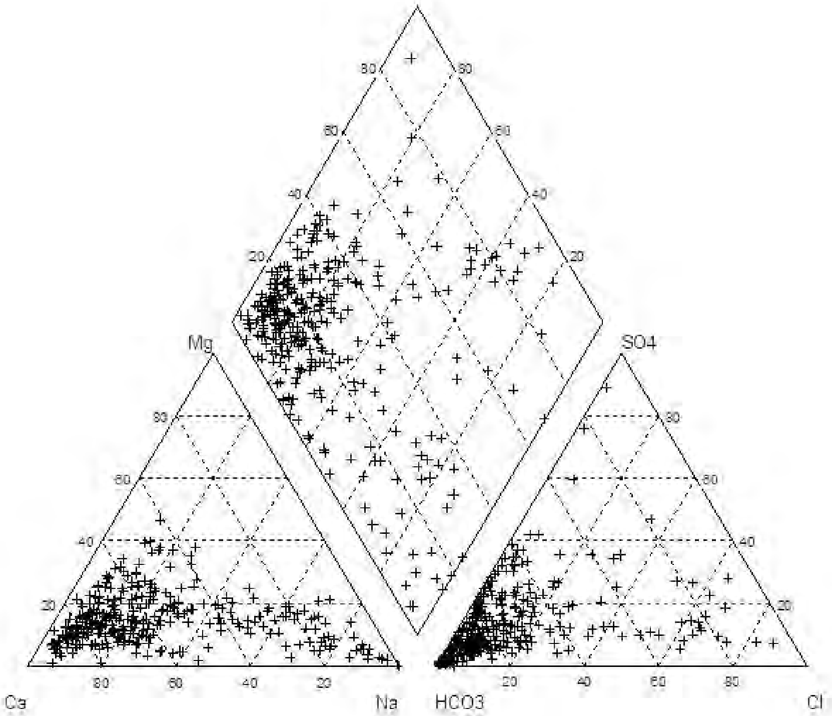

Figure 109: Piper Diagram for the groundwater samples from bedrock boreholes (n=346), which illustrates the water types based on major ion chemistry. The diagram is based on % meq/L of the major cations and anions.

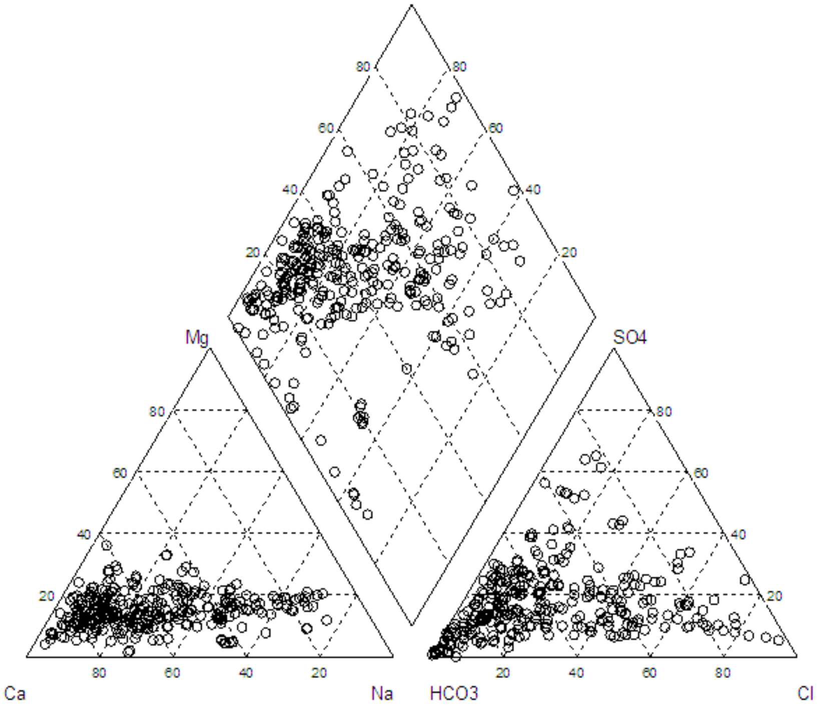

Figure 110: Piper Diagram for the groundwater samples from unconsolidated sediments (n=314), which illustrates the water types based on major ion chemistry. The diagram is based on % meq/L of the major cations and anions.

7.2 Evaluation of drinking water quality

In Table 2 the analyzed groundwater samples are compared with current or previous Norwegian drinking water standards or WHO recommendations.

Table 2: Comparison of groundwater samples with current or previous Norwegian drinking water standards or WHO recommendations.

	Unit	Norm	Samples outside norm (n=691)	Whole dataset (n=691) in %	Bedrock b. (n=346) in %	Uncons. seds. (n=314) in %	Unknown aquifer (n=31) in %
Ag	µg/L Ag	10 [c]	(0)	(0)	(0)	(0)	(0)
Al	µg/L Al	200 [a]	42	6	6.4	5.4	9.7
As	µg/L As	10 [a]	3	0.4	0.9	0	0
B	mg/L B	1 [a]	0	0	0	0	0
Ba	µg/L Ba	100 [b]	(43)	(6.2)	(8.7)	(4.1)	(0)
Ca	mg/L Ca	15-25 [b]	(247 >25mg/L)	(35.7)	(53.5)	(14.6)	(51.6)
			(332 <15mg/L)	(48)	(27.7)	(72.3)	(29)
Cd	µg/L Cd	5 [a]	0	0	0	0	0
Cl-	mg/L Cl	200 [a]	2	0.3	0.3	0	3.2
Cr	µg/L Cr	50 [a]	0	0	0	0	0
Cu	µg/L Cu	100 [a]	53	7.7	6.9	8.9	3.2
F-	mg/L F	1.5 [a]	54	7.7	14.7	0	9.7
Fe	µg/L Fe	200 [a]	115	16.6	21.4	10.8	22.6
K	mg/L K	12 [c]	(3)	(0.4)	(0.3)	(0.3)	(3.2)
Mg	mg/L Mg	20 [c]	(3)	(0.7)	(0.6)	(0.6)	(3.2)
Mn	µg/L Mn	50 [a]	139	20.1	28.3	10.2	29
Mo	µg/L Mo	70 [e]	(2)	(0.3)	(0.6)	(0)	(0)
Na	mg/L Na	200 [a]	2	0.3	0.3	0	3.2
Ni	µg/L Ni	20 [a]	20	2.9	3.5	2.2	3.2
NO_3	mg/L NO_3	44 [a]	0	0	0	0	0
Pb	µg/L Pb	10 [a]	14	2	1.4	2.9	0
Sb	µg/L Sb	5 [a]	0	0	0	0	0
Se	µg/L Se	10 [c]	(1)	(0.1)	(0.3)	(0)	(0)
SO_4^{2-}	mg/L SO_4^{2-}	100 [a]	9	1.3	1.2	0.3	12.9
U	µg/L U	30 [d]	(27)	(3.9)	(7.2)	(0.3)	(3.2)
Zn	µg/L Zn	300 [c]	(10)	(1.4)	(1.4)	(1.6)	(0)
pH		6.5-9.5 [a]	0 >9.5	0	0	0	0
			31 <6.5	4.5	2.3	6.7	6.5
Colour	mg/L Pt-Co	20 [a]	20	2.9	4	1.3	6.5
Turbidity	FTU	0.4 [a]	135	19.5	23.7	11.5	54.8
Alkalinity	meq/L	0.6-1.0 [b]	(358 >1.0)	(51.8)	(79.8)	(20.1)	(61.3)
			(256 <0.6)	(37)	(13.9)	(63.7)	(25.8)
Conductivity	mS/m at 25°C	250 [a]	1	0.1	0	0	3.2

Bedrock b.: Bedrock boreholes; Uncons. Seds.: Unconsolidated sediments.

[a] Maximum admissible concentration (MAC) in Norway (Mattilsynet 2005).

[b] No MAC in Norway. Previous guideline value (Sosial- og helsedepartementet 1995).

[c] No MAC in Norway. Previous MAC (Sosial- og helsedepartementet 1995).

[d] Guideline value (WHO 2011); [e] Recommended limit (WHO 2008);

Where values are in brackets, there is no MAC in Norway, and the result represents the percentage of samples above another MAC or guideline value.

In total there are 335 out of 691 samples (48.5%) that meet the Norwegian standards. Correspondingly, there are 356 out of 691 (51.5%) samples where at least one chemical or physical parameter or element concentration exceeds the Norwegian standards. Most of the samples exceeding the norm lie only slightly above the line. Yet, there are also some extreme concentrations that could have health implications.

Furthermore, several locations show elevated values for several elements or parameters. Table 3 shows the number of exceeded Norwegian standards in individual samples from different aquifer types.

About 40% of all groundwater samples from bedrock boreholes and about 60% of all groundwater samples from unconsolidated sediments do not exceed any limits. Generally, the element concentrations in groundwaters from bedrock boreholes are higher than the concentrations in sedimentary aquifers. The same applies to alkalinity, pH and conductivity.

The drinking water regulations which are most frequently violated are manganese (20.1%), turbidity (19.5%), iron (16.6%), and copper (7.7%). The limits for these parameters are basically set for aesthetical reasons. 7.7% of the wells yield water with a fluoride content which may affect children's teeth under formation. Other elements of health concern are lead (2.0%) and arsenic (0.4%). The health effect of elevated aluminium (6.0%) is unclear, while sulphate outside the norms (1.3%) may have a laxative effect

Table 3: Number of exceeded Norwegian standards in individual samples from different aquifer types

No. of MACs exceeded per location	**Dataset (n=691)**		**Bedrock b. (n=346)**		**Uncons. Seds. (n=314)**		**Unknown aquifer (n=31)**	
	Total number of locations	%	Total number of locations	%	Total number of locations	%	Total number of locations	%
0	335	48.5	134	38.7	194	61.8	7	22.6
1	179	25.9	101	29.2	67	21.3	11	35.5
2	90	13.0	53	15.3	34	10.8	3	9.7
3	53	7.7	37	10.7	10	3.2	6	19.4
4	21	3.0	11	3.2	7	2.2	3	9.7
5	10	1.4	8	2.3	2	0.6	0	0
6	2	0.3	2	0.6	0	0	0	0
7	1	0.1	0	0	0	0	1	3.2

7.3 Comparison of Waterworks with other wells

The emphasis of this report was on evaluating the water chemistry of groundwaters from bedrock and quaternary aquifers. It is not surprising that waters from different aquifer types show significant differences in their water chemistry. However, classification according to aquifer type is not the only possibility.

Altogether 459 wells serve public waterworks. 202 wells are either on private property or used for various other purposes. The water chemistry was compared with respect to these categories. The results were presented as boxplots in Figure 12 - Figure 14. Most element concentrations do not vary significantly between waterworks and other wells. However, as shown in Figure 111, a few elements and parameters are conspicuous. Corresponding median values are listed in Table 4.

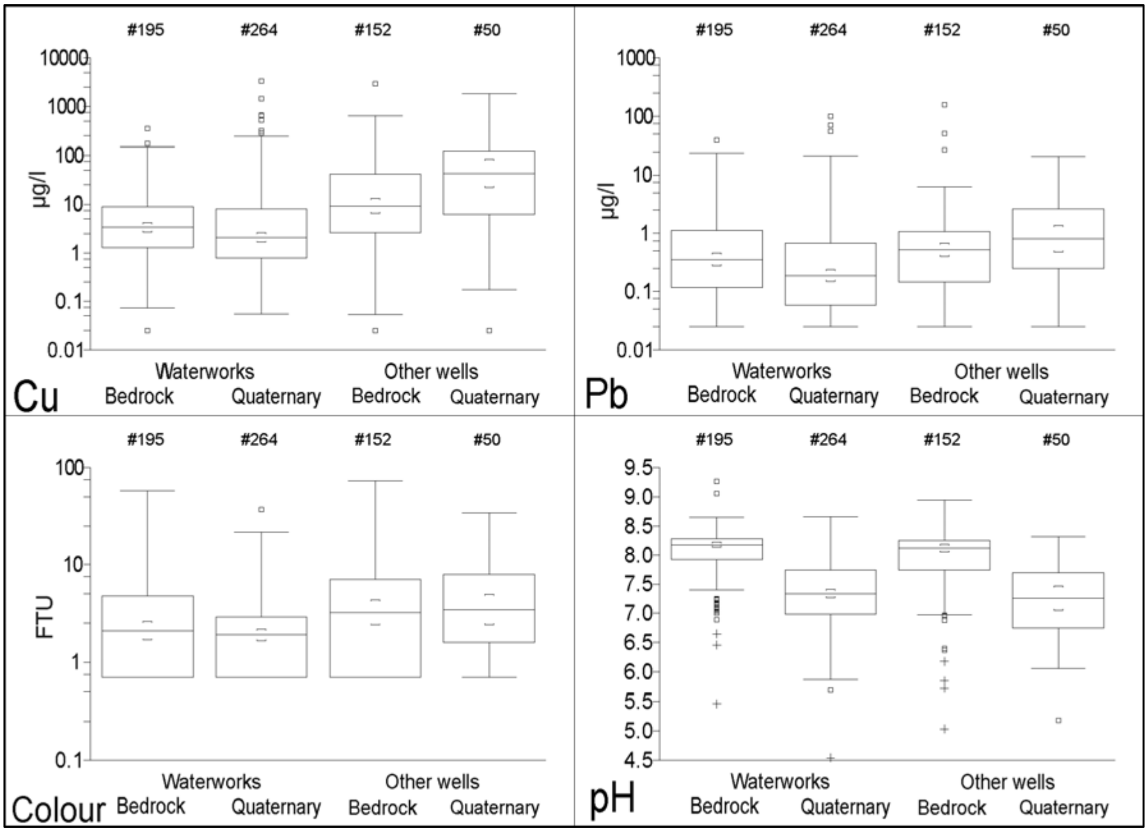

Figure 111: Comparison of copper (upper left) and lead (upper right) concentrations as well as colour (lower left) and pH (lower right) in waterworks and other wells.

Table 4: Median values of Cu, Pb, colour, and pH of water samples from different aquifer and well types.

Parameter	Unit	Waterworks Bedrock	Waterworks Quaternary	Other Wells Bedrock	Other Wells Quaternary
Median Cu	µg/L	3.36	2.07	9.21	43.3
Median Pb	µg/L	0.358	0.19	0.53	0.812
Median Colour	mg/L Pt	2.1	1.9	3.24	3.45
Median pH		8.18	7.34	8.12	7.26

Independently of the aquifer type, water samples from waterworks had lower values for colour than those from other wells. A high value is typically caused by a high concentration of humic substances or by high contents of iron and manganese. As shown in Figure 12, iron and manganese concentrations do not differ significantly between well types. The content of dissolved organic carbon was not determined and can therefore not be evaluated.

Copper concentrations in water were significantly higher for the classification group "other wells" than for waterworks. The median copper concentration for waterworks pumping from Quaternary aquifers was 2.07 µg/L, while corresponding private wells revealed a median value of 43.3 µg/L – more than one exponent of power difference in concentration. Similarly, lead concentrations are lower in waterworks than in water from other wells.

Due to their great durability and workability, copper and lead were a common choice for plumbing material. However, to counteract health implications, old pipes are progressively substituted with less corrosive materials such as plastic pipes. It is thus very likely that the differences in lead and copper concentrations between waterworks and other wells result from different pipe materials.

Furthermore, waterworks generally use pipes with large diameters while private households have rather narrow pipes. Narrow pipes increase the overall contact of water with the plumbing material, which in turn leads to a relative enrichment of dissolved elements.

The solubility of copper and lead is highest at low pH. Accordingly, pH is another important parameter. The measured pH values do not differ between waterworks and other wells, but they differ between aquifer types. The median pH of water samples from Quaternary aquifers is around 7, while that of bedrock aquifers is around 8. Accordingly, water from a Quaternary aquifer flowing through copper or lead pipes can be expected to contain higher concentrations of the respective elements than corresponding water from a bedrock aquifer.

Since many waterworks substituted copper and lead pipes with alternative materials, the aquifer type does not control the resulting concentration of the respective elements. However, private households that pump their drinking water from a Quaternary aquifer and use old plumbing might be exposed to comparably higher copper and lead concentrations. In order to reduce the exposure to these heavy metals, water should always flow some minutes from the tap before it is taken for drinking.

7.4 Comparison with previous surveys

In Table 5 the element concentrations from the bedrock boreholes in the current study are compared on a median basis to previous studies of bedrock boreholes in Norway. None of the studies has been planned as to be geographically representative of Norway. The study by Reimann et al. (n=145) was geographically restricted to the counties of Vestfold and Hordaland and has probably a larger proportion of host lithologies of granitic composition than the entire country. This might be seen by higher median concentrations of elements such as Be, Li, U, Th and Zr in this dataset. Most of the elements in the current study display slightly lower median concentrations than the other two, but all in all the results confirm the findings of previous studies.

Table 5: Comparison of the median concentration in crystalline bedrock groundwater of the current study and previous studies of Norwegian crystalline bedrock groundwater (n=145: Reimann et al. 1996, n=476: Frengstad et al.2000)

	Current study n = 346	Reimann et al. 1996 n = 145	Frengstad et al.2000 n=476		Current study n = 346	Reimann et al. 1996 n = 145	Frengstad et al.2000 n=476
Element	**Median µg/l**	**Median µg/l**	**Median µg/l**	**Element**	**Median µg/l**	**Median µg/l**	**Median µg/l**
Ag	<0.01	<0.001	< 0.002	Mg	3720	4250	3430
Al	11.2	12	13	Mn	6.8	7.5	12.2
As	0.12	0.2	0.18	Mo	<0.2	1.63	1.4
B	7.9	20.6	14	Na	8360	17300	11250
Ba	10	17	15	Nb	<0.05	0.008	0.004
Be	<0.01	0.04	0.012	Nd	0.14	0.155	0.12
Bi	<0.01	0.001	< 0.001	Ni	0.52	0.74	0.53
Br^-	<100	35	30	NO_3^-	280	n.a.	669
Ca	27700	25700	26900	PO_4^{2-}	<200	16.5	<200
Cd	<0.03	0.032	0.017	Pb	0.45	0.3	0.36
Ce	0.14	0.147	0.11	Pr	n.a.	0.04	0.027
Cl	6000	n.a.	9390	Rb	1.65	2.3	2.6
Co	0.040	0.062	0.065	Sb	<0.02	0.032	0.033
Cr	0.11	0.54	0.14	Se	<1	0.295	0.2
Cs	0.070	0.097	0.096	Si	4660	n.a.	4730
Cu	5.0	11.8	16	Sm	0.03	0.028	0.022
Dy	n.a.	0.021	0.022	Sn	n.a.	<0.005	0.008
Er	n.a.	0.016	0.015	SO_4^{2-}	10100	n.a.	11900
Eu	n.a.	0.011	0.003	Sr	140	179	142
F^-	220	330	212	Ta	<0.01	<0.001	0.002
Fe	30	25	28	Tb	n.a.	0.004	0.003
Ga	0,011	0.028	0.013	Te	n.a.	0.009	< 0.005
Gd	n.a.	0.029	0.024	Th	<0.02	0.013	0.006
Ge	<0.05	0.018	0.017	Ti	<5	0.64	0.59
Hf	n.a.	0.01	0.004	Tl	<0.050	0.003	0.007
Hg	n.a.	0.034	0.018	Tm	n.a.	0.002	0.002
Ho	0.006	0.0045	0.005	U	2.04	3.5	2.5
I	<5	2.03	0.6	V	0.24	0.5	0.24
In	<0.01	<0.001	< 0.001	W	<0.05	0.05	0.071
K	1580	2180	2260	Y	0.22	0.14	0.21
La	0.16	0.145	0.1	Yb	0.020	0.014	0.013
Li	2.04	3.6	2.9	Zn	6.4	23.4	14
Lu	n.a	0.003	0.003	Zr	<0.050	0.47	0.018

In Table 6 the median element concentrations of groundwater samples from Quaternary unconsolidated aquifers in the current study are compared with median values from previous studies of Quaternary aquifers. The first study by Cramer et al. sampled a selection of monitoring stations from the national groundwater monitoring networks of Norway, Sweden and Finland. The sampling sites comprised rather shallow wells (3-10 m) and springs. In this study the groundwater samples were taken directly at the source by trained personnel. The significantly lower levels of copper and lead in that study demonstrate how the samples in the current study are affected by plumbing material. In total, the results of the current study confirm the findings of previous studies.

Table 6: Comparison of the median concentration of groundwater from Quaternary unconsolidated aquifers of the current study and previous studies of selected monitoring stations of Fennoscandian Quaternary aquifers and of Norwegian private wells in Quaternary aquifers (n=89: Cramer et al. 2010, n=72: Banks et al. 1998). (n.a.= not available)

	Current Dataset n = 314	Cramer et al. 2010 n = 89	Banks et al. 1998b n=72		Current Dataset n = 314	Cramer er al. 2010 n = 89	Banks et al. 1998b n=72
Element	Median µg/l	Median µg/l	Median µg/l	Element	Median µg/l	Median µg/l	Median µg/l
Ag	< 0.01	0.009	n.a..	Mg	1190	1210	1560
Al	17.8	8.25	n.a.	Mn	2.75	1.05	n.a.
As	<0.05	0.04	n.a.	Mo	<0.2	0.12	n.a.
B	<5	3.48	n.a.	Na	3180	3040	4060
Ba	0.01	0.0077	n.a.	Nb	<0.05	n.a.	n.a.
Be	<0.01	<50	n.a.	Nd	0.35	n.a.	n.a.
Bi	<0.01	<0.01	n.a.	Ni	0.69	0.2	n.a.
Br^-	<100	9.9	n.a.	NO_3^-	1270	<50	1190
Ca	7000	4510	10600	PO_4^{2-}	<0.2	n.a..	n.a.
Cd	<0.03	0.0007	n.a.	Pb	0.23	0.016	n.a.
Ce	0.13	n.a.	n.a.	Pr	n.a.	n.a.	n.a.
Cl	4100	2800	4920	Rb	1.56	0.99	n.a.
Co	0.03	0.026	n.a.	Sb	<0.02	0.01	n.a.
Cr	<0.1	<0.1	n.a.	Se	<1	0.25	n.a.
Cs	0.01	<0.005	n.a.	Si	2950	5112	3160
Cu	2.71	0.2	n.a.	Sm	0.06	n.a.	n.a.
Dy	n.a..	n.a.	n.a.	Sn	n.a..	<0.05	n.a.
Er	n.a..	n.a.	n.a.	SO_4^{2-}	4720	5400	7480
Eu	n.a..	n.a..	n.a.	Sr	40	25.3	n.a.
F-	60	<50	51	Ta	<0.01	n.a.	n.a.
Fe	10	5	n.a.	Tb	n.a.	n.a.	n.a.
Ga	<0.01	n.a.	n.a.	Te	n.a.	n.a.	n.a.
Gd	n.a.	n.a.	n.a.	Th	<0.02	0.002	n.a.
Ge	<0.05	n.a.	n.a.	Ti	<0.005	n.a.	n.a.
Hf	n.a..	n.a.	n.a.	Tl	<50	0.01	n.a.

	Current Dataset n = 302	Cramer et al. 2010 n = 89	Banks et al. 1998b n=72		Current Dataset n = 302	Cramer er al. 2010 n = 89	Banks et al. 1998b n=72
Element	**Median μg/l**	**Median μg/l**	**Median μg/l**	**Element**	**Median μg/l**	**Median μg/l**	**Median μg/l**
Hg	n.a..	n.a.	n.a.	Tm	n.a..	n.a.	n.a.
Ho	0.007	n.a.	n.a.	U	0.53	0.079	n.a.
I	<5	1	n.a.	V	0.07	0.12	n.a.
In	<0.01	n.a.	n.a.	W	<0.05	n.a.	n.a.
K	900	860	1400	Y	0.26	n.a.	n.a.
La	0.49	n.a.	n.a.	Yb	0.02	n.a.	n.a.
Li	<0.5	0.48	n.a.	Zn	4.8	3.03	n.a.
Lu	n.a..	n.a.	n.a.	Zr	<0.05	n.a.	n.a.

8 Conclusions

The current survey of inorganic groundwater chemistry from Norwegian waterworks and regulated wells confirms the main findings of previous regional surveys of Norwegian groundwater chemistry.

Groundwater from crystalline bedrock aquifers are in general more hydrochemical mature than groundwater from Quarternary unconsolidated aquifers. This can be observed as significantly higher median values for pH, alkalinity and most major and trace elements. The only exceptions are aluminium and copper which are more soluble at low pH values and nitrate which is basically derived from agricultural contamination.

If only the dominating cation and anion are regarded, the groundwater samples from crystalline bedrock aquifers generally comprised the following water types: Ca-HCO_3 type waters 77% ; Na-HCO_3 type waters 15% ; Na-Cl type waters 6% ; and others 2%. The groundwater samples from Quaternary unconsolidated sediments included the following water types: Ca-HCO_3 type waters 68% ; Na-Cl type waters 13% ; Na-HCO_3 type waters 9% ; Ca-Cl type waters 6% ; Ca-SO_4 type waters 4%.

Around half of the groundwater samples did not fulfil the quality criteria given in Norwegian drinking water regulations for one or more parameters. In many cases, parameters of aesthetic significance (e.g. manganese, iron, copper, and turbidity) were outside the norms, and these problems can be detected by observation of colour, particles or taste.

Elements of health-related significance mainly display elevated concentrations in groundwater from crystalline bedrock aquifers. These include fluoride, uranium, lead, arsenic and molybdenum and can normally not be detected without a thorough water analysis. All bedrock boreholes used for drinking water should thus be analysed for these parameters in addition to radon.

No samples above the drinking water limits for cadmium, chromium, nitrate, and antimony were found.

The variation range is enormous for many parameters and span four to six orders of magnitude. The local variation is normally too large and the number of samples far too small to allow regional patterns to be discerned on a national scale. A few anomalies can be seen, such as elevated yttrium and rare earth element concentrations in groundwater from Quaternary aquifers in southernmost Norway.

The groundwater samples were not filtered prior to analysis and the drinking water were thus analysed 'as consumed'. Elevated levels of lead, copper and nickel might be derived from plumbing materials rather than from the aquifer. Household water should always flow for some minutes in the morning before it is taken for drinking.

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Appendix

Appendix 1: Number of samples and dates for the different batches analysed at NGU lab

Batch	Analytical report	Samples arrived before	# samples	# standards	# blanks
1	2004.0048	01.05.2004	360	18	
2	2004.0182	20.06.2004	21	1	
3	2005.0365	06.12.2005	221	11	5
4	2006.0032	23.01.2006	12		
5	2006.0168	09.05.2006	13	1	
6	2006.0344	21.08.2006	15	1	
7	2007.0132	09.04.2007	12		
8	2008.0029	22.01.2008	24	2	
9	2008.0183	09.06.2008	5		
In total			683	34	5

Appendix 2: The lower detection limit and the uncertainty of analysis for anions.

Anion	Lower detection limit (mg/L)	Analysis uncertainty (rel. %)
F-	0.05	± 10
Cl-	0.1	± 10
NO2-	0.05	± 10
Br-	0.1	± 10
NO3-	0.05	± 10
PO4 (3-)	0.2	± 10
SO4 (2-)	0.1 / 0.2	± 10

Appendix 3: The lower detection limit and the uncertainty of analysis using different methods.

Cation	Lower detection limit **(mg/L)** **With ICP_AES**	Analysis uncertainty (>5*LLQ) (rel. %)	Lower detection limit **(µg/L)** **With ICP_MS**	Analysis uncertainty (>5*LLQ) (rel. %)
Ag	0.01 (0.005)*	± 10	0.01	
Al	0.02	± 10	2	± 15
As	0.01	± 20	0.05	± 15
B	0.02	± 10	5	± 20
Ba	0.002	± 10		
Be	0.001	± 10	0.01	± 15
Bi			0.01	
Ca	0.02	± 10		
Cd	0.001 (0.0005)*	± 10	0.03	± 20
Ce	0.02	± 10	0.01	± 15
Co	0.001	± 10	0.02	± 15
Cr	0.002	± 10	0.1	± 15
Cs			0.002	
Cu	0.005	± 10	0.05	
Fe	0.002	± 10		
Ga			0.01	
Ge			0.05	
Ho			0.001	
I			5 (3)*	
In			0.01	
K	0.5	± 15	25	
La	0.005	± 10	0.01	± 15
Li	0.005	± 10	0.5	
Mg	0.05	± 10		
Mn	0.001	± 10	0.05	
Mo	0.01 (0.005)*	± 10	0.2 (0.06)*	± 15
Na	0.05	± 10		
Nb			0.05	
Nd			0.01	
Ni	0.005	± 10	0.2	± 15
P	0.05	± 10	5 (3)*	
Pb	0.005	± 15	0.05	± 15
Rb			0.05	± 15
S	Not given	± 20		
Sb	0.005	± 20	0.02 (0.01)*	± 15
Sc	0.001	± 10		
Se			1	± 15
Si	0.02	± 10		
Sm			0.002	
Sr	0.001	± 10		
Ta			0.01	
Th			0.02	
Ti	0.005 (0.001)*	± 10		
Tl			0.05	
U			0.0005	
V	0.005	± 10	0.02	
W			0.05	
Y	0.001	± 10	0.005	
Yb			0.002	
Zn	0.002	± 10	0.1	
Zr	0.005 (0.002)*	± 10	0.05	

* new detection limit

Appendix 4: Results of the statistical analysis. Technique used for analysis, lower detection limit, aquifer type and analytical results. Min = minimum, Med = median, Cond = Conductivity, Alk = Alkalinity, Turb = Turbidity.

	Technique	Unit	L. det. limit	Aquifer	Min.	Med.	75th perc.	95th perc.	Max.
Ag	ICP-MS	µg/L	0.01	All	< 0.01	< 0.01	< 0.01	0.02	1.03
				Bedrock	< 0.01	< 0.01	< 0.01	0.02	0.44
				Quaternary	< 0.01	< 0.01	< 0.01	0.02	1.03
Al	ICP-MS	µg/L	2	All	<2	13.3	56.8	229.5	7020
				Bedrock	<2	11.2	40.5	243.8	5690
				Quaternary	<2	17.8	71.7	212.4	1120
As	ICP-MS	µg/L	0.05	All	< 0.05	0.07	0.2	1.2	23.4
				Bedrock	< 0.05	0.12	0.3	2.0	23.4
				Quaternary	< 0.05	< 0.05	0.1	0.6	5.73
B	ICP-MS	µg/L	5	All	< 5	< 5	10.5	57.5	512
				Bedrock	< 5	7.9	23.3	98.8	376
				Quaternary	< 5	< 5	5.1	14.7	106
Ba	ICP-AES	mg/L	0.002	All	<0.002	0.01	0.03	0.1	0.23
				Bedrock	<0.002	0.01	0.04	0.14	0.23
				Quaternary	<0.002	0.01	0.03	0.10	0.16
Be	ICP-MS	µg/L	0.01	All	< 0.01	< 0.01	0.04	0.1	5.3
				Bedrock	< 0.01	< 0.01	0.03	0.1	5.3
				Quaternary	< 0.01	< 0.01	0.04	0.1	0.3
Bi	ICP-MS	µg/L	0.01	All	< 0.01	< 0.01	< 0.01	< 0.01	0.13
				Bedrock	< 0.01	< 0.01	< 0.01	< 0.01	0.13
				Quaternary	< 0.01	< 0.01	< 0.01	< 0.01	0.02
Br	IC	mg/L	0.1	All	< 0.1	< 0.1	0.14	0.45	9.04
				Bedrock	< 0.1	< 0.1	0.12	0.33	2.56
				Quaternary	< 0.1	< 0.1	0.15	0.50	4.93
Ca	ICP-AES	mg/L	0.02	All	0.08	16.1	33.2	57.5	201
				Bedrock	0.08	27.8	40.6	65.3	201
				Quaternary	0.22	7.0	15.8	44.2	145
Cd	ICP-MS	µg/L	0.03	All	< 0.03	< 0.03	< 0.03	0.1	1.65
				Bedrock	< 0.03	< 0.03	0.03	0.1	1.08
				Quaternary	< 0.03	< 0.03	< 0.03	0.09	1.65
Ce	ICP-MS	µg/L	0.01	All	< 0.01	0.14	0.8	6.4	57.2
				Bedrock	< 0.01	0.14	0.6	4.2	14
				Quaternary	< 0.01	0.13	1.3	7.7	57.2
Cl	IC	mg/L	0.1	All	0.2	5.2	10.2	39.0	3050
				Bedrock	0.2	6.0	11.5	54.2	677
				Quaternary	0.3	4.1	8.5	25.8	162
Co	ICP-MS	µg/L	0.02	All	< 0.02	0.04	0.16	0.76	127
				Bedrock	< 0.02	0.04	0.19	0.97	13.5
				Quaternary	< 0.02	0.03	0.14	0.52	22
Cr	ICP-MS	µg/L	0.1	All	< 0.1	< 0.1	0.20	0.68	30.2
				Bedrock	< 0.1	0.11	0.25	1.27	30.2
				Quaternary	< 0.1	< 0.1	0.15	0.40	4.38

	Technique	**Unit**	**L. det. limit**	**Aquifer**	**Min.**	**Med.**	**75th perc.**	**95th perc.**	**Max.**
Cs	ICP-MS	µg/L	0.002	All	< 0.002	0.03	0.10	0.68	2.37
				Bedrock	< 0.002	0.07	0.20	1.05	2.37
				Quaternary	< 0.002	0.01	0.03	0.13	0.61
Cu	ICP-MS	µg/L	0.05	All	< 0.05	3.59	16.8	139	3380
				Bedrock	< 0.05	4.94	17.0	125.75	2930
				Quaternary	< 0.05	2.71	17.2	210.20	3380
F	IC	mg/L	0.05	All	<0.05	0.11	0.37	1.89	5.67
				Bedrock	<0.05	0.22	0.85	2.35	5.67
				Quaternary	<0.05	0.06	0.14	0.45	1.48
Fe	ICP-AES	mg/L	0.002	All	<0.002	0.02	0.09	0.93	9.46
				Bedrock	<0.002	0.03	0.14	1.31	9.46
				Quaternary	<0.002	0.01	0.04	0.56	3.21
Ga	ICP-MS	µg/L	0.01	All	< 0.01	< 0.01	0.02	0.09	2.5
				Bedrock	< 0.01	0.011	0.02	0.11	2.5
				Quaternary	< 0.01	< 0.01	< 0.01	0.03	0.52
Ge	ICP-MS	µg/L	0.05	All	< 0.05	< 0.05	< 0.05	0.19	1.75
				Bedrock	< 0.05	< 0.05	< 0.05	0.28	1.75
				Quaternary	< 0.05	< 0.05	< 0.05	< 0.05	0.25
Ho	ICP-MS	µg/L	0.001	All	< 0.001	0.006	0.024	0.101	1.28
				Bedrock	< 0.001	0.006	0.023	0.083	1.28
				Quaternary	< 0.001	0.007	0.025	0.128	0.913
I	ICP-MS	µg/L	5	All	< 5	< 5	< 5	10.0	53
				Bedrock	< 5	< 5	< 5	10.7	53
				Quaternary	< 5	< 5	< 5	6.4	41.3
In	ICP-MS	µg/L	0.01	All	< 0.01	< 0.01	< 0.01	< 0.01	0.094
				Bedrock	< 0.01	< 0.01	< 0.01	< 0.01	0.029
				Quaternary	< 0.01	< 0.01	< 0.01	< 0.01	0.094
K	ICP-AES & ICP-MS	mg/L	AES:0.5 MS:0.025	All	0.045	1.17	2.0	5.25	27.3
				Bedrock	0.045	1.58	2.7	6.06	12.4
				Quaternary	0.107	0.90	1.5	3.41	12.2
La	ICP-MS	µg/L	0.01	All	< 0.01	0.24	0.86	5.13	69.1
				Bedrock	< 0.01	0.16	0.55	3.25	8.57
				Quaternary	< 0.01	0.49	1.71	10.17	69.1
Li	ICP-MS	µg/L	0.5	All	< 0.5	0.66	2.71	8.93	27.4
				Bedrock	< 0.5	2.08	4.28	11.75	27.4
				Quaternary	< 0.5	< 0.5	< 0.5	2.50	18.6
Mg	ICP-AES	mg/L	0.05	All	<0.05	2.21	4.25	10.5	173
				Bedrock	<0.05	3.71	5.99	11.7	23.1
				Quaternary	0.10	1.19	2.24	4.8	15.9
Mn	ICP-MS	µg/L	0.05	All	< 0.05	4.16	32.4	342	4630
				Bedrock	< 0.05	6.70	72.5	527.5	4630
				Quaternary	< 0.05	2.75	12.6	89.5	3310

	Technique	**Unit**	**L. det. limit**	**Aquifer**	**Min.**	**Med.**	**75th perc.**	**95th perc.**	**Max.**
Mo	ICP-MS	µg/L	0.2	All	< 0.2	0.30	1.43	8.08	272
				Bedrock	< 0.2	1.18	3.28	11.23	272
				Quaternary	< 0.2	< 0.2	0.27	1.30	24.9
Na	ICP-AES	mg/L	0.05	All	0.41	5.13	11.3	53.95	1540
				Bedrock	0.71	8.33	17.03	79.30	431
				Quaternary	0.61	3.18	5.37	13.57	105
Nb	ICP-MS	µg/L	0.05	All	< 0.05	< 0.05	< 0.05	< 0.05	0.26
				Bedrock	< 0.05	< 0.05	< 0.05	< 0.05	0.26
				Quaternary	< 0.05	< 0.05	< 0.05	< 0.05	0.06
Nd	ICP-MS	µg/L	0.01	All	< 0.01	0.20	0.81	3.65	45.5
				Bedrock	< 0.01	0.14	0.52	2.71	8.27
				Quaternary	< 0.01	0.35	1.35	6.67	45.5
Ni	ICP-MS	µg/L	0.2	All	< 0.2	0.61	1.82	10.70	834
				Bedrock	< 0.2	0.52	1.64	13.63	834
				Quaternary	< 0.2	0.69	1.90	8.69	125
NO2	IC	mg/L	0.05	All	< 0.05	< 0.05	< 0.05	0.17	2.28
				Bedrock	< 0.05	< 0.05	< 0.05	0.19	0.40
				Quaternary	< 0.05	< 0.05	< 0.05	0.16	2.28
NO3	IC	mg/L	0.05	All	< 0.05	0.68	2.14	10.55	38.4
				Bedrock	< 0.05	0.28	1.23	10.58	21.7
				Quaternary	< 0.05	1.27	3.23	10.74	38.4
P	ICP-MS	µg/L	5	All	< 5	< 5	< 5	20.9	1300
				Bedrock	< 5	< 5	< 5	24.1	276
				Quaternary	< 5	< 5	< 5	18.3	1300
Pb	ICP-MS	µg/L	0.05	All	< 0.05	0.30	0.98	4.3	157
				Bedrock	< 0.05	0.45	1.1	4.02	157
				Quaternary	< 0.05	0.23	0.82	4.28	99.3
PO4	IC	mg/L	0.2	All	< 0.2	< 0.2	< 0.2	0.23	7.72
				Bedrock	< 0.2	< 0.2	< 0.2	0.29	0.76
				Quaternary	< 0.2	< 0.2	< 0.2	< 0.2	7.72
Rb	ICP-MS	µg/L	0.05	All	< 0.05	1.60	2.72	5.04	30.5
				Bedrock	< 0.05	1.64	3.00	5.24	30.5
				Quaternary	< 0.05	1.56	2.57	4.54	14.5
S	ICP-AES	mg/L	not given	All	0.27	3.04	5.84	15.00	165
				Bedrock	0.27	5.50	8.32	20.47	165
				Quaternary	0.56	2.12	3.75	8.83	60.5
Sb	ICP-MS	µg/L	0.02	All	< 0.02	< 0.02	0.03	0.15	2.67
				Bedrock	< 0.02	< 0.02	0.03	0.29	2.67
				Quaternary	< 0.02	< 0.02	< 0.02	0.06	0.79
Sc	ICP-AES	mg/L	0.001	All	< 0.001	< 0.001	< 0.001	< 0.001	0.002
				Bedrock	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
				Quaternary	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001

	Technique	**Unit**	**L. det. limit**	**Aquifer**	**Min.**	**Med.**	**75th perc.**	**95th perc.**	**Max.**
Se	ICP-MS	µg/L	1	All	< 1	< 1	< 1	< 1	13.8
				Bedrock	< 1	< 1	< 1	< 1	13.8
				Quaternary	< 1	< 1	< 1	< 1	< 1
Si	ICP-AES	mg/L	0.02	All	<0.02	3.74	5.07	7.39	14.3
				Bedrock	<0.02	4.66	5.68	7.86	14.3
				Quaternary	<0.02	2.95	3.97	6.43	10.9
Sm	ICP-MS	µg/L	0.002	All	< 0.002	0.04	0.14	0.60	6.58
				Bedrock	< 0.002	0.03	0.10	0.46	1.62
				Quaternary	< 0.002	0.06	0.22	1.09	6.58
SO4	IC	mg/L	0.2	All	< 0.2	7.33	14.10	38.20	468
				Bedrock	< 0.2	10.10	18.00	47.50	468
				Quaternary	< 0.2	4.72	8.15	20.17	141
Sr	ICP-AES	mg/L	0.001	All	<0.001	0.07	0.21	0.96	5.27
				Bedrock	<0.001	0.14	0.35	1.21	5.27
				Quaternary	0.003	0.04	0.08	0.26	1.04
Ta	ICP-MS	µg/L	0.01	All	< 0.01	< 0.01	< 0.01	< 0.01	0.023
				Bedrock	< 0.01	< 0.01	< 0.01	< 0.01	0.023
				Quaternary	< 0.01	< 0.01	< 0.01	< 0.01	0.022
Th	ICP-MS	µg/L	0.02	All	< 0.02	< 0.02	< 0.02	0.16	4.76
				Bedrock	< 0.02	< 0.02	0.03	0.19	1.48
				Quaternary	< 0.02	< 0.02	< 0.02	0.12	4.76
Ti	ICP-AES	mg/L	0.005	All	< 0.005	< 0.005	< 0.005	0.01	0.4
				Bedrock	< 0.005	< 0.005	< 0.005	0.01	0.4
				Quaternary	< 0.005	< 0.005	< 0.005	< 0.005	0.06
Tl	ICP-MS	µg/L	0.05	All	< 0.05	< 0.05	< 0.05	< 0.05	0.20
				Bedrock	< 0.05	< 0.05	< 0.05	< 0.05	0.20
				Quaternary	< 0.05	< 0.05	< 0.05	< 0.05	0.09
U	ICP-MS	µg/L	0.0005	All	<0.0005	0.53	2.70	23.65	246
				Bedrock	0.005	2.05	6.80	44.53	246
				Quaternary	0.003	0.12	0.34	2.73	72.1
V	ICP-MS	µg/L	0.02	All	< 0.02	0.11	0.36	1.53	58.4
				Bedrock	< 0.02	0.24	0.59	2.08	58.4
				Quaternary	< 0.02	0.07	0.14	0.60	3.04
W	ICP-MS	µg/L	0.05	All	< 0.05	< 0.05	0.08	1.54	19.6
				Bedrock	< 0.05	< 0.05	0.31	3.03	19.6
				Quaternary	< 0.05	< 0.05	< 0.05	< 0.05	3.88
Y	ICP-MS	µg/L	0.005	All	< 0.005	0.22	0.82	3.83	50.3
				Bedrock	< 0.005	0.22	0.89	3.22	50.3
				Quaternary	< 0.005	0.26	0.78	5.72	30.6
Yb	ICP-MS	µg/L	0.002	All	< 0.002	0.02	0.06	0.23	1.88
				Bedrock	< 0.002	0.02	0.06	0.22	1.88
				Quaternary	< 0.002	0.02	0.06	0.29	1.56

	Technique	Unit	L. det. limit	Aquifer	Min.	Med.	75th perc.	95th perc.	Max.
Zn	ICP-MS	µg/L	0.1	All	< 0.1	5.6	18.5	113	16600
				Bedrock	< 0.1	6.4	20.7	97.7	960
				Quaternary	< 0.1	4.8	17.8	130.1	16600
Zr	ICP-MS	µg/L	0.05	All	< 0.05	< 0.05	0.05	0.46	2.52
				Bedrock	< 0.05	< 0.05	0.09	0.57	2.52
				Quaternary	< 0.05	< 0.05	< 0.05	0.18	1.22
pH				All	3.1	7.8	8.2	8.4	9.3
				Bedrock	5.0	8.1	8.3	8.4	9.3
				Quaternary	4.5	7.3	7.7	8.2	8.67
Cond.		mS/m		A	0.06	15.91	26.50	44.01	912
				Bedrock	0.06	24.20	31.20	49.32	100.3
				Quaternary	1.42	7.10	13.51	31.71	62.1
Alk.		meq/L		All	0.02	1.07	2.36	5.36	271.6
				Bedrock	0.02	2.12	2.73	6.72	271.6
				Quaternary	0.02	0.35	0.81	2.62	17.48
Colour		mg/L Pt-Co		A	0.7	2	4.3	13.3	73.5
				Bedrock	0.7	2.5	5.7	16.3	73.5
				Quaternary	0.7	2.0	3.5	9.7	37.2
Turb.		FTU		A	0.03	0.21	0.34	1.3	34
				Bedrock	0.03	0.23	0.39	2.45	34
				Quaternary	0.06	0.18	0.28	0.62	23