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Determination of trace elements in ground drinking water in Norway

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ABSTRACT

Drinking water is essential for life. However, unless standard quality of drinking water is maintained, water can be associated with health risks. The present study was conducted to determine primarily inorganic elements in Norwegian ground drinking water in a nationwide investigation including 201 well works. In addition, indicators of water quality such as pH, conductivity, alkalinity, turbidity, and color were also determined. Water samples were collected from the source (raw water) and from distribution network (clean/treated water) and analyzed for 64 inorganic elements using inductively coupled plasma-Mass spectrometry (ICP-MS). Anions (F^- , NO_3^- and SO_4^{2-}) were measured using Ion chromatography (IC).

The results show that aluminum (Al), manganese (Mn), copper (Cu), iron (Fe), nickel (Ni), and arsenic (As) had concentrations exceeding the Norwegian drinking water regulation limits. While the concentration of sodium (Na), boron (B), calcium (Ca), selenium (Se), antimony (Sb), cadmium (Cd), and chromium (Cr) were within the regulation limits. Moreover, the concentration of uranium (U) was higher than WHO and US drinking water guidelines at three waterworks and at seven waterworks compared to Canada water guideline. Among anions, fluoride (F^-) concentration was higher than the regulation limit at four waterworks. Considering water quality indicators, color was within the regulation limit set by health authorities in Norway. However, 40 out of 201 (20%) of the waterworks, 91 out of 201 (45%) waterworks, and 1 out of 201 (0.5%) waterworks, had levels above the regulation for conductivity, alkalinity, and turbidity, respectively. Moreover, the pH was lower than the regulation limit at six waterworks.

In general, the geological composition of bedrock and quaternary aquifers are among the factor affecting the level of elements. In particular, the concentrations of trace elements, such as Ni, Cd, Pb, As, Cr, and Sb were high in bedrock aquifers from mica schist, augengneiss, tonalite, and amphibolite, phyllite, and granite rocks. Similarly, higher concentration of elements such as Al, Zn, Mn, and Cu was found in Quaternary aquifers such as marine deposits and fluvial deposits compared to bedrock aquifers. The concentrations of F^- and U were high in bedrock aquifers were gneiss, granites, amphibolite and granite to tonalities rocks dominant. Drinking water samples from bedrock aquifers in coastal areas had high concentration for elements such as Na, I, Br, B, SO_4^{2-} , and Cl. The concentration of Na and Cl, Br and I increase in coastal marine derived areas and decrease with the distance to ocean.

Multivariate statistical analyses such as principal component analysis (PCA) was applied to 34 elements from clean water (treated water) and 33 elements from raw water analyzed by ICP-MS from 201 waterworks .PCA were used in order to describe the variability of measured elements. 51 % of the variability among the waterworks were explained by PC1 (35%) and PC2 (16 %) for clean water, and 58 % of the variability were explained by PC1 (39%) and PC2 (19 %) for raw water. Correlation loadings plot suggests high correlation exist between Al and REE, between the elements Cu, Zn and Mn and between U, K, Na and Cs.

LIST OF TERMS AND ABBREVIATIONS

Ag	Silver
Al	Aluminium
As	Arsenic
B	Boron
Ba	Barium
Be	Beryllium
Bi	Bismuth
Ca	Calcium
Cd	Cadmium
Ce	Cerium
Co	Cobalt
Cr	Chromium
CRM	Certified Reference Materials
Cs	Cesium
Cu	Copper
DO	Dissolved Oxygen
Dy	Dysprosium
Er	Erbium
Eu	Europium
Fe	Iron
Ga	Gallium
Gd	Gadolinium
Ge	Germanium
Hf	Hafnium
Ho	Holmium
IC	Ion Chromatography
ICP-MS	Inductively Coupled Plasma-Mass Spectrometry
In	Indium
K	Potassium
La	Lanthanum
Li	Lithium
LOD	Limit of detection
LOQ	Limit of quantification
Lu	Lutetium
Mg	Magnesium
Mn	Manganese
Mo	Molybdenum
Na	Sodium
Nb	Niobium
Nd	Neodymium
Ni	Nickel
NIPH	The Norwegian Institute of Public Health

NMBU	Norwegian University of Life Sciences
P	Phosphor
Pb	Lead
PCA	Principal Components Analysis
Pr	Prasedymium
Rb	Rubidium
S	Sulfur
Sb	Antimony
Sc	Scandium
Se	Selenium
Si	silicon
Sm	Samarium
Sn	Tin
Sr	Strontium
SVD	Singular Value Decomposition
Ta	Tantalum
Tb	Terbium
TDI	Tolerable Daily Intake
Te	Tellurium
Th	Thorium
Ti	Titanum
TI	Thallium
Tm	Thulium
U	Uranium
V	Vandadium
VREG	The Norwegian Waterworks Register
W	Tungsten
WHO	World Health Organization
Y	Ytterium
Yb	Ytterbium
ZN	Zinc
Zr	Zicronium

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1 INTRODUCTION

1.1 Background

Water is crucial for all aspects of life, the defining feature of our planet. However, not all water bodies are for immediate human consumption, because 97.5% of all water is found in the oceans. Only 2.5 – 2.75% is fresh water, including 1.75 – 2% frozen in glaciers, ice and snow, 0.5 – 0.75% as fresh groundwater and soil moisture, and less than 0.01% of it occurs as surface water in lakes, swamps and rivers (USGS, 2016).

Therefore, water is a valuable and scarce resource that needs to be managed with utmost care. Every person on earth requires 2 liter of clean drinking water each day, amounting to 12 million m³ of water per day for the global population. At elevated temperatures and increased level of activity, the need for water is higher. However, most of the world's fresh water is used for agricultural production, industrial production, power generation and mining (UNEP GEMS, 2008; WHO, 2012; Yassi et al., 2001). One of the major impacts of the growing human population has been an increasing pollution load that has greatly deteriorated the quality of aquatic ecosystems and water supplies (Boyd, 2015).

Although drinking water is essential to life, it can also be a source of human suffering if the standard quality of is not maintained. Exposure to pathogens, chemical, physical and radiological contaminants is some of the most important factors affecting the quality of drinking water (WHO, 2011). Natural and anthropogenic processes influence inland ground and surface water, which are globally important sources for drinking water. Water can be contaminated with different components; i.e. pathogens, organic compounds, synthetic chemicals, nutrients, organic matter, and heavy metals, that may have acute and chronic effects on consumers' health (Bhowmik et al., 2015; Yassi, 2001). Among these contaminants, trace elements represent a major group of contaminants of drinking water sources that can have severe implications for human health such as cardiovascular, skeletal diseases, neurotoxicity, and infertility problems (Bhowmik, 2015; WHO, 2011). Therefore, risk assessment of trace metals in drinking water sources is crucial to estimate the population at risk, to identify hotspots and to develop management strategies (Srinivasa & Govli, 2007).

In Norway, surface water is the main source of drinking water, supplying 57% of the water works, whereas 42% of the waterworks use ground water. In 2011, ground water used in Norway was estimated to be 88 million m³, whereas that of surface water was 827 m³ (Myrstad et al., 2015).

According to Frengstad (2002), about 200,000 people get their drinking water from bedrock groundwater wells, which chemical quality is not always suitable for drinking. However, the work conducted by Frengstad (2002) in which 1604 groundwater samples were analyzed was limited to bedrock chemistry. However, to give a full picture of water quality, information regarding inorganic elements, anions, organic constituents, as well as biological and physico-chemical parameters is required. Therefore, the present study was designed to determine the chemistry of groundwater, with especial emphasis on major and trace elements of groundwater from sedimentary and bedrock wells. Waterworks listed in the Norwegian Waterworks Register (VREG) were invited, and those who accepted the invitation to participated in the study cover all geographical regions of Norway. The study is instantaneous and has some important limitations, e.g. no information on intrusion of waters of short residence time. This study was carried out in a short period of time with a limited budget. Nevertheless, the outcome is expected to give a general view of the chemical quality of the ground drinking water in Norway.

1.2 Objectives of the study

1.2.1 Specific objectives

- Determine anions (F^- , NO_3^- and SO_4^{2-}) and halogens (Cl, BrI), major elements (Ca, K, Mg, Na, P, S, and Si) and trace elements (e.g. Al, Ag, As, B, Ba Be, Bi, Cd, Cs, Co, Cr, Cu, Fe, Li, Mo, Ni, Pb, Sb, Se, Tl, U, V, W, Zn, rare earth elements (REE)) in ground water for human consumption in all Norwegian counties.
- Compare the observed concentrations of inorganic elements and anions with the Norwegian drinking water regulation limits (*Drikkevannsforskriften*).
- Identify possible natural sources for elements with elevated concentrations
- Consider possible health effects; emphasize the anions, major or trace elements measured above the maximum admissible concentrations according to *Drikkevannsforskriften* or other international guidelines.
- Compare concentrations of trace elements currently with no limits in the Norwegian legislation, but still deemed to be of health concern (e.g. U), with regulations/guide values applied in different countries and values reported in the literature.

In order to answer the specific objectives, great effort were put on planning for representative sampling and good quality in the chemical analysis, that is to identify ground water wells representing different regions of Norway, plan for an efficient and safe sampling of water, and finally to choose the most appropriate technique for the quantitative chemical analysis.. Inductivity

coupled plasma-mass spectroscopy, in particular the AGILENT 8800 QQQ, was the preferred instrument to determine major and trace elements, and total concentration of Cl, Br, and I. Anions were determined using Ion-chromatography (IC). Physo-chemical parameters were determined using conventional standard methods.

1.2.2 Hypotheses

- 1) The concentration of trace elements in drinking ground water in Norway do not exceed the regulation limits set by the Norwegian health authorities.
- 2) The chemical composition of groundwater in Norway varies between regions with different geological formation.

2 LITERATURE REVIEW

2.1 Drinking water

Drinking water, also known as potable water is water safe enough for drinking and food preparation. Globally, in 2012, 89% of people had access to water suitable for drinking. Nearly 4 billion had access to tap water while another 2.3 billion had access to wells or public taps. In 2015, 91% of the world's population had access to an improved drinking water source, and 2.6 billion people have gained access to an improved drinking water since 1990 (WHO, 2015). Safe and readily available water is important for public health, whether it is used for drinking, domestic use, food production, or recreational purposes. Improved water supply and sanitation, and better management of water resources, can boost countries' economic growth and can contribute greatly to poverty reduction (WHO, 2015).

In 2010, the UN General Assembly explicitly recognized the human right to water and sanitation. Everyone has the right to sufficient, continuous, safe, acceptable, physically accessible and affordable water for personal and domestic use.

2.2 Quality of drinking water

Although essential for life, water can also be a source of harmful substances that can threaten life. These include metals such as mercury, lead, cadmium, pesticides, organic toxins and radioactive contaminants. The availability of water and its physical, chemical, and biological composition effect the aquatic environments to sustain healthy ecosystems. As water quality and quantity are eroded, organisms suffer and ecosystem services may be lost. Moreover, an abundant supply of clean usable water is a basic requirement for many of the fundamental uses of water on which humans depend.

The quality of drinking surface or ground water is a function of either or both natural influences and human activities. Without human influences, water quality would be determined by the weathering of bedrock minerals, by the atmospheric processes of evapotranspiration, by the deposition of dust and salt by wind, by the natural leaching of organic matter and nutrients from soil, by hydrological factors that lead to runoff, and by biological processes within the aquatic environment that can alter the physical and chemical composition of water (UNEP GEMS, 2008). As a result, water in the natural environment contains many dissolved substances and non-dissolved particulate matter. Dissolved salts and minerals are necessary components of good quality water as they help maintain the health and vitality of the organisms that rely on this ecosystem service (Stark *et al.*, 2000).

Inorganic contaminants of geological origin may raise great concern, especially in selected geographical areas. For instance, in Italy, arsenic and vanadium have received major consideration for their biological activity and potential health impact, as well as for the frequent occurrence in groundwater at levels above their parametric values (Crebelli & Leopardi, 2012). Chemical risk factors, however, may assume greater relevance in developed countries, where water supply is characterized by high standards of microbiological safety (Crebelli & Leopardi, 2012).

2.3 Physical and chemical characteristics of water body

One important point about drinking water is that water quality is neither a static condition of a system, nor can it be defined by the measurement of only one parameter. Rather it is variable in both time and space, and requires routine monitoring to detect changes over time. There is a range of chemical, physical, and biological components that affect water quality and hundreds of variables could be measured. Some variables provide a general indication of water pollution, whereas others enable the direct tracking of pollution sources.

pH and alkalinity: In water, a small number of water (H_2O) molecules dissociate and form hydrogen (H^+) and hydroxyl (OH^-) ions. If the relative proportion of hydrogen ions is greater than the hydroxyl ions, then the water is defined as being acidic. If the hydroxyl ions dominate, then the water is defined as being alkaline. The pH of an aquatic ecosystem is important because it is closely linked to biological productivity. Although the tolerance of individual species varies, pH values between 6.5 and 8.5 usually indicate good water quality and this range is typical of most major drainage basins of the world. Natural acidity in rainwater is caused by dissolution of atmospheric carbon dioxide (CO_2). The hydrogen ions entering a drainage basin in rainwater are neutralized by carbonate and silicate minerals as water percolates through soils. This neutralization capacity in soils determines whether or not acid precipitation will cause water quality impacts in receiving water bodies. The ability of rocks and soils in any given drainage basin to buffer the acidity of rainwater is related to the residence time of water in the soil as well as the levels of calcium carbonate, bicarbonate and silicate minerals (Friedl et al., 2004; Wetzel and Likens, 2000).

Alkalinity is a related concept that is commonly used to indicate a system's capacity to buffer against acid impacts. Buffering water that percolates through soil in poorly buffered catchments, usually those with hard igneous rocks, tends to be dominated by dissolved organic acids and can

produce pH values in watercourses as low as 4.0. This is typical in areas downstream of peat bogs and other wetlands. These conditions can produce acidic “blackwaters” that have very low water hardness and mineral content and low biological productivity. In contrast, catchments on sedimentary rock, especially calcareous rocks, which are rich in carbonate, have a high content of weatherable silicates, have high base saturation, and are well buffered and generally give rise to circumneutral (pH 7) or slightly alkaline hard water systems (pH 7.5 to 8.5) (Friedl et al., 2004; Wetzel and Likens, 2000).

Turbidity and suspended solids: Turbidity refers to water clarity. The greater the amount of suspended solids in the water, the murkier it appears, and the higher the measured turbidity. The major sources of turbidity in open water zone of most lakes is typically phytoplankton, but closer to shore, particulates may also include clays and silts from shoreline erosion, re-suspended bottom sediments, and organic detritus from stream and/or water discharges. The source of these are sediments natural and anthropogenic (human) activities in the watershed, such as natural or excessive soil erosion from agriculture, forestry or construction, urban runoff, industrial effluents, or excess phytoplankton growth (US EPA, 1997). Turbidity is often expressed as total suspended solids. Water transparency and Secchi disk depth are also commonly used measures of water quality that quantify the depth of light penetration in a body of water. Water bodies that have high transparency values typically have good water quality.

Salinity and specific conductivity: Salinity is an indication of the concentration of dissolved salts in a body of water. The ions responsible for salinity include the major cations (calcium, Ca^{2+} ; Magnesium, Mg^{2+} ; Sodium, Na^+ ; and potassium, K^+) and the major anions (carbonate, CO_3^{2-} ; and HCO_3^{2-} ; sulphate, SO_4^{2-} , and chloride, Cl^-). Salinity is measured by comparing the dissolved solids in a water sample with standardized solution. The dissolved solids can be estimated using total dissolved solids or by measuring the specific conductance. Specific conductance or conductivity measures how well the water conducts an electric current, a property that is proportional to the concentration of ions in solution. Conductivity is often used as a surrogate of salinity measurements and is considerably higher in saline systems than in non-saline systems (Dodds, 2002).

2.4 Contaminants of drinking water

Drinking water is derived from two basic sources, that is, surface waters such as rivers and reservoirs, and groundwater. All water contains natural contaminants, particularly inorganic

contaminants that arise from the geological strata through the water flows and, to a varying extent, anthropogenic pollution by both micro-organisms and chemicals. In general, groundwater is less vulnerable to pollution than surface waters. There are a number of possible sources of anthropogenic contaminants, some of which are more important than others. These fall into categories of point and diffuse sources. Discharges from industrial premises and sewage treatment works are point sources and as such are more readily identifiable and controlled; run-off from agricultural land and from hard surfaces, such as roads, are not so obvious, or easily controlled. Such sources can give rise to a significant variation in the containment load over time. There is a possibility of spills and chemicals from industry and agriculture and slurries from intensive farm units that can contain pathogens.

Badly sited latrines and septic tanks are a significant source of contamination, especially of wells. Local industries can also give rise to contamination of water sources, particularly when chemicals are handled and disposed of without proper care. The run-off or leaching of nutrients into slow flowing or still surface waters can result in excessive growth of cyanobacteria or blue –green algae (Chorus I & Bartram J, 1999). Many species give rise to nuisance chemicals that can cause taste and odor and interfere with drinking after treatment. However, they frequently produce toxins, which are of concern for health, particularly if there is only limited treatment (Fawell J & Nieuwenhuijsen MJ, 2003).

2.4.1 Chemical contamination

As indicated earlier, there are many sources of chemical contamination of drinking water. However, the most important contaminants from health standpoint are naturally occurring chemicals that are usually found in groundwaters (Fawell & Nieuwenhuijsen, 2003).

Water is a universal solvent and rocks are soluble chemical entities, therefore, groundwater fractures in bedrock are not just water. Newly formed groundwater is acidic; it contains CO₂ from respiratory processes in the soil zone, and oxidizing (it contains dissolved O₂). Most rocks consist of minerals, which are basic (carbonate, silicate) and/or reducing (sulphate, graphite). Thus, newly formed groundwater reacts with the bedrock and releases quantities of dissolved components depending on the mineralogical and geochemical composition of the rock, among others. These dissolved contaminants are, therefore, natural components of the groundwater and occur in highly varying concentrations (Midtgård et al., 1998). Many dissolved constituents in groundwater are

necessary for human metabolism and functions, although they may have a negative effect if present in excess (e.g., chlorine or fluoride).

2.4.2 Inorganic metals in drinking water

In general, metals with a density of $>5\text{mg/cm}^3$ are considered heavy metals. Among them, lead, cadmium, mercury, chromium, and arsenic broadly exist in the environment and are considered to be primary toxic heavy metals to human health (Järup L, 2003; Le B et al. 2013; Welling R et al. 2015). With the development of industrialization and urbanization, heavy metal contamination is a major environmental problem that affects organisms' metabolism in ecosystems due to their high toxicity, prevalence, and persistence existence (Järup L, 2003; He B et al. 2013).

However, heavy metals can play both positive and negative roles in human health (Reviewed in Shaheen et al., 2016). They can be classified as toxic (arsenic, cadmium, lead, mercury, nickel, etc.), probably essential (vanadium), and essential (copper, zinc, iron, manganese, selenium and cobalt) metals (Munoz-Olivas & Camara, 2001). However, toxic effects of the last two classes of metals have been identified when the intake is excessively high (Celik & Oehlenschläger, 2007). Lead and cadmium are among the most abundant, and their excessive intake is associated with cardiovascular, kidney, nervous, and bone diseases (WHO, 1992, 1995; Järup L, 2003).

According to Mosby *et al.* (1996), thirty-five metals pose a threat to human health because of residential and/or occupational exposure, 23 of which are heavy metals. In the following section, some characteristics (distribution, physical and chemical) properties, and health effects will be presented.

Aluminum (Al)

Occurrence and properties: Aluminum is the third most common element on earth's crust after oxygen and silicon and is contained in most rock types. All natural water contains some Al but the solubility is strongly dependent on pH and is very low unless the water acid ($\text{pH} < 5.5$) or extremely alkaline. Aluminum sulphates is as a coagulant for water treatment to entrain suspended and colloidal matter and may contribute to Al concentration in treated drinking water (Frengstad, 2002).

Exposure and effects on human health: Epidemiological and experimental findings indicate that aluminum is not as harmless as was previously thought. Elevated levels of aluminum-containing salts have been associated with different diseases such as kidney disease, and Alzheimer's disease

(Flaten, 1986; Bondy SC, 2016). A cohort study in southern Norway did not find any association between drinking water and inflammatory bowel disease (Aamodt et al., 2008).

Arsenic (As)

Occurrence and properties: Arsenic is a metalloid widely present in the earth's crust. The most common oxidation states are arsenite (As^{3+}) and arsenate (As^{5+}). Both As compounds can be found in inorganic and organic forms, the latter with lower or no toxicity. Concentrations of As in ground water, frequently the main source of drinking water, are usually less than $10\mu\text{g/L}$, but they can reach $10\text{-}5000\mu\text{g/L}$ in some areas (US EPA, 2001; EFSA, 2009). Generally, lower concentrations of As are found in surface drinking water. Essentially all arsenic in drinking water is present in its inorganic form As^{5+} .

Exposure and effects on human health: Diet is the main source of exposure to As compounds for the general population, with fish and seafood, cereals and cereal products as main contributors (Crebelli & Leopardi, 2012). Drinking water may represent a major contributor to oral exposure to inorganic As in area with high natural levels of As in groundwater. That is the major source of exposure worldwide, given that an estimated 160 million people live in regions with naturally elevated levels of As in drinking water due to the presence of arsenic-rich geological formations and /or anthropogenic activities (IARC, 2004).

There is a strong body of evidence linking As intake with a variety of health problems from acute toxicity to chronic diseases (IARC, 2004). The IARC and WHO classify As as a known (Group 1) human carcinogenic (IARC, 2004). Arsenic is related to cancer risk and skin damage, whereas Cd is linked to kidney damage and cancer. Smith et al. (1992) reported that drinking 1 L/day water with As of $50\mu\text{g/L}$ over one's life-time could lead to cancer of the liver, lung, kidney, or bladder in 13 per 1000 persons. Another study reported an increase incidence of skin lesions from an As dose of 0.0012 mg/kg/day through drinking water (Ahsan et al., 2006). In Bangladesh, approximately 6.8 million people were exposed to groundwater contaminated with As above $300\mu\text{g/L}$ (Chakraborti et al., 2010). Arsenical skin lesions were common among the populations in Bangladesh (Chakraborti et al., 2004). In addition, many other health conditions have been linked to As, such as retarded cognitive and nervous system development in children (Rosado et al., 2007). It was also found to accumulate in fingernails and hair (Choong et al., 2007); and increased stillbirths (von-Ehrenstein et al., 2006).

Nickel (Ni)

Occurrence and properties: Nickel is one of the most frequently identified contaminant known for its toxicity, mobility, and enormous use in different industries, including electroplating, steel manufacturing, pigments, storage batteries, etc. (Nandi et al., 2015). Ni is present in most foods, such as green beans, dried fruits, broccoli, peas, canned vegetables and spaghetti, canned fruits, nuts, cocoa and chocolates. Therefore, the principal contact modes between Ni and humans involve inhalation, ingestion and dermal retention (Zambelli B et al. 2016)

Exposure and health effects: Nickel gets into humans through inhalation, ingestion and dermal retention. Insoluble particulate nickel enters the vertebrate cells by phagocytosis, while nickel carbonyl, soluble in lipids, is able to pass through the plasma membrane. Ni is often considered for its poisoning potential. Ni contacts have unfavorable consequences to humans, such dermatitis, one of the most widely spread hypersensitivities in the world, and carcinogenesis. Health effects of nickel exposure rely on active changes in metabolism, inflammation, oxidative stress, cell proliferation and cell death. Many of those effects are non-specific, caused by Ni interaction with macromolecules that bind metal ions in general, and generation of radical oxygen species and other reactive compounds that mediate cellular damage (reviewed in Zambelli B et al. 2016).

Lead (Pb)

Occurrence and properties: Lead is a chemical element with atomic number 82. Lead has the second highest atomic number of all practically stable elements and its density of 11.34g/cm³ exceeds that of most common materials. Lead has several properties that make it advantageous to use, alongside its commonness: high density, softness, malleability poor electrical conductivity, high resistance to corrosion, low melting point, ductility, and the ability to react with organic chemicals (Audi et al., 2003).

Lead has four stable isotopes, Pb-204, Pb-206, Pb-207, and Pb-208. The high number of stable isotopes relies on the fact that lead's atomic number of 82 (Audi et al., 2003). The four stable isotopes of Pb could theoretically undergo alpha decay to isotopes of mercury with release of energy, but this has not been observed for any of them (Audi et al., 2003).

Lead is a heavy metal that is both poisonous and a ubiquitous environmental toxicant. It is distributed in all parts of the environment in three main forms: metallic Pb, Pb salts, and organic Pb containing carbon (Ahamed & Siddiqui, 2007a, 2007b). Although Pb occurs naturally in the

environment, anthropogenic activities such as fossil fuel burning, mining and manufacturing contribute to the release of high concentrations. Lead has many different industrial, agricultural and domestic applications. It is currently used in the production of lead-acid batteries, ammunitions, metal products (solar and pipes), and devices to shield X-rays (Gabby, 2006, 2003).

Exposure and effects on human health: Lead is considered as one of the most hazardous and cumulative environmental pollutants that affects all biological systems through exposure to air, water, and food sources (Patra et al., 2011). Lead can affect the central nervous, renal, hematopoietic, cardiovascular, gastrointestinal, musculoskeletal, endocrine, reproductive, neurological, developmental, and immunological systems (ATSDR, 2015). Exposure to Pb occurs via inhalation of Pb-contaminated dust particles or aerosols, and ingestion of Pb-contaminated food, water and paints (ATSDR, 1999, 1992). In the human body, the greatest percentage of Pb is taken into the kidney, followed by the liver and the other soft tissues such as heart and brain, however, the Pb in the skeleton represents the major body fraction (Flora, 2006). The nervous system is the most vulnerable target of lead poisoning. Headache, poor attention, spasm, irritability, loss of memory, and dullness are the early symptoms of the effects of Pb exposure on the central nervous system (CDC, 2001; ATSDR, 1999). Exposure to low levels of Pb can affect neurodevelopment. During brain development, the level of Pb in the blood interferes with the trimming and pruning of synapses, migration of neurons, and neuron/glia interactions. Alterations of any of these processes may result in failure to establish appropriate connections between structures and eventually in permanently altered functions (ATSDR, 2015).

Cadmium (Cd)

Occurrence and properties: Cadmium is a heavy metal that is widely distributed in the earth's crust at an average concentration of about 0.1 mg/kg. The highest level of Cd compounds in the environments is accumulated in sedimentary rocks. For instance, marine phosphates contain about 15mg/kg Cd. Cadmium is frequently used in various industrial activities, including production of alloys, pigments, and batteries (reviewed in Tchounwou et al., 2012)

Exposure and effects on human health: cadmium is the third most frequently reported heavy metal in drinking water, and it has been pointed as a public health concern (NTP, 2015). In the body, an important distribution route is the circulatory system, whereas blood vessels are considered to be organs of Cd toxicity. Several epidemiologic studies have documented an association of chronic low-level cadmium exposure with decreases in bone mineral density and osteoporosis (Åkesson et al., 2006; Callagher et al., 2008; Schutte et al., 2008). More importantly,

cadmium-contaminated drinking water was linked to chronic renal failure (Bawaskar et al., 2010; ATSDR, 2015); kidney failure (Gobe and Crane, 2010). Chronic exposure to Cd could lead to anemia, anosmia (loss of sense of smell), cardiovascular diseases, osteoporosis, and hypertension (Yoshida et al., 1999; ATSDR, 2015). Jaishankar et al. (2014) reported that Cd can cause bone mineralization either through bone damage or by renal dysfunction. Upon a very long exposure time at lower concentrations, it could be deposited in the kidney, ultimately leading to kidney disease, fragile bones, and lung damage (Bernard, 2008). Experiments on animals have shown that 50% of Cd is absorbed in the lungs and less in the gastrointestinal tract (Jaishankar et al., 2014).

Uranium (U)

Occurrence and properties: Uranium is the heaviest naturally occurring element and is found at an average concentration of 0.0003% (3mg/kg) in the earth's crust. Uranium is silvery-white, ductile, and slightly paramagnetic metal, which is pyrophoric when finely divided. It is slightly softer than steel and reacts with cold water when present in a finely divided state. In air it oxidize and becomes coated with a layer of oxide. Thus, in nature U mainly occurs in oxidized form (Bleise *et al.*, 2003). It occurs in numerous minerals and is also found in lignite, monazite sands, phosphate rock and phosphate fertilizers. Due to its presence in soil rocks, surface and underground water, air plants and animals it occurs also in rare trace amounts in many foods and drinking water (Bleise *et al.*, 2003). Naturally occurring U contains three isotopes, namely ^{238}U , and ^{235}U , and ^{234}U . All uranium isotopes have the same chemical properties because they all have the same number of protons (92), but have different radiological properties. All isotopes of U are radioactive, and radioactivity of U isotopes is dependent on the half-life (WHO, 2001; Bleise *et al.*, 2003).

Exposure and effects on human health: The toxicity of U is due to its radioactive and chemical properties (Brugge *et al.*, 2005; Taylor and Taylor, 1997). Uranium inhalation and or ingestion leads to malignant and non-malignant respiratory diseases, stomach and kidney cancer, kidney failure, and leukemia (Brugge *et al.*, 2005; Roscoe *et al.*, 1995). Most estimates of possible health effects following internal alpha exposure are derived from experimental animals, exposed to gamma radiation and x-rays (Walsh et al., 2015; Real et al. 2004; Howell *et al.* 1994; Spalding *et al.* 1966; Spalding et al. 1964). Uranium accumulated in the body results in chemical and radioactive effects (Bajawa *et al.*, 2015). The principal sites of U deposition in the body are the kidneys, the liver and the bones. The toxicity of U is a function of the route of exposure, particle solubility, contact time, and route of elimination (ATSDR, 1999). The concentration of radiotoxic elements like U in drinking water is kept under vigil by different health organizations. The World Health Organization

(WHO, 2004) has earlier recommended a reference level 15 mg/L but now the permissible limit of U in drinking water is 30 µg/L. The reference level is derived from epidemiological studies, based on the assumption of 60 kg adult consuming 2 liters of drinking water per day and 80% allocation of the Tolerable Daily Intake (TDI) to drinking water.

A guideline value for U in drinking water of 10 mg/L was proposed in 2005 as the maximum acceptable lifetime level compatible with health and protective for individuals against its chemically toxic effects (Konietzka *et al.*, 2005), and a limit of 10 µg/L was introduced in 2011 revision of the German drinking water ordinance. This value is lower than some other health-based limits (30µg/L) recommended for U in drinking water (WHO, 2012; US-EPA, 2009).

In addition to the kidney, other organ that is relevant to U toxicity is the liver. Because of its unique function and anatomical location, the liver is exposed to multitude of toxins and is highly susceptible to tissue injury. However, the mechanisms of cytotoxicity caused by U are not well understood, especially with respect to hepatic cells. Although U can enter the body when it is inhaled or swallowed or through cuts in the skin, most U reaching the body is removed by the kidneys and excreted in the urine a few days. However, small amounts of this element may accumulate in some tissues of mammals, especially in bone (US EPA, 2002).

In addition, there is an increasing concern on the role of environmental pollutants on male reproduction of wildlife and humans. An important role in the decline of quality and quantity of human semen (Linares *et al.*, 2006; Edwards *et al.*, 2006; Chitra *et al.*, 2003; Colborn *et al.*, 1993) has been noted with some environmental contaminants, which have been shown to induce reactive oxygen species generation in both intra-and extracellular spaces of cells or individuals leading to cell death and tissue injury (Murugesan *et al.*, 2005a; Chitra *et al.*, 2003).

Chromium (Cr)

Occurrence and properties: Chromium is a naturally occurring element present in earth's crust, with oxidation states (or valence states) ranging from chromium (II) to chromium (VI) (Jacobs & Testa, 2005). Chromium compounds are stable in the trivalent (Cr^{3+}) form and occur in nature in this state in ores, such as ferrochromite. The hexavalent (Cr^{5+}) form is the second most stable state (Patlolla A *et al.* 2009). Elemental chromium (Cr^0) does not occur naturally. Chromium enters into various environmental matrices (air, water, and soil) from a wide variety of natural and anthropogenic sources, with the largest release coming from industrial establishments (IARC, 1990;

US-EPA, 1992). In animals and humans, Cr^{3+} is an essential nutrient that plays a role in glucose, fat, and protein metabolism by potentiating the action of insulin (Goyer, 2001). However, occupational exposure has been a major concern because of the high risk of Cr-induced diseases in industrial workers occupationally exposed to Cr^{5+} (Guertin, 2005). Moreover, it is estimated that more than 300,000 workers are exposed to Cr and Cr-containing compounds in the workplace. It is estimated that 33 tons of total Cr are released annually into the environment (reviewed in Tchounwou et al., 2012).

Exposure and effects on human health: Occupational and environmental exposure to Cr^{5+} containing compounds is known to cause multi-organ toxicity, such as renal damage, allergy and asthma, and cancer of respiratory tract in humans (Goyer, 2001; WHO/IPCS, 1988). There are some reports that link health effects of Cr in drinking water. For instance, Gowd & Govil (2008) have reported higher Cr levels in water, which was associated with ulcers among the population surrounding an industrial area in India. Another study in Greece with Cr concentrations of 8.3–51 $\mu\text{g/L}$ in drinking water reported significantly higher standard mortality ratios for primary liver cancer, lung cancer, kidney cancer, and other genitourinary organs among women (Linos et al., 2011).

Copper (Cu)

Occurrence and properties: Copper is present in the Earth's crust in a proportion of about 50 parts per million. It occurs as native Cu, in the copper sulfides chalcopyrite and chalcocite, in the copper carbonates azurite and malachite, and in the copper (I) oxide mineral cuprite (Hammond et al., 2004). Copper is a soft, malleable, and ductile metal with very high thermal and electrical conductivity. A freshly exposed surface of pure Cu has a reddish-orange color. It is used as a conductor of heat and electricity, as a building material and as a constituent of various metal alloys, such as sterling silver used in jewelry, cupronickel used to make marine hardware and coins, and constantan used in strain gauges and thermocouples for temperature measurement. Copper is found as a pure metal in nature, and this was the first source of the metal to be used by humans (McHenry, 1992).

Exposure and effects on human health: copper is an essential trace element for normal body growth and development, and is the third most abundant transition metal in the body and imperative for neural functioning. Copper is present throughout the brain, being most prominent in hippocampus, basal ganglia, cerebellum and numerous synaptic membranes. Several central nervous system enzymes are dependent on Cu for their function. However, although indispensable,

excess copper can be cytotoxic as it can produce highly damaging free hydroxyl radicals by Fenton or Haber-Weiss reaction (reviewed in Pal, et al, 2014). Toxicity due to excess copper in body organs including liver and brain have been reported like in Wilson`s disease, Indian childhood cirrhosis, and idiopathic copper toxicities in humans (reviewed in Pal, et al, 2014). Exposure to Cu through contaminated water or other beverages has been associated with nausea, vomiting, and/or abdominal pain. This makes drinking water to be the primary source of excess Cu intake by humans (ATSDR, 2015). Several studies show that Cu concentrations in drinking water range from a few µg/l to 10 mg/l. However, the WHO interim guideline for drinking water recommends Cu concentration of 2 mg/l (reviewed in Pal, et al, 2014).

Iron (Fe)

Occurrence and properties: Iron is the second most abundant metal on earth`s crust, and it is a most crucial element for growth and survival of almost all living things as it is a cofactor for many vital proteins and enzymes (Valko et al., 2005). Water a high content of Fe may be brown-colored and precipitation of rusty residues in the well or the distribution system may cause unattractive taste and appearance. 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, and the mafic silicates and the reduction of Fe-oxy-hydroxides such as goetite/limonite (Appelo & Postma, 1994).

Exposure and effects on human health: Iron is an essential element to all organisms. Intake of iron in normal concentrations above 0.2 mg/L from drinking water has no negative effects (Reimann et al., 1998). There are not many studies that looked into the impact of chemical elements and human health in Norway. However, one study that evaluated the association of inflammatory bowel disease and supply of drinking water in southern Norway has shown that the risk of developing inflammatory bowel disease, including ulcerative colitis and Crohn`s disease was associated with high iron content. The relative risk of developing inflammatory bowel disease increased by 21% when the iron content in drinking water increased by 0.1 mg/ml (Aamodt et al., 2008).

Manganese (Mn)

Occurrence and properties: Manganese is the 12th most abundant element on earth`s crust (Nadaska et al., 2012). As a transition metal, Mn exists in more than five valence states, with a majority as a Mn²⁺ or Mn³⁺ (Aschner et al., 1999). In the environment, it is found mainly in its oxidized chemical form MnO₂ or MnO₃. Manganese is known to be released into the environment

from industrial sources such as the production of iron and steel, as well as power plants emissions. For human consumption, Mn is abundant in plant-based foods, including peanut butter, whole wheat bread and pineapple, and to some extent in whole grains (Freeland-graves et al., 2016).

Exposure and effects on human health: Manganese is an essential element to human health, acting as a co-factor in the catalytic activity of enzymes, and it is required for normal development, maintenance of nerves and immune cell functions, and regulation of blood sugar and vitamins (Frisbie et al. 2015). Manganese can also be toxic. It has been especially associated with neurotoxicity, depending on the amount of daily intake. According to the Institute of Medicine in the US, the upper tolerance limit for Mn is 11 mg/l per day. Most commonly, Mn toxicity results from exposure to a polluted environment. For instance, a study in Canada on the intellectual functioning of 362 schoolchildren has shown that manganese concentrations in water ranging from 1.0 to 27 mg/l were significantly positively associated with Mn content in the hair of the children. There are also reports that indicate strong association between exposure to elevated levels of Mn in drinking water and impaired intellectual development in children (reviewed in Frisbie et al. 2015). In another study in Bangladesh, it has been shown that exposure to Mn in drinking water was found to reduce performance in mathematics among schoolchildren (Khan et al., 2012).

Vanadium (V)

Occurrence and properties: Vanadium is a trace element widely distributed in the earth's crust at an average concentration of approximately 100 mg/kg. Vanadium exists in different oxidative states, the most common being V^{3+} , V^{4+} and V^{5+} . Pentavalent vanadium is chemically most stable, and it represents the most toxic form. Food is the main source of exposure to V for the general population, with an estimated dietary intake of the order of few tens of micrograms per person per day. Drinking water contributes to a lesser extent, as concentrations of V in drinking water generally do not exceed few micrograms per liter. However, considerably higher concentrations (above 100 mg/L) are recorded in some water supplies, notably, in groundwater from volcanic areas as a consequence of the leaching from V rich rocks (Wight & Belitz, 2009).

Exposure and effects on human health: Chemical form, oxidation status, and route of exposure play key role in determining the degree of toxicity of V compounds. Orally administered V compounds (sodium and ammonium meta-vanadate, sodium ortho-vanadate, vanadyl sulphates) have been reported to produce adverse effects in kidney, spleen and lungs of rodents, to raise blood pressure in rats, and to elicit reproductive and developmental toxicity in rats and mice (EFSA,

2004). In humans, mild toxic effects (gastro-intestinal discomfort) have been reported in subjects taking high V doses as food supplements (EFSA, 2004). Several studies that investigated the genotoxic potential of V indicate that both pentavalent and tetravalent vanadium are clearly genotoxic in test system *in vitro* where induction of DNA strand breaks, chromosome damage and altered chromosome segregation (EFSA, 2004).

2.5 Studies of trace elements in drinking water in Norway

There are a number of reports in regarding trace elements in drinking water in Norway (Rekstad, 1922; England & Myhrstad, 1980; Flaten, 1980, 1986; Hongve et al., 1994; Banks et al., 1995a, b; Reimann et al., 1996; Morland et al., 1997, 1998).

One of the first published notes on the quality of crystalline bedrock groundwater in Norway was given by Rekstad (1922), who evaluated the experience with drilled wells. The water from a borehole in granitic gneiss at Nesodden, outside Oslo, was described as “crystal clear and pleasant”, and in addition, radon containing. Rekstad (1922) further states that the groundwater flowing through granite has a rather low mineral content and is thus an ideal source of groundwater. The occurrence of radio-active groundwater in the granite of Østfold County is registered as “not unlikely”. In 1971, the Agricultural Research Council of Norway and the National Institute of Public Health initiated the first Norwegian survey of the chemistry of groundwater (England & Myhrstad, 1980). They analyzed 507 groundwater samples from 98 bedrock boreholes in three areas in southern Norway, Lake Mjøsa district, Ås (Follo) and Moss-Jeløy. On the basis of different electrical conductivity from different reservoir rock types, it was concluded that the groundwater quality was not only dependent on the weathering reactions in the unsaturated zone, but also on water rock interaction below the groundwater table. Groundwater samples from areas below the late post-glacial marine limit were to a variable extent found to be influenced by ancient sea salts, and average pH values ranged for the different lithological units ranged between 7.0 and 7.7 (England & Myhrstad, 1980).

A more comprehensive survey of the chemical quality of drinking water from all waterworks in Norway serving >1000 persons was carried out at the Geological Survey of Norway between 1981 and 1986 (Flaten, 1986). The study included 384 waterworks that together served 71% of the total Norwegian population. Among the 384 waterworks, 35 waterworks used groundwater sources. No distinction was made between groundwater from crystalline bedrock aquifers and quaternary aquifers, but only two major water works in Norway based on crystalline bedrock groundwater

(Morland et al., 1998). Flaten (1986) noted that pH, Ba, and NO_3^{2-} , concentrations were generally higher in the groundwater samples, while Al concentrations were lower (probably due to the higher pH values). A small number of measured high trace metal concentrations (Pb, Cu, Zn, Ni) were ascribed to contamination from plumbing materials during the period 1986-1991. The National Institute of Public Health investigated the chemical quality of drinking water from 566 waterworks serving 2,684,000 persons or 64% of the population in Norway. Of these, 30 waterworks were based on groundwater from crystalline bedrock aquifers. It was noted that most incidents of high sodium, fluoride, and/or alkalinity were connected to crystalline bedrock aquifers (Hongve et al., 1994). Some trace elements were determined (Pb, Cd, Cr, Ni, Cu, As, and Se) by means of graphite furnace atomic absorption (GFAAS), but only few values were above the detection limit (Hongve et al., 1994).

In 1992, Norwegian Geological Survey (NGU) sampled 28 bore wells in hard rocks in Nord-Trøndelag county and in the area around Oslofjorden (Banks et al., 1995a, 1995b). The water samples were analyzed by means of inductively coupled plasma-mass spectroscopy (ICP-MS), for the determination of 64 elements in all). The results showed great variation in groundwater quality among different rock types. In the precambrian Idddefjord granite 9 of 11 water samples had radon (Rn) contents exceeding the Norwegian recommended action level of 500 Bq/l, and the fluoride and the U contents were also at a level of concern.

In 1994, NGU surveyed the groundwater quality in more than 300 drilled bedrock wells in counties of Vesfold and Hordaland, which contain the greatest densities of such wells in Norway (Reimann et al., 1996; Morland et al., 1997). The radon content was higher than the recommended maximum level (500 Bq/l) in 17% of the wells and the fluoride concentration exceeded the drinking water norms (1.5 mg/l) in 16% of the wells. Around 13% of the water samples had uranium concentrations above the Canadian limit (20 µg/l at the time) and concentrations up to 2000 µg/l Uranium were revealed. In total, 53% of the wells failed the drinking water regulation on the basis of the five health related parameters, Rn, pH, U, fluoride (F-) or Na. Again, the most problematic rocks seemed to be of granite composition. It was recognized that the study possibly gave biased results, as investigated counties included granite rich Oslo Rift and Genesis areas around Bergen.

2.6 Geology of Norway

The Norwegian landscape is a function of a geological processes over a very long time span. Large portions of landforms in Norway were formed due to Quaternary glaciations and periglacial processes, spanning over the last 3 million years. This period is characterized by cool and variable climate with temperatures oscillating between relative mildness to frigid ice-age conditions. As glaciers move across the earth's surface they erode and transport sediments, making ice sheets and glaciers powerful agents of erosion (Fredin et al., 2013). It has been reported that up to 40 glacial cycles have been waxed and waned in Scandinavia during the last million years. Five full-scale glaciation cycles have been operating during the last 500 kyr ("thousand years") where the dominant mode of glaciation was centered around the mountain chain, resulting in major erosion (Storeven & Klemen, 1997). Several documents (reviewed in Olsen et al., 2013) on the Quaternary glacial history of Norway describe an enormous erosional impact on the Norwegian landscape, producing deep fjords and their extensions on the shelves, long U-shaped valleys, numerous cirques and many lakes in over-deepened bedrock basins. Quaternary map and Bedrock of Norway is given in Appendix D.

A major part of the present, remaining, onshore glacial deposits in Norway derive from the last glaciation (Weichselian) and the more than 90% ($>100,000\text{-}150,000\text{ km}^3$) of the Quaternary glacial erosional products from Norway have been transported and deposited offshore. These sediments are mainly deposited in large depocenters at the mid-Norwegian shelf and in trough-mouth fans at the mouths of the Norwegian Channel and the Bjørnøyrenna Trench (Olsen et al., 2013). Generally, Norway has large areas of exposed bedrock or bedrock with a thin cover of Quaternary sediments. However, the southeastern part of Norway (the lowland east and northeast of Oslo), areas adjacent to and under the former ice divide, in southern Norway, the Jæren area in southwest Norway, and Finnmarksvidda in Northern Norway, have large areas with a generally continuous cover of sediments (Olsen et al., 2013). The sediments are dominated by tills in most areas, but in the main valley and basins water-lain sediments, including glacio-fluvial, fluvial and marine deposits often represent the dominant sediment types (Olsen et al., 2013).

2.6.1 Sedimentary aquifer

Aquifer sediments are mainly composed of silt, silty sand, and fine sand. Due to gentle surface topography and low hydraulic conductivity of aquifer sediments, groundwater is mostly stagnant (Guo et al., 2008). However, shallow groundwater flow system has been substantially affected by irrigation channels and drainage channels. According to Banks et al. (1998b), there are only a few

studies on the chemistry of quaternary sedimentary aquifer in Norway. Results of 72 samples obtained from Norwegian Quaternary (largely glacio-fluvial or glacial) aquifers for major and minor hydro-chemical parameters have shown that no ground waters from quaternary deposits exceeded maximum recommended levels of radon, iron, sodium, while 10% of the sample fell outside the required pH range (Bank et al. 1998b).

2.6.2 Bedrock aquifers

A bedrock aquifer is an aquifer composed of consolidated material such as limestone, dolomite sandstone, siltstone, shale, or fractured crystalline rock (Dictionary of Ecology, 2010). Crystalline bedrock aquifers represent significant source of drinking water globally. The first account of groundwater chemistry of bedrock wells in Norway was done by the geological survey of in the mid-1990s (Bank et al., 1995; Morland et al., 1997; Reimann et al., 1996; Fregstad et al., 1998). However, most of these studies were limited to either certain areas of Norway, or to specific chemical elements. A more comprehensive study of the natural chemical quality of crystalline bedrock in Norway was done by Banks *et al* (1998). His works include analysis of 1600 samples from water wells drilled in bedrock throughout Norway for radon (Rn) content, major and minor elements, pH and alkalinity. The results showed that about 220 wells had Rn content of over the recommended level and over 250 well had a fluoride concentration of the recommended level (Midtgård et al., 1998). Considering many other elements studied, including pH, sodium, Rn, and fluoride, 30% of the wells had water that does not meet standards set by the authorities (Midtgård et al., 1998). Analyses of major and minor elements in 1604 crystalline bedrock groundwater samples showed that about 13.9% of the bedrock groundwater exceeded the recommended action level of radon, while 16.1% exceeded the drinking water norm for fluoride (Banks et al., 1998).

3 MATERIALS AND METHODS

3.1 Sources/sites of ground drinking water

3.1.1 Selection of water works

To get a representative picture of Norwegian groundwater from all geographical regions, waterworks that use groundwater as their source were taken into account for this study. In Norway 42% of waterworks use groundwater as source, supplying 10% of the Norwegian population.

The selection of waterworks was based on the Norwegian Institute of Public Health (NIPH) water register database. The Norwegian Waterworks Register (VREG) is a national water register of waterworks supplying at least 50 persons or 20 households. In addition, some small waterworks (private wells and public) that are not registered in (VREG) were included. There are 566 registered Norwegian waterworks with groundwater as their source of drinking water. The waterworks are distributed over the whole country, except Oslo County. Hedmark County stands out as the county with the most waterworks with groundwater source. In total, it was desirable to collect 400 water samples from waterworks spread out in the country. Due to the large number of waterworks in some of the counties, an upper limit was set to 40 waterworks. These counties were Hedmark, Oppland, Buskerud, Hordaland, Sør-Trøndelag, Møre and Romsdal and Nordland. A random sampling to ensure a representative picture for the country did the selection of waterworks from these counties. All large waterworks supplying persons ≥ 10000 were automatically included.

Out of the 400 waterworks selected, we received water samples from 201 (50.2%) waterworks spread over 111 municipalities (Fig. 1). The samples were distributed across municipalities from all Norwegian counties (except Oslo county), with a slightly fewer participation from the Northern part of Norway. Information about waterworks are given in appendix A

3.1.2 Sampling and fieldwork

Water samples were collected by an employee at each waterworks and immediately sent to the National Institute of Public Health (NIPH) for registration. Sampling procedure, sampling equipment and sampling sheet form were sent in advance to the waterworks, as given in appendix B. Collection of water samples was carried out from 11. April to 13. June 2016. Water samples were collected from the source (raw water) and from distribution network (clean/treated water). Raw water samples were taken directly from the source (well). Clean water was collected from the tap without the water flow being regulated to ensure minimum influence of contamination from the

pipelines. Two raw water and two clean water samples, respectively, were obtained in 15 ml polypropylene (PP, metal free) tubes. In addition, one 200 ml Low Density Polyethylene (LDPE, non-metallic) bottle were filled with clean water. A total of 201 waterworks supplying 4.9 % of the Norwegian population provided 603 clean water and 402 raw water samples.

The water samples were temporary kept in a refrigerated storage (1 – 4 °C) at NIPH until they were analyzed at the Faculty of Environmental Sciences laboratory, Norwegian University of Life Sciences (NMBU), Ås.

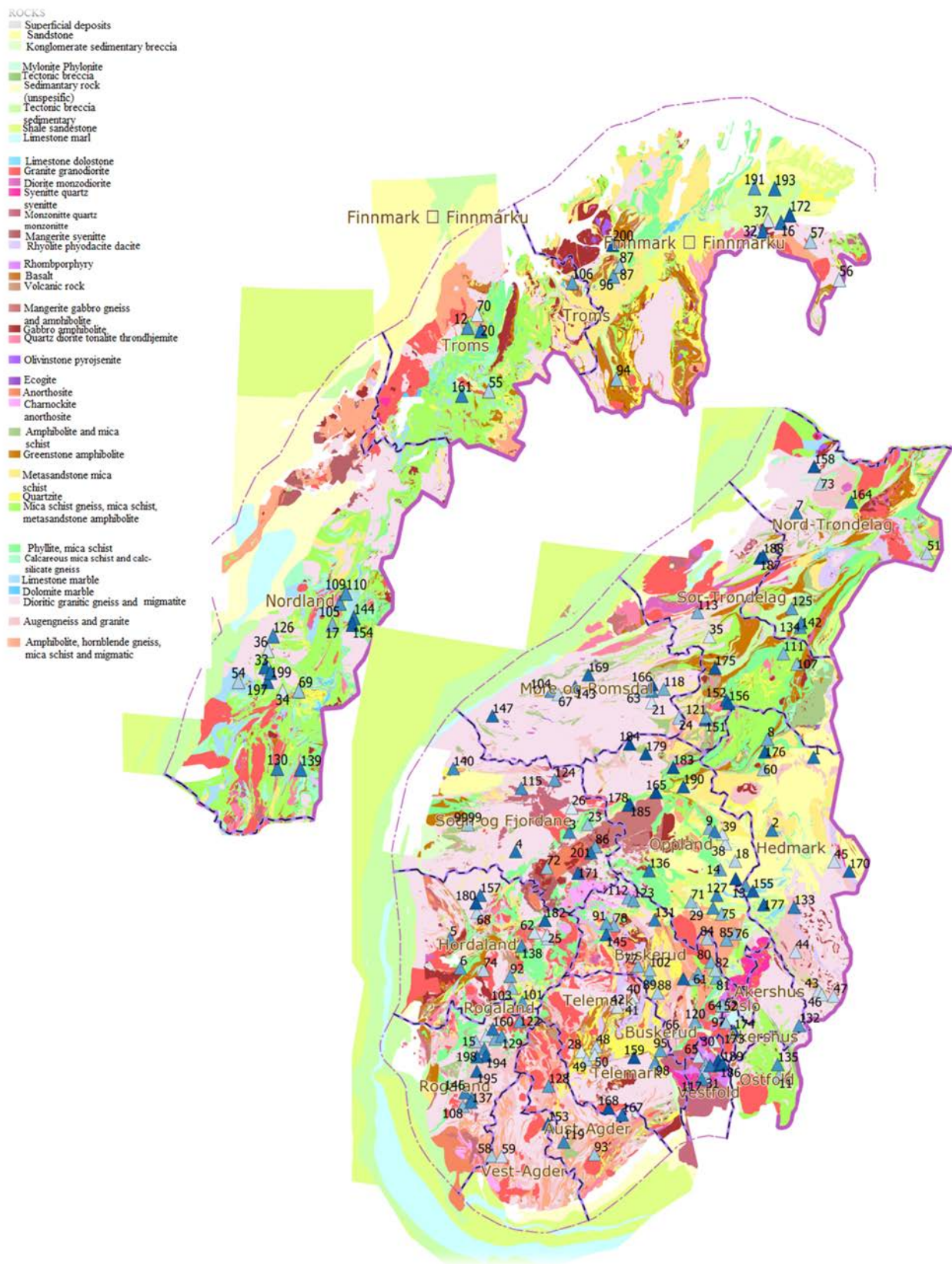


Figure 1. Bedrock geology map of Southern Norway and Northern Norway. Blue dots indicate the locations of waterworks where the samples were taken.

3.2 Laboratory analysis

3.2.1 Sample preparation

Groundwater samples were sorted and labeled according to the type of water (raw water or clean water) and preservatives (acid or base). The bottles containing 200 ml of clean water were refrigerate at 3°C, and was used for physio-chemical parameter analysis such as pH, alkalinity, turbidity, conductivity and color, as well as for determination of fluoride, nitrate, and sulfate.

One of the two parallels of clean water was acid preserved by adding 0.4 ml of nitric acid, HNO₃ (sub boiled ultrapure, 65% (w/w), NMBU), and the other one were subjected to alkaline preservation, by addition of 0.4 ml ammonia (NH₃) (Pro Analysis, 25 % (w/w), MERCK). Raw water was preserved in the same way as clean water. Accordingly, ten blank samples were made as laboratory quality controls for both the acid and the alkaline preserved clean and raw water. After preservation, water samples were corked, thoroughly mixed, and put to storage at room temperature until analysis using ICP-MS.

3.2.2 Chemical analysis

The ground water samples were analyzed using an Agilent 8800 Triple quadrupole ICP-MS (ICP-QQQ). The technique enables identification and determination of a broad range of elements that have not been determined previously (Agilent, 2014), including the halogens Cl, Br, and I, in order to determine their level in groundwater in Norway. Ion Chromatography (IC) was used for the determination of F⁻, nitrates and sulfates. Moreover, physio-chemical parameters such as pH, alkalinity, turbidity, conductivity and color were also determined as the basis for water quality indicators. The analyses were performed by conventional standardized methods. (Sosial- og Helsedepartementet, 2001).

Concurrent analysis of the certified reference material (CRM) 1640a Trace elements in Natural Water (National Institute of Standard & Technology, 2010) secured traceability in the ICP-MS method, as well as a supervision for method accuracy. In addition, to check the accuracy of REE analysis of the certified reference material SPS-SW1 Batch 123 and SPS-SW2 Batch131 Reference material for measurement of elements in surface water (Spectrapure Standards, 2008) were used. Unfortunately, 1640a or SPS-SW1 Batch 123 and SPS-SW2 Batch131 has no certified limits for the halogens (Cl, Br and I). To describe the accuracy of the determinations of fluoride, nitrate, sulfate, and water quality indicators (pH, alkalinity, turbidity, conductivity and color), the certified reference material CARNBERRY-05 (Environmental Canada, 2011) was used.

3.2.3 ICP-MS

The laboratory technical staff conducted the ICP-MS analysis. All samples were analyzed in June 2016. The Agilent 8800 ICP-QQQ is the only ICP-MS with a single quadrupole (Q1), a reaction collision cell and a second quadrupole (Q2) before the detector, which operates as unit mass filter reducing most of the interferences (Agilent, 2014). Helium was used when collision was useful, and oxygen whenever a reaction with the element of interest or with an interfering element was the best option to reduce an interference. The certified Inorganic Ventures ICPMS-71A calibration standard was used for drift correction. Multi-standards were used as internal standard. In addition, an In-House reference standard (1640H) was used for control of accuracy in calibration of the instrument.

3.2.4 Determination of anions: fluoride (F^-), nitrate-nitrogen (NO_3-N) and sulfate (SO_4^{2-})

Ion chromatography was the technique used for the analysis of water sample for determination of fluoride, nitrate, and sulfate. The analytic method is based on the Norwegian standard NS-EN ISO 10304-1 (NSF 1995). A laboratory engineer conducted the IC analysis. A Thermo Fisher Scientific Dionex ICS-5000 system was used. In ion exchange chromatography, to determine inorganic anions, samples are kept in an analytic column (anion-exchange), where the negatively charged anions are attracted to a positively charged surface. The eluent used was a mixing of different carbonate and bicarbonate (CO_3^{2-} / HCO_3^-). The eluent removes the anions from the column in different time depending on the electrical affinity among them. The suppressor (cation-exchange) converts the carbonate eluent to low (reduction) conductivity carbonic acid, while converting the sample anions to their more highly conductive acid form. A conductivity detector provides a sensitive method for detecting the eluting ions, thus the amount of anions in the sample is quantified.

3.2.5 Water quality indicators

3.2.5.1. Determination of pH

The pH of water samples was determined according to Norwegian Standard NS 4720 (NSF 1974), which is an outdated method, using a Radiometer PHM210 with an Orion Ross electrode (a combined glass electrode with integrated reference electrode). The instrument was calibrated with two buffers pH 4.0 and 7.00 at 24 °C. In advance, all water samples were brought to room temperature.

3.2.5.2. Determination of alkalinity

The alkalinity was measured according to the Norwegian standard ISO 9963-1 (NSF 1996). The temperature of the samples was allowed to reach room temperature (24°C) before analysis. Then, the samples were titrated with a 0.02 M hydrochloric acid solution until the pH reached 4.5. The HCl solution was titrated into the sample using a Digital Titrator (Metro 665 Dosimat) with a delivery tip to add titrant to the sample. During titration, Radiometer PHM210 was used to monitor the pH. After completing the titration, the alkalinity was calculated by a stoichiometric determination.

3.2.5.3. Determination of color

The color of the water samples was determined according to the Norwegian Standard NS-EN ISO 7887 (NSF 1994a). The instrument used was Shimadzu, UV-1201 to measure absorbance of light as it passes through a sample at 410 nm wavelength. Before the measurement, the temperature of samples were allowed to reach room temperature (24°C), and then filtered through 0.45µm polyethersulfone membrane filter. About 10 ml of water samples was placed into 5 cm sample cell holder to measure the absorbance at 410 nm. The instrument was calibrated using platinum - cobalt standard that provides absorbance 0.27 per 100 mg / l Pt.

3.2.5.4. Determination of turbidity

To determine turbidity, the Norwegian standard ISO 7027 (NSF 1994b) were followed. Turbidity meter HACH 2100AN IS was used to measure the turbidity (insoluble substance). The turbidity of a sample is measured from the amount of light scattered by the sample taking a reference with standard turbidity suspension. The scattered light (860 nm) was measured perpendicular to the direction of light. Formazin (C₂H₄N₂) was used as standard solution and a unit is set in FNU (Formazin Turbidimetric Units). For testing the given water samples the turbidity meter was calibrated. This was done by adding turbidity free deionized water to sample cell, wipe gently with soft tissue and place it in turbidity meter to adjust the reading to zero. To calibrate the Turbidity meter, Standard solution a 200 FNU solution was used. This was repeated three times. After instrument calibration, water sample was added to the sample cell up to horizontal mark and was wiped gently with soft tissue. The sample was placed in turbidity meter in such a way that the vertical mark in sample cell should coincide with the mark in the turbidity meter and cover the sample. The turbidity was noted down when the reading was stable.

3.2.5.5 Determination of conductivity

The analysis method is based on the Norwegian standard ISO 7888 (NSF 1993a). Using TetraCon® 925 the conductivity was determined. The instrument was calibrated by measuring 0.01 M KCl giving the conductivity of 1413 $\mu\text{S} / \text{cm}$. To measure the conductivity, the electrode probe was dipped into the water samples and the reading was noted down. The probe was washed twice with deionized water and wiped with soft tissue paper before taking the probe directly into new water samples.

3.3 Statistical methods

3.3.1 Raw data processing

The statistical analysis was done with Microsoft Office Excel (2013). Descriptive statistics was used to describe range, median/mean, and standard deviation, and the number and percentage of limit of quantification (LOQ). The concentration of elements measured by ICP-MS had values below the detection limits and the quantification limits. The non-detectable values were substituted by one-half the detection limit and quantification limit (LOD/2 and LOQ/2). This is the most commonly used method in environmental chemistry (Helsel, 2006). Elements with over 20 % of the concentration values under LOQ were not included in the statistics.

3.3.2 Principal Component Analysis (PCA)

The multivariate statistical method Principal Component Analysis was used to better exam the variation of data set. The statistical software R Studio (R core Team 2014) was used to perform the PCA. PCA is a technique used to examine the interrelations among a set of variables and bring out strong patterns in data set. The goal using PCA is to extract important information from the data set. The method is a mathematical procedure that uses an orthogonal transformation to covert a set of observations of correlated variables into a set of values of uncorrelated variables, called principal components (PCs), which account for the majority of the variability in the data. The number of principal components needed to explain most of the variability in the data is typically less than the number of original variables. The transformation is defined in such a way that the first principal component (PC1) has as high a variance as possible (explaining the most variability in the data), and each following components in turn has the highest variance possible under the restriction that it be orthogonal to (uncorrelated) the preceding components. Figure 7 shows an example of PCA analysis.

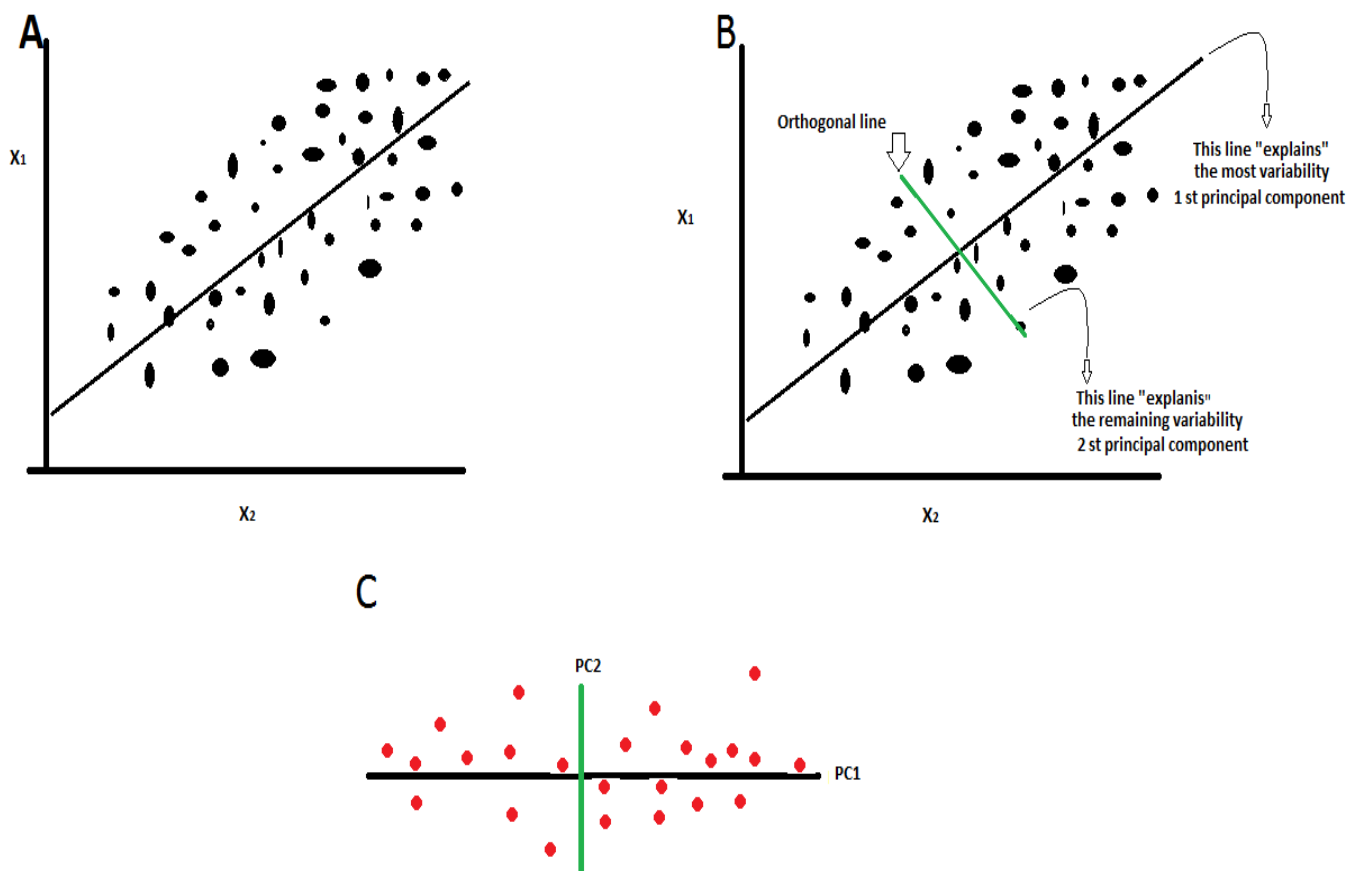


Figure 7 show an example of PCA illustration. In the figure, A shows a scatterplot of two correlated Variables X_1 and X_2 , PCA analysis determines potentially several (here two) orthogonal variables of maximum variance (in figure B). Figure C shows PCA transformation of the data into a new dimensional (a new coordinate system) in such way the greatest variance of data comes on the first axis (PC1) and the second greatest variance on the second axis (PC2).

The result of principal component can be presented as “score plot”. The co –ordinate values of the observations are called scores, and hence the plotting of such a projected configuration is known as score plot. With score plot, it is possible to visualize the observations structure of the investigated data. The most commonly used plot (in 2D plot) is score vector for PC1 versus the score vector for PC2. In PCA, it is also possible to examine which variables are responsible for the patterns seen among the observations. Meaning which variables are influential and how the variables are correlated. The “loadings plot” gives such knowledge. The loadings plot displays the relationships among all variables at the same times. Variables contributing similar information are grouped

together (they are correlated). When variables are negatively (inversely) correlated they are positioned on opposite sides of the plot.

In this study, the observations are waterworks and the variables are elements determined using ICP-MS. The Data set were divided in two groups; clean water (treated water) from waterworks and raw water from waterworks. Pre-processing of the data set is essential for relevant and valid modelling results. The data were log transformed ($\text{Log}(X+1)$). In addition, data were centered and standardized prior to the analysis. Variables with more than 25% missing observations (below limit of detection (LOD) and limit of quantification (LOQ)) were imputed. Hence, the missing values were replaced with reasonable values (imputation algorithm is based on iterative singular value decomposition (SVD) of data matrix), and the final data had 34 variables for clean water and 33 variables for raw water. From PCA analysis three PCA diagrams were made for interpretation; Score plot and correlation (circle) loadings plot.

4 RESULTS

4.1. Overview of total concentration of elements

A total of 201 water samples were analyzed for trace elements from 201 waterworks covering different geological regions of Norway. The trace elements determined are given in table 2. The total concentration of 61 trace elements were determined by ICP-MS.

Considering the concentration of calcium, magnesium, potassium, sodium, strontium, silicon, and sulfur in the water samples, every values were quantifiable. All the remaining elements had values under LOQ. Out of the 61 trace elements determined, sodium had the largest range (0.7 – 160 mg/L). Elements with over 20 % of the concentration values under LOQ and elements with value above 60 % of the concentration under LOD, but under 20 % LOQ are not included in table 2. These elements were Bi, In, Lu, Nb, Ta, Te, Sn and Ti. For instance, Bi and Ti had 98% value below LOD.

4.2. Components in drinking water with regulation limit in Norwegian Water Regulation

The Norwegian Water Regulation (Helse- og omsorgsdepartementet, 2001) is listing 16 inorganic elements and ions with regulation limits (Al, Sb, As, B, Fe, Cd, Cu, Pb, Cr, Hg, Mn, Na, Ni, Se, F⁻, and Cl⁻); and among these, all except Hg were determined. In addition, physio-chemical parameter such as pH, alkalinity, turbidity, conductivity and color, as well as nitrate and sulfate were determined.

4.2.1 Major and trace elements

Aluminum was above regulation limits (200 µg/L) at two waterworks (Fig. 3). The highest Al concentration was measured at water work 58 (280 µg/L), followed by water work 167 (230 µg/L). The median concentration of Al was 10 µg/L. The manganese concentration was higher than the regulation limits (50 µg/L) at nine waterworks (Fig. 4). The highest concentration of Mn was observed at water work 80 (270 µg/L), followed by water work 187 (230 µg/L) and water work 134 (200 µg/L). The median value of Mn was 2 µg/L. Copper was beyond the standard limits (100 µg/L) at ten waterworks (Fig. 5). The highest concentration of Cu was at water work 101 (630 µg/L), followed by water works 55 (570 µg/L), 56(530 µg/L), 117(460 µg/L), and 183(410 µg/L). The mean value of Cu was 30 µg/L and median value was 5µg/L. Iron was higher than the regulation limits (200 µg/L) at six waterworks (Fig. 6). The highest concentration of Fe was observed at water work 121 (2200 µg/L), followed by waterworks 187 (940 µg/L), 191 (640 µg/L),

Table 2. Concentration of elements in Norwegian groundwater (n = 201) measured by ICP-MS. An overview of minimum, maximum, mean, standard deviation, median, number and percentage of unquantifiable measurements.

Elements	Min – Max [µg/L]	Mean value [µg/L]	Standard deviation [µg/L]	Median [µg/L]	Number of measurements <LOQ	Percentage (%) of measurements <LOQ
Aluminium (Al)	<1.9 - 280	20	39	9	27	13.
Arsenic (As)	<0.011 - 14	0.3	1	0.05	11	5.5
Barium (Ba)	<0.12 - 260	20	33	10	2	1.0
Beryllium (Be)	<0.0079 - 0.4	0.03	0.01	0.018	36	18
Boron (B)	<2.19 - 180	<2.19	-	<2.19	67	33
Calcium (Ca)	$0.028 \cdot 10^3$ - $51 \cdot 10^3$	$20 \cdot 10^3$	$12 \cdot 10^3$	$10 \cdot 10^3$	0	0
Cerium (Ce)	<0.0025 - 110	0.9	7	0.06	21	10
Copper (Cu)	<0.12 - 630	30	85	5	3	1.5
Dysprosium (Dy)	<0.0024 - 4.1	0.09	0.3	0.02	23	11
Erbium (Er)	<0.0019 - 2.0	0.05	0.2	0.01	23	11
Gadolinium (Gd)	<0.0027 - 7.4	0.10	0.5	0.03	21	10
Iron(Fe)	<0.42 - 2200	40	179	5	17	8.5
Lanthanum (La)	<0.0025 - 120	2	9	0.2	6	3
Lead (Pb)	<0.0098 - 64	1	5	0.2	11	5.5
Lithium (Li)	<0.058 - 16	2	2	0.8	20	10
Magnesium (Mg)	$0.066 \cdot 10^3$ – $15 \cdot 10^3$	$2 \cdot 10^3$	$2 \cdot 10^3$	$2 \cdot 10^3$	0	0
Manganese (Mn)	<0.062 - 270	11	34	1	14	7
Molybdenum (Mo)	<0.013 - 30	1	3	0.3	6	3.0
Neodymium (Nd)	<0.0028 - 74	1	5	0.2	4	2
Nickel (Ni)	<0.058 - 84	2	6	0.4	12	6
Phosphor (P)	<4.9 - 67	8	8	6	12	6
Potassium (K)	$0.14 \cdot 10^3$ - $10 \cdot 10^3$	$2 \cdot 10^3$	$1 \cdot 10^3$	$1 \cdot 10^3$	0	0
Praseodymium (Pr)	<0.002 - 21	0.3	2	0.04	18	9
Rubidium (Rb)	<0.037 - 14	2	2	1	1	0.5
Samarium (Sm)	<0.0033 – 9.0	0.1	0.6	0.02	25	12
Sodium (Na)	$0.7 \cdot 10^3$ – $160 \cdot 10^3$	$14 \cdot 10^3$	$24 \cdot 10^3$	$5 \cdot 10^3$	0	0.
Strontium (Sr)	0.089 - 1000	110	160	50	0	0.
Silicon (Si)	$0.45 \cdot 10^3$ - $20 \cdot 10^3$	$4 \cdot 10^3$	$3 \cdot 10^3$	$4 \cdot 10^3$	0	0.
Sulfur (S)	$0.12 \cdot 10^3$ – $6 \cdot 10^3$	$3 \cdot 10^3$	$3 \cdot 10^3$	$2 \cdot 10^3$	0	0.
Uranium (U)	<0.0033 - 68	3	8	0.3	2	1
Vandadium (V)	<0.0069 - 8	0.3	0.7	0.09	1	0.5
Ytterbium (Yb)	<0.0022 - 1.3	0.04	0.1	0.01	21	11
Ytterium (Y)	<0.0007 - 28	0.6	2	0.1	0	0
Zinc (Zn)	<0.31 - 1700	35	160	7	12	6

149 (520 $\mu\text{g/L}$), 11 (260 $\mu\text{g/L}$) and 171 (250 $\mu\text{g/L}$). Considering Fe, the mean and median values were 4 $\mu\text{g/L}$ and 5 $\mu\text{g/L}$, respectively. Nickel had values higher than the regulation limits (20 $\mu\text{g/L}$) at one water works (Fig. 7). This was at water work 18 (84 $\mu\text{g/L}$), and the median concentration of Ni was 0.4 $\mu\text{g/L}$. Arsenic value was higher than regulation limits (10 $\mu\text{g/L}$) at one waterworks (Fig. 8). The highest concentration was measured at water work 152 (14 $\mu\text{g/L}$). However, most of the water works showed low concentrations of As with a median value 0.06 $\mu\text{g/L}$. The lead concentration was higher than the regulation limits (10 $\mu\text{g/L}$) at two waterworks (Fig. 9). The highest concentration was observed at water work 183 (64 $\mu\text{g/L}$), followed by water work 18 (14 $\mu\text{g/L}$). The mean value of Pb was 1 $\mu\text{g/L}$ and the median was 0.2 $\mu\text{g/L}$. On the other hand, the concentrations of boron, sodium, selenium, antimony, cadmium, and chromium were within the Norwegian regulation limits at all the 201 waterworks participating in this investigation (Figures 10-15).

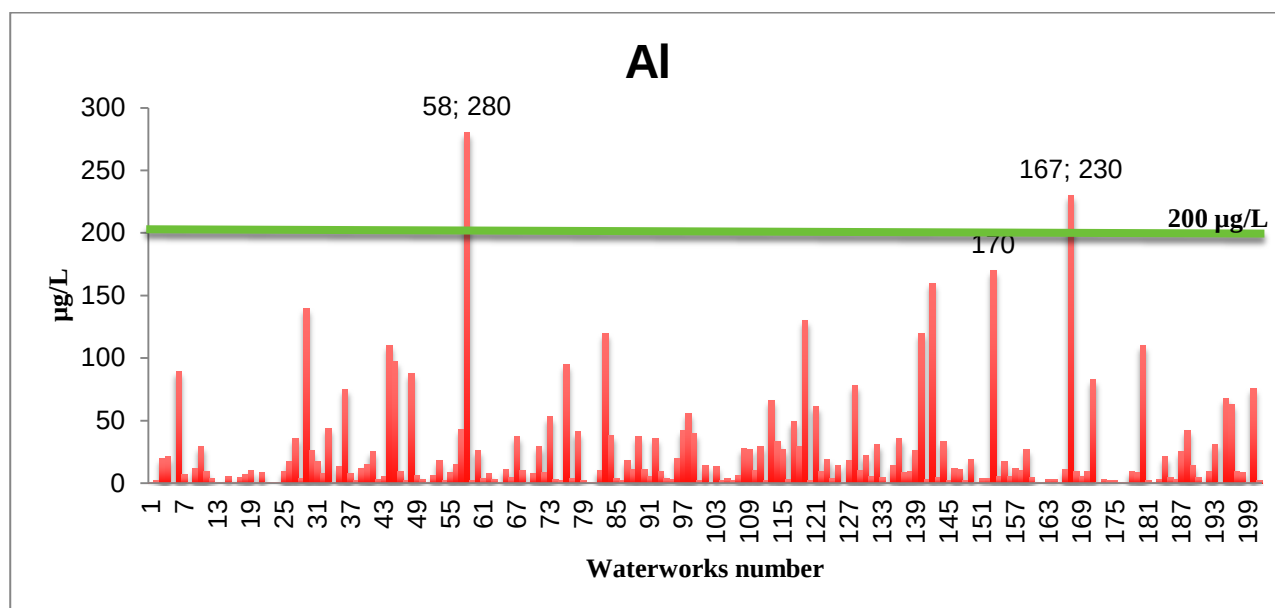


Figure 3. Concentrations of aluminum ($\mu\text{g/L}$) measured in groundwater samples collected at 201 Norwegian waterworks. The green line shows the Norwegian regulation limit for aluminum. At every waterworks $n=1$.

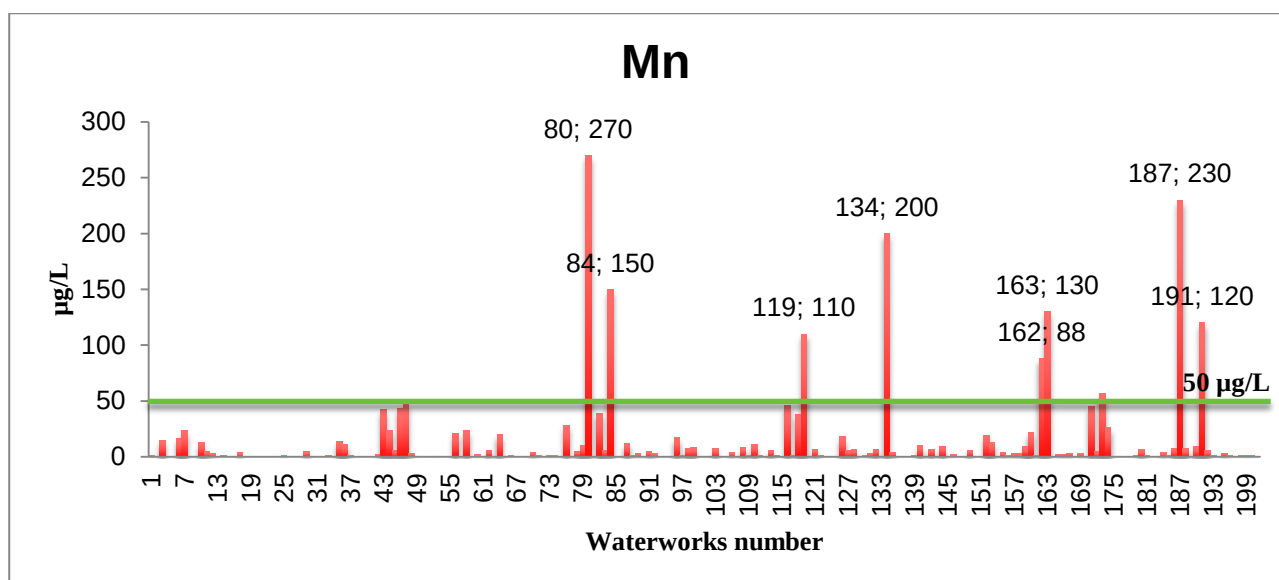


Figure 4. Concentrations of manganese (µg/L) measured in groundwater samples collected at 201 Norwegian waterworks. The green line shows the Norwegian regulation limit for manganese. At every waterworks $n=1$

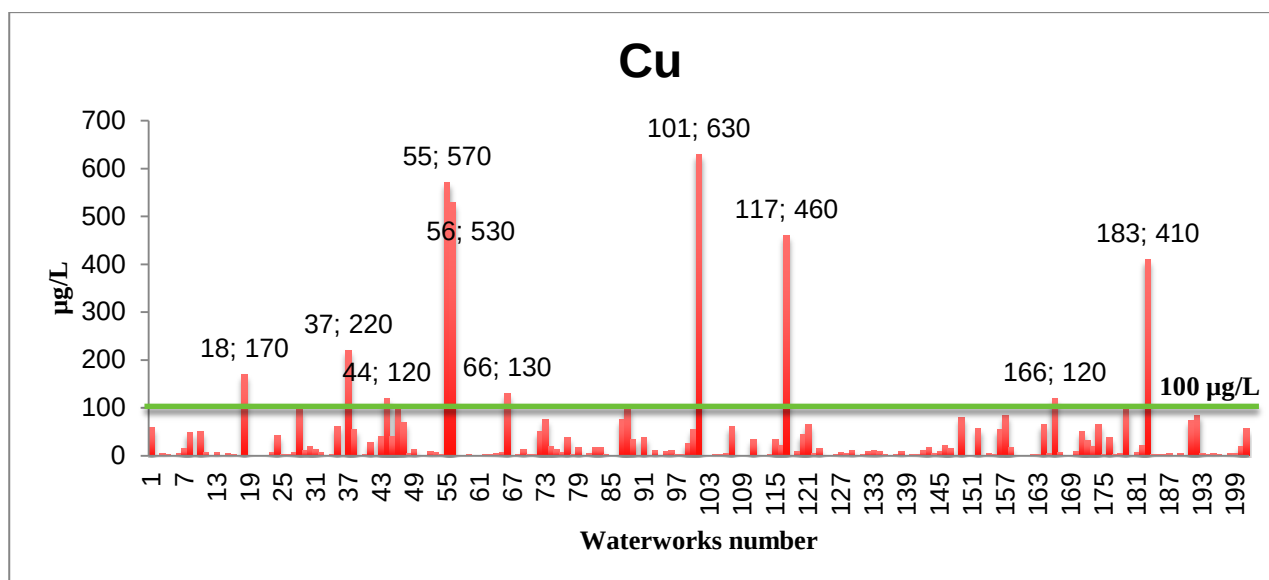


Figure 5. Concentrations of copper (µg/L) measured in groundwater samples collected at 201 Norwegian waterworks. The green line shows the Norwegian regulation limit for copper. At every waterworks $n=1$.

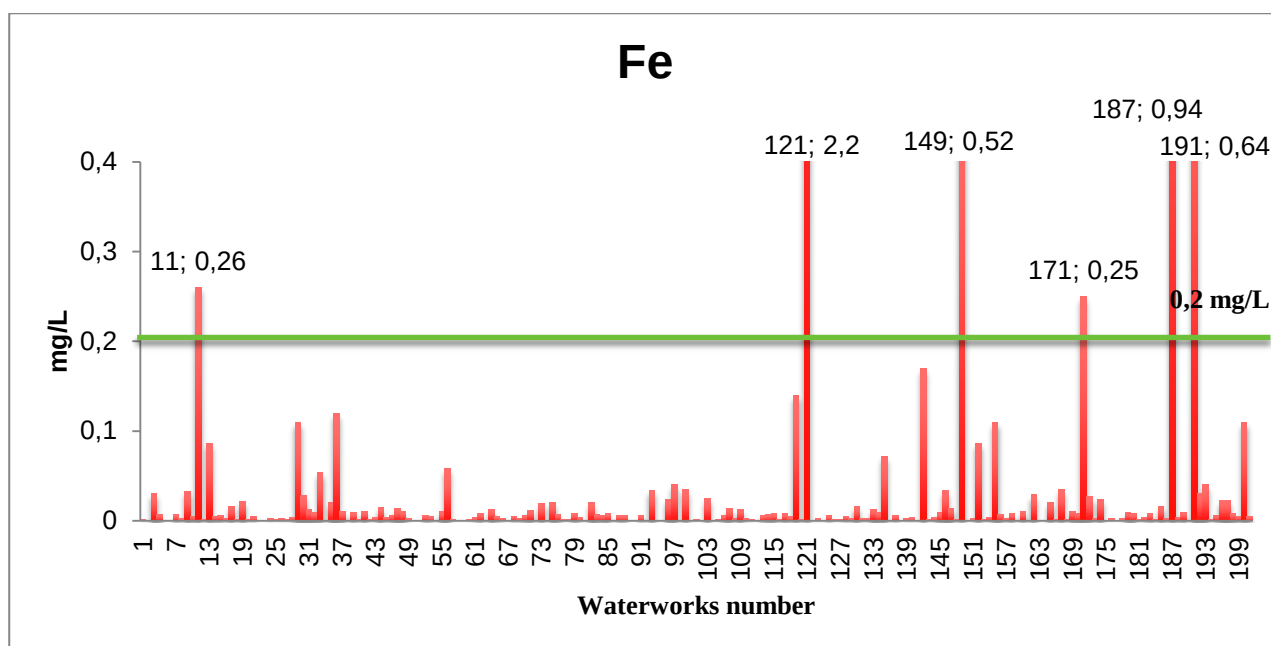


Figure 6. Concentrations of iron (mg/L) measured in groundwater samples collected at 201 Norwegian waterworks. The green line shows the Norwegian regulation limit for iron. At every waterworks $n=1$.

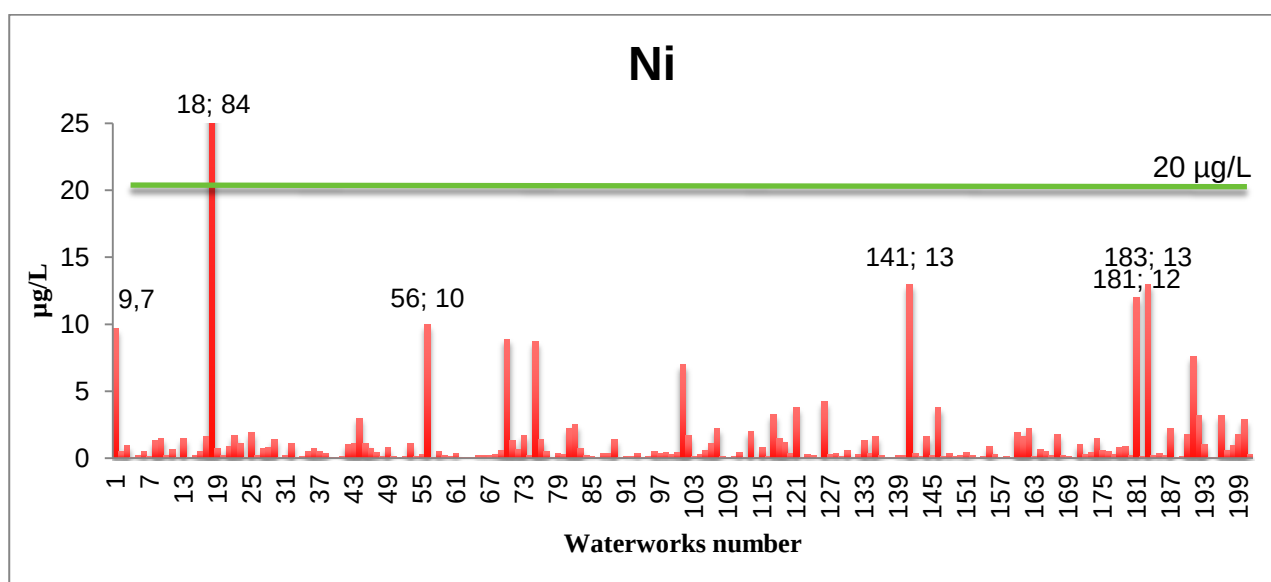


Figure 7. Concentrations of nickel (µg/L) measured in groundwater samples collected at 201 Norwegian waterworks. The green line shows the Norwegian regulation limit for nickel. At every waterworks $n=1$.

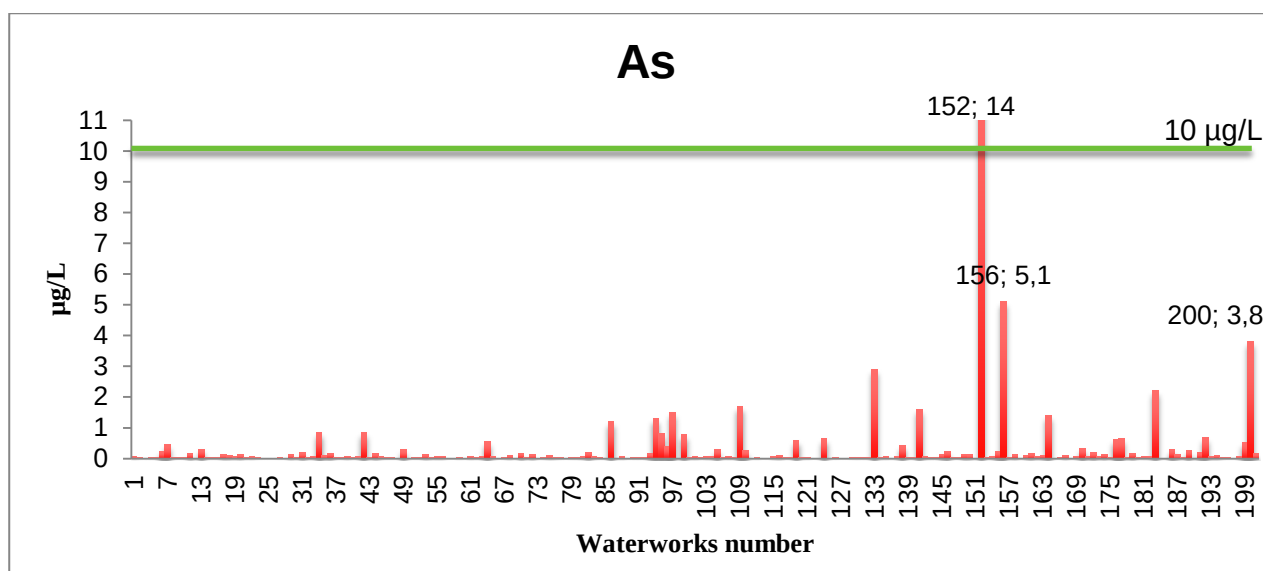


Figure 8. Concentrations of arsenic ($\mu\text{g/L}$) measured in groundwater samples collected at 201 Norwegian waterworks. The green line shows the Norwegian regulation limit for arsenic. At every waterworks $n=1$.

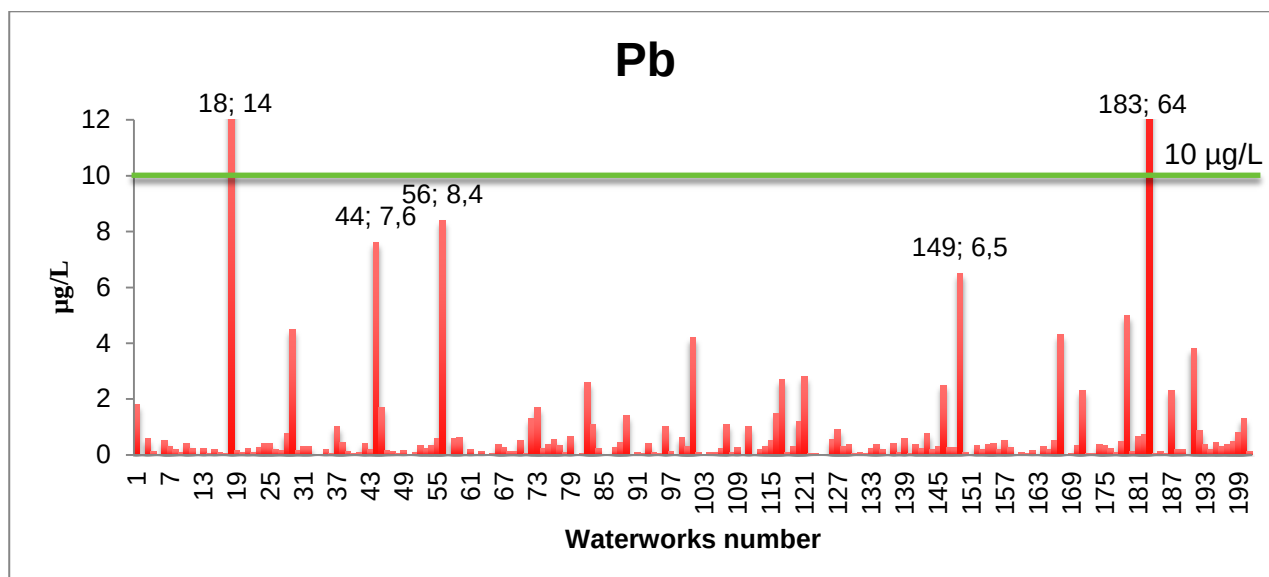


Figure 9. Concentrations of lead ($\mu\text{g/L}$) measured in groundwater samples collected at 201 Norwegian waterworks. The green line shows the Norwegian regulation limit for lead. At every waterworks $n=1$.

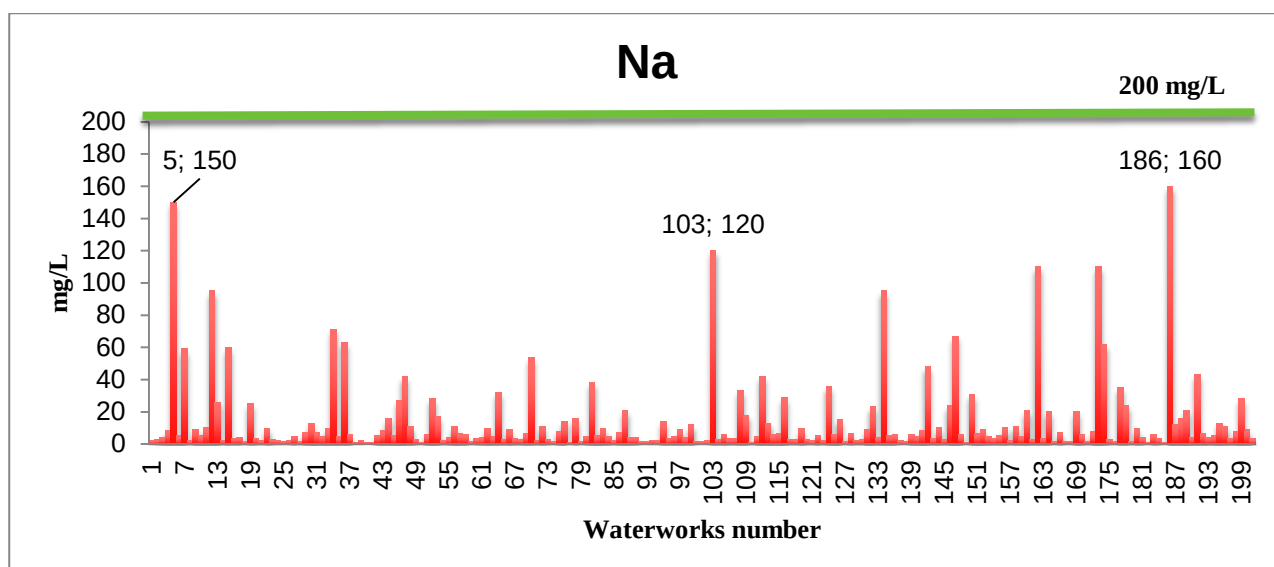


Figure 10. Concentrations of sodium ($\mu\text{g/L}$) measured in groundwater samples collected at 201 Norwegian waterworks. The green line shows the Norwegian regulation limit for sodium. At every waterworks $n=1$.

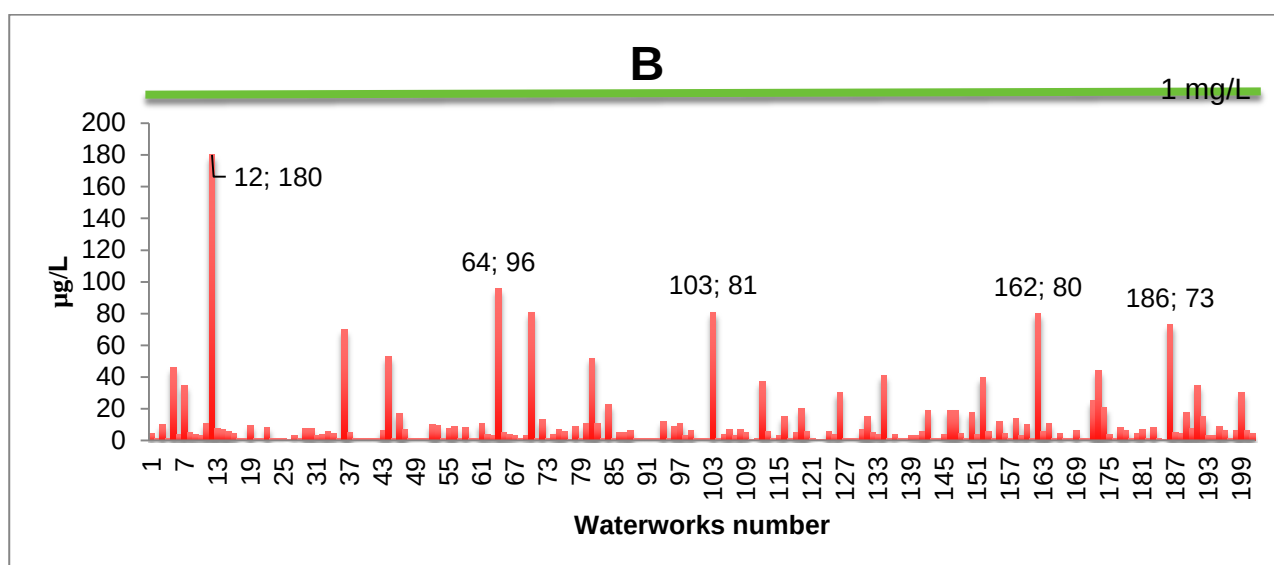


Figure 11. Concentration s of boron ($\mu\text{g/L}$) measured in groundwater samples collected at 201 Norwegian waterworks. The green line shows the Norwegian regulation limit for boron. At every waterworks $n=1$.

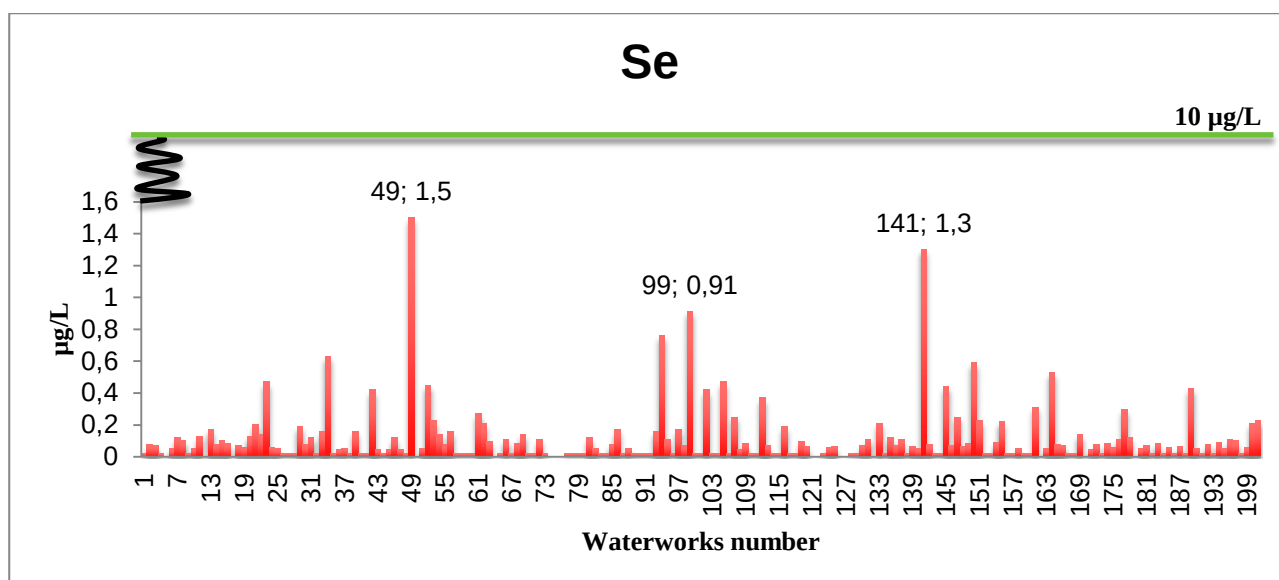


Figure 12. Concentrations of selenium ($\mu\text{g/L}$) measured in groundwater samples collected at 201 Norwegian waterworks. The green line shows the Norwegian regulation limit for selenium. At every waterworks $n=1$.

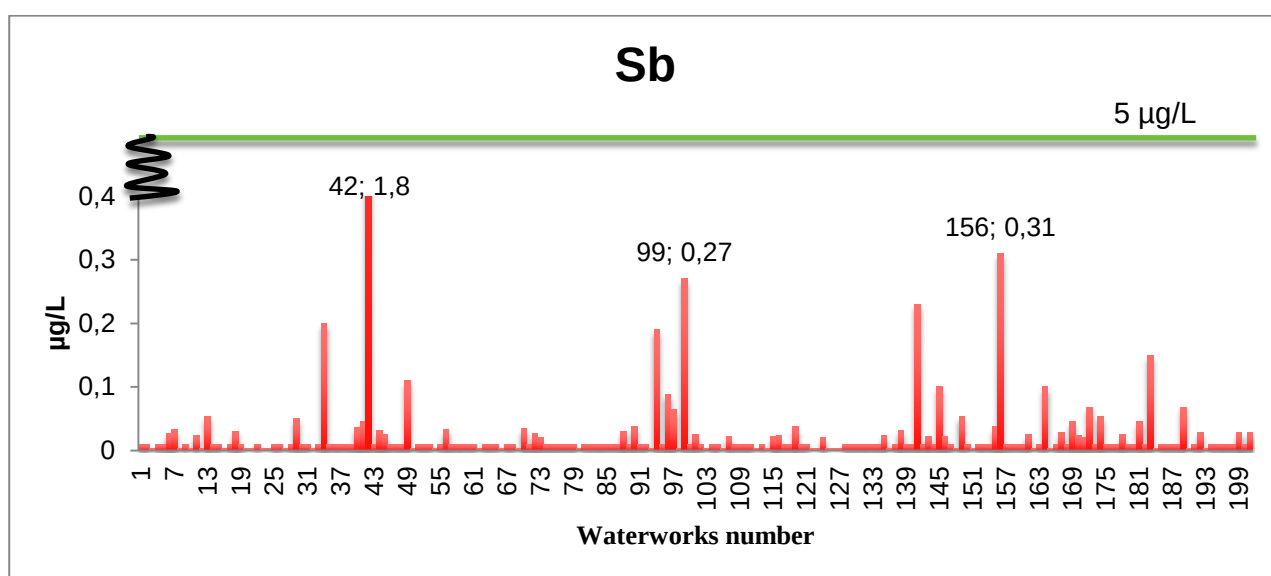


Figure13. Concentrations of antimony ($\mu\text{g/L}$) measured in groundwater samples collected at 201 Norwegian waterworks. The green line shows the Norwegian regulation limit for antimony. At every waterworks $n=1$.

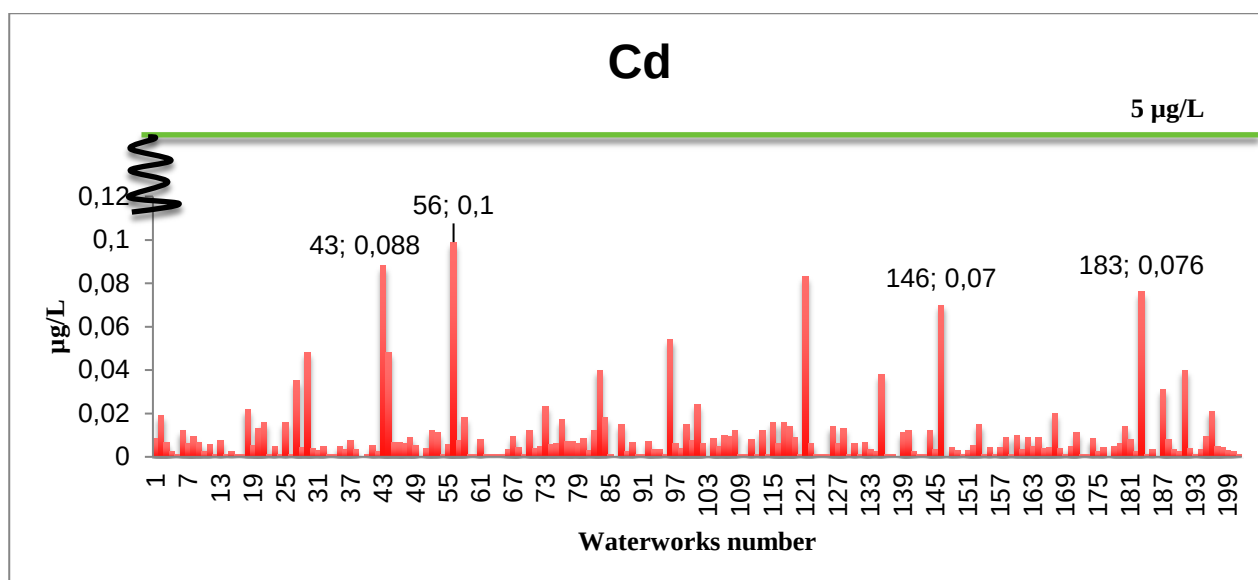


Figure 14. Concentrations of cadmium ($\mu\text{g/L}$) measured in groundwater samples collected at 201 Norwegian waterworks. The green line shows the Norwegian regulation limit for cadmium. At every waterworks $n=1$.

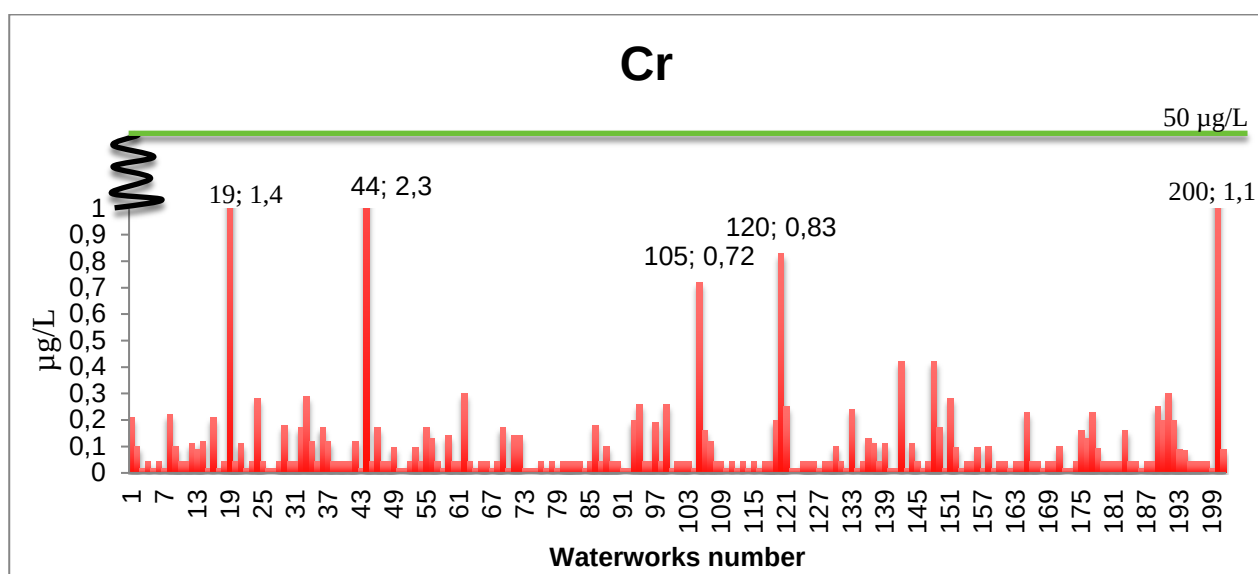


Figure 15. Concentrations of chromium ($\mu\text{g/L}$) measured in groundwater samples collected at 201 Norwegian waterworks. The green line shows the Norwegian regulation limit for chromium. At every waterworks $n=1$.

4.2.2 Anions

Among anions, fluoride was beyond the regulation limit (1.5 mg/L) at four waterworks (Fig. 16). The highest concentration was observed at water work 12 (4 mg/L), followed by waterworks 7 (1.86 mg/L), 84 (1.84 mg/L) and 52 (1.82 mg/L). Chlorine was within the regulation limits in all

waterworks (Fig 16& 17). Nitrate and sulfate were also within the regulation limit (Figures 18 and 19).

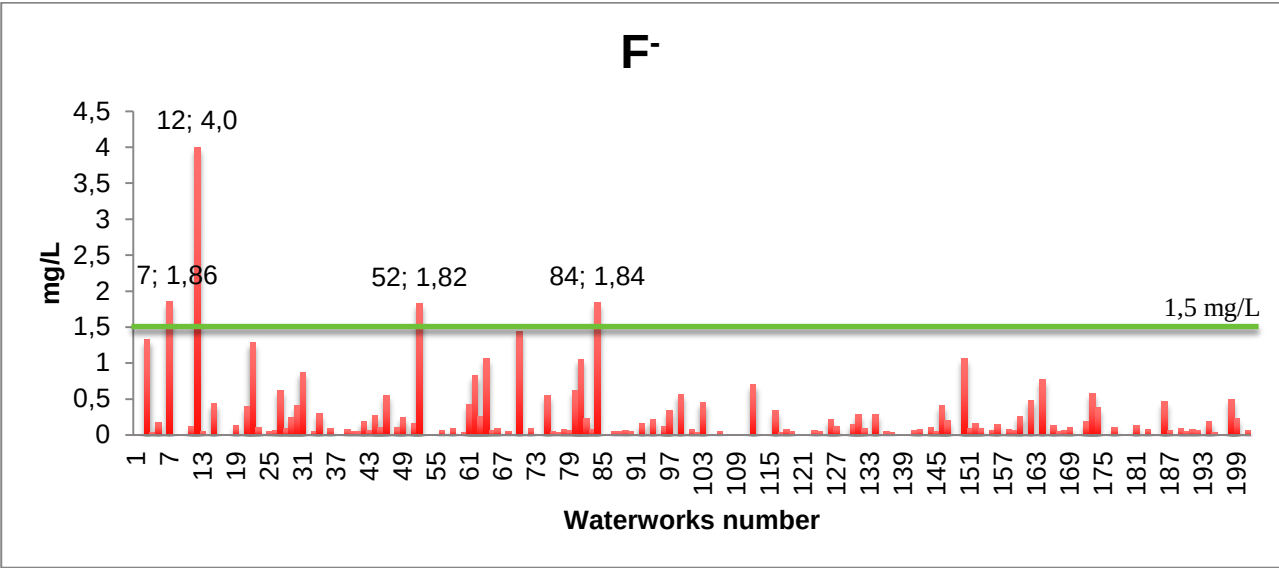


Figure 16. Concentrations of fluoride (mg/L) measured in groundwater samples collected at 201 Norwegian waterworks. The green line shows the Norwegian regulation limit for fluoride. At every waterworks $n=1$.

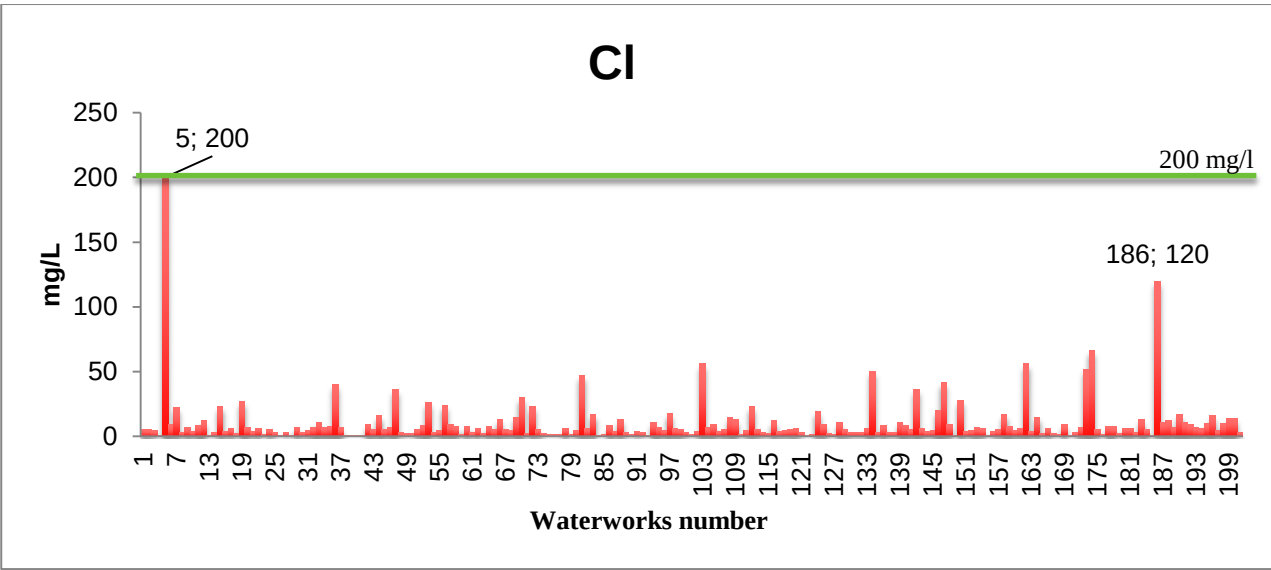


Figure 17. Concentrations of chlorine (mg/L) measured in groundwater samples collected at 201 Norwegian waterworks. The green line shows the Norwegian regulation limit for chlorine. At every waterworks $n=1$.

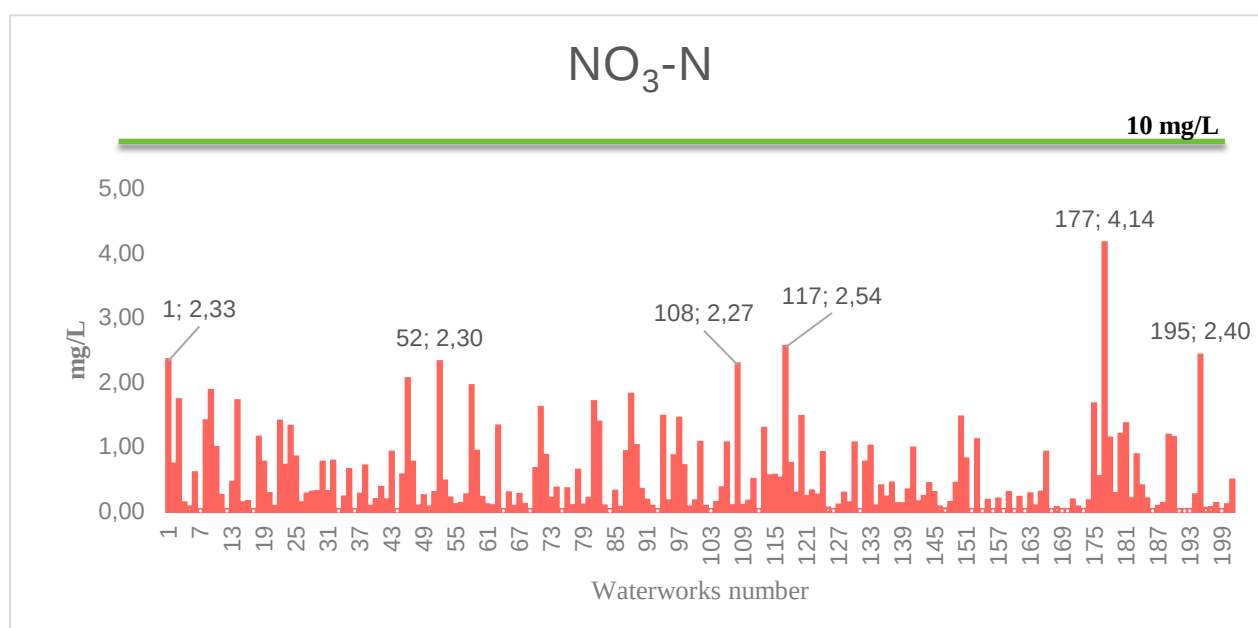


Figure 18. Concentrations of nitrate-N (mg/L) measured in groundwater samples collected at 201 Norwegian waterworks. The green line shows the Norwegian regulation limit for $\text{NO}_3\text{-N}$. At every waterworks $n=1$.

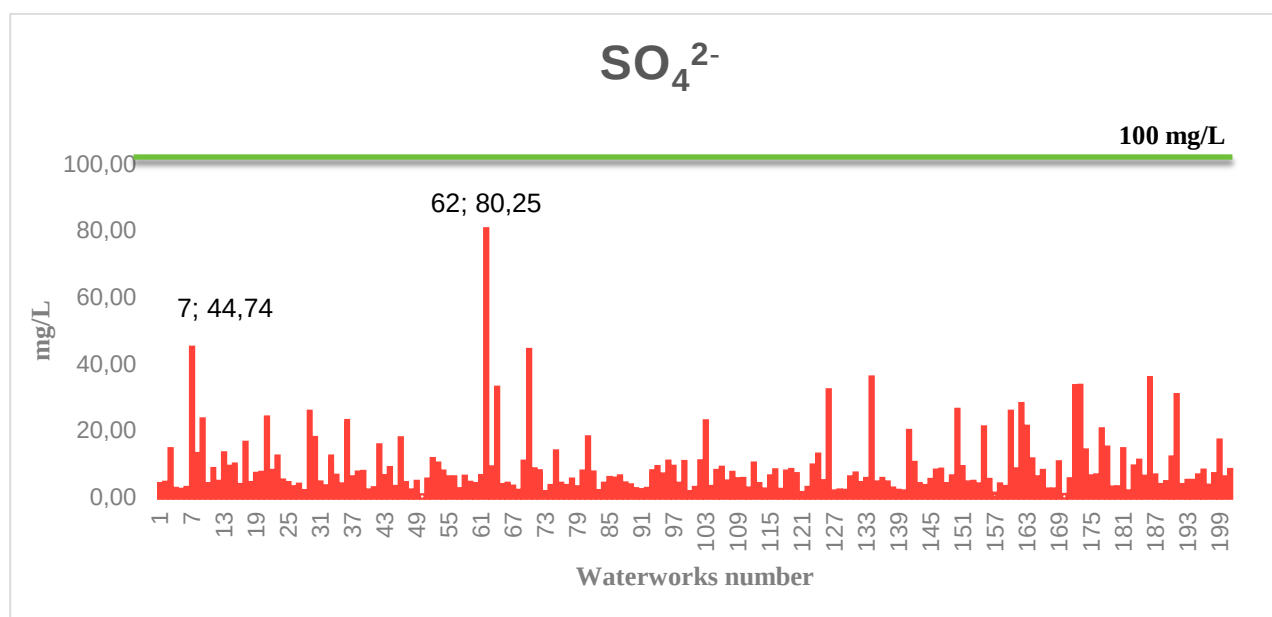


Figure 19. Concentrations of sulfate (mg/L) measured in groundwater samples collected at 201 Norwegian waterworks. The green line shows the Norwegian regulation limit for sulfate. At every waterworks $n=1$.

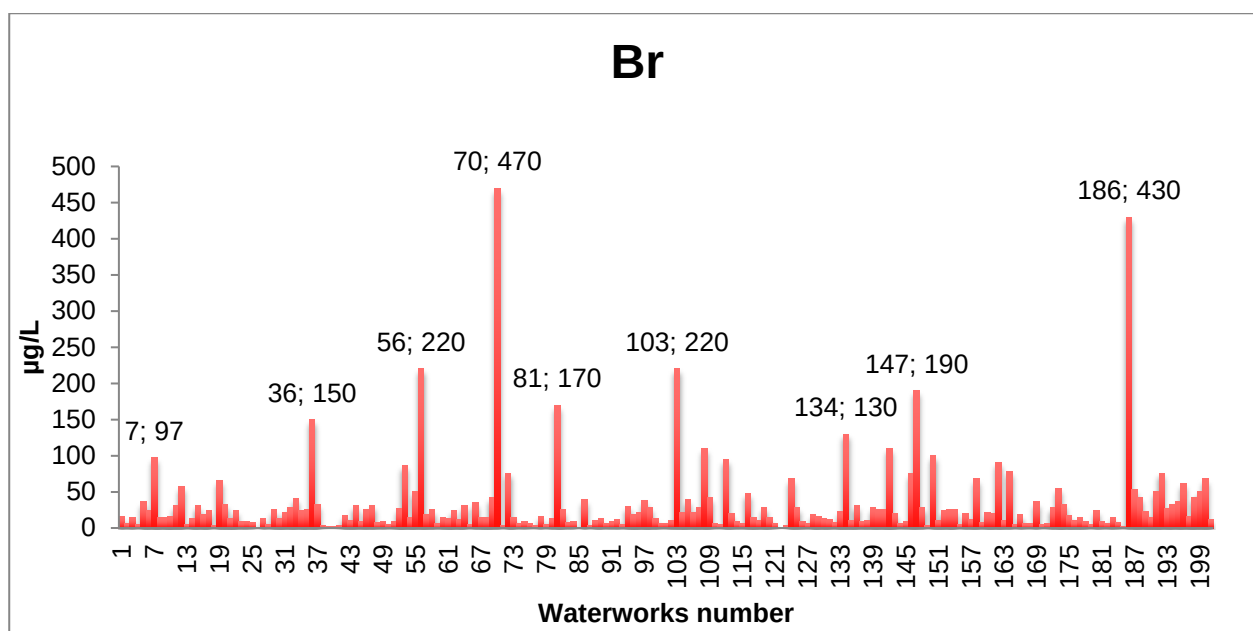


Figure 20. Concentrations of bromine ($\mu\text{g/L}$) measured in groundwater samples collected at 201 Norwegian waterworks. At every waterworks $n=1$.

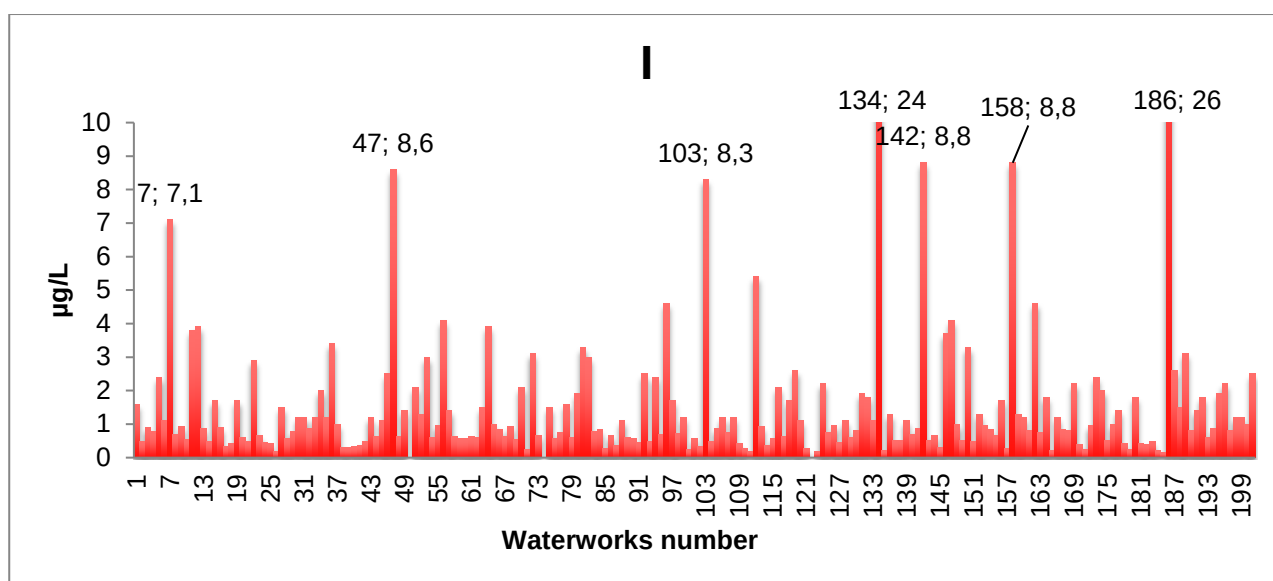


Figure 21. Concentrations of iodine ($\mu\text{g/L}$) measured in groundwater samples collected at 201 Norwegian waterworks. At every waterworks $n=1$.

4.2.3 Water quality indicators

4.2.3.1 Turbidity and color

Water quality analysis (Fig. 22) shows that water samples collected from one waterworks had a turbidity value higher (2.21 FNU) than the regulation limit (1.5 FNU). The median value was 0.18

FNU. However, with one marginal exception, the color quality analysis showed that the water samples collected from all waterworks located in different geographical regions of Norway had a color quality within the regulation limit (20 mgPt/L) (Fig. 23).

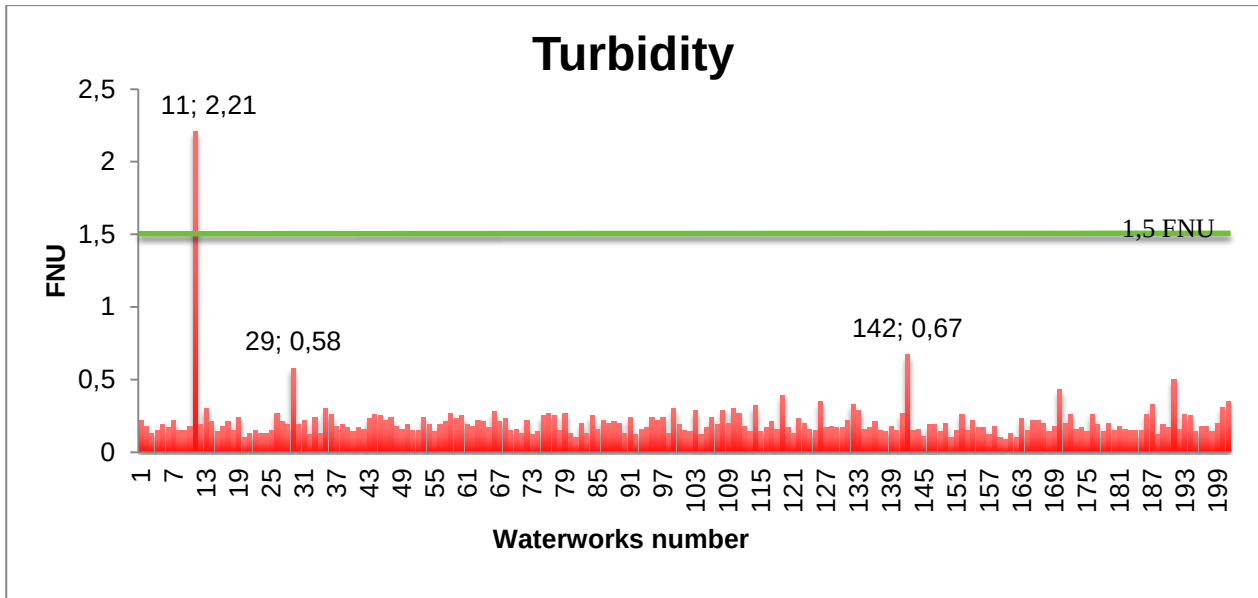


Figure 22. Turbidity measured in groundwater samples collected at 201 Norwegian waterworks. The green line shows the Norwegian regulation limit for turbidity. At every waterworks $n=1$.

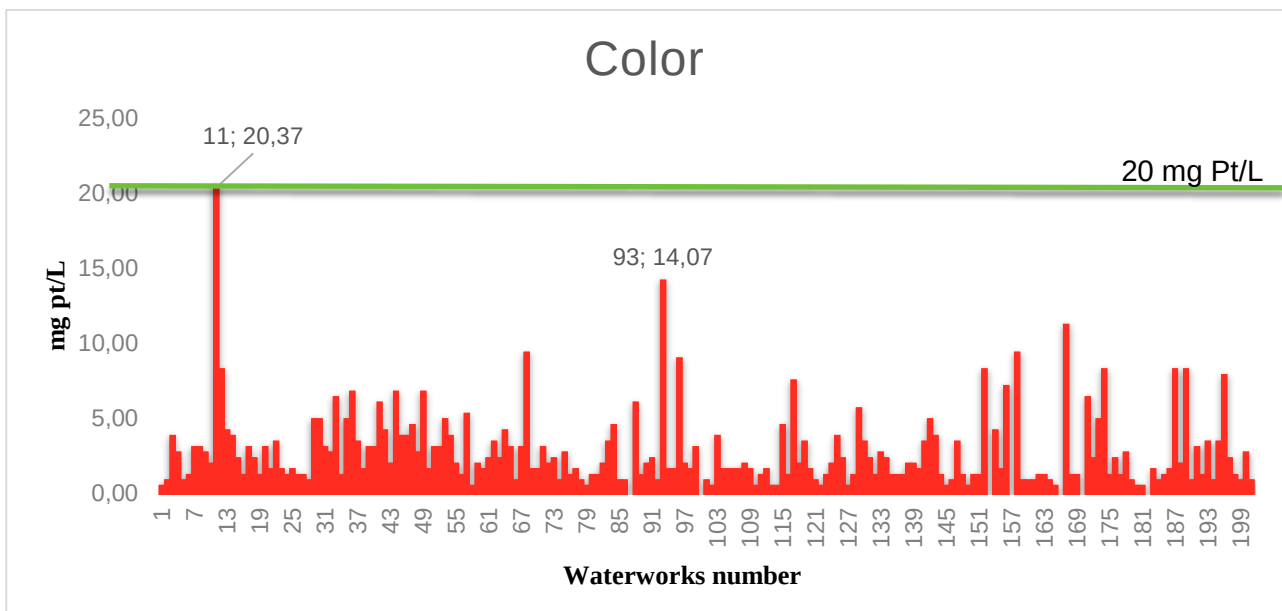


Figure 23. Color measured in groundwater samples collected at 201 Norwegian waterworks. The green line shows the Norwegian regulation limit for color. At every waterworks $n=1$.

4.2.3.2 pH, alkalinity and conductivity

According to the Norwegian Water Regulation, the pH limit for drinking water in Norway is between 6.5 and 9.5. Results of the present study show that samples from seven waterworks had pH values of below 6.5, and the remaining samples showed acceptable pH values (Fig. 24). The maximum pH value measured was 8.98, while the lowest value was 5.67. The median pH value was 7.65.

The regulation limit for alkalinity in drinking water in Norway is 1 mmol/L. The highest value of alkalinity in the present study was 4.93 mmol/L, recorded at water work 162; the median value was 0.85mmol/L. 91 of the waterworks had alkalinity values higher than the regulation limit.

Considering conductivity, the highest value measured in this study was 798 mS/m; the median value was 132 mS/m. However, the regulation limit for conductivity in drinking water in Norway is 250 mS/m. 40 of 201 water works had higher conductivity values than 250 mS/m.

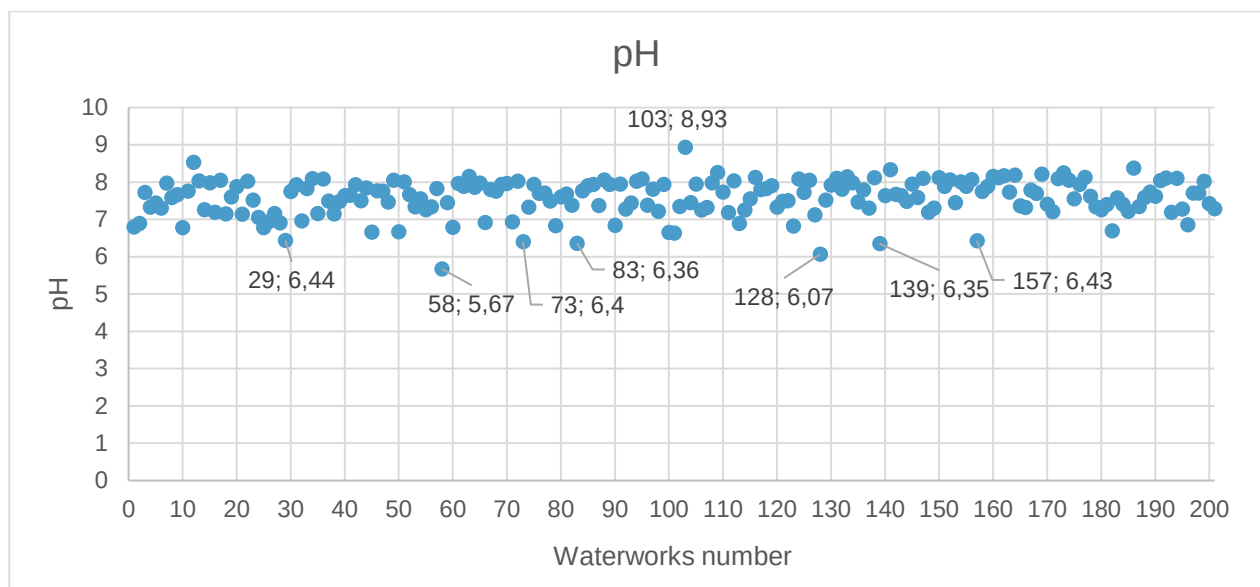


Figure 24. pH measured in groundwater samples collected at 201 Norwegian waterworks. At every waterworks $n=1$.

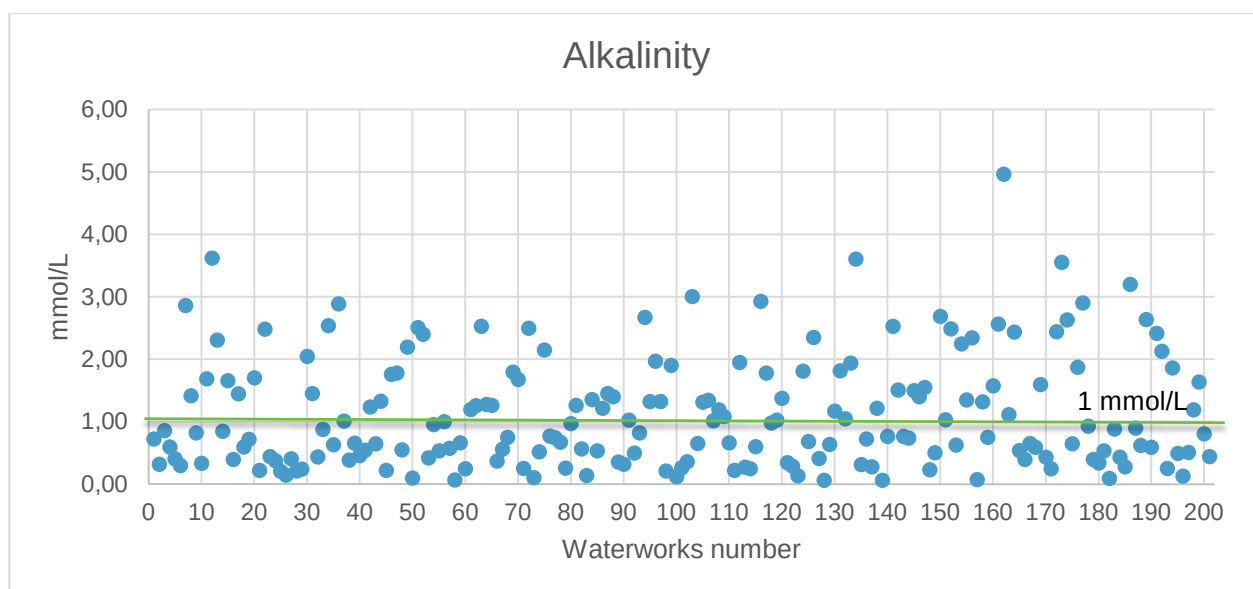


Figure 25. Alkalinity measured in groundwater samples collected at 201 Norwegian waterworks. The green line shows the Norwegian regulation limit. At every waterworks $n=1$.

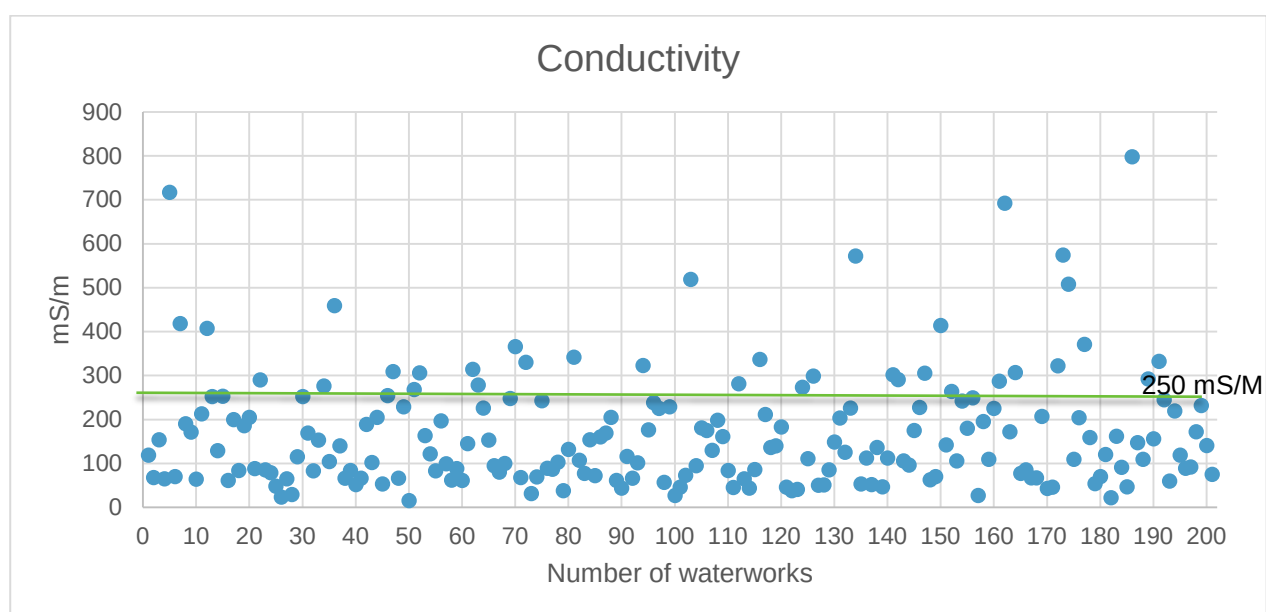


Figure 26. Conductivity measured in groundwater samples collected at 201 Norwegian waterworks. The green line shows the Norwegian regulation limit. At every waterworks $n=1$.

4.3. Elements with no regulation limits in Norway

Among the elements with no regulation limit in Norway, 45 elements were measured in the present study. Those with high concentration are shown in table 3. Among these elements, the highest concentration for U was 68 µg/L; the median value was 0.28 µg/L. Uranium was above the WHO and US guidelines (30 µg/L) at 5 waterworks, and two waterworks were above the Canadian guideline (20 µg/L). Higher values for U were recorded in bedrock waterworks compared to sedimentary water works, with values as high as 7.2µg/L. Ten waterworks had zinc (Zn) values above 100 µg/L. The highest concentration of Zn was 1700 µg/L in bedrock and 790 µg/L in sedimentary. The median value for Zn for all water works was 7.5µg/L. The level of strontium (Sr) was high in most of the water works. Strontium was above 100 µg/L in 57 waterworks, the highest being 1000 µg/L (in sedimentary aquifers) and the median value was 50 µg/L and the average value was 110 µg/L. The highest concentration of barium (Ba) was 280 µg/L, being below the WHO guideline. The median value of Ba was 10 µg/L. The level of Ba was higher in sedimentary aquifer compared to bedrock aquifer. The highest level of molybdenum (Mo) was 30 µg/L, being below the WHO guideline. The average value of Mo was 1 µg/L and the median value was 0.3 µg/L. Higher concentrations of Mo were recorded in bedrock aquifers compared to sedimentary aquifers. The highest level of Rubidium (Rb) was 14 µg/L and the average was 2 µg/L, while the median value was 1µg/L. Higher concentrations of Rb was measured in sedimentary aquifers compared to bedrock aquifers. The highest level of vanadium (V) was 8 µg/L and the median value was 0.1 µg/L. Higher concentrations of V were measured in bedrock aquifers compared to sedimentary aquifers. However, the highest recorded concentration of elements, Lithium (Li), Tungsten (W) and Cesium (Cs) were 31 µg/L in sedimentary, 16 µg/L in bedrock and 2.5 µg/L in bedrock, respectively. The presences of major elements such as phosphor (P), sulfur (S), silicon (Si), calcium (Ca), magnesium (Mg), and potassium (K) were determined with concentrations of 67 mg/L (bedrock), 16 mg/L (bedrock), 20 mg/L (sedimentary), 51 mg/L (sedimentary), 15 mg/L (sedimentary) and 8 mg/L (bedrock) as maximum values for each element, respectively.

Among rare earth elements, high concentrations were recorded for lanthanum (La) (120 µg/L), cerium (Ce) (110 µg/L), neodymium (Nd) (74 µg/L), and followed by yttrium (Y), praseodymium (Pr), samarium (Sm), gadolinium (Gd), dysposium (Dy), erbium (Er), ytterbium (Yb) and europium (Eu). All of the rare earth elements were higher in sedimentary waterworks compared to bedrock waterworks.

Table 3.Concentrations of elements in bedrock and sedimentary groundwater.

Element	Bedrock	Sedimentary	Threshold value	Waterworks No
Mn µg/ L	200	270	50 (0,05 mg/L) ^a	134, 80
Cu µg/ L	410	630	100 (0,1 mg/L) ^a	183, 101
Fe µg/ L	670	2200	200 (0,2 mg/L) ^a	191, 121
B µg/ L	81	96	1000 (1 mg/L) ^a	103, 64
As µg/ L	14	3,8	10 ^a	152, 200
Se µg/ L	1,5	1,3	10 ^a	49, 141
Pb µg/ L	64	14	10 ^a	183, 18
Ni µg/ L	13	84	20 ^a	183, 18
Al µg/ L	160	280	200 ^a	142, 58
Na mg/L	160	42	200 ^a	186, 47
Cd µg/ L	0,08	0,09	5 ^a	183, 43
Sb µg/ L	1,8	0,2	5 ^a	42, 141
Cr µg/ L	2,3	1,4	50 ^a	44, 19
U µg/ L	68	7,2	30(P) ^{b & c} , 20 ^d	164, 29
P mg/L	67	65	-	189, 53
S mg/L	16	11	-	7, 64&172
Ca mg/L	47	51	-	94, 72
Si mg/L	15	20	-	186, 76
Li µg/ L	16	5,3	-	70, 172
Mg mg/L	12	15	-	162 &22, 172
K mg/L	8	6,6	-	134, 46
Zn µg/ L	1700	790	-	183, 165
Sr µg/ L	830	1000	-	126, 142 &172
Ba µg/ L	260	280	0,7 mg/L ^b	162, 1
Mo µg/ L	30	15	0,07 mg/L ^b	49, 64
W µg/ L	6	31	-	44, 121
Rb µg/ L	5,1	11	-	173, 46
V µg/ L	8	2	50 (MCL) ^e	169, 192
Cs µg/ L	2,5	1,5	-	42, 141
La µg/ L	5	120	-	195, 58
Ce µg/ L	3	110	-	195, 58
Nd µg/ L	3,6	74	-	195, 58
Pr µg/ L	0,96	21	-	195, 58
Sm µg/ L	0,5	9	-	195, 58
Gd µg/ L	0,4	7,4	-	195, 58
Eu µg/ L	0,06	0,8	-	195, 58
Y µg/ L	4	28	-	164, 58
Dy µg/ L	0,3	4	-	164, 58
Er µg/ L	0,2	2	-	164, 58
Yb µg/L	0,1	1,3	-	96, 58

Key to abbreviations: a = Norwegian Water Regulation, b = WHO (WHO, 2011), c = U.S (US EPA. 2009), d = Canada (Heath Canada, 2017) and e = Italy (Roccaro, 2013). P = WHO, Provisional Guideline, MCL = Maximal Contaminate Level.

4.4 Principal component analysis (PCA)

4.4.1 Clean water (drinking water)

Results from PCA analysis of the total concentration of elements is shown in figure 27 (score plot) and figure 28 (correlation (circle) loadings plot). Principal component1 (PC1) explains 35% of the variation between the waterworks (n = 201) and the second principal component explains 16% of the variations. This means together 51% of the variation in waterworks is explained by these two components. Out of 61 elements determined by ICP-MS, only 34 of the element were analyzed in PCA. This is due to the removal of missing values of elements below the LOD and LOQ.

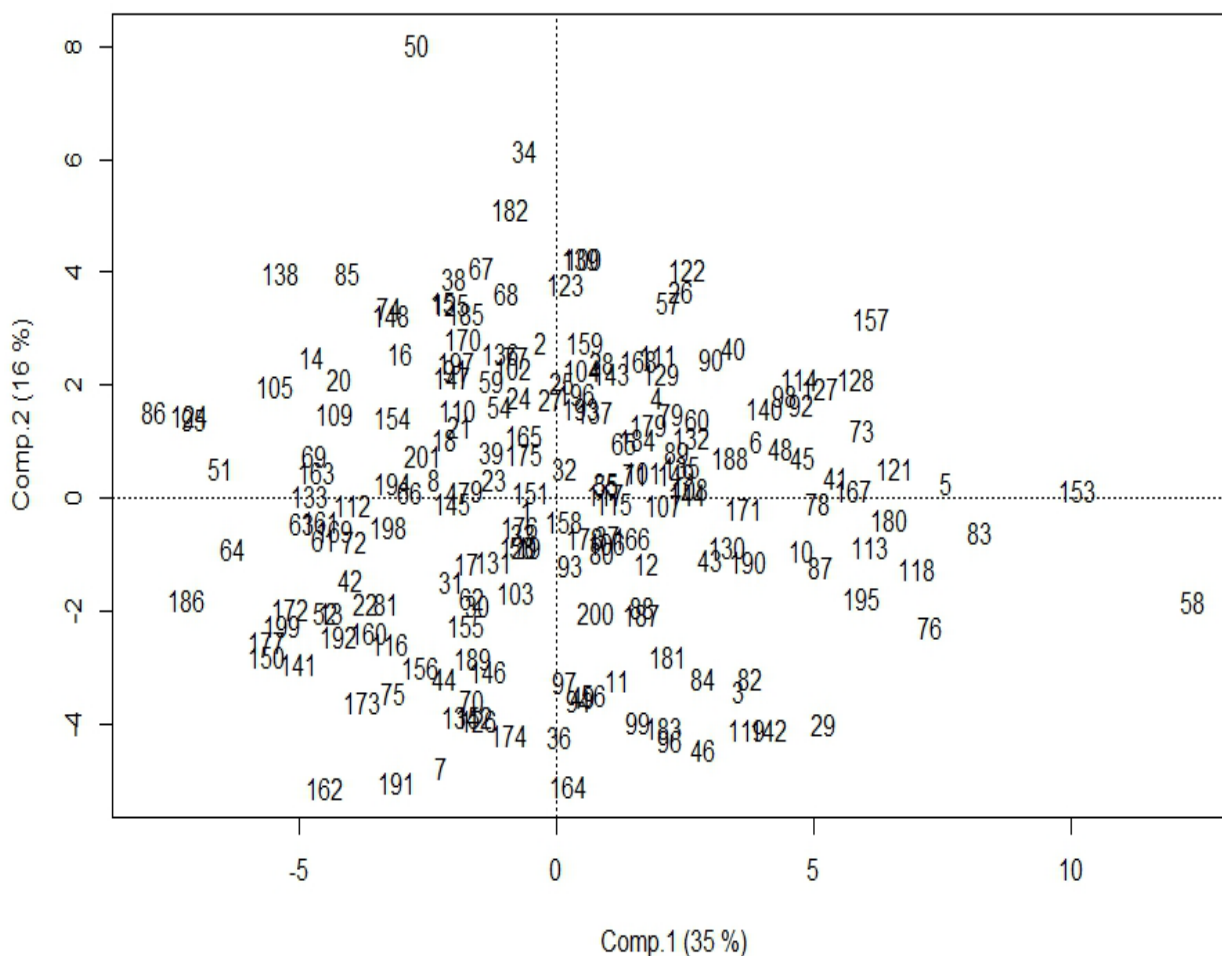


Figure 27. Score plot for clean water samples from different waterworks.

The observations of the waterworks in figure 27 is interpreted by that, the waterworks (objects) close to each other in the space of PCs are similar and those far away from each other are dissimilar. For example, waterworks in upper right are different from the waterworks lower left ones. The objects close to PC-coordinates are the most typical, “average”. The scores are to be examined paying attention to the correlation-loading plot. From figure 28 we see the variables Al and rare

earth elements (La, Nd, Pr, Gd, Sm, Ce, Dy, Y, Yb, and Er) strongly correlated with PC1 (35%), whereas the variables Si, U, K, Li, Cs, S, Mg, Sr, Mo, and Ca are more likely negatively correlated with PC2 (16%). Variables with the angle between the lines connecting them with the origin is small, this means they are strongly correlated. Most of the rare earth elements are strongly correlated with each other (for example Nd with Pr and Gd with Sm). Likewise is for variable U, K, Na, and Cs. The elements Mo, Ca, Mg, Sr, and S are also strongly correlated with each other. When the direction from origin is the same but the variables point is not close to each other, the ratio between them on the PCs is still the same for those variables, which means they are strongly correlated. For example, Al and La are strongly correlated and Ce and Dy are also strongly correlated. Variables close to origins are the most typical ones and have small weight of impotent. Those variables are P, Ba, Ni, Fe, Zn, Cu, and Pb.

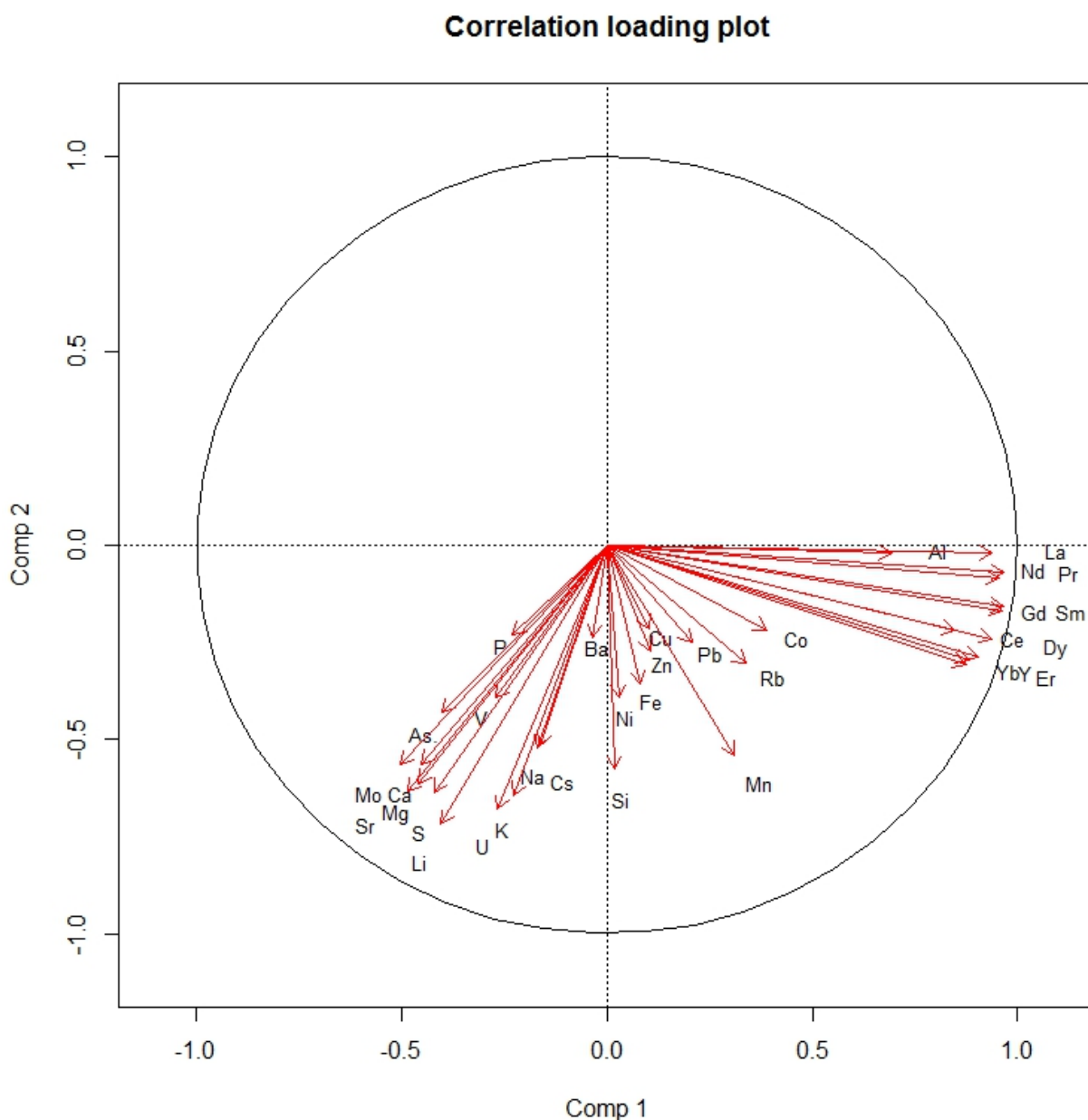


Figure 28. shows correlation loadings plot on PC1 and PC2 of the variables in clean water.

4.4.2 Raw water

The distribution of elements in raw water (not treated water) is shown in figure 29 and 30. In total PC1 and PC2 explains 58% of the variation. The variables (elements) with high level of missing values were removed, and the final data for PCA analysis contained 33 elements out of 61 elements analyzed by ICP-MS. During, ICP-MS analysis non-treated (raw water) samples from waterworks that was used as drinking water without any form of treatment were removed before analysis. A total of 41 samples from waterworks were removed (Table 1 shows which waterworks do not have

water treatment). Hence, the number of samples from waterworks (our observations) shown in scores plot is 160. However, those removed samples are included in PCA analysis of clean water.

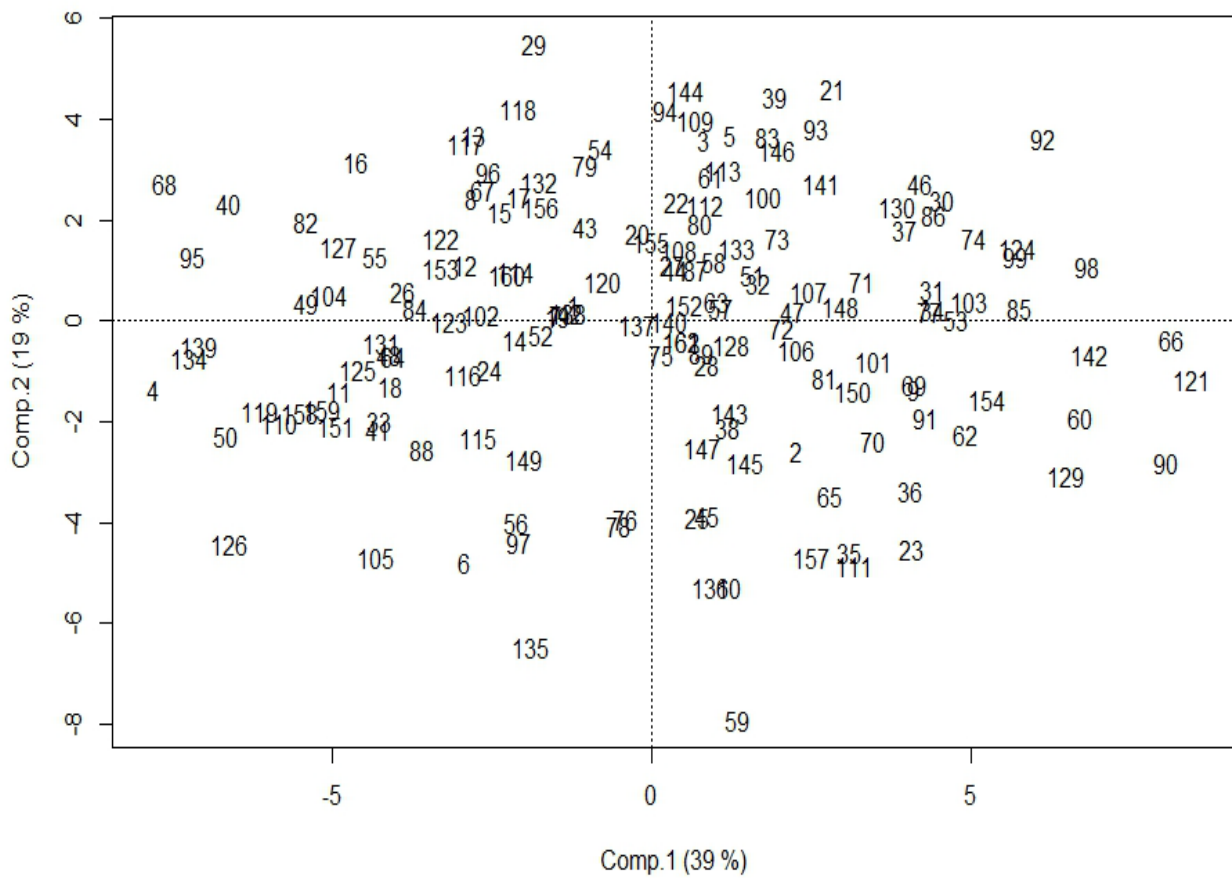


Figure 29. Score plot for raw- water samples from different waterworks.

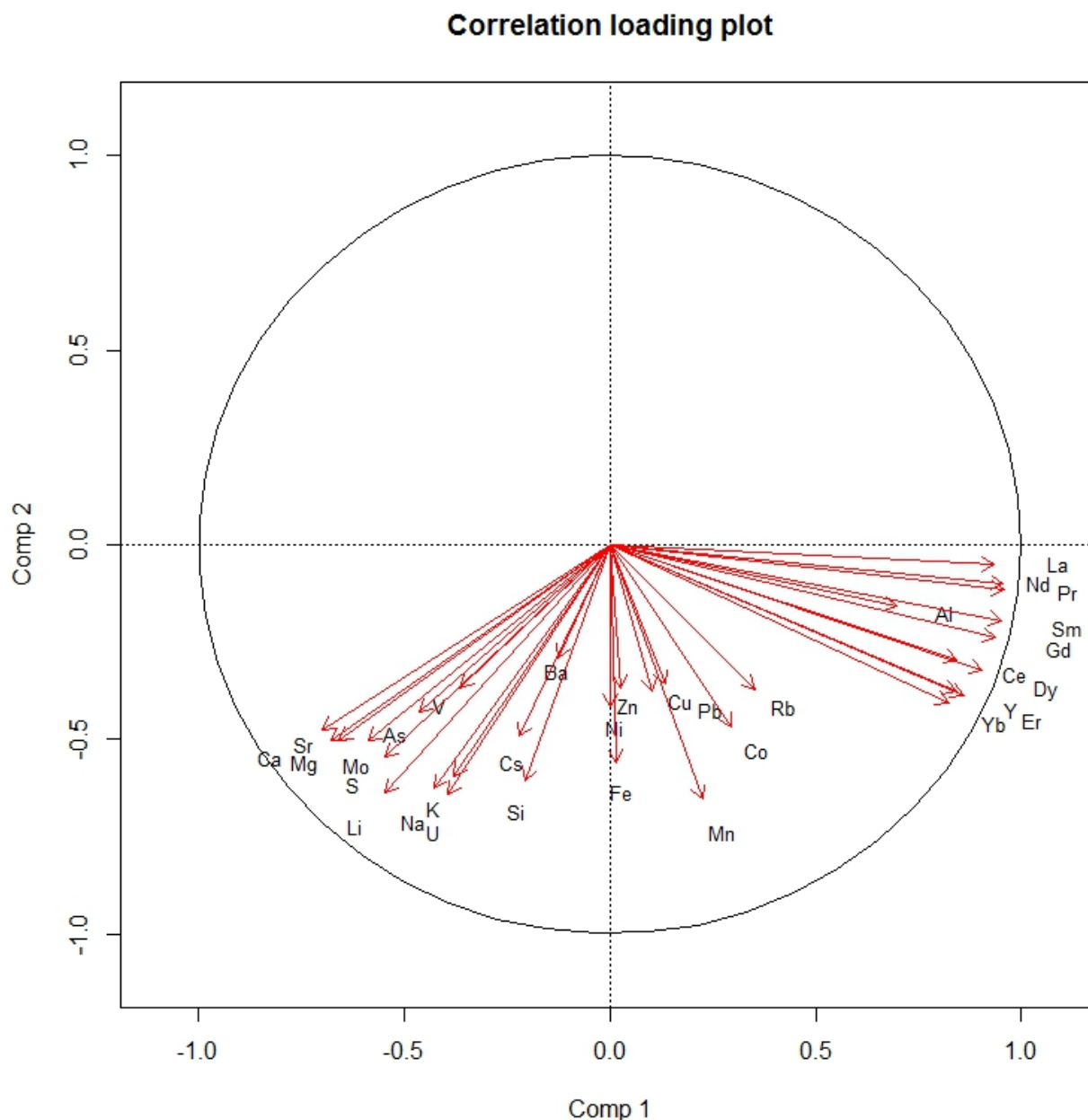


Figure 30. Shows correlation loadings plot on PC1 and PC2 of the variables in raw-water.

Figure 30 shows the correlation loadings plot of the two first components. The correlation plot for raw water reflects that in PCs follow the same trend as figure 28, with the respect to the variations explained by the components. The first component explains 39% of the variation, whereas the second component explains 19% of the variation. This suggests in similar way as figure 28, that the variables Al and rare earth elements (La, Nd, Pr, Gd, Sm, Ce, Dy, Y, Yb, and Er) strongly correlated with PC1 (39%). Likewise, the variables Fe, Mn, Si, U, K, Na, Li, S, Mo, S, Sr, Mg, and Ca are negatively correlated with PC2 (19%). In contrast, Al have lower loading on PC1, and is

correlated with Sm and Gd. Iron (Fe), Ni, Zn, and Mn have low loading values on PC1 and more negatively correlated with PC2.

5 DISCUSSION

5.1 Quality of the analysis

In order to discuss the result of the analytic data, it is important to discuss the quality of the analysis related to the quality control (QC). The accuracy (agreement between the expected value and measured value) of determination of major and trace metal concentrations analyzed by using ICP-MS was checked by the analysis of the certified reference material (CRM) 1640a. For determination rare earth elements (REE), P and S, using ICP-MS the analysis of the certified reference material SPS-SW1 Batch 123 and SPS-SW2 Batch131 was used as QC. Furthermore, the accuracy of the determinations of fluoride, nitrate, sulfate, and water quality indicators was tested the analysis of CRM CARNBERRY-05. Halogens I, Cl and Br did not have certified values. The results of the accuracy tested are shown in appendix C (Table C2, C3 and C4), which shows the reported CRM values and measured values. In the table (C2, C3 and C4), measured values of the elements are classified by green, yellow and red color. Meaning the elements are accurate, poorly accurate and low accurate, respectively. In general, the results of these certified reference materials shows that the accuracy of the method used were accurate.

In addition, blanks were used to determine the limit of detection (LOD) and limit of quantification (LOQ). LOD and LOQ are calculated from 10 blanks as $3 \times$ standard deviation (SD) and $10 \times$ standard deviation (SD), respectively. LOD and LOQ for measured elements are displayed in table C1 in appendix C. Elements concentrations values below LOQ were substituted by one-half the detection limit and quantification limit (LOD/2 and LOQ/2) for the statistical use. Elements with over 20 % of the concentration values below LOQ were not included in the statistics. LOQ values under 20 % of the concentration value below LOQ are displayed in table 2.

5.2 Discussion of results in relation to Norwegian regulation limit

Exposure to chemical elements, physical and radiological contaminants, and pathogens are some of the most important factors affecting the quality of drinking water (WHO, 2011). In the present study, water samples from 201 waterworks representing all regions of Norway were analyzed for major and trace elements, anions and water indices such as pH, alkalinity, conductivity, turbidity and color. These waterworks were from sedimentary and bedrock aquifers that supply drinking water for, at least 5% of the Norwegian population. The results show that some of trace elements (Mn, Al, Cu, Ni, Fe, As and Pb), anion (F-) and water indices (alkalinity and conductivity) exceeded the Norwegian regulation limit. For instance, Cu was above the regulation limit at 10 waterworks; Mn at 9; Fe at 6; Al at 2; Pb at 2; Ni at 1 and As at 1 waterworks.

Some heavy metals are essential in trace amounts to maintain normal metabolism, however, most of the heavy metals have potentially adverse effect on human health when their concentrations exceed certain threshold (Jaishankar et al., 2014). One of the chemical elements that exceeded the Norwegian regulation limits in the present study was Al. Aluminum exceeded the 200 µg/ml regulation limit by 40% at waterworks 58 and 15% at 167 (Fig 3). Aluminum is a very common component of the earth's mineral composition. However, epidemiological and experimental findings indicate that aluminum is not as harmless as was previously thought. Elevated levels of aluminum-containing salts have been associated with different diseases such as kidney disease, and Alzheimer's disease (Flaten, 1986; Bondy, 2016). However, one earlier cohort study in southern Norway did not find any association between drinking water and inflammatory bowel disease (Aamodt et al., 2008).

The second chemical element with a concentration over regulation limit in the present study is manganese. Manganese exceeded the Norwegian regulation limit (50µg/L) by 440%, 360%, 300%, 200%, 160%, 140%, 120%, 76%, and 14% at waterworks 80, 187, 134, 84, 163, 191, 119, 162, and 174, respectively (Fig 4). Manganese is an essential element to human health, acting as a co-factor in enzymatic activity, and it is required for development and function of the immune system, and the regulation of blood sugar and vitamins. However, manganese can also be toxic, and has been associated with neurotoxicity, depending on the amount of daily intake (Frisbie *et al*, 2015)

The concentration of copper was higher than the Norwegian regulation limit (100 µg/L) at 10 waterworks in the present study. Copper exceeded the Norwegian regulation limits by 530%, 470%, 430%, 360%, 310%, 120%, 70%, 30%, and 20% at waterworks 101, 55, 56, 117, 183, 37, 18, 66, 44 and 166, respectively (Fig 5). In some waterworks it was over 500 times higher than the regulation limit. Copper is an essential trace element for normal body growth and development. It is the 3rd most abundant transition metal in the body and is important for neuronal functioning (Pal, et al., 2014). Copper concentrations in drinking water can range from a few mg/ml to 10 mg/ml and regulation limits also vary between countries, and even within a country. For instance, in the US, 1300 µg/L of copper is allowed in drinking water, while in California the limit is 0.17 mg/ml (US EPA 1994). According to the WHO interim drinking water guidance the concentration of copper in drinking water should not exceed 2 mg/ml, a limit adopted by 26 countries (Pal, 2014). Although it is difficult to give the exact source of such high levels of copper in these waterworks, one possible source could be copper plumbing and leaching (Pal et al. 2014).

The concentration of iron was higher than the regulation limits (0.2mg/L) at 6 waterworks in the present study. Iron exceeded the Norwegian regulation limits by 1000%, 370%, 220%, 160%, 30%, 25% at waterworks 121, 187, 191, 149, 11, and 171, respectively (Fig 6). These results were obtained from sedimentary and bedrock aquifers but higher concentrations of iron were observed in sedimentary aquifer compared with bedrock aquifer. However, an earlier study carried out in Norway showed similar levels of iron in both sedimentary and bedrock aquifers (Banks et al., 1998). According to WHO (2004), iron and aluminum are the most abundant metals in the soil and bedrock, but corrosion of water pipes is also an important source of iron. Iron is a most crucial element for growth and survival of almost all organisms as it is a cofactor for many vital proteins and enzymes (Valko et al., 2005). There are not many studies that looked into the impact of iron on human health in Norway, however, one study that evaluated the association of inflammatory bowel disease and water supply in southern Norway has shown that the risk of developing inflammatory bowel disease, including ulcerative colitis and Crohn's disease was associated with high iron content. The relative risk of developing inflammatory bowel disease increased by 21% when the iron content in drinking water increased by 0.1 mg/ml (Aamodt et al., 2008).

Lead was another element whose concentration exceeded the regulation limit of 10 µg/ml at two waterworks. Lead concentration exceeded the Norwegian regulation limits by 540% and 40% at waterworks 183 and 18, respectively (Fig 9). Lead exposure usually results from lead in deteriorating household paints, lead in the work place, lead in crystals and ceramic containers that leaches into water and food (reviewed in Jaishankar et al., 2014). Several studies have shown that lead affects the health of both children and adults. In children, there is an association between lead blood level poisoning and diminished intelligence delayed or impaired neurobehavioral development. In adult population, reproductive effects such as decreased sperm count in men and spontaneous abortions in women have been associated with high lead exposure. Acute exposure to lead induces brain damage, kidney damage, and gastro-intestinal diseases, while chronic exposure may cause adverse effects on the blood, central nervous system, blood pressure, kidney and vitamin D metabolism (Tchounwou et al., 2012).

The concentration of nickel (84 µg/ml) exceeded the regulation limits of 20 µg/ml at one waterworks (Fig 7). Among heavy metals, nickel is usually known for its high toxicity, mobility, and different uses in industries. Nickel exposure has been associated with undesirable health effects

such as dermatitis and carcinogenesis, and unfavorable consequences of nickel exposure rely on active changes in metabolism, inflammation, oxidative stress, cell proliferation, and cell death (Zambelli et al., 2016). However, the present study may indicate that, in general, the health risks associated with nickel in drinking water in Norway is minimum for two reasons: 1) an elevated nickel level is geographically limited to one waterworks; 2) According to WHO drinking water quality guidelines, regulation limits for nickel has increased from 20 µg/ml to 70 µg/ml (Frisbie et al., 2015).

Similar to nickel, the concentration of arsenic was higher (14µg/ml) than the regulation limits (10 µg/ml) at a single waterworks (Fig 8). Although arsenic intake has been associated with a variety of health problems, from acute toxicity to chronic diseases in some countries (Tchouwou et al. 2012), our results indicate that most of drinking water in Norway has a low arsenic concentration and meets the regulation limits set by the authorities.

Among anions, it is only the fluoride concentration that exceeded the regulation limit at 4 waterworks (Fig 16). The proportion (2%, 4/201) of waterworks with high fluoride concentration in the present study is lower compared to results of an earlier study (Midtgård et al. 1998), which showed that 250 out of 1600 (16%) water wells had higher fluoride concentrations than the limit set for drinking water in Norway. In general, the study by Midtgård et al (1998) has indicated that about 30% of the wells had water that does not meet the standards set by health authorities. The only health benefit of fluoride is prevention of dental caries (infection of the enamel) due to acid producing bacteria. However, no fluoride deficiency disease has been documented for humans so far. Therefore, some suggest that fluoride should be classified as pollutant rather than as nutrient or medicine (reviewed in Peckham & Awofeso, 2014).

In the present study, among water quality indicators, color was within the regulation limits set by health authorities in Norway. However, 40 out of 201 (20%), 91 out of 201 (45%), and 1 out of 201 (0.5%) waterworks, respectively, had levels of conductivity, alkalinity, or turbidity above the regulation limits. Moreover, the pH was lower than the regulation limit (6.5-9.5) at six waterworks. Results of the present study are similar to earlier studies (Midtgård et al., 1998; Banks et al., 1998) which have reported pH levels outside the regulation limits. For instance, Midtgård *et al.* (1998) reported that considering pH, sodium, radon, and fluoride together, about 30% of the wells from bedrock ground water did not meet standards set for drinking water in Norway. In the present study, waterworks with low pH were also associated with high concentrations of aluminum, zinc, copper,

and REE. However, according to the Norwegian Public Health Institute (2016), pH range between 8 and 8.5 are recommended to prevent corrosion of water pipes, and dissociation of heavy metals.

5.3 International regulations/guide values of elements

The concentration of uranium was higher than WHO provisional guideline (WHO, 2011) and US regulation limit (US EPA, 2009) at five waterworks, but according to Canadian drinking water regulation (Health Canada, 2012), it is above regulation limit in seven waterworks. There is a wealth of information regarding the association of uranium with cytotoxicity (US EPA, 2002).

5.4 Element distribution in relation to geological background

Chemical composition of groundwater is derived in general, from reactions of rainfall with rock and soil minerals (Guler & Thyne, 2004). In Norway, a number of studies have been carried out on the hydrochemistry of groundwater from crystalline bedrock aquifers, this as a result of the observed high concentrations of some elements such as radon and fluoride beyond the regulation limit in drinking water (Banks et al., 1998). Studies of larger waterworks based on quaternary aquifers in Norway have indicated that radon is not a problem in groundwater from such aquifers. The work by Bank *et al.* (1998) who studied other chemical parameters in smaller and private wells has shown that the majority of chemical parameters are found in bedrock aquifers than in quaternary aquifers. The study also shows that relatively few parameters such as pH, Al, Cu, Zn, and Ni had higher concentration in quaternary aquifers than in bedrock aquifers (Banks et al., 1998).

Results of the present study show that trace elements such as Ni, Cd, Pb, As, Cr and Sb were predominantly found in bedrock aquifers from mica schist, augengneiss, tonalite, amphibolite, phyllite and granite. For instance, the highest concentration of lead (64 µg/L) was found in water works 183 (bedrock), situated in mica schist. Thus, high concentrations of these elements were also found in sedimentary aquifers derived from and overlying above mentioned rocks like fluvial deposits. In facts, the highest concentration of Ni (84 µg/L) and Cr (0.09 µg/L) was recorded from fluvial deposits with underlying phyllite and mica schist. Other studies have shown that these trace elements generally occur in sulphide minerals associated with granite, mica schist, gabbro, diorites, amphibolite, and phyllite, as well as trace elements in mafic silicates, e.g. olivine and pyroxene (Reimann & de Caritat, 1998).

Similarly, higher concentration of elements such as Al, Zn, Mn and Cu compared to bedrock aquifers was found in quaternary aquifers such as glacial-marine and fluvial deposits. However, high concentration of Mn, Cu and Zn were found in bedrock aquifers from greenstone, greenschist, augengneiss, phyllite, granite, quartzdiorite and tonalite. Solubility of the elements Al, Zn and Cu is strongly pH-dependent, but Cu and Zn may also be derived from domestic pipelines (Banks et al. 1998). For instance, in the present study concentration of Al was high at waterworks 58, with lowest pH value (5.67). Similarly, rare earth elements (REE) were found to have the same pattern as Al, being strongly correlated with Al, as shown in figure 28 and 30.

Higher concentrations of elements such as Na, I, Br, B, SO_4^{2-} , and Cl were found in some bedrock aquifers in coastal area, probably influenced by old seawater tapped in overlying sediments or seawater intruding laterally into aquifer due to heavy pumping. The composition of these bedrock aquifers varying widely, the element source is to be found in overlying marine deposit and marine shore deposit. In addition, elements such as B, I, SO_4^{2-} and Na were also found in sedimentary aquifers from inland wells with fluvial deposits and glacial-marine deposits. In coastal marine derived areas the concentration of Na and Cl, Br and I become higher, whereas B become lower. For instance, a study done by Steinnes and Frontasyeva (2002) shows that the Br/Cl and Br/I ratios decrease with the distance from the ocean. The highest concentrations of Cl and Na were found in water works in Hordaland (Bergen) county (Southwest Norway) and Vestfold (Horten) county, probably influenced by precipitation or run-off from road salt as suggested by (Banks et al. 1998). It has also been shown that high concentrations of Na and Cl is a signature for road run-off (Mason et al., 1997) and precipitation from coastal areas (Jeen et al., 2001). Similar, high concentration of Br and I were found at Vestfold (Horten) county which is near the coast.

In addition, the concentration of NO_3^- was also higher in sedimentary deposits, following a similar pattern with Na, Cl⁻, and SO_4^{2-} . The concentration of nitrate is usually influenced by agricultural activities of the surrounding catchment area. For instance, the highest concentration of NO_3^- was found in bedrock aquifer (177) in Hedmark County where high agricultural practices take place.

In the present study, the highest concentrations of F⁻ and U were found in bedrock aquifers (gneiss, granites, amphibolite and granite to tonalites). Elevated levels of fluoride concentrations have been attributed to the dissolution and weathering of F-bearing minerals in dominant rocks. Among them, apatite, micas, and amphiboles are the likely source of fluoride in natural waters in granite terrains (Garcia MG & Borginino L, 2015). A study by Borginino and co-workers (2013) has shown that

fluoride is preferentially released under acidic pH and low Ca^{2+} concentrations from fluvial sediments. In the present study, U was above the WHO and US guidelines (30 $\mu\text{g/L}$) at 5 waterworks, and two waterworks were above the Canadian guideline (20 $\mu\text{g/L}$). The highest concentration of U (68 $\mu\text{g/L}$) was found in Høylandet (164), followed by water work 75 (60 $\mu\text{g/L}$), 7 (34 $\mu\text{g/L}$), 61 (30 $\mu\text{g/L}$), 94 (30 $\mu\text{g/L}$), 146(27 $\mu\text{g/L}$) and 112(24 $\mu\text{g/L}$), situated in gneiss, granite to tonalite rocks. Similarly, in the study by Frengstad et al (2000), high concentrations of U were found in meta-basalt, meta-andesite and amphibolite, beside granites and granitic gneisses.

5.5 PCA Analysis

Principal component analysis was conducted on data for elements analyzed by ICP-MS. PCA were used in order to describe the variability of measured elements. The first principal component (PC1) describes the highest variability of the data (elements), while the second principal component (PC2) describes the second highest portion of element variability. In principal component analysis of treated water (clean water), the PC1 explained 35% and PC2 16 % of the variability in the waterworks (Fig 27). Together 51% of the variability of among the waterworks were explained for clean water by PC1 and PC2. In PCA of the raw water, the PC1 explained 39% and PC2 19 % of the variability among the waterworks, explaining 58% of the variability (Fig 29).

Results from Correlation loading plot (Fig 28 and 30) shows that raw water and clean water reflects that the PCs follow the same trend. The correlation loading plot describes the interrelationship between variables. Elements such as Al and REE elements strongly correlated with PC1, whereas elements such as U, K, Ca, Mg, Li, Sr, Si and S were negatively correlated with PC2. Moreover, Al and REE elements were strongly correlated with each other. Elements such as Cu, Zn, Mn, Fe, Ni and Pb correlated with each other. Likewise positive correlation exist between elements U, K, Na, and Cs, and between Mo, Ca, Mg, Sr and S. However, higher correlation exist between Al and REE, Cu, Zn and Mn, Pb, Cu and Mn, U, K, Na and Cs.

6 CONCLUSIONS

The present study analyzed 603 water samples from 201 waterworks, covering representative geographical regions of Norway. The concentration of 67 inorganic elements, and water quality indicators such as pH, conductivity, turbidity, alkalinity, and color were determined. The results show that the level of trace elements such as Al, Mn, Cu, Fe, Ni, and As exceeded the Norwegian regulation limits at some waterworks. Among anions, fluoride concentration was higher than the regulation limit at four (2%) of the waterworks. Among water quality indicators, alkalinity levels were higher than the regulation limits at 45%, conductivity at 20%, and turbidity at 1% of the waterworks. The pH levels were below the regulation limit at 6 waterworks, whereas colors were within the regulation limits. Put together, the results show that some inorganic elements, including As, Pb, and F⁻ known for causing health related problems had concentrations over the regulation limits. Moreover, uranium levels were higher than international guideline (WHO and US) at three waterworks, but there is no regulation limit for uranium concentration in drinking water in Norway.

In general, results of the present study show high concentrations of trace elements, such as Ni, Cd, Pb, As, Cr, and Sb in bedrock aquifers from mica schist, augengneiss, tonalite, amphibolite, phyllite, and granite rocks. Similarly, higher concentration of elements such as Al, Zn, Mn, and Cu was found in Quaternary aquifers such as marine deposits and fluvial deposits compared to bedrock aquifers. The highest concentrations of F⁻ and U were predominantly found in bedrock aquifers (gneiss, granites, amphibolite and granite to tonalites). Elements such as Na, I, Br, B, SO₄²⁻, and Cl were generally found in some bedrock aquifers in coastal area. The concentration of Na and Cl, Br and I increase in coastal marine derived areas and decrease with the distance to ocean. These results are based on a single measurement at each waterworks, and the study is not part of any periodic monitoring. Furthermore principal component analysis was conducted on data for elements analyzed by ICP-MS, in order to describe the variability of measured elements. Results of correlation loading plot show high correlations exist between elements such as Cu, Zn, Mn, Fe, Ni and Pb with each other. Likewise positive correlation exist between elements U, K, Na, and Cs, and between Mo, Ca, Mg, Sr and S. However, higher correlation exist between Al and REE, Cu, Zn and Mn, Pb, Cu and Mn, U, K, Na and Cs.

To assess whether or not the observed violations of the regulation limits for drinking water are actually associated with particular health risks, further investigations on temporal variation are

required. If corrective measures are expedient, additional knowledge on sources of the parameters measured beyond the Norwegian drinking water regulation limits is requisite.

7 REFERENCES

- Aamondt G, Bukholm G, Jahnsen J, Moum B, Vatn MH, IBSEN study Group. 2008. The association between water supply and inflammatory bowel disease based on a 1990-1993 cohort study in southeastern Norway. *Am J Epidemiol*; 168(9), 1065-72.
- Abdi H and Williams LJ. 2010. Principal component analysis. *John Wiley & Sons, Inc. WIREs Comp Stat* 2; 433-459.
- Agilent Technologies. 2014. Agilent 8800 Tripel Quadrupole ISP-MS. USA: Agilent Technologies, Inc. 12 pp.
- Ahamed M & Siddiqui MKJ. 2007. Low level lead exposure and oxidative stress: Current opinions. *Clinica Chimica Acta*; 382(1-2), 57-64.
- Ahsen H, Chen Y, Parvez F, Argos M, Hussain AI, et al. 2006. Health effects of Arsenic Longitudinal Study (HEALS); description of a Multidisciplinary epidemiologic investigation. *J Expo Sci Environ Epidemiol*; 16(2), 191-205.
- Åkesson A, Bjellerup P, Lundh T, Lidfeld J, Nerbrand C, Samsioe G. 2006. Cadmium-induced effects on bone in a population-based study of women. *Environ Health Perspect*; 111, 830-834.
- Appelo CAJ, Postma D, 1994. Geochemistry, groundwater and pollution. 2nd ed: Rotterdam and Brookfield, 536 pp.
- Aschner M, Vrana KE, Zheng W. 1999. Manganese uptake and distribution in the central nervous system (CNS), *Neurotoxicology*; 20, 173-180.
- ATSDR (Agency for Toxic Substances and Disease Registry). 1992. Case Studies in Environmental Medicine- Lead Toxicity. *US Department of Health and Human Services, Public Health Service*. Atlanta, GA.
- ATSDR (Agency for Toxic Substances and Disease Registry). 1999. Toxicological profile for lead. *US Department of Health and Human Services, Public Health Service*. Atlanta, GA.
- ATSDR (Agency for Toxic Substances and Diseases Registry). 1999. Toxicological Profile for Uranium. *US Department of Human and Health Services, Public Health service*. Atlanta, GA.
- ATSDR (Agency for Toxic Substances and Diseases Registry). 2015. Exposure Investigation: Biological Testing for exposure to Lead and Arsenic near COLORADO SMELTER

PUEBLO, COLORADO. *US Department of Human and Health Services, Public Health Service*. Atlanta, GA.

Audi G, Wapstra AH and Thibault C. 2003. *Nuclear Physics A*; 729, pp 337.

Bajwa BS, Kumar S, Singh S, Sahoo SK, Tripathi Rm. 2015. Uranium and other heavy toxic elements distribution in the drinking water samples of SW-Punjab, India. *Journal of Radiation Research and Applied Sciences*; DOI:10.1016/j.jrras.2015.01.002.

Banks D, Midtgård AaK, Frengstad B, Krog JR, Strand T. 1998b. The chemistry of Norwegian groundwaters. 2. The chemistry of 72 groundwaters from Quaternary sedimentary aquifers. *The science of the Total Environment*; 222, 93-105.

Banks D, Reimann C, Røyset O, Skarphagen H, Sæther OM. 1995a. Natural concentrations of major and trace elements in some Norwegian bedrock groundwaters. *Applied Geochemistry*; 10, 1994, 1-16.

Banks D, Røyset O, Strand T, Skarphagen H. 1995b. Radioelement (U, Th, Rn) concentration in Norwegian bedrock groundwaters. *Environmental Geology*; 25,165-180.

Banks D. Frengstad B, Midtgård AaK, Krog JR, Strand T. 1998a. The chemistry of Norwegian groundwaters. 1. The distribution of radon, major and minor elements in 1604 crystalline bedrock groundwaters. *The science of the Total Environment*; 222, 71-91.

Bhowmik AK, Alamdar A, Katsoyiannis I, Shen H, Ali N, Ali SM, Bokhari H, Schäfer RB, Eqani SAMAS. 2015. Mapping human health risks from exposure to trace metal contamination of drinking water sources in Pakistan. *Science of the Total Environment*; 538: 306-336.

Bleise A, Danesi PR, Burkart W. 2003. Properties, use and health effects of depleted uranium (DU): a general overview. *J. Environ. Radioact*; 64, 93-112.

Bondy SC. 2016. Low levels of aluminum can lead to behavioral and morphological changes associated with Alzheimer's disease and age – related neurodegeneration. *Neuro Toxicology*; 52, 222-229.

Boyd CE, 2015. *Water Quality: An introduction*. Second edition. Springer Cham Heidelberg, New York.

Boyd DR. 2006. *The Water We Drink: An International Comparison of Drinking Water Standards and Guidelines*. *Davisd Suzuzki Foundation*. Vancouver, Canada. ISBN 1-897375-02-6.

- Brugge D, Lemos JL, Oldmixon B. 2005. Exposure pathway and health effects associated with chemical and radiological toxicity of natural uranium: a review. *Environmental Health*; 20, 177-193.
- CDC (Centers for Disease Control and Prevention). 2001. Managing Elevated Blood Lead Levels Among Young Children: Recommendations From the Advisory Committee on Childhood Lead Poisoning Prevention. Atlanta: 2001.
- CDC (Centers for Diseases Control and Prevention). 2001. National report on human exposure to environmental chemicals. Centers for Disease Control and Prevention, Atlanta, GA.
- Celik U and Oehlenschlaeger J. 2007. High contents of Cd, Pb, zinc and copper in popular fishery products sold in Turkish supermarkets. *Food Control*; 18, 258-261.
- Chakraborti D, Rahman MM, Das B, Murrill M, Dev S, et al. 2010. Status of groundwater arsenic contamination in Bangladesh: A 14 – year study report. *Water Research*; 44 (19), 5789-5802.
- Chakraborti D, Sengupta MM, Rahman MM, Ahamed S, Chowdhury UK, et al. 2004. Groundwater arsenic contamination and its health effects in the Ganga – Meghna- Brahmaputra Plain. *Jour of Environ Monitor*; 6, 74-83.
- Chitra KC, Latchoumycandane C, Mathur PP. 2003. Introduction of oxidative stress by bisphenol A in the epididymal sperm of rats. *Toxicology*; 185, 119-127.
- Choong TSY, Chuah Tg, Robiah Y, Koay ELG, Azni I. 2007. Arsenic toxicity, health hazards and removal techniques from water: an overview. *Desalination*; 217, 139-166.
- Colborn T, Vom Saal FS, Soto AM. 1993. Developmental effects of endocrine-disrupting chemicals in wildlife and humans. *Environ. Health Perspect*; 101, 378-384.
- Crebelli R and Leopardi P. 2012. Long-term risks of metal contaminants in drinking water: a critical appraisal of guideline values for arsenic and vanadium. *Ann 1st Super Sanita*; 48(4), 354-361.
- Dodds WK, 2002. Freshwater Ecology. Concepts and Environmental Applications. Academic press, USA.
- Edwards TM, Moore BC, Guillette Jr LJ, 2006. Reproductive dysgenesis in wildlife, a comparative view. *Int. J. Androl*; 29 (1), 109-121.

- EFSA (European Food Safety Authority). 2004. Opinion of the Scientific Panel on Dietetic Products, Nutrition and Allergies on a request from the Commission related to the Tolerable Upper Intake Level of Vanadium. *EFSA J*; 33, 11-22.
- EFSA (European Food Safety Authority). 2009. Scientific Opinion on Arsenic in Food. *EFSA J*; 7 (10), 60-71.
- Englund J, Myhrstad JA, 1980. Groundwater chemistry of Some Selected Areas om Southeastern Norway. *Nordic Hydrology*; 11, 33-54.
- Environmental Canada, 2011. A lake water sample. Certified Reference Material CRANBERRY-05. Vancouver, Canada.
- Eriksson L, Byrne T, Johansson E, Trygg J, Vikstrøm C. 2013. Multi-and Megavariate Data Analysis: Basic Principles and Applications. Third revised edition. Umetrics AB, Umeå, Sweden.
- Esbensen KH. 2002. Multivariate Data Analysis in practice: an introduction to multivariate data analysis and experimental design. *Cano Process AS*; 19-40.
- Fawell J and Nieuwenhuijsen MJ, 2003. Contaminants in Drinking Water. *Br Med Bull*; 68,199-208.
- Flaten TP, 1986. An investigation of the chemical composition of Norwegian drinking water and its possible relationships with the epidemiology of some diseases. Doktor Ingeniør Thesis 51-Desember 1986. *Institution for Uorganisk Kjemi, NTH, University of Trondheim*; 202 pp + Appendices.
- Flaten TP, 1988. Geographical Associations between Aluminium in Drinking Water and Registered Death Rate with Dementia (including Alzheimer`s Disease) in Norway. In. Thorntton, I. (ed) *Geochemistry and Health. Proceedings of the second International Symposium. Science Reviews Limited, Northwood*; 245-256.
- Fredin O, Olsen L and Olesen O, 2012. Quaternary geology of Norway. *Geological survey of Norway special publication 13*. Geological survey of Norway; NO-7491 Norway.

- Freeland-Graves Jh, Mousa TY, Kim S.2016. International variability in diet and Requirements of manganese: causes and consequences. *J Trace Elm Med Biol*; 38. 24-32.
- Frengstad B, Banks D, Siewers U, 2001. The Chemistry of Norwegian Groundwaters: IV. The pH-Dependence of Element Concentrations in Crystalline Bedrock Groundwaters. *The science of the Total Environment*; 277, 101-117.
- Frengstad B, Midtgård S, Banks D, Krog JR, Siewers U, 2000. The Chemistry of Norwegian Groundwaters: III. The Distribution of Trace Elements in 467 Crystalline Bedrock Groundwaters, as Analysed by ICP-MS Techniques. *The science of the Total Environoment*; 246, 21-40.
- Frengstad, B, 2002. Groundwater quality of crystalline bedrock aquifers in Norway. Dr. Ing. Thesis. Department of Geology and Mineral Resources Engineering. The Norwegian University of Science and Technology, NTNU Trondheim. ISBN 82-471-5449-8.
- Friedl G, Teodoru C and Wehrli B, 2004. “ Is The Iron Gate I reservoir on the Danube River asink for dissolved silica?” *Biogeochemistry* 68; 21-32
- Gabby PN. 2006. Lead: in Mineral Commodity Summaries. U.S. Geological Survey; 2006. Available at http://minerals.usgs.gov/minerals/pubs/commodity/lead/lead_mcs05.pdf.
- Gallagher CM, Kovach JS, Meliker JR, 2008. Urinary casmiu, and osteoprosis in U.S. Women $\geq$ 50 years og age. *Environ Health Perspect*; 166, 1338-1343.
- Gobe G and Crane D. 2010. Mitochondria, reactive oxygen species and cadmium toxicity in the kidney. *Toxicology Letters*; 1, 49-55.
- Gowd SS and Govil PK, 2008. Distribution of heavy metals in surface water of Ranipet industrial area in Tamil Nadu, India. *Environ Monitor & Asses*; 136 (1), 197-207.
- Goyer RA, 2001. Toxic effects of metals. The Basic Science of Poisons. New York, McGraw-Hill; 811-867.
- Guertin J, 2005. Toxicity and health effects of chromium. Chromium (VI) Handbook; 216-234.
- Güler C & Thyne GD, 2004. Hydrological and geological factors controlling surface and groundwater chemistrey in India Wells-Owens valley area southerner Calufonia, USA. *Journal of Hydrology*; 285 (1-4), pp 177-188.

- Guo H, Zhang B, Li Y, Berner Z, Tang X, Norra S, Stüben D, 2011. Hydrogeological and biogeochemical constrains of arsenic mobilization in shallow aquifers from the Hetao basin, Inner Mongolia. *Environmental Pollution*; 159: 876-883.
- Guo HM, Yang SZ, Tang XH, Li Y, Shen ZL, 2008a. Groundwater geochemistry and its implications for arsenic mobilization in shallow aquifers of the Hetao basin, Inner Mongolia. *Science of the Total Environment*; 393: 131-144.
- Hammond CR. 2004. The Elements, in Handbooks of Chemistry and Physics. 81st ed. CRC press. ISBN 0-8493-0485-7.
- He B, Li R, Chai M, Qiu G. 2014. Threat of heavy metal contamination in eight mangrove plants from the Futain mangrove forest, China. *Environ Geochem Health*; 36 (3), 467-476.
- Helse- og omsorgsdepartementet. 2001. Forskrift om vannforsyning og drikkevann (Drikkevannsforskriften). [*Directive on water supply and drinking water – in Norwegian*]. FOR-2016-12-22-1868.
- Helsel DR. 2006. Fabricating data: How substituting values for non-detects can ruin results, and what can be done about it. *Chemosphere* 65; 2434-2439.
- Hongve D, Weideborg M, Andruchow E, Hansen R, 1994. Landoversikt drikkevannskvalitet. Spormetaller i vann fra norske vannverk. *Folkehelse vann report 92, Statens institutt for Folkehelse*; Oslo, 110 PP.
- Howell RW, Azure MT, Narra VR, Rao DV, 1994. Relative biological effectiveness of alpha-particle emitters *in vivo* at low doses. *Radiat Res*; 137, 352–360.
- IARC (International Agency for Research on Cancer). 1990. IARC Monographs on the Evaluation of Carcinogenic Risks to Humans, Vol. 49. IARC Science Publications, IARC.
- IARC (International Agency for Research on Cancer). 2004. Some drinking-water disinfectants and contaminants, including arsenic. *IARC mongr Eval Carcinog Risks Hum*; 84, 1-477.
- IEA (International Energy Agency), 2012. Water for Energy: *is energy becoming a thirstier resource?* Excerpt from the World Energy Outlook 2012. OECD/IEA, Paris.
- Jacobs JA, Testa SM, 2005. Overview of chromium (VI) in the environment: background and history. 1-22.

- Jaishankar M, Tseten T, Anbalagan N, et al 2014. Toxicity, mechanism and health effects of some heavy metals. *Interdisciplinary Toxicology*; 7(2), 11-15.
- Järup Lars, 2003. Hazards of heavy metal contamination. *Br Med Bull*; 68 (1): 167-182. doi: 10.1093/bmb/ldg032.
- Jarvis KE, 1997. Inductively coupled plasma-mass spectrometry. Modern analytical Geochemistry. *Addison Wesley Longman Limited*; 171-187.
- Jean SW, Kim JM, Ko Ks, Yum B, Chang HW. 2001. Hydrogeochemical Characteristics of groundwater in Mid-Western coastal aquifer system, Korea. *Geoscineces journal*; 5 (4), 339-348.
- Khan K, Wasserman GA, Liu X, Ahmed E, Parvez F, Slavkovich V, et al. 2012 Manganese exposure from drinking water and children`s academic achievement. *Neurotoxicology*; 33, 91-97.
- Konietzka R, Dieter HH, Voss JU. 2005. Proposal for Health based guide value for uranium in drinking water. *Umweltmedizin in Forschung und Praxis*; 10 (2), 133-143.
- Linares V, Bells M, Albina ML, Sirvent JJ, Sanchez DJ, Domingo JL. 2006. Assessment of the Pro-oxidant activity of uranium in kidney and testis of rats. *Science Direct. Toxicology Letters*; 167, 152-161.
- Linos A, Petralias A, Christophi C, Christoforidou E, et al 2011. Oral ingestion of hexavalent chromium through drinking water and cancer mortality in an industrial area of Greece – An ecological study. *Environ Health*; pp 11-50.
- Mason CF, Norfon SA, Frenandez IJ, Katz LY. 1997. Deconstruction of the chemical effects of road salt on stream water chemistry. *Journal of Environ Quality*.
- Massart DL and Heyden Y. 2005. From Tables to Visuals: Principal Component Analysis, Part 2. *LC-GC Europe*; 8489.
- McHenry C, 1992. The New Encyclopedia Britannica. 15 (3), 102-612.
- Midtgård AaK, Grenstad B, Banks D, Krog JR, Strand T, Siewers U, Lind B. 1998. Drinking water from Crystalline Bedrock Aquifers-not just H₂O. *Mineralogical Society Bulletin*; 9-16.
- Mohammad Ali Zare Chahouki. 2011. Multivariate Analysis Techniques in Environmental Science, Earth and Environmental Sciences, Dr. Imran Ahmad Dar (Ed.), *InTech*; DOI: 10.5772/26516. Available from: <http://www.intechopen.com/books/earth-and->

environmental-sciences/multivariate-analysis-techniques-in-environmental-science. [Last accessed 2016 December].

- Morland G, 1997. Petrology, Lithology, Bedrock Structures, Glaciation and Sea Level. Important Factors for Groundwater Yield and Composition of Norwegian Bedrock Boreholes? Doctor Dissertation. *Istitut Fur Geowissenschaften*. 274 pp + Appendices.
- Morland G, Reimann C, Strand T, Skarphagen H, Banks D, Bjorvatn K, Hall GEM, Siewers U, 1997. The Hydrogenchemistry of Norwegian Bedrock Groundwaters – selected parameters (pH, F, Rn, U, Th, B, Na, Ca) In Samples from Vestfold and Hordaland, Norway. *Norges Geologiske undersøkelse Bulletin*; 432, 103-117.
- Morland G, Strand T, Furuhaugen L, Skarphagen H, Banks D. 1998. Radon Concentrations in Groundwaters from Quaternary Sedimentary Aquifers in Relation to Underlying Bedrock Geology. *Ground Water* 36(7), 143-146.
- Mosby CV, Glanze WD, Anderson KN, 1996. Mosby Medical encyclopedia. The Signet: Revised Edition. St. Louise.
- Munoz-Olivas R and Camara C, 2001. Speciation related to human health. In: *Ebdon L et al 2001. Trace Element Speciation for Environment, Food and Health. The Royal Society of Chemistry*; pp 331-353.
- Myrstad L, Nordheim CF, Janak K, 2015. Water report 122 [Vannrapport 122]. Report form Waterworks Registry [Rapport fra vannverksregisteret]. Drinking water status (data 2011) [Drikkevannsstatus (data 2011)]. *Norwegian Institute of Public Health*. Oslo, Norway. ISSN 1503-2167
- Nadaska G, Lesny J, Michalik I. 2012. Environmental aspect of manganese chemistry. 1-16 pp.
- Nandi D, Saha I, Rav SS, Maity A. 2015. Development of a reduced- graphene-oxide based superparamagnetic nanocomposite for the removal of nickel (II) from an aqueous medium via a fluorescence sensor platform. *Jour of Colloid and Intref Scienc*; 454, 69-79.
- National Institute of Standard & Technology. 2010. Trace elements in Natural Water. Standard Reference Material 1640a. Geithersburg, MD, USA. 6 p.
- NIPH (Norwegian Institute of Public Health (February, 2016). Chemical and physio-chemical water quality (<http://www.fhi.no/nettpub/mihe/vann/vannkvalitet/>).

- NSF. 1979. Vannundersøkelse. Måling av pH. NS 4720. Norsk standardiseringsforbund, Oslo. 7 pp.
- NSF. 1994a. Vannundersøkelse. Bestemmelse av farge (ISO 7887:1994). NS-EN ISO 7887. 1. Utgave. Norsk standardiseringsforbund, Oslo. 7 pp.
- NSF. 1994b. Vannundersøkelse. Bestemmelse av turbiditet (=EN 27027:1994). NS-ISO 7027. 1. Utgave. Norsk standardiseringsforbund, Oslo. 8 pp.
- NSF. 1995. Vannundersøkelse. Bestemmelse av oppløst fluorid, klorid, nitritt, ortofosfat, bromid, nitrat og sulfat med væskeskromatografi, Del 1: metode for lite forurenset vann (ISO 10304-1:1992). Norsk standardiseringsforbund, Oslo. 12 pp.
- NSF. 1996. Vannundersøkelse. Bestemmelse av alkalitet. Del 1: Bestemmelse av total og sammensatt alkalitet (ISO 9963-1:1994). NS-EN ISO 9963-1. Norsk standardiseringsforbund, Oslo. 5 pp.
- NSF. 2002. Vannundersøkelse. Bestemmelse av farge. Metode for spektrofotometrisk måling av absorbans ved 140 nm. (NS 4787:2002). 2. Utgave. Norsk standardiseringsforbund, Oslo. 9 pp.
- NTP (National Toxicology Program). 2015. Report on carcinogens, 11th ed. U.S. Department of Health and Human Services. Public Health Service, Research Triangle Park, NC.
- Pal A, Jayamani J, Prasad R. 2014. An urgent need to reassess the safe levels of copper in the drinking water: Lessons from studies on the healthy animals harboring no genetic deficits. *Neuro Toxicology*; 44, 58-60.
- Patlolla A, Barnes C, Yedjou C, Velma V, Tchounwou PB. 2009. Oxidative stress, DNA damage and antioxidant enzyme induced by hexavalent chromium in Sprague Dawley rats. *Environ Toxicol*; 24(1), 66-73.
- Patlolla A, Tchounwou PB. 2005. Cytogenetic evaluation of arsenic trioxide toxicity in Sprague-Dawley rats. *Mut res-Gen Tox Environ Mutagen*; 587 (1-2), 126-133.
- Patra RC, Rautary AK, Swarup D. 2011. Oxidative Stress in Lead and Cadmium Toxicity and Its Amelioration. *Vet Med Int*; 9 pages.
- Peckham S and Awofeso N. 2014. Review Article. Water Fluoridation: A Critical Review of the Physiological Effects of Ingested Fluoride as a Public Health Intervention. *The Scientific World Journal*, 10 pp.

- Rapant S, Cveckova V, Fajcikova K, Dietzova Z, Stehlikova B. 2016. Chemical composition of groundwater/drinking water and oncological disease mortality in Slovak Republic. *Environ Geochem Health*; DOI 10.1007/s10653-016-9820-6.
- Rasmus B, Age KS. 2014. Principle component analysis. *Anal. Methodes*; 6, 2812.
- Real A, Sundell-Bergman S, Knowles JF, Woodhead DS, Zinger I. 2004. Effects of ionising radiation exposure on plants, fish, and mammals: Relevant data for environmental radiation protection. *J Radiol Protect*; 24 (A), 123–137.
- Reimann C and de Caritat P. 1998. Chemical Elements in the Environment. Springer –Verlag, Berlin Heidelberg. 398 pp.
- Reimann C, Ayas M, Chekushin V, Bogatyrev I, Boyd R, Caritat P, Dutter R, Finne TE, Halleraker JH, Jæger Ø, Kasjulina G, Lehto O, Niskavaara H, Pavlvo V, Raisanen ML, Strand L, Volden T. 1998. Environmental Geochemistry Atlas of the Central Barents Region. *Norges Geologiske Undersøkelse*; 745 pp.
- Reimann C, Hall GEM, Siewers U, Bjorvatn K, Morland G, Skarphagen H, Strand T. 1996. Radon, Fluoride and 62 Elements as Determined by ICP-MS in 154 Norwegian Hard Rock Groundwater Samples. *The Science of the Total Environment*; 192, 1-19.
- Rekstad J, 1992. Grunnvatnet. *Norges Geologiske undersøkelse*; 92, Kristiania, pp 30.
- Roccaro P and Vagliasindi FGA. 2013. Coprecipitation of vanadium in natural water with iron (hyde) oxides. Environmental Science and Technology. Athens, Greece.
- Rosado JL, Ronguillo D, Kordas K, Rojas O, Alatorre J, Lopez, P, et al. 2007. Arsenic Exposure and Cognitive Performance in Mexican Schoolchildren. *Environ Health Perspect*; 115 (9), 1371-75.
- Roscoe RJ, Deddens JA, Salvan A, Schnorr TM, 1995. Mortality among Navajo uranium miners. *Am. J. Public Health*; 85, 535-540.
- Schutte R, Nawrot TS, Richart T, Thijs L, Vanderschueren D, Kuznetsova T. 2008. Bone resorption and environmental exposure to cadmium in women: a population study. *Environ Health Perspect*; 166, 777-783.
- Shaheen N, Irfan MN, Khan IN, et al 2016. Presence of heavy metals in fruits and vegetables: Health risk implications in Bangladesh. *Chemosphere*; 152, 431-38.

- Smith AH, Hopenhayn RC, Bates MN, Goeden HM, et al. 1992. Cancer risks from arsenic in drinking water. *Environ Health Perspect*; 97, 259-267.
- Spalding JF, Brooks M, McWilliams P, 1964. Observations on lifespan, radioresistance, and productivity in offspring from 5 to 25 generations of x-irradiated male mice. *Genetics*; 50, 1179–1186.
- Spalding JF, Brooks M, McWilliams P. 1966. Reproductively and life span of mouse populations from 25 generations of irradiated sires. *Genetics*; 54, 755–761.
- Spectrapure Standards. 2008. Reference Material for Measurement of Elements in Surface Water. Certified Reference Material SPS-SW1 Batch 123. Oslo, Norway. 1 p.
- Spectrapure Standards. 2008. Reference Material for Measurement of Elements in Surface Water. Certified Reference Material SPS-SW1 Batch 131. Oslo, Norway. 1 p.
- Srinivasa G & Govil PK. 2007. Distribution of heavy metals in surface water of Ranipit industrial area in Tamil Nadu, India. *Environment Monitoring and Assessment*; 136: 197-207.
- Stark JR, Hanson PE, Goldstein RM, Fallon JD, Fong AL, Lee KE, Kroening SE, Andrews WJ. 2000. Water Quality in the upper Mississippi River Basin, Minnesota, Wisconsin, South Dakota, Iowa, and North Dakota. United States Geological Survey, Circular 1211.
- Steinnes E, Frontasyeva MV. 2002. Marine gradients of halogens in soil studied by epithermal neutron activation analysis. *Journ of Radioanalytic and Nuclear chem*; 253(1), pp 173-177.
- Stroeve AP and Kleman J. (1997). Periglacial surface remnants and Quaternary glacial in northwestern Sweden. *Geomorphology*; 19, p. 35-54.
- Taylor DM and Taylor SK. 1997. Environmental uranium and human health. *Rev. Environ. Health*; 12, 147-157.
- Tchounwou PB, Yadjou CG, Patlolla AK, Sutton DJ. 2012. Heavy Metal Toxicity and the Environment. *Clinical & Environ Toxicol*; 101, 133-164.
- UNEP GEMS (United Nations Environmental Program Global Environmental Monitoring System), 2008. Water Quality for Ecosystem and Human health, 2nd Edition. Burlington, Canada. ISBN 92-95039-51-7.
- UNEP GEMS, United Nations Environmental Programme Global Environmental Monitoring System, 2008. Water Quality for Ecosystem and Human health, 2nd Edition. Burlington, Canada. ISBN 92-95039-51-7.

- US EPA (United States Environmental Protection Agency). 1997. Volunteer Stream Monitoring: A Methods Manual. EPA 841-B-97-003.
- US EPA (United States Environmental Protection Agency). 2002. EPA facts about Uranium. Available from: <https://semspub.epa.gov/work/HQ/175267.pdf>. [Last accessed on 2016 December].
- US EPA (United States Environmental Protection Agency). 2009. National Primary Drinking Water Regulation. EPA 816-F-09-004.
- USGS, US Geological Survey's (02-Dec-2016). The World's Water. Available: <http://water.usgs.gov/edu/earthwherewater.html> (accessed 20 January 2017).
- Von-Ehrenstein OS, Maszumder DNG, Hira-Smith MH, et al. 2006. Pregnancy outcomes, infant mortality, and arsenic in drinking water in West Bengal, India. *Am. J. Epidemiol*; 163(7), 662-669.
- Walsh S, Satkunam M, Su B, Festarini A, Bugden M, Peery H, Mothersill C, Sturart M. 2015. Health, growth and reproductive success of mice exposed to environmentally relevant levels of Ra-226 via drinking water over multiple generations. *International Journal of Radiation Biology*; 91 (7), 576-684.
- Welling R, Beaumont JJ, Petersen SJ, Alexeeff GV, Steinmaus C. 2015. Chromium VI and stomach cancer: a meta-analysis of the current epidemiological evidence. *Occup Environ Med*; 72(2), 155-159. DOI 10.1136/oemed-2014-102178.
- Wetzel RG and Likens GE. 2000. Limnological Analysis. Third Edition. New York: Springer-verlag, Inc.
- WHO (World Health Organization). (2016, November). Drinking – water. Fact sheet. Available: <http://www.who.int/mediacentre/factsheets/fs391/en/> (accessed 13 December 2016).
- WHO (World Health Organization). 2001. Depleted Uranium. Sources, Exposure and Health Effects-Full Report. WHO, Geneva 2001 (WHO/SDE/PHE/01.1).
- WHO (World Health Organization). 2005. Nutrients in drinking water. Report 2005. Available from: http://www.who.int/water_health/dwq/nutrientsindw/en/index.html.
- WHO (World Health Organization). 2011. Guidelines for drinking – water quality, -4th Edition. Geneva, Switzerland. ISBN 978 92 4 154815 1.

- WHO (World Health Organization). 2012. Uranium in Drinking-water. Background Document for Development of WHO Guidelines for Drinking-water Quality. WHO, Geneva 2012.
- WHO (World Health Organization). 2016. Guidelines for drinking – water quality -4th Edition. Geneva, Switzerland. ISBN 978 92 4 154815 1.
- WHO (World Health Organization). 2017. Guidelines for drinking – water quality: fourth edition incorporating the first addendum. Geneva, Switzerland. ISBN 978-92-4-154995-0.
- Wright MT, Stollenwerk KG, Belitz K. 2014. Assessing the solubility controls on vanadium in the groundwater, northeastern San Joaquin Vally, CA. *Applied Geochemistry*; 48, 41-52.
- Yassi A, Kjellestrøm T, De Kok T, Guidotti TL. 2001. *Basic Environmental Health*. New York, USA. Oxford University press, Inc. p 209-41.
- Yoshida F, Hata A, Tonegawa H. 1999. Itai-Itai disease and the countermeasures against cadmium pollution by the Kamioka mine. *Environ. Econ. Policy stud*; 2, 215-229.
- Zambelli B, Uversky VN, Cicurli S. 2016. Nickel impact on human health: AN intrinsic disorder perspective. *Biochim Biophys Acta*; 1864 (12), 1714-31.

Appendix A: Information about waterworks

Table A1: shows the names of waterworks, municipalities, total population supplied, type of groundwater source and type of water treatment for each waterworks included in the study

Water supply system/Waterworks Name	Samples number	Municipalities (Communes) - Name	Total population supplied	Water source	Water treatment
Rafsbøtn vannverk	86	Alta	500	Sedimentary	Pressure filtration
Alta by vannverk	95	Alta	14 500	Sedimentary	No
Nyvoll vannverk	200	Alta	50	Sedimentary	UV - disinfection
Andebu Vannverk	31	Andebu	1 623	Other	Chlorine disinfection
Høyjord vannverk	52	Andebu	290	Bedrock	UV -disinfection and Softening
Vidaråsen vannverk	116	Andebu	150	Bedrock	UV - disinfection
Orreleiken 51, privat. Vannforsyning, fritidsbygg	96	Asker	3	Bedrock	No
Syltømtjern vannverk	131	Aurskog-Høland	455	Bedrock	UV - disinfection
Nedre Bardu vannverk	161	Bardu	270	Sedimentary	No
Tollåkkila vannverk	17	Beiarn	177	Sedimentary	UV - disinfection
Torvetua vannverk	5	Bergen	150	Bedrock	Filtration and softening
Birkeland vannverk	78	Birkenes	2 570	Sedimentary	Aeration and pH-Adjustment
Herefoss vannverk	92	Birkenes	201	Sedimentary	CO ₂ -stripping(removal), marble filtration and UV-disinfection
Misvær vannverk	104	Bodø	450	Sedimentary	UV - disinfection
Breivik vannverk	109	Bodø	87	Sedimentary	UV - disinfection
Hauge vassverk	139	Bremanger	175	Other	particulate filtration and UV-disinfection
Sollihøgda vannverk	51	Bærum	132	Bedrock	Chlorine disinfection
Bø vassverk	159	Bø	4 406	Sedimentary	Ozonation, sand filter, liming
Dovreskogen vannverk	190	Dovre	60	Bedrock	UV -disinfection and Aeration
Øvre Eidfjord vassverk	25	Eidfjord	250	Sedimentary	No
Eidfjord vassverk	27	Eidfjord	540	Sedimentary	No
Bu vassverk	61	Eidfjord	40	Bedrock	UV - disinfection
Åbøgen Vannverk	45	Eidskog	105	Sedimentary	Aeration and UV - disinfection
Elverum vannverk	132	Elverum	17 380	Sedimentary	VYREDOX

Water supply system/Waterworks Name	Samples number	Municipalities (Communes) - Name	Total population supplied	Water source	Water treatment
Moajordet vannverk	29	Etnedal	55	Sedimentary	UV - disinfection
Bruflat vannverk	70	Etnedal	290	Bedrock	UV - disinfection
Røyrkilen vannverk	118	Evje og Hornnes	2 500	Sedimentary	Marble filtration
Dale Vassverk	98	Fjaler	1 400	Sedimentary	Aeration and pH-Adjustment
Sira vannverk	57	Flekkefjord	600	Sedimentary	Marble filtration and UV-disinfection
Gyland vannverk	58	Flekkefjord	200	Sedimentary	No
Forsand kommunale vannverk	136	Forsand	439	Sedimentary	UV - disinfection
Meling vannverk	146	Forsand	65	Bedrock	UV – disinfection
Helle vannverk	148	Forsand	102	Sedimentary	UV - disinfection
Sylteosen Vassverk SA	169	Fræna	480	Bedrock	UV - disinfection
Forset vannverk	14	Gausdal	2 423	Sedimentary	Filtration, Ozonation, UV-disinfection and pH-adjustment
Olstad vannverk	18	Gausdal	50	Sedimentary	UV - disinfection
Oltedal vannverk IVAR IKS	108	Gjesdal	945	Sedimentary	UV - disinfection and pH-adjustment with lye (Sodium hydroxide)
Sande vassverk	114	Gloppen	2 730	Sedimentary	Natural filtering through sand, pH-adjustment with water glass
Gol vassverk	130	Gol	3 500	Sedimentary	Marble filter, Chlorine disinfection and Uv
Grane kommunale vannverk	129	Grane	62	Bedrock	UV - disinfection
Hattfjelldal vannverk	138	Hattfjelldal	750	Sedimentary	No
Tuv vannverk	111	Hemsedal	220	Sedimentary	UV-disinfection, krystazil 40R2(water glass) and Chlorination
Krikken vannverk	122	Hemsedal	1 200	Sedimentary	UV-disinfection and lye (Sodium hydroxide)
Kvalsvikøy Vassverk A/L v/ Trond Kvalsvik	147	Herøy	230	Bedrock	Liming and UV-disinfection
Jøsenfjorden Vannverk	194	Hjelmeland	68	Bedrock	UV - disinfection
Årdal vannverk	195	Hjelmeland	670	Bedrock	UV- disinfection and pH-adjustment with water glass
Skiftun Vannverk	198	Hjelmeland	100	Sedimentary	UV - disinfection
HOL vannverk	77	Hol	701	Sedimentary	pH-adjustment

Water supply system/Waterworks Name	Samples number	Municipalities (Communes) - Name	Total population supplied	Water source	Water treatment
Geilo vannverk	89	Hol	500	Bedrock	Chlorine disinfection
Hovet vannverk	90	Hol	236	Sedimentary	UV - disinfection
Geilo nye vannverk	145	Hol	2 468	Sedimentary	UV - disinfection
Sollihøgda vannverk Hole kommune	63	Hole	75	Bedrock	UV - disinfection
Nykirke Østre	186	Horten	100	Bedrock	No
Falkenstein Vannverk SA	189	Horten	100	Bedrock	UV - disinfection
Midtre Høylandet vannverk	164	Høylandet	774	Bedrock	No
Kautokeino vannverk	93	Kautokeino	2 000	Sedimentary	UV - disinfection
Hvittingfoss vannverk	64	Kongsberg	1 170	Sedimentary	Reverse osmosis to remove Fluoride
Kongsberg Vannverk	65	Kongsberg	21 463	Sedimentary	Liming filter
GIVAS - Granli	43	Kongsvinger	15 400	Sedimentary	Adding lye
GIVAS Austmarka	46	Kongsvinger	385	Sedimentary	Adding lye
Slettemoen vannverk	60	Krødsherad	900	Sedimentary	Aeration
Noresund vannverk	181	Krødsherad	765	Sedimentary	Aeration
Ænes Vassverk	73	Kvinnherad	100	Sedimentary	No
Burfjord vannverk	105	Kvænangen	360	Sedimentary	No
Lesjaverk vannverk	179	Lesja	50	Sedimentary	Alkalize with marble
Joramo vannverk	183	Lesja	150	Bedrock	Alkalize with marble
Bjørli Vannverk	184	Lesja	100	Sedimentary	Alkalize with marble
Torhaugen Vannverk	124	Levanger	718	Sedimentary	Ion exchange, UV-disinfection and aeration
Jule Boligområdes vannverk	50	Lierne	75	Bedrock	Membrane filter and UV-disinfection
Lillehammer vannverk - Korgen	163	Lillehammer	21 117	Sedimentary	UV - disinfection
Garmo vassverk	165	Lom	230	Sedimentary	No
Leirimo vassverk	178	Lom	71	Other	UV - disinfection and adding of lye
Galdesand vassverk	185	Lom	63	Sedimentary	No
Konsvik vannverk	33	Lurøy	125	Bedrock	No
Lovund vannverk	53	Lurøy	430	Sedimentary	UV - disinfection
Tonnes vannverk	196	Lurøy	99	Other	UV - disinfection
Aldersund vannverk	197	Lurøy	100	Other	UV - disinfection
Kvina vannverk	199	Lurøy	40	Bedrock	UV - disinfection
Gaupne vassverk	3	Luster	1 041	Sedimentary	CO2- aeration
Skjolden vassverk	23	Luster	300	Sedimentary	UV - disinfection
Gjerde vassverk	26	Luster	80	Sedimentary	UV-disinfection, water glass and aeration

Water supply system/Waterworks Name	Samples number	Municipalities (Communes) - Name	Total population supplied	Water source	Water treatment
Kvås vannverk	153	Lyngdal	125	Sedimentary	Marble to raise pH and calcium
Naddvik Vassverk	171	Lærdal	75	Bedrock	UV- disinfectio and sand filter
Meldal vannverk	175	Meldal	2 550	Sedimentary	Aeration
Gåsbakken vannverk	107	Melhus	208	Sedimentary	No
Åg Vannverk AL	125	Meløy	80	Other	Dual UV- disinfection
Søre Midøy Vassverk	103	Midsund	145	Bedrock	No
Djupdalen Vassverk	142	Molde	167	Bedrock	UV - disinfection
Øverbygd Vannverk	54	Målselv	560	Sedimentary	Aeration
Statland vannverk	7	Namdalseid	160	Bedrock	UV - disinfection
Kirkåsen Vannverk	173	Nesodden	252	Bedrock	UV - disinfection
Fagerstrand Vannverk	174	Nesodden	3 000	Bedrock	UV – disinfection and chlorine disinfection
Karlebotn Vannverk	16	Nesseby	450	Other	UV - disinfection
Nesseby vannverk	172	Nesseby	260	Sedimentary	Chlorine disinfection
Felle Vassverk	167	Nissedal	85	Sedimentary	UV- disinfection and marble filter
Høgefoss Vassverk	168	Nissedal	100	Sedimentary	UV- disinfection and marble filter
Givas Botner	44	Nord-Odal	873	Bedrock	Adding lye
Dokka vannverk	115	Nordre Land	2 758	Sedimentary	UV- disinfection and adding krystazil 40R2 (water glass)
Torpa/Elverom vannverk	126	Nordre Land	98	Bedrock	Green sand filter and UV- disinfection
Uvdal vannverk	76	Nore og Uvdal	222	Sedimentary	Water glass and aeration
Norefjord vannverk	88	Nore og Uvdal	243	Sedimentary	No
Hvammen vannverk	101	Nore og Uvdal	50	Sedimentary	No
Lund fellesvannverk	72	Nærøy	29	Sedimentary	No
Eidshaug Vassverk	158	Nærøy	70	Sedimentary	No
Odda vannverk	91	Odda	4 300	Sedimentary	Marble filter , pH-adjustment and UV-disinfection
Røldal vannverk	100	Odda	400	Sedimentary	No
Skare vannverk	102	Odda	300	Other	UV-disinfection
Vollan Vannverk A/L	120	Oppdal	52	Other	No
Oppdal Sentrum vannverk	151	Oppdal	4 200	Sedimentary	pH-adjustment
Orkdal vannverk	35	Orkdal	7 800	Other	UV - disinfection

Water supply system/Waterworks Name	Samples number	Municipalities (Communes) - Name	Total population supplied	Water source	Water treatment
Midtdal Vannanlegg A/L	1	Os	43	Sedimentary	No
Sander vannverk Rakkestad kommune	11	Rakkestad	3 550	Bedrock	Aeration, filtration, and chlorine disinfection.
Kirkeng vannverk, Rakkestad kommune	134	Rakkestad	275	Bedrock	Potassium permanganate, Filtration, Softening and chlorine disinfection
Sør-Sjona og Utskarpen vannverk	34	Rana	500	Bedrock	Softening
Sletten/ Lillealteren vannverk	68	Rana	50	Bedrock	Filtration and UV - disinfection
Vivestad vannverk	22	Re	134	Bedrock	No
Krakken vannverk	150	Re	256	Bedrock	UV - disinfection
Almedalen syd vannverk	162	Re	82	Bedrock	UV - disinfection
Ulsberg vannverk	152	Rennebu	107	Bedrock	No
Havdal vannverk	156	Rennebu	120	Bedrock	No
Fåvang vannverk	38	Ringebu	980	Sedimentary	Aeration
Ringebu Vannverk	39	Ringebu	1 540	Sedimentary	No
Ringmoen vannverk	79	Ringerike	97	Sedimentary	UV - disinfection
Ringerike vannverk	80	Ringerike	24 343	Sedimentary	No
Hallingby vannverk	81	Ringerike	738	Sedimentary	UV - disinfection
Sokna vannverk	82	Ringerike	1 063	Sedimentary	No
Vestre Nes vannverk	83	Ringerike	173	Sedimentary	UV - disinfection
Åsen vannverk, Åsmarka	13	Ringsaker	197	Bedrock	Softening with salt
Lismarka, vannforsyning	155	Ringsaker	179	Bedrock	Chlorine disinfection
Narud vannverk	177	Ringsaker	12 165	Bedrock	Softening with salt
Veggli Vannverk	87	Rollag	440	Sedimentary	Adding Soda ash/ sodium hydroxide
Rødøy vannverk	36	Rødøy	175	Bedrock	No
Russånes Vannverk	143	Saltdal	132	Sedimentary	UV - disinfection
Røklund vannverk BA	154	Saltdal	272	Bedrock	UV - disinfection
Holm og Wee Vannverk	30	Sande	145	Other	No
Hjuksebø vannverk	94	Sauherad	317	Bedrock	UV - disinfection
Nedre Sauherad vannverk	97	Sauherad	2 700	Sedimentary	No
Holtsås vannverk	99	Sauherad	57	Bedrock	UV - disinfection
Flora vannverk	106	Selbu	155	Sedimentary	No
Storøra vannverk	110	Selbu	2 500	Sedimentary	No

Water supply system/Waterworks Name	Samples number	Municipalities (Communes) - Name	Total population supplied	Water source	Water treatment
Vingvågen vassverk v/Sverre Jacobsen	112	Snillfjord	30	Bedrock	UV - disinfection
Flora vannverk	133	Stjørdal	120	Sedimentary	UV - disinfection
Moen vannverk	141	Stjørdal	90	Sedimentary	UV - disinfection
Koppang vannverk	2	Stor-Elvdal	2 000	Sedimentary	No
Loen vassverk	123	Stryn	378	Other	UV - disinfection and pH-adjustment with water glass
Marvik vassverk	15	Suldal	70	Bedrock	No
Sand vassverk	19	Suldal	1 226	Sedimentary	No
Mosrøysane vassverk	113	Suldal	54	Sedimentary	UV - disinfection
Nesflaten vassverk	121	Suldal	130	Sedimentary	UV-disinfection and marble filter
Suldalsosen vassverk	128	Suldal	397	Sedimentary	UV - disinfection
Erfjord Vassverk	140	Suldal	475	Sedimentary	No
Vanvik vassverk	160	Suldal	43	Bedrock	UV - disinfection
Ålvundeid vassverk	10	Sunndal	500	Sedimentary	pH-adjustment
Kalken vassverk	21	Sunndal	1 000	Other	UV - disinfection
Gjøra vassverk	24	Sunndal	150	Sedimentary	No
Jordalsgrenda vassverk	62	Sunndal	60	Bedrock	No
Ålvundfjord vassverk	166	Sunndal	500	Sedimentary	Water glass
Bjøråa vassverk	117	Surnadal	75	Sedimentary	UV - disinfection
Ånes vannverk	74	Søndre Land	420	Sedimentary	Membrane filter and UV-disinfection
Trevatn vannverk	75	Søndre Land	300	Bedrock	Sand filter
Grimebakken vannverk	84	Søndre Land	110	Bedrock	No
Harpefoss vassverk (PVG6)	9	Sør-Fron	750	Sedimentary	UV-disinfection and pH adjustment with krystazil 40R2
Lia vassverk (PVG13)	149	Sør-Fron	386	Sedimentary	UV-disinfection and pH adjustment with krystazil 40R2
Svanvik vannverk	55	Sør-Varanger	150	Other	UV - disinfection
Bugøyfjord vannverk	56	Sør-Varanger	70	Other	Sand filter and UV-disinfection
Torhop vannverk	191	Tana	11	Sedimentary	No
Polmak vest vannverk	192	Tana	8	Sedimentary	UV - disinfection
Austertana vannverk	193	Tana	240	Bedrock	UV - disinfection
Båteng vannverk	32	Tana	70	Sedimentary	UV - disinfection
Skipagurra vannverk	37	Tana	250	Sedimentary	UV - disinfection
Atrå vannverk	40	Tinn	700	Sedimentary	UV-disinfection and alkalize
Miland vannverk	41	Tinn	580	Sedimentary	UV-disinfection and alkalize

Water supply system/Waterworks Name	Samples number	Municipalities (Communes) - Name	Total population supplied	Water source	Water treatment
Våer vannverk	42	Tinn	75	Bedrock	UV - disinfection
Dalen vassverk VB1	28	Tokke	1 000	Sedimentary	No
Høydalsmo vassverk VB2	47	Tokke	200	Sedimentary	Lye (Sodium hydroxide), potassium permanganate, sand filter og UV-disinfection
Åmdals Verk vassverk VB4	48	Tokke	110	Sedimentary	Lye (Sodium hydroxide)
Lårdal vassverk VB3	49	Tokke	120	Bedrock	Aaration and UV-disinfection
Vingelen Vassverk	8	Tolga	239	Sedimentary	Aeration
Småslett og Marislett vannverk	12	Tromsø	62	Other	No
Fagernes Vannverk Vann og avløp	20	Tromsø	218	Other	UV - disinfection
Linkveien vannverk	69	Tromsø	45	Bedrock	Fiberglass tank
Jordet vannverk	4	Trysil	355	Sedimentary	UV - disinfection and water glass
Innbygda vannverk	144	Trysil	2 597	Sedimentary	UV- disinfection and water glass
Østby vannverk v/ Geir Kristian Øvervik	170	Trysil	280	Bedrock	Water glass (kyrstazil 40R2)
Midtbygda Vannverk	59	Tynset	175	Sedimentary	No
Østigård og Nærverrøsten vannverk BA	176	Tynset	95	Other	UV - disinfection
Lunde vasslag	6	Tysnes	900	Sedimentary	Marble filtration and UV-disinfection
Lofthus vassverk SA v/ Harald Gjernes	137	Ullensvang herad	150	Other	UV - disinfection
Ulvik Vassverk	182	Ulvik herad	682	Sedimentary	UV - disinfection
Dale/Stanghelle vassverk	67	Vaksdal	1 900	Sedimentary	Marble filtration and UV-disinfection
Eidsland vassverk	157	Vaksdal	50	Sedimentary	No
Stamnes vassverk	180	Vaksdal	100	Other	UV- disinfection and water glass
Kvislistøyl Vassverk Brokke Vatn- og Avlaupsverk AS	127	Valle	50	Sedimentary	Marble pool and UV - disinfection
Vang vassverk	135	Vang	168	Sedimentary	UV-disinfection and aeration
Rekdal Vassverk	66	Vestnes	160	Bedrock	Aeration
Fresvik vassverk	71	Vik	85	Bedrock	UV - disinfection
Øvre Eiker Strømbo	119	Øvre Eiker	10 830	Sedimentary	chlorination and water glass(Krystazil 40R2)

Water supply system/Waterworks Name	Samples number	Municipalities (Communes) - Name	Total population supplied	Water source	Water treatment
Børmark Vannverk	187	Åfjord	59	Sedimentary	No
Lonin-Butli Vannverk	188	Åfjord	33	Sedimentary	No
Øvre Årdal vassverk	85	Årdal	3 480	Sedimentary	Marble filtration
Årdalstangen vassverk	201	Årdal	2 020	Sedimentary	No
		Total population supplied	256 607		
		% population supplied in Norway	4,9		

Appendix B: Sampling procedure and sampling sheet form

Prosedyre for prøvetaking av drikkevatt

Viktig moment: Unngå forureining av kork og opning av sentrifugerørret. Hald derfor nedst på røret. Ikkje ta på opninga av røret eller innsida av korken. Prøv å unngå å legge frå deg korken. Dersom du må legge korken frå deg, legg den med innsida opp.

Kvart prøverør er nummerert. Noter prøvenummer, dato, klokkeslett, prøvetakingspunkt, namn på kjelde for råvatn og vassbehandling på prøvetakingstidspunktet på vedlagt skjema.

Reint vatn: 2 x 15 mL-rør og ei 200 mL-flaske

1. Opne krana og la vatnet renne sakte i 3 minutt. Du skal ikkje regulere vasstraumen under tapping og prøvetaking.
2. Opne korken og hald prøverøret under vasstraumen. Fyll sakte opp til 15 mL-merket og skru fast korken. Gjer det same for 200 ml flaske.

Råvatn frå brønn: 2 x 15 mL-rør

1. Dersom det fins uttak av vatn direkte frå brønnen gjennom eiga tappekran:
 - a. Opne krana og la vatnet renne sakte i 3 minutt. Du skal ikkje regulere vasstraumen under tapping og prøvetaking.
 - b. Opne korken og hald sentrifugerørret under vasstraumen. Fyll sakte opp til 15 mL-merket og skru fast korken.
2. Dersom det ikkje fins eige uttak av vatn frå brønnen:
 - a. Ta på vedlagt hanske.
 - b. Opne korken og hald sentrifugerørret under vatn i brønnen. Fyll røret fullt og skru fast korken.



Prøveskjema – drikkevannsprosjekt
[Sampling sheet form – drinking water project]

Vannverkets navn[Waterworks Name]:

Kommune[Municipality]:

Fylke[County]:

Koordinat[Coordinates]:

Tidspunkt forprøvetaking (dag.måned.år + klokkeslett):
[Sampling time (date.month.year + O'clock):

Prøvenummer rent vann 2 x 15-mL-rør og en 200mL-flaske:
[Sample number clean water 2 x 15-mL-tube and one 200-mL-bottle]:

Prøvenummer råvann 2 x 15-mL-rør:
[Sampling number raw water 2 x 15-mL-tube]:

Råvannskilde navn:
[Source water Name]:

Vannbehandling på det tidspunktet prøvene ble tatt:
[Water treatment]:

Prøvetaker/kontaktperson:
[Sampler/ Person of Contact]:

TELEFON:

Eventuelle tilleggsopplysninger:
[Any additional details]:

APPENDIX C: Information about the measurement quality

Table C1. Limit of detection (LOD) and limit of quantification (LOQ) for all measured parameters.

All except F⁻, NO₃-N and SO₄²⁻ were measured in ICP-MS QQQ. F⁻, NO₃-N and SO₄²⁻ were measured by using IC.

Elements	Unit	LOD	LOQ		Elements	Unit	LOD	LOQ
Li	µg/L	0.02	0.058		Zr	µg/L	0.001	0.0034
Be	µg/L	0.002	0.0079		Nb	µg/L	0.001	0.0035
B	µg/L	0.9	2.9		Mo	µg/L	0.004	0.013
Na	mg/L	0.008	0.028		Ag	µg/L	0.002	0.005
Mg	mg/L	0.0009	0.0031		Cd	µg/L	0.0007	0.0023
Al	µg/L	0.6	1.9		In	µg/L	0.001	0.0048
Si	mg/L	0.03	0.091		Sn	µg/L	0.005	0.016
F ⁻	mg/L	0.04	0.1		Sb	µg/L	0.006	0.02
NO ₃ -N	mg/L	0.02	0.07		Te	µg/L	0.003	0.0095
SO ₄ ²⁻	mg/L	0.08	0.03		Cs	µg/L	0.0009	0.0029
Cl	mg/L	0.06	0.2		Ba	µg/L	0.04	0.12
Br	µg/L	0.7	2.5		La	µg/L	0.0008	0.0025
I	µg/L	0.04	0.15		Ce	µg/L	0.001	0.0035
P	µg/L	1	4.9		Pr	µg/L	0.0006	0.002
S	mg/L	0.0008	0.0028		Nd	µg/L	0.0008	0.0028
K	mg/L	0.004	0.013		Sm	µg/L	0.001	0.0033
Ca	mg/L	0.002	0.0075		Eu	µg/L	0.0008	0.0026
Sc	µg/L	0.01	0.034		Gd	µg/L	0.0008	0.0027
Ti	µg/L	0.2	0.54		Tb	µg/L	0.0007	0.0025
V	µg/L	0.002	0.0069		Dy	µg/L	0.0007	0.0024
Cr	µg/L	0.03	0.085		Ho	µg/L	0.0007	0.0022
Mn	µg/L	0.02	0.062		Er	µg/L	0.0006	0.0019
Fe	µg/L	0.1	0.42		Tm	µg/L	0.0006	0.002
Co	µg/L	0.002	0.0064		Yb	µg/L	0.0007	0.0022
Ni	µg/L	0.02	0.058		Lu	µg/L	0.0007	0.0023
Cu	µg/L	0.04	0.12		Hf	µg/L	0.0008	0.0026
Zn	µg/L	0.09	0.31		Ta	µg/L	0.0007	0.0024
Ga	µg/L	0.002	0.0056		W	µg/L	0.001	0.0034
Ge	µg/L	0.006	0.021		Tl	µg/L	0.0008	0.0028
As	µg/L	0.003	0.011		Pb	µg/L	0.003	0.0098
Se	µg/L	0.01	0.045		Bi	µg/L	0.003	0.0097
Rb	µg/L	0.01	0.037		Th	µg/L	0.001	0.0042
Sr	µg/L	0.02	0.052		U	µg/L	0.001	0.0033
Y	µg/L	0.0007	0.0023		-	-	-	-

Table C2. Certified reference material (CRM) 1640a Trace elements in Natural Water (National Institute of Standard & Technology, 2010) values used in ICP-MS and the measured value of CRM. Green color indicates the measured value is within the CRM and yellow color indicates that it is close to CRM value.

Elements	Unit	Measured value	CRM 1640a
Al	µg/L	54.36	53 ± 1.8
Sb	µg/L	5.064	5.105 ± 0.046
As	µg/L	8.02	8.075 ± 0.070
Ba	µg/L	151	151 ± 0.83
Be	µg/L	3.07	3.028 ± 0.028
B	µg/L	304.8	303.1 ± 3.1
Cd	µg/L	4,032	3.992 ± 0.074
Cr	µg/L	39.78	40.54 ± 0.30
Co	µg/L	19.98	20.24 ± 0.24
Cu	µg/L	85.68	85.75 ± 0.51
Fe	µg/L	36.82	36.8 ± 1.8
Pb	µg/L	12.42	12.101 ± 0.050
Mn	µg/L	39.4	40.39 ± 0.36
Mo	µg/L	43.92	45.39 ± 0.61
Ni	µg/L	25.14	25.32 ± 0.14
Se	µg/L	20.18	20.13 ± 0.17
Ag	µg/L	8.236	8.081 ± 0.046
Sr	µg/L	125.8	126.03 ± 0.91
Tl	µg/L	1.618	1.619 ± 0.016
U	µg/L	25.04	25.35 ± 0.27
V	µg/L	14.92	15.05 ± 0.25
Zn	µg/L	56.58	55.64 ± 0.35
Li	µg/L	0.3628	0.4066 ± 0.0094
Rb	µg/L	1.14	1.198 ± 0.011
Ca	mg/L	5.51	5.615 ± 0.021
Mg	mg/L	1.0114	1.0586 ± 0.0041
K	mg/L	0.5624	0.5799 ± 0.0023
Si	mg/L	5.246	5.210 ± 0.021
Na	mg/L	3.03	3.137 ± 0.031
Cl	mg/L	-	-
Br	µg/L	-	-
I	µg/L	-	-

Table C3. Certified reference material SPS-SW1 Batch 123 and SPS-SW2 Batch131 Reference material for measurement of elements in surface water (Spectrapure Standards, 2008) values used in ICP-MS and the measured value of CRM. Green color indicates the measured value is within the CRM value and yellow color indicates that it is close to CRM value. While, the red color means the measured value is outside the CRM value.

Elements	Unit	Measured value	SPS-SW1 batch 123	Measured value	SPS-SW2 batch131
P	µg/L	98	100	499	500
S	µg/L	2002	2000	10240	10000
Sc	µg/L	0.5	0.5	2.5	2.5
Y	µg/L	0.5	0.5	2.5	2.5
Cs	µg/L	2	2	10	10
La	µg/L	0.5	0.5	2.5	2.5
Ce	µg/L	0.5	0.5	2.5	2.5
Pr	µg/L	0.5	0.5	2.6	2.5
Nd	µg/L	0.5	0.5	2.5	2.5
Sm	µg/L	0.5	0.5	2.5	2.5
Eu	µg/L	0.5	0.5	2.6	2.5
Gd	µg/L	0.5	0.5	2.5	2.5
Tb	µg/L	0.5	0.5	2.5	2.5
Dy	µg/L	0.5	0.5	2.5	2.5
Ho	µg/L	0.5	0.5	2.5	2.5
Er	µg/L	0.5	0.5	2.5	2.5
Tm	µg/L	0.5	0.5	2.5	2.5
Yb	µg/L	0.5	0.5	2.5	2.5
Lu	µg/L	0.5	0.5	2.5	2.5
Th	µg/L	0.5	0.5	2.4	2.5

Table C4. Certified reference material CARNBERRY-05 (Environmental Canada, 2011) values used in IC and the measured value of CRM. Green color indicates the measured value is within the CRM.

Elements	Unit	Measured value	CRANBERRY-05
F-	mg/L	0.065	0,068 ± 0,025
NO3-N	mg/L	0.140	0.158 ± 0,023
SO4^(2-)	mg/L	9,17	8,86 ± 0.70

APPENDIX D: Geological map of Norway.

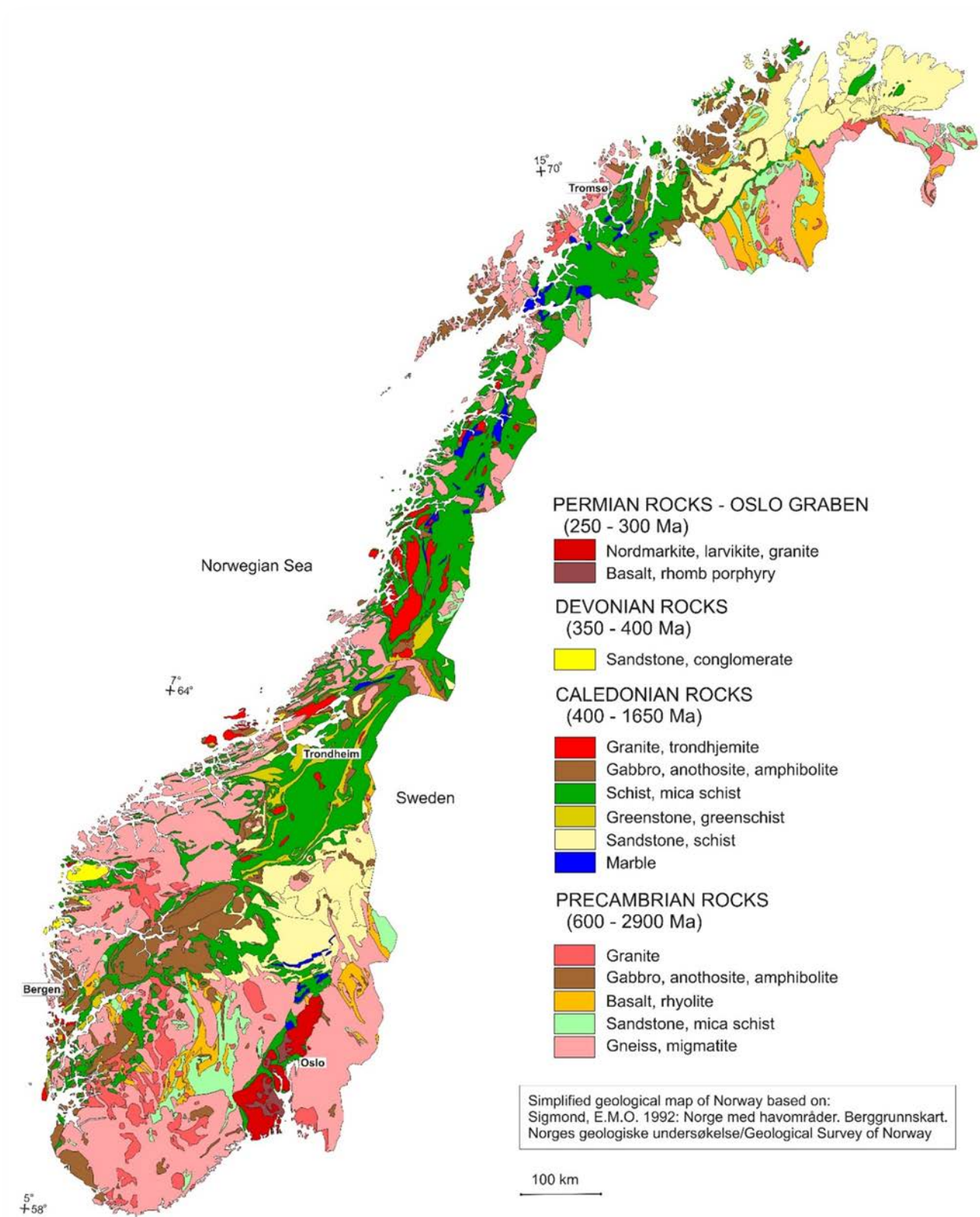


Figure D1. Bedrock geology map of Norway.

TEGNFORKLARING

Legend

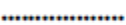
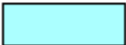
	BART FJELL OG FJELL MED ET TYNT ELLER USAMMENHENGENDE LØSMASSEDEKKE Exposed bedrock and bedrock with a thin or discontinuous cover of surficial deposits
	BLOKKHAV, FORVITRINGSMATERIALE Block field, weathered material
	MORENEMATERIALE Till
	MORENE MED HAUGFORMET OVERFLATE Hummocky moraine
	RANDMORENER/RANDMORENEBELTE Marginal moraine/zone of marginal moraine
	RANDMORENE, ANTATT ELDRE ENN SISTE NEDISNING Marginal moraine, probably pre-late Weichselian
	BREELV- (GLACIFLUVIAL) OG/ELLER BRESJØ (GLACILACUSTRIN) AVSETNING Glacifluvial and/or glacialacustrine deposit
	ESKER OG KAME Esker and kame
	ELVE- OG BEKKEAVSETNING (FLUVIAL AVSETNING) Fluvial deposit
	HAV- OG FJORDAVSETNING (MARIN AVSETNING) Marine deposit
	STRANDAVSETNING Shore deposit
	TORV OG MYR (ORGANISK MATERIALE) Peat and bog (organic material)
	SKREDMATERIALE Rapid mass-movement deposit
	VINDAVSETNING (EOLISK AVSETNING) Eolian deposit

Figure D3. Legend for Quaternary map.



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