Chemical quality and regulatory compliance of drinking water in Iceland

Maria J. Gunnarsdottir[a*], Sigurdur M. Gardarsson[a], Gunnar St. Jonsson[b], and Jamie Bartram[c]

a) Faculty of Civil and Environmental Engineering, University of Iceland, Hjardarhaga 2-6, 107 Reykjavik, Iceland
b) Rorum ehf, Brynjólfsgötu 5, 105 Reykjavik, Iceland
c) Water Institute, Gillings School of Global Public Health, University of North Caroline at Chapel Hill, United States

*Corresponding author. Email: mariag@hi.is

Abstract

Introduction

Icelandic drinking water is generally considered pristine at source and free of contamination of either anthropogenic or natural origin. Iceland (103.000 km^2, 329 thousand inhabitants) is rich in groundwater due to high precipitation and porous bedrock. The water sources for drinking water are predominantly groundwater (95%) with no treatment unless there is a danger of surface water intrusion. When surface water (5%) is used it is filtered and disinfected with UV treatment (EEA, 2010). Residual disinfection is not practised (Gunnarsdottir et al. 2013). Water availability is high, though in some parts of the country, depending on geology, communities have to rely on groundwater from unconsolidated gravel deposits which may be affected by surface water and is less reliable.

Groundwater is mainly meteoric water that has percolated through soil and rock into the aquifers. Therefore the natural chemical composition of groundwater depends on chemicals dissolved in the precipitation, those absorbed on the way through soil and unsaturated strata down to the aquifer, depending on both the water-rock interaction and contact time. The chemical composition of water comprises the major cations (sodium, calcium, magnesium, potassium), anions (bicarbonate, chloride, and sulphate) and trace elements (including heavy metals such as chromium, cadmium, nickel, selenium). Levels above natural background concentrations can indicate anthropogenic influence.

Without chemicals water would have no taste and what is considered acceptable drinking water can vary. Where people are used to water high in chloride, other water might be considered tasteless and unacceptable. Usually water high in minerals is considered more palatable. Some chemical are essential for health, such as calcium and magnesium; while others may be beneficial or toxic or impair aesthetic quality of water depending on intake or concentration (e.g. fluoride, copper, chromium, nickel, selenium, zinc and iron). It has been suggested that hardness or hardness-associated parameters may be beneficial to health, for example in decreasing cardiovascular mortality, though it has been difficult to establish clear and conclusive scientific evidence (Cotruvo and Bartram, 2009).

Iceland is volcanic and mostly basaltic. In general groundwater from basaltic rock has lower chemical concentrations of major elements compared to many other rock types (Reimann et al. 1996) and Icelandic groundwater has low chemical content compared to many other countries, it is also very soft and has low temperature. The concentration of total dissolved solids (TDS) is higher in the geologically young regions (Postglacial) were there is higher content of glassy rocks than in other regions (Sigurðsson and Sigurbjarnason, 1989; Gíslason et al., 1996; Oskarsdottir et al., 2011; Gunnarsdottir et al., 2015c). Precipitation with marine components has considerable incluence on chemical status of groundwater in Iceland due to meteorological conditions (Sigurdsson & Einarsson, 1988) and proximity of aquifers to the sea.

Analysis of water from 79 aquifers in Iceland demonstrated TDS between 4 and 140 mg/l with median 75 mg/l, hardness is 90% of the time below 2,8°dH and the average temperature is 4.6°C with the range between 2 to 10°C (Gunnarsdottir et al. 2015c). This TDS would be classified according to the EU mineral water directive as “very low” to “low mineral content” (EC, 2009). The weighted average of TDS in the main rivers of southwest Icelands is 73 mg/l (Gislason et al., 1996), which is very similar to the median of Icelandic groundwater aquifers. Frengstad et al. (2010) measured the median for concentration of 71 inorganic chemicals in Nordic tap water (N=18) from Norway, Sweden, Finland and Iceland (one sample from Iceland) and compared it to Nordic and European bottle water. The median concentration of chemicals in aquifers in Iceland is usually somewhat lower than in Scandinavia, except for a few chemicals that are higher due elevated concentration in the young geological region. Median concentrations of sulphate, calcium and nitrate in Iceland are three to five times lower in Iceland than in Nordic tap water whereas it is two to five times higher in sodium and sulpur and also higher in aluminium, chromium and selenium, due to higher content in Pleistocene and Postglacial region.

The goal of this study is to evaluate compliance of drinking water quality and monitoring results with the requirement of Icelandic drinking water legislation in terms of chemical quality, analytical quality and frequency of sampling. Supplementary goals is to identify contaminant source type by comparing non-compliance, synthetic pollutant over detection limits and exceedance of natural background level of chemicals. The aim is to assist in finding likely pollution source.

Regulation of drinking water

The current Icelandic Drinking Water Regulation (IDWR) was introduced in 2001 to fulfill the European Drinking Water Directive of 1998 (Ministry for the Environment, 2001; EC 98/83). The requirements of the regulation were to be fulfilled by the 5th of December 2003. A systematic proactive approach for protecting drinking water, a water safety plan, was adopted into Icelandic legislation in 1995 when drinking water was classified as food (Parliament, 1995). This has proven to be beneficial to drinking water quality and public health as well as changing the attitudes of staff and the utility culture on water quality issues (Gunnarsdottir et al., 2012a; 2012b).

A new act on chemicals were recently issued by the Icelandic parliament (Parliament of Iceland, 2013). The act replaces a previous act from 1988 and will restrict the import and use of pesticides in the future. Based on 2010-2012 data the herbicides dichlobenil and glyphosate were the most used pestisides in Iceland. Annual use of the two combined is estimated to have been 3200 kg in the period. About 50% is used in agriculture and 50% in other settings such as golf courses, green areas, roadsides and airports (Weisshappel et al., 2013). The application in agriculture was 0,043 kg/ha/yr per utilized agricultural area (UAA), which is only a small fraction of the use per UAA in other European countries (Weisshappel et al., 2013; Johannesson, 2010). Dichlobenil is no longer authorised within the European Union (Regulation (EC) No 396/2005) and The European Food Safety Authority (EFSA) has glyposate under re-evaluation (http://www.efsa.europa.eu/en/press/news/150730). Pesticides are seldom monitored in drinking water in Iceland.

According to IDWR surveillance of drinking water quality is to be carried out through frequent “regular monitoring” of some microbiological and indicator parameters, and also by less frequent “audit monitoring” of chemical parameters and indicators. Responsibility for surveillance is at the municipal government level with the ten Local Competent Authorities (LCAs) operating in the country. At the national level it is the Icelandic Food and Veterinary Authority (IFVA), acting on behalf of the Ministry of Industries and Innovation, that is to oversee that the objective of the IDWR is fulfilled and to supervise the LCAs. Each LCA is usually run by several neighboring municipalities and managed by a politically-appointed health committee.

Each separated water system is an independent unit in terms of surveillance when serving more than 50 persons or 20 dwellings /summerhouses or food businesses (processing or distribution of food). It is considered indepentant water supply when it is a system that gets its water from one or more sources, or in wholesale from another utilitiy, distribute it and where water quality may be considered as being approximately uniform. The sampling frequency of regulated water supplies depends on population. Audit monitoring of chemicals is to be carried out at water supplies serving more than 500 inhabitants; and also at smaller supplies if the LCA, in cooperation with the IFVA, decides it is needed. The interpretation of the word ‘population’ has important consequences and has mostly been interpreted as meaning only permanent inhabitants, in spite of the fact that some supplies serve large transient population, tourists and summerhouse dwellers. In 2012 there were 796 water supplies classified as regulated by the LCAs and of these 48 serve more than 500 inhabitants (Gunnarsdottir and Gardarsson, 2015a).

Method

The data set contains results from audit monitoring of 345 samples provided by the LCAs or the water utilities. The samples were from 79 aquifers serving 74 water supply systems. These 345 samples were all collected as part of audit monitoring of drinking water undertaken from the implementation of the EU directive into Icelandic legislation in 2001 until the end of 2012. The samples were collected by the LCAs. Chemical analysis was performed by ALS Scandinavia AB in Sweden and some parameters, such as pH, turbidity, conductivity and temperature, were measured by local laboratories or on site by the LCAs. Information on the sampling and the water supplies according to size are given in Table 1.

Table 1 Number of water supplies and audit monitoring according to size, samples and place of sampling

Size inhabitants	Nr of regulated water supplies	Nr of water supplies tested	Nr of samples tested 2002-2012	Places of sampling			Nr of samples required in IDWR 2004-2012
				Source	Storage tank*	Tap	
> 5000	9	9	115	50	28	37	135
501-5000	39	39	193	75	47	71	328
50-500	138	26	37	22	1	14	+
Sum	186	74	345	146 (43%)	76 (22%)	123 (35%)	463

*Storage tanks are most often situated upstream of the distribution network and can therefore be considered to be mostly unaffected by the distribution system. + Audit monitoring decided by the Local Competent Authorites.

In the EC directive on quality of water intended for human consumption (EC 98/83) parameters are arranged in microbiological parameters, chemical parameters of health concern and indicator parameters.This classification is used in this study. In all 53 parameters were gathered, 36 of which are required under the IDWR. The focus of this study was on chemical quality. The results include analysis of: major elements, indicators (chemical and physical) and health-related chemicals (both natural and synthetic pollutants).

According to the IDWR changes in odor and taste should be observed by organoleptic methods, but these results were not registered. The indicator parameters colour, total organic compounds (TOC), and turbidity were measured. In the regulation it is stated that there should be "observed no abnormal change and be acceptable to consumers" but no limit or guidance values are given. WHO Guidelines (WHO, 2011) were used to evaluate compliance for colour, the Danish drinking water regulation (BEK nr. 1024 af 31/10/2011) was used for evaluating TOC, and for turbidity the parametric value given in the IDWR for treated water, 1 NTU, is used, which is in alignment with WHO Guidelines (2011). Hardness (°dH) was calculated from calcium and magnesium content.

Nine synthetic organic pollutants are listed in the regulation to be tested in audit monitoring whereas many more are reported in the analytical results from the ALS Scandinavia AB. Detection of these pollutants is always an indication of anthropogenic influence. Therfore three organic pollutants, dichloromethane, anthracene and fluoranthene, are included in this study though not part of the IDWR as these are detected above detection limits in the analysis from ALS and indicate pollution. The disinfection by-products (DBP) acrylamide, bromate and epichlorohydrin are derivative from treatment with ozone or chlorine, which is not practiced in Iceland and therefore not mesured.

To include also measurements below detection limit (DL) when calculating the median, values below DL were labelled as a negative number. This was a method used in the EU project BRIDGE (Background Criteria for the Identification of Groundwater Thresholds) as decribed by Pauwels et al. (2007). Calculation of the median with only real values is too high when there are many measurements below DL. If DL was always the same it could be set as real value but in some parameter DL varies greatly and then high DL would give too high median. This is especially the case with arsenic where DL is from <7,0 down to <0,05.

The starting point for evaluation of compliance with the required frequency of sampling was when IDWR was to be fulfilled by the end of 2003 whereas all audit monitoring carried out in the period 2002-2012 are included. Some water utilities buy water wholesale from other utilities and under these circumstances samples taken at the source will be counted for both utilities when evaluating compliance in frequency of sampling.

The following data were derived from the data set: number of samples, number of samples over detection limit, median, minimum and maximum value of the parameters, number of exceedences of IDWR chemical quality limit values, compliance in each parameter, permitted DL according to IDWR and number of exceedance of permitted DL. Estimates of natural background levels (NBLs) from a recent study of 79 Icelandic aquifers were added (Gunnarsdottir et al., 2015c).

The data collected were analyzed with respect to; Compliance with parametric value in IDWR, with compliance in detection limit (DLs) requirement in IDWR, and with compliance in minimum frequency of sampling and testing parameters in IDWR. To assess the likely pollution source type non-compliant samples are listed together with detection of synthetic organic pollutant and exceedance of NBLs. Information on geological area and site of sampling is also gathered. This information is used to trace pollution source.

Results and discussion

Compliance with chemical standard in legislation

Compliance for each of the 36 parameters required in the IDWR is shown in Table 2. The proportion for all parameter is 99,76 %. Compliance in health based chemical parameters is 99,97% and in indicator parameters it is 99,44%.

Figure 1 shows non-compliance according to size of water supply. Non-compliance in health based chemicals is rare in all size categories whereas non-compliance with indicators parameters is more frequent in small supplies. However the measurement in the smallest category less than 500 are so few in audit monitoring, as shown in Table 1 (37 samples in 26 water supply of the 138 in this size category), that findings should not be seen as representative for the chemical quality in small supplies.

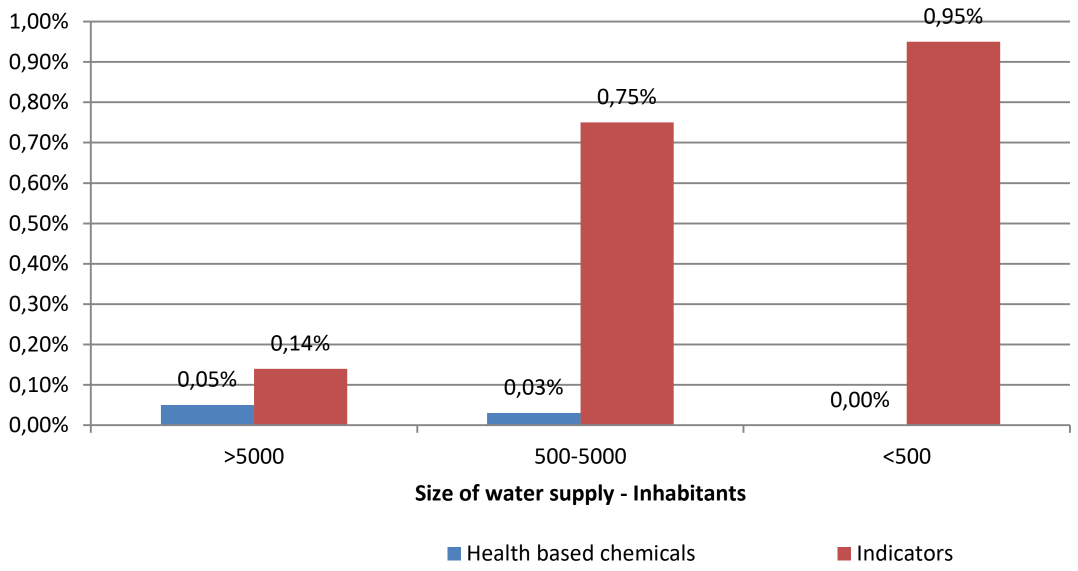

Figure 1 Non-compliance in health related chemicals and indicators according to size of water supply.

Non-compliance occurs 25 times and is most commonly (23 times) associated with indicator parameters as pH, turbidity, chloride, iron and aluminium, and only two times in health based chemicals, (nickel and benzene). These 25 incidents of non-compliance occurred at 21 water supply systems.

The European Commission has recently published a report on quality of drinking water in EU with examing the member state reports for 2008-2010 (EC, 2014). Compliance in analyses of parametric value in health based chemicals in the large supplies (>5000) is 99-100% in 11 of the 27 member states, 11 member states are between 95-99%, 2 between 90-95% and 3 with less than 90% compliance whereas all supplies in Iceland are with compliance in health based parameters 99,97%. Full compliance with the parametric values was considered if more than 99% of the analyses where in compliance.

Compliance in detection limits

Required limit of detection is specified in regulation. It gives the lowest concentration the laboratory must be able to reliably distinguish from zero. That limit was breached 486 times in the 10453 parameter tests or in 4,6% of the analysis. Evaluation of the performance characteristics of the measurements show that violation of the detection limits occurs most often in five parameters: 1,2-Dichlorethane, vinyl chloride, fluoride, ammonium, and arsenic.

Non valid testing

Detection limit was sometimes given higher than permitted levels so these measurement were not valid to confirm compliance and not included as results in Table 2. This was the case with vinyl chloride in 132 samples and of benzo(a)pyrene in 14 samples.

Compliance in frequency of testing

Water supplies serving more then 500 inhabitants are required to sample for audit monitoring. All the 48 water supply systems with over 500 inhabitants had sampled for audit monitoring in the period 2002-2014 (Table 1). However only 14 had complied fully with requirement for frequency of sampling. Average compliance in frequency of sampling was 67%. For the 138 water supplies serving 50-500 inhabitants, audit monitoring was conducted at 26 supplies or 19% and most as a single measurement to investigate chemical status. Table 2 shows also that all the parameters were not tested every time. Pesticides were only tested 12 times in the period 2002-2012 and only in two water supplies and valid vinyl chloride and benzapyren measurements are lacking. Taking this into account compliance in frequency of testing parameters was 63%.

Organic pollutants over detection limit

Organic substances were reported at concentrations above detection limits on twelve occasions, only one of which were near the permitted health limit in the IDWR. The presence of these chemicals is always an indication of anthropogenic pollution of water somewhere along the chain from catchment to the laboratory. The detected chemicals are PCE/TCE (thrice), benzene (twice), dichloromethane (once), anthracene (twice) and fluoranthene (twice), 1,1,1 trichlorethene (once) and toluene (once).

Sometimes contamination can occur during sampling or at the laboratory. The aromatic hydrocarbons benzene, anthracene and fluoranthene were over detection limits six times. These chemicals generally degrade under aerobic conditions but very sparsely under anaerobic conditions such as those encountered in groundwater (Gerritse et al., 2009). Anthracene and fluoranthene are primarily found in drinking water from coal-tar lining of cast iron or ductile iron pipes (WHO, 2011). Steel pipes with coal-tar lining were layed until late seventies in Iceland and most are still in use. These chemicals can also be formed in pyrolysis of fossil fuels such as in as tobacco smoke or automobile exhaust gas. Benzene can be found in wells contaminated by leaky gasoline storage tanks and landfills. It has also been used in many industrial products: as thinner for paint, as degreasing agent in dry cleaning and in rubber in the tire industry. The two times benzene was detected it was in samples taken by the same LCAs on the same day at two different water supplies. This indicates contamination during sampling or laboratory work. The same scenario applies to both anthracene and fluranthene. Both were found in samples taken by the same LCAs on the same day at different sites. None have had such contamination detected previously.

Chlorinated aliphatic hydrocarbons were reported to be over the detection limit in four samples. This group of organic chemicals belong to the most serious groundwater pollutants worldwide (Gerritse et al., 2009). The chlorinated solvents dichloromethane and the sum of tetrachloroethylene and trichloroethylene (PCE/TCE) are a part of that group. The PCE/TCE value was three times over detection limits at three different water utilities, LCAs surveillance zone and time of sampling. Dichloromethane was once found over detection limits in the same sample as one of the PCE/TCE. Dichloromethane is a degradation product of PCE and TCE. These are solvents used for cleaning grease from machinery, electronic parts or clothing, and paint removers.

This is not the first time that these organic pollutants are detected in drinking water in Iceland. Benzene, PCE and TCE were all found far above permitted level in a number of boreholes for the town of Keflavik and Njardvik near the former NATO military base thirty years ago as was nitrate from de-icing of the runways of the airport. Leaks from old oil tanks were also discovered in the area. This discovery led to a abandonment of the water source twenty years ago and establishment of a new one 15 km away from the town (R.E. Wright Associate Inc. 1989; Magnús H. Guðjónsson, 1991; Snorri P. Snorrason, 1991, Gunnarsdottir, 2005). These areas are still considered the most polluted groundwater waterbodies in Iceland (Weisshappel et al., 2013).

Pollution source

All natural water contains chemicals. Elevated concentrations can be of natural occurance or an indication of anthropogenic pollution. Antropogenic contamination can occur in the catchment, at the source, in the network or on the premises with the consumer. Water can be polluted in the catchment from human activity (e.g. agriculture, traffic, industry or human settlement); or at the water intake depending on state of the construction or leaching from pipes or other installations in the distribution network. The contamination can be from surface water intrusion, as shallow aquifers are vulnerable to contamination; and could also be due to lack of maintenance of water intakes, for example following heavy rainfall or thawing period. It could also be due to old waste dumps near to the intakes or infiltration into leaking water pipes during pressure loss e.g.when near to sewage pipes in the network.

Several naturally occurring chemicals have parametric limit values in drinking water standards. Some of these chemicals are mainly of marine origin (chloride, sodium and sulphate). Boron is also in sea water and correlates (modest correlation R=0,58-0,66) with the three above and is also more abundant in volcanic areas. Antimony and mercury can be found in trace constituent in active volcanic areas (Thompson et al., 2007). Geothermal areas are common in volcanic region and geothermal water can mix with groundwater and increase certain chemicals (arsenic, boron, fluoride, sodium and sulphate) (Sigurdur & Sigurbjarnarson, 1989). Lead can be associated with geothermal fluid and cyanide occurs naturally only in geothermal water in volcanic areas (Thompson et al., 2007). Usually these chemicals, though in elevated concentration, are far below health limits in Iceland and cyanide is never above DL in this data set.

Increased chloride concentration from sea intrusion into aquifers in some postglacial areas is known. In the Reykjanes peninsula median concentration for the elements abundant in sea; chloride, sodium, sulphate, potassium, magnesium, sulphur and strontium is four to ten times higher than median for all data. Natural origin includes also high alkalinity, especially in Pleistocene aquifers (Gunnarsdottir et al., 2015c). Chromium and selenium are usually higher in the younger geological areas compare to other areas and aluminum is significantly higher in the Pleistocene areas (Gunnarsdottir et al., 2015c). Mercury is found in geothermal steam that can travel long distances and has been detected in Iceland (Olafsson, 1992). In the 345 samples mercury was detected above DL in 18 samples though always far below health limits.

The main chemicals of concern used in agriculture are fertilizers and pesticides. Chemicals found in fertilisers include ammonia, phosphate, arsenic, chlorides, lead and nitrates. Cadmium has a weak correlation to nitrate in this study that could be partly explained by the fact that phosphorous fertilizers are known to contain cadmium (Camelo et al., 1997; WHO, 2011). Cadmium concentrations were detected over DL in 90 samples though always below 2% of health limits. Excessive use of fertilisers, (chemical, animal manure and sewage sludge) can allow nitrate to be leached into groundwater. Nitrate was in compliance in all 345 samples and only once over the NBL in the 27 samples inspected here, indicating little impact from agriculture on groundwater quality.

Metals and organic pollutants have been shown to leach from material used in the drinking water system (Tomboulian et al., 2004; WHO, 2011). For example iron from iron pipes, nickel and chromium from plated taps, copper and antimony from solder, lead from joints and sealing, vinyl chloride monomer from PVC plastic pipes and trichloroethylene (TCE) from polyethylene plastic pipes. Antimony has been shown to leach from concrete and plastics including plastic bottles and temperature has a significant effect on release (Tomboulian et al., 2004; Westerhoff et al., 2008; Reimann et al., 2010; Reimann et al., 2012). Frengstad et al. (2010) report that the median concentrations of antimony in both Nordic and European bottled water to be ten to fifteen times higher than in Nordic tap water, indicating leaching of antimony from plastic bottles. The data set in this study shows that lead and nickel correlate with copper, modest (R=0,44) to strong correlation (R=0,76) respectively, indicating that these metals are coming from pipes and fittings. It is also know in Iceland that pollutant from contaminated soil can leak into plastic pipes and detection of PAH's in water from plastic pipes going through oil contaminated soil has occurred.

Tracing pollution source

There are non-compliance incidents for chemicals and/or synthetic organic pollutants over detection limit in 27 samples from 23 aquifers. These are listed and categorized according to suspected source of pollution in Table 3. The table also shows; information on the four geological classes (Postglacial, Pleistocene, Tertiary and unconsolidated gravel deposit) that are representative of Iceland, as well as site of sampling and parameters that are exceeded in natural background levels according to these geological settings.

Pollution during sampling or monitoring. These six samples are three pairs sampled on the same day by the same LCA at difference sites all polluted by the same synthetic organic pollutant (anthracene, fluorantene or benzene). All samples are suspected to be polluted during or after sampling.

Natural origin. These five samples are with small exceedance suspected to be of natural origin. Acidity is over IDWR (pH<9,5) in four samples all in the Pleistocene area where NBL for pH is significantly higher than in other areas (pH=9,6). In all four samples elevated levels are interpreted as being of natural origin and connected to geology and not anthropogenic influence. One sample has pH <6,5 indicating surface water influence though no other chemicals are over limits. One sample is with iron just over the IDWR limit and manganese, arsenic and fluoride over NBLs. Iron is present naturally in most water sources and usually manganese occur with iron. Arsenic and fluoride are often associated with volcanic activity and this sample is in an impact area of an active volcano.

Organic pollution at source. These six samples are from aquifers suspected to be affected by surface water intrusion resulting in organic pollution. The samples are either with elevated level of total organic carbon (TOC) or turbidity. TOC is non-compliant in four samples, all taken at source or in storage tank. TOC comes from decaying natural organic matter (NOM) as well as synthetic organic chemicals such as those used in pestizides. Here it is likely to be an indication of increased microbes as a result from surface water intrusion at the source. In one of these samples colour is also over NBL. Colour is usually caused by natural organic or elevated levels of iron and manganese.

Chemical pollution at source. These seven samples are with suspected chemical pollution at source. The first is from an aquifer in a gravel deposit. It exceeded the IDWR limit for nickel and was over the detection limit for chlorinated solvents. It is also over NBLs in four metals. One would expect this to be either from some waste dump nearby or from poor installations at the water intake. The next four samples are samples from aquifers near to the area that was restricted to military use during WWII and up to the sixties. These areas were used for various activites as ammunition depot, oiltanks, target practice and waste dumping. This is similar to pollution mentioned before in the chapter on organic pollutants over detection limits and applies to the municipalities surrounding Keflavik Airport. Three of these samples are high in chemicals related to salt water intrusion; chloride, sodium and sulphate. They are all also high in other metals (iron, manganese, aluminum, cadmium and lead). One sample is over IDWR limit in chloride and this water supply has since installed nano filtration to reduce it. The source with iron and aluminum over IDWR was closed down in 2011. The last two samples are also with an indication of anthropogenic influence at the source, one with chlorinated solvent and the other one with heavy metals and high exceedance of IDWR for iron and colour.

Chemical pollution in the network. These three samples are taken from tap and suspected to be polluted in the distribution system or in the house. Two have heavy metals over NBLs, and iron and turbidity over IDWR limit. One (Sample ID 165) has PCE, Dichloromethan, 1,1,1-trikloretan and toluene over detection limits. These compounds have been used as ingredience in solvent mixtures and are also associated with gasoline hydrocarbons. All are among the most frequently detected volatile organic compounds in groundwater near waste dumps in both USA and Germany (Lawrence, 2006). This could indicate that contamination is from contaminated soil penetrating plastic pipes. The sample high in iron and other metals (Sample ID 306) led to repeted sampling in a nearby house which gave low iron concentration leading to the conclusion that the problem was on the premises and not in the water supply.

Conclusions

Chemical quality of drinking water is generally good in Iceland with few incidents of non-compliance to regulation and then mostly in indicators or aesthetic parameters. Compliance of Icelandic drinking water in chemical quality is over 99% which is as it is best in the 27 member states of the European Union. In all there are 27 samples with incidents of non-compliance. Analyse revealed that there are 10 water supply systems of the 74 tested where there is an indication of anthropogenic chemical pollution either at the source or in the network and would need further investigation and site visits to confirm and trace. In further 6 water supplies there is a need to improve water intake to prevent surface water intrusion.

Analytical requirement is in non-compliance for 4,8% of the samples. This should be improved and the LCAs should aim at measuring bicarbonate though not required in IDWR to be able to check mass balances and improve analytical quality. Compliance in frequency of sampling is on average 67% whereas it is 63% in compliance in frequency of testing parameters. This should be improved as sufficient monitoring to detect trends towards the health based level of concern are essential.

Research and development of methods for tracing the source of pollution is needed and it should build on estimate of natural background level for inorganic chemicals in Icelandic groundwater aquifers in similar geological settings as well as other measurement in the same aquifer. If elevated level though below health limits some procedure for repeated sampling and further investigation should be applied. Icelandic aquifers are largely pristine and low in chemicals compared to European aquifers and it is important to registrer anthropogenic influence at an early state to prevent further pollution trends.

Table 2 Chemicals and indicators in drinking water, compliance with quality standards, detection limits in IDWR and natural background level of parameters

Parameter	No Samples	No. Samples over DL	Units	Min	Median	Max	IDWR 2001	No of IDWR exceeded	Compli-ance %	WHO DWG 2011	Perm. DL	No of perm. DL exceeded	NBLs for 79 aquifers 90 %ile
Parameters with no parametric value in IDWR													
Hardness	340	340	°dH	0,29	1,14	9,70	n.l.				n.l.		2,80
Silica SiO2/Si	345	345	mg/l	2,28	7,41	18,40	n.l.				n.l.		12,00
Potassium K	345	221	mg/l	0,24	0,54	5,27	n.l.				n.l.		1,33
Calcium Ca	345	345	mg/l	1,27	5,50	52,80	n.l.				n.l.		11,20
Magnesium Mg	345	344	mg/l	<0,09	1,67	25,20	n.l.				n.l.		6,20
Sulphur S	222	218	mg/l	<0,2	0,82	12,20	n.l.				n.l.		2,70
Phosphor P	345	345	µg/l	1,04	20,80	96,40	n.l.				n.l.		0,05
Barium Ba	345	323	µg/l	<0,01	0,12	2,24	n.l.			700	n.l.		0,51
Cobalt Co	345	198	µg/l	<0,01	0,01	22,70	n.l.				n.l.		0,024
Molybdenum Mo	345	291	µg/l	0,028	0,10	1,55	n.l.			70	n.l.		0,45
Strontium Sr	343	318	µg/l	0,26	6,19	145,00	n.l.				n.l.		27,00
Zink Zn	344	317	µg/l	<0,20	2,11	910,00	n.l.			3000	n.l.		30,50
Indicator parameters													
Colour[2]	272	57	mg Pt/l	2,5	<5,0	25,0	15	1	99,63	15	n.l.		5,80
Conductivity	246	246	µS/cm 20°C	35	89	890	2500	0	100,00		250	0	190,00
pH	233	233	pH units	6,34	8,00	9,80	6,5-9,5	6	97,00	6,5-8,5	n.l.		8,95
Temperature	172	172	°C	2	4,60	14,20	max 25°C	0	100,00		n.l.		7,80
TOC[2]	292	87	mg/l	0,50	<0,5	56,00	4	4	97,88		n.l.		1,60
Turbidity[2]	189	148	NTU	0,08	0,19	4,83	1,00	5	97,35	0,2	n.l.		0,50
Aluminium Al	344	340	µg/l	<0.2	5,68	720,00	200	1	99,71	100-200	<20	0	18,70
Ammonium NH_4	327	13	mg/l	0,01	<0,03	0,12	0,5	0	100,00		<0,05	18	DL
Chloride Cl	340	339	mg/l	2,30	9,90	284,00	250	2	99,41	250	<25	0	22,70
Iron Fe	343	300	µg/l	0,32	2,60	1040	200	4	98,83	n.l.	<20	0	31,00
Manganese Mn	344	273	µg/l	0,03	0,12	32,50	50	0	100,00	400	<5	0	1,46
Sodium Na	345	345	mg/l	1,63	9,47	149,00	200	0	100,00	200	<20	0	15,50
Sulphate SO_4	340	319	mg/l	0,72	2,40	42,30	250	0	100,00	500	<25	0	6,80
Chemical parameters													
Antimony Sb	332	94	µg/l	<0,01	<0,01	0,41	5	0	100,00	20	<1,25	0	0,02
Arsenic As	342	65	µg/l	<0,05	<0,05	0,74	10	0	100,00	10	<1	25	0,11
Boron B	326	74	µg/l	2,83	<10	90	1000	0	100,00	2400	<100	0	12,10
Cadmium Cd	345	90	µg/l	<0,002	<0,002	0,061	5	0	100,00	3	<0,5	0	0,005
Chromium Cr	345	343	µg/l	<0,01	0,34	6,37	50	0	100,00	50	<5	0	0,96
Copper Cu	344	301	µg/l	<0,10	0,33	46,30	2000	0	100,00	2000	<200	0	1,53
Fluoride F	340	135	mg/l	<0,01	<0,1	0,57	1,5	0	100,00	1,5	<0,15	74	0,14
Lead Pb	344	265	µg/l	<0,01	0,03	3,43	10	0	100,00	10	<1	0	0,13
Mercury Hg	345	18	µg/l	<0,002	<0,002	0,031	1	0	100,00	6	<0,2	0	DL
Nickel Ni	345	216	µg/l	0,02	0,09	23,10	20	1	99,71	70	<2	0	0,46
Nitrite NO_2	326	4	mg/l	<0,01	<0,01	0,10	0,5	0	100,00	3	<0,05	0	DL
Nitrate NO_3	315	235	mg/l	<0,02	0,18	7,90	50	0	100,00	50	<5	0	1,36
Selenium Se	329	319	µg/l	0,02	0,14	0,66	10	0	100,00	40	<1	2	0,28
Synthetic chemical parameters													
Benzene	329	2	µg/l	<0,20	<0,20	1,00	1	1	99,70	10	<0,25	0	0
Bens(a)pyren[3]	312	0	µg/l	<0,001	<0,002	<0,026	0,01	0	100,00	0,7	<0,003	18	0
Cyanide CN	324	0	µg/l	<0,5	<5,0	<5,0	50	0	100,00		<5	0	0
1,2 Dichloroetha	331	0	µg/l	<0,10	<1,0	<1,0	3	0	100,00	30	<0,3	323	0
PAHs	325	0	µg/l	<0,004	<0,012	<0,08	0,1	0	100,00		<0,025	23	0
Pesticide	12	0	µg/l	<0,01	<0,01	<0,01	0,1	0	100,00		<0,025	0	0
∑Pesticide	12	0	µg/l	<0,045	<0,045	<0,055	0,5	0	100,00		<0,125	0	0
PCE and TCE	323	3	µg/l	<0,20	<0,30	1,30	10	0	100,00	60	<1	0	0
THM[4]	317	0	µg/l	<0,35	<0,70	<1,4	100	0	100,00	460	<10	0	0
Vinyl chloride[3]	3	0	µg/l	<0,30	<0,50	<0,50	0,5	0	100,00	0,3	<0,05	3	0
Dichloromethane	315	1	µg/l	<0,1	<2,0	61,00	n.l.			20			0
Anthracene	307	2	µg/l	<0,001	<0,005	0,034	n.l.						0
Fluoranthene	307	2	µg/l	<0,003	<0,005	0,081	n.l.			4			0
Acrylamide[4]	0		µg/l				0,1			0,5	<0,01		0
Bromate BrO_3 [4]	0		µg/l				10			10	<2,5		0
Epichlorohydrin[4]	0		µg/l				0,1			0,4	<0,01		0
SUM IDWR[5]	**10474**							**25**	**99,76%**			**483**	

1) Natural background levels is for 79 aquifers but may differ according to geology (Postglacial, Pleistocene, Tertiary and Unconsolidated)

2) In the IDWR the limits for colour, TOC and turbidity are given as NO CHANGE ALLOWED but this has not been evalutate but instead the following limit is choosen for colour 15 mgPt/l, TOC 4 mg/l and turbidity 1 NTU.

3) 132 measurements for Vinil chloride and 14 for Bens(a)pyren are not valid and left out as DL are higher than permitted value in IDWR

4) Disinfection by-product (DBP) and shall be measured if water is treated

5) Only measurement for parameters given limits in the IDWR are summarized

n.l. = no limits given in IDWR

Table 3 Tracing pollution with non-compliance, synthetic organic pollutants and NBLs exeedance

	Sample ID	Name of water supply – name of aquifer	Geo-logical area+	Place* of sampling	Parameters in non compliance and/or synthetic pollutant over DL	Additional parameters with NBLs exceedance
Pollution during sampling or monitoring	326	Thorlakshofn-Hafnarsandur	1	S	Fluorantene	TOC
	329	Thorlakshofn-Unubakki	1	S	Fluorantene	TOC, Pb, Ni
	251	OR Reykjavik-Gvendarbrunnar	2	S	Anthracene	Cr
	252	OR Reykjavik-Vatnsendakriki	1	T	Anthracene	Al
	21	Arborg - Ingolfsfjall	2	T	Benzene	Se, Fe
	95	Grimsn.Grafn.hr.-Burfell	2	T	pH>9,5, Benzene	Cr, Al
Natural origin at source	26	Arborg - Ingolfsfjall	2	S	pH>9,5,	Hg
	30	Blásk.byggd - Laugarvatn	2	ST	pH>9,5	Al
	326	Thorlakshofn-Berglind	2	S	pH>9,5	TOC
	280	Rangárþ. Ytri - Lækjarbotnar	1	S	Fe (205 µg/l)	As, F, Mn
	299	Skagafj.v.-Varmahlid	4	T	pH<6,5	
Organic pollution at source	49	Dalvík-Bakkaeyrar	4	S	Turb (4,83 mg/l)	
	145	Húsavík – v/ Botnsvatn	2	S	TOC (6,22 mg/l)	As
	164	Isafjordur-göng	3	S	TOC (4,2 mg/l)	
	215	OR Kjalarnesi-Gvendarbrunnar	2	T	Turb (1,2 NTU).	F, SO4
	297	Skagafj.v. Hólar-Biskupslind	4	ST	TOC (56 mg/l)	Sb
	319	Vopnafjordur-Svinabakkahlaup	4	S	TOC (5,8 mg/l)	Sb, Colour
Chemical pollution at the source	3	Akureyri - Vagleyrar	4	S	Ni (23,1 µg/l), PCE/TCE (0,6+0,7=1,3 µg/l), cis-1,2-dichloreten (0,5µg/l)	Cu, Pb, Mn, Zn
	116	HS veitur Garði-Heidarbraut	2	S	Fe (1040 µg/l), Al (720 µ/l)	Sb, B, Cd, Cu, Pb, Ni, NO_3, °d Cond.

	Sample ID	Name of water supply – name of aquifer	Geo-logical area+	Place* of samplin	Parameters in non compliance and/or synthetic pollutant over DL	Additional parameters with NBLs exceedance
	120	HS veitur Garði-Skalareykir	2	T	Turb (1,5 NTU), Cl (284 µg/l)	B, Cd, Ni, °d, Cond, Fe, Mn, Na, SO_4
	122	HS veitur Garði-Skalareykir	2	S	Turb (1,8 NTU)	Sb, B, Cd, Cu, °d, Cond, Cl, Fe, Mn, Na, SO_4
	123	HS veitur -Hafnir	1	S	Cl (274 µg/l)	Sb, B, Cd, Na, SO_4
	263	OR Stykkisholmur-Svelgsarhraun	1	ST	PCE/TCE (0,34+0,38=0,72 µg/l)	F, Turb
	292	Skagafj.v. Saudarkr –Vedramot/Skardsd	2	ST	Colour (25 mgPt/l), Fe (454 µg/l)	Pb, Hg, Ni, Mn, SO_4, Zn
Chemical pollution in the network	81	Flóahreppur-Neistastadir	1	T	pH<6,5	Cd, Cu, Pb, Ni, Zn, °d, Temp, Cond
	306	Snæf.b. Hellis/Rif-Skardshraun	1	T	Turb (1,5 NTU), Fe (284 µg/l)	Cu, Pb, Mn, Zn, Colour
	165	Isafjordur - göng	3	T	PCE/TCE (PCE=1,2 µg/l), Dichloromethan (61 µg/l), 1,1,1-trichlorethene (0,1 µg/l), toluene (12 µg/l)	

+1=Postglacial, 2=Pleistocene, 3=Tertiary, 4=Unconsolidated gravel deposit; *S=Source, ST=Storage tank, T=Tap

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