Environ Sci Pollut Res (2018) 25:32964–32974
DOI 10.1007/s11356-017-9556-6

Greenlandic water and sanitation systems—identifying system constellation and challenges

Kåre Hendriksen[1] · **Birgitte Hoffmann**[2]

Received: 3 February 2017 / Accepted: 14 June 2017 / Published online: 6 July 2017

Abstract A good water supply and wastewater management is essential for a local sustainable community development. This is emphasized in the new global goals of the UN Sustainable Development, where the sixth objective is to: "Ensure availability and sustainable management of water and sanitation for all" (United Nations 2015). This obviously raises the question of how this can be achieved considering the very different conditions and cultures around the globe. This article presents the Greenlandic context and elucidates the current Greenland water supply system and wastewater management system from a socio-technical approach, focusing on the geographic, climatic and cultural challenges. The article identifies a diverse set of system constellations in different parts of Greenland and concludes with a discussion of health and quality of life implications.

Keywords Greenland · Water systems · Sanitation · Infrastructure · Socio-technical system · Sustainable development · Island operation · Context

Responsible editor: Philippe Garrigues

✉ Kåre Hendriksen
krhe@byg.dtu.dk; kahe@sanilin.gl

Birgitte Hoffmann
bhof@plan.aau.dk

[1] Arctic Technology Centre, DTU Byg, Technical University of Denmark, Kongens Lyngby, Denmark

[2] Section for Sustainable Design and Transition, Dept. of Development and Planning, Aalborg University, Copenhagen, Denmark

Introduction

Access to clean fresh water is a prerequisite for an acceptable life and is therefore included in the United Nations' 6th sustainability requirement: 6.1 "By 2030, achieve universal and equitable access to safe and affordable drinking water for all." (United Nations 2015). This should apply both to public hygiene and health and to the development of individual and societal livelihoods.

The challenges of working with the supply structure in Greenland are considerable. The special contextual conditions such as the extreme and changing climate conditions, the diverse settlements in the huge and disparate geography and the on-going encounter between indigenous and modern cultures and practices challenge system building and operation. Island operation is a special feature that challenges the technical features of water supply and sanitation and creates a strong dependency on the systems in relation to local sustainable development. Island operations in Greenland are based on the fact that with very few exceptions, there are no roads between settlements in Greenland, which means that the transport infrastructure includes only ships, planes and helicopters. In this way, it is not possible to commute between various settlements on a daily basis and all settlements have to have its own power supply, water supply and waste handling. Furthermore, all settlements are dependent on their own social infrastructure such as a shop, school, church and healthcare (Hendriksen 2013). The island operation naturally creates great challenges in order to supply services to the citizens and business activities. The services are thus practiced and scaled in many different ways, e.g. while most cities have a small hospital with at least some nurses and periodically a medic, most smaller settlements have a nurse or a so-called health worker (with a 22-week education) and a tele-medical station online with a regional hospital (Naalakkersuisut / Government of Greenland 2017).

In view of the complicated climatic conditions in Greenland and the challenges of the many isolated societies, since the Second World War, there has been made great efforts to ensure water supply to the population of Greenland. As part of this modernisation of Greenland, in larger towns and in some villages, there has been developed everyday practices that include showers, washing machines, dishwashers and cleaning with an associated water use which is similar to other Western countries. However, as with other infrastructures, there are significant geographical differences that create very different conditions for the population.

Thus, it is a key question if it is possible and desirable that the same system is extended to all of Greenland, and the article explores the differences existing system constellations to conclude on the hygiene and health implications.

The analysis is based on a mix of historical data, policy documents, statistics and qualitative case studies. During the last 20 years, Kåre Hendriksen has visited 90% of all Greenlandic settlements to explore the conditions for local sustainable development (Hendriksen 2013). This includes local citizens showing and explaining their practices and experiences with the local infrastructures and conditions for making a living. Among other studies, the authors in 2014 and 2015 conducted three extensive one month long study trips to Qaanaaq and Qeqertarsuaq to study how the local infrastructure supply and operation can be developed to support local sustainable development. Finally, data have been collected in relation to teaching at the Arctic Engineering Programme about arctic infrastructure, environment and planning since the programme was established in 2001.

This article analyses the development of the water system as a socio-technical system where technical elements are developed in cooperation with institutional and professional practices, as well as cultural norms and everyday life. Hence, the systems must be understood as interwoven with the development of society (Hughes 1987; Lindegaard 2001a; Shove 2003).

In the second section, the existing water supply is described with the different contextual system configurations found in Greenland, first for households and then for private and public companies. In the third section, the wastewater management is described, focusing on the areas that today have a system with dry closets. Finally, the fourth section discusses the health consequences, and in the fifth section, the article concludes on how the system can be developed in relation to achieving the UN sustainability goals.

The Greenlandic context

With its 2,146,000 km^2 and a length of 2.670 km, Greenland is the largest island in the world. The length of Greenland equals the distance from the central southern part of Norway to Gibraltar in southern Spain, and in area, Greenland would cover most of central Europe. See Fig. 1.

The Greenlandic ice cap and smaller glaciers cover 88% of the island, and by far, the largest amount of the ice-free area along the coasts are alpine mountains. Generally, it is estimated that less than 3% of the island is fit for human habitation.

The Polar Stream, which runs south along the east coast, transports enormous amounts of sea ice from the North Pole as well as Greenlandic icebergs along the east coast and around the most southern point of Greenland, Cape Farewell. This means that it is only possible to sail along the east coast in shorter periods, in the late summer and fall, and that South Greenland periodically is closed in behind the sea ice.

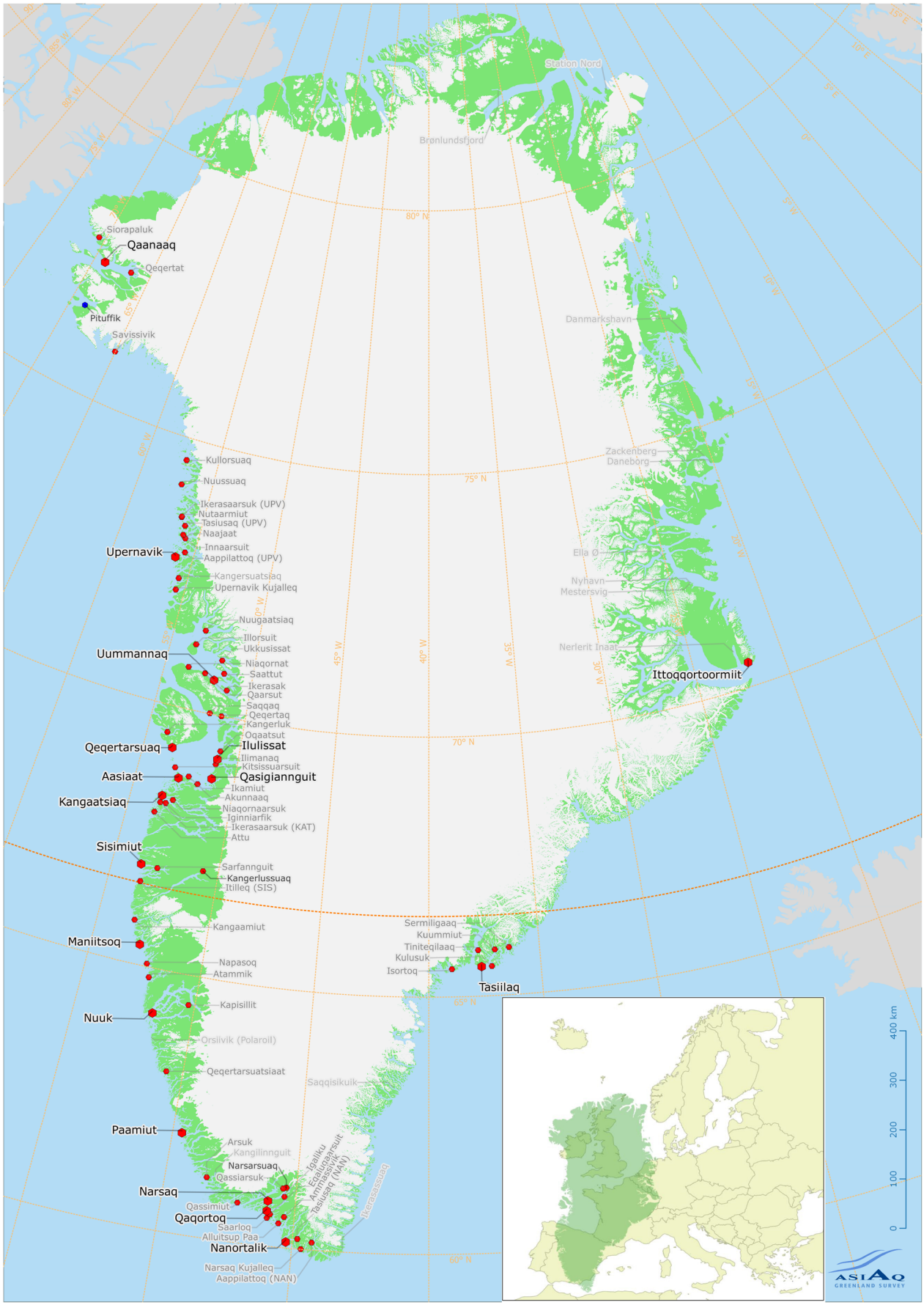
Along the southern part of the west coast, the sea is ice-free the entire year, but further north, the sea is closed for sailing during the winter, because of the sea ice. The most northern region, Qaanaaq can only be navigated in July and August.

Only 56,000 people live on this enormous island, and thereby Greenland is one of the most sparsely populated areas in the world. The majority of the population are descendants from the Inuit, who through the last millennium gradually emigrated from Canada. The last app. 15% primarily comes from outside of Greenland, mainly Denmark in order to work in Greenland for a shorter or longer period of time since Greenland is still very dependent on skilled labour from the outside.

Greenland was a Danish colony until 1953, when Greenland was declared a county and thus formally became an equal part of Denmark. In 1979, Greenland gained home rule, and in 2009, this was extended to the self-rule. Greenland is, however, still a part of the Danish realm (the Kingdom of Denmark), and Denmark is still funding half of Greenland's public spending and thereby contributes almost a third of Greenland's disposable gross national income.

The population has always been dependent on the living resources from the sea and therefore primarily is spread along the west coast. While the Inuit originally lived as nomads, the colonial history gradually led to more permanent settlements. During the last century, the number of settled location has decreased and today, there are 73 settlements in Greenland, reaching from 20 inhabitants to 17,000 inhabitants in the capital Nuuk.

Greenland has a historical administrative division of the country's settlements with 17 towns and 56 villages that are not necessarily related to the settlement's size. For example, the largest village has about 460 inhabitants, while the smallest town has only 380 inhabitants. About 13% of its population lives in the 56 small villages. Apart from just under 40 sheep farmers in South Greenland, no one in Greenland lives outside of either a city or village (Statistic Greenland 2016). In addition, there are a handful of meteorological, military or research stations which are only inhabited by the stations' temporary staff. Finally, the USA still has a military base, Thule Air Base, (Pituffik) in the Northern Greenland. The establishment of this in agreement with the Danish


Station Nord
Brønlundsfjord
Danmarkshavn
Zackenberg
Daneborg
Ella Ø
Nyhavn
Mestersvig
Nerlerit Inaat
Ittoqqortoormiit
Tasiilaq
Sermiligaaq
Kuummiut
Tiniteqilaaq
Kulusuk
Isortoq
Sioràpaluk
Qaanaaq
Qeqertat
Pituffik
Savissivik
Kullorsuaq
Nuussuaq
Ikerasaarsuk (UPV)
Nutaarmiut
Tasiusaq (UPV)
Naajaat
Upernavik
Innaarsuit
Aappilattoq (UPV)
Kangersuatsiaq
Upernavik Kujalleq
Nuugaatsiaq
Illorsuit
Ukkusissat
Uummannaq
Niaqornat
Saattut
Ikerasak
Qaarsut
Saqqaq
Qeqertaq
Kangerluk
Oqaatsut
Qeqertarsuaq
Ilulissat
Ilimanaq
Kitsissuarsuit
Aasiaat
Qasigiannguit
Ikamiut
Kangaatsiaq
Akunnaaq
Niaqornaarsuk
Iginniarfik
Ikerasaarsuk (KAT)
Attu
Sisimiut
Sarfannguit
Kangerlussuaq
Itilleq (SIS)
Kangaamiut
Maniitsoq
Napasoq
Atammik
Kapisillit
Nuuk
Orsiivik (Polaroil)
Qeqertarsuatsiaat
Saqqisikuik
Paamiut
Arsuk
Kangilinnguit
Narsarsuaq
Qassiarsuk
Narsaq
Qassimiut
Qaqortoq
Saarloq
Alluitsup Paa
Nanortalik
Narsaq Kujalleq
Aappilattoq (NAN)
Igaliku
Aappilattoq (NAN)
Tasiusaq (NAN)
Ilerassuaq
80° N
75° N
70° N
65° N
60° W
55° W
50° W
45° W
40° W
35° W
30° W
25° W
20° W
15° W
10° W
5° W
0°
5° E
10° E
15° E
400 km
300
200
100
0
ASIAQ
GREENLAND SURVEY

◀ **Fig. 1** Greenland with illustration of the dimensions of Greenland (Henrik Forsberg, Equivalent Projection map based on data from OpenStreetMap.org).

Government in 1953 led to the forceful transfer of the original settlement to the current Qaanaaq.

In the article, the administrative Greenlandic distinction between 'town' (by) and 'village' (bygd) is applied. To allow for a comparison with other Arctic areas, a definition from the US Census of Urban Clusters (UCs) is used: at least 2500 and less than 50,000 people (US Census http://www.census.gov/geo/reference/ua/urban-rural-2010.html). In Greenland, there are six towns with more than 2500 inhabitants, while the other 11 towns by this definition will fall under the category settlement (village).

Water supply systems

The water supply system was developed in Greenland since WW2 with a corresponding development of professional practices. Even though the developed solutions were adapted to the local conditions, the system was directly based on European technological solutions and standards, with a strong focus on ensuring a hygienic water quality (Lindegaard 2001a, b).

Greenland national energy and water company, 'Nukissiorfiit', is responsible for power and water supply to both households and public and private companies in all the towns and villages. In spite of the great distances and geographical conditions, which do not allow for the establishment of a coherent electricity network, 60% of Greenland's consumption of electricity today is produced as renewable energy from hydropower plants, covering consumption in five of the country's major towns, while the remaining settlements each have their own electricity supply based on diesel generators (Nukissiorfiit 2017). A future development of small scale water power plants is an example of how innovative infrastructure technology will make the island operation more flexible and sustainable.

Hence, even though there are large variations in household supply systems, the system is built on a public supply thinking so that extraction, transport, cleaning and setting up of pipes and taps is planned, maintained and controlled by Nukissiorfiit. This is done through centralized expertise of engineers and plumbing specialists located in the largest cities as well as through locally hired personnel who have some training in the running and maintenance of the installations.

System constellations for households

Where energy supply historically was expanded through external supply of fossil fuels stored in large tanks, the water supply in the Greenlandic island operation society has been based on local resources. Local water resources have not been a factor for the historical location of settlements and therefore there are large differences in relation to the settlements access to water resources.

The Greenlandic towns are almost all founded in connection with the Danish colonial rule from 1721. Most often, the criteria for the localization of Greenlandic towns were a safe natural harbour for sailing ships, while the settlements were commonly placed near good hunting grounds. When these settlements were built, the settlements' population were much smaller than today. Furthermore, the water consumption was much smaller, primarily for drinking and cooking, and with substantially different practices for cleaning and personal hygiene. Similarly, the consumption of water for the processing of food etc. was limited as it was generally accepted to flush catch and fish in sea water—even if it were to be exported. So, local freshwater resources were not a decisive parameter for the settlement location, and a small river or lake was considered sufficient. Some settlements were built on islands with no real water resources, where the water supply was ensured by collecting and melting the ice floes that washed up on the beach with the tide.

Hence, while the power system was developed using similar technology in most settlements, the reliance on local resources has made the construction of the water system more complicated. Not only because water resources in some places are limited, but also because the piping everywhere has to be kept frost-free with electric heating cables. Therefore, a variety of system configurations have been developed. Here, we present the three typical supply constellations for households in Greenland:

- Piped water.
- Tank water where a tanker truck brings water to the individual household water tank. Nukissiorfiit does not provide water directly in this way, and this is thus a private-based system correction in the sense that the individual household establishes a water tank and pays a fee to get a private contractor to provide water, which is bought from Nukissiorfiit's waterworks.
- The households themselves fetch water in plastic cans from Nukissiorfiits nearest 'tap house'. The distance to the nearest tap house can vary greatly. 200 m is not unusual and some households have longer, and often transport takes place on small bumpy paths. In winter, the cans will typically be towed across the snow.

Except for three smaller villages in northern Greenland without public water supply, where the population has to collect and melt ice floes or collect water in a nearby lake during the summer (Nukissiorfiit 2016), the above constellations apply for all citizens.

There is no record of how many households in Greenland have piped water. For an overview, one option would be to

review the map material of piping for individual residences, but the technical maps for several settlements have not been updated. Therefore, the analysis is based on Nukissiorfiit's overview of how many water meters are present in each settlement.

In the six biggest towns with more than 2.500 inhabitants, there is a mix of apartment buildings, row-houses and single family homes. Apartment buildings always have piped waters, but often, there is only one water meter for the entire property, and not one for each apartment, and therefore, it cannot be concluded how many households have piped water in the major towns, based on the number of water meters. In all major towns, there are single-family houses, some of which have piped water while others do not, but the vast majority without piped water will have a water tank. In the major towns, there are also a small proportion of households that rely on fetching water at the nearest tap house.

For the 11 smaller towns, the dominant form of housing is single family houses supplemented with two-family houses and row-houses in some places, and to a less extent, apartment buildings. Thus, in these settlements, there is an increasing convergence between the number of water meters and household numbers. In the smaller towns, some few households will have tap water. Most houses will have a water tank, and the rest of the population will depend on collecting water at the nearest tap house. Upernavik stands out as virtually no one has tap water.

In the villages, almost all households are single family houses, and the number of households with or without piped water can be estimated from the number of water meters by subtracting the number of public buildings with piped water, such as the shop, health station, school and maybe a fish factory. Only a few villages in Greenland have a road network that allows the transport of water trucks, which is why the tank solution is rare in the villages. However, creative solutions can be found all over, where for example, in the summer, unauthorized hoses have been pulled from tap houses to the individual homes.

Based on the above division and available data, it is estimated that at least 10% of Greenland's households have neither piped water or a tank solution, and this applies to more than 66% of the village households. The population has to fetch water at the nearest tap house. When it comes to tap houses, the water is free, while prices for water varies greatly from settlement to settlement.

There is a link between this kind of supply and the socio-economic status of the household, as the population groups who rely on collecting water themselves often are among the socially disadvantaged. The heavy transport means that to a great extent, their water consumption is reduced to a minimum, such as 20 to 25 l per household which corresponds to fetching one can each day. It is not uncommon to find that the households' only wash basin, which is used for hand washing after using the toilet as well as when cooking etc. is filled with the same water throughout the day.

In most villages, a community-driven service centre has been established, where citizens for a fee can rent a washing machine and get a shower. This option is not always available in the towns, where citizens without piped water or water tank have to bathe at their workplace or at the public sport facility. Or they have to wash at home using a wash cloth and water in the sink—a practice that has been prevalent until the '60s, before bathrooms with showers or bathtubs became dominant. The modern practice with shower etc. has also increased the cultural expectations of cleanliness beyond what is hygienically necessary, hence today, bathing is not only a matter of cleanliness, but must also be understood as a matter of comfort (Qiutzau and Røpke 2009).

Water supply to industry and local production

Supply of water is obviously essential for public and private companies, such as public services and especially the fishing industry where international markets dictate specific hygiene demands.

The Greenlandic fishing industry, which contributes more than 90% of the country's export income (Statistic Greenland 2016), is entirely dependent on the supply of clean water. There are fish factories or first sales facilities in more than half of Greenlandic settlements, and with only a few exceptions, it is Nukissiorfiit that supplies water to them. In general, the industry is supplied with piped water. Similarly, Nukissiorfiit supplies water to the other public and private companies in Greenland. Finally, it is important to note that there are many settlements where the catch of fish or marine mammals is an essential part of the livelihood both in terms of personal consumption and private sale. In many small settlements, publicly run buildings have been established where people can wash and process skins and other catch.

Water extraction and quality

The modernization of Greenland after WW2 meant a transition from hunting to fishing and related industries in need of clean water, and thus the centralization to the major towns with more modern construction and lifestyle. This led to a radical transformation of the water supply in many parts of Greenland. Today, the water supply for most settlements comes from a lake or directly from a river, so the water resource is dependent on rainfall and melting.

Southern Greenland sees lots of rainfall with an average of 858 mm annually in Qaqortoq and 752 mm in Nuuk, but in the north, rainfall decreases sharply to 266 mm in Ilulissat and

down to 127 mm in Pituffik (Thule Air Base in Qaanaaq district) (Average 1961–1990) (The Danish Meteorological Institute 2017). This means that Northern Greenland is high arctic desert. At the same time, several northern settlements are challenged by the fact that the lakes and rivers are freezing, and lakes are not replenished with water during the long winter, while much of the lake's water reserve freezes. For these settlements, the winter water capacity is limited, and for some settlements, the water extraction stops completely. In several of these habitats. Nukissiorfiit has established large water tanks for storage of summer water, thus the size of the water tank becomes critical for the settlement's potential winter water consumption, although there are also other solutions.

Hence, six of the northern settlements and one southern rely on the relatively costly process of seawater desalination by reverse osmosis (RO), and a couple of other towns and villages use RO as a backup in the winter. At these locations, the water capacity depends on the RO plant (Nukissiorfiit 2016). In Qaanaaq, ice is melted to supply the system as described below.

The quality of the water supplied is generally good in terms of hygiene. Not at least in the major towns where the technology and the technical competences are concentrated. To meet EU requirements in relation to food production for export, the water in most places is also UV-treated. Here too, however, differences exist. There are formal programs for continuous control of the water quality, but a study launched by the Greenlandic government shows that there are problems in implementing sampling, particularly in the villages. Moreover, the conducted bacteriological tests have led to recommendations of boiling water for a shorter or longer period in almost one of every three waterworks. Especially village waterworks have problems, but also waterworks in the towns have been hit (Naalakkersuisut / Government of Greenland in 2015b).

The report concludes that this is not satisfactory, and that in the settlements, it often takes a long time before the problems that led to the boiling recommendation are resolved. There are examples of settlements having had continuous boiling recommendations for several years (Ibid.: p 3). The recommendation is to develop better testing programs and plans for emergency responses. In the smaller villages, the local employee who operates the waterworks is a key figure in ensuring water quality and implementing control. The local system is very dependent on the skills and engagement of this single person.

The discussion on water quality can be qualified from a citizen perspective. When chlorine in varying amounts is added to the water supply not at least in spring, where snow melting from the area often contaminates the water resources, there are many who do not like the taste. It is therefore not uncommon to see families who periodically complement piped water with fetching water in containers for drinking purposes from the nearby river. This happens across social statuses. However, in the larger town, this practise often requires a car or a snow mobile and the water is considered a treat.

Qaanaaq—an example

Qaanaaq is the world's northernmost naturally inhabited district with almost 4 months of winter darkness and a long period of midnight sun, and the fjord system is covered by sea-ice eight to 10 months a year.

Qaanaaq town with 640 inhabitants is situated on a moraine slope with permafrost and in a diffuse riverbed, where the river drains the local water catchment, and to a lesser extent, the local glacier located above the city, during the short summer. In the four summer months, water is supplied from the river and two large water tanks are filled, which ensures the water supply for another 4 months. The remaining 4 months, icebergs are retrieved with a wheel loader and 'dump' (construction machinery) on the sea ice, and then ice floes are crushed, melted and cleaned in a special facility connected to the distribution network. The task of collecting fresh water ice on the sea ice is dangerous, especially late in the season, where the sea ice is becoming increasingly uncertain. And climate change exacerbates this problem, because the sea ice is thinning in much of the winter, without the period for supplies of fresh water from the river extending accordingly. In addition, the method is very costly and in the winter season, this results in Greenland's most expensive water with a production cost of about 600 DKK (90 $) per m3.

Qaanaaq is one of Greenland's last hunting districts, and until recently, the catch of marine mammals, reindeer and musk constituted the district's primary livelihood. But the interplay of numerous concurrent factors has gradually undermined the economy of hunting. With the reduced sea ice caused by climate change, e.g. walruses seek further out into the sea which results in longer transport of catch. And less sea ice is also reducing the polar bears' hunting opportunities etc. The hunting quotas, especially for marine mammals and polar bears, have been reduced, and at the same time, the possibility of selling skins and ivory or crafts produced of ivory have been significantly diminished as a result of international regulations. There is therefore a gradual transformation from a hunting society towards a fishing society where fishing for Greenland halibut is becoming increasingly important. A transformation that is similar to the rest of Greenland.

Qaanaaq has a small fish factory with limited freezer capacity for halibut. Halibut is only fished during the period of sea-ice, because it migrates out of the fjord when the narwhals journey into the fjords during the summer. This means that the fishery of Greenland halibut takes place in the period when the freshwater is produced by melting icebergs, and from a simple socio-economic perspective, it is not attractive to support a local processing of halibut. Therefore, local jobs otherwise

potentially enabled by the local fishery are not created. Instead, halibut are frozen without being cut, which means that the freezer fills up relatively quickly. As the freezer is not emptied until ships reach Qaanaaq in the summer, first sales are halted when the freezer is full. There is thus a clear link between ensuring a cheap year-round water supply and the development of the district's industrial base (Hendriksen and Hoffmann 2016).

It is crucial for the development of the district that a solution is found, with cheaper and stable water supply. With this in mind, ARTEK (Arctic Technology Centre) have made a cooperation agreement with the self-rule and Nukissiorfiit, which states that ARTEK in the summer of 2017 undertakes feasibility studies to assess the possibility of extending the water recovery period through the creation of 'natural' basins or where additional winter storage tanks can be founded, taking into account that the active layer of permafrost will gradually increase with climate change. A parallel project is exploring the subsequent potentials for developing local businesses by developing and branding local food productions.

Wastewater handling system challenges

When it comes to the handling of wastewater and thus the UN sustainability goal 6.2: "By 2030 achieve access to adequate and equitable sanitation and hygiene for all", (United Nations 2015), the question explored in this section is how to build a sustainable wastewater management system adapted to the local context, and how far Greenland has come in this regard.

The modernization has also brought great changes in this area. No one needs to sit outside with their pants down, as in the traditional Inuit society. With the establishment of permanent settlements for the majority of the population in the first half of the twentieth century, toilet visits moved indoors with an indoor dry closet and thus sheltered users from weather. But with indoor dry closets came new hygienic challenges, such as odour and the potential risk of infection.

In Greenland today, three typical system configurations for handling toilet waste (black water) can be identified:

- Drainage where the uncleaned black wastewater is discharged into the sea
- Sludge tank for a single household which is emptied by a tanker truck, and where the uncleaned wastewater is discharged into the sea
- Dry closet with a plastic bag, where the bags are collected by refuse collectors and emptied into the sea or stored at the dump

There are individual households with alternative solutions, such as composting toilets or a private discharge into the sea. But the alternative solutions represent a very limited part of Greenlandic households.

Institutional systems and local practices

Wastewater management in Greenland, like the water supply, is included in an institutional system regulated and governed by the self-rule. But where the water supply is organized by the national and publicly owned utility Nukissiorfiit, the municipalities are responsible for the sewers and for ensuring the collection, handling and emptying of the toilet bags. This work may be outsourced to a private contractor. As with tank water, which is described above, the solution with toilet tanks is a private correction to the institutional system. Here, individual households finance and establish a tank and agreements with a contractor to empty the tank. Despite this, the system is institutionalized and includes system approved bulk tanks, and the contractor empties the tanker truck at the municipal discharge of black water to the sea (Naalakkersuisut / Government of Greenland in 2015c).

Wastewater handling is thus formally regulated with regard to issues such as responsibilities, payment structure, integration with building codes regarding installation of tanks in houses and integration in municipal physical planning concerning discharge to the sea (Naalakkersuisut / Government of Greenland in 2015c). The legislation is thus based on fundamental values of hygiene and environment very similar to demands from Danish law, although they are translated to the very different local conditions in Greenland. A large difference is that the wastewater is not cleaned, but discharged directly into the sea. The regulation challenges the municipalities, as they have to implement it in many and varied settlements. These already have different forms of established systems and practices, which in large part have historical reasons.

Due to the island operation, the wastewater management employees who participate with operation on a daily basis have to reside locally. In the villages, it is often a part time, e.g. a half-time position, which means that the employee will also have income or supplementary subsistence income from fishing or hunting. These kinds of posts in the public sector constitute key sources of income for many families in the settlements and are thus an essential part of the village's revenue base.

Although there are similarities, it is also clear that locally based practices are developed, so even if the systems are technically similar, they act differently depending on a variety of local conditions, built practices and specific individuals. The systems are highly dependent on a few local people. In a settlement, the collection and deposit of toilet bags may be regular and thorough, while a renovation worker in another

village, who formally has the same pay and the same technologies, can oversee a more unsystematic and irregular operation. Both forms obviously have an impact on the living conditions of the residents in the village and also on the perception of the system and its values, which may have implications for residents' hygiene practises. In a village where the system has worked well for many years and which has built up a good practice, the system is often more robust to problems encountered. This can be a problem with a breakdown of the ATV (four-wheeled motor cycle) that is used for transport of toilet bags, where the employee uses a wheelbarrow for a period of time. In another settlement, this can mean the lack of pickup until the municipality has the ATV repaired, which may take some time. A changing of the employee due to retirement or relocation can also break down a well-functioning practice very quickly. Thus, the development of a good system comprises not only technical upgrades, but to a large extent, also the education, engaging and support of the local employees.

Dry closet with toilet bags

Nationally, about 25% of households[1] use 'bag toilets' which are dry closets with replaceable plastic bags. Internationally, this kind of toilet technology are often referred to as 'honey buckets', but to underline the contextual practise of the technology in Greenland where the technology is integrated into a public system, we use the notion of 'bag toilets' which is a translation of the local way to refer to the system of 'toilets with a replaceable bag'. Today, these bag toilets use a large plastic bag, which is placed in a specially designed bucket with seating and a lid and exhaust through the roof. It is the individual household, who must close the plastic bag after use with a metal strip and put it outside the front door.

The bags as well as the metal strips are distributed by the municipality. The bags are designed for the task with a particularly high quality and with a double welding, in order to avoid that the toilet bag leaks. Still, there is a risk of a puncture with the consequence of drips inside the house. And outside, in areas with sled dogs in North and East Greenland, it is not unusual for puppies or wild dogs to tear a hole in a toilet bag left out for pickup, so the waste leaks by the entrance door.

The toilet bags are also collected by the municipality, even though this may be outsourced to a private contractor. Thus, the individual households do not transport or handle toilet bags outside of the house. In the towns, toilet bags are collected by sanitation workers with a truck, and then the toilet bags are manually emptied in a dedicated building where the sanitation worker can stand inside and the black water is led by a pipeline into the sea. In the villages, sanitation workers also collect toilet bags, but the means of transport vary. Different local solutions are used to transport the bags, e.g. in some settlement, the workers uses an ATV with a trailer in the summer and a snowmobile with a sleigh in the winter, while others use wheelbarrows and hand-pushed sleds. In the villages, the emptying of toilet bags is done manually and outdoors or in an open shed by a ramp where the black water slides into the sea. A case from Oqaatsut is shown in Fig. 2. When emptying the bags, with the sanitation worker holding the bag with one hand and cutting a hole in the bottom with the other, there is a great risk that the waste splashes onto the sanitation worker.

The sanitation workers jobs are formally regulated as part of the overall regulation of the work environment with the goal of securing a safe and healthy working environment (The Working Environment Authority in Greenland 2017). There are no specific regulations on working conditions when handling toilet bags, these are the responsibility of the municipality. In some of the larger towns, there are facilities for the sanitation workers with changing and showering. Meanwhile, here, the number of homes with bag toilets is falling. However, based on a study of waste management in Greenland from 2014, Naalakkersuisut / Government of Greenland concludes in a sector plan from 2015, that the majority of towns and villages have not established sanitation facilities for handling toilet bags that meet applicable law (Naalakkersuisut / Government of Greenland in 2015a). Thus, their mapping shows that the practical collection of wastewater generally works as a regular practise, but that from a health point of view, the collection schemes for bag toilet waste are problematic (Ibid.).

Black water must, according to current legislation, be discharged into the sea (Naalakkersuisut / Government of Greenland in 2015a, c). In some few towns and villages, toilet bags are deposited at the dump together with other waste. This is the case in Qaanaaq, where the discharge of black water is challenged by the fact that there is a reef located some hundred meters ashore, so the waste will not be washed away. The large tide and the ever changing weather condition with the

Fig. 2 Local system from a village with about 40 people for discharge of black water from the toilet bags. A local sanitation worker cuts the bags open and pours out the contents. Beside the ramp is a metal bucket for the bags and a bottle with liquid for cleaning

[1] Data is based on municipal records of households registered for pickup of toilet bags at the individual settlements.

sea freezing most of the year complicate a piped solution. Therefore, the filled toilet bags are left at the dump, resulting in uncontrolled leakages to the surrounding environment. This method is unhygienic and unacceptable from a health perspective, because of the risk of spreading diseases.

As with the water supply, there are very large geographical differences in the handling of wastewater. In major towns with over 2500 inhabitants, only about 6% of households uses bag toilet. But in smaller towns with less than 2500 inhabitants, it is about half of the households, and in the villages, it applies to more than 90%.[2]

The Government of Greenland concludes that the conditions are not satisfactory, but that building piped solutions in all settlements would have a huge economic impact and is not realistic to implement. A working group has been set up that comprised of the Environment, Veterinary and Health authorities and the National Health Board in order to identify new solutions with waste that can be tested through pilot projects (Naalakkersuisut / Government of Greenland in 2015a).

Grey water

In areas without sanitation where households use bag toilets, grey water from cooking and dish washing, showering and other personal hygiene is discharged onto the ground through a drain in the building's outer wall. In summer, depending on the topography and the ground, a small lake or stream appears outside the house. The wastewater evaporates, seeps down and runs to the sea. In some cases, the grey water may drain towards a neighbouring building. This will often be handled with the excavation of small trenches, leading the water on. In winter, a growing ice build-up is formed from the house drains that can be so large that it runs into paths and roads. In the spring, the grey water ice melts and runs away with the thawing snow, which means that lakes and streams close to towns and villages are often polluted during this period.

Industrial and institutional wastewater

The larger fish factories that have piped water will often have their own sewer line into the sea, where both industrial wastewater and wastewater from the bath, toilet etc. is discharged. Other industrial plants with piped water which is located near a sewer will typically be connected to the sewer network. The small villages' first sale facilities will often use bag toilets regardless of whether they have piped water. There is a similar differentiation for public buildings and institutions. In the larger towns, the vast majority will be connected to a sewage network. But in some of the smaller towns and villages, bag toilets are used in schools, hospitals, the village health station, service houses etc.

[2] Re the municipalities' registration of households paying for bag toilets.

Health consequences

Greenland's water and sanitation system can be seen as a transfer of the Danish system with a basic hygienic focus that was reflected by a direct goal of improving health and a hygienically embedded professional practice (Rosendahl 1989, Lindegaard 2001b).

This was an answer to the problems surfacing on the Danish political agenda after WW2 with the poor social and health conditions of the Greenland population. The number of deaths caused by tuberculosis was more than 0.8% per year, and the living conditions for a large percentage of the traditional Inuit population were rather poor and far below Danish standards. For Denmark to keep Greenland as part of the nation and for internal socio-political reasons, something had to be done. This led the government to send a medical expedition to Greenland in 1947 to map the problems and identify their causes.[3]

The development of higher quality housing and heat and water supply systems together with an improvement of health care services definitely improved the health conditions with respect to infectious diseases. This is also shown by the fact that the Greenlandic population have grown from app. 20.000 after WW2 to around to the current app. 47.000 (plus the foreign workforce).

Looking at today's situation, there is no systematic overview of the health consequences for the population that has no piped water or water tank, as well as for the even greater part of the population with bag toilets. Studies in the USA indicate a correlation between lack of running water and increased health risks in Arctic communities (Hennessy et al. 2008). For example, parts of the population who rely on collecting water at a tap house will have a risk of saving too much on the water, resulting in inadequate handwashing after using the toilet, creating a danger of contagion. The same challenge applies to the relatively few schools and other common functions that do not have piped water.

In addition, there is an occupational health risk for the employees who handle toilet bags. Consequently, they are vaccinated against hepatitis A + B and diphtheria / tetanus. Similarly, they are subjected to significant ergonomic risks associated with the collection, transport and in particular the emptying of toilet bags. At the same time, these jobs often represent an important part of the local earnings.

There is a close link between water supply and sanitation and other housing conditions, which is not treated in this article. Thus, many houses in the villages are small and old with varying degrees of maintenance. Heating has various system configurations that create different conditions for indoor air

[3] A rather well-known film was even produced to support the conclusions from this expedition. It showed a family living in a remote area being visited by a doctor and the son being sent for care to a hospital in the city.

quality and health. The development of water supply and sanitation must be linked with a plan for developing housing standards and renovation.

Finally, it is very important to point to that the quality of the water systems is decisive for the potential for local sustainable businesses development.

The modernisation with the development of water systems created new conditions for everyday life in Greenland, so that technical improvements simultaneously changing everyday practices around cleanliness and comfort and thus water consumption and norms. In the largest towns, the system is in many ways a copy of the systems in other western cities with piped water and flushing toilets and sanitation, with a technical adaptation to the extreme climatic and topographical conditions, with pumps and electric heating cables.

Meanwhile, several system variations have been developed especially in in the rest of Greenland, often rooted in the climatic conditions and the large number of geographically isolated towns and villages that create specific local conditions for water supply and wastewater management. However, all over Greenland, wastewater is not treated before it is discharged directly into the sea.

It is a central point that the water supply and wastewater management as a consequence of the Danish modernisation is seen as a basic service offered in a public system, and that the system, as mentioned, can be seen as regulated from a hygienic tradition. In spite of Greenland's large geography and island operation, the system reaches all towns and virtually all settlements, so residents in even the most isolated settlements are offered cleaned and chlorinated water from tap houses and approved toilet bags are distributed and collected.

As the above analysis shows, parts of the existing system are clearly not satisfactory in relation to the UN Sustainability goal. One problem is that comfortable systems in the large cities with piped water and flushing toilets redefining the norm for water supply and sanitation in Greenland are not realistic to implement in all settlements of Greenland. Furthermore, as a consequence of the diversity of the existing systems, Nukissiorfiit and the municipalities are left with very different conditions in their ongoing development of the local systems. Therefore, it is important to point to that reasonable supply can be handled with solutions other than piped water and sewerage, like tank water and low-flow toilets with tank solutions or compost toilets (Gunnarsdottir et al. 2012).

Conclusion—the challenges of developing the system

Implementing institutional water supply directly to all households in Greenland is a key objective for both reducing health risks for parts of the population and improving the quality of life, and also water supply in many cases is a prerequisite for the development of local businesses. Thus, the Greenlandic community is facing significant challenges in developing this in a sustainable way.

The analysis of the systems shows a number of different system configurations with different qualities and problems. The analysis shows that the water supply should not necessarily be rolled out in the form of piped water and sanitation, as it will be very expensive to achieve with existing technologies. Such a level of service will put pressure on the further dismantling of villages, thus contributing to the continued centralization of the Greenlandic settlement pattern and make it difficult to maintain cultural traditions and everyday practices.

The challenge is thus to develop other solutions to meet UN goals and strengthen local sustainable development. There are a number of alternative technologies that can offer a local and robust development. For example, means of transport to supply water have been developed, also to the households in the smallest settlements, which means that the tank solutions may be implemented. Similarly, a substitute for the bag toilets should be implemented, partly to raise the quality of life for the individual citizen, and partly to eliminate the impacts on the sanitation workers. Again, excellent technologies have been developed to meet these challenges. There is a need for systematic testing and development of solutions such as incineration and / or compost toilets, incinerators that can burn residue or other trials with, e.g. chemical toilets where there is a treatment of the residue.

For both the supply of water directly to individual households and the handling of black water, a solution is primarily based on a societal priority and is thus a political decision. The existing supply of different system constellations has been developed since WW2 in the transition from Danish colonial rule to home rule to the current self-rule. It is now the task of the young self-rule to realize a development of these systems that can create the best environment for citizens' everyday life and sustainable development of Greenland.

References

Gunnarsdottir R, Villumsen A, Jensen PE, Deinboll Jenssen P (2012) Wastewater treatment in Greenland, Technical University of Denmark, Department of Civil Engineering, DTU Civil Engineering Report; No. R-265

Hendriksen K (2013) Greenland settlements—economy and development dynamics, Inussuk, Arktisk forskningsjournal 3, Greenlands Self Rule. (in Danish)

Hendriksen K, Hoffmann B (2016) Qaanaaq district—infrastructure and businesses development—resume of a pilot project on locally based businesses development, Report, Technical University of Denmark, Department of Civil Engineering. *(in Danish)*

Hennessy TW, Ritter T, Holman RC, Bruden DL, Yorita KL, Bulkow L, Cheek JE, Singleton RJ, Smith J (2008) The relationship between in-home water service and the risk of respiratory tract, skin, and

gastrointestinal tract infections among rural Alaska natives. Am J Public Health 98(11):2072–2078

Hughes T (1987) The evolution of large technical systems. In: Bijker WE, Hughes TP, Pinch T (eds) The social construction of technological systems. New directions in the sociology and history of technology. MIT Press, Cambridge

Lindegaard H (2001a) Out of the pipe—plans, processes and paradoxes around the sewer system of Copenhagen 1840–2001. Ph.d report. Deparment of Production and Management. Thechnical Universiety of Denmark. (in Danish)

Lindegaard H (2001b) The debate on the sewerage system in Copenhagen from the 1840s to the 1930s. In Ambio, Vol. 30, No. 4/5, Man and the Baltic Sea (Aug., 2001), pp. 323–326

Naalakkersuisut / Government of Greenland (2015a) Construction sector plan for waste management, Departementet for Natur, Miljø og Justitsområdet. (in Danish)

Naalakkersuisut / Government of Greenland (2015b) Tap water quality in Greenland 2011–2013. Departementet for Natur, Miljø og Justits, Miljø- og beredskabsafdelingen. Departementet for Fiskeri, Fangst og Landbrug, Veterinær og Fødevaremyndigheden i Grønland. (in Danish)

Naalakkersuisut / Government of Greenland (2015c) Selv Rule's Act n. 10 from June 12th. 2015 about disposal of nigh soil and waster water. (in Danish)

Naalakkersuisut / Government of Greenland (2017) Catalogue on health services in the regions, Departementet for Sundhed. (download 31.1.2017) (in Danish)

Nukissiorfiit (2016) Inventory of water extraction method and water potential for each settlement. (in Danish)

Nukissiorfiit (2017): www.nukissiorfiit.gl (download 28.1.2017) (in Danish)

Qiutzau M, Røpke I (2009) Bathroom transformation: from hygiene to well-being? Home Cult 6(3):219–242

Rosendahl GP (1989) Greenland in this way. Frames for everyday life, Nuna-tek. (in Danish)

Shove E (2003) Comfort, cleanliness and convenience. The social organization of normality. Berg, Oxford and New York

Statistic Greenland (2016) http://bank.stat.gl/pxweb/da/Greenland/Greenland__BE

The Danish Meteorological Institute (2017) www.dmi.dk (download 28.2.2017)

United Nations (2015) Resolution adopted by the General Assembly on 25 September 2015. http://www.un.org/ga/search/view_doc.asp?symbol=A/RES/70/1&Lang=E

Working Environment Authority in Greenland (2017) The Greenland Working Environment Act. Executive Order No. 1048 of 26 October 2005 subsequently amended—unofficial version. http://at.gl/da/regler/love/sam-lov-om-arbejdsmiljoe-uk. (Download 28.1.2017)