Norges miljø- og
biovitenskapelige
universitet

Master's Thesis 2018 30 ECTS

Faculty of Environmental Sciences and Natural Resource Management

(MINA)

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Current Treatment Performance and Rehabilitation of the Decentralized Wastewater Treatment Systems in Frøya

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Master of Science in Environment and Natural Resources - Specialization
Sustainable Water and Sanitation, Health and Development

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DECLARATION

I declare that this compiled work is a result of my research investigations and my own findings. All aided material has been referred and acknowledged. This work has never been previously submitted to any other university for the award of any degree or diploma.

Asad Khan

Signature ___________________________________

Place and Date ______________________________

DEDICATION

To Mehnaz Beghum (Late), May her soul rest in peace. The painting of my life is incomplete without your color.

ACKNOWLEDGEMENT

Many thanks to Petter D. Jenssen for his guidance and supervision in this work. His belief in me give me the confidence to complete this work within the given framework.

Thanks to Bjørnor Grytvik (leder vann og avløp Frøya Kommune) for giving green signal of providing the data and arranging visits to several facilities. Tuft of thanks to Muhammad Abbas for his hospitality and guidance throughout the project and overall studies. Without his contribution, it would have been difficult to meet the deadlines of this project.

Thanks to Imran Ali, Yasir Nadeem, Molana Qamar Chisti Maratabi Nizami Rizviani Dambeli, Haider Ali Shah and Ali Akbar for their sacrifices and support.

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ABSTRACT

Frøya Kommune is the westernmost and one of several coastal kommunes of the Fosen region in Trøndelag County, Norway. Frøya relies on the onsite facilities, mainly septic tanks, for the treatment of wastewater. Norwegian regulations allow direct discharge of septic tank effluent to the sea, but in Frøya there are many recreational and commercial interests as well as shallow zones that makes the sea a sensitive recipient. Thus, the wastewater treatment by these systems is inefficient in term of BOD, N and P because their treatment capacity is far lower than the commonly required/recommended of both Norwegian and European standards for wastewater water treatment. In addition most of the systems on the island are not properly handled and maintained. There are also some houses which discharge the water directly to the recipients and have no installed treatment facility. Data in WebGIS, a GIS-based registration and monitoring program especially designed for onsite systems, from Frøya Kommune has been used to estimate the total discharge and treatment of the pollutants by the onsite facilities in Frøya area. The collected data has been analyzed, the reasons of malfunction of these facilities and possible upgrading and rehabilitation are discussed in this report.

Based on the findings of this report, most of the facilities operational in Frøya are inefficient in term of BOD, nitrogen and phosphorus removal. They are categorized into different groups on the basis of the vulnerability of the recipients. Some of the systems need rehabilitation on urgent basis and others can be upgraded/replaced within the different deadlines set by the kommune on the basis of their vulnerability (within 3- 10 years). Some of the possible rehabilitation techniques are; the use of a biofilter coupled with filter of crushed local seashells and also a biochar filter, the use of source separation (this opens for biogas and fertilizer production or package treatment plants).

1 INTRODUCTION

In the rural Norwegian areas, like Frøya with population density is 21.5 inhabitants per square kilometer (SSB, 2017), the houses are scattered. It is financially not feasible to connect all the houses to a centralized sewer network due to excessive distance. Norway as a member country of the European Wastewater Treatment Directive (91/271/EEG) is bound (like other members) to treat their urban water efficiently since 2005. To meet the standards in the urban areas where it is difficult to connect every single house to a centralized treatment facility, the onsite individual wastewater treatment systems are financially attractive alternatives (Moelants et al., 2008b). Many onsite systems are simple robust and well proven (Jenssen and Siegrist, 1990, Jenssen et al., 2010) but some, package treatment plants especially, relatively new so there are some operational problems and shortcomings in their designs which are affecting the performance of these systems (Johannessen et al., 2012). Furthermore, practical experiences and long term observations and field studies about the individual onsite systems are lacking. (Moelants et al., 2008a). According to Moelants et al. (2008b) and Johannessen (2012), a survey was carried out and the results of the survey revealed that most of the house owners neither perform necessary maintenance and predictable operation nor they have an agreement with manufacturer for the proper maintenance of the facility. This suggest that the treatment performance is affected by improper handling of the facilities and thus the required treatment levels, to protect the surface and ground waters, are not obtained.

The sustainable future of freshwater resources has focused on the need of minimizing the environmental impact of wastewater by utilizing the resources in wastewater treatment systems. A centralized wastewater treatment plant is often deployed in urban area for treating the municipal wastewater in most industrialized countries. In countryside, the onsite treatment systems are used to protect the nearby surface and ground waters from the impact of the wastewater produced. In Frøya agriculture, the wastewater from the recreational houses and sparsely populated areas is the second major source of phosphorus loading to the water systems today. This leads to eutrophication of surface water bodies such as lakes and small rivers. In addition to eutrophication, health and hygiene issues are also a major impact of improperly treated sewage (Lehtoranta et al., 2014).

Figure 01: Google map of Frøya area. It is part of a chain of coastal Kommunes of the Trondheimfjord. Sistranda is the administrative hub and the most densely populated region of the Frøya Kommune. Map is taken from (googlemaps.com).

Unfortunately, some decentralized systems are still not successful due to the reasons mentioned above and also volume of wastewater treated per day exceeding design values and their buffering capacity, changing quality of influent and fluctuations in the hydraulic load (Gaydon et al., 2007). Due to improper treatment, the nutrient/pathogen rich effluent released from these systems has an impact on the surface and ground waters. The treatment performance and maintenance requirements of these systems need detailed observation and assessment so that their performance and designs are improved (Moelants et al., 2008b, Johannessen et al., 2012). Major challenges are to identify the onsite systems that will provide a reliable solution for each individual household (Lehtoranta et al., 2014). To authenticate this statement, the field performance of currently operational onsite wastewater treatment systems in Frøya area have been investigated and compiled as basis for suggesting improvements.

1.1 Brief Picture of Frøya Kommune

Frøya Island is the westernmost kommune of the Fosen region in Trøndelag County, Norway. It is connected through under-water Frøyfjorden tunnel to the Hitra Island in the south and Sistranda is the administrative hub of Frøya. Frøya is the 203rd most populous (with 4,937 inhabitants) and 311th largest by area out of the 422 municipalities in Norway with area of 241-square-kilometre (93 sq. mi). The population density is 21.5 inhabitants per square kilometer (56/sq. mi) and its population has increased by 21.8% over the last decade (SSB, 2017).

1.2 Problem Statement

Frøya Kommune is one of the few coastal Kommunes of Trøndelag County. The kommune has onsite wastewater treatment facilities. The wastewater treatment by these systems is inefficient in term of wastewater treatment because their treatment capacity is far low than the required/recommended standard in term of both Norwegian and European standards for wastewater water treatment. The onsite systems operating here are out dated (improper handled and maintained) and can cause serious pollution in the recipients as well as freshwater bodies such as groundwater, lakes and streams. The phosphorus and nitrogen, organic matter and bacteria discharge of such systems are causing eutrophication, health and hygiene issues. The purpose of this study is to identify the shortcomings of these system. The systems were visited and sampled to see that what is the current performance of the onsite wastewater treatment plants in the area and how the existing treatment flaws rehabilitated, if there are any?

1.3 Objectives

Objective of this project is

- To investigate a wide selection of onsite wastewater treatment plants already operational in the area and to identity their performance problems.
- The necessary suggestions and measurements that can improve the performances of these treatment systems.

1.4 Data Used

The data collected by the Frøya Kommune during the summer 2017 survey and data collected during field project of this thesis during March 2018 is used in this report. The data collected was saved in the WebGIS database of the Frøya Kommune. Data was collected from 1678 houses is used in this project.

1.5 Scope

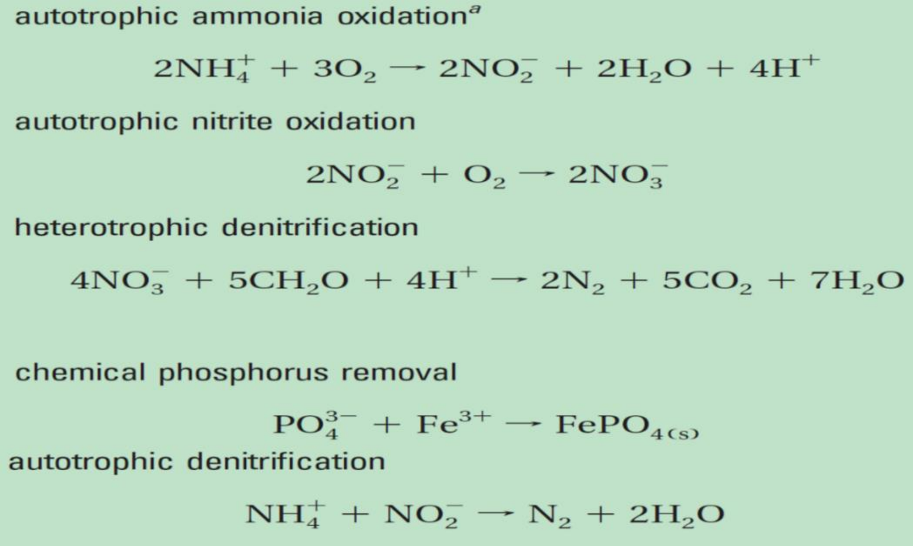
This study is an insight to the field performance of currently operational onsite wastewater treatment systems in Frøya area. The purpose of this survey is point out the shortcomings (if any) of the existing individual on-site wastewater treatment systems in the area and suggest a possible solution for improving their designs and performance in term of wastewater treatment. So that their negative effects on the recipient are decreased. In addition, this compiled data will provide a foundation for the long-term investigation and observation of small on-site treatment plants in Frøya area.

1.6 Research Questions

- What types of decentralized wastewater systems are operational in the area?
- Do they meet the Norwegian wastewater treatment standards?
- How efficient are these plants in term of removal of N, P and BOD?
- What are the reasons of their malfunctioning?
- Which systems need to be upgraded?
- How can be these systems upgraded in economical feasible way?

2 ON-SITE WASTEWATER TREATMENT

Human activities are mainly responsible for the eutrophication of many waterbodies throughout the world. Runoff from the humus rich agricultural lands and nutrient rich household wastewater have excess of nitrogen and phosphorus that are the most common factors of eutrophication. They need to be removed and the generalized reactions for their removal are given in snap below.



autotrophic ammonia oxidation[a]

$$2NH_4^+ + 3O_2 \rightarrow 2NO_2^- + 2H_2O + 4H^+$$

autotrophic nitrite oxidation

$$2NO_2^- + O_2 \rightarrow 2NO_3^-$$

heterotrophic denitrification

$$4NO_3^- + 5CH_2O + 4H^+ \rightarrow 2N_2 + 5CO_2 + 7H_2O$$

chemical phosphorus removal

$$PO_4^{3-} + Fe^{3+} \rightarrow FePO_{4(s)}$$

autotrophic denitrification

$$NH_4^+ + NO_2^- \rightarrow N_2 + 2H_2O$$

Figure 02: Reactions for nitrogen and phosphorus removal. Snap is taken from Larsen et al., (2009).*

Mineral phosphorus in concentrated form, that is used as fertilizer, is depleting globally and mining of fossil phosphorus involve addition of cadmium to the biosphere because it is often contaminated with cadmium and similarly nitrogen fertilizer production involve complex processes and huge amount of energy (Smil, 1990). Therefore, it is important to recycle them from wastewater.

In Norwegian lakes, the growth of algae is often associated with the phosphorus availability. To reduce the eutrophication, the phosphorus discharged to the vulnerable watersheds must be reduced (Johannessen et al., 2012). This is achieved by extracting nutrients (especially phosphorus) from the wastewater by using centralized or/and onsite treatment systems. A variety of onsite wastewater treatment systems are used in rural areas for treating the wastewater. On-site systems are either natural or conventional (Parkinson and Tayler, 2003). Natural systems are broadly categorized into two groups, constructed wetlands (CW) and soil infiltration systems. Conventional systems, also termed as package treatment plants, are compact form of centralized wastewater treatment plant because it utilizes the same processes in a small-scale system (usually in a tank) (Johannessen et al., 2012). Soil infiltration system is used in the area with fair hydraulic conditions whereas the conventional and CW systems can be used in regions with low to no hydraulic conductivity. Some of the onsite wastewater treatment systems will be discussed below.

2.1 Septic Tank

Septic tanks are the most frequently used onsite wastewater treatment tanks. It is the older most and simplest technology without any external energy source and consists of a watertight chamber for the primary treatment of household sewage. It consists of three chambers. It is categorizes as primary treatment technique because it is not efficient in removing the pathogens, phosphorus compounds and nitrates from the wastewater (Butler and Payne, 1995). Therefore, to avoid odor problems they must be emptied at a suitable interval of time. They are used in the areas where land available for treatment is small, site is sensitive, and the soil is poor. These tanks are economical because of their simple operating system and easy maintenance (Paulo et al., 2013).

To provide the advance primary treatment for wastewater, the ordinarily used septic tank need some modifications. A septic tank with attached growth or effluent filter vault can be fruitful modifications and sometimes filters can also be introduced. Filters stops most of the solid particles from entering the discharge and avoid blockage of the treatment assembly (Butler and Payne, 1995).

Septic tank of $4m^3$ is recommended for the primary treatment of sewage of a single household. In modern designs half of the tank consists of first chamber as it holds the settled solid wastes and the remaining half portion is equally divided between the other two chambers (Sasse, 1998).

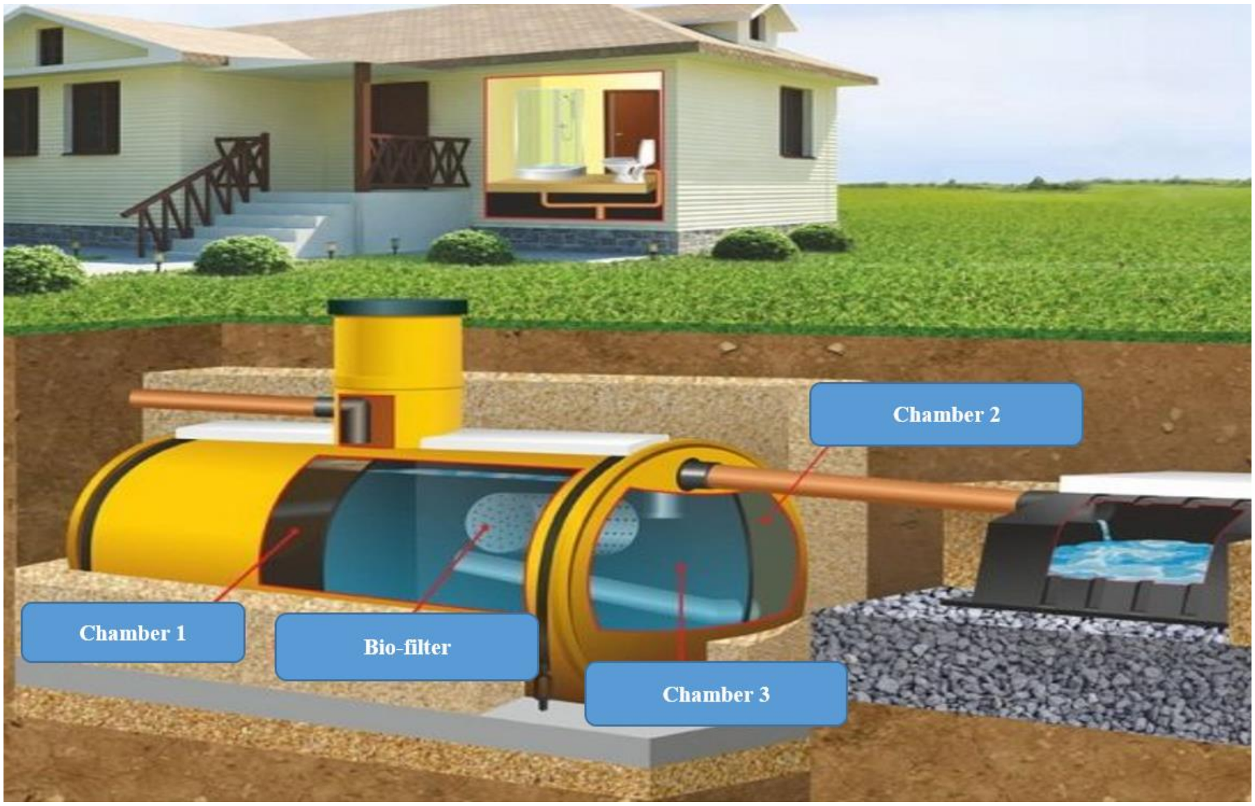


Figure 03: Basic components of a septic tank, discharging effluent to an infiltration system. Sketch is modified from (www.akitasmexico.com).

2.1.1 Mode of Working and Treatment Performance

The sewage water enters the water tight box or cylinder-shaped tank normally made of concrete, fiberglass or plastic. Lighter pollutants such as human fat, lubricants, hairs and detergents are usually floating in the form scum layer while the heavier ones are settled down in the form of sludge. Which is broken down partially by the bacteria and the remains must be pumped out after a suitable interval of time (Butler and Payne, 1995). Household sewage should stay at least 18 hours before it is flushed out to the secondary treatment unit (Paruch et al., 2017).

The water treated in the septic tanks is then out to the secondary treatment medias such as CWs, soil infiltration system or the drain field. The soil used must be suitable and thick enough for the water treatment before it enters the groundwater. The soil separates the large particles and pathogens from the wastewater where they die off due unsuitable habitat (Paulo et al., 2013).

The treatment performance of septic tanks in term of nutrients and pathogens removal is 20-30% BOD_5, 5-10% Nitrogen (tot-N), 30-60% Suspended Solid, 5-10% Phosphorous (tot-P) and 40-50% Thermotolerance Coliform Bacteria (TKB) (von Sperling, 1996).

2.1.2 Pumping Interval

Pumping interval of the tank depends on the amount of wastewater received, size of the tank, age of the system and the concentration of solid waste components. The periodic inspection of tank will be helpful in deciding the interval of pumping. Moreover, the life cycle of the system will be prolonged, and the maintenance cost will be lowered. Under following three condition the septic tank must be pumped if:

- Half of the tank capacity is occupied by the sludge and scum.
- The height difference of the outlet pipe (tee) and sludge is less than 12 inches.
- The height difference of the outlet tee and scum layer is less than 3 inches (missouri.edu).

2.2 Holding Tank

Holding tank is also sometimes referred as wastewater holding tank or blackwater tank. It is a storage tank usually mounted on a vehicle or installed above the ground. The wastewater stored is transported for treatment to a nearby plant. Powerful pumps are used for removing wastewater and settled solids from the holding tank. The tank is watertight and can store water for several days. They are often discouraged under normal situations and are used under extenuating conditions and in recreational facilities. They are also installed in the areas with running water far away from the sewage connection/line.

Figure 04: Holding tank for wastewater storage. These tanks are watertight and can store the wastewater from a household or industry for several days. They are in different shapes and sizes. Image is taken from the (plumbersportabletoilets.com).

These tanks are not widely operational because of few reasons. The difficulty to know about the exact conditions of tank, maintenance and service, and expenses of transportation. In many cases due to improper servicing and maintenance, these systems can go undetected for years which can be a serious threat to hygiene, health and environment (Carmody, 2008).

2.3 Bio-filter

Bio-filter is installed to bring the pollutants present in the wastewater stream in direct contact with micro-organisms which break them in the presence of oxygen (Srivastava and Majumder, 2008). It is not a complete filtration system by itself and is used for pretreatment (Paruch et al., 2017). The recommended grain size of the material used is 2–10 mm and its depth is 0.6 m as a standard. The BOD removal is independent of the depth whereas the removal of bacteria declines in the filter installed at shallow depths. The filter material used is Shell-sand (1–4 mm), the light weight aggregates (LWAs), FiltraliteP (2–4 mm) and Perlite (1–7 mm). The bio-filter is usually a dome of porous filter material with vertical flow with aerobic condition and sheltered bed or tank installed based on the hydraulic conductivity of the area. Porous filter media favors the growth of biofilm and thus enhance the filtration performance (Jenssen et al., 2005).

Figure 05: Bio-filter with nozzle for even distribution over the filter material. Picture is taken from (fbprocedes.com).

Bio-filter with spray nozzle, for even distribution of wastewater over the filter media, leads to high performance treatment (Jenssen et al., 2005). The secrets of achieving high treatment efficiency is even distribution of effluent over the surface of deployed filter in a single-pass coarse media bio-filter, the volume of dosage and the number of doses (Paruch et al., 2017).

The pollutant removal efficiency is 70% for SS and BOD in an efficient full-scale system. In addition, the removal of total N is 20–40% due denitrification in the anoxic portion of the filter. Indicator bacteria is removed by 2–3 logs or more in such system (Jenssen et al., 2005).

2.4 Sand Filter

Sand filters are beds of usually well sorted medium grained sand that utilize the naturally occurring biological, chemical, and physical processes for treating wastewater (Lesikar and Persyn, 1999). Physical process involved is filtration of particles from the wastewater, chemical process is in the form of sorption which involve sticking of contaminants to the sand and micro-organism community on the sand surface whereas in biological process the assimilation occurs in which the nutrients in wastewater are consumed by the microbes (Bahgat et al., 1999). Oxygen is must for life (of microbes) so for the successful treatment of wastewater air must percolate through the system. Besides oxygen, temperature also play an important role in the growth of microbes and the chemical reactions active during the process (Lesikar and Persyn, 1999).

There are two types of sand filters intermittent and recirculating intermittent sand filters. In intermittent sand filter a 24- to 36-inch-deep bed of sand receive intermittent dosage of wastewater through distribution pipes. It percolated vertically through the bed which is collected and discharged to the underlying graded gravel bed or collecting area. The recirculating intermittent filter involve an additional process of mixing the filtrate with primary treated effluent and filtering it several times before sending it to the filter bed. For better filtration pumps are used to distribute the wastewater over the filter bed (Lesikar and Persyn, 1999).

It is one of the oldest technology used for additional onsite treating wastewater and is operational in areas where septic tank/soil absorption systems cannot work due to shallow groundwater, thin coverings over the bedrocks, soil with low hydraulic conductivity, or other site conditions (Healy et al., 2007). Depending on the local conditions, sand filters can be either partially/completely buried or can be on surface in the areas with high water table or shallow bedrock. They are covered in rainy areas and regions with subfreezing temperatures (Lesikar and Persyn, 1999).

Sand filters can serve small communities, single households, businesses and institutions away from the centralized wastewater treatment plants (Healy et al., 2007). It is low cost and simple system and can be installed by the people themselves. The influent for sand filters is pretreated for solid removal in an aerobic unit or septic tank. The effluent of sand filter is usually odorless and colorless. The effluent cannot be discharged directly to any water body. It is usually discharged to soil sorption fields or for irrigation purposes (Lesikar and Persyn, 1999).

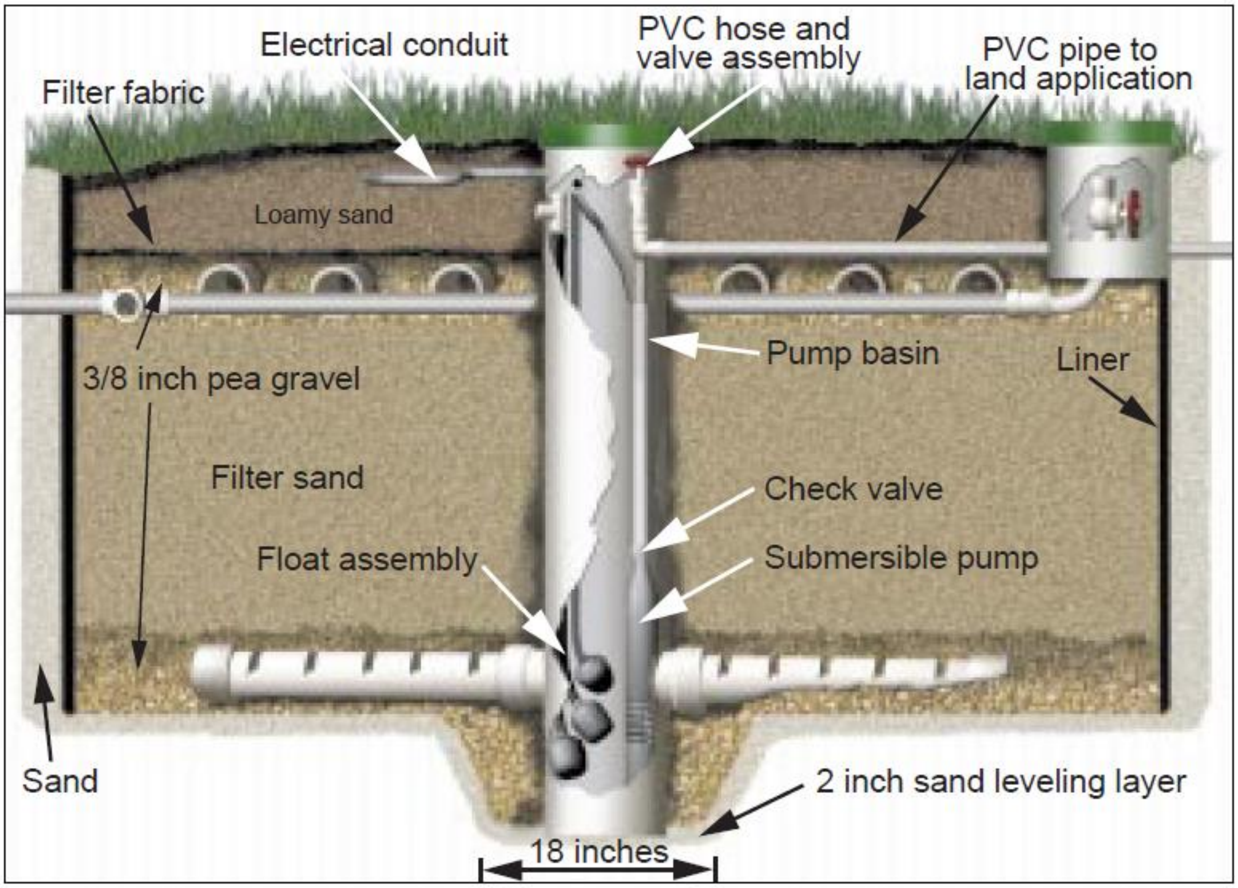


Figure 06: Sand Filter is typically a concrete- or PVC-lined box filled usually with a well sorted medium sand material. Design of sand filter shown is taken from Lesikar and Persyn (1999).

The sand filter can experience biological or physical clogging. Biological clogging is the result of excessive nourishment of microbes while physical clogging due to the accumulation of solids on the surface or in the intergranular space between the sand grains and thus block the water percolation through the system. Better pretreatment techniques for removing oil, grease and solids can be used to minimize the clogging (Lesikar and Persyn, 1999).

In Norway the sand filtration has decreased by 43% during the period of 2002 to 2005 (SSB, 2017) mainly due to clogging and ineffective treatment performances (Eikum and Seabloom, 2012).

2.5 Soil Infiltration System

Soil infiltration onsite wastewater treatment systems generally depend on infiltration of primary effluent through soil to achieve purification before it is discharged to the groundwater. The processes active in soil infiltration systems are biotransformation, chemical reactions, die-off & predation, uptake of nutrients by plants, sorption and straining & filtration. Complex interactions of decontamination and hydraulic processes is the key factor of the performance efficiencies of soil infiltration systems. In addition, the long-lasting contact between the soil particles, microbes and pollutants in the sewage during the unsaturated flow also play an important role in purification process. Unsaturated flow is achieved by deploying the distribution unit.

Soil infiltration systems is three component system in which a soil bed receive wastewater from the septic tanks or other pretreatment unit using the dozing pumps. First component is pretreatment system which is deployed for the de-gritting, removal of oil, grease and suspended solids and it avoid the blockage of pipeline and soil pore system. Second is distribution pumps that spreads the wastewater over the filter bed in a recommended way. Third component is soil profile which purify the wastewater and finally discharge it to the groundwater system. Soil infiltration systems can of three types such as burried system, open system and surface infiltration and sometimes the gravel trenches are also used (Jenssen and Siegrist, 1990).

For an efficient soil infiltration system, the dosage of pretreated effluent is 1-5 cm/d and the depth of unsaturated zone greater than 0.3-0.6 m is recommended (Van Cuyk et al., 2001). Minimum number of basins is 3-4, basin size 0.5-2 ac, application peroid of 1-9 days and drying peroid of 5-20 days. These loading cycles can vary with changing climates. For mild climates short drying peroids are applied while for wet and cold climates the drying peroids are longer (Overcash and Pal, 1979). Desinging of such systems requires these necessary steps (Overcash and Pal, 1979).

1. Permeability measuremt in field to characterize the soil and groundwater conditions
2. Find thickness of vidose zone
3. Modelling the hydraulic pathway of filterate
4. Infiltration rate deduced from field data
5. Set of treatment requirements
6. Proper selection of pretreatment methods

7. Calculation of basin area and annual hydraulic load
8. Proper selection of hydraulic loading cycles
9. Deteremine number of basin required
10. Selection of proper montoring technique

In Norway Rena infiltration system is the largest soil infiltration system in the country treating wastewater of almost 8000 person equivalent from Rena and nearby army training camp. It is locate d 500 m to the east of Glomma River in a glaciofluvial and gravel profile. It is open system with rapid infiltration through a thick soil profile to the groundwater. Wastewater is pumped from Rena and army camp to the infiltration site. The treatment system has four basins each with 1000 m^2 and depth of vedose zone is nearly 40m (Jenssen, 2012). There are some failure examples of such systems and the failure is probably due to insufficient expertise, improper designs, monitoring problems and improper operation of the systems (Beal et al., 2005).

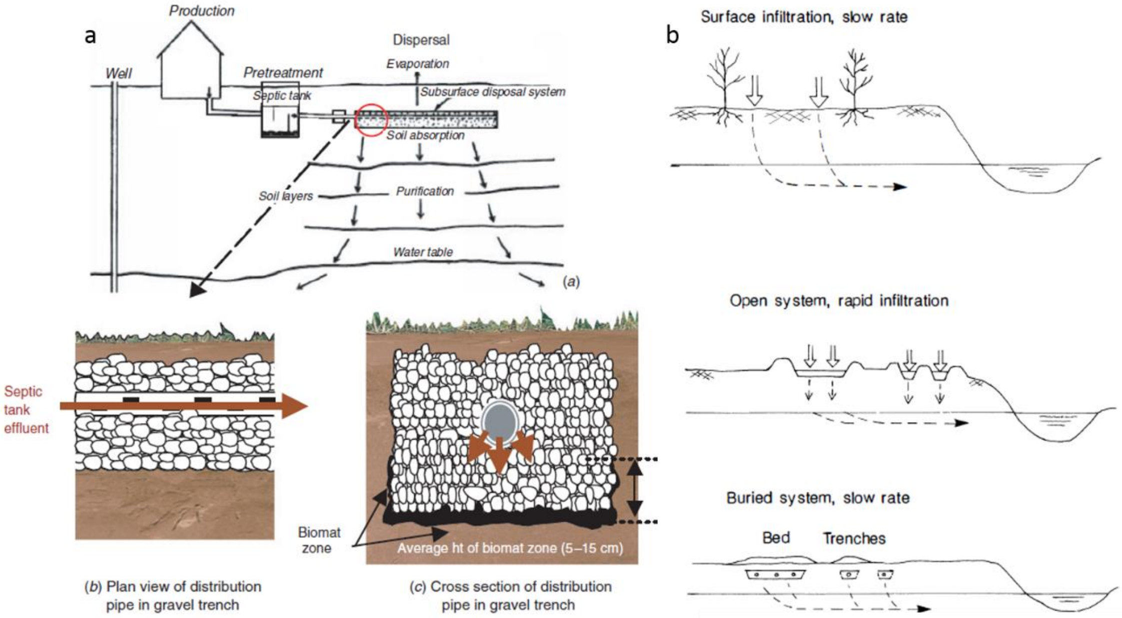


Figure 07: Schematic representation of buried soil infiltration system (a) Beal et al. (2005). Three different types of infiltration systems (b) Jenssen and Siegrist (1990). Each system has different capacity of treatment. Purification is mainly achieved by the flow in the unsaturated zone.

2.6 Constructed Wetland

Constructed wetlands are the most economical natural systems for the decentralized treatment of wastewater. It is economical due to low maintenance and setup costs, easy control measures, more engineered setup, aesthetic appearance and reuse of the material and being environment friendly. The nutrients are removed by trimming and seed fall and accumulation in the soil (Vymazal, 2007). It is favorable way of treatment for household wastewater in the developing countries due to their low maintenance and setup costs. In addition, it is a treatment unit that provides aesthetic appearance as well as reuse possibility possibly (Ayaz and Akça, 2001). Due to their easy control measures and more engineered organizations, the constructed wetlands (CWs) are ideal (Kadlec, 1995). Based on Kadlec (1995), wetlands have four types:

- Floating leaved aquatics
- Submerged aquatic beds
- Surface flow marshes
- Vegetated subsurface flow beds

The surface flow constructed wetlands are characterized by dense vegetation with the water depth less than 0.4 m and hydraulic loading of 0.4- 4 cm/day (Heistad et al., 2006). Submerged aquatic beds are of two types such as vertical flow and horizontal flow. The latter is mostly operational in Norway. Commonly it has two parts, a septic tank and a horizontal flow wetland bed. In Norway, an additional part is added to the assembly of wetland in the form of bio-filter to achieve efficient treatment (Paruch et al., 2017).

2.6.1 Functioning of Wetlands

Biological/Biochemical Oxygen Domain (BOD), Chemical Oxygen Domain (COD) and bacterial pollutants are removed very efficiently by the wetlands, but their performance is limited in term of nutrient removal. BOD and COD are segregated from wastewater by the swift disintegration in the upper layers of soil and water. Sedimentation of suspended solids also aids the removal. Nutrient removal is also an important goal, so the attempts should be always made to enhance this process (Kadlec, 1995).

Various processes are operational for the removal of nutrients. The ideal redox condition, soil acidity and important nutrients are listed. Bacterial transformations of the organic matter (nitrification-denitrification) lead to the removal of nitrogen. Nitrifying bacteria transform the ammonium to nitrate under aerobic conditions while denitrifying bacteria break the organic matter under the anaerobic conditions (Ayaz and Akça, 2001). During denitrification of waste material nitrate is used as an electron acceptor instead of oxygen. Denitrification occurs in two steps, in first step nitrous oxide is produced due to reduction of nitrate and finally atmospheric nitrogen is produced. The flora in wetlands is itself a temporary storage for nutrients and they decelerate the production of greenhouse gases (Kivaisi, 2001).

2.6.2 Performance of Wetlands

Based on the performance of experimental wetlands in the Netherland (Lauwersoog), it has been found that the COD, BOD and bacteriological pollutants are removed in very percentages by the wetlands but their performance in term of nitrogen and phosphorus elimination is comparatively lower (Ayaz and Akça, 2001). Accumulation in soil organic matter, harvesting of the cane stands, seed fall from the cane inflorescences, and denitrification are all the four processes that are equally acting for removing about 35% of nitrogen from wastewater. Phosphorus is removed (25%) by trimming, seed fall and accumulation in the soil. The later one has very important role (Kivaisi, 2001).

The performance of wetlands can be improved by harvesting in October instead of January. In addition, it has been found that the shortening of wet-dry cycle is also helpful in enhancing the N and P removal by 50 and 40% respectively. The cycle is usually shortened to 5 days of low water levels followed by 2 days of excessive water levels (Kadlec, 1995). The removal efficiency of pollutants is very high with bacteria >99%, BOD > 90%, Nitrogen > 50%, and Phosphorus >90% (Paruch et al., 2017). CWs with pre-treatment bio-filters discharge the effluent that is suitable for swimming in term of indicator bacteria and meets the European standards for swimming water quality. The effluent quality in such wetlands is free from seasonal effects (Jenssen et al., 2005).

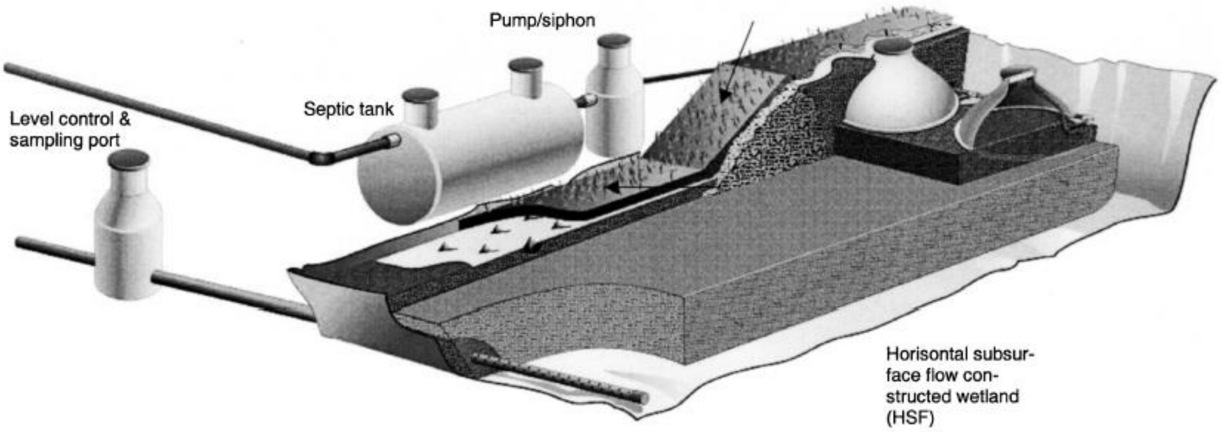


Figure 08: Basic components of a constructed wetland (with pre-treatment bio-filter) are shown. Septic tank effluent enters the system through an inlet pipeline system which is processed by the natural means such as wet plants and is spilled out the effluent pipeline system after proper treatment. The cartoon is taken from Jenssen et al., (2005).

2.7 Source segregation

Source segregation is a recent advancement in a decentralized household wastewater treatment system. In source segregation domestic wastewater is collected separately at its source of generation. Source segregation makes it easier to treat blackwater as well as to reuse greywater in a complex and decentralized system. However, this technique required large area and high constructional, operational and maintenance costs (Larsen* et al., 2009). To stimulate the household wastewater treatment, an effective and low-cost system is required. Therefore, in this concern, the best ecological treatment alternative is the constructed wetlands (CWs) system. Mostly this system is used for the decentralized greywater treatment. The characteristics of this system includes; higher treatment capabilities, good elimination rate of bacteria and other pathogens, high load flexibility, free from operational cost and no need of external energy source (Paulo et al., 2013).

Two methods have been proposed, first is the separation of grey and black water only. Whereas in the second method; grey, yellow and brown or black water are collect separately.

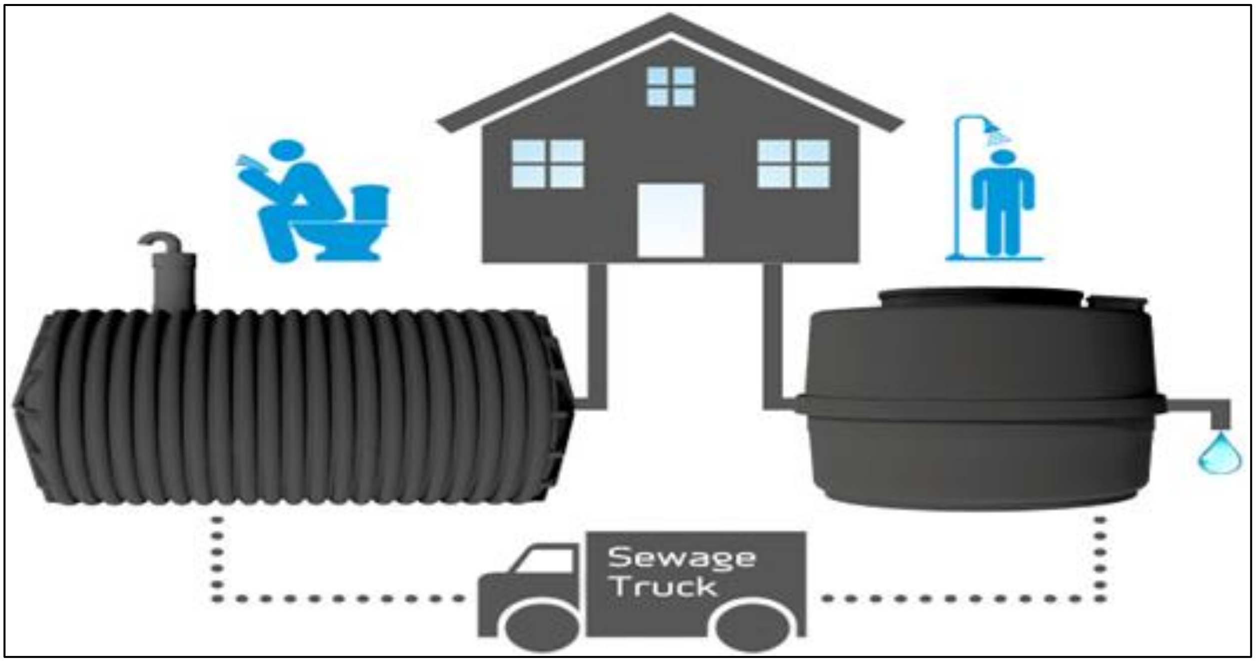


Figure 09: Basic principle of the source segregation is shown in the figure. Taken from ecomotive.com (illustration courtesy of jets vacuum).

According to the recent “Ecological Sanitation” (EcoSan) concept. “Yellow water is separately collected human urine while brown water is separately collected human feces”. EcoSan claims that household wastewater is not only a waste i.e. to be discharged whereas it is a resource that has to be revaluated. EcoSan recommends that each stream of wastewater (grey, brown and black water) should be handled separately and carefully. So that afterword it can be used for irrigation, as a fertilizer, compost or energy resources (Langergraber and Muellegger, 2005).

2.8 Biological Toilets

These toilets use the biological processes (by employing bacteria) for the degradation of organic matter. They are dry and operate without flushing water. They are safe and hygienic alternative for the rural area where there is no conventional wastewater treatment plants. They reduce the water consumption and cost of treatment of waste. Composting toilets can considerably reduce household water consumption and the costs for wastewater treatment because they use the source separation technique in which feces and urine are segregated from the wastewater. Organic matter and plant nutrients are reused in the form of compost and the remaining wastewater is easier to treat (Berger, 2011).

The composting process includes the degradation of organic matter by thermophilic2 aerobic bacteria. Under optimal conditions the bacteria can produce temperatures within the composting heap above 50°C and can therefore provide a fast and substantial pathogen reduction. Due to its complexity, however, the composting process may be difficult to manage within the composting vault. Temperature measurements have shown that it is not easy to reach temperatures above 40° C in the composting vault and the normal operating temperature range is often mesophilic (Berger, 2011).

2.9 Prefabricated Package Treatment Plant

Package treatment plants are compact form of centralized wastewater treatment plant and they utilize the same process configurations in a small-scale system (usually in a tank) (Johannessen et al., 2012). They are usually prefabricated plants that be placed in garage, basement or buried in the ground.

They are widely used in Norway and other European countries. They are serving since last 2-3 decades in Norwegian rural areas where soil is missing or is poor. Approximately 14,200 plants are operational in the rural areas of Norway especially around the Oslofjord and western coast. And its use is increasing in the country from 2002 onward. A new set of regulations for wastewater treatment is imposed since January 01, 2007 and only those package plants which meet the European standards (NS-EN 12566-3), will be allowed to sell and operate in the country. Some of the Norwegian minirense (package treatment) plants do not meet the standard in term of maintenance and service requirements and thus they will be ceased. SINTEF is responsible for deciding about the selling licenses of package treatment plant selling companies and it has allotted license to 16 companies so far (SSB, 2017).

2.9.1 Processes in the Package Plant

2.9.1.1 Biological Treatment for Removal of Organic Matter

Oxygen supply from the air to microbes' community is key for successful biological cleansing. Two processes are active in the biological treatment such as active sludge and biofilm. In the first one the microbes are suspended in the liquid phase while in second one the micro/organisms are grow on the surfaces of the treatment assembly/tank. The main purpose of biological treatment is to reduce organic matter and particles. Because of the fact that these plants are not efficient in phosphorus removal, they are used in the regions less sensitive for pollutant discharge (Hensel and Yri, 2008).

2.9.1.2 Chemical Treatment for Removal of Phosphorus

In chemical treatment of wastewater, Fe, Al or Ca based chemicals are added to the wastewater. These chemicals react with phosphorus and precipitate it partly. The rest is coagulated and removed during the sedimentation phase. The first one is quicker because the chemical reactions are initiated suddenly after the addition of chemicals while latter one take long time during flocculation and consequent settling. The removal of organic matter and particles is 50-70% during this process. It removes phosphorus and particulate matter so the effluent is safe to release to both sensitive and normal areas as it can not cause any eutrophication (Hensel and Yri, 2008).

2.9.1.3 Biological/Chemical Treatment for Organic Matter & Phosphorus

Coupling of biological and chemical treatment system give an efficient solution to the removal of phosphorus, organic matter and particles. These both process occur in a filter. The process can occur in two ways. In first design the chemical is added during biological stage. In second, the biological processes is followed by the chemical processes. Some of the plant selling companies have claimed 90% removal of organic matter and phosphorus, 20% removal of Nitrogen and up to 99% elimination of thermostable coliform bacteria (TKB). Effluents from such plants can be sent to area with both sensitive and normal pollution regulations (Hensel and Yri, 2008).

2.9.2 Post Polishing of Effluent

Before the effluent of package treatment plants is discharged to an infiltration system or a sensitive recipient, the post polishing step is carried out. Based on the interest, it can be designed in different ways. Post polishing for pathogens removal will be different from the one for the detention of particles. It can be:

- Sludge Screens to hold solid particle
- Sludge separator and hygiene step to eliminate the pathogens
- Infiltration into loose masses
- Particulate filter to deal with mud and many more based on the interest and threats to the environment (Hensel and Yri, 2008).

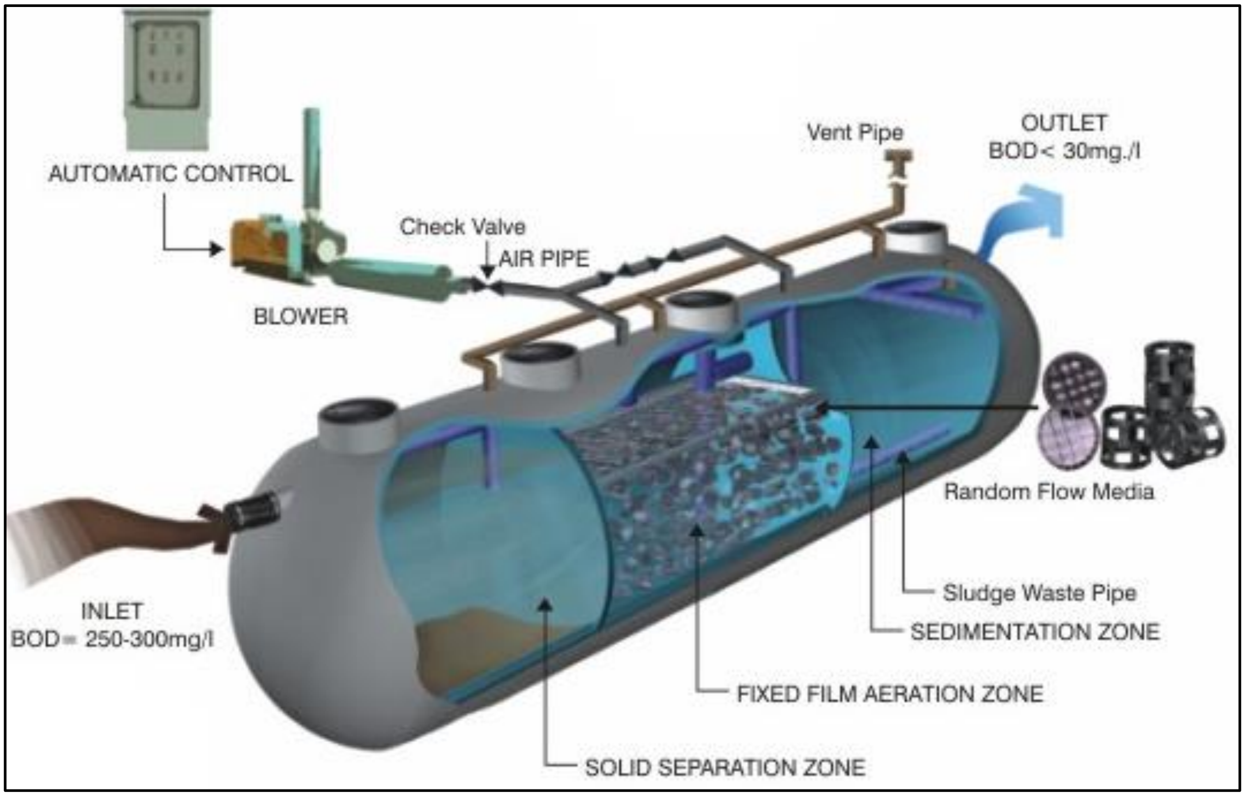


Figure 10: Conventional system with labelled components. It is compact form of the same technology used in the centralized wastewater treatment plants. Wastewater enters the tank with three chambers where it is treated by reducing its BOD. Cartoon is taken from (navyaawatertechsolutions.com).

3 HISTORY OF WASTEWATER TREATMENT IN NORWAY

An extensive national research program was launched by the Norwegian authorities for the wastewater treatment in 1970. The research had many sub-projects and onsite disposal methods for wastewater treatment was one of them (Liseth, 1980). Soil investigations to check its suitability for treatment purposes, rehabilitation of sludge & wastewater media and testing of biological toilets in term of performance were some of the duties of the Agricultural University of Norway (NLH) and during the period of 1971-78, circa 7.05 million NOK were given to NLH for 13 sub-projects. The on-site treatment project started in 1972.

In Frøya, the wastewater treatment is decentralized and the kommune is planning to install a centralized wastewater treatment plant for the processing of wastewater from the populated areas of the kommune such as Sistranda. There are a vast number of treatment systems used in the area. Septic tank is the major mean of treatment in the area. Direct emission, septic tank to terrain, septic tank to watercourses, infiltration systems, sand-filter, biological/chemical package plant, chemical package plant, holding tank, holding tank for blackwater, biological toilet, biological toilet and infiltration and holding tank and infiltration are the treatment practice applied in the Frøya Area. There are 973 permanent houses while 642 holiday cottages (hytte) using onsite wastewater treatment facilities in Frøya Area.

4 INTRODUCTION TO WEBGIS

As discussed earlier 20% of rural Norwegian population relies on the on-site wastewater treatment systems and using circa 0.8 million on-site wastewater treatment systems. Some of the decentralized systems have performance equal to or more than a centralized system (Heistad et al., 2006). However, most of the old on-site systems need upgrading and replacement due to their malfunctioning or poor treatment. Improper knowledge and handling of these systems are causing fecal contamination and eutrophication of water bodies. Because of the enforcement of new national and European standards, the onsite treatment systems must ensure the proposed treatment performance. To meet these goals and improve catchment management, the tool "WebGIS Wastewater" was developed during 1900's by the Norwegian Institute for Agricultural and Environmental research (Bioforsk). It is a Global Information System (GIS) based application that is used for municipal administration and registration of on-site wastewater treatment systems. The tool use information like age and type of the system used, load on the system and its geographical location to estimate the performance and environmental impact of the treatment plant within the catchment area. The system also helps in facilitating the operation, control, maintenance and rehabilitation of the plants. Around 50 Kommunes in Norway are using the tool for management, estimating the environmental impacts and rehabilitation of decentralized systems (Bioforsk).

The tool use an empirical formula, derived from long term research on the decentralized system, to calculate the environmental impact index for the treatment performance of the system. The output from the system is categorized by color-codes. Red color represents the system with very high impact; pink point out the high, green for moderate, light blue is for low and dark blue for very low environmental impact by an onsite system.

However, it must be remembered that machine has no brain so sometime the results are over/under-estimated by the machine as it uses a specific algorithm for result computing. Therefore, it is always good to crosscheck the results and find the possible outliers in the results computed.

5 METHODOLOGY

5.1 Field Methods

Field data has been collected using conventional method of field and a very professional approach for collecting, labelling and storing the sample from each individual package treatment plant. The data was collected under the supervision of professional engineer from Frøya Kommune. The owners were informed in advance about the survey. The sample are taken without damage or disturbance to the facility and its surroundings. Grab sampling procedure was used as it is cost effective and quick technique for collecting samples.

5.2 Laboratory Techniques

The samples collected in field are transported to the chemistry lab of Frøya Kommune and are analyzed for the parameters that are helpful in describing the field performance of these plants. The proposed procedure has been followed to determine each required parameters. Precaution measures have been followed very strictly to avoid damage, contamination of samples and personal errors in the results. Four different parameters have been determined in the laboratory. The data for each individual sample has been added to the database of Kommune. Compact Photometer PF-12 (mn-net.com) and Colifast Field Kit (colifast.no) have been used during the examination of the filed sample and results of each test are recorded on the laboratory notebook and later on to the database.

5.2.1 Ammonium Test

Ammonium ion is readily found in domestic sewage and tests are performed using compact photometer PF-12 and ammonium tube test method. Its presence in water is sign of decomposition of organic matter. These values can be used as contamination indicator. The procedure of test is described below.

5.2.1.1 *Material*

Probe, test tube, sample to be analyzed, distilled water, chemical set (NH_4^{-1}, NH_4^{-2} & NH_4^{-3}), laboratory book, laboratory glasses, hygiene kit, gloves and paper.

5.2.1.2 *Precautions*

- Avoid direct contact with the wastewater sample.
- Avoid contamination of instruments.
- Rinse all the instruments at least three times.

5.2.1.3 *Procedure*

- The samples are poured in the rinsed test tubes by using probe.
- Ten drops of NH_4^{-1} have been added to the samples.
- After shaking the sample, one spoon of NH_4^{-2} has been added to the sample.
- The sample is shaken and allow for 5 minute before the addition of four drops of NH_4^{-3}.
- The sampled has been shaken and then the test tube is dried and cleaned by using paper before putting it in the photometer.
- The photometer give the result after 7 minutes.

5.2.1.4 *Chemical Reaction*

The reaction occurs between the ammonium ion and chlorine in alkaline medium and chloramine is produced. In the presence of phenols (it is in the reactant part of the reaction), chloramine form indophenol which is blue colored as shown in sample 02 in the figure 11.

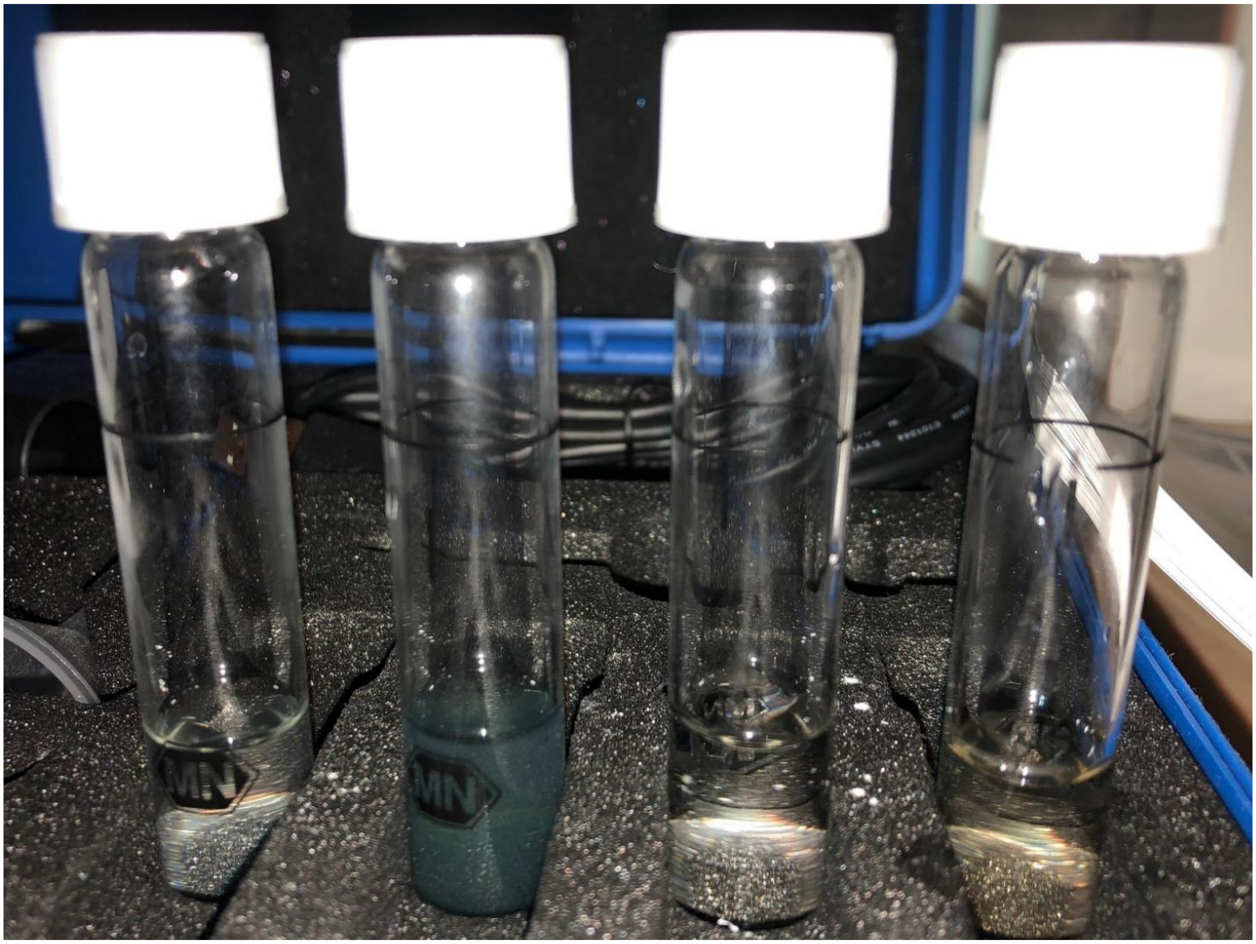


Figure 11: The samples are assigned with numbers from 1 to 4 from left to right. Blue color of sample 2 is obvious probably due to the presence of phenols in the sample (reactants part).

The procedure is same for the other two parameters. The only difference is the chemical used for each parameter. In addition, the time interval of photometer to analyze the sample is different.

5.2.2 Phosphate Test

Phosphorus content support the growth of certain organisms and is frequently added by the domestic sewage to the water bodies and is main cause of eutrophication. Precise content of phosphate is important to control these things. In addition, strategies can be made to extract phosphorus from water as its very important nutrient. The reaction for the process is between ammonium molybdate and phosphate ions that yields phosphomolybdic acid. The acid is reduced to molybdenum blue. Procedure is described in the figure.

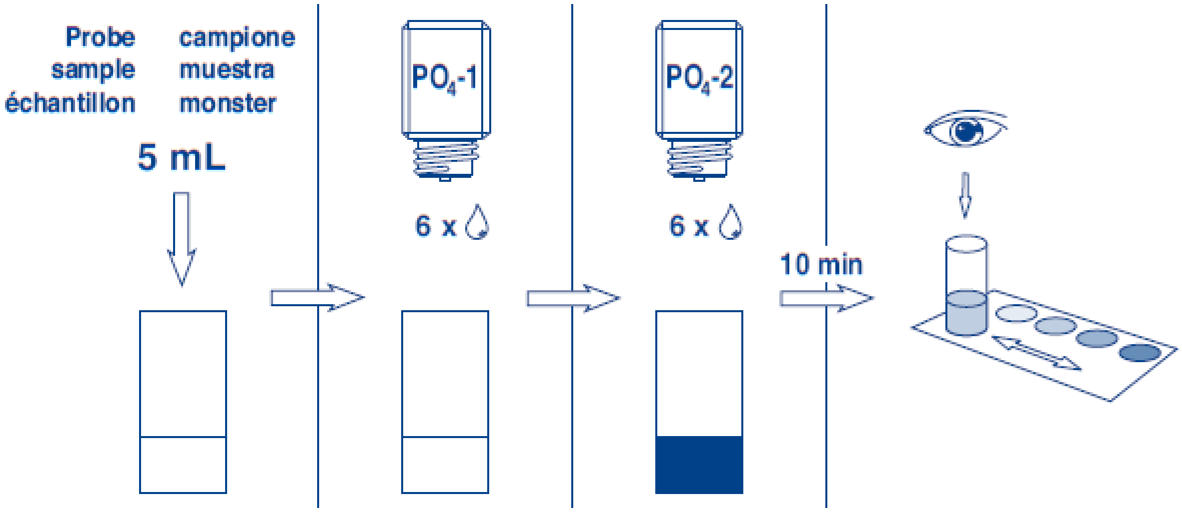


Figure 12: Procedure and apparatus for phosphate test (mn-net.com).

5.2.3 Nitrate Test

Nitrate is found in most surface and groundwater in concentration as high as 20 mg/L. Nitrate concentration is effected by fertilizer as well as industrial wastewater. It can also influenced by geology. The test involve reduction of nitrate to nitrite followed by diazotization of nitrite with aromatic amine. Final product is azo dye that results from simultaneous coupling of aromatic amine. Nitrite hampering can be avoided by boiling with amidosulphuric acid. High concentration of oxidizing substances can lower the results of reaction or can completely obstruct the reaction. Basic procedure is described in the cartoon below.

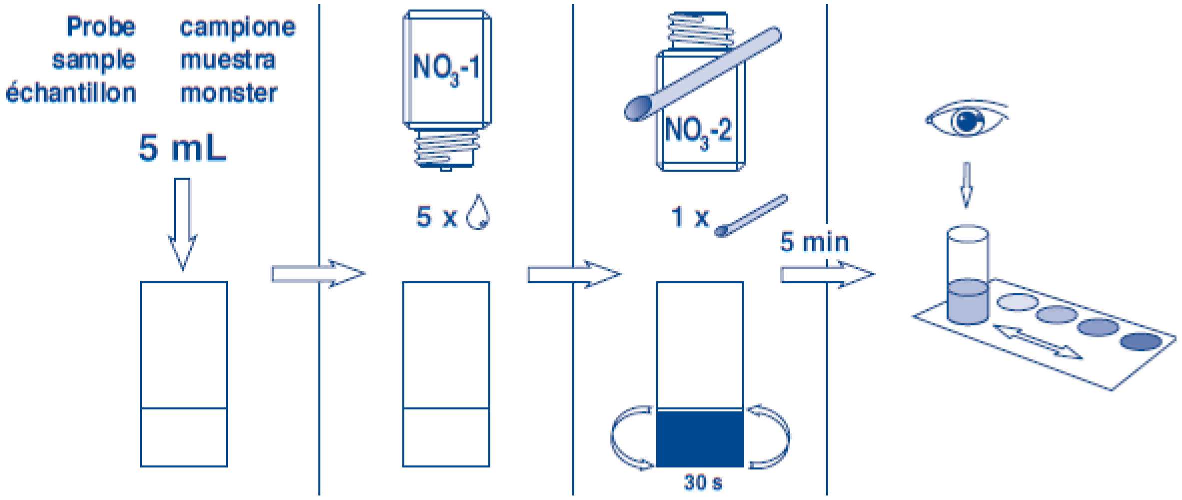


Figure 13: Procedure and apparatus of the nitrate test (mn-net.com).

5.3 Indicator Bacteria

Colifast Field Kit has been used to rapidly detect the E. coli, fecal or total coliforms in water. The rapid screening test range from 15 minutes to two hours and count the bacteria in water. The technique is based on the chemical reaction of substrate and enzymes of bacteria in a growth medium. The product is in the form of measurable fluorescent which can be correlated with the count of bacteria present. The growth media has growth factors, inhibitors and activators. The inhibitors prevent the growth of non-coliform bacteria in the Colifast growth media.

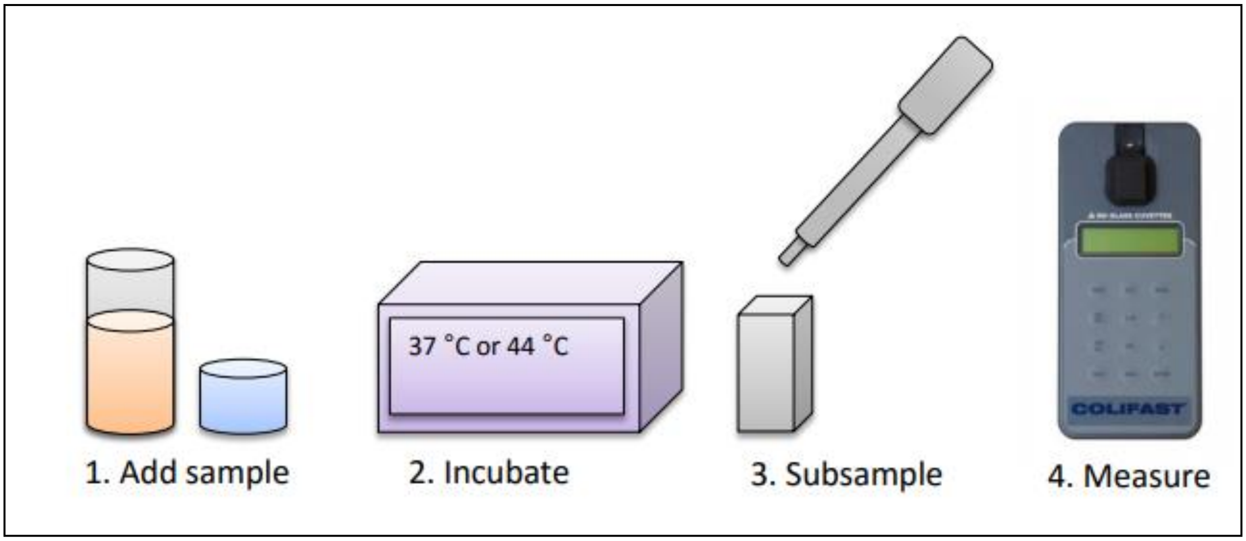


Figure 14: Four steps of the Rapid Screening Test for fecal coliform bacteria detection. It has been demonstrated that after selective incubation at 44 °C the majority of the fecal coliforms is E. coli. In step 01, sample is added to growth media, step two is incubation, step three is transfer of incubated sample to cuvette and finally examined by tool in last step (colifast.no).

A 10 ml sample of effluent is added to a flask containing the growth media and incubated at 37 °C for total and 44 °C for fecal coliform bacteria. The incubated sample (3 ml) is poured in a plastic cuvette and placed in the detector for fluorescent measurement. The results are recorded at 5 different time intervals for a given sample. Usually 15, 45, 75, 105 and 135 minutes are the incubation intervals. This repetition is for the purpose of detection of fluorescence development over time.

6 RESULTS

In Frøya Kommune, there is no centralized wastewater treatment system. All the wastewater generated by permanent houses and holiday huts/cottages is treated by the onsite treatment systems. All these systems were visited, data was collected and registered in the WebGIS. In addition, each system was put on map by using Cartesian system. Each individual system can be seen in the form of colored points on the map of Frøya. Data from 1678 onsite systems of different nature was collected during the survey. Treatment system from cottages are 642 and the rest are from permanent residential houses.

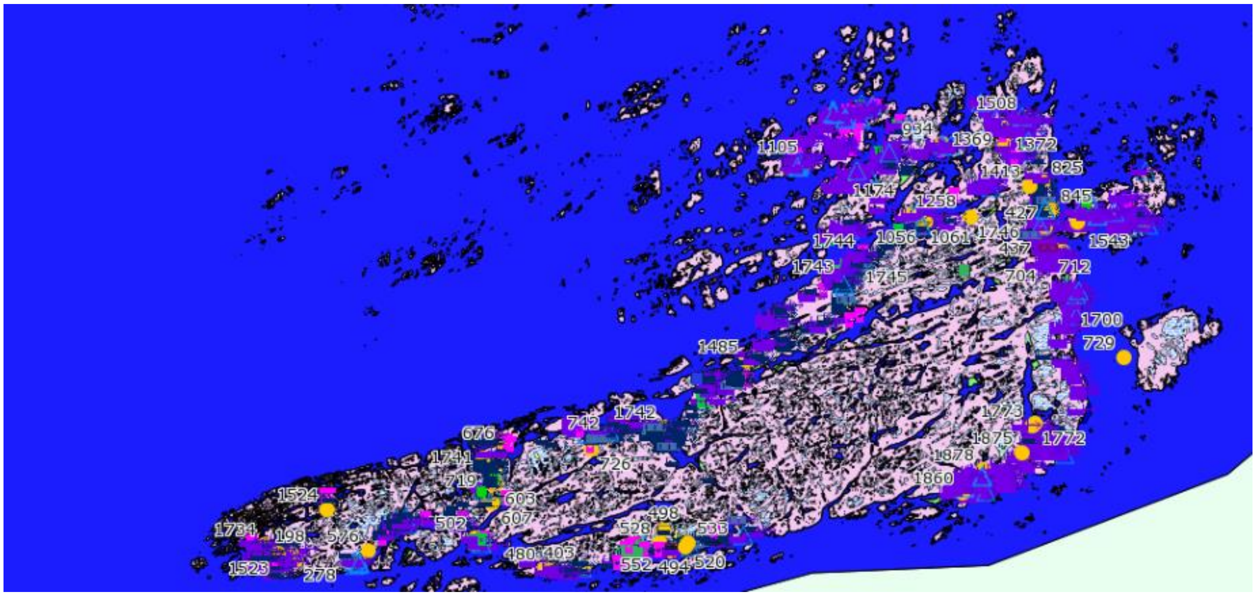


Figure 15: Map of Frøya showing treatment systems. The purple points on the map are representing each individual system. Image is processed in WebGIS.

6.1 Types of On-site Treatment Facilities used in Frøya Area

Septic tanks discharging their effluents to the terrain or watercourses are the most common onsite treatment units for the wastewater produced. Infiltration systems, biological toilets and direct emission are the second most abundant systems in the area. Almost 80% of the treatment facility is septic tank discharging to water bodies or terrain (mostly rocky). As discussed in the previous section, the treatment performance of septic tank is very low so the effluent is still loaded with nutrients that can harm the environment and cause hygiene issues in the form of fecal contamination and eutrophication of the nearby water bodies. In addition, some houses have direct discharge to the terrain or watercourses and is even more threat for the environment and health. Furthermore, some houses have holding tanks that have negligible treatment efficiency. The biological toilets alone and sometimes coupled with infiltration are also very common. Sand filter and infiltration system are also used in the area. Package treatment plants are very rare (6-7).

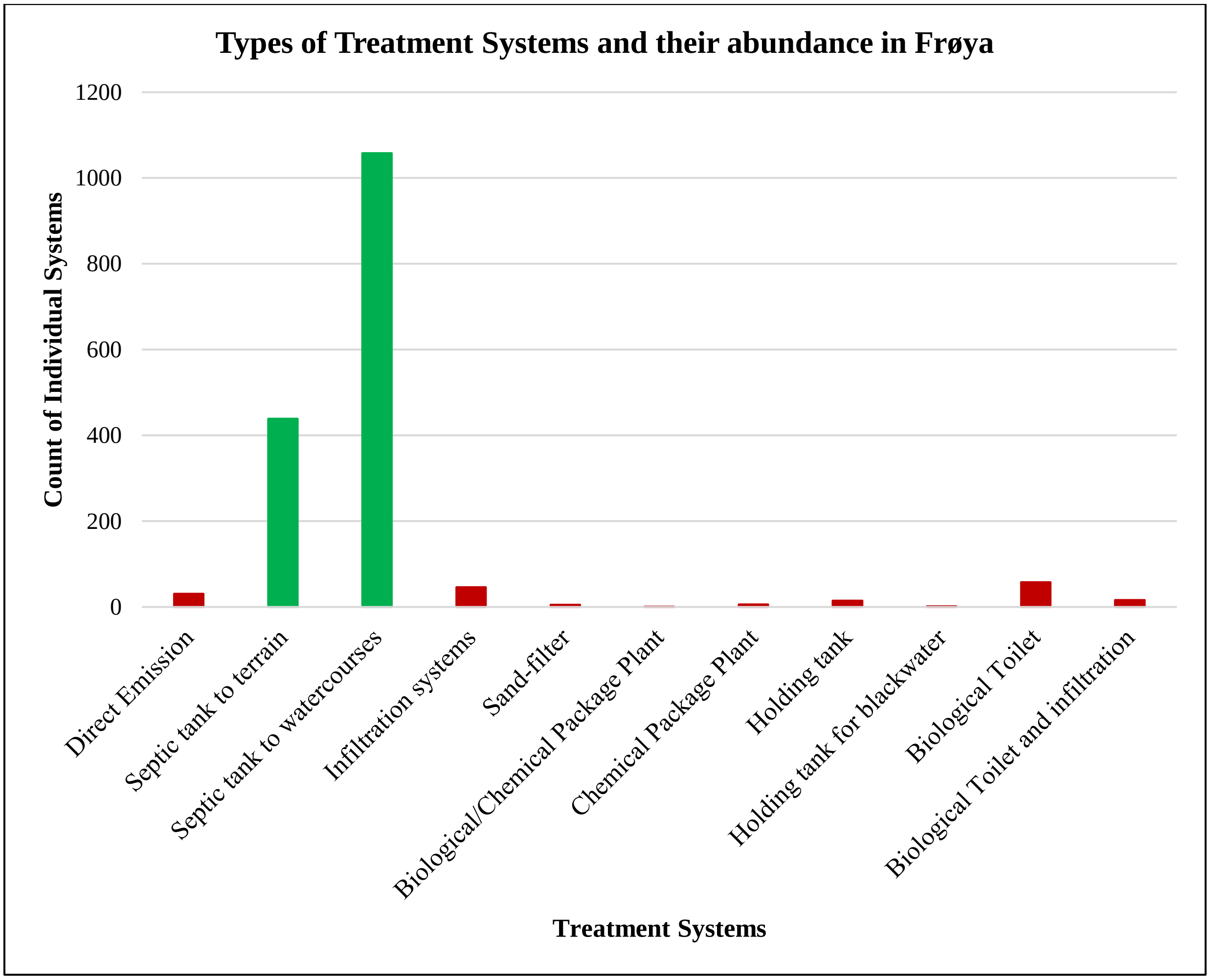


Figure 16: Twelve different types of wastewater treatment systems in Frøya area. Septic tanks, discharging their effluents to the watercourses and terrain, are the most common treatment systems in the permanent houses and holiday cottages in the area. Package treatment plants are also operational in the area with a very low proportion.

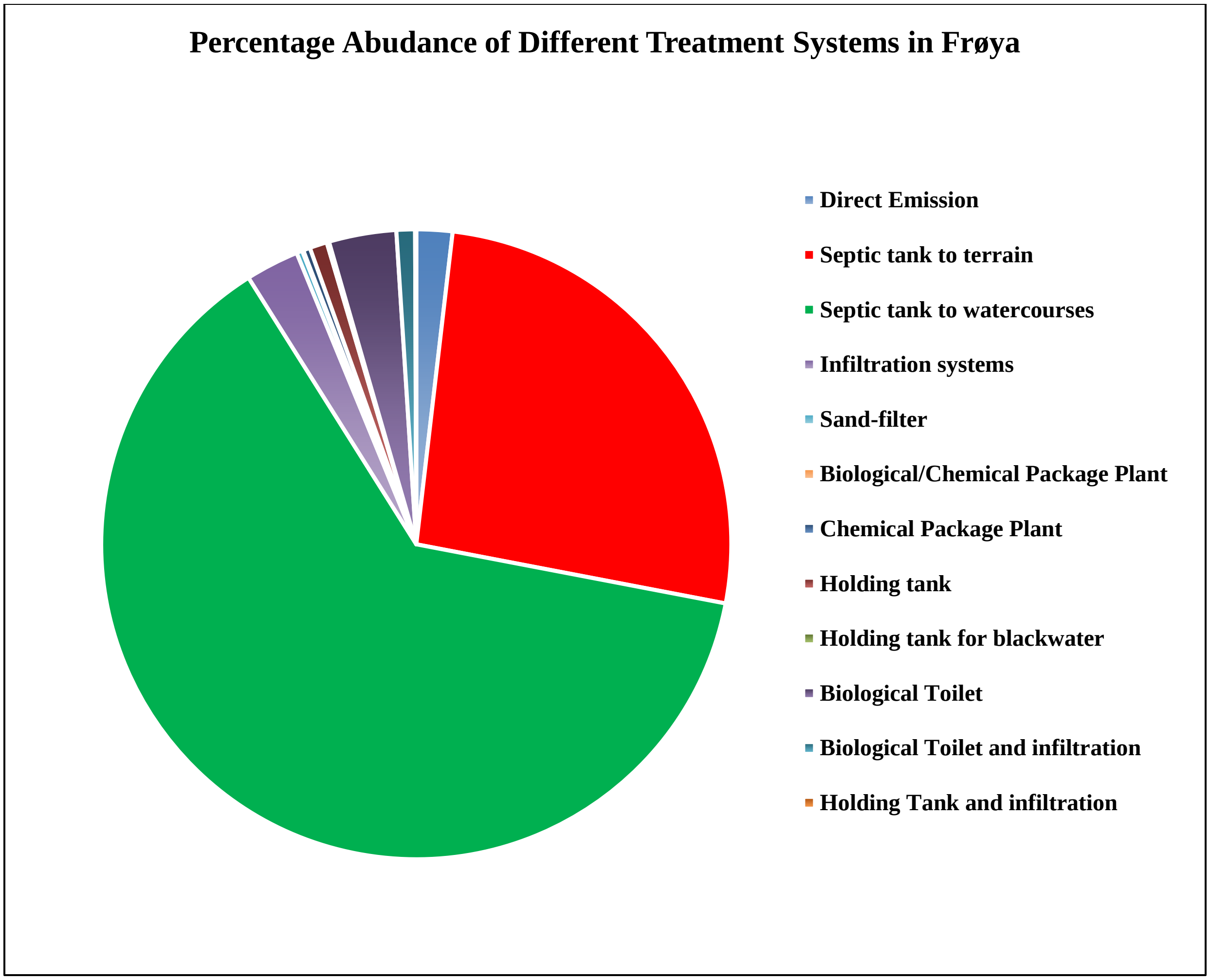


Figure 17: Relative percentage abundance of each treatment system. The pie chart show that septic tank has major shares in the area. Biological toilets are the second major shareholder in the area.

6.2 Number of Facilities Discharging in Each Recipient

Some area on the island are more populated than the others and therefore the nutrient loading is different in each recipient as shown on the bar chart. “Kystfelt Strandheim-Fjøyafjorden” is receiving wastewater from 173 treatment units and is the most loaded recipient in the area while “Elv Fra Steinsvatnet” is the most relaxed recipient and is receiving effluent from only one facility. Most of the recipient are receiving moderate to low amount of pollutants. Very few recipients, probably near the populated region of the island, are receiving high amount of pollutants as by red colored bars on the bar chart.

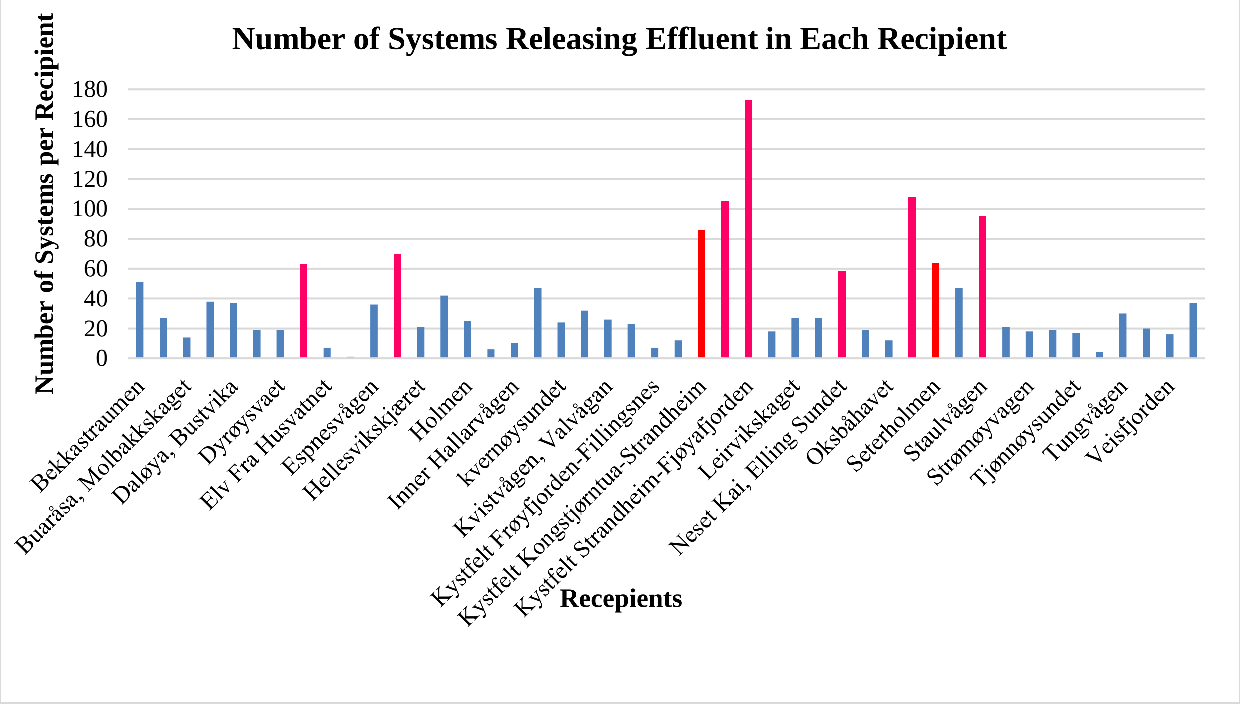


Figure 18: Count of systems per recipient. Red colored bars are separating comparatively high loaded recipient from the low loaded (blue) recipient.

6.3 Pollutants Discharged by these Systems

Major proportion of sewage produced in the area is treated by the septic tanks that has very poor treatment and nutrient removal efficiencies and the effluent is heavily loaded with nutrients/pollutants. Emission of nutrients by these systems in Frøya is 2827 kg Phosphorus, 21061 kg Nitrogen and 44544 kg TOC annually. The nutrient rich effluents from these systems are discharged into 46 recipients as shown. Most of the area is very sparsely populated and that is the only reason for low nutrient load in the recipient. Therefore, must not be confused with the treatment abilities of the systems operational in the area. The areas that are densely populated are discharging high amounts of N, P and TOC to the recipient. Pollutant released in the recipients like Kystfelt Kongstjørntua-Strandheim, Kystfelt Skaget-Kongstjørntua, Kystfelt Strandheim-Fjøyafjorden, Neset Kai, Elling Sundet, Sandviksundet, Seterholmen, Sjøhals-sundet and Staulvågen are in high quantities because of the huge number of the treatment units, used in the comparatively densely populated surrounding areas, discharging their nutrients. In addition, some houses are have direct discharge system with zero treatment before it reaches the nature.

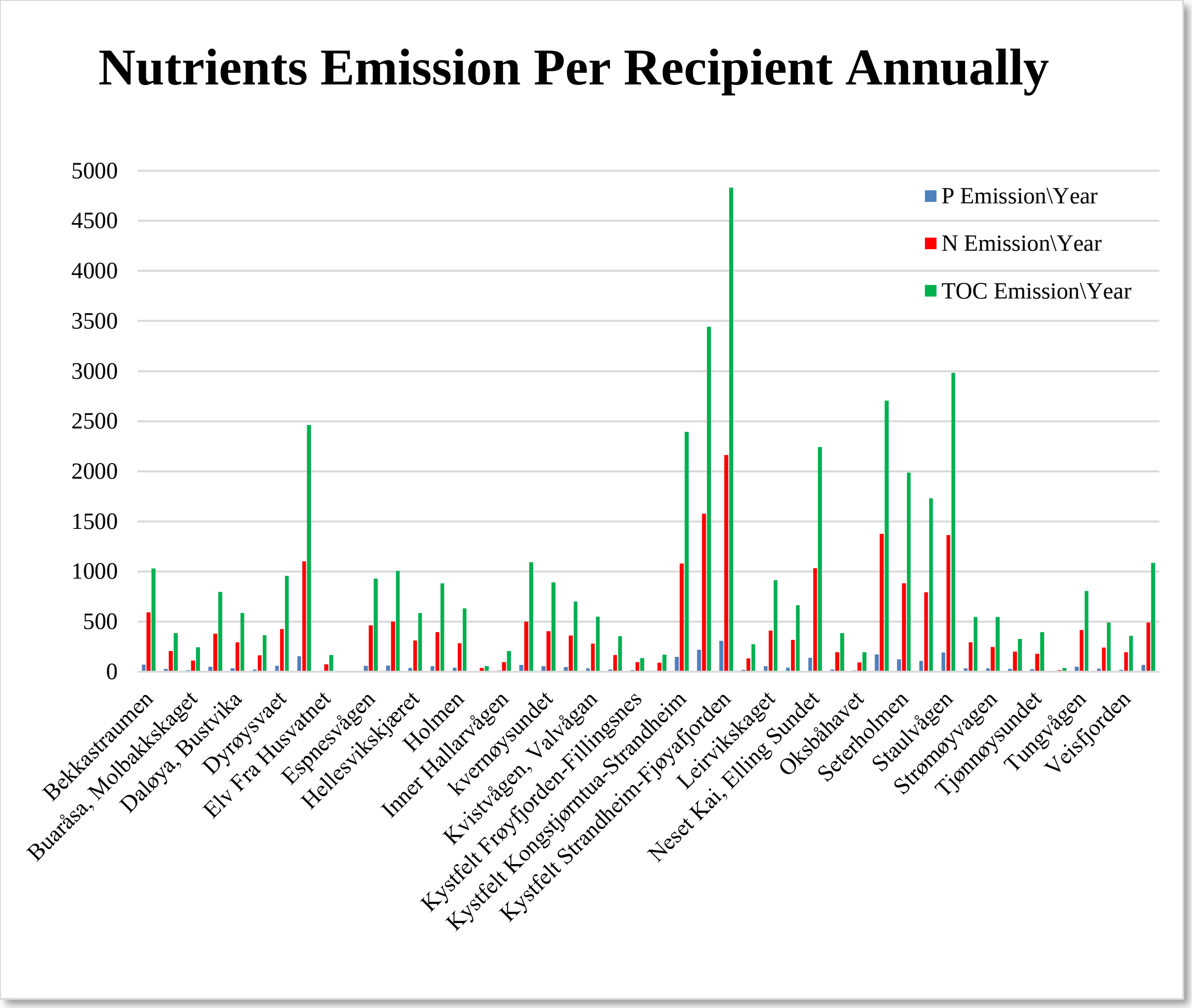


Figure 19: Annual emission of P, N and TOC in each recipient is shown on the bar diagram. Each recipient has different numbers of houses that are discharging their waste directly or indirectly. The recipient like Kystfelt Kongstjørntua-Strandheim Kystfelt Skaget-Kongstjørntua and Kystfelt Strandheim-Fjøyafjorden area receiving effluent from densely populated areas.

The amount of phosphorus, nitrogen and carbon released to the recipients in calendar year is shown separately per recipient in the following three bar charts respectively. Nitrogen removal is the difficult most task in the wastewater treatment.

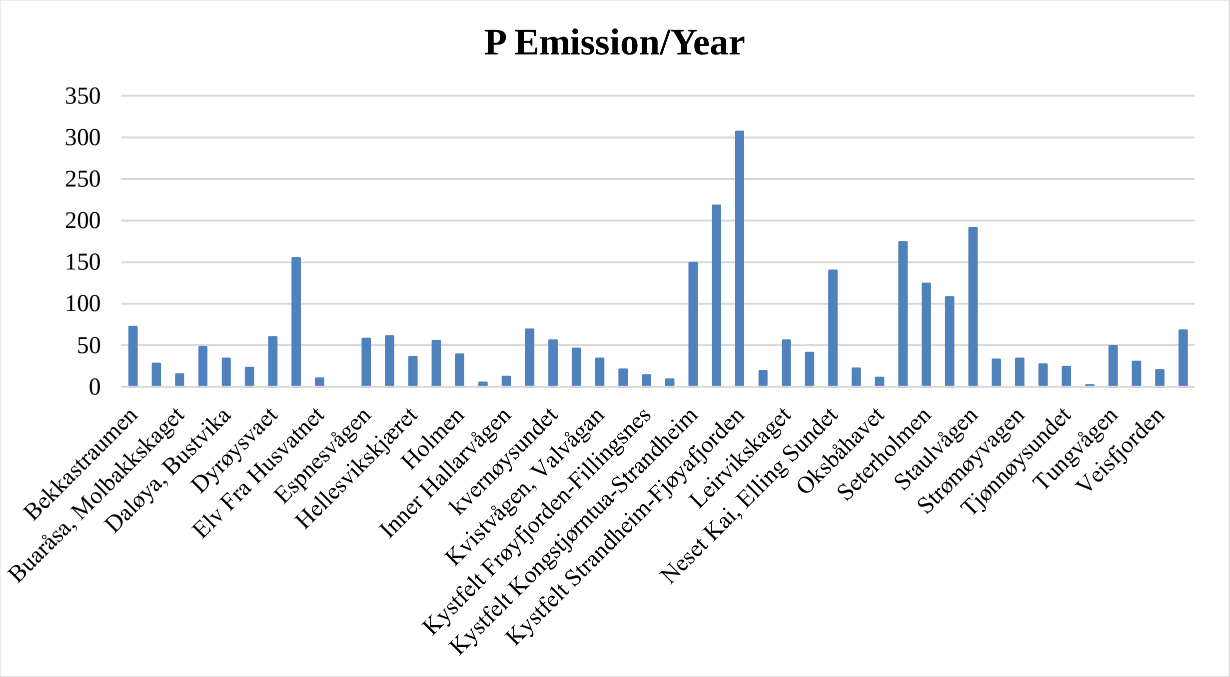


Figure 20: Phosphorus emission in an annual calendar in the recipient.

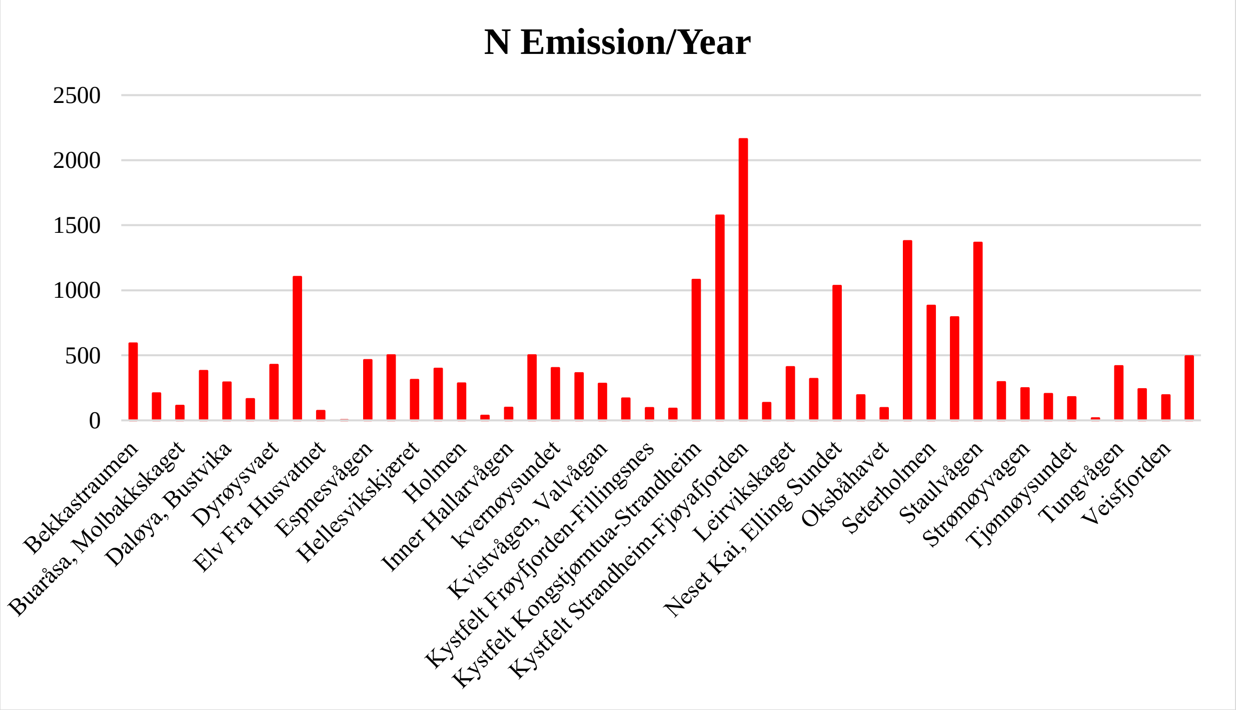


Figure 21: Nitrogen emission in an annual calendar in each recipient.

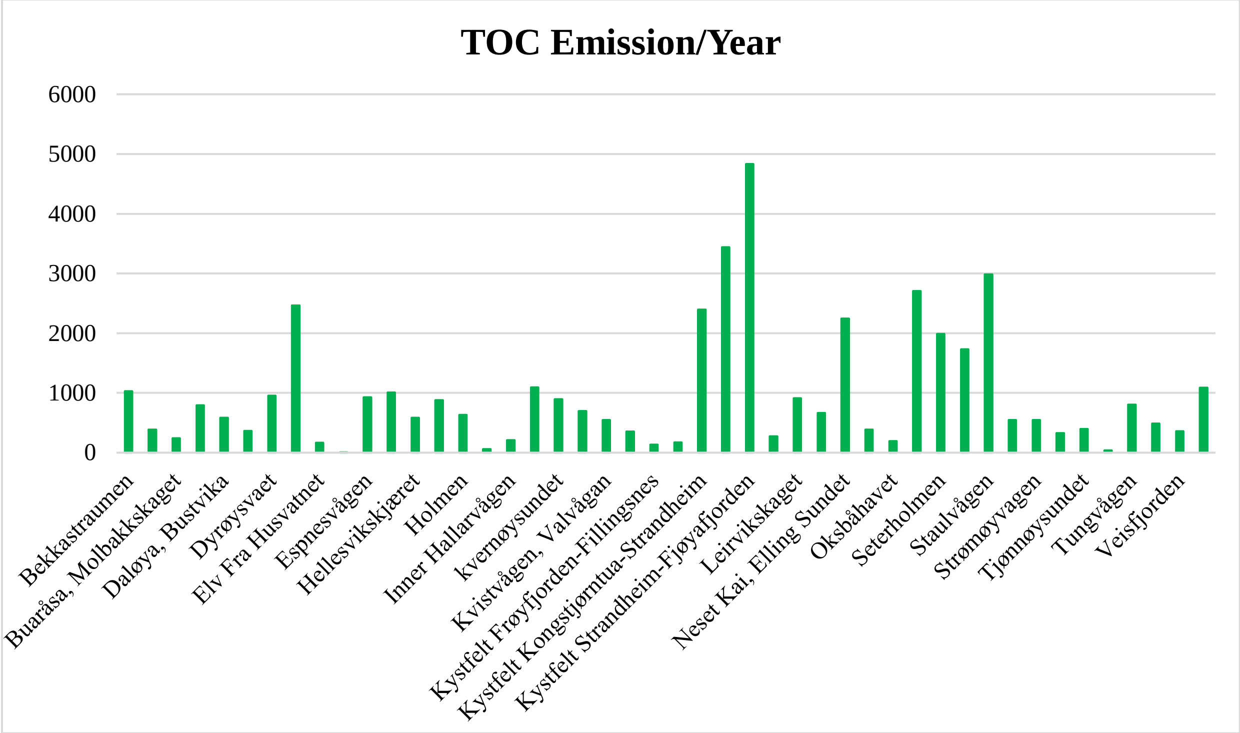


Figure 22: Total Organic Carbon (TOC) emission in an annual calendar in the each individual recipient. The values are high for the recipient entertaining comparatively densely populated regions of Frøya.

6.4 Environmental Index

Environmental index is one of the many parameters used to address the performance of a treatment facility. The output from the WebGIS for the environmental index is colour-coded as shown in the bar chart. Red colour represents the system with very high impact; pink point out the high, green for moderate, light blue is for low and dark blue for very low environmental impact by an onsite system. Recipients in the area are categorized on the basis of their sensitivity to the pollutants and pathogens discharged from the household wastewater and their wave's intensity and connectivity with the open ocean (high energy environment). In high energy environments the discharge of pollutants is not a big issue because of the strong dilution effects. However, in the area where the water bodies have dead ends, nutrient discharge is a big issue because there is no dilution and the nutrients and pathogens get saturated after certain period of time and thus become a threat to the ecosystem. Therefore, the regulation and requirements of treatment in such area is very high.

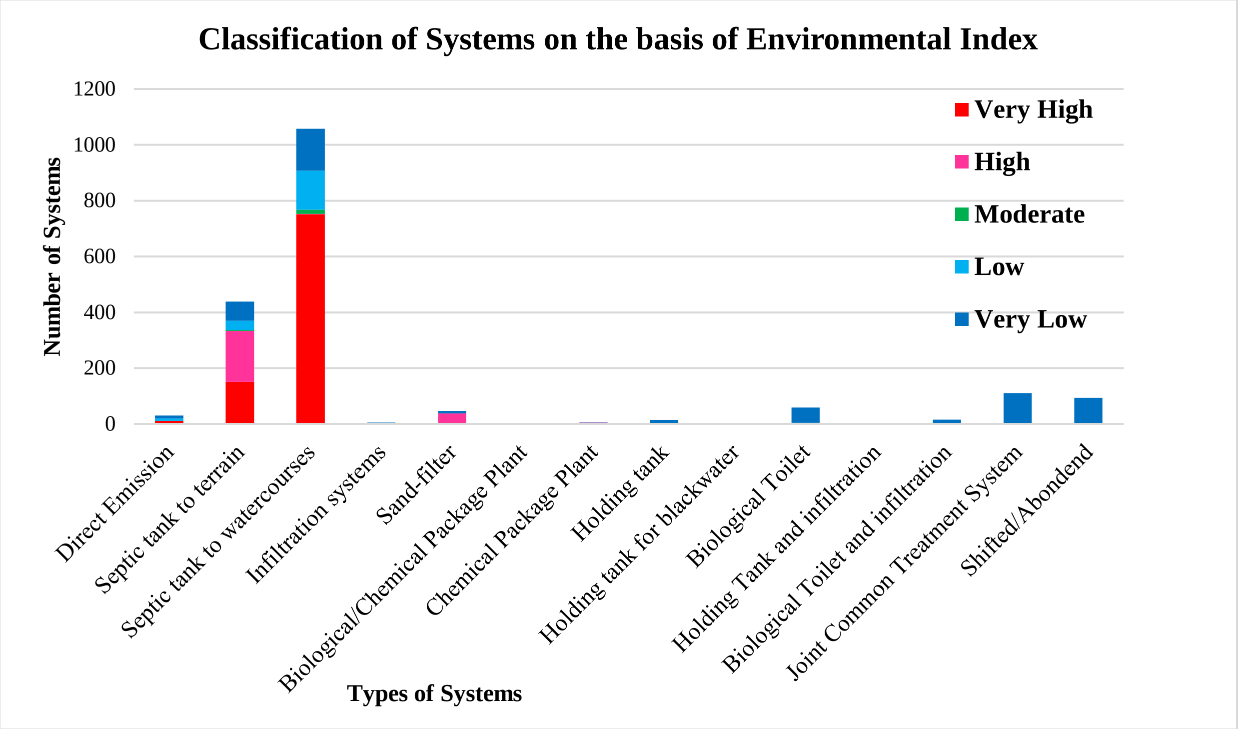


Figure 23: Bar chart for all the decentralized wastewater treatment facilities in Frøya area. Most of the onsite treatment facilities in the area are falling in high to very high impact zone of the chart.

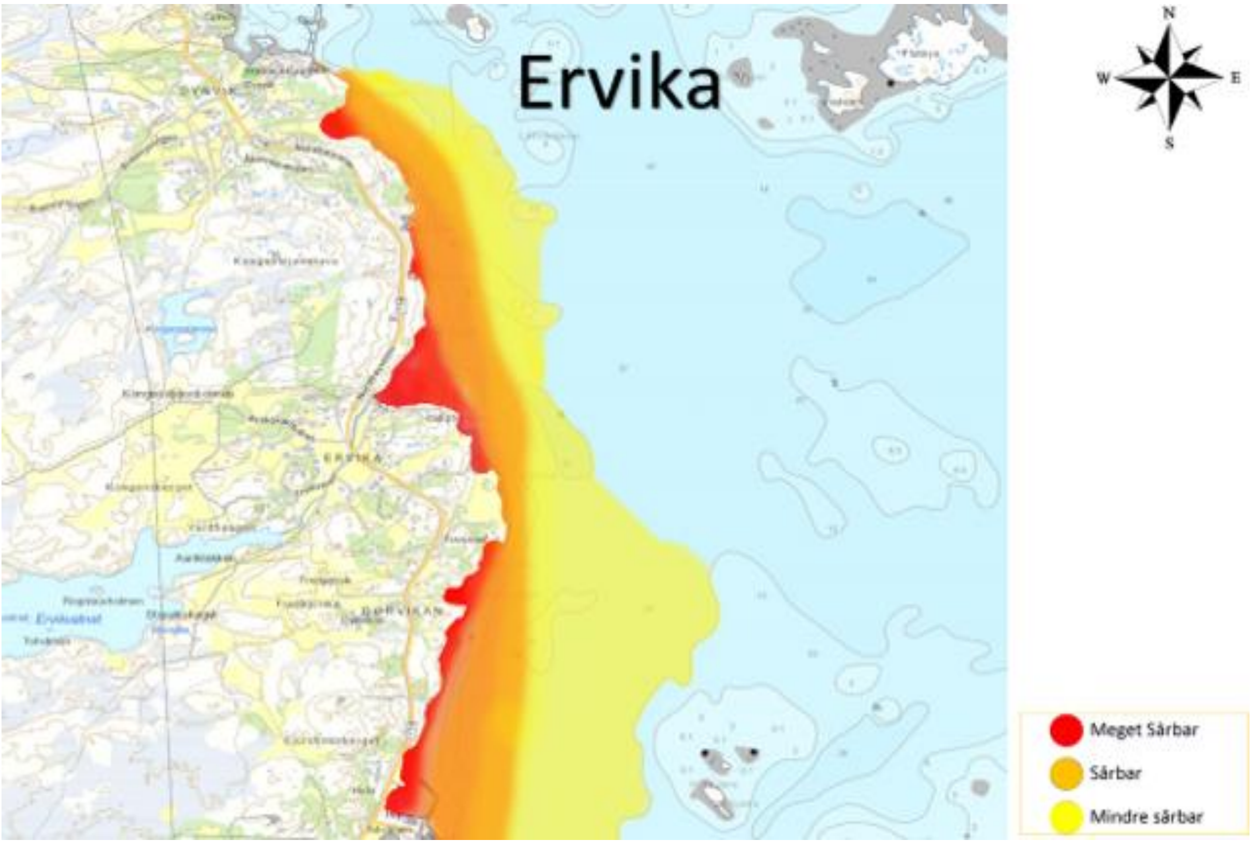


*Figure 24***:** *Digital map of recipients in Frøya classifying areas as less and more vulnerable (mindre & meget sårbar). The areas near the high energy environments have low vulnerability and have treatment requirements (yellow color on the digital map).*

On the digital map for recipient vulnerability, it can be seen that the area that in the restricted (narrow) channels, valleys, and galleys; where there is no or very less mixing, are very much vulnerable to the pollutant discharge. Such areas are marked red and have very high treatment requirements. Because in the case of improper treatment, the effluents can flourish the growth of algal blooms which can destroy the smell, taste and beauty of water. In intermediate areas, the treatment requirements are comparatively low. In yellow zones as shown on the map, the energy level of water is very high and thus a little bit pollutant discharge is not a big issue. As the dilution factor is very high and the pollutants are carried away by the waves into the open ocean where they eventually decay. The color codes on the digital map are based on the local legislation of Frøya Kommune for its wastewater recipients. Moreover, it also suggests different onsite facilities for each zone. Light yellow zone is characterized by high energy, less vulnerable recipients and has less treatment requirements as compare to red and deep yellow zones.

Many systems fall in the red and pink zone of the environmental index bar chart. Almost 70% of the on-site treatment facilities are harmful for the environment based on the result computed by the WebGIS. However, by looking at the results from different facilities, it is clear that some of the results computed are wrong or under-estimated by the tool. For example, on the bar chart the abandoned/shifted treatment facilities are with very low impact on the environment that is certainly an outlier. Similarly, the impact of holiday cottages is also very low as the algorithm use 365 day in the formula for calculating the environmental index. As cottages are used very rarely so the algorithm is under-estimating the effects of the effluents from such facilities. By looking into these details, it become clear that the percentage of facilities with high to very high impact is much more than the one calculated by the tool. Some of the septic tanks and even direct discharges are also in the zone of low to very low environmental impact. These systems were traced out in the database and it was found that they belongs to holiday cottages.

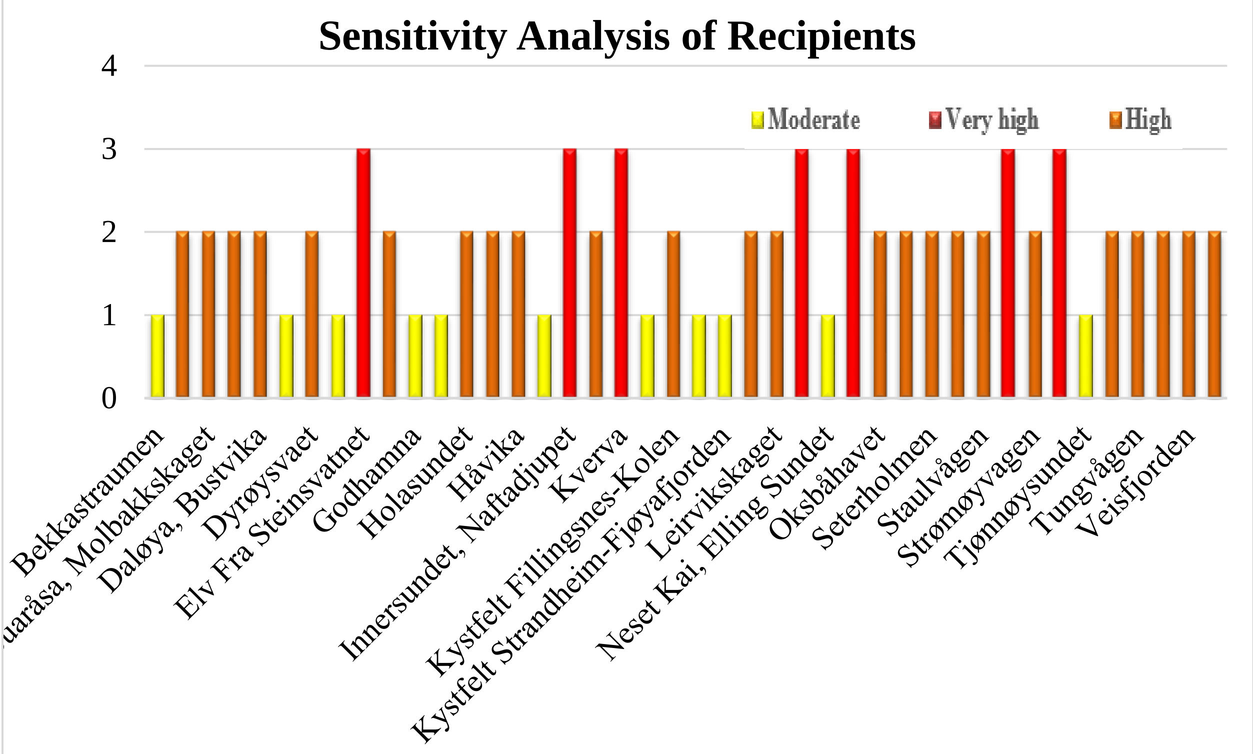


Figure 25: Most of the recipients lie within high range of sensitivity to the pollutants. Bar graph is based on the digital map in figure 24.

Based on the required treatment, the recipients are categorized from very low to very high vulnerable and are assigned different colors. The recipients in Frøya are of three categories.

1. Moderate vulnerable recipient has the treatment requirements of 50% phosphorus, 30% nitrogen, 50% BOD_5 and 90% *E.coli*. removal from the wastewater before it enters the recipient.
2. High vulnerable recipient has the treatment requirements of 70% phosphorus, 40% nitrogen, 70% BOD5 and 98% *E.coli*. removal from the wastewater before it enters the recipient.
3. Very high vulnerable recipient has the treatment requirements of 90% phosphorus, 60-70% nitrogen, 90% BOD5 and 99.9% *E.coli*. removal from the wastewater before it enters the recipient.

6.5 Package Treatment Plants

There are eight package treatment plants in Frøya area. Four are treating the household sewage while the rest needs the connection of household sewage. The operational treatment plants are sampled and the samples are analysed in the chemistry laboratory of Frøya Kommune to calculate and compute the parameters of interest. These parameter are helpful to determine the practical performances of the package treatment plants. The package treatment plants visited, are installed by BioVac and Wallax. The claimed performance of both companies are quoted below.

The claims of treatment efficiencies of plants from these companies are quoted below. According to Wallax "*For vulnerable areas, where the requirements for wastewater treatment are particularly strict, purification plants with post-polishing are the best option. After polishing removes and meets the strictest cleaning requirements (residual values of bacteria <1000 TBK). Post-polishing plants limit themselves to a pump and do not require a hot air pump.*" (wallax.no)

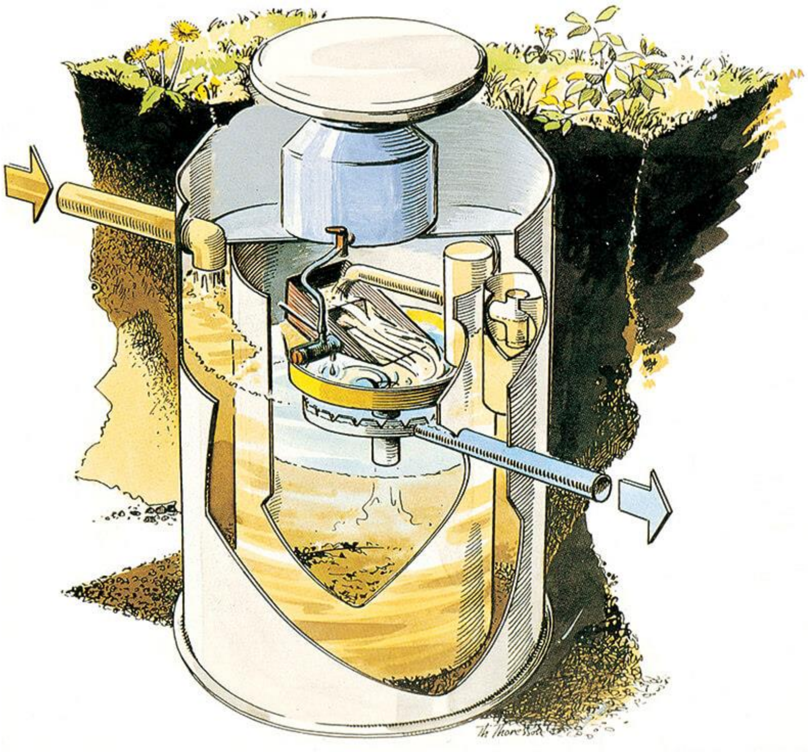


Figure 26: Cross section of the Wallax package treatment plant. Light orange arrow is for influent while the light blue arrow is for treated effluent from plant. Cartoon is taken from Wallax.no.

According to Biovac "*Biovac treatment plant is biological / chemical wastewater treatment plant for the purification of total wastewater for up to 50 people. Treatment plants for gray water and / or total wastewater are dimensioned and adapted to different conditions and especially suitable for vulnerable areas. The plants are 100% biological filter-based treatment plants, and achieve high purification effects on phosphorus, organic matter and bacteria. Chemicals are not used in the cleaning process. The cleanliness is well within the authorities' requirement for more than 90% of the wastewater treatment. In particularly vulnerable areas a minirense system is also combined with a post-polishing solution to achieve even less stress on the environment.*" (biovac.no).

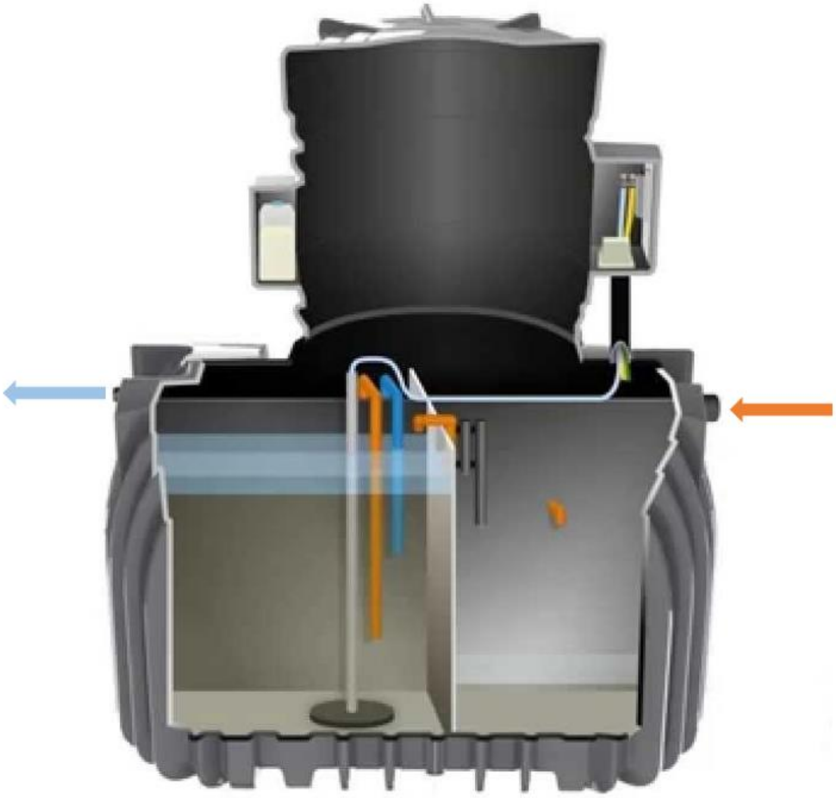


Figure 27: Basic assembly of Biovac package treatment plant. Light orange arrow is for influent while the light blue arrow is for treated effluent from plant. Sketch is taken from biovac.no.

The field performance of some visited package treatment plants in Frøya is given in the table below. Phosphorus, nitrogen and coliform bacteria in the effluent were measured by examining the samples. These values are slightly higher than the claimed performances by the supplier companies. Two of the facilities are on the permanent houses whereas two are from the holiday cottages. The values for the holiday cottages are different than the permanent houses. The reason can be the saturation of effluents in the holiday houses as the samples were collected in the off season. In order to get a true representative sample of the facility, it is recommended to sample the plant again during the period of its peak use and also many samples are required to be collected to draw the true analysis of their performances in term of nutrients and pathogens removal.

Table 1: Phosphorus, nitrogen and bacteria count for the four package treatment plants operation in the area.

S.No.	Name	PO_4P (Mg/L)	NH_4N (Mg/L)	NO_3N (Mg/L)	Coliform (TKB/5ml)
1	Wallax	0.7	4	1.1	1512
2	Wallax	4.8	<0.4	4.6	218.38
3	Wallax	<0.2	>6.2	>14	22.58
4	Biovac	>5	>6.2	>14	358.31

The annual discharge by these systems, calculated by assuming four persons in a household and each one consuming 150 litres of water per day, is given in the bar chart. The performance of these plants is good. The latter two results are from holiday cottages so the high amount of nutrients can be the result of saturation of solution as the houses are not used permanently. This can be one of the several possible explanation for high concentration of nitrogen and phosphorus in the effluents from these two plants. Therefore, to check their actual performances, it will be better to take the samples during the peak load time.

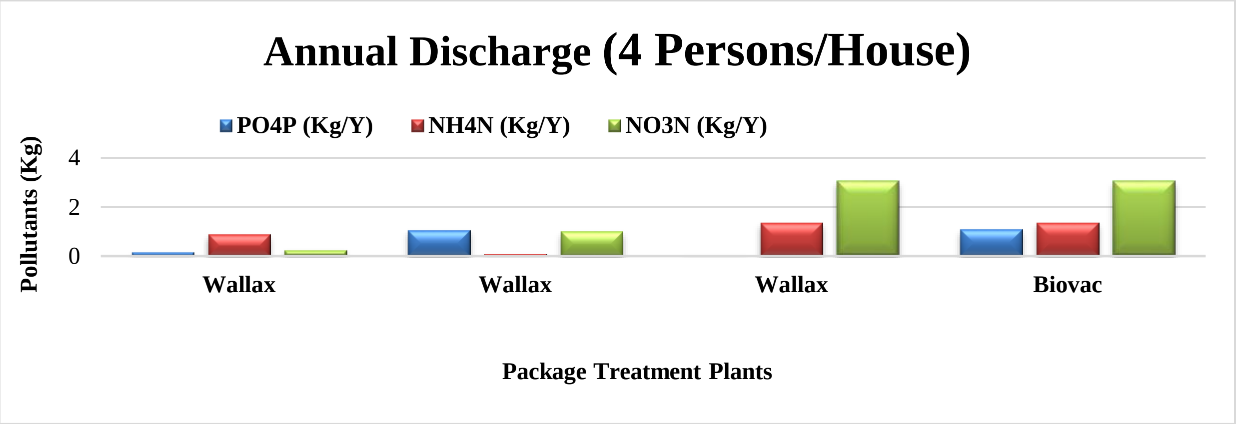


Figure 28: Annual estimated discharge for four prefabricated package treatment plants in Frøya by assuming four persons in a household. First two plants have very low values of discharged pollutants.

WebGIS calculations use 2.5 persons in a Norwegian house. Based on that the amount of pollutant calculated for these plants will be decreased as shown.

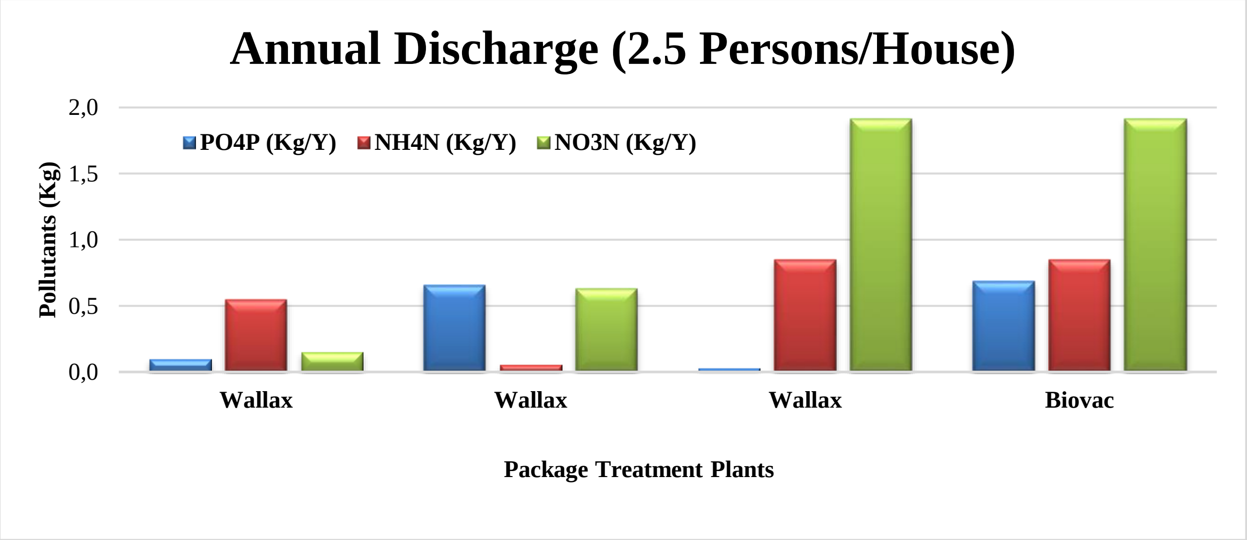


Figure 29 : Annual estimated discharge for four prefabricated package treatment plants in Frøya by assuming four persons in a household.

6.5.1 Replacement of current Systems with the Package Treatment Plants

Two of the operational package treatment plants are selected for comparison with current on-site treatment systems. These two specific plants are selected because they are in the permanent houses and have comparatively regulated flow. The emission of pollutants by the current systems has been replaced with the ones from the package treatment plants operational in the area as shown. The comparison suggest that the emission of N and P will be minimized as much as 25 times for package treatment plant (PTP1) while for PTP2 the emission will be minimized by 25 and 4 times respectively. The field performance of these system suggest that they will reduce the environmental impact of wastewater pollutants.

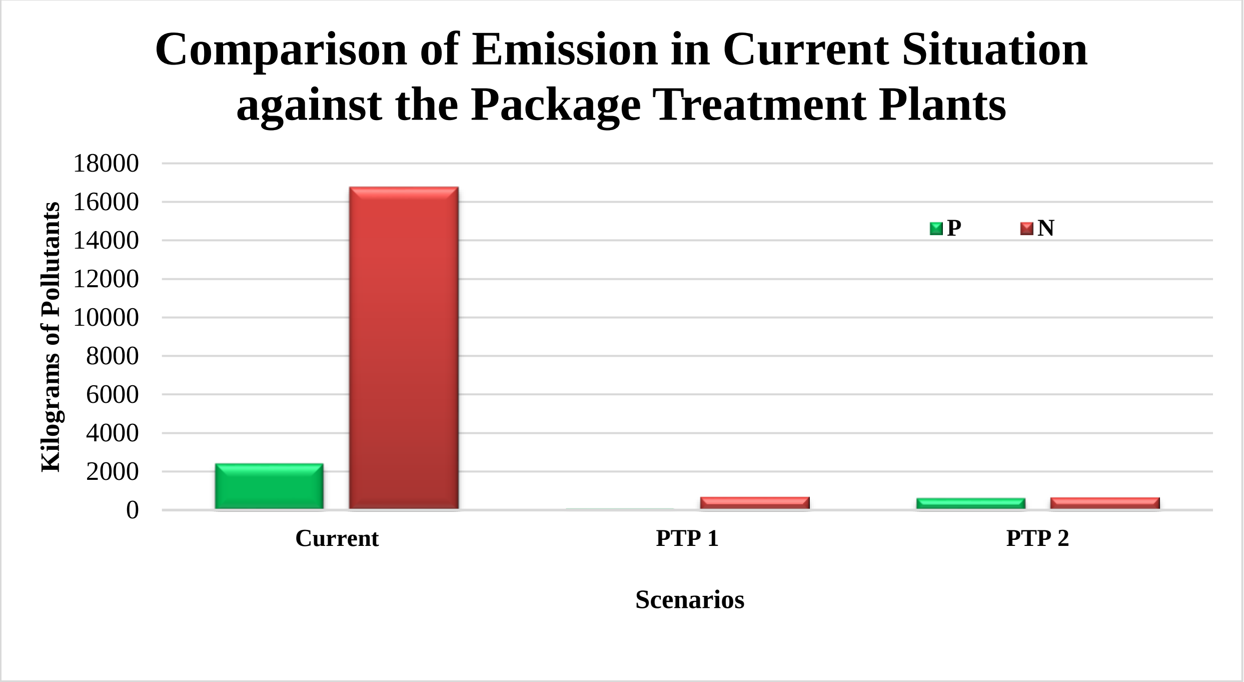


Figure 30 : Comparing the discharge results from the two representative package treatment plants and the current situation. The reduction in pollutant discharge is very obvious on the bar graph.

7 DISCUSSION

Besides the permanent residential facilities, Frøya also hosts holiday huts. Wastewater from all the houses and huts are treated by decentralized wastewater treatment facilities. Almost 80% of the decentralized facility in Frøya is a septic tank which has very high environmental impacts. Moreover, the condition and maintenance of most of the septic tanks is awful as shown in the following photo mosaic. Fecal contamination and eutrophication of the nearby water bodies are main threats to the ecosystem. Fecal contamination trigger health and hygiene issues. Some of the houses discharge the wastewater directly and is even more dangerous in term of the two factors described earlier, because there is minimal removal of pollutants and pathogens from such discharges. In addition very few houses are using biological toilets, sand-filter and package treatment plant. And these system usually have very good performances in term of nutrients and pathogen removal. But these systems need proper maintenance and unfortunately some of them are not maintained in the recommended way so their performances are not as expected. There are 111 joint common treatment systems in the Frøya area with very low environmental impact index probably due to good hydraulic load and proper maintenance and the kommune is installing many more for the small clusters of houses.

There are only few approved onsite wastewater treatment facilities in the area. The rest need to be upgraded. The approved facilities in Frøya have very low percentage with the highest (10%) in the Yttersundet recipient followed by the Holmen with 7.7% of approved systems based on the results from WebGIS. Kystfelt Kongstjørntua-Strandheim, Kystfelt Skaget-Kongstjørntua, Kystfelt Strandheim-Frøyfjorden recipients have 1.7% approved onsite systems. The remaining recipients are receiving water from unapproved onsite systems. The results presented in the previous section will be discussed in more details in this section.

According to Von Sperling (1996) the treatment performance of septic tanks in term of nutrients and pathogens removal is 20-30% BOD5, 5-10% Nitrogen (tot-N), 30-60% Suspended Solid, 5-10% Phosphorous (tot-P) and 40-50% Thermotolerance Coliform Bacteria (TKB). This is very low and the environmental impact of these systems is high to very high depending upon the conditions of recipient.

Figure 31: Mosaic picture of some septic tanks and their surroundings in Frøya. Some tanks have holes, the others are filled from sludge due to lack of proper pumping out of sludge and so on. Photo courtesy: Frøya Kommune.

If all these systems are replaced by the prefabricated package treatment plants, the impact can be decreased because most of the package treatment plant's manufacturing companies claim very high pollutant and pathogen removal efficiencies of their systems. Besides, their replacement by the package treatment plants, these systems can also be upgraded/rehabilitated. Because on the basis of local legislations for treatment of wastewater, the treatment requirements are low in some areas. Moreover, the replacement process is relatively expensive so, the facilities in areas with low treatment requirements can be upgraded economically to attain the required level set by the municipality. The effluents from most of the septic tanks are discharged directly to the terrain or recipient so, different systems can be coupled with these tanks to increase their performances. Some of the possible techniques that be coupled with the septic tank will also be discussed.

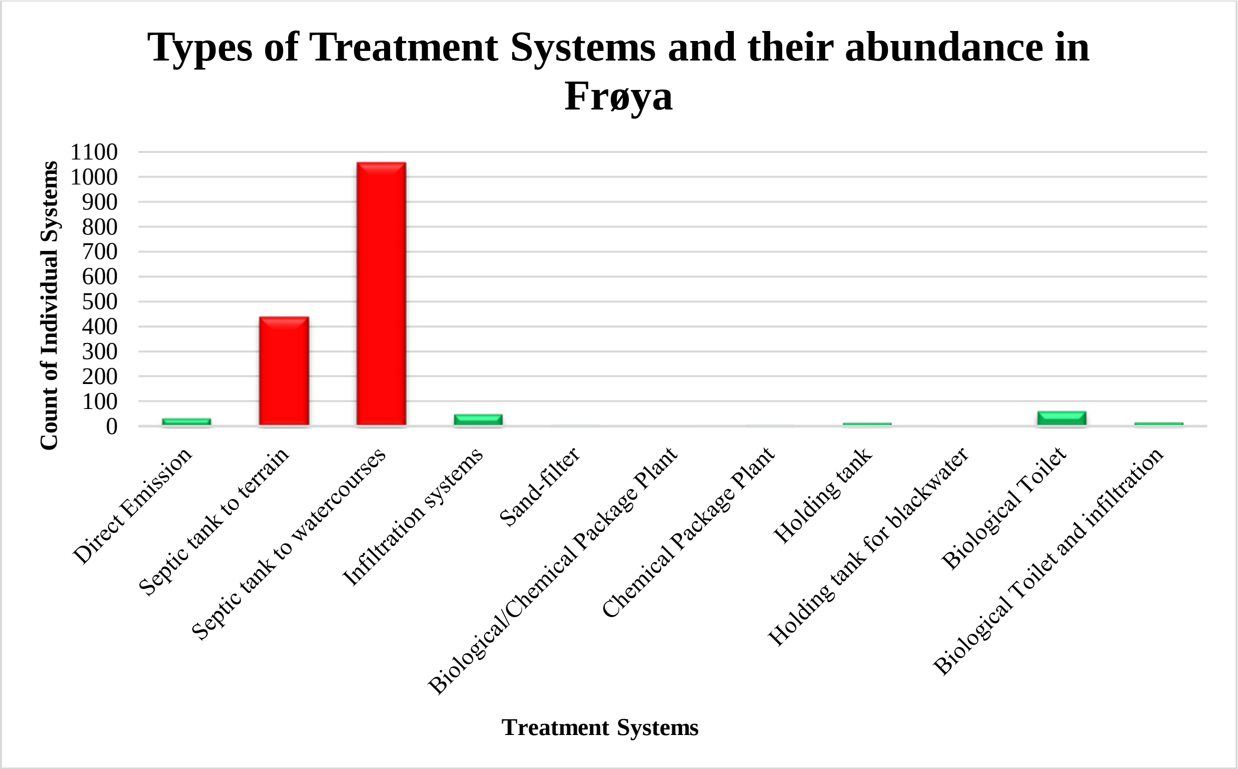


Figure 32: Decentralized wastewater treatment systems in Frøya area. Two colors are used in the bar chart for the purpose of differentiation between the systems. Red color represents the dominant treatment facilities in the area whereas the rest are colored green. Septic tank with effluent discharged to the terrain and watercourses are the dominant treatment units in the area. Infiltration systems, direct emission and biological toilets are the other major stockholders after the septic tank systems. Sand-filter, package treatment plants and infiltration systems are very rare in the area.

The geological map of surface material in the area suggest that the terrain is rocky, so the natural infiltration systems are seldom possible in such conditions. However, the prefabricated facilities can be installed. The facilities that are simple, economical and easy operated as well as suitable for the circumstances and environmentally and hygienically safe will be discussed as a possible mean of rehabilitation/ replacement of the already existing facilities.

Figure 33: Geology map of surface covering material in the Frøya Area. Most of the exposed surfaces are in the form of barren rocks and mountains (bart fjell, stedvis tnyt dekke). Some area also have peats & bogs (torv og myr). Natural infiltration is impossible in most of the terrain. Bogs can be also used as a recipient. Map is taken from ngu.no.

7.1 Environmental Index as a Tool for Selecting Proper Onsite Facility

The environmental index calculated for the onsite wastewater treatment facilities in Frøya is shown on the map in figure below. Most of the systems are performing poor to very poor as suggested by the environmental codes (red & pink). These systems are treating water inefficiently and far lower than the recommended requirements in term on treatment.

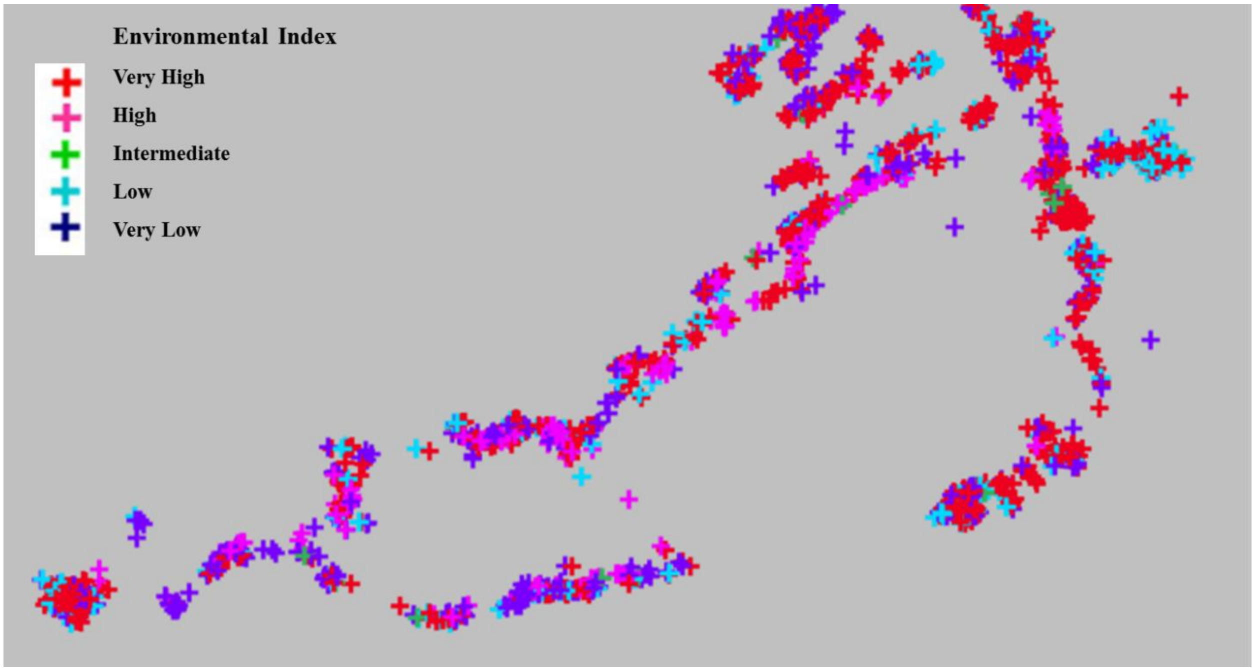


Figure 34: Environmental index map of onsite facilities in Frøya. Green, pale blue and blue crosses on the map are very few whereas the red and pink crosses are dominant. Most of the systems in the area have very high environmental index. Their rehabilitation or replacement is required. It must be noted that the index is influenced hugely by P contents.

The systems with high to very high environmental index need keen attention and probably replacement by more efficient onsite facilities. Whereas the systems with intermediate to low index will probably need some modification and rehabilitation. The treatment systems in Frøya fall in the following categories of environmental index.

Table 2: Number of onsite facilities in each environmental index group. Most of the system are ranked high to very high on the index.

Environmental Index	**Number of Systems**
Very high	914
High	226
Intermediate	22
Low	190
Very Low	326

The onsite treatment systems that are removing 0-5% of phosphorous, nitrogen and TOC are categorized very high by the WebGIS. Based on this information, it can be seen that more than 1000 onsite treatment plants need serious attention because the amount of pollutants discharged by these facilities is enormous.

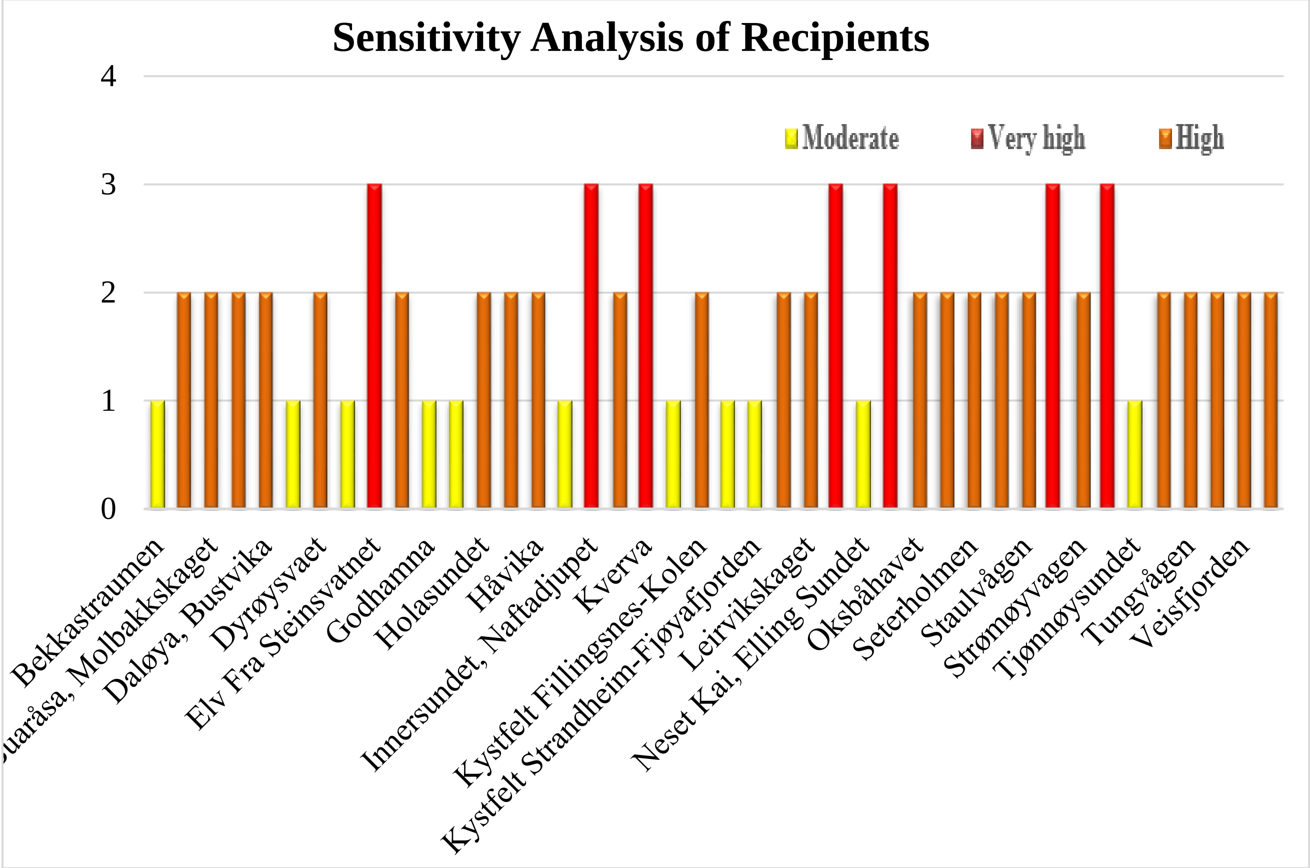


Figure 35: Vulnerability analysis of recipients of the wastewater generated in Frøya. Most of the recipient are marked highly vulnerable to the pollutant loaded wastewater.

A list of onsite facilities are suggested as a rehabilitation option on the basis of the recipient vulnerability (see appendix 1). Any of these suggested facilities, that attain the required level of treatment, can be deployed in these zones.

7.2 Bio-filter

According to Jenssen et al., (2005), the pollutant removal efficiency is 70% for SS and BOD in an efficient full-scale system. In addition, the removal of total N is 20–40% due denitrification in the anoxic portion of the filter. Indicator bacteria is removed by 2–3 logs or more in such system. So by introducing bio-filters after the septic tank, the pollutants and pathogens discharge can be reduced. This will improve the quality of effluent. Note that it is not a treatment system by itself rather it is a part of treatment system that enhance the performance. And can be combined with treatment facilities to obtain fair treatment results. For example, in the areas where the recipient is not vulnerable to pollutant contents such as sea-water recipients with high waves, septic tank effluents can be sprayed over the aerobic bio-filter to reduce the amount of pollutants as well as pathogens. The bio-filters covered by domes are well suited for Nordic countries. This type of bio-filter is covered by a hemispherical dome which facilitates spraying of the septic tank effluent over the bio-filter surface to ensure better air circulation and even distribution of effluent over the filter medium. BOD values below 10 mg/l and phosphorus removal is <1.0mg P/l in many case studies (Jenssen et al., 2010). They meets the requirements of Norwegian Standards (1.0 mg P/l) for small systems in many Norwegian municipalities (Johannessen et al., 2012).

Based on the digital map and bar chart showing the vulnerability analysis of different recipients, very few recipients allow the low treated wastewater. Bio-filter can be applied on the septic effluents in several areas before the effluent is discharged to the designated recipients. Especially to the recipients that are colored yellow on the bar graph (see figure 35). The facilities discharging water to the moderately vulnerable recipients, can be rehabilitated by the coupling of bio-filters. The material for bio-filter (shell-sand) is locally available in sufficient amounts and have good performance (Nadeem, 2018).

According to Nadeem (2018), 221 m^3/year (276 tons/year) shell aggregate is required to remove 81% of the total phosphorus produced by household wastewater in Frøya. The annual production in the island is 2200 tons annually. This locally produced shell material is otherwise dumped in the sea. So, it would be a local available cheapest and efficient bio-filter for recovering phosphorus from wastewater and can be used as fertilizer. Findings in this project are based on a batch experiment and the filter material was not applied to the wastewater.

7.3 Constructed Wetland with Pre-treatment Bio-filter

In such systems, the removal efficiency of pollutants is very high with bacteria >99%, BOD > 90%, Nitrogen > 50%, and Phosphorus >90% (Paruch et al., 2017). CWs with pre-treatment bio-filters discharge the effluent that is suitable for swimming in term of indicator bacteria and meets the European standards for swimming water quality. The effluent quality in such wetlands is free from the influence of season and the bio-filter is a necessary part of such systems, for the cold climates because they are helpful in reduction and nitrification of BOD, especially in Nordic countries where due to cold climate the plants are dormant during the winter season (Jenssen et al., 2005). This can be the rehabilitation option for various facilities on the island as the area is sparsely populated and there is no space restriction in the area.

7.4 Biochar for Pharmaceutical Removal

Despite of major advancements in the wastewater treatment, pharmaceuticals removal is still a challenge and in fact they are recognized as a contaminant of emerging concern (CEC) by the EPA. They are gaining much attention as they end up in the water sources. They can reach the water bodies from human sewage, agriculture and improper disposal. They become part of aquatic life and human when these water sources are used for drinking (Inyang and Dickenson, 2015).

It is important to remove these pharmaceuticals from the wastewater and there are research programs (drug take-back programs) underway for this purpose. Biochar has been found effective in some recent research studies. These studies have shown that biochar can be used as an adsorbent in removing pharmaceuticals from wastewater sources and consequently keeping them any from the aquatic bodies. In addition, it is a promising and cost-effective solution for pharmaceutical removal and thus can be an economical, accessible and reliable solution in meeting the water quality demands for a sustainable future. There is a list of products that ends in the drinking and other water sources and are summarized in appendix 6. Biochar has some associated challenges such as poor settling during backwashing and release of OM in treated water at low temperatures. But besides, these challenges it is still feasible and economic replacement for the expensive traditional sorbents such as granular activated carbons and ion exchange resins (Inyang and Dickenson, 2015).

Biochar can be coupled with the bio-filter media such as leca, filtralite or shell-sand to remove both phosphorus and pharmaceuticals from wastewater. It can be tried in two combinations; either mixed with the bio-filter media or applied after the effluent is treated by the bio-filter media. In the first combination it can remove both phosphorus, unwanted organic chemicals and pharmaceuticals simultaneously but the porosity of this arrangement can be a challenge (it can be tested). The filter media can be possibly used as a fertilizer. Biochar for pharmaceutical removal, will possibly be the requirement of municipality in the future.

In the case of deploying such filters, only septic tank is sufficient for the onsite treatment of household wastewater.

7.5 Source Segregation

As presented earlier in the result section of this report, the source segregation is a recent achievement in onsite wastewater treatment. It is highly recommended to be installed in the new constructed facilities to reduce the treatment efforts and get a high quality treated effluents. Source segregation is most attractive in areas where the houses are not connected to centralized facility and in coastal areas without wastewater infrastructure where eutrophication and hypoxic conditions (reduced oxygen content in water bodies "dead zones") are threats, due to excess of N and P. The technique separates approximately 80% N by collecting urine from wastewater at the source and thus can compete with many denitrifying treatment facilities which normally eliminates 50-60% N (Larsen* et al., 2009).

Sustainable wastewater treatment system emphasizes on the agricultural uses of nutrients from human feces and urine. Urine has contain 70% P and 90% N of blackwater and thus separation of urine make the treatment easy. Urine must be as saturated as possible therefore, for the success of this operation well designed low flush toilets and user behavior are key factors (Hanæus et al., 1997).

Source separation can be applied to the recreational houses in the island and newly constructed houses as there is population influx in the Frøya area and new houses will be constructed.

7.5.1 Holding Tank and Biogas Reactors

The household waste can be collected in holding tanks by employing low flush toilets and transported to the biogas production plant (instead on their use for landfill). This can prevent the spreading of pathogens and greenhouse gas emissions from the landfills. In this way hazardous components can be converted in to an asset in the form of biogas generation, recycling of organic and return of inorganic nutrient to the land (Colleran, 2000). In addition, the bio energy can be produced from the waste generated fish farming and breeding in the area. In this way the pollutant load on the water bodies will be reduced and the hazardous substances are also converted in an energy assets. Similarly, sludge can be also transported to the biogas plants. In this way all these different wastes can be recycled in the form of fertilizers and green energy in environment friendly way.

7.6 Package Treatment Plant

Package treatment plant is the most efficient onsite system for the treatment of wastewater for an individual household or a group houses. As shown on the geological map for Frøya, most of the area is not suitable for natural infiltration systems so package treatment plant can be the most effective system for the area.

7.6.1 Treatment Performance of Package Treatment Plants in Frøya

Package treatment plant from two companies, Wallax and Biovac, are installed in Frøya. The performances of both plants, claimed by the companies, are compared with the field results obtained by examining their samples in laboratory. And the comparison between these claimed and field performance is presented.

7.6.1.1 Claimed Performance

The performances claimed by the companies are quoted in the result section (6.5 Package Treatment Plants).

7.6.1.2 Field Performance

The actual performance of package treatment plants (PTPs) in Frøya is compared with their theoretically claimed performance as shown in the bar graph (see figure 36). The approximate amount of nitrogen and phosphorus produced in Frøya has been estimated on the basis of released amount into the recipient in a calendar year and is used for the comparison purpose in the bar graph (left most bars in figure 36). Field data from two Wallax and one Biovac plants is compared; it can be clearly seen that the claimed performance by Wallax is agree with its filed performance in term of nitrogen and phosphorus removal. The only disagreement is for the phosphorus production for Wallax 2 package treatment plant. The amount produced is almost three times higher than the claimed performance by Wallax. But this must be noted that Wallax 2 is installed in a recreational household so this factor can also contribute to the saturation of wastewater in the plant as it is not used regularly. And it must be also noted that 150/day/person is assumed in this calculation.

Similarly, there is a mismatch between the claimed and actual field performances of the Biovac plant. The amount of nitrogen and phosphorus in the treated effluent is slightly higher than the claimed performance. It is also installed on a recreational house. So it is hard to decide their performances on the basis of the samples taken from these facilities. The samples from these houses were collected during the off season so it is highly recommended to sample these plants during peak days of their use to decide their actual performances. Moreover, one sample cannot be the true representative for deciding the performance of any facility. So these facilities need to be sampled after a suitable interval of time and much samples and data must be collected over time to decide their actual performances. And to decide whether to mark them safe or recommend an upgradation plan for them. But unfortunately due to the insufficient and strict time frame of this project, it was not possible to sample these plants at regular and recommended time intervals. The bar graph is based on the one time sampled data from these package treatment plants.

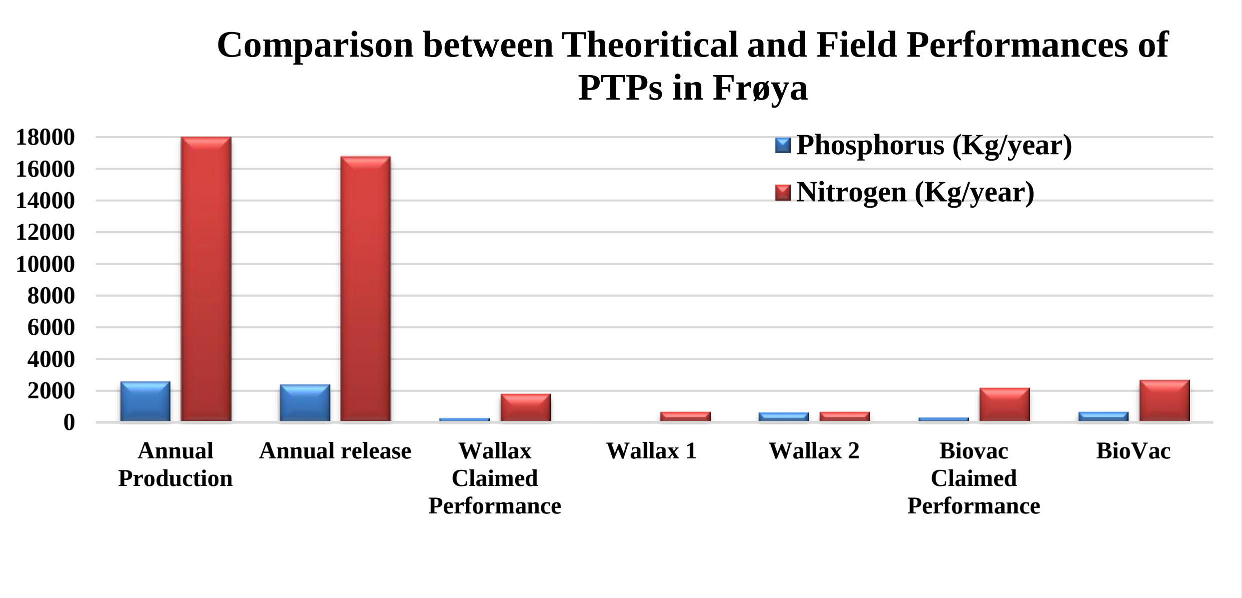


Figure 36: Comparison of actual versus field performances of the package treatment plants (PTPs) operational in the Frøya area. First and second values to the left are the estimated annual amount of phosphorus & nitrogen produced in Frøya and released to the recipients respectively.

When these results from the field performances are compared with the amount released in to the recipients annually, it is clear that by applying these package treatment systems, the load on the recipients can be decreased as much as 80% in term of total nitrogen and even more for the phosphorus. The mismatch in these results can be due to improper handling and lack of maintenance.

In the above discuss solutions for rehabilitation, the interest of the individuals using the facilities is important. The municipality need to create awareness events and specific legislations for maintenance and control of these systems.

8 CONCLUSIONS

- The onsite systems in Frøya are not attaining the level of wastewater treatment recommended by the Norwegian Standards (EU Urban Wastewater Treatment Directive (917271/EEC)) for wastewater treatment.
- Most of the investigated facilities are malfunctioning and the municipality need to launch proper rehabilitation plan.
- High amount of phosphorus and nitrogen are causing eutrophication in the water bodies (recipients).
- The bacteria count of these systems is also very high and can cause serious health issues if the existing infrastructure for the wastewater treatment continues.
- Houses with direct discharge to terrain or recipient, malfunctioning facilities and the facilities which do not meet the required treatment levels; should urgently install onsite facilities meeting the treatment requirements set by the municipality.
- Houses using with malfunctioning sludge separation or older septic tanks in vulnerable recipients must upgrade the sludge treatment prior to be coupled with any of the suggested facilities to attain the required level of treatment.
- Upgrading the functioning septic tank facilities in sensitive areas in Frøya can be achieved in several ways:

  1. Applying a bio-filter for BOD removal and filter of crushed local sea shells for P-removal (Nadeem 2018 in preparation) if supported by a biochar filter unwanted organic chemicals as pharmaceutical can also be removed.

  2. Applying source separation and carrying the toilet waste to a biogas facility where bioenergy and fertilizer can be produced.

  3. Use a package treatment system, but this might need a polishing filter for bacteria removal (package treatment plants often include sludge treatment.

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10 APPENDICES

10.1 Appendix 1

Local legislation of Frøya Kommune for wastewater treatment in different zones.

Appendix 1: Local legislations for recipients and suggested system on the basis of vulnerability of recipient for both permanent residential and holiday cottages.

Zone Description	Percent decrease in pollutants	Possible treatment solutions $^{(1)}$	
		Permanent Houses	Holiday Cottages
Very vulnerable recipient and lot of user area	P. 90% N. 60-70 % BOF$_5$. 90 % E.coli. 99.9%	• Biological chemical package treatment plant with biofilter or other type of post polishing • Filterbed system • Compact filter bed • Prefabricated infiltration solution with post polishing • Other (1)	• Biological chemical package plant with biofilter or other type of post polishing • Filterbed system • Compact filter bed • Prefabricated infiltration solution • Combustion toilet for black water and graywater sludge separator with post polishing in biofilter • Other (1)
Vulnerable Recipient and Usage Area	P. 70% N.40% BOF$_5$. 70 % E.coli. 98 %	• Biological-chemical plant • Biological mining plant • Chemical mining plant • Filterbed system • Compact filter bed • Prefabricated infiltration solution • Other (1)	• Biological-chemical plant • Filterbedanlegg • Compact filter bed • Prefabricated infiltration solution • Dense tank for blackwater and greywater solution • Biological toilet (utedo) and gray water purification (1) • Composting toilet for black water and graywater sludge separator with post polishing in biofilter • Other
Moderate recipient and user area	P. 50 % N. 30% BOF$_5$. 50 %	• Sand filter • Biological mining plant • Chemical mining plant • Filterbedanlegg • Compact filter bed • Prefabricated infiltration solution • Other (1)	• Sludge separator with biofilter or sand filter after polishing. Emit line 10 long into the sea and at least 2 m below the lowest water level • Chemical mining plant • Biological mining plant • Combustion toilet and gray water sludge separator

	E.coli. 90 %		- Other (1)
Good recipient and non-user area	P.20% N.20 % BOF$_5$.30 % E.coli. 90%	• Sludge separator with biofilter or sand filter after polishing. Emit line 10 long into the sea and at least 2 m below the lowest water level	• Sludge separator. Repolishing in terrain if possible. Discharge line 10 m long in the sea and at least 2 m below the lowest water level • Combustion toilet and gray water without cleaning
Very good recipient and no user area	P. 10 N. 10 TOC. 20-30 E.coli. 90%	3 compartment sludge separator Discharge line 10 m long in the sea and at least 2 m below the lowest water level • Other	• 3 compartment sludge separator • Dismantle line 10 m long in the sea and at least 2 m below the lowest water level • Combustion toilet and gray water with no cleaning. • Other

(1) This is an example of the wastewater treatment solutions. Other facilities, that meet the required parameters, can also be deployed.

10.2 Appendix 2

Grading of recipients on the basis of vulnerability or sensitivity to pollutants.

Appendix 2: Classification of recipients on the basis of vulnerability.

Recipient	**Assigned Number**	**Sensativity Grading**
Bekkastraumen	1	Moderate
Bremnesvågen	2	High
Buaråsa, Molbakkskaget	2	High
Dalasundet	2	High
Daløya, Bustvika	2	High

Dragsneset	1	Moderate
Dyrøysvaet	2	High
Dørviksvaet	1	Moderate
Elv Fra Steinsvatnet	3	Very high
Espnesvågen	2	High
Godhamna	1	Moderate
Hellesvikskjæret	1	Moderate
Holasundet	2	High
Holmen	2	High
Håvika	2	High
Inner Hallarvågen	1	Moderate
Innersundet, Naftadjupet	3	Very high
kvernøysundet	2	High
Kverva	3	Very high
Kvistvågen, Valvågan	1	Moderate
Kystfelt Fillingsnes-Kolen	2	High
Kystfelt Kongstjørntua-Strandheim	1	Moderate
Kystfelt Strandheim-Fjøyafjorden	1	Moderate
Kystfelt Tungvågen-Skaget	2	High
Leirvikskaget	2	High
Måsøyvalen	3	Very high
Neset Kai, Elling Sundet	1	Moderate

Nordskagsvaet	3	Very high
Oksbåhavet	2	High
Sandviksundet	2	High
Seterholmen	2	High
Sjøhals-sundet	2	High
Staulvågen	2	High
Steinvatnet	3	Very high
Strømøyvagen	2	High
Sundet, Salmar	3	Very high
Tjønnøysundet	1	Moderate
Tungvågelva	2	High
Tungvågen	2	High
Valavågen	2	High
Veisfjorden	2	High
Yttersundet	2	High

10.3 Appendix 3

Appendix 3: Number of onsite facilities in each category of environmental index.

Environment Index	**Very High**	**High**	**Moderate**	**Low**	**Very Low**
Direct Emission	11			9	11
Septic tank to terrain	151	182	4	33	69
Septic tank to watercourses	752	1	15	139	151

Infiltration systems			2	1	2
Sand-filter		38		1	7
Biological/Chemical Package Plant			1		
Chemical Package Plant		5		1	
Holding tank					14
Holding tank for blackwater					2
Biological Toilet				4	55
Holding Tank and infiltration				1	
Biological Toilet and infiltration				1	15
Joint Common Treatment System					111
Shifted/Abondend					93

Environment Index	Very High	High	Moderate	Low	Very Low
Direct Emission	11			9	11
Septic tank to terrain	151	182	4	33	69
Septic tank to watercourses	752	1	15	139	151
Infiltration systems			2	1	2

Sand-filter		38		1	7
Biological/Chemical Package Plant			1		
Chemical Package Plant		5		1	
Holding tank					14
Holding tank for blackwater					2
Biological Toilet				4	55
Holding Tank and infiltration				1	
Biological Toilet and infiltration				1	15
Joint Common Treatment System					111
Shifted/Abondend					93

10.4 Appendix 4

Appendix 4: Percentage of approved onsite wastewater treatment facilities in each recipient.

Recipient	**Approved facilities (%)**
Bekkastraumen	0.0 %
Bremnesvågen	0.0 %
Buaråsa, Molbakkskaget	0.0 %
Dalasundet	0.0 %
Daløya, Bustvika	0.0 %
Dragsneset	0.0 %
Dyrøysvaet	7.7 %
Dørviksvaet	0.0 %

Elv Fra Husvatnet	0.0 %
Espnesvågen	0.0 %
Godhamna	0.0 %
Hellesvikskjæret	0.0 %
Holasundet	0.0 %
Holmen	7.7 %
Håvika	0.0 %
Inner Hallarvågen	0.0 %
Innersundet, Naftadjupet	0.0 %
kvernøysundet	0.0 %
Kverva	0.0 %
Kvistvågen, Valvågan	0.0 %
Kystfelt Fillingsnes-Kolen	0.0 %
Kystfelt Frøyfjorden-Fillingsnes	0.0 %
Kystfelt Kolen-Tungvågen	0.0 %
Kystfelt Kongstjørntua-Strandheim	1.6 %
Kystfelt Skaget-Kongstjørntua	1.5 %
Kystfelt Strandheim-Frøyfjorden	1.5 %
Kystfelt Tungvågen-Skaget	0.0 %
Leirvikskaget	0.0 %
Måsøyvalen	0.0 %
Neset Kai, Elling Sundet	0.0 %
Nordskagsvaet	0.0 %

Oksbåhavet	0.0 %
Sandviksundet	0.0 %
Seterholmen	3.3 %
Sjøhals-sundet	0.0 %
Staulvågen	0.0 %
Steinvatnet	0.0 %
Strømøyvagen	0.0 %
Sundet, Salmar	0.0 %
Tjønnøysundet	0.0 %
Tungvågen	0.0 %
Valavågen	0.0 %
Veisfjorden	0.0 %
Yttersundet	10.0 %

10.5 Appendix 5

Appendix 5: Annual discharge and number of facilities discharging in each recipient.

Recipient	P Emission/Year	N Emission/Year	TOC Emission/Year	No. Of Systems
Bekkastraumen	72	591	1031	51
Bremnesvågen	28	207	387	27
Buaråsa, Molbakkskaget	15	112	243	14
Dalasundet	48	380	796	38
Daløya, Bustvika	34	292	586	37
Dragsneset	23	163	364	19

Dyrøysvaet	60	427	956	19
Dørviksvaet	155	1102	2463	63
Elv Fra Husvatnet	10	73	166	7
Elv Fra Steinsvatnet	0	2	5	1
Espnesvågen	58	463	929	36
Godhamna	61	501	1005	70
Hellesvikskjæret	36	312	585	21
Holasundet	55	396	881	42
Holmen	39	285	632	25
Håvika	5	36	57	6
Inner Hallarvågen	12	97	207	10
Innersundet, Naftadjupet	69	501	1092	47
kvernøysundet	56	403	893	24
Kverva	46	362	699	32
Kvistvågen, Valvågan	34	282	549	26
Kystfelt Fillingsnes-Kolen	21	168	354	23
Kystfelt Frøyfjorden-Fillingsnes	14	96	136	7
Kystfelt Kolen-Tungvågen	9	90	171	12
Kystfelt Kongstjørntua-Strandheim	149	1080	2394	86

Kystfelt Skaget-Kongstjørntua	218	1575	3442	105
Kystfelt Strandheim-Fjøyafjorden	307	2162	4831	173
Kystfelt Tungvågen-Skaget	19	134	275	18
Leirvikskaget	56	410	913	27
Måsøyvalen	41	318	663	27
Neset Kai, Elling Sundet	140	1034	2244	58
Nordskagsvaet	22	193	386	19
Oksbåhavet	11	94	193	12
Sandviksundet	174	1377	2707	108
Seterholmen	124	882	1986	64
Sjøhals-sundet	108	793	1732	47
Staulvågen	191	1365	2983	95
Steinvatnet	33	293	545	21
Strømøyvagen	34	248	546	18
Sundet, Salmar	27	202	327	19
Tjønnøysundet	24	178	395	17
Tungvågelva	2	16	38	4
Tungvågen	49	418	805	30
Valavågen	30	241	489	20
Veisfjorden	20	193	359	16

Yttersundet	68	492	1086	37

10.6 Appendix 6

Appendix 6 : List of pharmaceuticals sorbed on various biochars. Taken from Inyang and Dickenson (2015).

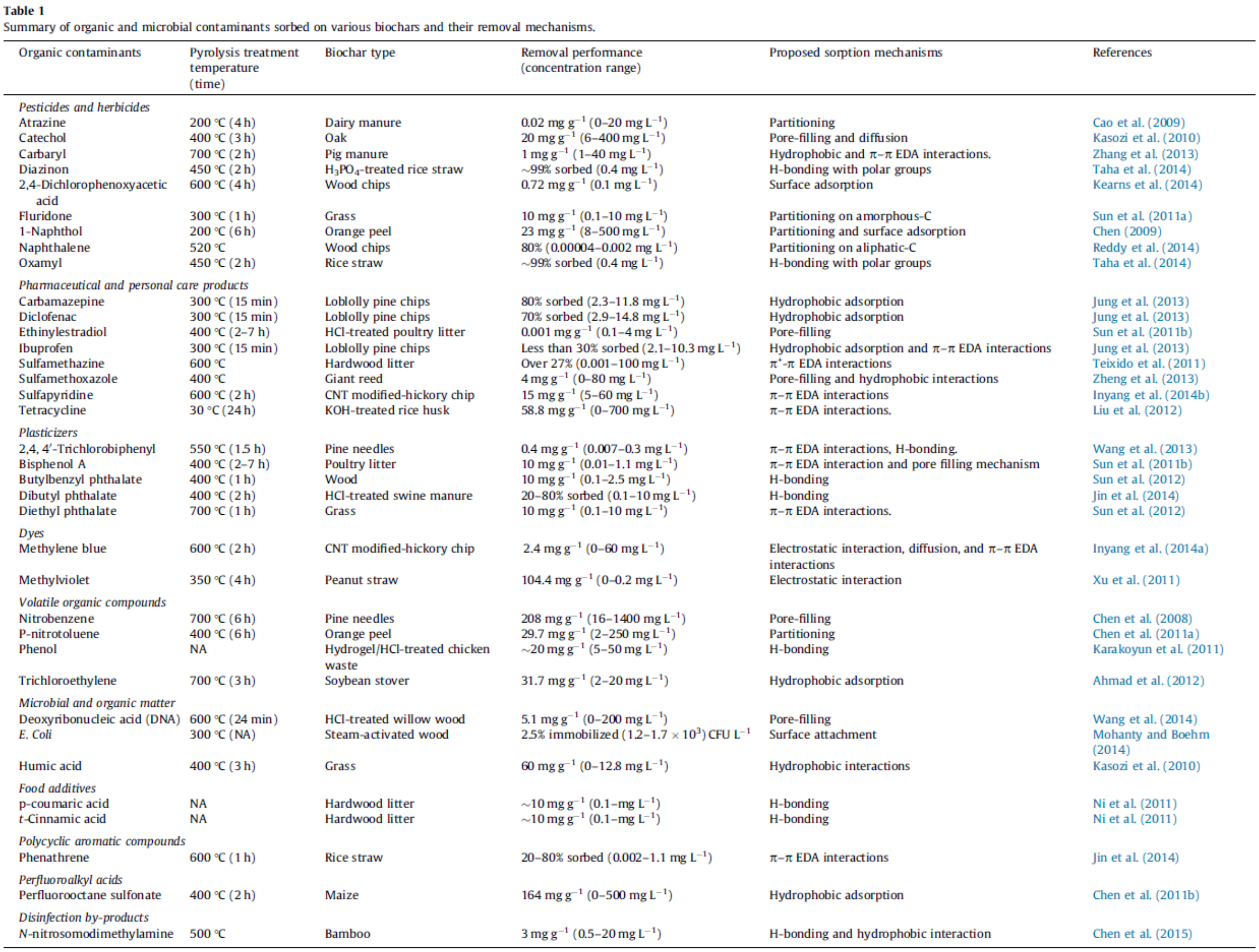

Table 1

Summary of organic and microbial contaminants sorbed on various biochars and their removal mechanisms.

Organic contaminants	Pyrolysis treatment temperature (time)	Biochar type	Removal performance (concentration range)	Proposed sorption mechanisms	References
Pesticides and herbicides					
Atrazine	200 °C (4 h)	Dairy manure	0.02 mg g^{-1} (0–20 mg L^{-1})	Partitioning	Cao et al. (2009)
Catechol	400 °C (3 h)	Oak	20 mg g^{-1} (6–400 mg L^{-1})	Pore-filling and diffusion	Kasozi et al. (2010)
Carbaryl	700 °C (2 h)	Pig manure	1 mg g^{-1} (1–40 mg L^{-1})	Hydrophobic and π–π EDA interactions.	Zhang et al. (2013)
Diazinon	450 °C (2 h)	H_3PO_4-treated rice straw	~99% sorbed (0.4 mg L^{-1})	H-bonding with polar groups	Taha et al. (2014)
2,4-Dichlorophenoxyacetic acid	600 °C (4 h)	Wood chips	0.72 mg g^{-1} (0.1 mg L^{-1})	Surface adsorption	Kearns et al. (2014)
Fluridone	300 °C (1 h)	Grass	10 mg g^{-1} (0.1–10 mg L^{-1})	Partitioning on amorphous-C	Sun et al. (2011a)
1-Naphthol	200 °C (6 h)	Orange peel	23 mg g^{-1} (8–500 mg L^{-1})	Partitioning and surface adsorption	Chen (2009)
Naphthalene	520 °C	Wood chips	80% (0.00004–0.002 mg L^{-1})	Partitioning on aliphatic-C	Reddy et al. (2014)
Oxamyl	450 °C (2 h)	Rice straw	~99% sorbed (0.4 mg L^{-1})	H-bonding with polar groups	Taha et al. (2014)
Pharmaceutical and personal care products					
Carbamazepine	300 °C (15 min)	Loblolly pine chips	80% sorbed (2.3–11.8 mg L^{-1})	Hydrophobic adsorption	Jung et al. (2013)
Diclofenac	300 °C (15 min)	Loblolly pine chips	70% sorbed (2.9–14.8 mg L^{-1})	Hydrophobic adsorption	Jung et al. (2013)
Ethinylestradiol	400 °C (2–7 h)	HCl-treated poultry litter	0.001 mg g^{-1} (0.1–4 mg L^{-1})	Pore-filling	Sun et al. (2011b)
Ibuprofen	300 °C (15 min)	Loblolly pine chips	Less than 30% sorbed (2.1–10.3 mg L^{-1})	Hydrophobic adsorption and π–π EDA interactions	Jung et al. (2013)
Sulfamethazine	600 °C	Hardwood litter	Over 27% (0.001–100 mg L^{-1})	π^+-π EDA interactions	Teixido et al. (2011)
Sulfamethoxazole	400 °C	Giant reed	4 mg g^{-1} (0–80 mg L^{-1})	Pore-filling and hydrophobic interactions	Zheng et al. (2013)
Sulfapyridine	600 °C (2 h)	CNT modified-hickory chip	15 mg g^{-1} (5–60 mg L^{-1})	π–π EDA interactions	Inyang et al. (2014b)
Tetracycline	30 °C (24 h)	KOH-treated rice husk	58.8 mg g^{-1} (0–700 mg L^{-1})	π–π EDA interactions.	Liu et al. (2012)
Plasticizers					
2,4, 4′-Trichlorobiphenyl	550 °C (1.5 h)	Pine needles	0.4 mg g^{-1} (0.007–0.3 mg L^{-1})	π–π EDA interactions, H-bonding.	Wang et al. (2013)
Bisphenol A	400 °C (2–7 h)	Poultry litter	10 mg g^{-1} (0.01–1.1 mg L^{-1})	π–π EDA interaction and pore filling mechanism	Sun et al. (2011b)
Butylbenzyl phthalate	400 °C (1 h)	Wood	10 mg g^{-1} (0.1–2.5 mg L^{-1})	H-bonding	Sun et al. (2012)
Dibutyl phthalate	400 °C (2 h)	HCl-treated swine manure	20–80% sorbed (0.1–10 mg L^{-1})	H-bonding	Jin et al. (2014)
Diethyl phthalate	700 °C (1 h)	Grass	10 mg g^{-1} (0.1–10 mg L^{-1})	π–π EDA interactions.	Sun et al. (2012)
Dyes					
Methylene blue	600 °C (2 h)	CNT modified-hickory chip	2.4 mg g^{-1} (0–60 mg L^{-1})	Electrostatic interaction, diffusion, and π–π EDA interactions	Inyang et al. (2014a)
Methylviolet	350 °C (4 h)	Peanut straw	104.4 mg g^{-1} (0–0.2 mg L^{-1})	Electrostatic interaction	Xu et al. (2011)
Volatile organic compounds					
Nitrobenzene	700 °C (6 h)	Pine needles	208 mg g^{-1} (16–1400 mg L^{-1})	Pore-filling	Chen et al. (2008)
P-nitrotoluene	400 °C (6 h)	Orange peel	29.7 mg g^{-1} (2–250 mg L^{-1})	Partitioning	Chen et al. (2011a)
Phenol	NA	Hydrogel/HCl-treated chicken waste	~20 mg g^{-1} (5–50 mg L^{-1})	H-bonding	Karakoyun et al. (2011)
Trichloroethylene	700 °C (3 h)	Soybean stover	31.7 mg g^{-1} (2–20 mg L^{-1})	Hydrophobic adsorption	Ahmad et al. (2012)
Microbial and organic matter					
Deoxyribonucleic acid (DNA)	600 °C (24 min)	HCl-treated willow wood	5.1 mg g^{-1} (0–200 mg L^{-1})	Pore-filling	Wang et al. (2014)
E. Coli	300 °C (NA)	Steam-activated wood	2.5% immobilized (1.2–1.7 × 10^3) CFU L^{-1}	Surface attachment	Mohanty and Boehm (2014)
Humic acid	400 °C (3 h)	Grass	60 mg g^{-1} (0–12.8 mg L^{-1})	Hydrophobic interactions	Kasozi et al. (2010)
Food additives					
p-coumaric acid	NA	Hardwood litter	~10 mg g^{-1} (0.1–mg L^{-1})	H-bonding	Ni et al. (2011)
t-Cinnamic acid	NA	Hardwood litter	~10 mg g^{-1} (0.1–mg L^{-1})	H-bonding	Ni et al. (2011)
Polycyclic aromatic compounds					
Phenathrene	600 °C (1 h)	Rice straw	20–80% sorbed (0.002–1.1 mg L^{-1})	π–π EDA interactions	Jin et al. (2014)
Perfluoroalkyl acids					
Perfluorooctane sulfonate	400 °C (2 h)	Maize	164 mg g^{-1} (0–500 mg L^{-1})	Hydrophobic adsorption	Chen et al. (2011b)
Disinfection by-products					
N-nitrosomodimethylamine	500 °C	Bamboo	3 mg g^{-1} (0.5–20 mg L^{-1})	H-bonding and hydrophobic interaction	Chen et al. (2015)

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