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Survey of Onsite Wastewater Treatment Systems in Kristiansand Municipality Norway: Pollutants Removal Performance and Solutions: Performance Analysis Based on Web-GIS Model

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DECLARATION:

I, Muhammad Abbas, declare that this thesis is a result of my research investigation and my own findings. All of sources other than my own knowledge have been acknowledged and a reference list has been attached at the end. This work has never been previously submitted to any other university for the award of any degree or diploma.

Signature ________________________

Place and Date _____________________________

DEDICATION:

This thesis submitted to fulfill the requirement for master degree in Sustainable Water Sanitation and Public Health from the department of Environmental Sciences (IMV, NMBU).

I dedicate this work to my beloved family and especially to my sweet daughters Eishal and Aimen Abbas. God bless you for sacrificing to stay away during the days when I was working on my thesis. With the help of God and your constant encouragement to enable me to complete this task.

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Table of Contents

List of Figures

List of Tables

Abstract

In Norway, 16% of the population lives in rural areas where centralized infrastructure for wastewater treatment is neither cost effective and nor sustainable due to topography and long distance to connect a treatment facility. There are 330,000 small decentralized wastewater treatment plants in Norway and out of those 1,500 plants are located in Kristiansand municipality. Eutrophication and fecal contamination in the recipients are the major cause of concern to wastewater disposal from such onsite systems. In order to avoid pollution in the wastewater recipients from such onsite treatment systems, City and Community department (By- og Samfunnsenheten) of Kristiansand municipality initiated a project to inspect and registration of all small onsite wastewater treatment systems in the locality. However in the first phase (June-August 2016), almost 500 treatment systems was surveyed and out of those 406 treatment systems are analyzed for this thesis through WebGIS model develop by NIBIO. The statistics of the survey shows that there are 183 soil infiltration systems, 91 septic tank with direct discharge to the recipients, 42 with no treatment and direct discharge to recipients and 18 package treatment plants out of total 406 plants. The WebGIS analysis shows that 262 kg of P, 3225 kg N and 4468 kg of TOC per year discharge to different recipients from these onsite systems. Septic tank with direct discharge to recipients, septic tank discharge terrain and sand filter systems significantly contributed to the overall total burden of the pollutants on the recipients. Only these three categories discharge 235 kg of P, 1709 kg N and 3442 kg TOC out of out of total pollutants 262 kg, 3225 kg and 4468 kg respectively. However, it is calculated that if septic tank with direct discharge to the recipients, septic tank effluent discharge to the direct terrain and sand filter systems are upgraded with new system, this may reduce 85% P, 36% N and 69% of TOC. It is therefore, suggested that these systems replaced with new systems because they are significantly responsible for pollution in the recipients. Further, it is recommended that some older infiltration systems should be upgraded with bio-filter system depending on the feasibility.

Chapter 1

Introduction

In Norway, 16% of the population lives in rural areas where centralized infrastructure for wastewater treatment is neither cost effective and nor sustainable due to topography and long distance to connect nearby treatment facility (Eggen et al. 2010; Jenssen et al. 2010; Norskvann 2014). Therefore, such houses and recreational places rely on small-decentralized wastewater treatment systems. In Norway, small-onsite wastewater treatment systems started operation in the beginning of 20^{th} century and initially had very simple design with main purpose was improved wastewater disposal (Eggen et al. 2010). The design of traditional onsite system comprises of a septic tank and soil infiltration or sand filter etc. Such 'natural systems' were very simple and made with local knowledge, material and without any complex technology that did not require energy for operation.

In 1970's and 80's researches have been done to investigate environmental impact of these initial simple design onsite systems (Bouma 1975, USEPA 1980, Winneberger, 1984) in Eggen et al. (2010) and (Kristiansen 1982). Later on due to stringent local wastewater regulations, soil condition and technological advancement and research in this sector introduced fiberglass septic tanks and added other components like bio filters, distribution chamber and intermittent dosing pump or other type of dosing devices as siphons or tipping buckets. Small package treatment plants are combination of mechanical, biological and chemical treatment in one unit and were introduced in Norway in 1990's (Jenssen et al. 2010). Now package treatment plants are available in a variety of options, either as batch or continuous process with and without chemical precipitation (Johannessen et al. 2012). However, package treatment plants were not able to completely replaced the traditional small onsite systems in Norway because they have difficulties in meeting current discharge limits for phosphorous but they are considered good solution for wastewater treatment along coast line, mountainous places and less soil area (Johanessen et al 2008).

Approximately there are 330,000 small decentralized wastewater treatment plants are operating in overall Norway and out of those 1,500 plants are in Kristiansand municipality (Norskvann 2014). Since Norway follows EU Urban Water Treatment Directive, (91/271/EEC) strict rules and regulation regarding effluent discharge implemented to preserve wastewater effluent recipient. The foremost challenge is to identify different source of pollution in the recipient.

Eutrophication and fecal contamination of water bodies are the most problematic effects of such anthropogenic pollution that is really needed to assess and solve. In order to meet national and EU Urban Water Treatment Directive (91/271/EEC) standards, many of the Norwegian municipalities need either to partly upgrade or entirely replaced the out dated and malfunctioning small onsite treatment systems (Eggen et al. 2010). In order to compliance with EU water directive and to improve the local environment, many municipalities have started to register small onsite systems as for basis for planning further action.

In summer 2016, Kristiansand municipality by City and Community (By- og Samfunnsenheten) department initiated a project for inspection and registration of all small onsite wastewater treatment systems and private wells. The plan is to inspect and registered 1,500 small onsite treatment systems during 2-3 year period and start upgrading or replacement of malfunctioning treatment systems. In the first phase from June 15 until 15 August 2016, approximately 500 systems have been inspected by trained water engineering students from Norwegian University of Life Sciences (NMBU) having water and wastewater background.

However, this registration only gives subjective evaluation of the treatment performance and does not quantify the pollution potential. In order to assess the amount of pollution discharge to the recipient from systems WebGIS been used for this study. In the WebGIS program (Eggen et al. 2010) an estimate of the potential pollution is given based on system registration. This can facilitate the work regarding onsite systems and ease the decision-making and priorities. WebGIS is based on a geographical information system. This WebGIS tool was developed in 1990s by the predecessor to the Norwegian Institute of Bio-Economy (NIBIO) and is one output from the research project ''Natural systems for wastewater treatment NAT'' (Jenssen & Syversen 1996).

The focus of the NAT project was on water pollution from onsite treatment systems. In WebGIS the treatment of each of the systems is calculated on based on the input data to the model and presented in the amount of phosphorous (P) nitrogen (N) and total organic carbon (TOC) that discharge to the recipient after treatment in the system. The model has both administrative (data storage) and analysis purposes and more than 50 municipalities are currently using the WebGIS system to support administration of the onsite systems. The model generate reports tables, statistics and graphical presentation of the treatment systems. The mathematical calculation behind the model is based on empirical data from 20 years of research on small onsite systems (Eggen et al. 2010).

In the current study, the data of 500 small onsite systems from Kristiansand municipality have been analyzed through the WebGIS model.

1.1 Problem Statement

Kristiansand is located on the Southern part of Norway, on the seacoast between Norway and Denmark. The city has population of 137,000 inhabitants (Kristiansand municipality webpage). The city called the green city and the municipality spend high amount of money to clean the bay and rivers and also takes many initiatives to reduce CO_2 emission from the city for instance by promoting electric bicycles for schoolchildren and for municipality employees. The municipality has substantial rural population; lakes, rivers and coastline attract peoples to build their recreational houses (summerhouses) as well as permanent houses along these water bodies.

However, many of the dispersed houses and cabins are not connected to centralized treatment and collection systems and the peoples have large variety of their own small onsite systems. Apart from some newly constructed homes, most of these houses have very old onsite systems that built in 1980s. The pollutants removal efficiency of such systems is questionable and such old wastewater treatment systems can cause serious pollution in the rivers, lakes and streams where their water discharged. If the wastewater not cleaned well enough this will pollute recipient with phosphorus and nitrogen, organic matter and bacteria that can lead to eutrophication and potential health problems. Hamresanden beach a part of Topdalsfjorden has lost it Blue Flag last year (2016) because of too much bacteria in the water. Most of the small onsite systems that have been investigated in this study discharge their effluent to Topdalsfjorden via Topdals River and Ålefjord. There might be possibility that these small onsite systems along the Topdals River are responsible for the contamination in the Topdalsfjorden.

1.2 Objectives

This study use WebGIS as a tool to address the following objectives

- Estimate the pollutant load from onsite systems along the Topdals River in Kristiansand municipality
- Evaluate the impact of polluted effluent on the recipients
- Identify the systems that are unable to meet local and EU water directive discharge requirements

- Provide some possible solution for malfunctioning treatment systems

1.3 Scope of the Field Survey

The survey of small onsite treatment systems was an excellent initiative taken by Kristiansand municipality. Despite that, more than 50 municipalities using WebGIS for managing and data storage of decentralized sewage systems but little has been published on WebGIS as tool to evaluate treatment performance of onsite systems. In this thesis, the environmental side of the WebGIS tool is in focus and the analysis would make great ease for relevant consultants in Kristiansand and other municipalities to act against malfunctioning treatment systems. In addition to this, this is first time WebGIS is used for thesis in NMBU.

1.4 Research Questions

The study has following research questions:

- What type (category) of small onsite wastewater treatment systems are functioning in the municipality?
- How many of the visited systems meet standard discharge limits?
- How much of phosphorous (P) nitrogen (N) and total organic carbon (TOC) discharge to the recipient? How much pollutants can be reduced through upgrading or construction of new systems?
- If there is no upgradation of malfunctioning systems, how will this affect the water quality of the recipients and what are long-term consequences? How wise it is to upgrade these systems considering cost and the amount of pollutants discharged from these systems?
- What are possible solutions for malfunctioning systems?

Chapter 2

Literature Review

2.1 Short History of Research on On-Site Wastewater Disposal Systems in Norway

In 1970, an extensive national research program initiated with variety of research area focusing on wastewater treatment. The Agricultural University of Norway (NLH) presently known as Norwegian University of Life Sciences (NMBU) was given responsibility to inspect soil and wastewater recipient's quality (Liseth 1980) in Kristiansen (1982). The project also inspect performance of biological toilet. For this whole project, approximately NOK 7.05 million allocated with 13-sub project at Norwegian University of Life Sciences for the period 1971-78 (Kristiansen 1982).

On-site wastewater inspection started in 1972 by Hans Erik Stadshaug until 1974 and then Per Lindbak continued until 1978. This project and research well recognized among relevant institutions and got more funding from Agricultural Research Council and Norwegian State Pollution Control Authority (SFT). Afterwards project managed by department of soil pollution research at NMBU by Rolv Kristiansen worked as responsible coordinator (Kristiansen 1982).

In the first phase, Stadshaug inspected 100 soil absorption and sand-filter systems. The result revealed that only few of them were functioning satisfactory. Clogging found one of the main reason due to malfunctioning of pre-treatment step (septic tank). In the next phase, 13 sand filters systems were analyzed and 5 of them inspected intensively. However, the results showed very high treatment performance. Stadshaug's research group found that there is lack of knowledge about designing, operation and management of on-site treatment system in the country and this group started to work as consultant to design the on-site treatment systems. The research work took over by Lindbak and produced many research reports. Lindbak reported very high purification efficiencies of sand-filter and these results got criticize due to much more pessimistic in nature. It was found that there is a gap between research results and field experience with on-site systems (Kristiansen 1982).

Later on 1980, it was felt that there is need of new research program with new strategies and goals. However, a three-year program was started and coordinated with ongoing Swedish research program. The aim of this joint research program was to enhance knowledge about site selection, clogging of infiltration and sand-filter trenches and renovating process of soil absorption system. The Norwegian research program focus on rural wastewater disposal while

Swedish program focus on secondary effluent and storm water management. Here are main highlights of that research program on Norwegian dimension. This section is extracted from Eikum and Seabloom (2012) written by Kristiansen (1982).

1. Site selection criteria for onsite wastewater treatment system

    Institution: Agricultural Research Council of Norway, Section Soil Pollution Research

    Aim of the Project: Development of usable methods for site selection and for evaluating the hydraulic capacity of soil for wastewater

2. Microbial process important to clogging and purification in soil absorption beds

    Institution: Department of Microbiology, Norwegian University of Soil Sciences, Norway

    Aim of the project: A. To increase knowledge about microbial clogging of infiltrated surface

    B. to optimize process important to decomposition and turnover of pollutants in on-site soil adsorption systems

3. Removal of Phosphorous in soil filters for renovation of wastewaters

    Institution: The Norwegian Forest Research Institute

    Aim of the project: To find sustainable phosphorous adsorption index for Scandinavian soil types. This will be used in soil selection procedures when choosing site for on-site soil disposal of septic tank effluent.

4. Hygienic questions concerning removal of pathogens from percolating wastewater

    Institution: Department of Food Hygiene, Veterinary College of Norway

    Aim of the project: the Norwegian part in this join Swedish- Norwegian project is to investigate the travel-distance of microorganisms and parasites in different soil types loaded at varying rates, frequencies and temperature.

5. Frost in Septic System

    Institution: Agricultural Research Council of Norway, Section Soil Pollution Research

    Aim of the project: To evaluate needed insulation of soil adsorption systems under different soil and climatic conditions

6. Leachate treatment through soil percolation

    Institution: Agricultural Research Council of Norway, Section Soil Pollution Research

Aim of the Project: To increase knowledge of necessary pre-treatment needs for leachate from small solid waste disposal sites before disposing in soil adsorption fields

7. Development of improved full-scale soil disposal systems

   Institution: Agricultural Research Council of Norway, Section Soil Pollution Research.

   Aim of the project: Based on In house studies and literature, improve existing types of on-site soil disposal systems in Scandinavia.

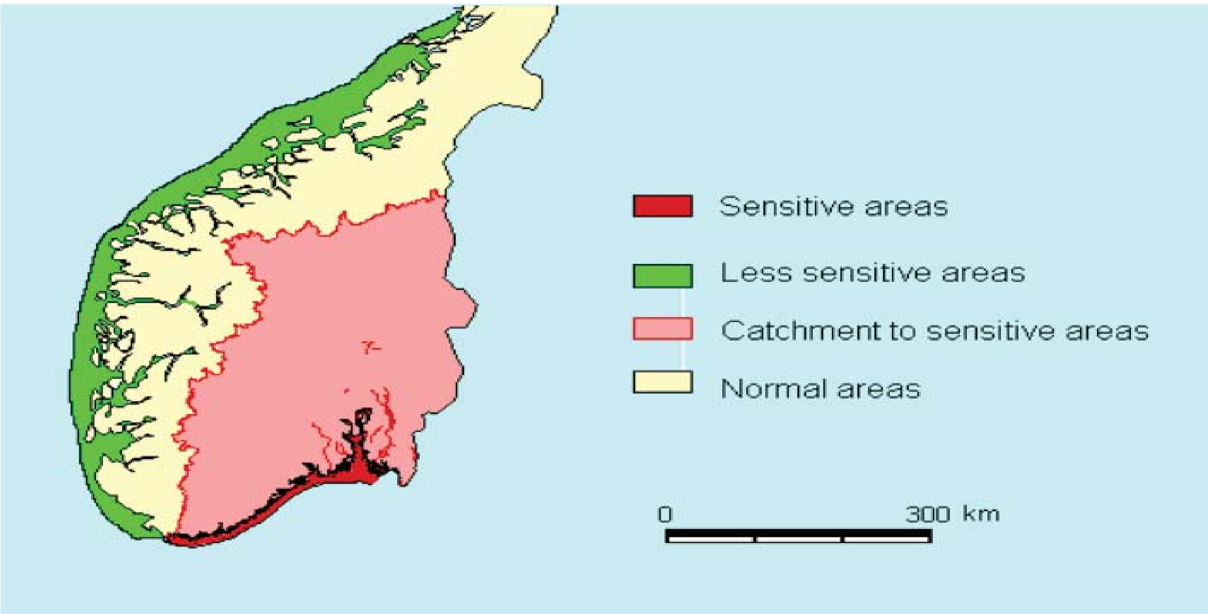
2.2 Wastewater Treatment in Norway

Eutrophication and organic load due to algae decomposition are most problematic issues related to wastewater disposal. However, in Norway phosphorous removal from wastewater becomes very crucial from any sort of wastewater treatment system since Norway followed EU Urban Wastewater Treatment Directive (917271/EEC) (Källqvist et al. 2002). In 2015, 65 per cent of Norway's population connected to advance treatment plants – biological/chemical treatment that is 3 percent increase compared to 2014. The chemical/biological treatment plants have the ability to remove more of the pollutants from the wastewater before being discharged into rivers and water systems compared to only mechanical treatment plants. This applies in particular to phosphorous and organic material, but also other types of pollutants. Moreover, the Norwegian statistics show that 18 per cent of the population was connected to only mechanical or other types of treatment, 2 per cent had direct discharges and the remaining 15-16 per cent of the population connected to small wastewater facilities (< 50 pe) (SSB 2016).

The Norwegian pollution control authority requires permit for any activity that may produce pollution in the environment. The municipality is the competent authority that gives discharge permits of sanitary and wastewater systems according to Pollution Regulations Sec. 12 and 13 (NEA 2012). In order to achieve permit from the municipality, the house owner who wants to build small wastewater treatment plant needs to send application to the relevant municipality. The application should have standardized content requirements (utslippssøknad) and the municipality process the applications more extensively and detailed requirements are required for the application. For example, requirements for documentation of cleaning solution and requirements for operation and maintenance of smaller wastewater facilities (Hensel 2010). However, the content of the application and water pollution sensitivity in the areas may provide faster and delay processing of the application and more predictable pollution requirements from authorities might need to investigate.

In Norway, the pollution abatement policy not fully adopted as described in the water directive but with little adjustment. The pollutants removal standards are not general for all areas within the country but adjusted according to receiving water condition and pollutants sensitivity of the receiving bodies (figure 1). There is more focus on P removal and less on BOD. Whereas, full implementation of European Union Waste Water Directive required reconstruction of wastewater treatment with the target not only phosphorous removal but also organic matter and other nutrients depending on the sensitivity of the area (Källqvist et al. 2002). According to EU Urban Wastewater Treatment Directive (91/271/EEC) the treatment plant with hydraulic capacity of more than 10,000 PE which discharge their effluent in the sensitive area need to remove 90% phosphorous, total nitrogen and 70% BOD (Lindholm 2015)

Figure 1 Areas in Norway Defined Sensitive and Less Sensitive by Urban Wastewater Treatment Directive (Källqvist et al. 2002)



Sensitive areas: The coastline Swedish border-Lindesnes and associated watersheds and Grimstad fjord area (Nordåsvannet, Grimstadfjord, Mathopen and Dølvik)

Normal areas: freshwater Instances in Norway that is not classified as sensitive

Less sensitive areas: Coastal waters and estuaries from Lindesnes to Pasvik not classified as sensitive

Table 1 Wastewater Treatment Discharge Requirement (Hensel 2010)

Discharge to	Type of Recipient	Total P Removal	BOD_5 Removal	Suspended Stuff
Sensitive Area and less sensitive	Catchment used for water supply	90%	90%	
	Sensitive to Eutrophication	90%	70%	
	Neither use for drinking water nor Eutrophication problem	60%	70%	
Normal areas	-	-	-	20% or 180 mg/l

In 2015, 915 tons of phosphorous (TOT-P) discharges from municipal treatment facilities ≥50 PE. This is 3 per cent decrease compared to previous year. The number of advanced treatment (chemical/biological) have been increasing and this is one of the possible reason of this decline. Per inhabitant connected to treatment facility, this discharge corresponds to 0.20 kg phosphorous per year. Wastewater leakage from pipes is a big issue in Norway and about 40-45% wastewater leak (Lindholm 2016). However, it is estimated that about 1 420 tons of phosphorous discharge from whole wastewater sector including leakage from pipeline system (150 tons) and discharges from onsite wastewater facilities (355 tons) are also added. In comparison of this, Norwegian fertilizer statistics shows that 15 200 tons of phosphorous in the form of inorganic fertilizer and manure was applied to agricultural areas in Norway in 2013. Thus, in a "resource perspective in an ideal world" the wastewater sector could potentially cover around 9 per cent of the phosphorous demand in the agricultural sector (SSB 2016).

2.2 Centralized Wastewater Treatment Systems

Approximately, there are 2,500 municipal wastewater treatment plants in Norway. Out of these 400, have discharge permits from the County Governor whereas the rest are under municipalities' control. The municipality has the pollution control authority. Majority of these centralized wastewater treatment plants in Norway were built during the period 1970 to 1985.

At the moment, there are still 500 untreated discharges, covering approximately 350,000 persons, where treatment plants have yet to be built (SSB 2016).

There are different treatment technologies that individually or in combination can be used for wastewater treatment. Some of these technologies are well appropriate according to particular location. In open coastal waters, mechanical treatment is more common, since the aquatic environment there is less sensitive to this type of discharge. There are many factors such as capital cost, operation and maintenance, land requirement and performance efficiency are involved in the final selection of appropriate treatment technology. The following table shows the removal efficiency of different treatment methods.

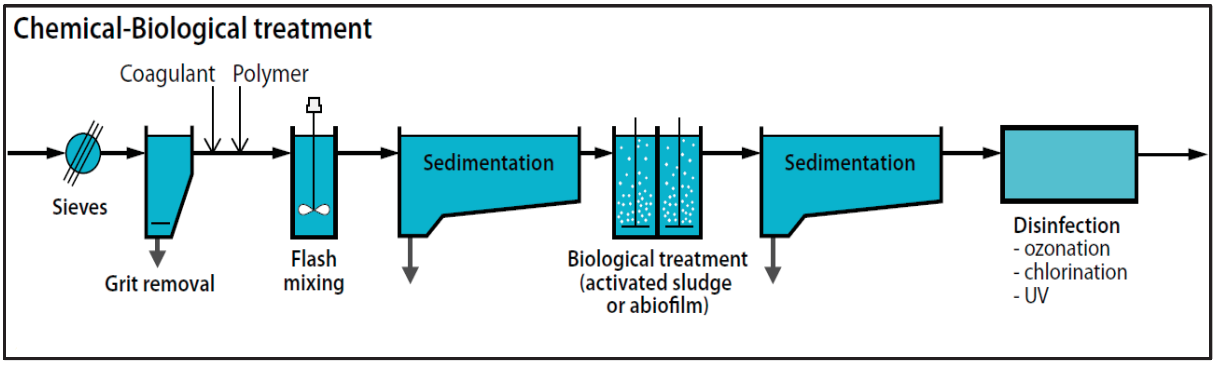
Table 2 Removal Efficiency of Different Treatment Methods (Ødegaard 1992)

Treatment method and their efficiency	**SS (%/**	**BOD_5 (%)**	**Tot-P (%)**
Preliminary treatment	<30	<20	<10
Primary sedimentation	50	30	25
Biological Treatment	85	90	45
Chemical Treatment	90	75	85
Bio-Chemical Treatment	95	95	95

In the above table the pollutants removal efficiency is described. Apart from first two options, biological and chemical treatment can remove enough amount of the pollutants but still there are not very satisfactory according to new regulation. Single method either biological or chemical treatment plant also accompanied many problems for example the biological treatment is very sensitive to temperature, required lot of space, may produce lot of sludge etc. However, the combination of chemical and biological treatment is best option in order to achieve optimal removal efficiency (table 2).

There are a variety of available configurations of each process unit and the possible compositions of the processes. However, generally conventional chemical-biological treatment plant consist of physical, chemical, and biological process (Figure 2). The general purpose of this configuration is remove solids, organic matters and nutrients from the wastewater. The disinfection part is also included in the following configuration but generally disinfection is used if the effluent discharge to drinking water source.

Figure 2 Chemical-Biological Treatment Plant Configuration (Ratnaweera 2016)



In 2015, the phosphorous treatment efficiency of the wastewater sector as a whole has been estimated at 69 per cent of the incoming amount. However, there is a big regional variety, and treatment efficiencies are generally higher in counties on the eastern part of the country and in the Trøndelag area, where treatment permits are more stricter (more sensitive to pollution) (SSB 2016).

2.4 Decentralized wastewater treatment systems in Norway

Generally, the decentralized wastewater treatment plants categorized into package treatment plants, infiltration/filtration and filter beds systems. The last two categories also called nature based wastewater treatment systems. The nature based systems are defined 'any systems that utilize porous soil and vegetation to purify wastewater' (Paruch et al. 2017). There are three main types of nature based wastewater treatment: soil infiltration, constructed wetland and sand filter. These systems are developed and successfully operated in Norway since last century in order to treat grey and black water from household and small industry. The focus of these systems is to remove BOD, P, N and bacteria.

In 2015, there were around 330,000 decentralized treatment systems in Norway. However, these numbers are reduce compare to 2012 when total number of treatment systems were 340,000 (SSB 2016). The following figure shows different categories of decentralized systems operated in Norway (Figure 3)

Figure 3 Number of Decentralized Treatment Systems (less than 50pe), by type of Treatment. The statistics of small-decentralized treatment systems with a capacity of < 50 pe are normally single houses or small privately owned or joint ownership with their neighborhood. These are located in scattered settlement (SSB 2016).

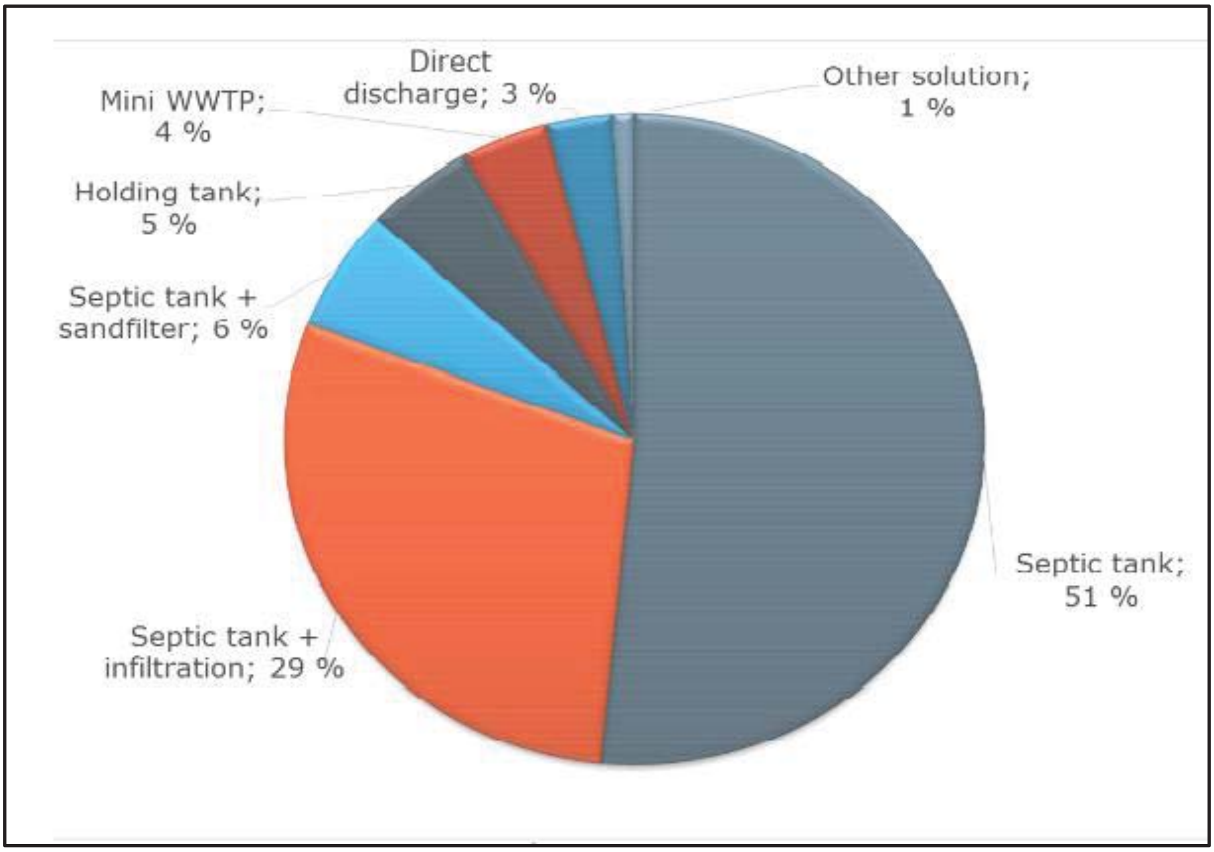


Figure 4 Trends of Onsite System with Time Scale (SSB 2016)

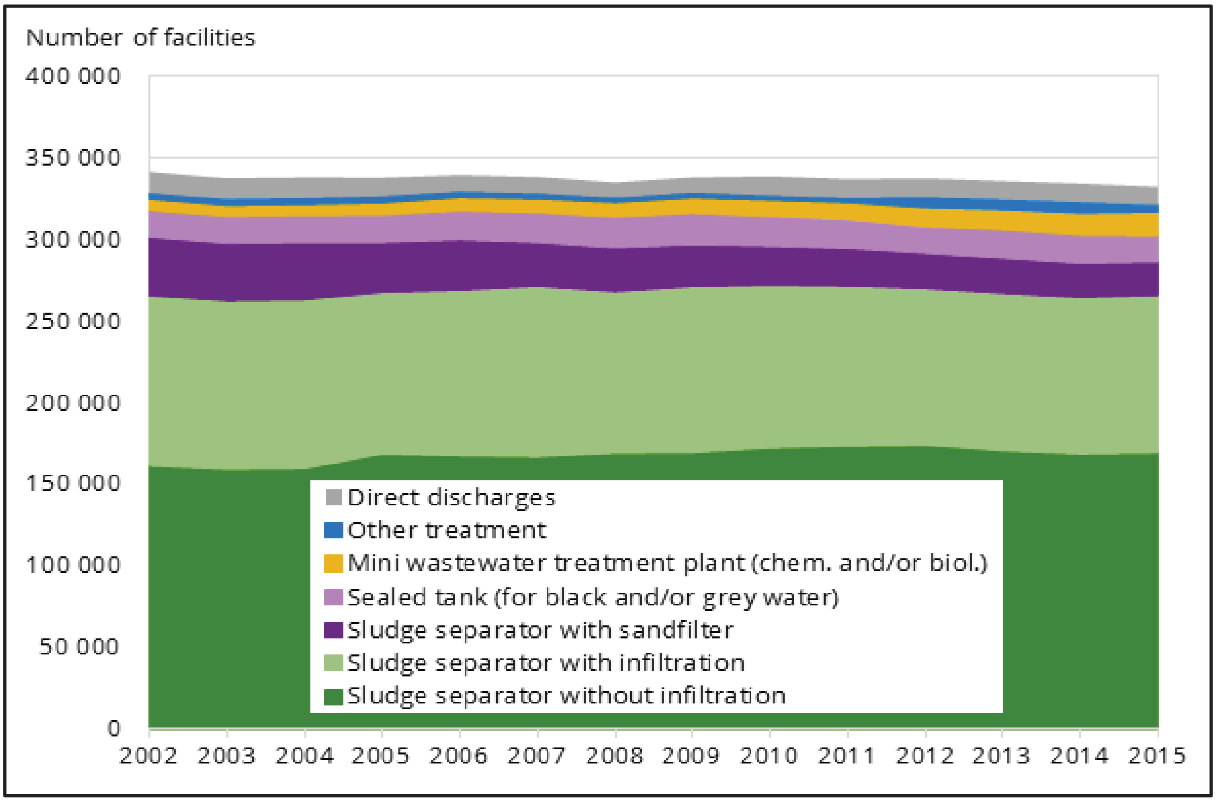


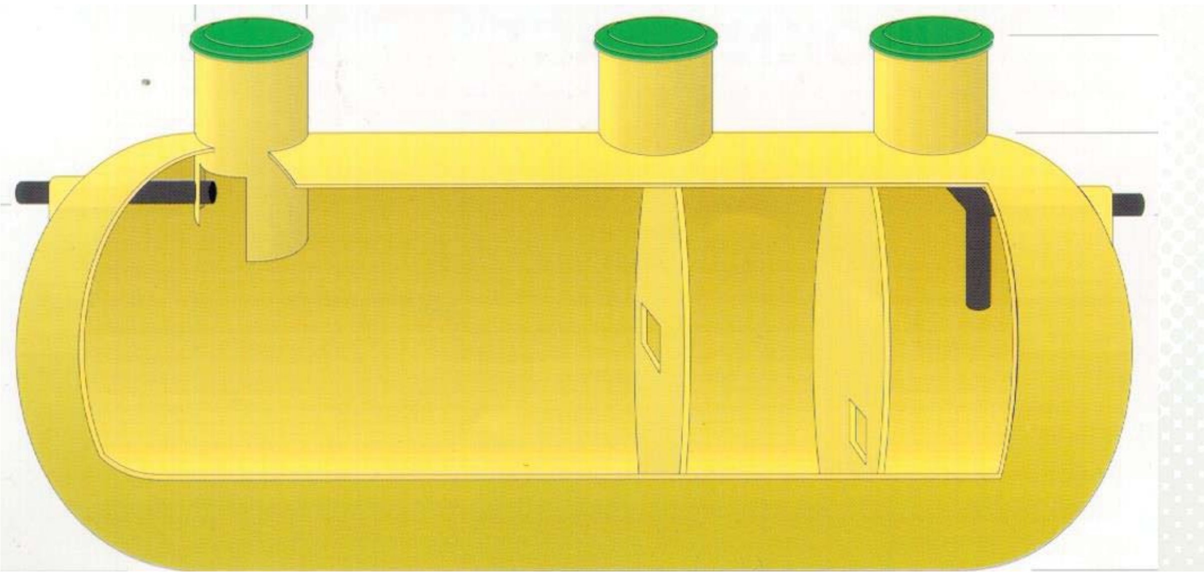
Figure 4 shows that septic tank in combination with sand filters has changed from 35 600 to 20 400 facilities over the time period 2002-2015, and this is clearly the type of treatment that is fluctuating the most throughout the time series (SSB 2016). However, the number of package treatment plant also increased since. The following section briefly described about onsite system operated in Norway.

2.4.1 Septic tank

Septic tank is watertight chamber and one of the most oldest and primary treatment step of domestic wastewater treatment. It is based on simple and robust technology that does not require electricity. The wastewater flow through the chambers and solid particles settle down and degrade under anaerobic condition in the chamber while oil, grease and foam float on the top. However, the rate of solid accumulation is higher than decomposition. So in order to better performance, the sludge and scum should remove periodically (SSWM Webpage).

Septic tank is a sedimentation tank either in shape of rectangular or cylinder. Currently, in the recent designs fiberglass, PVC and other plastic material based septic tank are widely used in Norway (SSWM Webpage). However, in the past concrete and bricks septic tank were common.

Figure 5 Fiber Glass Septic Tank with Three Chambers (Heistad 2017a)



Now a days, three chambers septic tank with minimum volume of $4m^3$ recommended for single household. Normally, the first chamber is large than others as it is designed to retain sludge inside (see figure 5). The first chamber should have 50% of the total length while second and third chamber comprises on 25% (Sasse 1998). It is recommended to have 18 hours retention time for domestic wastewater in the septic tank before it goes to another treatment section (Paruch et al. 2017).

The use of septic tank for wastewater treatment has been changed with passage of time. Currently it uses as pre-treatment step before bio-filter or soil treatment system. However, in the past in most of the houses in the coastal area septic tank was the only treatment method to treat domestic wastewater in Norway. Even though wastewater treatment performance of septic is very low but it has been used commonly in coastal areas in less sensitive water recipient (Heistad 2017a). As it has shown in figure 2.2 51% of the decentralized system in Norway comprises on only septic tank. In recent past, the effluent wastewater quality standards are more stricter whereas the septic tank effluent quality does not meet current wastewater standards that require to add more components after septic tank. Here is a table shows wastewater quality after septic tank treatment.

Table 3 Treatment Performance of Septic Tank (Chr.Køhler 2008)

Parameters	**Removal Efficiency**
BOD_5	20-30%
Phosphorous (tot-P)	5-10%
Nitrogen (tot-N)	5-10%
Suspended Solid	30-60%
Termotolerance Coliform Bacteria (TKB)	40-50%

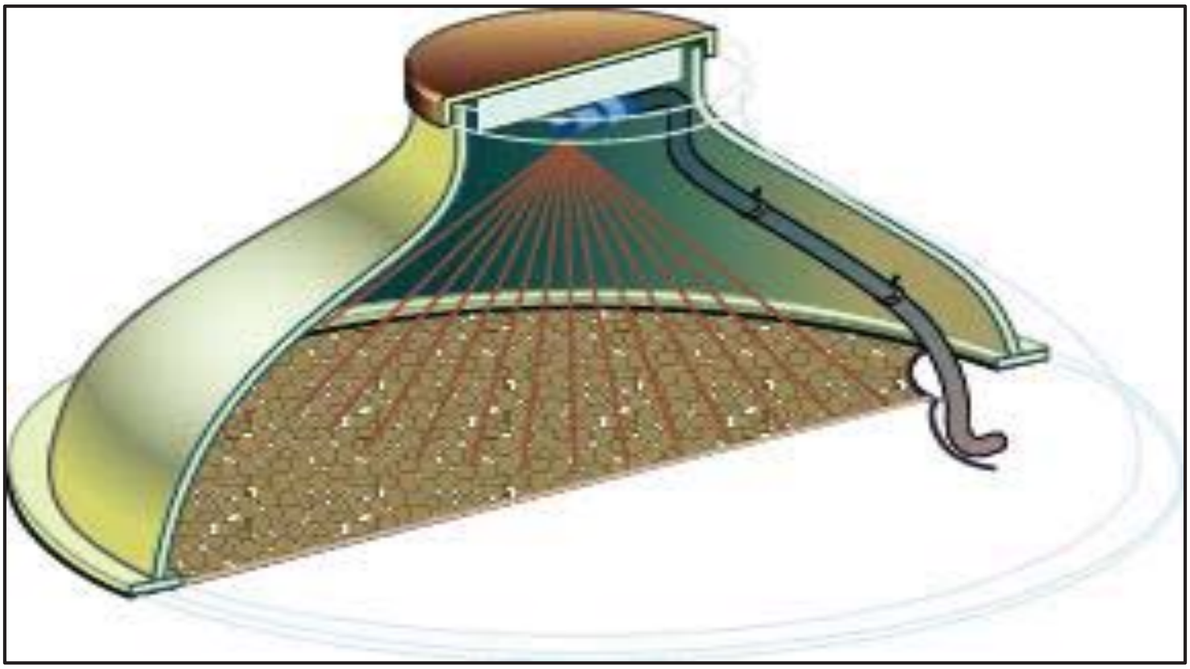
2.4.2 Bio-Filter

The bio-filter itself is not a complete treatment system but it is used as pretreatment step prior to soil treatment. The plants play important role in constructed wetland system in order to remove pollutants from wastewater. However, in cold climate like Norway the aerobic bio-filter, prior to soil treatment, is essential to remove BOD and achieve nitrification when the plants are dormant during the cold season (Jenssen et al. 2005). The bio-filter provides air supply in the winter season that further helps to enhance nitrification process and pre-treat effluent from septic tanks by reducing organic matters. Moreover, also helps to reduce clogging in the third step. Overall, bio-filter effluent load on third treatment step and increase treatment efficiency of the entire systems (Paruch et al. 2017) .

In order to achieve best performance of bio-filter, the effluent from septic tank should pump to bio-filter and evenly distributed to surface of filter media. This can be done through spray nozzles (see in the figure 6) or holes in the infiltration pipes (Paruch et al. 2017). However, spray nozzles found relatively more effective and provide equal distribution that further leads to higher treatment performance (Jenssen et al. 2005).

The bio-filter comprises on vertical down flow aerobic filter with special media. Light weight aggregates (LWA) used as a media that can build in a dome, tank or sheltered bed depending on local condition and environment (Jenssen et al. 2005; Paruch et al. 2017). These porous media is ideal for biofilm growth. There are specific design requirement for bio-filter and it is stated that there should be minimum 0.5m depth of the pre-filter material (Jenssen et al. 2005).

Figure 6 Bio-Filter with Spray Nozzle (Robertsen 2016)



2.4.3 Constructed Wetlands

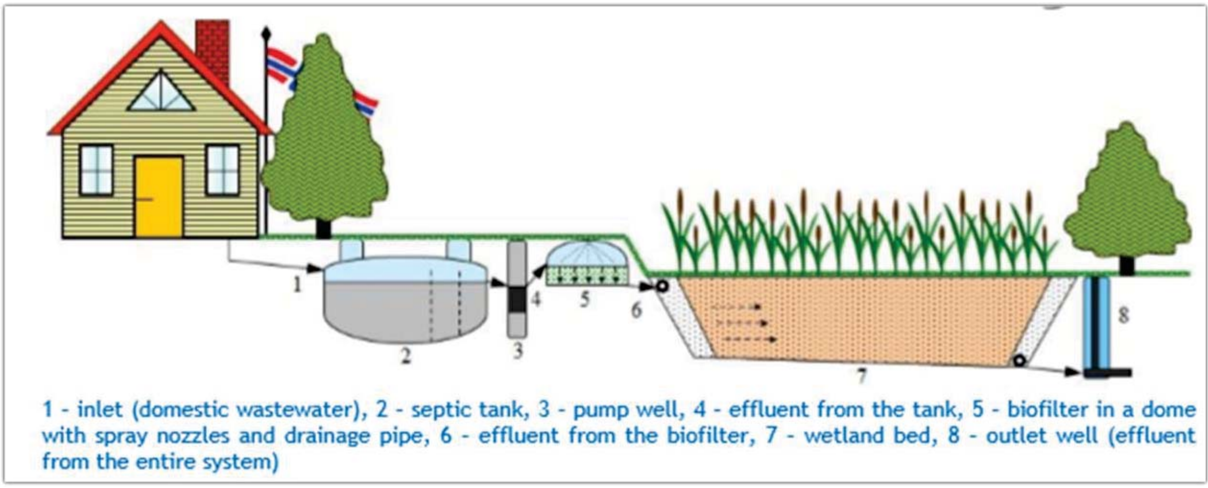
Constructed wetland is one of the most efficient nature based treatment systems in order to remove organic matters, nutrients and bacteria. The effluent from pre-treatment units flow into underlying submerged basin or into gravel mass integrated with the saturated filter (Paruch et al. 2017). This constructed wetland basin is one of the major component of the entire wastewater system that build with aim to achieve discharge limit of at least 1.0 mg P/L (Heistad et al. 2006; Jenssen et al. 2005). The removal efficiency of pollution parameters is very high: BOD > 90%, N > 50%, P >90% and bacteria >99% (Paruch et al. 2017).

There are two major categories of constructed wetlands: surface flow and subsurface flow wetlands. The surface flow constructed wetlands (SFCWs) also commonly known as free water surface wetlands with dense vegetation. The water depth normally less than 40cm and hydraulic loading rate between 0.4- 4 cm/d (Heistad 2017b).

There are two types of subsurface constructed wetlands: vertical flow and horizontal flow. In Norway, horizontal subsurface flow constructed wetland (HSFCWs) are widely operated. The constructed wetland includes three fundamental parts: septic tank, pre bio-filter (aerobic vertical flow) and horizontal flow wetland bed. The first and third step is common everywhere but bio-filter is mainly known in Norway (Paruch et al. 2017).

The role of the plants in constructed wetland is very important in order to remove pollutants that reported in many studies. With plenty of benefits, plants extract nutrients from wastewater that help in their growth, provides higher surface area for attachment of microbial population, transport oxygen down to roots, evapotranspiration and reduce water discharge in peak flow time, and finally help to remove heavy metals from the wastewater (Heistad 2017b).

Figure 7 Layout of HSFCW with Bio-Trickling Filter (Paruch et al. 2017)

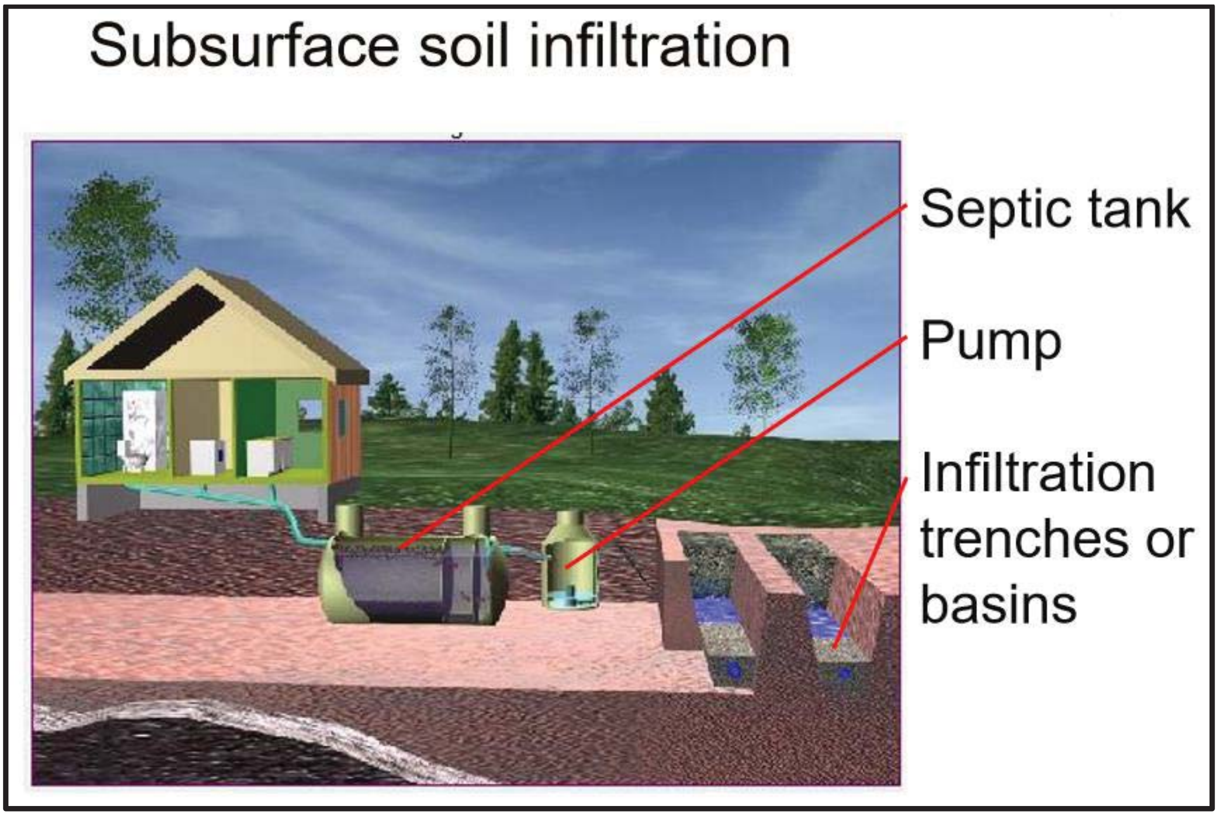


2.4.4 Soil Infiltration Systems

Soil infiltration is one of the preferred onsite wastewater treatment system if local soil condition, geology and distance to nearby water bodies is appropriate. So in order to figure out these factors there is necessary to carry out satisfactory investigation prior to construction of such system. Somehow, the investigation further give hint to select other technologies if local condition are not appropriate for soil infiltration.

There are three main component of soil infiltration including, septic tank where sedimentation and degradation of organic matter took place, pump that distribute septic tank’s effluent into trenches and finally soil filter (infiltration trenches) (figure 8). Normally coarse soil material uses in the trenches and more than one trenches are preferred. The actual purification take place above ground water table and below top layer of cleaning medium (unsaturated zone). This treatment method is highly efficient and expected life expectancy at least 20-30 years (Maehlum et al. 2010).

Figure 8 Soil Infiltration System (Robertsen 2016)



There are three types of soil infiltration systems that includes: subsurface infiltration: Open basin: Combined systems (chemical/infiltration). All three categories have different treatment capacity as subsurface infiltration system can treat wastewater from 5-600 pe equivalent, open basin from 150-6000 p.e and combined systems from 5-2000 pe (Robertsen 2016). In the open basin normally more than one basins are used (basin for sedimentation and basin for infiltration). Rena municipality in Norway has open basin rapid infiltration system. This is one of the largest infiltration system in Norway with the capacity of 8,000 pe. The system is treating wastewater from Rena town and nearby army camp. Before the wastewater discharge to open it goes through mechanical screening step. Apart from Rena, Koppang also has open basin soil infiltration system (Jenssen 2012; Robertsen 2016).

The subsurface soil infiltration systems treat the wastewater from single household, cluster of houses less than 600 pe, camping sites, cabins area, hotels boarding houses and military bases. It is a low tech system that is easy to build and maintained. Low cost and high purification ability if properly design and well maintained. The subsurface soil infiltration has four types: deep infiltration, shallow infiltration, surface infiltration and mound system.

The deep infiltration used where the ground water table and bedrocks are very deep and the top soil cover is not suitable for infiltration (clay). There will be good cleaning effect in the soil before infiltrated water reaches closer masses or groundwater. Urban masses are refilled over the filter, and an infiltration filter based filter usually does not limit the use of the area above the filter. Shallow infiltration used where the inherent masses have too low conductivity in deeper layer. So the infiltration is possible in the upper layer of soil around 10-50cm deeper. The main purification take place in this soil masses before water reach to either underlying clay or groundwater table (Maehlum et al. 2010)

Surface infiltration can be used where the indigenous masses have too low water conductivity so that infiltration plants can be established. An infiltration filter based on surface infiltration is placed on top of the terrain surface after the vegetation has been removed. The effluent needs to descend into the upper layers of soil where it is cleaned before the water penetrates into underlying and denser masses (Maehlum et al. 2010).

The mound system is design where the original soil is not suitable for infiltration. It is design where slow or fast permeability of the soil and shallow ground water table or bedrocks. The basic purpose of mound system is to provide sufficient enough soil for wastewater treatment. There are three principal components that include: pretreatment units, dosing chamber and elevated mound system (EPA 1999).

The infiltration systems are failed in some places in Norway and here are some possible reasons (Robertsen 2016):

- Lack of knowledge and expertise to design the systems
- Insufficient soil survey
- Low or very high hydraulic capacity of the soil
- Loading rate is too high
- Old and small filters
- Change in groundwater table and ground water intrusion in pipes
- Clogging due to sediments
- No or inadequate maintenance

2.4.5 Sand Filter

Sand filter is one of the oldest wastewater treatment technology. The sand filter is a bed of granular material or sand. The wastewater applied on the top surface of the sand bed and drained underneath so that the wastewater can be treated. It is used as pretreatment to polish effluent from septic tank. However, it is also used as complete wastewater system with septic tank (Lesikar 1999).

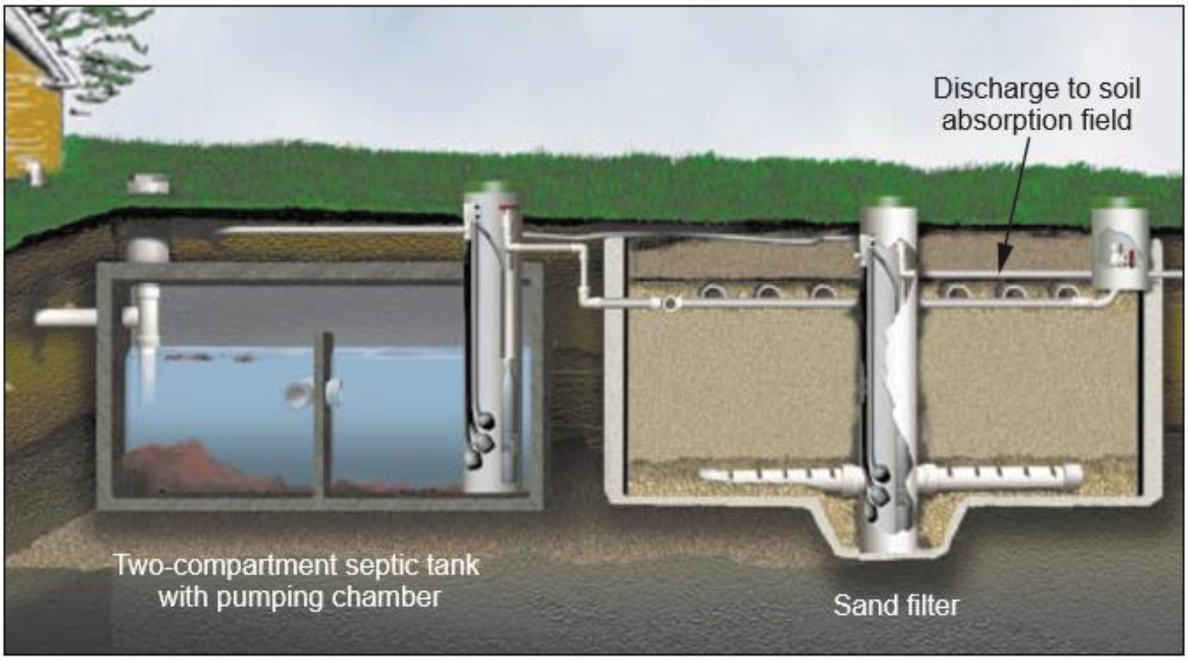
The wastewater is applied through distribution pipes periodically to 24-36 inches deep bed of sand. Sand filter can buried in the ground or free open access. Free access sand filter normally have lid above the ground and easy access to inspect.

Sand filter purify wastewater in three ways (Lesikar 1999)

- Filtration: in which particles are physical screen in sand from incoming wastewater
- Chemical sorption: in which the pollutants attach to the sand surface and biological film develop
- Assimilation: in which aerobic microorganism eat nutrients from wastewater. In order to achieve better performance there should be air supply for this process

Concrete or PVC lined box filled with specific material or sand is a typical design of sand filter. It should be important to have same grain size or atleast less variation of the material used as media. Larger the grain size means less purification ability whereas very small grain size can enhance clogging of the system.

Figure 9 Sand Filter with Septic Tank as Pretreatment (Lesikar 1999)



Several factors are important for better performance of sand filter. However, temperature and aeration are the most important factors while designing or dimensioning of sand filter system. The temperature directly affects microbial growth in the media and chemical adsorption of pollutants whereas oxygen needs to be available in the pores for breakdown of microbes (Lesikar 1999).

Clogging of sand filter is one of the most common problem. This clogging may occur due to physical or biological factors. Physical clogging refer to situation when large particles accumulate on media surface. This may happened due to insufficient pretreatment or failure in the pretreatment section. Biological clogging caused due to high microbiological growth in the media and slime layer hindered the filtration of wastewater through media.

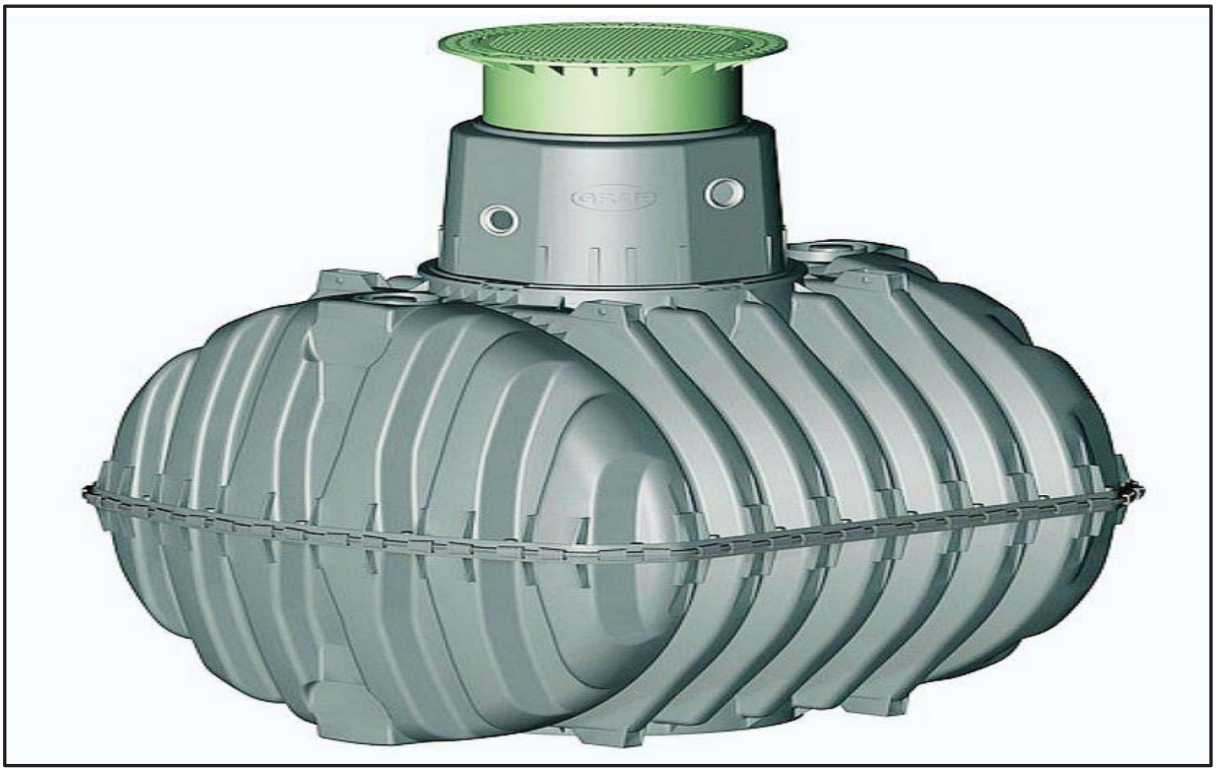
According to statistics, the number of sand filter treatment have been decrease 43% since 2002 to 2015 in Norway (SSB 2016). In figure 2.4, the trend shows that this is the only treatment method that decline the most. One of the strong reason of this decline is, poor treatment performance and clogging in the sand filter systems reported in some investigated studies (Eikum & Seabloom 2012).

2.4.6 Holding Tank

A holding tank is onsite wastewater collection system that is incorporate a plastic, cement or fiberglass tank. It is a mean to collect and temporarily store wastewater and especially black water from a facility. The tank needs to empty when it is filled by large vehicle and transport to nearby conventional wastewater treatment sites. Depending on the number of persons and usage, the transportation of sewage is very expensive especially on long-term basis.

As it is mention, it is quite expensive method to collect and treat wastewater, so the applications are very limited. It can use for summerhouses where the facility will use only for few weeks or months in a year, in emergency situation like disaster or where an approved repair or replacement sewage system installation is delayed due to weather conditions, and/or weather-induced soil or site conditions. Moreover, it also uses at places where other onsite facilities are not appropriate due to less soil or water bodies close to facilities.

Figure 10 Septic Holding Tank (BARR 2015)



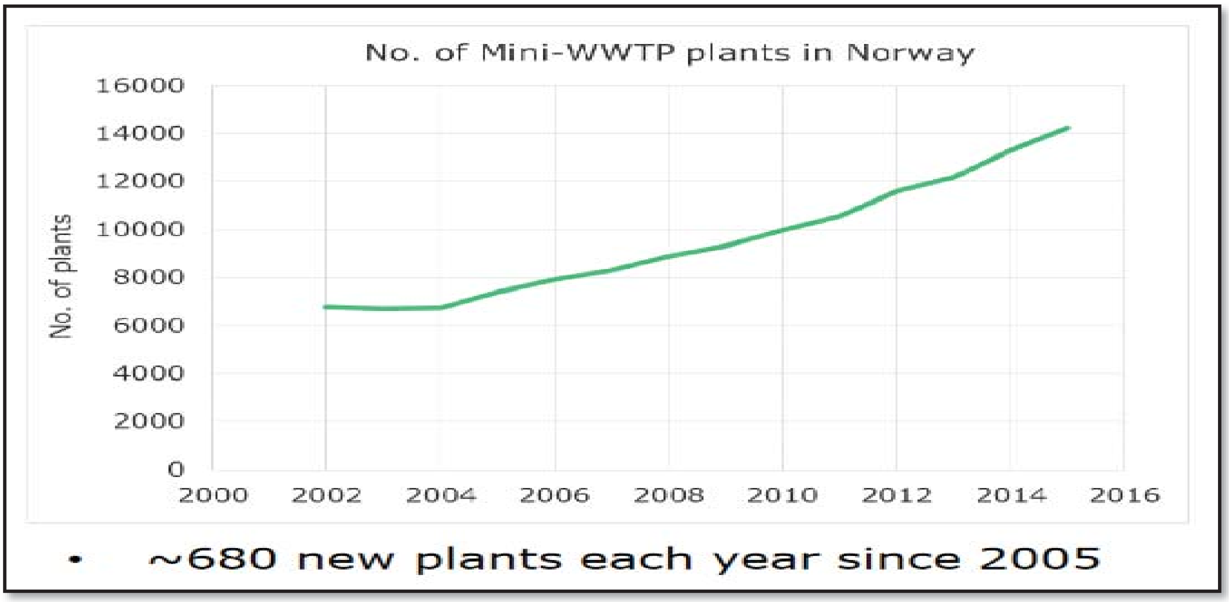
The holding tank has inlet pipe and in some of the design overflow pipe as well. The tank has alarm that give message to house owner to empty the tank. From top green cover in the figure 2.8 use to suck the sewage into truck by pumping.

2.4.7 Package Treatment Plants

The package treatment plants are small version of large-scale wastewater treatment plants. They are prefabricated plants equipped with chemical and biological technology in a single tank to remove pollutants from wastewater. In Norway, package treatment plant are in operation from last 20-30 years. Since last 15 years, the number of package treatment plant has increased (Yri 2007).

Figure 2.10 Growth Trend of Package Treatment Plants in Norway (Johannessen 2017)

Figure 11 Growth Trend of Package Treatment Plants in Norway (Johannessen 2017)



Currently, 14,200 of such treatment systems are in operation around Oslofjord and West coast, also scattered around the country. Statistics shows 110% growth rate in package treatment plants in the country since 2002-15 (SSB 2016). The treatment performance of package treatment plants highly criticized by different researchers. However, some defended this criticism by saying 'package treatment plants can perform just like advanced municipal treatment systems if they are properly maintained and operated'.

Package treatment plants are functioning since 20-30 years in Norway. However, some design and plumbing regulations have been changed since that time. Lastly, the wastewater regulation have been updated in January, 2007 in which it was mentioned to sell package treatment plant only with European standard tag NS-EN 12566-3 (Yri 2007). In Norway, SINTEF has authority to give certificate to some companies that can sell package treatment plants.

There are 16 companies providing package treatment plants technologies in Norway at the moment. However, these numbers are very less compare to Germany where 400 companies are working, while in Sweden almost 30 (Johannessen 2017). The following table shows certified companies from SINTEF that are providing package treatment solution in Norway.

Table 4 Package Treatment Plant's Registered Companies in Norway (SINTEF 2017)

Product	**Certification expiry date**	**Company**
August-At Package Treatment plant (chemical)	01.04.2022	August Norge As

August-At Package Treatment plant (chemical)	01.04.2022	Biorens Skandinavia as
Biovac package treatment plant 5-50 p.e	01.07.2017	Biovac Environmental Technology As
In-drån Bio-bed 5 package treatment plant	01.01.2020	FANN VA-teknik
Green Rock IISI S6 PRO	01.10.2019	Green Rock As
Bio-Flow package treatment plant	01.01.2018	Ipec Miljø as
Klargester BioDisc package treatment plant	01.04.2022	Kingspan Miljø As
Klargester Bio-safe package treatment plant	01.04.2019	Kingspan Miljø As
Klaro 5-50 p.e package treatment plant	01.07.2017	Klaro Renseanlegg Norge As
Odin Batchpur package treatment plant	01.04.2022	Odin Miljø As
WehoPuts 5-50 p.e	01.07.2017	Uponor Infra As
Uponor Clean 1 package treatment plant	01.04.2019	Uponor Infra As
Baga Easy package treatment plant with Biotank	01.10.2021	Vestfold Plastindustri As
Baga Easy package treatment plant with Bio-moduler	01.10.2021	Vestfold Plastindustri As
Wallax package treatment plant	01.07.2020	Wallax As
Wallax package treatment plant with biological treatment	01.07.2020	Wallax As

Treatment Processes in Package Treatment Plants

Currently following treatment processes are available in the package treatment systems.

Septic Tank

The septic tank is refer to sedimentation tank that has three chambers in the current manufacturing design. In package treatment, the third chamber is normally used as pumping station and balancing chamber that regulate the flow into next treatment step. Due to cold climate in winter, rarely give any anaerobic treatment.

Biological treatment with aerobic units

This include:

- Activated sludge
- Fixed film process
    - Bio-filter (Trickling filter)
    - Bio-disc (Rotating biological contactor)

Biological-Chemical treatment

- Simultaneous precipitation
- Post precipitation

Chemical Treatment (phosphorous removal)

- Post or Pre-precipitation with primary treatment

In Norway, the primary aim of a biological/chemical plant is to remove phosphorus, organic materials and particles. In some of the area pathogens are also prioritized where the effluent water is discharge into drinking water supply source (Johannessen 2017). In the market, they are several companies who claimed purification efficiency of 90% for both phosphorus and organic matter. Moreover, they also claim for 99% removal of thermo- stable coliform bacteria (TCB). Biological / chemical package treatment plant also used in the areas defined as sensitive and normal in pollution (rensegrad jf. §12-8 i forskriften) (Yri 2007). Sludge production also vary within type of treatment technology applied. The literature shows that chemical based package treatment system produces more sludge than biological treatment processes. Normally sludge is collected once in a year (Johannessen 2017).

The treatment performance of package treatment plant depends on configuration of the system. Yri (2007) described theoretical treatment performance of package treatment plants with different treatment processes in the following table.

Table 5 Treatment Performance of Package Treatment Plants

Parameters	**Treatment performance**		
	Biological .P.T.P	Chemical .P.T.P	Bio-Che. P.T.P
Phosphorous	15-60%	90%	90%
Nitrogen	80%	60%	90%
BOD	20%	20%	20%
Tarmbakterier (TKB)	90%	99%	99%

The effluent after package treatment plant needs post-polishing step to meet standard requirement depending on the sensitivity of the area. The Polishing step formed differently depending on whether it be focused on disease-causing organisms or retention of particles, or alternatively both (Yri 2007).

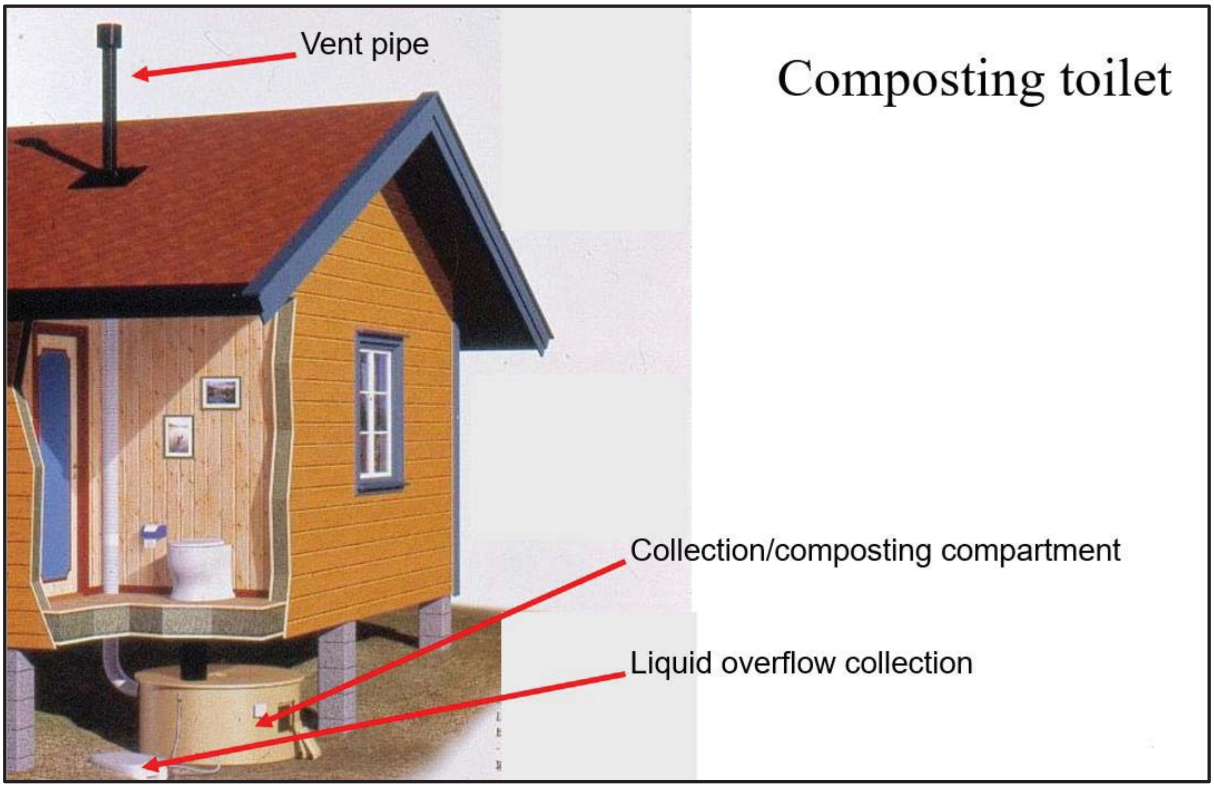
In order to investigate treatment performance of package treatment plant in the field, a study conducted in Norway in 2006-2008. In that study, about 91 package treatment plants have been inspected in the Vansjø and Hobøl watershed. The results of study shows that organic matter removal of package treatment was satisfactory with effluent concentration of 17.7 mg BOD. However, phosphorous removal efficiency did not meet discharge requirement, as effluent concentration of P was 1.9 mg/L. The study also found out possible factors that causes poor P removal in package treatment plants. Those include suboptimal pH for precipitation, suspended solids loss, insufficient sludge collection, low chemical dosage, equipment malfunction and insufficient maintenance. Many plants experienced un- intentional nitrification (Johannessen et al. 2012).

Gill (2012) conducted a review study in Ireland with the title 'The suitability of packaged wastewater treatment systems for direct surface water discharge in rural Ireland - A review of performance and cost efficiencies'. In this study 40 package treatment (6 large and 34 small package treatment plant) has been investigated. The review demonstrate that, the package treatment plant highly remove organic solids and ammonia and discharge effluent meet standard requirement level. However, the nutrients removal like phosphorous was not remove sufficient enough to meet standard requirement and need further treatment processes if the wastewater needs to discharge in sensitive areas.

2.4.8 Composting/dry Toilet

Composting or try toilet are water less toilet frequently used in cabins, near sports grounds and in some rural houses. This type of toilets use in Scandinavia and also widely used in dry areas and poor countries. (Hanssen et al. 2005). In Norway, composting toilet widely used in summerhouses (hytte). Composting toilet design with or without urine diverting toilet. Urine contains most the wastewater nutrients and separate urine collection from feces has multiply benefits but this required extra labor. In order to avoid containments from urine and compost WHO formulate guidelines for proper disposal and reuse. According to WHO (2006) in Scandinavia there is atleast needs 2 years resting time for compost before it applies to the field because in cold climate the microorganism can survive for longer time. For warm climate countries this limit is 6 months. Dry toilet considered best alternative option that give equal or higher reduction of pathogens if right measures are taken during operation and handling (Hanssen et al. 2005). Potential health risk may occur while handling or emptying the compost tank that counteracted with removal compartment.

Figure 12 Composting/dry Toilet Design (Hanssen, Paruch et al. 2005)



2.5 Discussion (Centralized Vs Decentralized Treatment Systems)

There are many factors that can define the sustainability of the wastewater treatment plant. According to (Muga & Mihelcic 2008; Prihandrijanti et al. 2008) the sustainability of a wastewater treatment plant is a function of economic, environmental and social sustainability. The economic sustainability can obtained by looking at capital, operational and management cost of the plant. The environmental sustainability can further see through energy use because it is a direct use of resources, pollutants removal (BOD, ammonia, nitrogen, phosphorous, pathogens) efficiency, reuse of resources and carbon footprints etc. For societal sustainability the indicators includes the general acceptance of that specific technology and improved local environment (less odor and nuisance).

The centralized wastewater treatment systems are costly to construct and operate. Both in mega cities and the areas with low population densities, the investment cost of sewer systems is very high (Massoud et al. 2009; Wilderer & Schreff 2000). This investment issue even more severe for developing countries that are lack of funding to build centralized collection systems and lack of technical manpower to operate such systems effectively (Massoud et al. 2009).

By contrast, to this, decentralized systems treated wastewater close to where it is generated, that does not require costly sewer network. The decentralized treatment systems can be single onsite or cluster of small treatment systems ranging from simple to complex technologies (Massoud et al. 2009). Modern prefabricated industrial package treatment systems are available in the market and the degree of technology that should use and their treatment performance is under dispute (Heistad et al. 2006; Jenssen et al. 2010; Wilderer & Schreff 2000). However, when it is produce at large scale the cost of manufacturing package treatment plant become very low (Wilderer & Schreff 2000).

In order to assess the economic aspects of the both approaches a case study was conducted in Indonesia with the title 'Cost–Benefit Analysis for Centralized and Decentralized Wastewater Treatment System (Case Study in Surabaya-Indonesia)'. This study investigate the economic aspect of three scenarios of wastewater in a densely populated urban area. Cost benefit analysis was made to support the decision making process by brining element of transparency and objectives. The results of this case study demonstrate that the decentralized systems was more economically feasible because centralized wastewater treatment system had the highest net present value cost and the lowest cost—benefit ratio (C/B ratio). This study only focus on economic aspect of both of the approaches whilst it is recommended to have further assessment on environmental, health and social aspects in order to support decision making process (Prihandrijanti et al. 2008).

The principal of environmental sustainability related to treatment facility not to be harmful to the environment or depleting natural resources. In order to assess environmental sustainability, the impact of pollutants (organics, nutrients and pathogens) discharge from treatment plants on natural water resources as well as the amount of greenhouse gases released from energy use for the treatment needs to estimate.

In order to protect public health and environment from bad performing wastewater treatment systems, different studies have been done in recent years. Many of the studies have done to investigate the causes of failure of the onsite systems while other studies focused on the consequences (Carroll et al. 2006).

There are three treatment steps in most of the onsite treatment systems (also described in previous section). These treatments includes septic tank, pretreatment bio-filter and finally soil media either in infiltration or wetland systems. The treatment performance of whole of the system entirely depends on the efficiency of each of the treatment steps. This linear removal performance effect the efficiency of the rest of the treatment system (Vymazal 2016). For example, in the septic tank the degradation of organic matters and settling or floatation of solid happened. If the degradation and settling of organic matters is not happening properly, the solids will go into bio-filter that may clog the filter media and treatment performance of this step will effect. In the bio-filter greater than 99% BOD, 40% nitrogen and significant amount of phosphorous is removed (Heistad et al. 2006; Jenssen et al. 2005; Jenssen et al. 2010). However, if the efficiency is not at optimal level, this would increase pollutants burden on next step (soil bed). This may lead to bad removal performance of the whole system.

Properly designed, constructed and maintained onsite wastewater treatment systems are efficient source to treat and dispose the wastewater. It is considered economically and ecologically best way to treat wastewater at places which are not connected to centralized wastewater collection systems. However the failure of such systems have potential to pollute the watersheds with nutrients (nitrogen and phosphorous), pathogens and pharmaceutical and personal care chemicals (GWPC 2007).

US EPA (1997) publish a report and demonstrate that septic tank soil absorption system were the second leading cause of contamination in the water bodies. Borchart and others (2003) said that 8-11% of human enteric viruses presence was found in drinking water wells that close to septic tank soil absorption systems. Further they elaborate that magnitude rate could contaminate 1.2 million U.S households (Carroll et al. 2006). Yates (1985) wrote that in US 50% of water born disease due to consumption of contaminated drinking water and septic tank systems were most prominent reason of this contamination. Hepatitis A outbreak happened at Wallis Lake in the state of New South Wales Australia where 444 local residents got positive Hepatitis A virus in their body. Further it was investigated that the presence of this virus was due to eating contaminated shellfish from wastewater (Carroll et al. 2006). (Goonetilleke et al. 2002) investigated the causes of poor performance in Australia and demonstrated that inadequate soil assessment before construction was the major attribute.

The potential environmental impact become higher if the onsite systems not constructed properly. Even, problem become more severe in the areas, with low or high permeability in the subsoil and where ground water is very shallow. The low permeability leads to ponding while high permeability leads to discharge to pollutants in the groundwater (Dubber & Gill 2014).

2.6 Summary of Literature Review

Phosphorous removal is one of the main criteria from any sort of wastewater treatment methods. The number of advanced treatment systems (chemical/biological) are increasing in the country because they are more efficient to achieve pollutants discharge standards. The number of package treatment plant increasing while sand filter are decreasing in Norway. Package treatment considered often the most affordable option where there are strict effluent water quality standards and there are no opportunities for infiltration into local earth masses. These systems are very compact and require little space and can usually be placed in a basement, garage or buried. However, the operating cost costs of package treatment plant is high. Moreover, the treatment efficiency of many package treatment plant gradually decreased with passage of time. In some cases where the requirements relating to bacterial and / or nitrogen purge, polishing step is necessary afterwards. The plants have good medium of infection protection (Yri 2007).

To have a sustainable wastewater treatment system, an integrated assessment of each alternative based on its economical, environmental, social, health and institutional aspects is necessary (Prihandrijanti et al. 2008). In order to reduce energy consumption due to wastewater treatment, and climate change vulnerability, onsite wastewater systems are best alternative solution. The joint treatment of grey water and storm water in the onsite systems is less energy intensive and low investment cost (Muhammad Umar 2016). Matos et al. (2014) also demonstrate that onsite treatment systems use less energy and produce less CO_2 footprints than conventional treatment systems. The treated grey and storm water's quality is more than enough to use this water for laundry, toilet flushing, gardening and washing that can significantly reduce burden on freshwater resources in any country. However, there is need to regulate policies that can focus on such issues as Copenhagen implement three tiered systems for rainwater, storm water and black water (Muhammad Umar 2016). The decentralized system is not only a long-term solution for small communities but is more reliable and cost effective (Massoud et al. 2009).

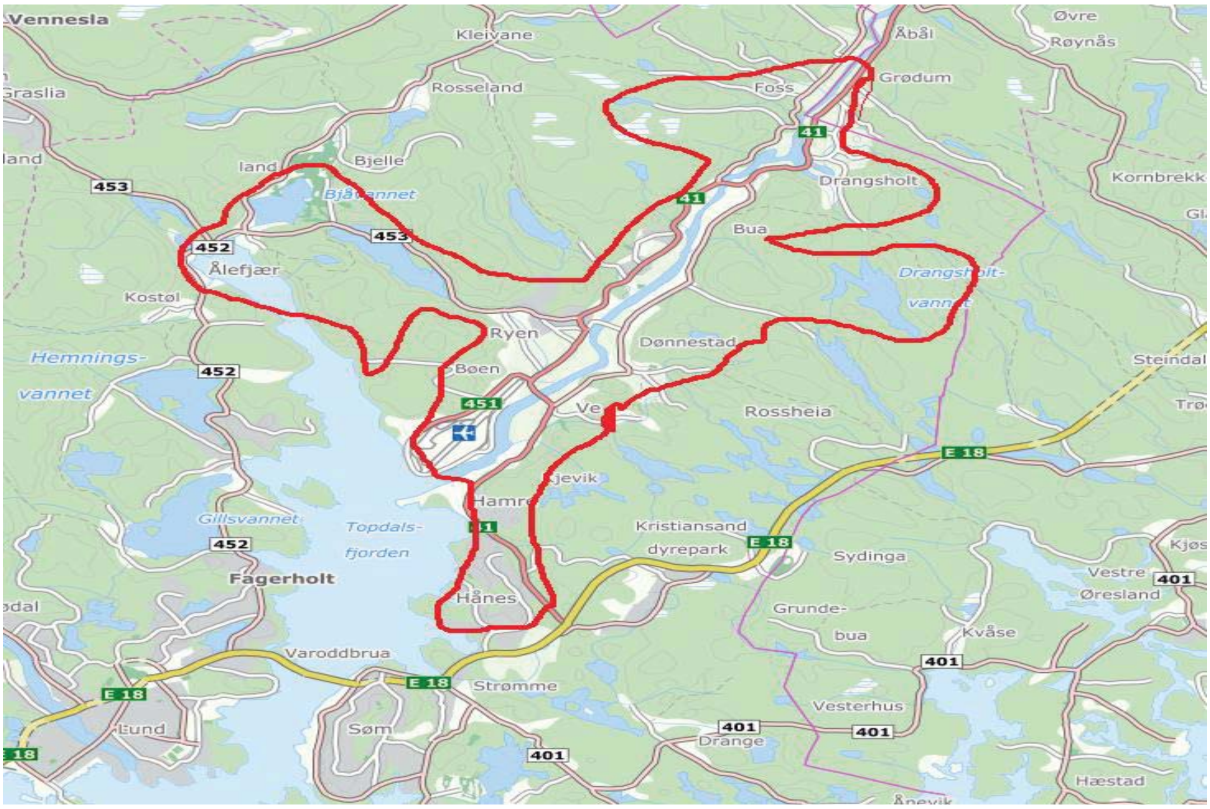
Chapter 3

Methodology

3.1 Study Area

In the first phase of small onsite treatment systems inspection, North and East side of Kristiansand city has been visited. The survey site approximately half an hour away from city center. More than 500 treatment systems surveyed, and visited system located along Topdals River and Ålefjær watershed. For data analysis 406 has used because some of the visited systems were dig down under the soil. The red line in figure 13 demark the visited area. Along Topdals River most of the houses used as permanent settlement while some of recreational house found in Ålefjær area.

Figure 13 Location of the visited small onsite systems



Adapted from Kristiansand Kommune Gisline

3.2 Information Collection Strategy

Broadly, survey has two major categories 'questionnaire' and 'Interviews'. For this study, the municipality used its pre design form (questionnaire) ''called field form'' to obtain relevant information about treatment systems. If the house owner was at home and willingly interested to ask questions and answer, he/she was welcomed to participate in the inspection.

The survey conducted between 15/06/2016 and 15/08/2016 and was performed by four students (including writer) from Norwegian University of Life Sciences (NMBU) Ås, Norway. For field visit, two groups were made (two persons in each group). The inspection performed during working hours from 8.00 to 16.00. The students employed on summer job in the municipality and provided all basic office equipment, PC to record the data, tablet for GPS, printer, ID card for entrance to municipal building and to show in the field. The students recorded the type of sewer systems founded on the properties, plot exact location of the system on the map and update municipality data.

3.2.1 Pre and Post Survey's Notification

A pre notification to get aware about inspection was send to each relevant house owner at least two days before the visit. The basic purpose was to make facilities available for inspection, but it was not necessary to be present at home while inspection team arrive. However, buried manholes were requested to be dug up by the house owner and overflowing or central covered manhole cover must be made available. Due to widely and high vegetation throughout the summer in the region, it was encouraged therefore that facility owners with treatment plants that have located in areas where vegetation is very high and difficult to find manholes, select the plant site by putting down a high pole at one or more on the tanks. This is so that those who conducts an inspection of the property should be able to find the treatment system easier. Some of the house owners accept this request and do how they supposed to. After visiting the system, inspection team left a note in the pertinent mailbox so they know the team was there.

3.2.2 Training prior to survey

The students trained for inspection at Hurdal municipality in Akershus from small onsite wastewater system's professionals including Guro Randem Hensel (siv.ing/seniorrådgiver divisjon miljø og naturressurser Seksjon Grøntanlegg og miljøteknologi) and Petter D. Jenssen (Head of Master program in Sustainable water sanitation and public health at NMBU). This one day training consisted on two-hour presentation about nature based onsite wastewater treatment systems and 4 hours actual visits of small onsite treatment plants in Hurdal municipality. The focus of this training was

- To give overview what type of onsite systems and different component with them
- Check points for various components in a separate
- Hygienic safety while visiting the plants
- Physical security measures

- Performance criteria
- Insight of some issues and problem while visiting the plants

3.2.3 Vaccination

It is not possible that wastewater treatment system has no fecal contamination because it treat and pass through the feces. The inspection of such systems demand to touch the system that can cause to any pathogenic infection to the visitors if proper health measures are not adopted. Therefore, four of the students got DT and Hepatitis A and B Vaccination before survey in order to avoid any disease.

3.3 Information gathering and data registration in the municipal database system

Figure 14 Data Collection Form

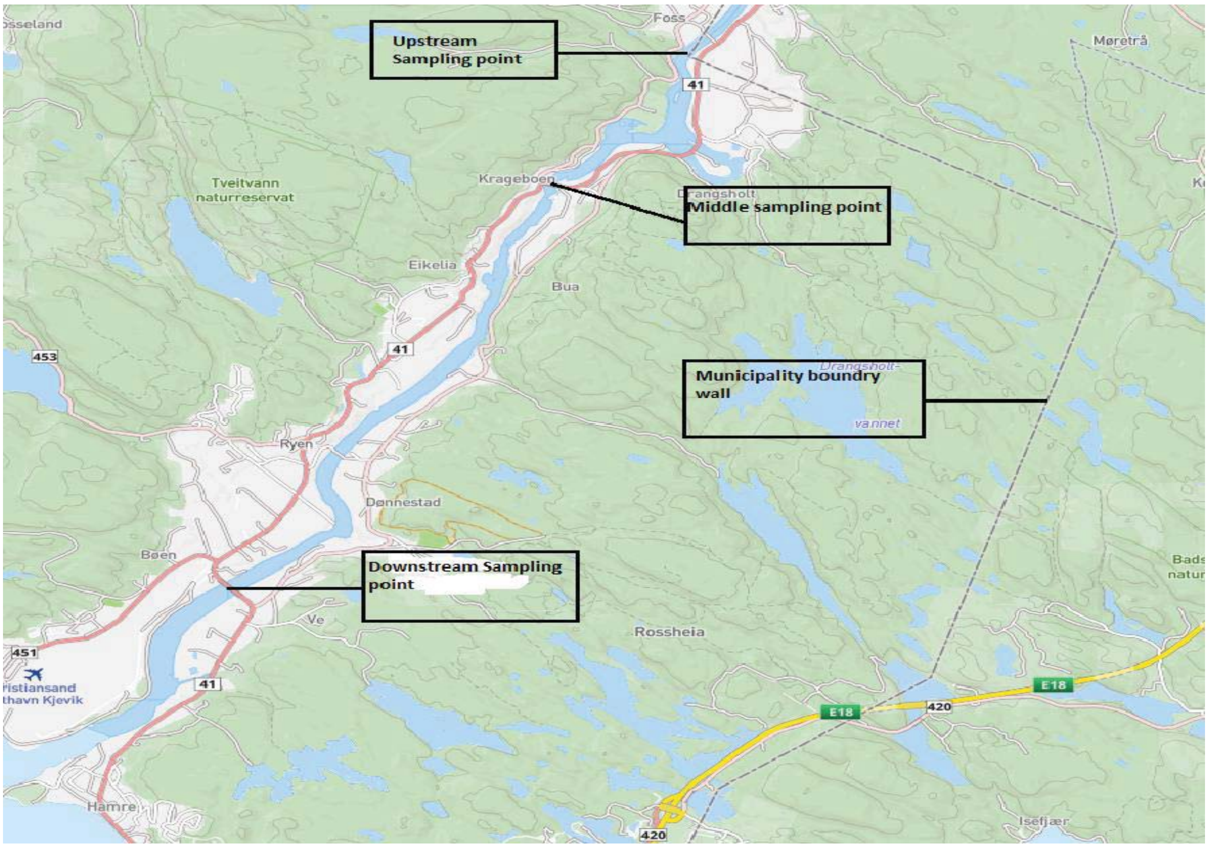
Feltregistreringsskjema avløpsanlegg Kristiansand							
LOKALITET					Registrert av:		Dato:
Anleggs nr.		GNR					
Anleggsadresse		BNR			EIER		
X		FNR			Navn		
Y		SNR			Adresse		
Koordsys					Poststed		
ANLEGG					RESIPIENT		
Type anlegg:					Avst. Til resipient		
0 Anleggstype ikke registrert		Anlegg år	fra arkivet?				
1 Direkte utslipp		PE			BYGNING		
2 Slamavskiler med utslipp til terreng		volum			bygninstype		
3 Slamavskiller med utslipp til vann		ant. Kammer			brukstid		
4 Infiltrasjonsanlegg		ant. Grøfter			ant. hustander		
5 Sandfilter		grøftelengde			innlagt vann		
6 Minirenseanlegg kl 1		sttøtbelaster					
7 Minirenseanlegg kl 2		vannopstuving			TOTAL VURDERING AV ANLE		?
8 Minirenseanlegg kl 3		vannutslag terreng			1		
9 Tett tank					2		
10 Tett tank for svartvann					3		
11 Biologisk toalett					4		?
12 Konstruert våtmark					5		?
13 Tett tank for svartvann, gråvannsfilter							
14 Biologisk toalett, gråvannsfilter							
BRØNN			BILDER				
avstand til brønn			KART				
type brønn	(fjell/løs masser)						
MERKNAD							

3.4 Recipient Water Sampling

In order to assess pollutants (nitrogen and phosphorous) concentration in the recipient, water sample were taken from Topdals River on 22nd March, 2017. Total three samples were taken (1 L for each sample and two bottle of 500 g for one sample) from three different locations called up stream, middle and downstream. In order to have random sampling, the samples were taken from middle of the river bridge by dropping the sample bottle down to the river with help of rope and almost 500 g heavy stone attached with the bottle so that It could sink in water and water can fill in the bottle.

The upstream location is a sampling point in the North of the river where we started to visit the first treatment system under Kristiansand municipality. It is a boundary point between Kristiansand and Birkenes municipality. The middle point is a bridge on the junction of Fosseveien and towards Drangholt and Birkeland. In other words, it is a middle point between upstream and downstream sampling location. The downstream sampling location is a bridge close to Kjevik airport. It is almost close to the end point of river where the river entered into Topdalsfjord (see in the figure 14).

Figure 15 Location of Recipient Water Sampling Collection

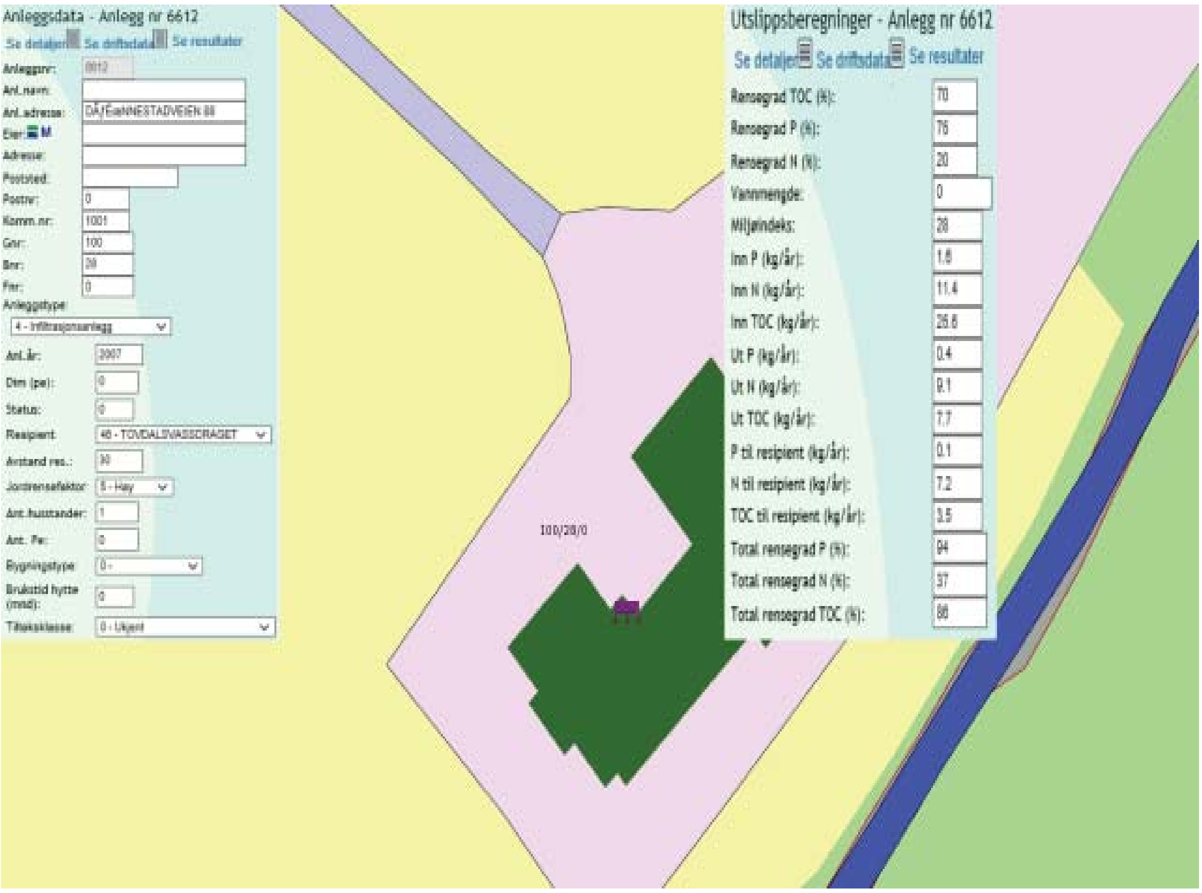


The water sample collected and stored in cold place and handed over to IMV department lab for total P, PO_4, NO_3 and total nitrogen analysis. In order to avoid any biological growth in the sampling bottle, few drops of 0.2M H_2SO_4 added in each of the bottle.

3.5 Data Analysis

Primarily, data stored in municipal database system called 'Gemini'. The data transferred from Gemini to WebGIS model for further analysis. The information registered into the WebGIS model by coping the data from Gemini with minor extra work. The information registered such as, what type of system (infiltration, sand filter, wetland, package treatment) design, size, age and wastewater load etc. The geographical location of each of the system also adjusted on the map according to their exact location.

Figure 16 WebGIS Interface Shows Treatment Performance of the System



In order to assess treatment performance of each of the system, need to zoom into the relevant system in WebGIS. A window will open with close view on the map and also with full detail of the system called anlegg data as see in figure 3.3 left hand side. To obtain results need to click on 'se resultater' and right hand side window will open shown in figure 3.2. This gives information about pollutants removal performance 'how much entered in the system and how much removed’. Every system ranked by environmental index 1-5 where highest (5) ranked for severe environmental impact on the recipient (Eggen et al. 2010). The model evaluate the performance of single system as well as group of systems and generate combine graphs and tables. The assessment of environmental impact index based on following formula that drive from long time empirical research on small onsite wastewater treatment performance (Eggen et al. 2010).

$$\text{Environmental Impact Index} = \frac{1000}{365}\ \frac{(P.16+N.3+TOC)}{Pe}$$

Where,

P.16	phosphorous multiply with molecular weightage
N.3	nitrogen multiply with molecular weightage
TOC	total organic carbon that is equal to 1
Pe	person equivalent or number of people living in each house
365	number of days in a year

WebGIS model calculate the environmental impact assessment through this formula and determined the color for each of the system if the value,

<11	Blue	(very low impact)
<31	Light Blue	
<51	Green	
<71	Pink	
>71	Red	(very high impact)

Chapter 4

Results of the Survey

The pervious chapter demonstrate the general description about onsite systems. One of the main objective of this survey and data analysis through WebGIS is the need to assess where an upgradation require and which of the systems needs to replaced completely. In addition, which of the systems should prioritized first? Environmental impact index gives indication from which of the treatment systems are most seriously polluting the recipients.

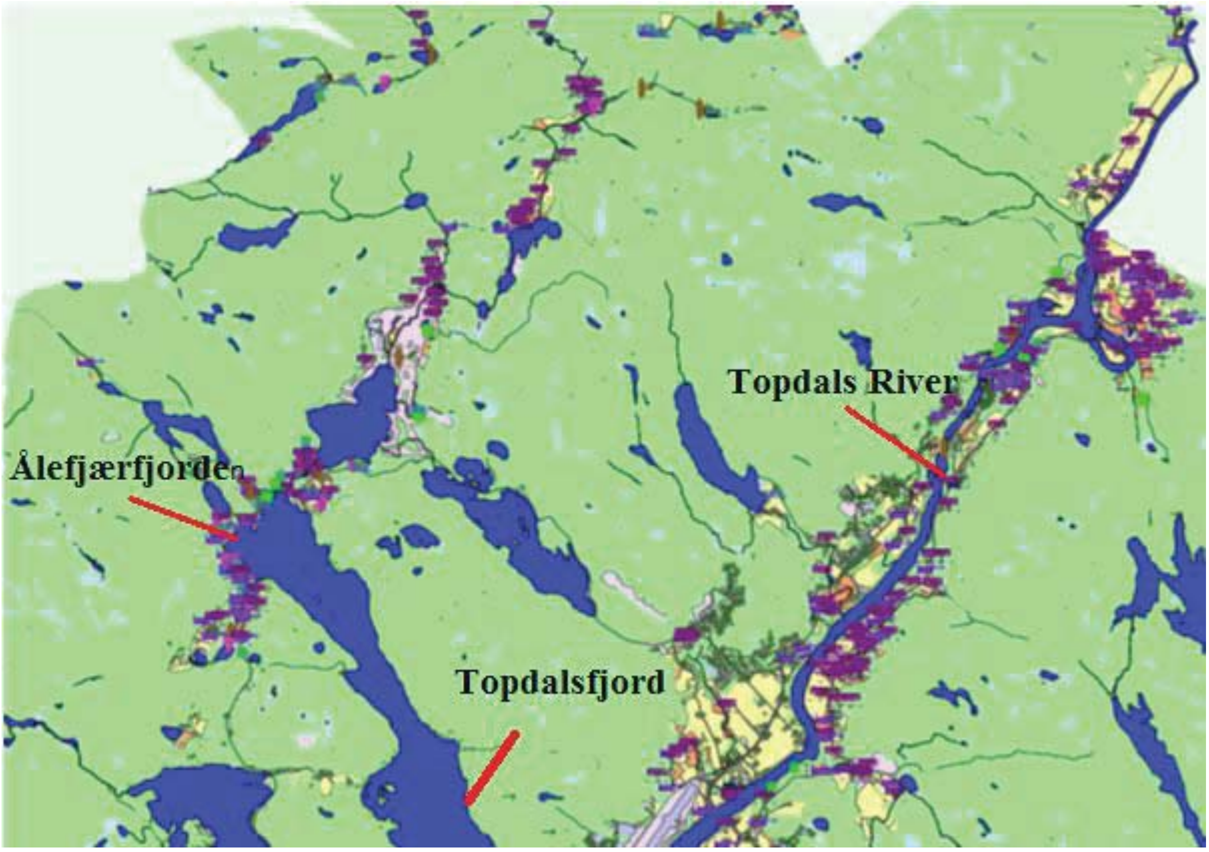
Keeping in mind the main aim of the survey, this chapter comprises on three parts. In the first part simple description and situational analysis of the visited plants has documented. Second part explain the severity and the intensity of the pollutants from malfunction systems (‘very high, and ‘high, environmental impact indexes category). Third part focus on the amount of pollution reduce from such systems through intervention.

4.1 Description of the Visited Treatment Plants

4.1.1 Map of the visited onsite systems

The below figure 17 shows the location of the visited onsite systems on the map. Purple color represent the different types of treatment systems in the locality. Most of the treatment located along Topdals River and some of them along Ålefjær fjord. The final destination of these effluent is Topdalsfjord.

Figure 17 Location of the Visited Systems

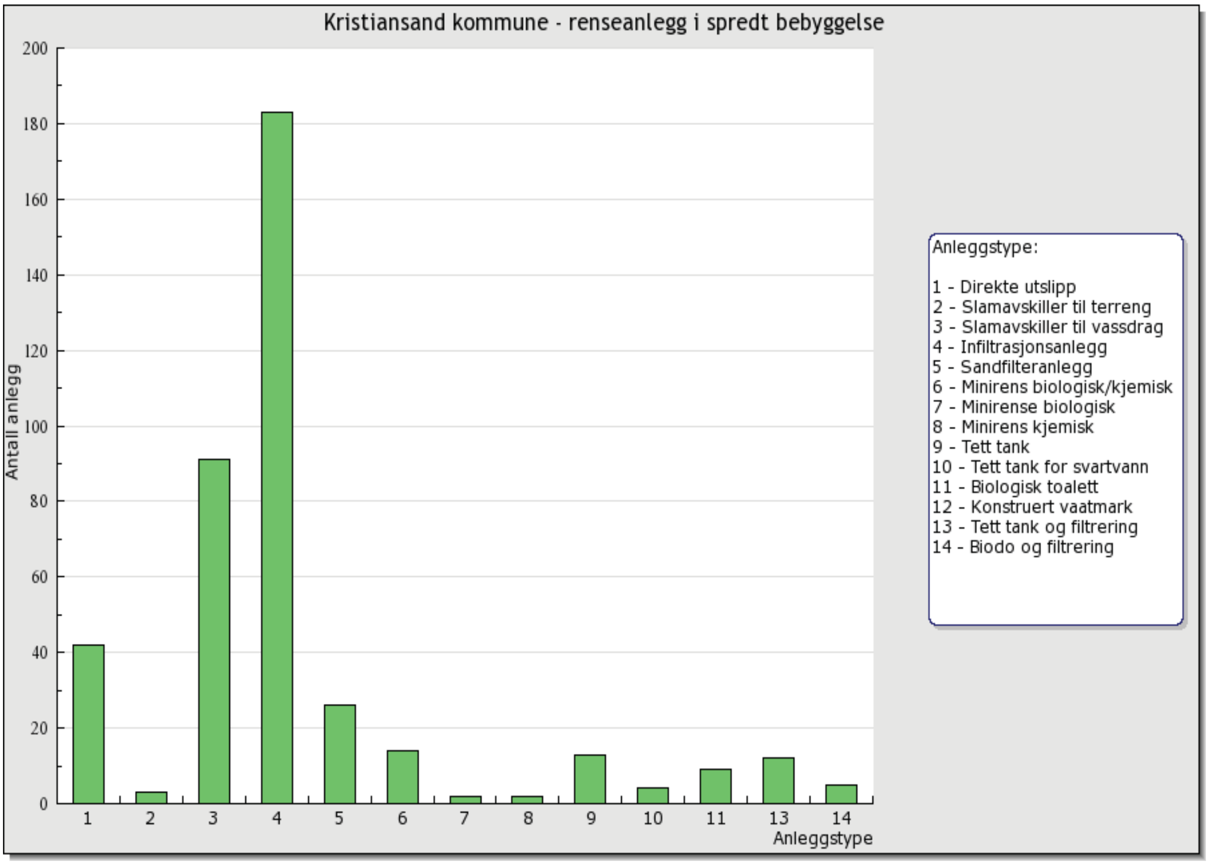


4.1.2 Small onsite systems in Kristiansand Municipality

The visited field area was not very rocky and soil Infiltration systems found most common onsite wastewater treatment system. As figure 18 shows 183 out of 406 are infiltration systems. Septic tank direct discharge to the recipient are the second most common treatment system with 91 numbers in total. 42 of the houses discharge their wastewater direct to the recipient without any treatment. Moreover, 18 of the houses have package treatment plants due to newly renovated their houses and in some places due to less soil for treatment. Biological toilet were found in 5 recreational places.

Figure 4.2 Graph Explaining Different Onsite Treatment Categories

Figure 18 Graph Explaining Different Onsite Treatment Categories



4.1.3 Pollutants Discharge to the Recipient

Figure 19 and table 6 explain the amount of phosphorous, nitrogen and total organic carbon discharge at different recipients. North right, left, and similar others in the table and graph represents the exact location from where the wastewater discharge to the recipients and different locations given different numbers to differentiate.

The table shows 262 kg of phosphorous, 3225 kg nitrogen and 4468 kg of total organic carbon per year discharge to different recipients from 406 visited treatment plants. Topdalselva and Ålefjord are two major recipients receiving effluents wastewater and pollutants. Further down these two major recipients entered into Topdalsfjord and all of these pollutants accumulated there. As it is mention earlier, most of the visited treatment systems located along Topdalselva and by summing up all of the location along the river about 170 kg P/year, 2063 N and 2993 of TOC is discharge to Topdals River. This may potentially cause to pollute Topdalsfjord.

Figure 19 Amount of Pollutants Discharge to Different Recipient at Different Location

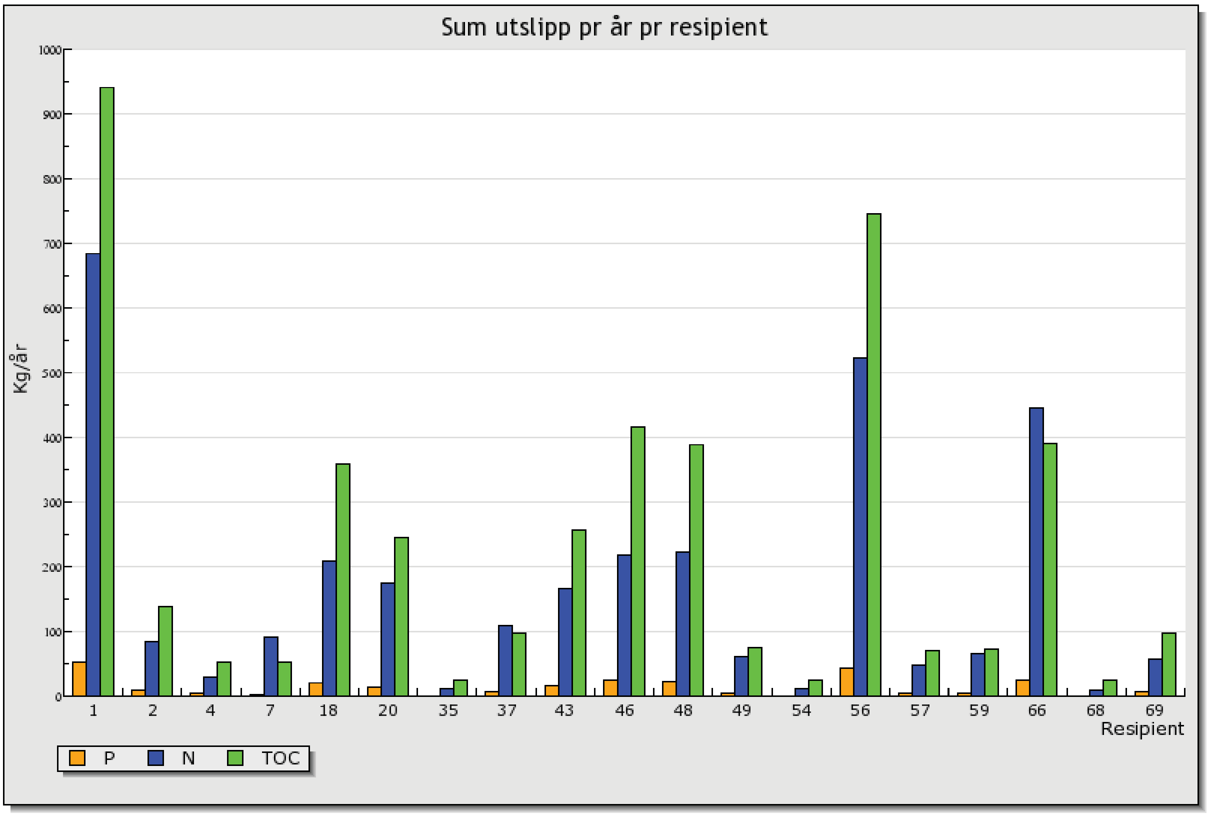


Table 6 Amount of Pollutants Discharge to Different Recipient at Different Location

Resipient	**Number of Treatment plants**	**P Discharge** kg/year	**N Discharge** kg/year	TOC Kg/year
1-Topdalselva North R	78	52	685	940
2-Topdalselva West L	9	8	84	138
4-Kvåsefjorde	5	4	30	52
7-Topdalselva East R	15	2	91	53
18-Topdalselva North L	24	21	210	359
20-Topdalselva North West L	20	14	175	246
35-Studevannet	1	1	11	25
37-Bjåvannet	20	6	109	97
43-Ålefjærfjorden	25	16	167	256
46-Topdalselva North East R	25	25	219	415
48-Ålefjærfjorden west N	35	23	223	388
49-Topdalsfjoden	7	5	61	74
54-Drangholtsvannet	1	1	11	25

56-Topdalselva North 1	65	43	523	746
57-Topdalsfjorden East S	8	5	48	70
59-Topdalselva West L 1	8	4	66	72
66-Haugevannet og Bjåvannet	60	25	445	390
68-Topdalselva North L 1	1	1	10	24
69-Ålefærfjorden North	7	6	57	98
Total	**406**	**262**	**3225**	**4468**

4.1.4 Onsite system with Environmental Impact Assessment

Table 7 Number of Treatment System with Environmental Index

Rank	Total
Very high (Meget høy)	133
High (Høy)	30
Average (Middels)	31
Low (Lav)	184
Very Low (Meget Lav)	28
Total	**406**

The table explains the numbers of the treatment system with their potential environmental impact on groundwater and surface water. The explanation of these rank described in chapter 3. Very high rank represents the most severe impact on the environment. The results about treatment performance of the systems in the municipality are very dangerous for the recipients and for community in general. As shown in the table about 50% (including very high, high and average) of the total visited treatment systems has very low pollutants removal efficiency. According to WebGIS model very high rank treatment systems only remove phosphorous 0-5%, nitrogen 0-5% and TOC also 0-5%.

The figure below demonstrate the pollutants removal performance of the treatment system with respect to their category. The red color represents the worst treatment systems. WebGIS results shows that wastewater discharge after septic tank to the recipient and direct discharge to the recipient from point of source has the most severe impact on the ecosystem of the recipients. Moreover, sand-filter and septic tank percolation to the soil also cause severe pollution in the water bodies. During field inspection of such systems, it have been observed that these systems are very old and build long time ago and poor maintenance. The treatment performance of sand-filter is highly depend on the age and the maintenance. However, direct discharge after septic tank and terrain is not a proper way to dispose of their wastewater and there is no way to justify it. The performance of soil infiltration systems of the visited houses is also not very satisfactory as it shows 14 systems have average performance.

Figure 20 Environmental Indexes With Reference to Category of the Treatment System

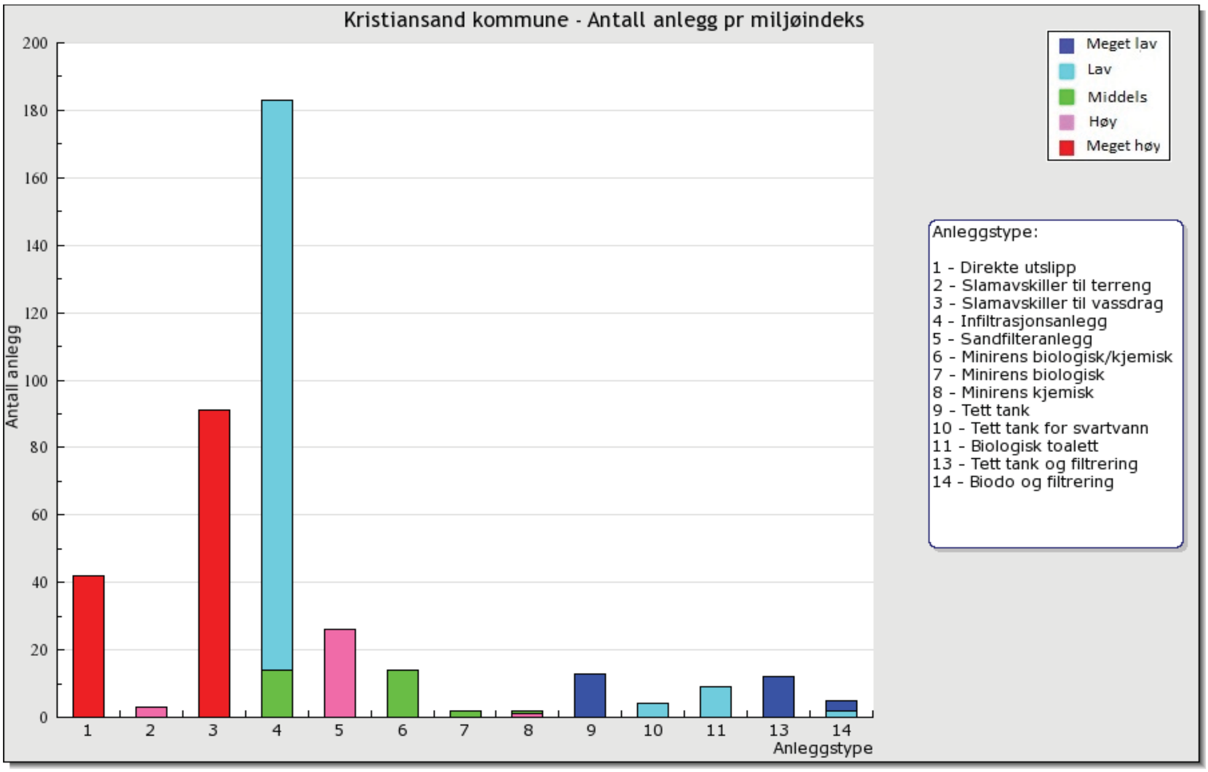
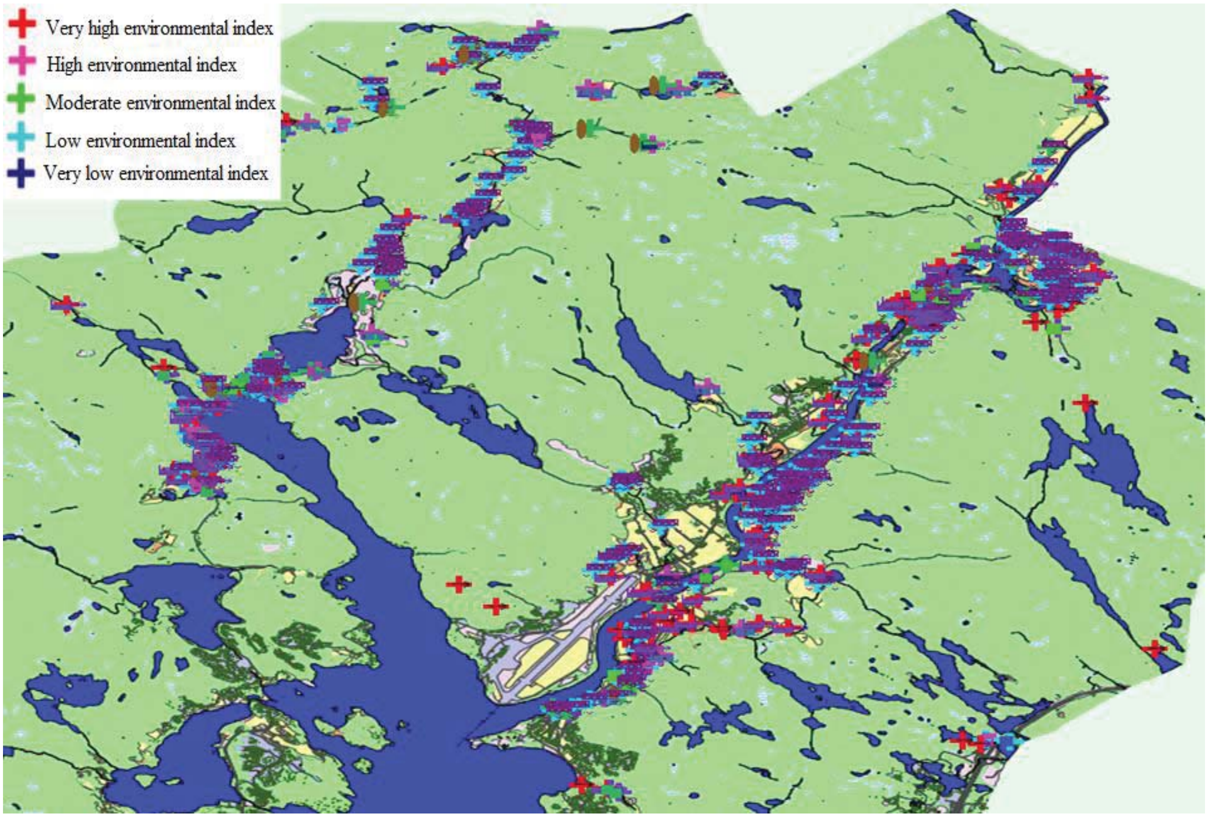


Figure 21 Environmental Index Location on the Map in the Inspection Area



4.2 The amount of pollutants removed by replacing the old system

In order to make an assessment 'how much pollution can be reduce by prioritizing the most worst treatment system' very high and high rank system are selected for analysis. Such treatment systems are shown in Figure 21 with Red and Pink color and table 7 shows the numbers 133 and 30 respectively.

One of the simple solution of these 'very high' and 'high' rank index system is to changed them completely and construct new systems according to the feasibility which are discuss in the next chapter. As shown in figure 4.3 these system belongs to category 'direct discharge and sand filter'. The direct discharge means no treatment or little treatment in the septic tank and the sand filters were build long ago and might not functioning at all. These systems are not meeting standard requirement for wastewater disposal.

Through WebGIS it is possible to make calculation how much pollution discharge and how much reduced by changing such systems. According to WebGIS analysis, the pollutants removal performance of individual systems, very high rank index can remove following amount of pollutants.

Table 8 Current Performance of Very high Environmental Impact Index treatment System (one household having 2.5 persons)

Pollutants	Current Reduction %	Amount entered in the system kg/year	Amount discharge to the recipient after treatment kg/year	Total amount of Pollutants discharge kg/ year*	Burden on total pollutant load **
Phosphorous	0-5	1.6	1.5	199.5	76%
Nitrogen	0-5	11.4	10.8	1436.4	45%
TOC	0-5	25.6	24.3	3231.9	72%

*the total amount of pollutants is obtain from total number of very high rank systems multiply with amount discharge to the recipient 133×1.5=199.5

**the share of the burden is obtain from total amount of pollutant load of high environmental impact index divided by total amount of load from all categories (see in the table 4.1) 199.5/262= 76%

The above table 8 explains the treatment performance of very high environmental impact index category that mark in red color in figure 20 and 21. The treatment performance of such systems is very low and the maximum pollutant reduction capacity is only 5% shown by WebGIS model. In category of ‘direct discharge to the recipient without septic tank’, the treatment performance is even 0% as there is no mechanism of treatment at all and wastewater is direct discharge to nearby recipient. Anyhow, for general analysis 5% reduction used in this category.

Very high environmental impact index rank is severely responsible for pollutant discharge to the recipient that may deplete the eco system of the recipient. As shown in the table, about 199.5 kg/year of phosphorous discharge to watersheds from such treatment systems and this solely account 76% of the total phosphorous, 45% nitrogen and 72% pollutant’s burden.

Table 9 Treatment Performance of New Small Onsite Systems (one household having 2.5 persons)

Pollutants	% Reduction claim by manufacturer and literature	Amount of pollutants entered in the system kg/year	Amount of pollutants discharge to the recipient kg/year	Total amount of Pollutants discharge kg/ year*	Pollutants Removal Difference between current and New system kg/year **	%***
Phosphorous	95%	1.6	0.08	10.64	188.86	95%
Nitrogen	70%	11.4	3.42	454.86	981.54	68%
TOC	Above 90%	25.6	2.3	305.9	2926	91%

*the total amount of pollutants is obtain from by changing the very high rank index systems with new systems multiply with amount discharge to the recipient 133×0.08=188.86

** Pollutants difference amount obtain from the amount of pollutants currently discharge from worst (very high rank) treatment system and if we alter them with New onsite systems. For example 199.5-10.64= 188.86 kg P/year

*** Pollutants removal difference by changing the current systems with new system divided by the amount of pollutants discharge to the recipient from such systems 188.86/199.5 = 95%

The pollutant removal performance of 'very high environmental index category' is very low. The table 9 describe the situation if those systems replace with very new treatment system how much pollution can remove. The treatment performance of new system is high and it depends on different factors and components. Anyhow, here general removal efficiency of new systems is used which described by the manufacturers and well documented in the literature. The calculation shows that significant amount of pollutants can removed i.e. 95% phosphorous, 68% nitrogen and 91% TOC, if very high environmental index treatment systems changed by new small onsite systems like soil infiltration or package treatment plants.

Table 10 Current Performance of 'High Environmental Impact Index Systems' (Each house have 2.5 persons)

Pollutants	Current Reduction %	Amount entered in the system kg/year	Amount discharge to the recipient after treatment kg/year	Total amount of pollution discharge to the recipients kg/year*	Burden on total pollutant load **
Phosphorous	25	1.6	1.2	36	13%
Nitrogen	20	11.4	9.1	273	8%
TOC	70	25.6	7.7	231	5%

* Total amount of pollution discharge to the recipients obtain from total number of systems in this category multiply with amount of pollution discharge to the recipient 30×1.2=36 kg/year

**

High environmental impact index category also needs to prioritize along with 'very high' because they are discharging significant amount of pollutants in the recipient. About 30 treatment systems belong to this category shown in table 7 and in figure 20 pink color. Sand filter is major type of treatment systems in this section and removal efficiency of sand filter highly depend on age and maintenance. Table 10 demonstrate that 'high environmental impact index' category responsible for 36 kg of phosphorous, 273 kg of nitrogen and 231 kg of total organic carbon TOC to the recipients annually.

Table 11 Pollution Reduction by Replacing 'High Environmental Impact Index System' with New Systems

Pollutants	% Reduction claim by manufacturer and literature	Amount of pollutants entered in the system kg/year	Amount of pollutants discharge to the recipient kg/year	Total amount of Pollutants discharge kg/ year*	Pollutants Removal Difference between current and New system kg/year **	%***
Phosphorous	95%	1.6	0.08	2.4	33.6	93%
Nitrogen	70%	11.4	3.42	102.6	170.4	62%
TOC	Above 90%	25.6	2.3	69	162	70%

* Total amount of pollution discharge to the recipients obtain from total number of systems in this category multiply with amount of pollution discharge to the recipient 33×0.08=2.64 kg/year

** Pollutants difference amount obtain from the amount of pollutants currently discharge from ‘high’ rank treatment system and if we alter them with New onsite systems. For example 39.6-2.4= 36.96 kg P/year

*** Pollutants removal difference by changing the current systems with new system divided by the amount of pollutants discharge to the recipient from such systems 36.96/39.6 = 93%

Table 11 explains the situation if ‘high environmental impact index, systems are replace with new systems how much pollution might remove. Similar to previous section, the alteration of current high rank systems with new systems will give 93% phosphorous, 62% nitrogen and 70% TOC removal efficiency.

Table 12 Pollutants Reduction Due to Changing Red and Pink Systems with New Systems

Pollutants	Total amount of pollutants reduction from both ‘very high’ and ‘high’ rank index kg/year *	% Reduction from total amount of Pollutants discharge to recipients from all Index **
Phosphorous	222.46	85%
Nitrogen	1151.94	36%
TOC	3088.2	69%

* the total amount obtain by adding pollutants from both ‘very high’ and ‘high’ environmental impact assessment index from previous tables 188.86+33.6= 222.46 kg/year

** % Reduction obtain from total amount of pollutants reduce from very high and high index divided by total amount of pollutants discharge from all categories from table 4.1 225.82/262= 86%

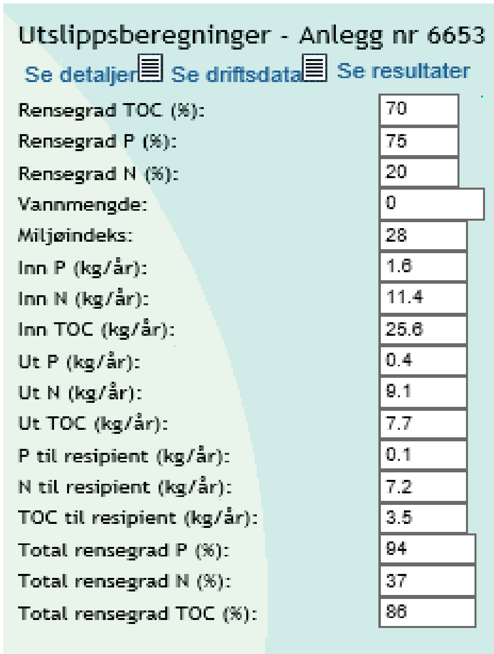
Table 12 is an explanation of how much pollution can reduce if replace septic tank effluent discharge to the recipient, direct discharge without any treatment and sand filter systems. The results shows to do immediate actions and planning to construct new treatment system instead of direct discharge of wastewater to the recipients and old sand filters. Very high and high environmental impact index system are significantly responsible for overall total burden of pollutants on the recipients from in the visited area. Both of these categories responsible for 235.5 kg of phosphorous, 1709.4 kg nitrogen and 3442.9 kg TOC discharge out of total 262, 3225, 4468 respectively from all indexes annually. This accounts for 90% of total burden of phosphorous, 53% of nitrogen and 77% of TOC discharge to the recipients in the visited area. However, the table 4.7 shows if we change current systems with new updated system with proper rules and regulation this may lead to reduce significant amount of pollutants like 85% phosphorous, 36% nitrogen and 69% of total organic carbon.

4.3 Pollution Reduction from ‘Low’ and ‘Medium’ Environmental Impact Indexes Category

About 184 and 31 treatment systems have low and medium range environmental impact on the recipients (see table 4.2). These systems belong to soil infiltration and package treatment plants categories and shown in light blue and green color in figure 4.3.

This piece of result (figure 22) clipped from WebGIS model. Anlegg nr 6653 is a soil infiltration system and have low pollution impact on the recipient and figure 4.5 reveals the treatment performance of the system. As shown in the result, this system removes 94% of phosphorous, 37% nitrogen and 86% of total organic carbon (TOC). The treatment performance of this category (light blue) is sufficient to meet standard discharge requirement. Hence, upgradation needed to improve for more nitrogen removal.

Figure 22 Treatment Performance of ‘Low’ Environmental Impact Index Category



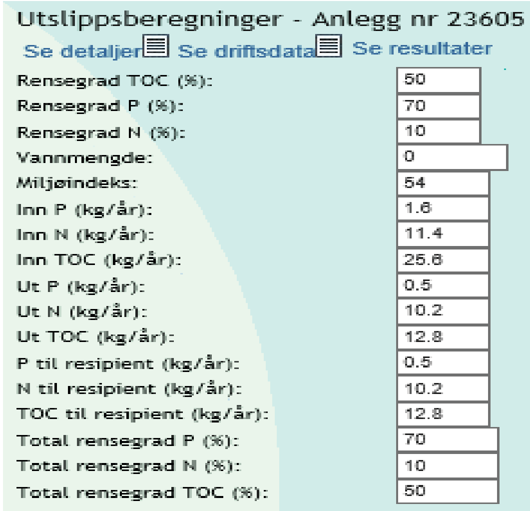
Utslippsberegninger - Anlegg nr 6653

Se detaljer Se driftsdata Se resultater

Rensegrad TOC (%):	70
Rensegrad P (%):	75
Rensegrad N (%):	20
Vannmengde:	0
Miljøindeks:	28
Inn P (kg/år):	1.6
Inn N (kg/år):	11.4
Inn TOC (kg/år):	25.6
Ut P (kg/år):	0.4
Ut N (kg/år):	9.1
Ut TOC (kg/år):	7.7
P til resipient (kg/år):	0.1
N til resipient (kg/år):	7.2
TOC til resipient (kg/år):	3.5
Total rensegrad P (%):	94
Total rensegrad N (%):	37
Total rensegrad TOC (%):	86

Anlegg nr. 23605 results represents Green color in figure 20. Package treatment and some soil infiltration systems are in this range. Figure 23 shows the treatment performance of package treatment and result are not satisfactory (70% P, 10% Nitrogen and 50% TOC removal). Whereas the soil infiltration in Green category removed 88% phosphorous, 94% nitrogen and 94% TOC. For calculation in the next table the soil infiltration systems will used

Figure 23 Treatment Performance of 'Medium' Environmental Impact Index Category



Utslippsberegninger - Anlegg nr 23605

Se detaljer Se driftsdata Se resultater

Rensegrad TOC (%):	50
Rensegrad P (%):	70
Rensegrad N (%):	10
Vannmengde:	0
Miljøindeks:	54
Inn P (kg/år):	1.6
Inn N (kg/år):	11.4
Inn TOC (kg/år):	25.6
Ut P (kg/år):	0.5
Ut N (kg/år):	10.2
Ut TOC (kg/år):	12.8
P til resipient (kg/år):	0.5
N til resipient (kg/år):	10.2
TOC til resipient (kg/år):	12.8
Total rensegrad P (%):	70
Total rensegrad N (%):	10
Total rensegrad TOC (%):	50

Table 13 Pollutants Load from 'Low' and 'Medium' Environmental Impact Indexes

Pollutants	Pollutants load on the recipient from 'low' index kg/year	Burden on total amount of Pollutants*	Pollutants load on the recipient from 'medium' index kg/year	Burden on total amount of Pollutants*
Phosphorous	18.4	7%	6.2	2%
Nitrogen	1324.8	41%	21.7	0.6%
TOC	644	14%	46.5	1%

*the share of the burden obtain from amount of pollutant discharge from that category divided by total amount of pollutant discharge to the recipient

The table 13 shows the effluent discharge to recipient from low (light blue) and medium (green) range environmental indexes category. The calculation based on treatment performance of each of the category as shown in figure 22 and 23. Phosphorous removal efficiency of such plants is very good and both of the categories accounts only 9% of the total phosphorous burden on the recipients. However, significant amount of nitrogen (41%) and total organic carbon (14%) discharge from low (light blue) and only 0.6% and 1% discharge from medium (green) range treatment plants respectively.

The results indicate that significant amount (1324.8 kg/year) of nitrogen discharge to the recipient from soil infiltration systems. However, the phosphorous removal efficiency meets standard requirements. Therefore, demolishing of existing system is not wise but there is need of some upgradation for efficient nitrogen removal. Aerobic and anaerobic bio-filter prior to infiltration trenches help a lot to remove nitrogen more efficiently.

Chapter 5

Discussion

In the previous chapter, the treatment performance of visited onsite treatment system has been interpreted. Enormous amount of pollutants discharge to the recipients according to WebGIS model. This chapter focus more about the effects of these pollutants on the recipients and consequences. In the later part will discuss about possible solution.

5.1 Water Quality Status of Topdals River

Tovdal water area includes Tovdalsvassdraget, which is 120 km long and consists of two main branches, a western and an eastern origin in the upper part. The eastern branch, Tovdalselva, originates in the boundaries between Straume, Setesdal and Fyresdal, and the western section, Uldalgreina, has three supply systems, Skjeggedalsåna, Vatnatalsåna and Hovlandsåna. The watercourse flows into the Topdalsfjord between Hamresand and Kjevik Airport, northeast of Kristiansand city center. The watercourse is characterized by a wide range of natural habitats from nude mountains in the north to poor barskog inland to small-capped Southern Norway with elements of Edellauvskog in the south. Large areas consist of bogs. In the middle of the water area is the forest boundary. The watercourse is a typical southern watercourse with low pH values and conductivity that increases below the watercourse. No watering was started in the waterway before 1996 and therefore the watercourse is considered to be one of the most important reference waterways in the context of acidification. The Topdals water area consists of 150 rivers and streams, 56 lakes and 22 coastal waters. There are 179 water bodies in Topdals River that are at risk of not reaching environmental targets by 2021 (Vannmiljø 2014).

Table 14 Pollutants Concentration in Topdals River

Sampling location	**Total. Phosphorous µg/L**	**PO_4-P µg/L**	**NO3- µg/L**	**Tot. Nitrogen µg/L**	**TOC mg/L**
Upstream	4.00	1.50	160	450	5.25
Middle	4.00	1.00	160	450	5.4
Downstream	4.00	1.00	160	450	5.45

The above table shows the water quality results of Topdals River. The water samples collected from three different locations during March 2017 describe in chapter 3. Having high TOC in the river due to different source it is found that Topdals River belong to category no 6 of river classification (humic and low in calcium) according to Norwegian Water Directive's guidelines. In order to see the severity of these pollutants in the river, the below table is made.

Table 15 Environmental Indexes Standard Limits (vannportalen 2015)

Parameters Class and Limits	Very good	Good	Moderate	Not Good	Not Very Good
Total Phosphorous μg/L	1-17	17-24	24-45	45-83	≥ 84
Total Nitrogen μg/L	1-200	200-400	400-650	650-1300	≥1300

The table 15 adapted from vannportalen report. This table gives environmental index class limits for total phosphorus and nitrogen in the rivers. Comparing these class limits with table 5.1 indicate that phosphorous concentration in the sample water falls in the range of very good environmental index category (blue color). This shows that there is very less phosphorous concentration in Topdals River. Whereas there is moderate concentration of nitrogen in Topdals River representing with yellow color in the table

The webGIS analysis of current study shows that 170kg of phosphorous, 2063 kg of nitrogen and 2993 kg of TOC discharge to Toppdals River every year from visited treatment plants located alongside the river. On average, there is water flow in the river (Molvær 2003). The water samples result shows not significant amount of phosphorous in the Topdals River. This may be because there is high water flow and dilution capacity of the river high enough to assimilate this amount of P load. A local action study about Topdals river shows that on-site wastewater treatment systems are little responsible in the water pollution of the river (Vannmiljø 2014).

5.1 Pollutant’s impact on Topdalsfjord

Norway is rich with freshwater resources and only 0.7% of the available fresh resources utilized for municipal and industrial use. Somehow, due to better management and low population density, wastewater discharge into exploited freshwater resources is very low that indicate the oxygen demand resulting from depletion of organic matter is low in the receiving water. Some of the studies shows that the accumulated load of TOC from urban wastewater in Norway rarely exceeds 2.5 mg/l. This represents the up- per limit for the best quality class in the Norwegian water quality classification system (Källqvist et al. 2002) but this is not the case from existing performance of ‘very high’ and ‘high’ treatment systems. In the current study about 4468 kg of TOC discharge to Topdalsfjord from all visited treatment systems. This may lead to oxygen depletion with passage of time if this issue is not prioritize. Norwegian institute for water research NIVA conduct a survey on ‘‘Monitoring Topdalsfjorden and Ålefjærfjorden, Kristiansand Municipality, 2002-2003. Inflows, water quality, soft-bottom fauna and sediment’’ and found out that in the deep water of the fjord poor oxygen condition with concentrations <1 ml O2 / l in autumn 2002. Oxygen consumption had increased compared to previous surveys (Molvær 2003).

Figure 24 Oxygen concentration in Topdalsfjord in July-October 1994 (Molvær 2003)

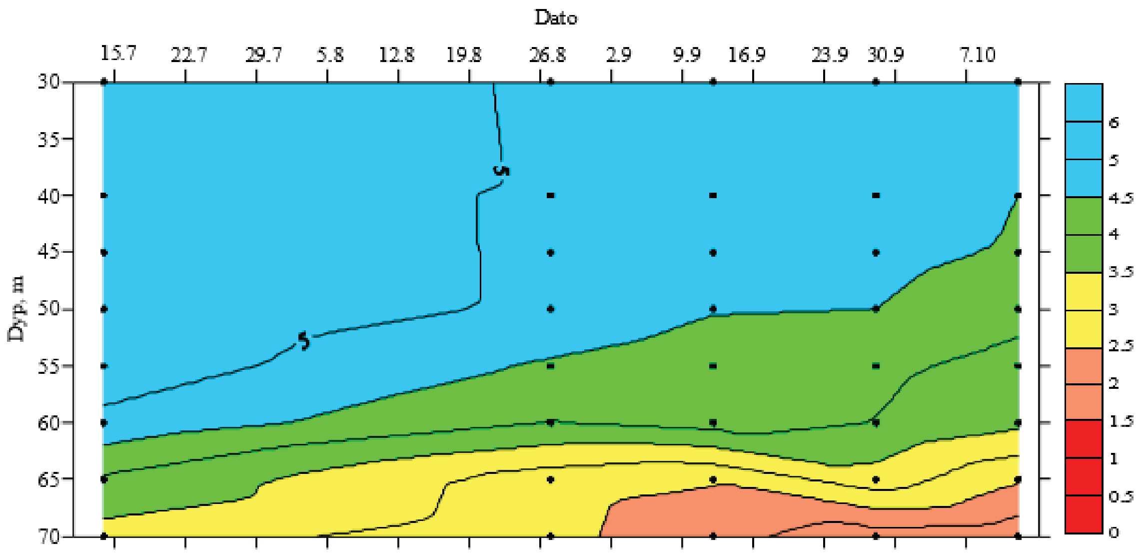
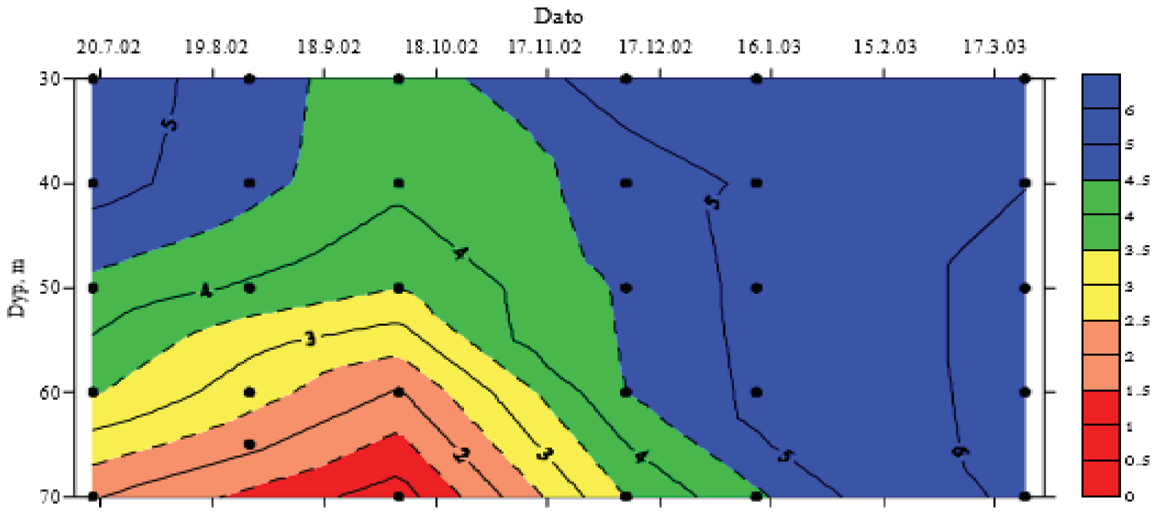


Figure 25 Oxygen concentration in Topdalsfjord in July 2002 till March 2003 (Molvær 2003)



The oxygen depletion in Norwegian fresh water resources is not as big problem as far as eutrophication is concern particularly in lakes and coastal zone (Källqvist et al. 2002). About 1709 kg of nitrogen discharge to Topdalsfjord annually from visited 'Red' and 'Pink' treatment systems. Molvær (2003) demonstrated that nitrogen concentration had found on the surface layer of the Todalsfjord and Ålefjærfjord and these input might derived from run off and wastewater discharge to Topdals River. Generally, N/P ratio in coastal area is less than fresh water and nitrogen has considered limiting nutrients for primary production of algae in the coastal and fjord areas. However, these views have changed now and N/P ratio may influenced from local input from rivers and wastewater discharge (Sakshaug et al., 1983, Paasche and Erga, 1988, Larson, 1988). As in Oslofjord phosphorous is the primary nutrients for algae growth (ANON 1996).

In the current study, it is estimated that 236 kg of phosphorous discharge to recipients annually from 'Red' and 'Pink' treatment systems and this may potential source of nutrients for algae in the Topddalsfjord. According to NIVA report the concentration of phosphorus varied relatively little, but there was an elevated value in Ålefjærfjorden in October 2002 (Molvær 2003). Phosphorous is the primary element for algae growth and the organic biomass that produced after algae decomposition, is fifteen times higher than the amount of organic matters in the wastewater (Källqvist et al. 2002). The P-load from one person in Norway to the wastewater has been estimated at 1.6g P/d. Using this yield for S. capricornutum algae this amount of P can be converted to approx. 900g of algal biomass and a theoretical oxygen consumption of approx. 1000 g O_2 for complete aerobic degradation. This secondary demand is 15 times higher than typical primary oxygen demand (Källqvist et al. 2002). That mean 236 kg of phosphorous can produced 103,104 ton of algae biomass and even more high oxygen depletion annually in the recipients due to poor performance of 'very high' and 'high' environmental impact systems. Furthermore, eutrophication also associated with the growth of harmful algal blooms and this stimulate growth of benthic algae and bottom fauna.

Norwegian Water Research Institute (NIVA) conduct a study about water quality in Topdalsfjord and shows that bottom sediments were healthy with normal organic content shallower than 45 m, while there were black sediments with smell similar to hydrogen sulfide in the greatest depths of the fjords. The fauna was rich in species and had normal biodiversity at stations shallower than 45 m. Sediments at greatest depths in Topdalsfjorden had moderate to low content of metals, while there was a slightly elevated concentrations of PAHs (Molvær 2003).

Above-mentioned study from NIVA was conduct in 2003 and pointed out the presence of nutrients and oxygen depletion in Topdalsfjord. Fourteen years passed to date and enormous amount of nutrients and pathogens discharge from wastewater treatment plants that may impact to the fjord at great extent. That perhaps leading reasons why Kristiansand municipality stop people to swim in Topdalsfjord last year.

In 1950 and 1960 Oslo fjord represent similar situation. The fjord severely polluted by wastewater and phosphorous considered limiting nutrient for algae. Measures were taken in 1960s and till 1998 and about 70% of phosphorous reduced from land based and wastewater managed activities (Källqvist et al. 2002). The Kristiansand municipality should also learn from such experiences and should take immediate action to reduce pollution in the Topdalfjord.

5.2 Upgradation of 'Low' and 'Medium' Environmental Impact Assessment Index Systems

There are 184 treatment systems having low and medium pollutants removal categories shown in light blue color in figure 20 respectively. These systems are old soil infiltration systems probably constructed long ago. The treatment performance of these systems are close enough to meet the standard requirement. About 1324.8 kg/year of nitrogen discharge from both of these categories into the recipients than can cause severe impact on the eco systems of the Topdals River and further down to fjord as time passing and no measures would take. During the survey, it has observed, maintenance and some upgradation of those soil infiltration systems can enhance the treatment performance. This section will discuss what should needs to add in the existing soil infiltration systems in order to improve the treatment performance of wastewater and also that fit in new local regulations.

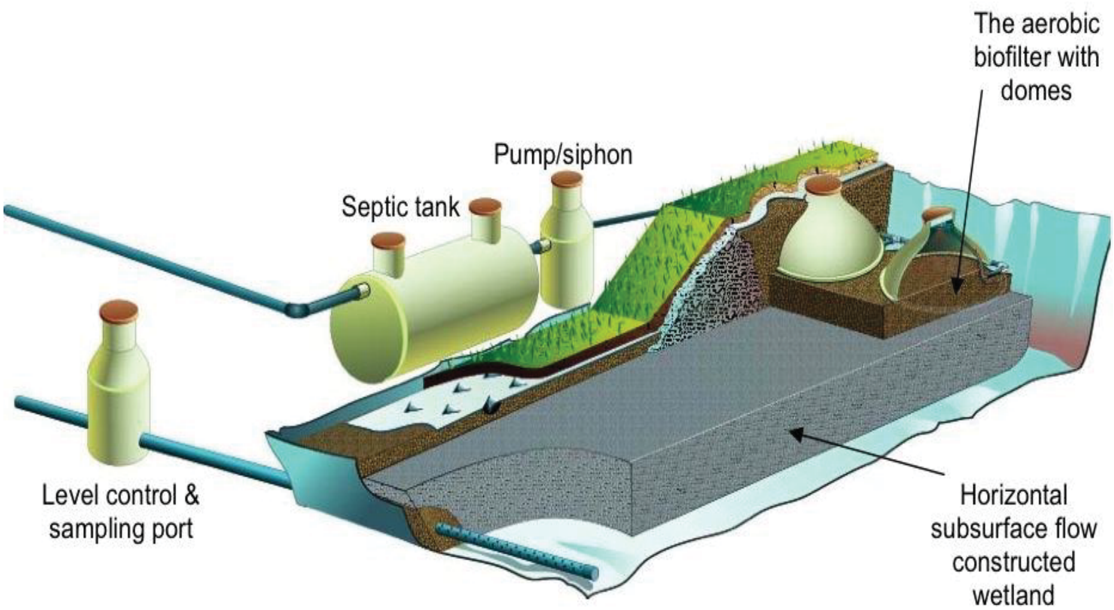
The wastewater treatment systems has three basic functions (Ridderstolpe 1999)

- To prevent the transmission of diseases
- Reduce pollutants and nutrients to spread in the recipients
- Recycle the nutrients

In Norway, the wastewater regulation does not stick to any specific technology to use for wastewater treatment. However, these three functions are really important either designing new or upgrading the old system.

The existed soil infiltration systems in the visited area were septic tank and then infiltration trenches. The new stringent local regulation for small onsite systems limit the use of such systems (Jenssen et al. 2010). The best onsite wastewater treatment systems are, combination of septic tank, intermittent pump, aerobic and anaerobic bio-filter followed by infiltration trenches as shown in figure 26 (Jenssen, 2004). This system is low cost, low maintenance and high removal of pollutants and pathogens (Heistad et al. 2006).

Figure 26 Flow Sheet of Onsite System in Addition with Bio-filter (Jenssen, 2004)



The aerobic bio-filter help to remove organic matters (BOD) and perform nitrification processes whereas up-flow filter mostly remove pathogens and phosphorous and polish the effluent (Heistad et al. 2006). The treatment performance of such systems is very stable if they designed according to present and proper guidelines. The empirical investigations shows that such system remove P- >90% and up to 98% and consistent results can expected for 15 years using natural iron or calcium rich sand or a new manufactured lightweight aggregate (LWA) with P-sorption capacities, which exceeds most natural media (Jenssen et al. 2005). The filter media should renew after 5 years to have better performance. When the media is saturated with P it can be used as soil conditioner and P-fertilizer (Jenssen et al. 2010) and may have better phosphorous available for plants compare with chemical P removal in the conventional systems. This saturated media additionally has a liming effect and meet the Norwegian regulations for reuse in agriculture with respect to heavy metals, bacteria and parasites (Jenssen et al. 2010). Moreover, up to 40-60% nitrogen removal obtained and documented in the literature. Removal of indicator bacteria is high and <1000 thermotolerant coliforms/100 ml is normally achieved and effluent concentrations of fecal indicator bacteria met the European bathing water quality criteria in all systems. (Jenssen et al. 2005).

Low temperature is a big challenge for small onsite wastewater systems in Scandinavia and North America. The biological activities occurs in relatively moderate temperature. However, the empirical results from different studies shows that aerobic pretreatment with bio-filter obtain high removal of organic matters and nitrogen in cold climates at temperature between 0-5°C. The result shows that 55% nitrogen and 98% of phosphorous removed during winter season with bio-filter (Jenssen et al. 1993).

Due to considerable removal of BOD, nutrients, and microorganisms, the effluent will not negatively effect on water and ecosystems of the recipients. The construction of 184 new infiltration systems will require huge public investment. A complete new soil infiltration system may cost between 150,000 to 250,000 NOK. Whereas addition of bio-filter in the existing infiltration systems (low environmental impact assessment index category) can remove enormous amount of pollutants, pathogens and recycle nutrients that discharged to the recipient at the moment. More importantly, the bio-filter remove pathogens that may improve the water quality in the Topdalsfjord that would help to bring swimming again at fjord.

5.3 Upgradation of 'Medium' Environmental Impact Assessment Index Systems: Package Treatment Plants

There are 31 treatment systems belong to this category including soil infiltration and package treatment plants see figure 20. The upgradation of soil infiltration systems described in previous section. However, this section will focus on only package treatment plants.

Package treatment plants are small compact onsite wastewater treatment that increasing day by day in Norway. They are getting popularity because they required less space compare to conventional onsite systems and provides best pollutants removal efficiency for places where no soil for wastewater treatment or difficult to build alternative systems. However, the critiques over package treatment plants are (1) unable to meet current phosphorous discharge limits and their performance is not stable (Jenssen et al. 2010) (2) expensive solution and required maintenance in 2-4 months (Heistad et al. 2006).

The treatment performance of visited package treatment systems shown in figure. Anlegg nr 23605 is a chemical package treatment plants. The results shows that it remove 10% of nitrogen, 50% TOC and 70% of Phosphorous. These results does not meet standard requirement for wastewater disposal. During the survey, it has been observed that the maintenance was not enough as it required regular visits of professionals (Heistad et al. 2006). So one possible solution to improve the performance of these package treatment systems is to have regular maintenance and municipality should ensure it.

Chapter 6

Conclusion

In Norway, small-onsite wastewater treatment systems started operation in the beginning of 20th century. The traditional design of onsite systems was very simple and made up of local material and knowledge. However, due to stringent wastewater disposal requirements such traditional systems, in many cases, require to be upgraded. For this reason, some of the municipalities have started surveying of decentralized sewage system located in their jurisdiction.

Kristiansand municipality started this survey in summer 2016 and in the first phase, almost 500 treatment systems are inspected. The basic purpose of this survey was to registered the operating decentralize systems in the municipality database (Gemini) and to determine their existing condition. However, it is quite difficult to assess accurate treatment performance through observation. Therefore, WebGIS wastewater models is used calculate the pollutants removal performance of small onsite wastewater systems and further downstream impact on the recipients. WebGIS used as data storage and managing daily work about sewage systems but this is first attempt to publish a report about treatment performance of onsite systems in Norway.

Eutrophication and organic load due to algae decomposition are most problematic issues related to wastewater disposal in Norway. However, phosphorous removal from wastewater becomes very crucial from any sort of wastewater treatment system since Norway followed EU Urban Wastewater Treatment Directive (917271/EEC) (Källqvist et al. 2002). In the onsite system, soil treatment is one of the best and cheap option to remove phosphorous and other pollutants. Whereas package treatment plants considered best alternative solution at places where soil treatment is not possible. The number of package treatment plants increasing in Norway but their treatment performance is highly criticized.

The survey result showed 183 systems belong to infiltration category. Septic tank direct discharge to the recipient are the second most common treatment system with 91 numbers in total and 42 of the houses discharge their wastewater direct to the recipient. The WebGIS analysis shows that 262 kg of phosphorous, 3225 kg nitrogen and 4468 kg of total organic carbon per year discharge to different recipients from 406 treatment plants considered for this study. Septic tank direct discharge to recipients, septic tank discharge into soil and sand filter systems found significantly responsible for overall total burden of pollutants on the recipients. Both of these categories responsible for 235.5 kg of phosphorous, 1709.4 kg nitrogen and 3442.9 kg TOC out of total pollutants. However, it is calculated that if septic tank direct discharge to the recipients, septic tank effluent discharge to the direct soil and sand filter change with new updated system with proper rules and regulation this may reduce significant amount of pollutants: 85% phosphorous, 36% nitrogen and 69% of total organic carbon. It is suggest that these systems should be totally replace with new systems because they are major cause of pollution in the recipients.

Topdals River is one of the major recipient where 170 kg of phosphorous discharge every year from visited sewage systems. However, water samples from river found 4 µg P/L and this concentration of phosphorous falls very good environmental index range. The less concentration of P may be because there is high water flow (12-16 m3/s) and dilution capacity of the river high enough to assimilate this amount of P load. A local action study about Topdals river shows that on-site wastewater treatment systems are little responsible in the water pollution of the river (Vannmiljø 2014). But, this does not mean that the municipality should not act against malfunctioning systems. One person in Norway produced 1.6g P/d and this amount of P can be converted to approx. 900g of algal biomass and a theoretical oxygen consumption of approx. 1000 g O_2 for complete aerobic degradation. This shows that if the municipality will not take serious action to reduce pollutants and microorganisms from wastewater treatment systems this may lead to high algae growth and bacterial contamination in the Topdalsfjord. Few year back, this fjord was used to swim and other recreational activities but now it is not allowed to swim because of contamination. For long run, the socio-economic benefits of utilizing the water are often so high and important that this is at the expense of other important values such as recreation / outdoor life and life in and around the waters. Examples may be that bathing areas disappear because of a regulation, drinking water is exposed to contamination and cannot be drank, the fish disappears from the water due to effects such as acid rain and other influences. These are just a few examples of how activity in and around our waters can adversely affect. However, exploiting our waters is an important and natural part of good social development. Therefore, there are major challenges in achieving a good water resource management that takes care of all interests. In order to safeguard the user interests in the best possible way.

As it is mention previous there is need to change malfunctioning systems completely. However, in order to continue further on this issue, there is need of in depth research that will find best possible treatment systems according to location and soil types. A feasibility study is required for new treatment systems.

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