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Irrigation Water Disinfestations

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Table of Contents

SUMMARY

Irrigation with untreated or low quality water often disperses many infectious diseases. In Sweden, 90 to 99.9% reduction of microorganisms in the water can be achieved by waste water treatment but potential risk of high number of sewage, substantial loads of pathogens could still remain. The main objective of this work was to observe the irrigation water quality at Norrvidinge gård located in Kävlinge community, Scania. Advanced oxidation technology (AOT, Wallenius Water AB, Stockholm, Sweden) was employed in the irrigation pipeline and three disinfestation treatments named as 'stationary- AOT', 'mobile- AOT' and 'combined-AOT' was used for water disinfestations. Water samples were taken for investigation at ten occasions during the season 2007. Presence of elevated numbers of heterotrophic organisms was common phenomenon in the water samples. The hygienic quality of the investigated water was good. Coliform bacteria and *Escherichia coli* loads were found very low in the samples comparing to the World Health Organization (WHO) standard for irrigation water or German standard for irrigation water (DIN 1965). Advanced oxidation Technology (AOT) was found effective for the reduction of microbial loads and placement of the AOT-device within the pipeline system was essential. Investigated organic compounds (total organic carbon, TOC; chemical oxygen demand, COD; total nitrogen, TN and total phosphate, TP) and inorganic compounds (ammonium-nitrogen, NH_4-N; nitrate-nitrogen, NO_3-N; phosphorus, P; and sulphur, S) did not seem to be affected by the disinfestation treatments. The amount of the organic compounds in the sample water was much lower compared to the standard value. Measurements of the electrical conductivity and pH confirm the non-saline character of the irrigated water.

Keywords: Advanced oxidation technology (AOT), heterotrophic, coliform, *Escherichia coli*, disinfestations, total organic carbon (TOC), chemical oxygen demand (COD), total nitrogen (N) total phosphate (TP).

1. BACKGROUND

In the year 2005, an outbreak of enterohaemorrhagic *Escherichia coli* (EHEC) 0157 was recorded at the west coast of Sweden (Västra Gotland and Halland counties) from locally produced lettuce. At the beginning of the outbreak, only 10 cases were notified but gradually the number rose up to 120. Among the patients most of them were women and some were children. Around 7 of the patients had developed haemolytic uraemic syndrome. Few other people in some other places of Sweden also became infected due to infection with the dominant outbreak strain during this period. The implicated lettuces were produced in a local farm and used to irrigate with water from nearby stream (Söderström *et al.* 2005).

An escalating alliance between field grown vegetables and food borne infection outbreaks has led to concern about contamination of vegetables with fecal pathogenic bacteria in the agricultural environment (Tauxe et al., 1997). Leafy vegetables that are grown near to the ground are a recognized cause of *E. coli* O157 outbreaks. Contamination of vegetables may occur in several possible ways; irrigation practices, inadequate cleaning, cleaning with contaminated water, non-hygienic farm workers or cross contamination from other products (Solomon et al., 2002).

Escherichia coli (*E. coli*) is the predominant nonpathogenic facultative flora of the human intestine. However, several strains of *E. coli* have developed the ability to cause disease in humans. *Escherichia coli* are also universal inhabitant in the gut of many warm-blooded animals. In most cases, cattle have been found an important reservoir of infection by the EHEC. While the main EHEC serotype is *E. coli* O157:H7, other serotypes such as O111:H8 and O104:H21 are diarrheogenic in humans (Nataro & Kaper, 1998). One of the most frequent ways in which *Escherichia coli* may be introduced hooked on crops is by flood irrigation with water contaminated with cattle feces or by unhygienic surface runoff. *Escherichia coli* O157:H7 has been isolated with increasing frequency from fresh produce, including bean sprouts, cantaloupes, apples and leafy lettuce (Solomon, 2002). According to Faith *et al*. 1996, epidemiological data indicates the presence of *E. coli* O157 could be 8.3% of dairy and beef cattle and which is shed asymptomatically in the feces. *E. coli* causes a broad spectrum of diseases in humans, ranging from mild to bloody diarrhea, hemorrhagic colitis, and complications including hemolytic uremic syndrome and seizures, which are particularly severe in children (Adams & Moss, 2002).

1.1. INTRODUCTION

Irrigation is the replacement or supplementation of rain fall with water from another source in order to grow crops. Almost 60 percent of all the world's freshwater withdrawals are used for irrigation. Irrigation is basically an attempt by man to locally alter the hydrologic cycle and to promote increased agricultural productivity. Locally, altering the hydrologic cycle and increasing agricultural productivity, the impact of irrigation on the development of modern civilization has been profound (Cuenca, 1989).

Irrigation water use includes water that is applied by an irrigation system to sustain plant growth in all agricultural and horticultural practices. Irrigation also includes water that is applied for pre-irrigation, frost protection, application of chemicals, weed control, field preparation, crop cooling, harvesting, dust suppression, leaching salts from the root zone, and water lost in conveyance (US geological survey report, 2000). The obvious dimensions of irrigation are tangible - how much water is used, what acreage of land is irrigated, quality of water used for irrigation, what crops are grown, what forces of change and responses are seen.

Water is expensive and therefore must be used as efficiently as possible. Moreover water is unique in its overwhelming importance to plant growth than other agricultural inputs. A significant increase in irrigation investment in many countries of the world in recent times can be considered to be due to the widely held belief that, irrigation not only increases production, but also reduces variability by enabling better control over the environment. Agricultural sector is the largest user of water. Modern irrigated agriculture always depends on available water supply of useable quality. But most of the time this sector suffers from desired quality and quantity of water supply. Quality control for the irrigation water has often been ignored as good quality water supplies have been plentiful and readily available in many parts of the world.

According to Tuijl (1993), the volume of water used for irrigation varies from country to country and riverbasin to riverbasin. According to Statistical Office of the European Communities (EUROSTAT), in Sweden area equipped for irrigation in the year 2003 was 188470 hectors, while the area actually used for irrigation was 53430 hectors in the same year. Area equipped for irrigation by different region of Sweden has shown in the table below.

Table1: Distribution of irrigated area in Sweden in the year 2003. (Source: EUROSTAT 2006).

Region	**Area(in hectors) equipped for irrigation 2003**	**Area actually irrigated 2003**
Stockholm	4130	510
Östra Mellansverige	26500	3460
Sydsverige	78340	31440
Norra Mellansverige	7530	920
Mellersta Norrland	1740	230
Övre Norrland	2100	360
Småland med öarna	27440	9550
Västsverige	40690	6960
Total	188 470	53430

1.2. WATERBORNE PATHOGENS

The most common risk to human health associated with water stems from the presence of pathogenic micro organisms. A large number of these microorganisms found to be originating from polluted water with human excrement. Human faeces can contain a variety of intestinal pathogens which cause diseases ranging from mild gastro-enteritis to the serious and possibly fatal, dysentery, cholera and typhoid (WHO, 2001). Depending on the prevalence of certain other diseases in a community, other viruses and parasites may also be present. Indigenous microorganisms are not only present in the polluted water but also in the fresh water sources. Pathogens that can be found in the freshwaters are bacteria, fungi, protozoa (single-celled organisms) and algae (microorganisms with photosynthetic pigments), a few of which are known to produce toxins and transmit, or cause, diseases.

According to World Health Organization (WHO), these intestinal bacterial pathogens are distributed world-wide and the most common water-borne bacterial pathogens being *Salmonella, Shigella,* enterotoxigenic *Escherichia coli, Campylobacter, Vibrio* and *Yersinia.* Other pathogens that are occasionally found include *Mycobacterium, Pasteurella, Leptospira* and *Legionella* and the enteroviruses. Adenoviruses, reoviruses, rotaviruses and the hepatitis virus may also occur in water bodies.

Irrigation with untreated or low quality water has been accused for dispersion of many infectious diseases which are transmitted from one person to another and include various environmental pathways. For example, *Salmonella* species, responsible for some diseases like, typhoid, paratyphoid or gastro-enteritis and food poisoning, can be excreted by an healthy person acting as a carrier. These infectious pathogens can also be carried by some birds and animals. Therefore, contamination of water bodies by animal or human excrement introduces the risk of infection to those who use the water for drinking, food preparation, personal hygiene and even recreation (Blumenthal et. al., 2000).

According to Westrell (2004), in Sweden 90 to 99.9% reduction of microorganisms in the water can be achieved by waste water treatment. There is still potential risk of pathogens. If the treated wastewater is discharged into receiving waters, the pathogens can be transmitted to humans via waters used for recreation or food production. According to Westcot (1997), water supplies (wastewater or natural water) for both irrigation and human consumption are likely to contain pathogenic organisms similar to those in the human excreta. Water is considered the first exposure of excreted pathogenic organisms outside the body .Usually four main groups of pathogens potentially present in wastes that contaminate water sources: bacteria, viruses, protozoa and helminthes and have potential to reach the crops grown in the field.

All the pathogens have the potential to reach the field. The survival of microbiological pathogens, once discharged into a water body, is highly variable depending on the quality of the receiving waters, particularly oxygen levels, nutrients and temperature. Survival of bacteria also depends greatly on how hostile the environment is including other microorganisms in the water that might provide competition or predation. Bacteria often survive longer in clean water than in dirty water but survival in excess of 50 days is most unlikely and at 20-30°C, 20-30 days is a more common maximum survival time (Westcot, 1997). According to Rogers and Haines (2005), *Escherichia coli 0157:H7* survival in contaminated water can be more than 56 days at 20-29°C, while the survival time can be longer, more than 300 days at -4 to -20°C. Salmonella bacilli have been reported in excess of 50 miles downstream of the point source, indicating an ability to survive, under the right conditions for several days. Once in a water body, microorganisms often become adsorbed onto sand, clay and sediment particles and the settling of these particles results in the accumulation of the organisms in river and lake sediments. The speed at which the settling occurs depends on the velocity and turbulence of the water body. Survival time of the pathogenic organisms that are transmitted in the filed through water is shown in the table below.

Table 2: Survival times of selected excreted pathogens in soil and on crop surfaces at 20-30°C (Modified) (Sources: Westcot D.W., 1997).

Pathogen	**Survival time**	
	In soil	**In crops**
Viruses		
Enteroviruses	<100 but usually <20 days	<60 but usually <15 days
Bacteria		
Faecal coliform	<70 but usually <20 days	<30 but usually <15 days
Salmonella spp.	<70 but usually <20 days	<30 but usually <15 days
Vibrio cholera	<20 but usually <10 days	<5 but usually <2 days
Protozoa		
Entamoeba histolytica cysts	<20 but usually <10 days	<10 but usually < 2 days
Helminths		
Ascaris lumbricoides eggs	Many months	<60 but usually <30 days
Hookworm larvae	<90 but usually <30 days	<30 but usually <10 days

Taenia saginata eggs	Many months	<60 but usually <30 days
Trichuris trichiura eggs	Many months	<60 but usually <30 days

Coliforms are commonly used as the bacterial indicator of sanitary quality of foods and water. According to Washington State Department of Health (2007), 'Total coliforms' refers to the bacteria that are available both in the soil and in the water. The total coliform group is a large collection of different kinds of bacteria. 'Fecal coliforms' are types of total coliform that mostly exist in the gut and feces of warm-blooded animals. Total Coliform do not necessarily indicate recent water contamination by fecal waste, however the presence or absence of these bacteria in treated water is often used to determine whether water disinfection is working properly. Fecal coliforms are considered a more accurate indication of animal or human waste than the total coliforms.

Most of the fecal coliform is comprised of *E. coli*, and the serotype *E. coli* 0157:H7 is known to cause serious human illness. Serotype can be explained as a taxonomic subdivision or the type of a microorganism determined by its constituent antigens based on one of several different antibody-antigen reactions. *E. coli* is an almost universal inhabitant of the gut of humans and other warm blooded animals where it is the predominant facultative anaerobe through only a minor component of the total microflora. It can be opportunistic pathogen causing a number of infections such as gram-negative sepsis, urinary tract infections, pneumonia in immunosuppressed patients, and meningitis in neonates. Its common occurrence in feaces, readily culturability, and generally non-pathogenic character and survival characteristics in water led to the adaption of *E. coli* as an indicator of faecal contamination and the possible presence of enteric pathogens. (Adams & Moss, 2000).

Plants irrigated with low quality water can be attacked by these pathogens. *E. coli* 0157:H7 can be introduced through flood irrigation with water contaminated with cattle feces or contact with contaminated surface runoff. There are four major categories of diarrhoeagenic *E. coli* has been identified: Enterotoxigenic *E. coli*(ETEC), Enteroinvasive *E. coli* (EIEC), Enteropathogenic *E. coli* (EPEC) and Enterohaemorrhagic *E. coli* (EHEC). *E. coli O 157: H7* is the most common EHEC serotype and cause life threatening haemolytic uraemic syndrome (HUS). Investigation says that, in the Western Europe and North America about 10% of children under the age 10 with symptomatic *E. coli* 0157:H7 infection go on to develop haemolytic uraemic syndrome (HUS); half will require kidney dialysis and mortality rate is generally 3-5% (Adams & Moss, 2000).

A number of recent *E.coli 0157:H7* outbreaks have been linked to contaminated water; furthermore, studies have demonstrated the ability of the pathogen to survive for extended periods in water. According to Solomon et al., (2002), consumption of green leafy vegetables like lettuce could be a major source of the infection by the pathogen *E. coli* 0157:H7 and presence of the cattle in the adjacent fields are very much susceptible for outbreaks. He found that, *E. coli O157:H7* is capable of entering the roots of mature lettuce plants and can be transported upward to locations within the edible portions of the plant. Direct contact between the leaves and a contamination source is not required for the organism to become integrated into edible lettuce tissue.

1.3. SOURCES OF IRRIGATION WATER

Irrigation is considered as the most important use of water. Almost 60% of all the world's freshwater withdrawals go towards irrigation uses. Large-scale farming could not provide food for the world's large populations without the irrigation of crop fields by water taken from rivers, lakes, reservoirs, and wells. About 90% of water that is used for domestic or industrial uses,

eventually returned to the environment where is replenishes water sources and can be used for other purposes again. But only one-half of water that is used for irrigation is reusable. The rest of the water lost by evaporation, transpiration from plant or lost in transit, by a leaking pipe (USGS Water Resources of the United States, 2006). Freshwater withdrawal by the different regions of the world has been shown in the table below.

Table 3: Fresh water withdrawal by sector in the different regions of the world in 2001(Modified) (Source: FAO, 2006. AQUASTAT database).

Region	Internal renewable water resources (IRWR)	Total volume of freshwater utilization	Freshwater withdrawal by sector					
			Domestic		Industrial		Agricultural	
	km^3/year	km^3/year	km^3/year	%	km^3/year	%	km^3/year	%
World	**43 659**	**3 830**	**381**	**10**	**785**	**20**	**2664**	**70**
Africa	3 936	215	21	10	9	4	184	86
Asia	11594	2378	172	7	270	11	1936	81
Latin America	13477	252	47	19	26	10	178	71
Caribbean	93	13	3	23	1	9	9	68
North America	6253	525	70	13	252	48	203	39
Oceania	1703	26	5	18	3	10	19	72
Europe	6603	418	63	15	223	53	132	32

Generally the water needed to supply an irrigation scheme is taken from a water source. Water sources for irrigation can be groundwater extracted from springs or by using wells, surface water withdrawn from rivers, lakes or reservoirs. There are some non-conventional sources like treated wastewater, desalinated water or drainage water.

Rivers are used all over the world as sources of irrigation water. A river can be defined as surface water that moves over land from a higher to a lower altitude due to gravity and it's not a reservoir which contains a fixed amount of water. Rivers are unique as water sources that, at each moment a new amount of water are passing any given location along the river. But the flow of some small river fluctuates greatly over a short period of time because they respond promptly to rainfall in their catchment area (Brouwer et al., 1992). Not all the form of water can be used for irrigation. Only 3% of the earth's water is fresh and the rest of it is saline water. Of all the freshwater on earth, only about 0.3% is contained in the rivers and lakes. The distribution of earth's water has been shown below.

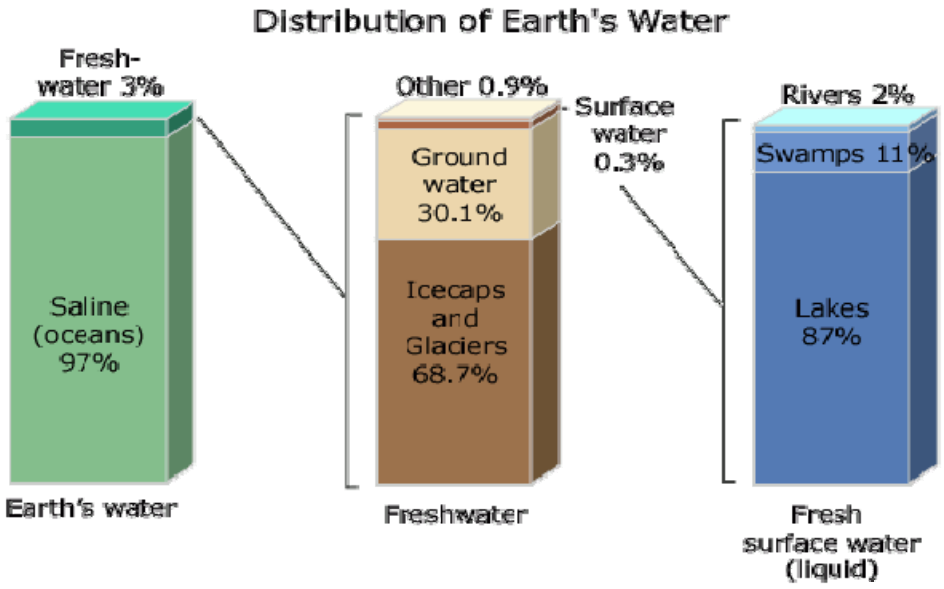

Figure 1: Earth's water distribution (Source: USGS Water Resources of the United States, 2006. http://ga.water.usgs.gov/edu/wuir.html).

Other sources of water like lakes, reservoirs or ponds can be considered as excellent sources of irrigation water, if their storage capacity and the water flowing into them are adequate. Lakes are natural depressions of the land which are filled up with water. Fresh water lakes have a natural outlet through which the lake discharges surplus water. Rainfall that falls directly on the surface of the lakes or run-off water that comes from nearby small streams or adjacent lands are the supplier of water into the lakes.

The most conventional uses of ground water include irrigating field crops, drinking or other types of human consumptions. Groundwater flows beneath the earth's surface through small pores and cracks in the rock or soil and stands for a major portion of the world's freshwater resources. According to Chapman (1996), groundwater as being considered more important in arid or semi-arid areas and surface water as more important in the humid areas. In some extent groundwater considered more superior than surface water as its convenient availability close to where water is required, excellent natural quality and the relatively low capital cost of development. In the United sates, 69.8 billion gallons of ground water is being used per day which is around 21 % of the total daily water consumption. Ground water consists of 0.6% of global water and 60% of the available total fresh water resources. Total volume of available groundwater is 4.2 x 10^6 km^3 compared to 0.126 x 10^6 km^3 stored in the lakes and streams (USGS Water Resources of the United States, 2006).

1.4. QUALITY OF SURFACE WATER

Water quality problems can be caused by one or more of several sources. Surface water quality of the same water source could be different from time to time because it is more susceptible to various pathogens and polluting agents. Surface water pollution from natural geologic sources is almost impossible to control. Geologic pollution becomes more evident as the high quality of water from the upper watersheds deteriorates as it flows downstream. Point sources of pollution are usually from municipal and industrial facilities. Other sources of pollution include contaminants from man-caused nonpoint sources, runoff from pastures, over-irrigation of agricultural croplands and abuse of the upper watersheds pollute water supplies (USGS Water Resources of the United States, 2006).

According to Kristensen and Bøgestrand (1996), surface water quality fluctuates greatly due to different variables and the numbers of variables that describe the quality of a waterbody have increased and are constantly being modified. So the various groups of water users have to define their own approaches and methods to describe and measure water quality. Variables like biological oxygen demand (BOD) and chemical oxygen demand (COD) have been used for some decades for evaluating sewage discharge and oxygen problems in the surface water. For the purpose of human consumption and public water supply, a set of microbiological indicator organisms (Faecal coliform bacteria) have been identified and their enumeration is now commonly applied to determine the hygienic suitability of water. Some environmental factors like temperature, UV light, water currents and rainfall affect the concentration of viable pathogens in the waterbodies due to pathogen adhesion to particles and sediments and interaction with autochthonous populations of microorganisms will also have a substantial effect on the survival of pathogens in aquatic environments.

According to Chapman (1996), irrigation of field crops presents a possible health risk to the consumers if the quality of the irrigation water is inadequate, especially with respect to pathogens and toxic compounds. The risk for microbial contamination has been found greatly if the water is sprayed directly onto the crop rather than flooded around the plants. Presence of certain inorganic ions can also affect the soil quality and, therefore, the growth potential of the crops. The water quality variables proposed by the National Environment Research Institute of Denmark, has been shown below:

- Basic variables used for a general characterization of water quality (water temperature, pH, conductivity, dissolved oxygen, and discharge).

- Suspended particulate matter (suspended solids, turbidity and organic matter (TOC, BOD and COD).

- Organic pollution indicators (dissolved oxygen, biochemical oxygen demand (BOD), chemical oxygen demand (COD), and ammonium).

- Indicators of eutrophication: nutrients (nitrogen and phosphorus), and various biological effect variables (chlorophyll a, Secchi disc transparency, phytoplankton, zoobenthos).

- Indicators of acidification (pH, alkalinity, conductivity, sulphate, nitrate, aluminium, phytoplankton and diatom sampling).

- Specific major ions (chloride, sulphate, sodium, potassium, calcium and magnesium) as essential factors in determining the suitability of water for most uses (public water supply, livestock watering and crop irrigation).

- Metals (cadmium, mercury, copper and zinc)

- Organic micropollutants such as pesticides and the numerous chemical substances used in industrial processes (PCB, HCH, PAH).

- Indicators of radioactivity (total alpha and beta activity, 137Cs, 90Sr)

- Microbiological indicator organism (total coliforms, faecal coliforms and faecal streptococci bacteria)

- Biological indicators of the environmental state of the ecosystem (phytoplankton, zooplankton, zoobenthos, fish, macrophytes and birds and animals related to surface waters).

1.4.1. Electrical conductivity (EC)

Electrical conductivity, or specific conductance, is a measure of the ability of water to conduct an electric current. It is responsive to variations in dissolved solids, mostly mineral salts. The degrees to which these dissociate into ions, the amount of electrical charge on each ion, ion mobility and the temperature of the solution all have an influence on the electrical conductivity. Conductivity is expressed as microsiemens per centimeter ($\mu S\ cm^{-1}$) and for a given water body, is related to the concentrations of total dissolved solids (TDS) and major ions. Total dissolved solids (TDS) may be obtained by multiplying the conductance by a factor which is commonly between 0.55 and 0.75. This factor must be determined for each water body, but remains approximately constant provided the ionic proportions of the water body remain stable.
The conductivity of most freshwaters ranges from 10 to 1,000 $\mu S\ cm^{-1}$ but may exceed 1,000 $\mu S\ cm^{-1}$, especially in polluted waters, or those receiving large quantities of land run-off. According to Chapman (1996), EC is a rough indicator of mineral content of the sample water and very useful when other methods cannot easily be used. Electrical conductivity (EC) can be used for measuring a pollution zone, e.g. around an effluent discharge or the extent of influence of run-off waters. It is usually measured *in situ* with a conductivity meter, and may be continuously measured and recorded. Such continuous measurements are particularly useful in rivers for the management of temporal variations in total dissolved solids (TDS) and major ions.

1.4.2. pH, acidity and alkalinity

In water quality assessment pH is an important variable and at the same time it influences many biological and chemical processes within a water body and all processes associated with water supply and treatment. When measuring the effects of an effluent discharge, it can be used to help determine the extent of the effluent plume in the water body. According to James & Gerald (2000), pH is an important parameter since it influences the relative solubility of certain nutrients and can impact the solubility of certain chemicals or pesticides used in grower operations.
Generally, pH is a measure of the hydrogen ion concentration. The pH can vary on a scale from 0-14 with a pH of 7 being neutral, less than 7 considered acid and above 7 called basic or alkaline. Irrigation water with a pH of 4 might be termed very acid and water with a pH of 8.5 very alkaline. In unpolluted waters, pH is principally controlled by the balance between the carbon dioxide, carbonate and bicarbonate ions as well as other natural compounds such as humic and fulvic acids. The natural acid-base balance of a water body can be affected by industrial effluents and atmospheric deposition of acid-forming substances. Changes in pH can indicate the presence of certain effluents, particularly when continuously measured and recorded, together with the conductivity of a water body (Chapman, 1996).

1.4.3. Dissolved oxygen (DO)

Oxygen is essential for the living organisms and for many of the chemical processes that occur in the water. The measurement of DO can be used to indicate the degree of pollution by organic matter, the destruction of organic substances and the level of self-purification of the water. Its determination is also used in the measurement of biochemical oxygen demand (BOD). There are two ways that dissolved oxygen (DO) enter into the water, either from photosynthesis by the aquatic plants or through diffusion with the surrounding air. Oxygen is consumed into the water through respiration of aquatic animals and plants, decomposition of organic matter by microorganisms and different chemical reactions. The oxygen content of natural waters varies with temperature, salinity, turbulence, the photosynthetic activity of algae and plants, and

atmospheric pressure. The solubility of oxygen decreases as temperature and salinity increase. It is found that, in fresh-waters dissolved oxygen (DO) at sea level ranges from 15 mg l^{-1} at 0° C to 8 mg l^{-1} at 25° C. According to Chapman (1996), concentrations in unpolluted waters are usually close to, but less than, 10 mg l^{-1}.
Fluctuations in the amount of dissolved oxygen (DO) could be seasonally or even over 24 hour periods, in relation to temperature and biological activities like photosynthesis and respiration. Biological respiration, which is related to decomposition processes, reduces dissolved oxygen (DO) concentrations in the water. Depending on the rates of biological processes, pockets of high and low concentrations of dissolved oxygen can form in still water. According to James & Gerald (2000), fast-moving water generally has more oxygen than still water because the movement mixes the air into the water. However, if the water is very turbulent, it may hold too much oxygen, causing stress to the aquatic organisms.
Determination of dissolved oxygen (DO) concentrations is an elementary part of a water quality assessment since oxygen is involved in, or influences, nearly all chemical and biological processes within water bodies. Concentrations below 5 mg l^{-1} may adversely affect the functioning and survival of biological communities and below 2 mg l^{-1} may lead to the death of most fish. Dissolved oxygen is of much more limited use as an indicator of pollution in groundwater, and is not useful for evaluating the use of groundwater for normal purposes.

1.4.4. Total organic carbon (TOC)

Sources of organic carbon in freshwaters come from living materials, directly from plant photosynthesis or indirectly from terrestrial organic matter and also as a constituent of waste materials and effluents. Total organic matter in the water has been found as an indication of the degree of pollution, particularly when concentrations are compare with upstream and downstream of potential sources of pollution (sewage or industrial discharges or urban areas). In the surface water, TOC concentrations are generally less than 10 mg l^{-1} and in groundwater less than 2 mg l^{-1}, unless the water receives municipal or industrial wastes, or is highly colored due to natural organic materials. Depending on the level of wastewater treatment, TOC concentrations in municipal wastewaters range from 10 to > 100 mg l^{-1}. Total organic carbon consists of dissolved and particulate material and affected by fluctuations in suspended solids, which can be quite pronounced in rivers (Chapman, 1996).

1.4.5. Chemical oxygen demand (COD)

The chemical oxygen demand (COD) is a measure of the oxygen, equivalent of the organic matter in a water sample that is susceptible to oxidation by a strong chemical oxidant. The chemical oxygen demand (COD) is widely used as a measure of the susceptibility to oxidation of the organic and inorganic materials present in water bodies and in the effluents from sewage and industrial plants. According to Chapman (1996), the concentrations of chemical oxygen demand (COD) in surface waters range from 20 mg l^{-1} oxygen or less in unpolluted waters and 200 mg l^{-1} oxygen or greater in the waters that receiving effluents. In the industrial wastewaters, the value of COD has been found ranging from 100 mg l^{-1} to 60,000 mg l^{-1} oxygen.

1.4.6. Microbiological indicator organisms

Faecal coliforms originate in the digestive tract of warm-blooded animals and are discharged to the environment with faecal wastes. Faecal coliform bacteria may indicate sewage pollution entering water bodies. Faecal coliform measurements indicate human health risks associated with drinking contaminated water, contact recreation (swimming), and from harvesting and ingesting contaminated shellfish. Another parameter indicative of faecal coliform presence is the bacteria *E. coli* which is also used as an indicator of water quality.

As mentioned before sewage, agricultural and urban run-off or domestic wastewaters are discharged to water bodies, particularly into the rivers. The pathogens associated with these

discharges subsequently distributed through the water body and presenting a risk to downstream water users. The range of coliform bacteria in the traditional sewages reported around 10 to 100 million per 100 ml and *Escherichia coli* or faecal streptococci near 1 to 50 million per 100 ml (Westcot, 1997). Different levels of wastewater treatment could reduce this by a factor of 10 to 100 and concentrations are reduced further after dilution by the receiving waters.

According to Westrell (2004), sources of pathogens for the surface water contamination are sewage effluents and agricultural run-off and the concentrations of pathogens in raw water vary substantially depending on the degree of anthropogenic activities. A large proportion of river water flow may constitute of wastewater discharge and any enteric pathogen that occurs in the population can potentially be found in surface waters impacted by wastewater discharges. Again, run-off from agricultural land can contain pathogens from livestock, such as *Cryptosporidium* and EHEC. Hansen & Stenström (1998) mentioned that in a Swedish survey of surface water resources, Giardia was detected around 26% and *Cryptospordium* about 32% of the investigated waters. When screened for *Campylobacter*, 7% of all samples from Swedish surface waters were found positive. With repeated sampling in some water sources the bacterium was found in 38% of the samples, often in the absence of faecal indicator bacteria. *Campylobacter* was also detected in groundwater with clear faecal contamination. In Norway *Campylobacter* was isolated from 53% of the samples from a river and from 17% of Finnish lakes and rivers. Concentration of different pathogens in surface water has been shown in the table below.

Table 4: Concentration (L^{-1}) of different pathogens in surface water (Westrell, 2004).

Pathogens	**Mean**	**Range**	**Pos[a]**	**Place**
Campylobacter	Det. In 100 ml 40-70[b]	n.a. <10-600	7% 94%	Sweden UK
EHEC	Det. in 90 mL	n.r.	1.7%	Canada
Enterovirus	0.3 41	0.003-0.90 0-190	100% n.r.	The Netherlands Japan
Hepatitis A	Det. In 1 L	n.a.	43%	Spain
Rotavirus	0.2-29	0-41	8-100%	North & South America
Norovirus	Det. In 1 L 40 390	n.a. <1-240 12-1700	9.4% 38% 100%	 The Netherlands The Netherlands
Giardia	0.5 0.1	<0.01-4.6 <0.1-4	26% 16%	Sweden Norway

[a] Percent positive samples. [b] Geometric mean.
Det. = detected, n.r. = not reported, n.a. = not applicable

1.5. REGULATIONS OF IRRIGATION WATER

There has been growing concern for the last few decades that, the world is moving towards a water crisis situation as because water is highly scarce in some parts of the world. Irrigation with treated water may not be possible in some countries as it is expensive and lack of implementations of water-quality guidelines promote the risk of water borne diseases by the irrigation water. At the same time, issues of both water quantity and quality are of concern. So reuse of waste water is being considered as a new source of water in the regions where water

supply is not adequate. The standard required for the safe use of water either for drinking or irrigating crops, amount and type of untreated waste water treatment needed are contradictory (Blumenthal et al., 2000).

According to Pescod (1992), treatment of waste water has been widely adopted as the major control measure in controlled effluent use schemes, with crop restriction being used in a few cases. A more integrated approach to the planning of wastewater use in agriculture will take advantage of the optimal combination of the health protection measures available and allow for any soil/plant constraints in arriving at an economic system suited to the local socio-cultural and institutional conditions. Various reports from WHO has discussed the integration of the different measures available to achieve effective health protection. There are some limitations which can act as the barriers for the implementation of water quality standard in different countries. Limitations of the administrative or legal systems in some countries will make some of these approaches difficult to apply, whereas shortage of skilled technical staff in other countries will place doubt upon reliance on wastewater treatment as the only control mechanism.

Waste water reuse guidelines was first drawn up by WHO (world health organisation) in California in 1918. These guidelines could differ from country to country. According to Blumenthal et al. (2000), 'There are currently several alternative approaches to establishing microbiological guidelines for reusing wastewater. These have different outcomes as their objectives: the absence of faecal indicator bacteria in the wastewater, the absence of excess cases of enteric disease in the exposed population and a model generated risk which is below a defined acceptable risk'.

A revised waste water use guideline was formulated by WHO in 1989, based on waste treatment technologies and waste management options. The levels of this guideline were constructed from the results of the available epidemiological studies of wastewater use and consideration of what was achievable by wastewater treatment processes. There was quite a numbers of evidence available on the risk-exposure to raw wastewater and excreta and on the risks to farm workers and local populations inhabiting nearby irrigated areas. However, there was less evidence of the effect of use of treated wastewater, particularly in relation to consumption of vegetable crops. In case of the lack of enough epidemiological evidences, data on pathogen removal by applications of wastewater treatment processes, pathogen die-off in the field and prevailing guidelines for water quality were taken into consideration (WHO, 1989). WHO recommended microbiological quality guidelines for irrigation water has been shown in the table below:

Table 5: Recommended microbiological quality guidelines for wastewater use in agriculture. (source: WHO 1989).

Category	Reuse conditions	Exposed group	Intestinal nematodes[b] (/litre*[c])	Faecal coliforms (/100ml**[c])	Wastewater treatment expected to achieve required quality
A	Irrigation of crops likely to be eaten uncooked, sports fields, public parks[d]	Workers, consumers, public	≤1	≤1000	A series of stabilisation ponds designed to achieve the microbiological quality indicated, or equivalent treatment
B	Irrigation of cereal crops, industrial crops, fodder crops, pasture and trees[e]	Workers	≤1	None set	Retention in stabilisation ponds for 8-10 days or equivalent helminth removal
C	Localised irrigation of crops if category B exposure of workers and the public does not occur	None	n/a	n/a	Pre-treatment as required by the irrigation technology, but not less than primary sedimentation

[a] In specific cases, local epidemiological, sociocultural and environmental factors should be taken into account, and the guidelines modified accordingly

[b] *Ascaris* and *Trichuris* species and hookworms

[c] During the irrigation period

[d] A more stringent guideline (≤ 200 faecal coliforms/100ml) is appropriate for public lawns with which the public may come into direct contact

[e] In the case of fruit trees, irrigation should cease two weeks before the fruit is picked and none should be picked off the ground

* Arithmetic mean

** Geometric mean

The microbiological quality guidelines derived by the WHO, have been used as the basis for standard setting in several countries and regional administrations. Bontoux (1998), confirms that, the guideline levels has been adopted unchanged as standard in some places like Balearic Islands and Catalonia in Spain. In some places where management practices and restrictions are closely specified, the quality guideline levels have been adopted within a more cautious approach. In France, sanitary recommendations for the use of wastewater for the irrigation of crops and landscapes are used to guide wastewater reuse projects. Standards will be drawn up after the evaluation of these projects. The French standard for water quality guidelines requires additional safety measures like protection of groundwater and surface waters, distribution networks for treated wastewater, hygiene regulations at treatment and irrigation facilities and restricting the use of wastewater according to the quality of the treated effluents.

In Germany, the quality of irrigation water is regulate by DIN 19650 and these microbial aspects of irrigation water applies in the field of agriculture, landscaping, gardening and as well as in parks and sport facilities. DIN 19650 regulations divide the hygienic safety of irrigation water into four distinctive classes, which need to verify for each intended use (German Association for Water Reuse, and Rainwater Harvesting, 2005).

Table 6: Hygienic / microbiological qualification classes of irrigation water and their application according to DIN19650, 1999. [Adapted from **fbr Information Sheet H201** (German Association for Water Reuse, and Rainwater Harvesting, 2005)].

Qualification class	**Application**	**Faecel streptococci number of colonies/ 100 ml**	***E. coli* number of colonies/ 100 ml**	**Salmonellae/ 1000 ml (according to DIN 38414-13)**	**Potentially infectious stages of human and pet parasites 2) in 1000 ml**
1 (Drinking water)	All crops in greenhouses and on open land without restriction	Not detectable	Not detectable	Not detectable	Not detectable
2[3])	Crops on open land and in greenhouses for raw consumption, schools sport fields, public parks	< 100 4)	< 200 4)	Not detectable	Not detectable
3[3])	Crops in greenhouses not intended for consumption Crops on open land for raw consumption up to the fruiting stage or for vegetables up to 2 weeks prior to harvesting Fruits and vegetables for conservation Greenland or forage plants up to 2 weeks before cut or grazing All other crops on open land without restriction Other sport fields 5)	< 400	< 2000	Not detectable	Not detectable
4 [3]), [5])	Wine and fruit cultures for protection against frost Forest, polder and wetlands Sugar-beets, starch potatoes, oil fruits and non-food plants for industrial processing and seeds up to two weeks prior to harvesting Grain up to the germination phase (not intended for raw consumption) Feed for conservation up to 2 weeks prior to harvesting	Wastewater which has undergone at least one biological treatment			For intestinal nematodes, no standard recommend-ations are possible for Taenia stages: not detectable

1) Microbiological surveys according to the methods applied for bathing water.
2) As far as it is necessary for the protection of the health of humans and animals, an examination of the irrigation water for intestinal nematodes (Ascaris and Trichuris species as well as hookworms) and/or life stages of tapeworms (especially Taenia) may be accommodated according to WHO recommendation.

3) If a wetting of the parts of the crop products which are appropriate for consumption is excluded, a restriction according to the hygienic / microbiological qualification classes may be dropped.
4) Guide value, below which measured values should lie, according to the German Drinking Water Ordinance TrinkwV § 2 Para 3 "as far as the state-of-the-art and a justifiable expenditure allow, taking into consideration each individual case".
5) In case of spray irrigation, it has to be ensured through protective measures that employees and the public are not at risk.

2. Hypotheses

1) Advanced oxidation technology (AOT) is efficient to guarantee highly hygienic irrigation water.

2) Placement of the AOT-device within the water conduct is essential.

3) Length of the connecting pipeline between stationary and mobile unit affects bacterial loads.

4) Total organic carbon (TOC) and chemical oxygen demand (COD), total nitrogen (TN) and total phosphate (TP) are affected by the AOT treatment.

5) Nutrients in the irrigation water are also affected by the placement of the AOT-device.

6) pH and electrical conductivity (EC) is influenced by the AOT device.

3. Materials and methods

The study was carried out at Norrvidinge gård located in Kävlinge community, Scania. This farm is engaged for producing field crops mostly leafy vegetables. Surface water was used for irrigating these crops and collected in a pond from a nearby stream. For disinfestation, advanced oxidation technology (AOT, Wallenius Water AB, Stockholm, Sweden) was used.

3.1. Experimental overlay

Three disinfestation treatments differing in location of the AOT within the pipeline system were examined with respect to water quality parameters:

i. stationary equipment close to the collection pond (treatment 1)
ii. mobile equipment close to the irrigation ramp (treatment 2)
iii. both stationary and mobile equipment (treatment 3).

Samples were taken at ten occasions during the season 2007 with three parallels at five places within the pipeline system (Figure 2):

i. before the prefilter (treatment 1, 2, 3)
ii. after the prefilter (treatment 1, 2, 3)
iii. after the stationary AOT (treatment 1)
iv. before the mobile AOT (treatment 2, 3)
v. at the irrigation ramp (treatment 1, 2, 3)

Sampling place displayed "before AOT" for treatment 1; for treatment 2 & 3, sampling place 5 was identical with "after AOT-treatment".

The water samples were analyzed with respect to

i. water hygienic indicator organisms (heterotrophic organisms at 22°C, coliform bacteria, *Escherichia coli*)
ii. organic compounds (total organic carbon, TOC; chemical oxygen demand, COD; total nitrogen content, TN; total phosphate content, TP) as well as
iii. inorganic compounds (NH_4, NO_3, P, S).

The bacteriological analyses were performed by Alcontrol laboratories, Malmö, where as the organic and inorganic chemical analyses were conducted at the Department of Horticulture, SLU, Alnarp and Lennart Månsson International, respectively.

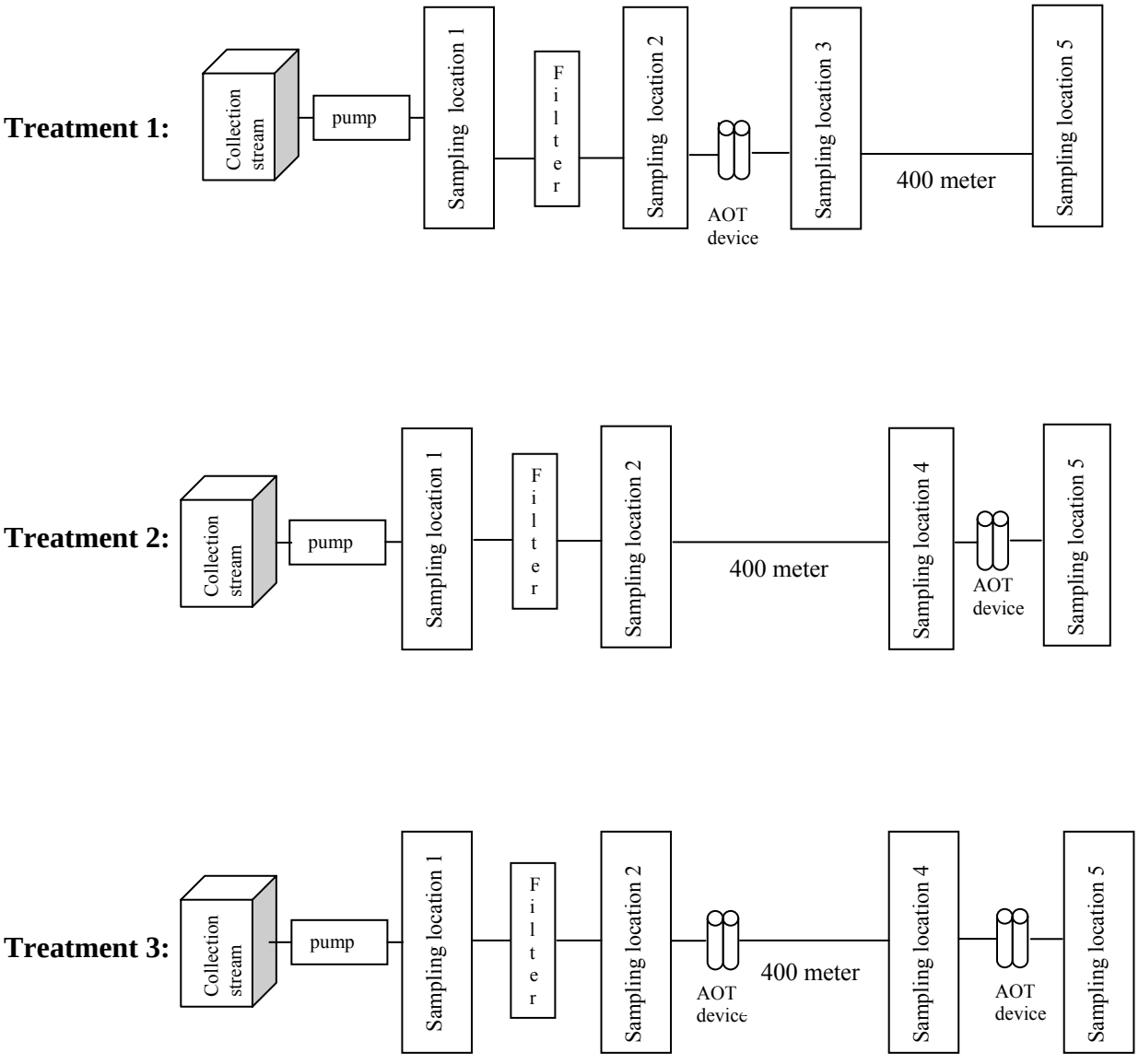

Figure 2: Schematic diagram of the sampling procedure followed during sample water collection in Norrvidinge gård

3.2. ANALYSES

3.2.1. Bacteriological analyses

Heterotrophic organisms were defined as organisms using organic compounds and degrading them within a given time of incubation. All aerobic microorganisms, yeasts as well as moulds that can form colonies on yeast peptone agar (pH 7.2) are considered. Analysis of heterotrophic organisms was based on SS-EN ISO 6222:1999 and SLV 2741/03(National Food Administration 2003). Sample flasks were shaken vigorously and aliquots of 1 ml were serially diluted. For analysis, the pour plate technique using 1 ml of suspension and 15 ml of temperate yeast peptone agar was adopted. Agar plates were incubated at 22 °C ± 2 for 68 h ± 4. Plates with 30-500 colonies detectable at 10 x amplification were considered.

Coliform organisms were defined as oxidase negative, gram negative, non spore forming rods that produce acid and aldehyde when cultivated at 35° C for 24 h. Coliform colonies have metallic glance. Coliform bacteria and *Escherichia coli* were analyzed according to SS 028165-3 and SS 028167-2 modified according to SLV 2741/03 (National Food Administration 2003). The sample flasks were shaken and aliquots of 10 ml were membrane filtrated (0.45 µm). The filter was then placed upside down to the surface of Les endoagar and incubated for 35 °C ± 0.5 for 24 h ± 4. All metallic shining colonies were enumerated. For verification, five colonies were incubated on yeast peptone agar and cultured at 35 °C ± 0.5 for 24 h ± 4 and then subjected to oxidase test. There is no color change for oxidase negative colonies, whereas the medium changes from colorless to blue within 10 s in the presence of oxidase positive colonies.

Oxidase negative colonies were transferred to tubes containing LTLSB and incubated at 44 °C ± 0.5 for 24 h ± 4, before addition of 0.5 ml of Kovac's solution. An indol positive reaction identifies the colony as *E. coli*.

3.2.2. Organic chemical analyses

Analysis of total organic carbon (TOC), chemical oxygen demand (COD), total nitrogen (TN) and total phosphate (TP) of the water samples were done by using test kits from Hach Lange, Germany combined with Lange cuvette photometric techniques. These analyses followed the instructions of the producer. Analysis of total organic carbon (TOC) was based on test kit: LCK 385 (3-30 mg l^{-1}), while analysis for COD, TN and TP had been done on the basis of LCK 314 (15-150 mg l^{-1}), LCK 138 (1-16 mg l^{-1} TN_b) and LCK 348 (0.5-5.0 mg l^{-1} PO_4-P) respectively.

To prepare the photometric analysis of total organic carbon of the water samples, 2ml of sample water was taken into the indicator tubes and placed in the shaker (TOC-X5) for 5 minutes. After shaking properly, barcode caps were put on each of the indicator tubes. Then these indicator tubes were joined together quickly with other barcode included tubes and placed into the heat block (LT 200). Incubation temperature and time at the heat block were 100°C and 120 minutes, respectively. Analysis of total organic carbon has been done in two simple steps. In the first step, total organic carbon was expelled from the sample water with the help of the shaker (TOC-X5) and oxidized to carbon dioxide (CO_2). In the second steps the CO_2 passed through a membrane into the indicator tubes and cause a colour change which was evaluated by the Xion 500 spectrophotometer.

For COD analysis, 2 ml of sample water was taken into each of the indicator tubes supplied by the LCK 314 (15-150 mg/L O_2) test kit and had been shake properly. At the heat block (LT 200), incubation temperature and time were set to 148°C and 120 minutes, respectively. The chemical oxygen demand (COD) analysis used a strong chemical oxidant in an acid solution and heat to oxidize organic carbon to CO_2 and H_2O. Then after the incubation, the tubes were placed outside for cooling down and data was recorded by using spectrophotometer (Xion 500).

For total nitrogen (TN) analysis,1.3 ml of water sample, 1.3 ml of sodium hydroxide solution and oxidant tablet from the LCK 138 (1-16 mg l^{-1} TN_b) test kit were filled into the reaction tube. Time and temperature at the heat block (LT 200) were adjusted to 60 minutes and 100°C, respectively. The principles involve in the total nitrogen (TN) analysis were, inorganically and organically bonded nitrogen were oxidized to nitrate by digestion with per-oxodisulphate. Then the nitrate ions react with 2.6-dimethylphenol in a solution of sulphuric and phosphoric acid to form a nitrophenol. After incubation, these reaction tubes were placed outside the heat block for cooling. 0.5 ml of reagents from the reaction tube was taken into the 'LCK 138' indicator tubes and mixed with 0.2 ml of latoN. After 15 minutes, the data were recorded using the (Xion 500) spectrophotometer.

Total phosphate (TP) analysis was performed by filling 0.5 ml of water sample into the 'LCK 348' indicator tubes and adding dosi caps. After shaking, indicator tubes were placed in the LT 200 heat block for incubation. Incubation temperature and time was set to 60 minutes and 100°C, respectively. The phosphate ions react with the molybdate and antimony ions in an acidic solution to form an antimonyl phosphomolybdate complex. This was reduced by ascorbic acid to phosphomolybdenum blue. After incubation, indicator tubes were placed outside the heat block for cooling 18-20°C. Then, 0.2 ml of reagents and dosi caps were added from the test kits. After 10 minutes, the readings were taken spectrophotometrically.

3.2.3. Inorganic analyses

All nutrients were analyzed by ICP-MS. whereas ammonium (NH_4), nitrate (NO_3) and chlorine (Cl) were analyzed spectrophotometrically.

3.3. Statistical analyses

Bacteriological data were log-transformed before statistical analyses. The statistical analyses were carried out using ANOVA followed by Tukey's test, $p< 0.05$. All statistical analyses were done in the statistical program Minitab, version 15.

4. RESULTS

4.1. Bacterial flora

4.1.1. Heterotrophic bacterial flora at 22°C

The log values of the heterotrophic bacterial mean flora at 22°C showed significant differences (Fig.3) at the mobile disinfestation treatment and combination of stationary and mobile disinfestation treatment. During these treatments, mean bacterial flora was recorded 3.023 log CFU ml^{-1} and 3.14 log CFU ml^{-1} at the beginning of the pipeline, while at the end of the pipeline the bacterial occurrences were reduced to 2.58 log CFU$ml^{-1}$and 2.3742 log CFUml^{-1} respectively. No significant differences variations were observed for the heterotrophic bacterial flora at 22°C for the stationary treatment, when comparing the start and the end of the water conduit.

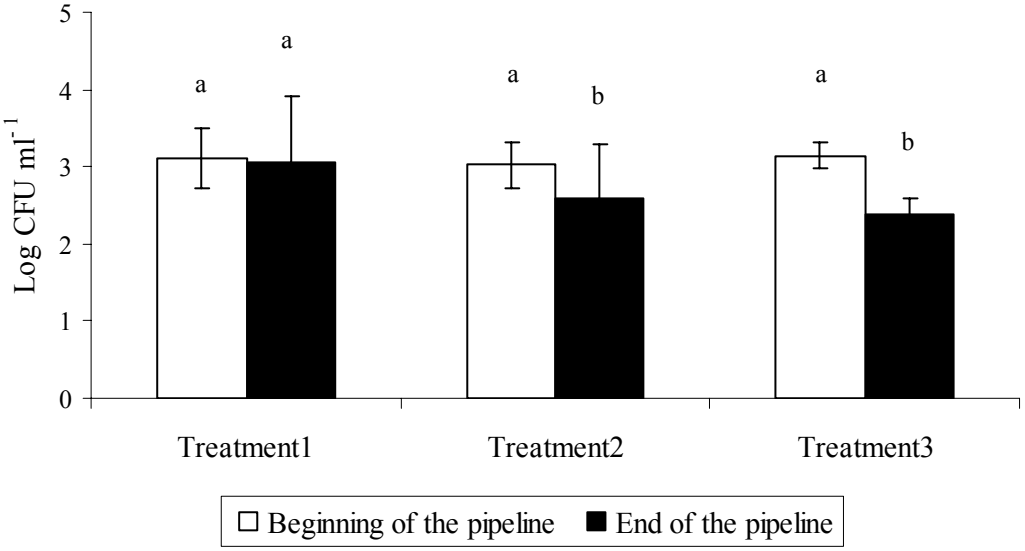

Figure 3: Occurrence of heterotrophic bacterial flora (log CFU ml^{-1}) at the beginning and end of the pipeline. Columns labelled with different letters are significantly different (Tukey-test; $p<0.05$).

Heterotrophic bacterial flora before and after AOT treatment has shown significant differences in the stationary, mobile and combined disinfestation treatment (Fig. 4). Before AOT treatment, concentration of the heterotrophic bacterial flora was 3.20 log CFU ml^{-1}, 3.28 log CFU ml^{-1} and 2.96 log CFU ml^{-1} respectively, in the first, second and third treatment, which was reduced to 2.41 log CFU ml^{-1}, 2.58 log CFU ml^{-1} and 2.37 log CFU ml^{-1} after AOT treatment.

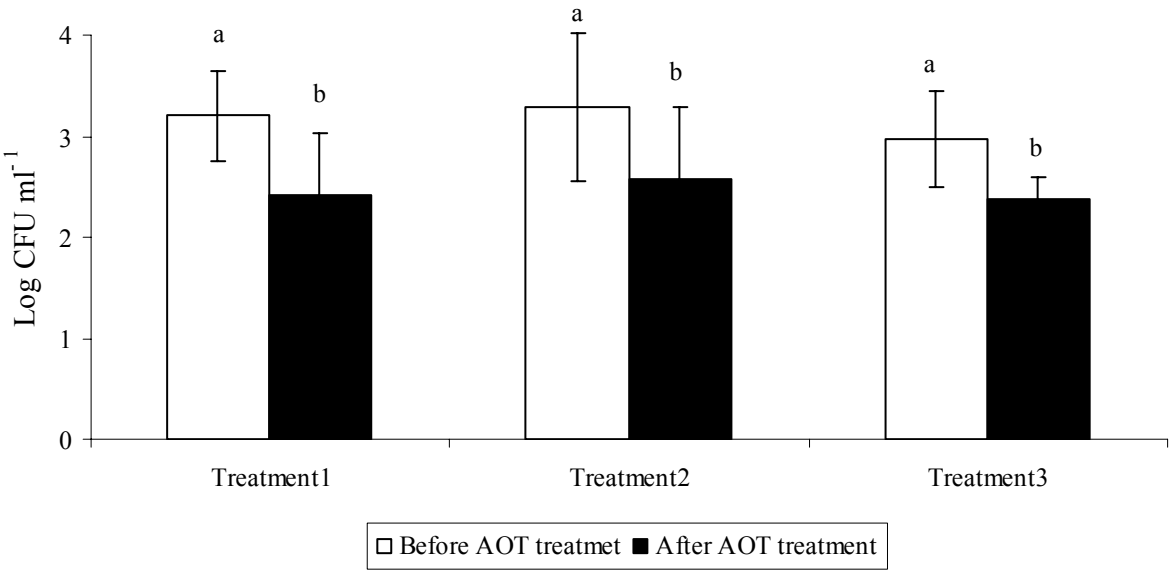

Figure 4: Occurrence of heterotrophic bacterial flora (log CFU ml^{-1}) before and after AOT treatment. Columns labelled with different letters are significantly different (Tukey-test; $p<0.05$).

Heterotrophic flora at the beginning and end of the connecting pipeline was differing significantly at the stationary disinfestation treatment (Fig.5). Starting of the connecting pipeline, heterotrophic mean flora was log 2.41CFU ml^{-1}, which went higher to log 3.05 CFU ml^{-1} at the end of the connecting conduit.

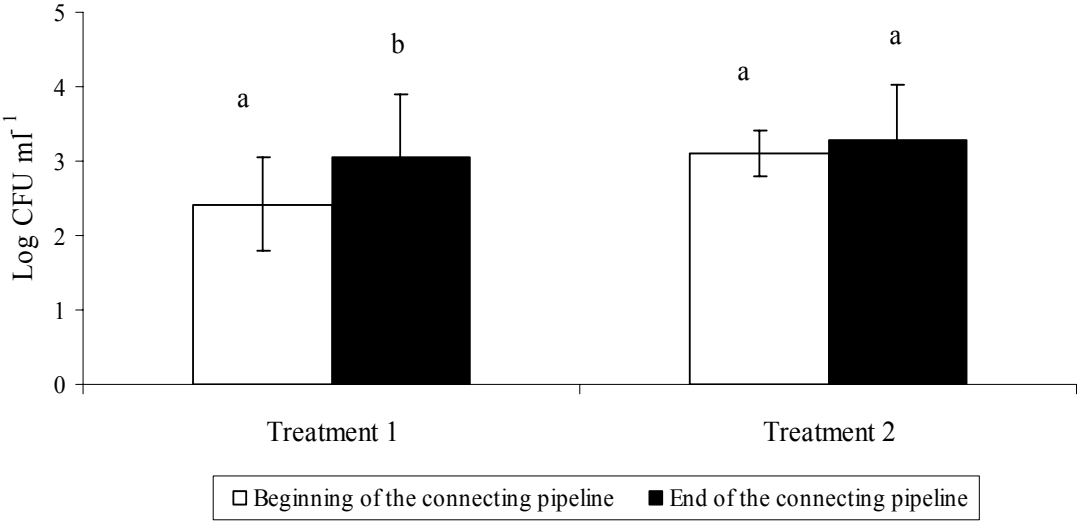

Figure 5: Occurrence of heterotrophic bacterial flora (log CFU ml^{-1}) at the beginning and end of the connecting pipeline between stationary and mobile unit. Columns labelled with different letters are significantly different (Tukey-test; $p<0.05$).

4.1.2. Coliform bacterial flora

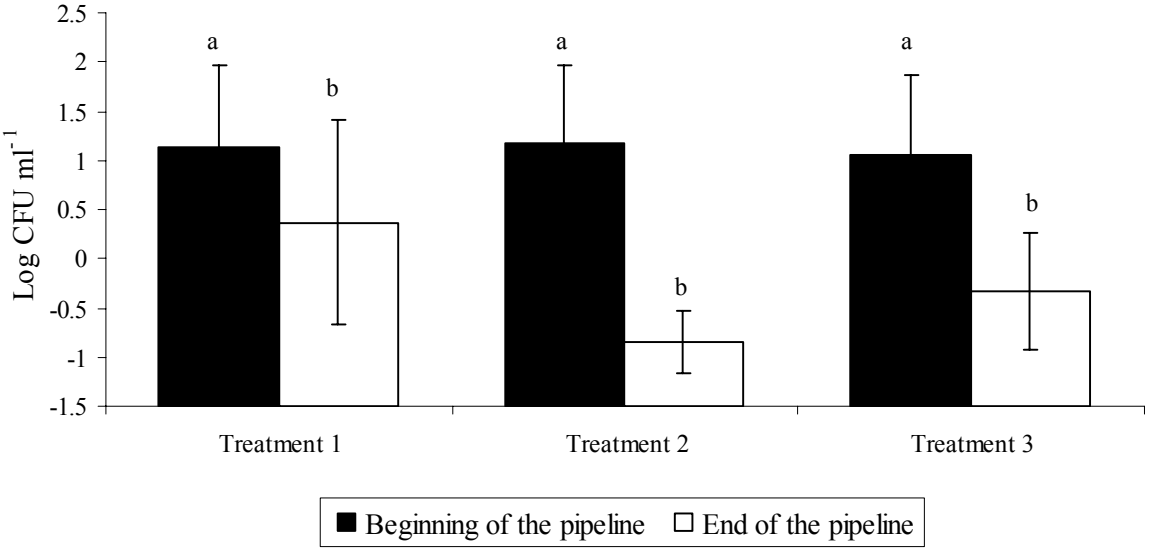

Figure 6: Occurrence of coliform bacterial flora (log CFU ml^{-1}) at the beginning and end of the pipeline. Columns labelled with different letters are significantly different (Tukey-test; $p<0.05$).

From the figure 6, the mean coliform bacterial flora at the beginning and end of the conduit was differing significantly during stationary, mobile and combined disinfestation treatments. Coliform flora at the end of the conduit has been reduced in all the treatments. Log value of the coliform flora was recorded 1.14 CFU ml^{-1}, 1.17 CFU ml^{-1} and 1.06 CFU ml^{-1} during stationary, mobile and combined disinfestation treatment at the starting of the conduit. While at the end of the conduit, coliform flora reduced to log 0.37 CFU ml^{-1}, log -0.8501 CFU ml^{-1} and log -0.3302 CFU ml^{-1} respectively.

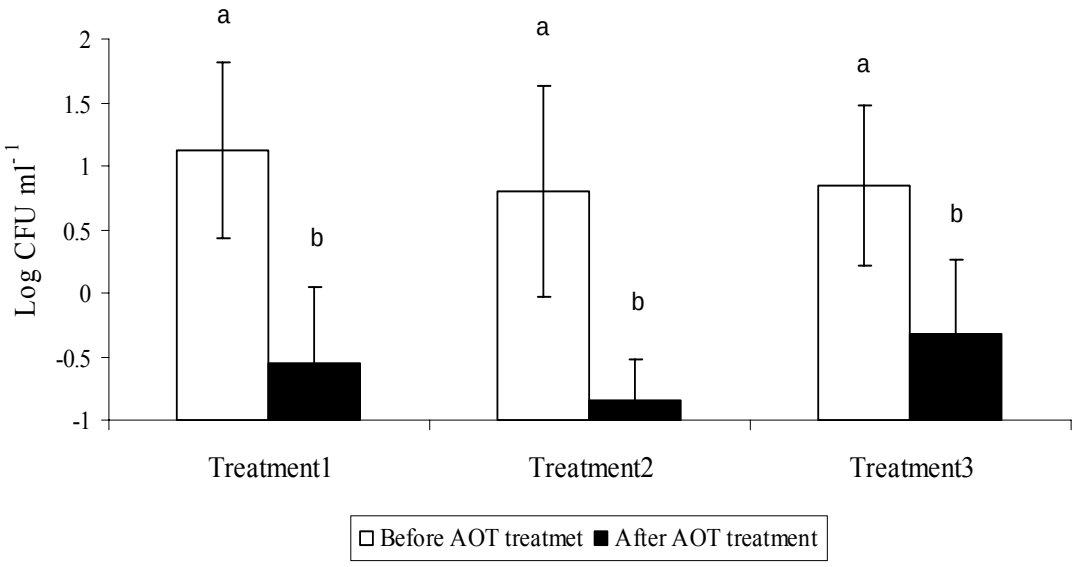

Figure 7: Occurrence of coliform bacterial flora (log CFU ml^{-1}) before and after AOT treatment. Columns labelled with different letters are significantly different (Tukey-test; $p<0.05$).

Occurrence of the coliform bacterial flora (Fig. 7) showed significant variations for all the disinfestation treatments. Before treated with the AOT-device, log value of the coliform flora was 1.12 CFU ml^{-1}, 0.80 CFU ml^{-1} and 0.85 CFU ml^{-1} respectively during stationary, mobile and

combined disinfestation treatment. While after AOT treatment, coliform flora lowered down to log -0.5489CFU ml $^{-1}$, log -0.8501 CFU ml $^{-1}$ and log -0.3302 CFU ml $^{-1}$ respectively. So, after treated with the AOT- device, coliform bacterial loads become lower than 0 ml $^{-1}$ in all the three disinfestations treatment.

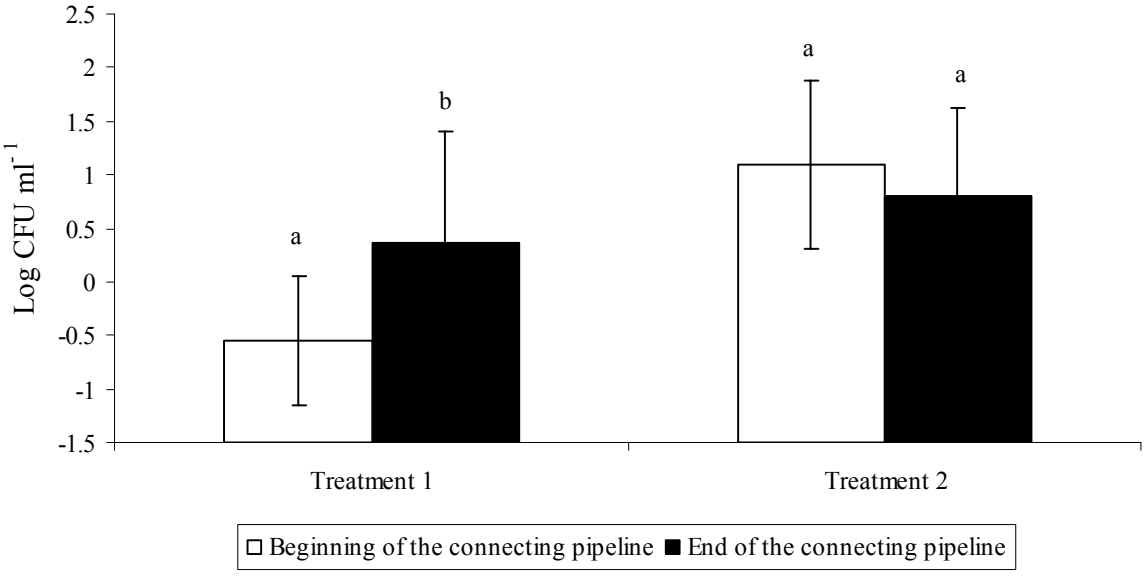

Figure 8: Occurrence of coliform bacterial flora (log CFU ml^{-1}) at the beginning and end of the connecting pipeline between stationary and mobile unit. Columns labelled with different letters are significantly different (Tukey-test; $p<0.05$).

Similar to the heterotrophic bacterial flora, coliform bacteria varied only in the stationary disinfestation treatment (Fig. 8). Starting of the connecting pipeline, mean coliform flora was log -0.55 CFU ml^{-1} which has increased to log 0.37 CFU ml^{-1} at the end of the connecting pipeline. In the mobile disinfestation treatment, no significant differences were found for the coliform bacteria.

4.1.3. Escherichia coli

E. coli showed significant differences during stationary, mobile and combination of stationary and mobile disinfestation treatment (Fig. 9). At the beginning of the conduit, mean occurrence of the *E. coli* was log -0.6178 CFU ml^{-1}, log -0.4656 CFU ml^{-1} and log -0.496 CFU ml^{-1} respectively during the disinfestation treatments. While at the end of the conduit, *E. coli* was lowered to log -0.8311 CFU ml^{-1}, log -1.0441 CFU ml^{-1} and log -1.0191 CFU ml^{-1} respectively during stationary, mobile and combined disinfestation treatment.

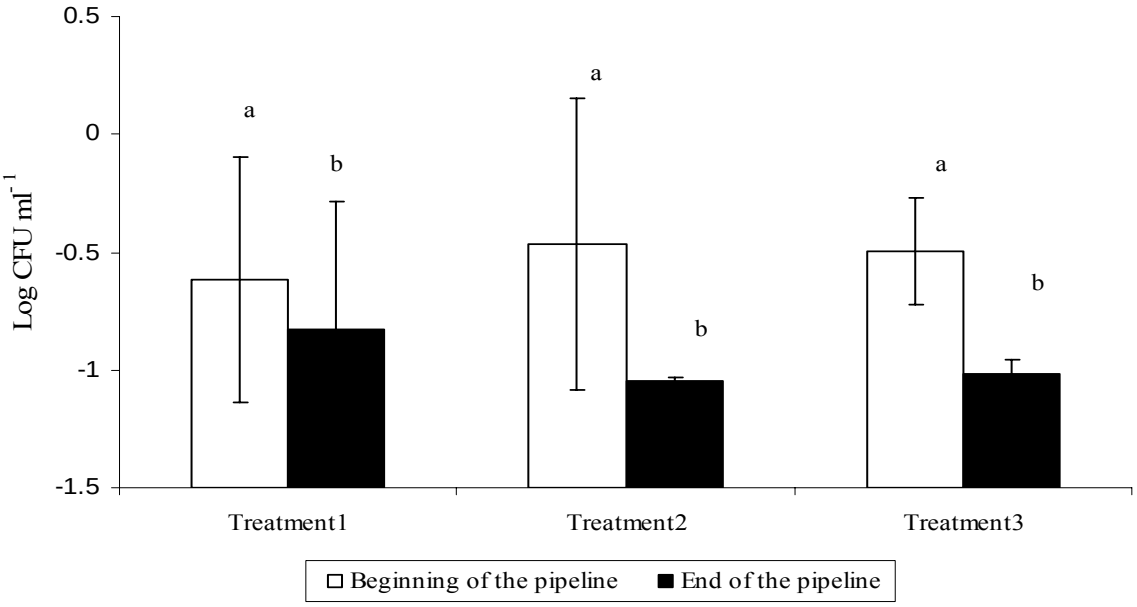

Figure 9: Occurrence of *E. coli* bacterial flora (log CFU ml^{-1}) at the beginning and end of the pipeline. Columns labelled with different letters are significantly different (Tukey-test; $p<0.05$).

From the figure 9, mean occurrences of the *E. coli* has shown significant differences in the stationary and mobile disinfestation treatments. During stationary disinfestation treatment, log value of the *E. coli* lowered down to -1.02 CFU ml^{-1} from -0.57 CFU ml^{-1} after treated with the AOT-device. Similarly, during mobile disinfestation treatment, mean occurrence of the *E. coli* was lower down to log -1.0441CFU ml^{-1} from log -0.5923 CFU ml^{-1} after treated with the AOT-device.

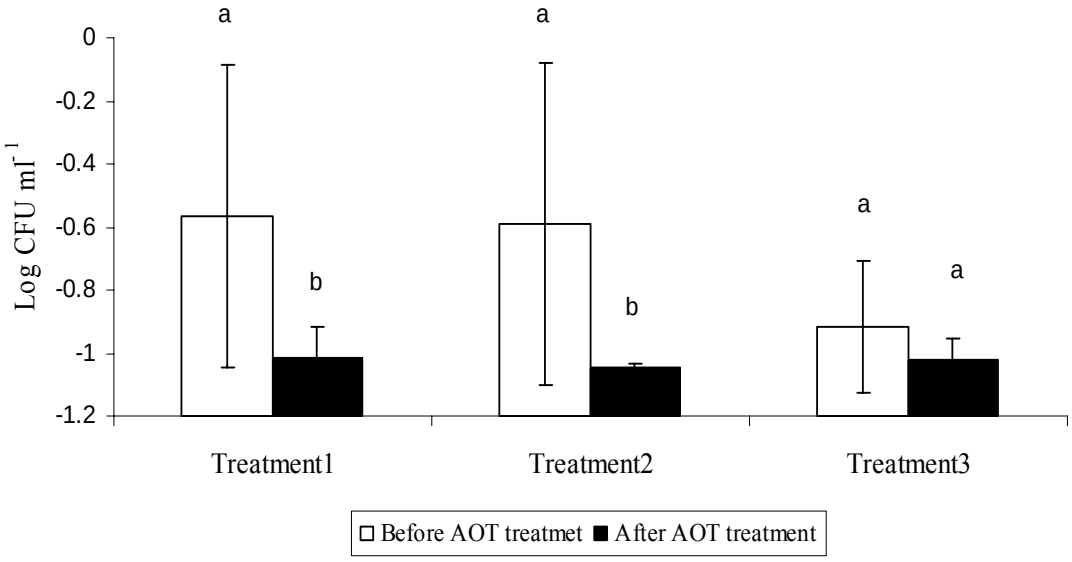

Figure 10: Occurrence of *E. coli* bacterial flora (log CFU ml^{-1}) before and after AOT treatment. Columns labelled with different letters are significantly different (Tukey-test; $p<0.05$).

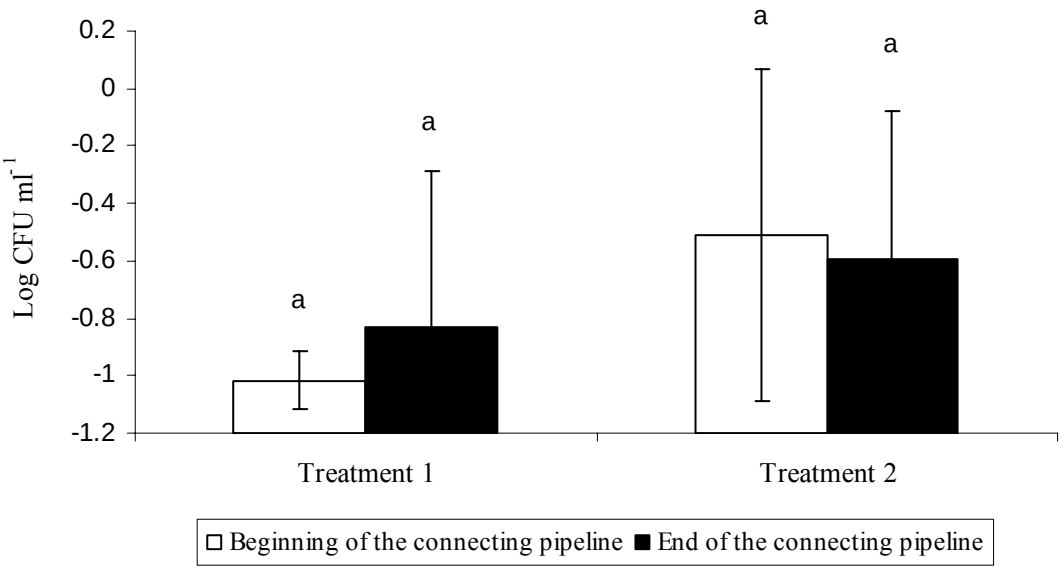

Figure 11: Occurrence of *E. coli* bacterial flora (log CFU ml^{-1}) at the beginning and end of the connecting pipeline between mobile and stationary disinfestations unit. Columns labelled with different letters are significantly different (Tukey-test; $p<0.05$).

4.2. Total organic carbon and chemical oxygen demand (TOC and COD)

Total organic carbon (TOC) content of the water samples did not show any significant differences in the disinfestation treatments and different sampling locations (Table 7). The range of total organic carbon (TOC) concentrations in different treatments varied from 6.09 mg l^{-1} to 7.82 mg l^{-1}. TOC concentrations, at the stationary and mobile disinfestation treatment were 7.37 mg l^{-1} and 7.37 mg l^{-1} respectively before treated with the AOT-device. After the AOT treatment, TOC concentrations were lower down to 7.10 mg l^{-1} and 7.18 mg l^{-1} respectively. Similar to the TOC, there was no significant differences found for chemical oxygen demand (COD) in the disinfestation treatments and different sampling locations (Table 8). COD content were same at the beginning and end of the pipeline in the mobile and combined disinfestation treatment. In the stationary disinfestation treatment, the mean COD content were raised from 19.53 mgl^{-1} to 28.14 mgl^{-1} at the end of the pipeline.

Table 7: Mean ± stdv of total organic carbon (TOC; mg l^{-1}) content in different treatments.

	Beginning of the pipeline	**End of the pipeline**
Treatment 1	7.822 ± 2.942 a	7.369 ± 1.475 a
Treatment 2	6.919 ± 1.182 a	7.183 ± 1.554 a
Treatment 3	7.304 ± 1.376 a	7.161 ± 2.296 a
	Before AOT treatment	**After AOT treatment**
Treatment 1	7.368 ± 1.72 a	7.103 ±1.409 a
Treatment 2	7.366 ± 1.591 a	7.183 ±1.554 a
Treatment 3	6.088 ± 1.039 a	7.161 ± 2.296 a
	Beginning of the connecting pipeline	**End of the connecting pipeline**
Treatment 1	7.103 ± 1.409 a	7.369 ± 1.475 a
Treatment 2	7.284 ± 1.795 a	7.366 ± 1.591 a

Values within the same row followed by the same letter are not significantly different.

Table 8: Mean± stdv of chemical oxygen demand (COD; mg l^{-1}) content in different treatments.

Beginning of the pipeline		**End of the pipeline**
Treatment 1	19.53 ± 16.89 a	28.14 ± 26.29 a
Treatment 2	21.16 ± 21.35 a	20.63 ± 19.41 a
Treatment 3	16.654 ± 4.5 a	16.418 ± 7.552 a
Before AOT treatment		**After AOT treatment**
Treatment 1	23.13 ± 22.22 a	24.1 ± 21.49 a
Treatment 2	23.82 ± 24.61 a	20.63 ± 19.41 a
Treatment 3	13.72 ± 5.324 a	16.41 ± 7.552 a
Beginning of the connecting pipeline		**End of the connecting pipeline**
Treatment 1	24.1 ± 21.49 a	28.14 ± 26.29 a
Treatment 2	26.2 ± 27.67 a	23.82 ± 24.61 a

Values within the same row followed by the same letter are not significantly different.

4.3. Total nitrogen, nitrate-nitrogen and ammonium-nitrogen (TN, NO_3-N and NH_4-N).

No significant differences found for the total nitrogen (TN) concentrations in any of the treatment (Table 9). In the stationary and combined disinfestation treatment, total nitrogen (TN) values went higher from 5.24 mg l^{-1} and 6.57 mg l^{-1} to 5.62 mg l^{-1} and 6.92 mg l^{-1}, respectively at the end of the pipeline. There were also no differences found for the total nitrogen (TN) in the water samples take before and after AOT treatment. During mobile disinfestation treatment, total nitrogen (TN) concentration of the water samples has decreased from 5.02 mg l^{-1} to 4.97 mg l^{-1} after treated with the AOT-device. It was also confirmed that, there were no differences of total nitrogen (TN) concentrations at the starting point and end point of the connected pipeline between stationary and mobile disinfestation unit. Concentrations of total nitrogen (TN) varied form 5.02 mg l^{-1} to 6.93 mg l^{-1} in all the three treatments.

Concentrations of the nitrate-nitrogen (NO_3-N) did not show any significant differences in the disinfestation treatments and sampling locations (Table 9). Nitrate-nitrogen (NO_3-N) concentrations ranged from 3.48 mg l^{-1} to 4.90 mg l^{-1} in the disinfestation treatments. Highest nitrate concentrations were found in the combined disinfestation treatment from the water samples taken before and after AOT treatment.

Ammonium-nitrogen (NH_4-N) concentration of the water samples differed significantly only in the combined disinfestation treatment from the samples taken before and after AOT treatment (Table 9). Ammonium concentrations significantly decreased from 0.15 mg l^{-1} to 0.09 mg l^{-1} after the AOT treatment.

Table 9: Mean concentrations ± stdv of total nitrogen (TN; mg l^{-1}), nitrate-nitrogen (NO_3-N; mg l^{-1}) and ammonium-nitrogen (NH_4-N; mg l^{-1}) in different treatments.

TN	**Beginning of the conduit**		**End of the conduit**
	Treatment 1	5.236 ± 1.61 a	5.621 ± 2.01 a
	Treatment 2	5.081 ± 1.599 a	4.972 ± 1.369 a
	Treatment 3	6.567 ± 1.442 a	6.927 ± 1.505 a
	Before AOT treatment		**After AOT treatment**
	Treatment 1	5.387 ± 1.655 a	5.382 ± 1.798 a
	Treatment 2	5.018 ± 1.242 a	4.97 ± 1.369 a
	Treatment 3	6.412 ± 1.269 a	6.927 ± 1.505 a
	Beginning of the connecting pipeline		**End of the connecting pipeline**

	Treatment 1	5.328± 1.798 a	5.621± 2.01 a
	Treatment 2	5.191± 1.488 a	5.018± 1.218 a
NO_3-N		**Beginning of the conduit**	**End of the conduit**
	Treatment 1	3.739± 1.509 a	3.804± .525 a
	Treatment 2	3.484± 1.356 a	3.62± 1.468 a
	Treatment 3	4.766± 1.204 a	4.836± 0.975 a
		Before AOT treatment	**After AOT treatment**
	Treatment 1	4.005± 1.547 a	3.851± 1.59 a
	Treatment 2	3.574± 1.346 a	3.576± 1.477 a
	Treatment 3	4.909± 1.205 a	4.836± 0.975 a
		Beginning of the connecting pipeline	**End of the connecting pipeline**
	Treatment 1	3.851± 1.59 a	3.804± 1.525 a
	Treatment 2	3.783± 1.436 a	3.574± 1.346 a
NH_4-N		**Beginning of the conduit**	**End of the conduit**
	Treatment 1	0.214± 0.1586 a	0.217± 0.1975 a
	Treatment 2	0.241± 0.1827 a	0.234± 0.2086 a
	Treatment 3	0.097± 0.01986 a	0.09± 0 a
		Before AOT treatment	**After AOT treatment**
	Treatment 1	0.273± 0.2 a	0.245± 0.18 a
	Treatment 2	0.222± 0.12 a	0.234± 0.21 a
	Treatment 3	0.154± 0.07 a	0.09± 0 b
		Beginning of the connecting pipeline	**End of the connecting pipeline**
	Treatment 1	0.24± 0.1892 a	0.21± 0.1975 a
	Treatment 2	0.28± 0.187 a	0.22± 0.1282 a

Values within the same row followed by the same letter are not significantly different.

4.4. Total phosphate (TP), phosphorus (P) and Sulphur (S)

There were no significant differences found for the total phosphate (TP) concentrations in the disinfestation treatments and sampling places (Table 10). TP concentrations were higher at the end of the pipeline comparing to the starting of the pipeline. No variation has been found for the water samples taken before and after AOT treatment also. Total phosphate (TP) concentrations were ranging from 0.72 mg l^{-1} to 1.54 mg l^{-1} in the disinfestation treatments.

Mean phosphorus (P) concentrations at the beginning of the pipeline for all the disinfestation treatments were found 0.049 mg l^{-1}, 0.06 mg l^{-1} and 0.04 mg l^{-1} respectively. These concentrations were reduced to 0.043 mg l^{-1}, 0.049 mg l^{-1} and 0.02 mg l^{-1} respectively at the end of the pipeline (Table 10). Phosphorus (P) concentrations were higher at both of the sampling places in the combined disinfestation treatment than the other two treatments. In the third treatment, mean phosphorus concentrations were 31.06 mg l^{-1} at the beginning of the pipeline which was lower down to 16.88 mg l^{-1} at the end of the pipe.

Table 10: Mean concentrations ± stdv of total phosphate (TP; mg l^{-1}) and phosphorus (P; mg l^{-1}) concentrations in different treatments.

TP		**Beginning of the conduit**	**End of the conduit**
	Treatment 1	0.743 ± 0.4333 a	0.9306 ± 0.7898 a
	Treatment 2	0.78 ± 0.425 a	1.231 ± 1.674 a
	Treatment 3	0.759 ± 0.367 a	1.545 ± 2.37 a
		Before AOT treatment	**After AOT treatment**
	Treatment 1	1.0145 ± 1.1061a	0.7057 ± 0.4011 a

	Treatment 2	0.725 ± 0.343 a	1.231 ± 1.674 a
	Treatment 3	1.152 ± 1.136 a	1.545 ± 2.374 a
	Beginning of the connecting pipeline		**End of the connecting pipeline**
	Treatment 1	0.7057 ± 0.4011 a	0.9306 ± 0.7898 a
	Treatment 2	0.6921 ± 0.1932 a	0.7245 ± 0.3427 a
P	**Beginning of the conduit**		**End of the conduit**
	Treatment 1	0.0485 ± 0.0343 a	0.0426 ± 0.0281 a
	Treatment 2	0.062 ± 0.03974 a	0.0485 ± 0.03664 a
	Treatment 3	0.035 ± 0.03338 a	0.024 ± 0.01346 a
	Before AOT treatment		**After AOT treatment**
	Treatment 1	0.0383± 0.03032a	0.058± 0.03326a
	Treatment 2	0.062± 0.03313a	0.049± 0.03673a
	Treatment 3	0.048± 0.02502a	0.024± 0.01346a
	Beginning of the connecting pipeline		**End of the connecting pipeline**
	Treatment 1	0.058± 0.0332a	0.042± 0.028a
	Treatment 2	0.0512± 0.038a	0.0621± 0.033a

Values within the same row followed by the same letter are not significantly different.

Sulphur (S) concentrations were relatively higher at the beginning of the pipeline during combination of stationary and mobile treatment. In the combined treatment, concentration of the sulphur (S) was lower down to 16.88 mg l^{-1} from 31.06 mg l^{-1} (Table 11) at the end of the pipeline. While there were so significance variations found for sulphur (S) concentrations in different disinfestation treatments and sampling locations.

Table11: Mean concentrations ± stdv of sulphur (S; mg l^{-1}) in different treatments.

	Beginning of the conduit	**End of the conduit**
Treatment 1	20.35± 3.534a	20.3± 3.52a
Treatment 2	20.67± 3.526a	20.618± 3.562a
Treatment 3	31.06± 49.14a	16.88± 0.5a
	Before AOT treatment	**After AOT treatment**
Treatment 1	20.237± 3.496a	20.747±3.052a
Treatment 2	21.126± 3.063a	20.785±3.516a
Treatment 3	17.378± 0.471a	16.875± 0.498a
	Beginning of the connecting pipeline	**End of the connecting pipeline**
Treatment 1	20.747± 3.052a	20.3± 3.52a
Treatment 2	21.044± 3.539a	21.126± 3.063a

Values within the same row followed by the same letter are not significantly different.

4.5. pH and electrical conductivity (EC)

No significance differences have been found at the beginning and end of the pipeline in the disinfestation treatments for the pH (Table 12). In all the three treatments, mean pH value ranges from 7.41 to 7.64 units which indicate there was no abnormality of the pH value in the sample water.

Significance differences have been found for the mean pH value of the water samples taken before and after AOT treatment. In the mobile and combined disinfestation treatment, mean pH value was found 7.62 and 7.58 unit after treatment with the AOT device. While pH value was

7.98 and 7.97 unit respectively before AOT treatment. But in the stationary disinfestation treatment, pH value was higher after the AOT treatment.
Mean pH value of the sample waters were differing significantly at the starting and end of the connecting pipeline. In the first treatment, mean pH value for the sample waters was recorded 7.93 units at the starting of the connecting pipe, which was lower down to 7.64 units at the end of the connecting pipeline. But in the second treatment higher pH was found at the beginning of the connecting pipeline than at the end of the pipe.

Table 12: Mean ± stdv of pH value in different treatments.

	Beginning of the conduit	**End of the conduit**
Treatment 1	7.54± 0.4167a	7.64± 0.2458a
Treatment 2	7.588± 0.3955a	7.63± 0.2614a
Treatment 3	7.41± 0.2934a	7.58± 0.2588a
	Before AOT treatment	**After AOT treatment**
Treatment 1	7.62± 0.21a	7.93±0.1295b
Treatment 2	7.98± 0.2381a	7.62±0.2611b
Treatment 3	7.97± 0.2224a	7.58± 0.2588b
	Beginning of the connecting pipeline	**End of the connecting pipeline**
Treatment 1	7.933± 0.1295a	7.64± 0.2458b
Treatment 2	7.692± 0.2702a	7.985± 0.2381b

Values within the same row followed by the same letter are not significantly different.

Table 13: Mean ± stdv of electrical conductivity (EC; µS cm^{-1}) in different treatments.

	Beginning of the conduit	**End of the conduit**
Treatment 1	0.56± 0.0687a	0.59± 0.06056a
Treatment 2	0.57± 0.06463a	0.59± 0.06534a
Treatment 3	0.55± 0.0735a	0.61± 0.0727a
	Before AOT treatment	**After AOT treatment**
Treatment 1	0.576± 0.05518a	0.594±0.04946a
Treatment 2	0.586± 0.05891a	0.589±0.06358a
Treatment 3	0.616± 0.06384a	0.615± 0.0727a
	Beginning of the connecting pipeline	**End of the connecting pipeline**
Treatment 1	0.594± 0.04946a	0.591± 0.06056a
Treatment 2	0.587± 0.04793a	0.586± 0.05891a

Values within the same row followed by the same letter are not significantly different.

From the table 13, electrical conductivity (EC) of the water samples has shown no significance differences in the disinfestation treatments. In the combined disinfestation treatment, conductivity was found at the beginning of the pipeline 0.56 µS cm-1, 0.57 µS cm^{-1} and 0.55 µS cm^{-1} respectively. At the end of the pipeline the value were 0.59 µS cm^{-1}, 0.59 µS cm^{-1} and 0.61 µS cm^{-1}. Therefore, in all the treatments higher electrical conductivity (EC) value has been shown at the end of the pipeline.
Electrical conductivity of the sample waters didn't also show any significance differences before and after AOT treatment (Table 13). During stationary disinfestation treatment, mean EC value has increased from 0.576 µS cm^{-1} to 0.594 µS cm^{-1} after treatment with the AOT device. While, in case of mobile and combined treatment, conductivity remains quite same before and after AOT treatment.

5. DISCUSSION

The purpose of this study was to observe if the advanced oxidation technology (AOT) is effective to guarantee high quality irrigation water. Bacterial loads of the water samples were differing substantially in the disinfestation treatments. Occurrences of heterotrophic bacterial flora were much higher in the sample waters comparing to the other indicator organisms; coliform and *Escherichia coli*. According to Bartram et al. (2003) heterotrophic organisms are the natural microbiota of water and sometimes they include organism derived from different pollutant sources. Higher numbers of heterotrophic bacteria also indicates regrowth of microorganism in the water distribution system. The coliform bacterial analyses are not always specific to faecal origin bacteria but more related to decaying organic matter in the water system. Sometimes higher number of coliform bacteria is an indication of presence of grazing cattle or wild lives (Fisher and Endale, 1999). World health organization (1989) guidelines for safe use of wastewater indicates that, mean coliform bacterial limit in the irrigation water should less than 1000 faecal coliform$^{-100\ ml}$. In the present study the highest mean of the coliform bacterial flora was log 1.17 CFU ml^{-1}, which confirms less abundance of the colifrom bacteria in the irrigation water that was used for the field crops. Occurrences of *Escherichia coli* in the water samples were much lower than heterotrophic and coliform bacteria. According to German water legislation, DIN 19650, *Escherichia coli* limit in the water used for irrigating crops in the open land or in the greenhouse are 200 *E. coli* $^{-100\ ml}$. This also proves lower abundance of *E. coli* in the sample water. So the first hypotheses- *Advanced oxidation technology (AOT) is efficient to guarantee highly hygienic irrigation water;* have been confirmed in this study. Microbial indicator organisms i,e; *E.coli*, coliform and heterotrophic bacterial loads in the irrigation water has been reduced by the disinfestation treatments. Although, there were some exceptions for the heterotrophic and coliform flora in the stationary disinfestation treatment. But in most of the cases, these disinfestations treatments have shown a reduction of the bacterial load.

The second hypotheses- *Placement of the AOT- devices within the water conduit is essential;* has been proved. Sample waters treated with the AOT-deivce have shown less abundance of bacterial flora compared with the water samples taken before AOT treatment. Both in the stationary and mobile disinfestations treatment, less occurrences of the *E.coli*, coliform and heterotrophic bacterial flora was confirmed through out the sampling period. Although heterotrophic and *E.coli* loads has remained unchanged after treated with the AOT-device in the combined disinfestation treatment.

The third hypotheses- *Length of the connecting pipeline between stationary and mobile unit affect bacterial loads;* could be accepted. Although *E. coli* loads in the water samples has not been affected during mobile disinfestation treatment but heterotrophic and coliform bacterial populations were influenced by the AOT- device. Both the heterotrophic and coliform bacterial flora has shown elevated numbers at the end of the connecting pipeline in the stationary disinfestation treatment.

In the present study, total organic carbon (TOC) content and chemical oxygen demand (COD) content were ranging from 6.08 mg l^{-1} to 7.82 mg l^{-1} and 13.72 mg l^{-1} to 28.14 mg l^{-1}. According to Chapman (1996), total organic matter in the water has been found as an indication of the degree of pollution. TOC concentrations are generally less than 10 mg l^{-1} in the surface water unless the water receives municipal or industrial wastes, or is highly colored due to natural organic materials. Concentrations of chemical oxygen demand (COD) in surface waters range from 20 mg l^{-1} or less in unpolluted waters and 200 mg l^{-1} or greater in the waters that receiving effluents (Chapman, 1996). German water legislation, DIN 19650 suggests, COD content in the water should lower than 60 mg l^{-1}. According to Lazarova & Bahri (2005), total nitrogen (TN) and total phosphate (TP) concentrations in the irrigation water ranges from 20-85 mg l^{-1} and 4-15 mg l^{-1} respectively. While the mean highest TN and TP concentrations of the water samples were 6.92 mg l^{-1} and 1.54 mg l^{-1} during combined disinfestation treatment. The value of the organic compounds was much lower than the standard value derived by different expertise. Meanwhile

the fourth hypotheses - *Total organic carbon (TOC) and chemical oxygen demand (COD), total nitrogen (TN) and total phosphate (TP) are affected by the AOT treatment;* will have to be discarded. None of the disinfestation treatments was able to reduce the concentrations of the organic compounds.

Fifth hypotheses- *Nutrients in the irrigation water also affected by the placement of the AOT-device;* has to be rejected as nitrate (NO_3), phosphorus (P), sulphur (S) and ammonium (NH_4) concentrations in the water samples did not show any significance variations after the impact of the AOT-device. The most beneficial nutrients for plants is nitrogen. Both the concentration and forms (ammonium and nitrate) of nitrogen need to be considered for irrigation water. Ammonium (NH_4), which is the principal from, generally present in a concentration range of 5 to 40 mg l^{-1}. According to the German water legislation, DIN 19650, range of ammonium (NH_4) concentrations in the irrigation water should be below 1 mg l^{-1}. Ammonium (NH_4) concentrations have been found significantly lower in the water samples taken after treated with the AOT-device in the combined disinfection treatment. This was the single variation observed from all of the nutrients in the irrigation water during this study period.

pH and electrical conductivity is influenced by the AOT device; this hypothesis could be supported only for the pH. Mean pH value of the water samples ranged from 7.41 to 7.64 units which indicate there was no abnormality of the pH value in the sample water. According to Lazarova and Bahri (2005), normal pH value for irrigation water ranges from 6.5 to 8.4 unit. Electrical conductivity of the irrigation water is also a measure of the salinity. Non saline water is characterized by the conductivity value less than 0.7 µS cm^{-1} (Lazarova and Bahri, 2005). The range of electrical conductivity of the investigated water samples ranges from 0.56 µS cm^{-1} to 0.61 µS cm^{-1}, indicating the non- saline character of the irrigation water during the study.

5.1. Concluding remarks

According to Lazarova and Bahri (2005), ‘‘ Water quality is the most important issue in water reuse systems that determines the acceptability and safety of the use of recycled water for given reuse application.’’ Advanced oxidation technology (AOT) for irrigation water disinfestations was found effective at minimizing the loads of microbial indicator organisms. The water hygienic quality was fair, but elevated numbers of heterotrophic flora were observed throughout the study period. Coliform and *E. coli* loads were much lower compared to WHO or DIN 1965 water quality guidelines for irrigation. Organic chemicals and inorganic parameters of water did not seem to be affected by the AOT.
Meanwhile, there are no standards for threshold values for different groups of micro organisms in irrigation systems in Sweden, nor for open land or for greenhouse cultivations. For suggesting a guideline for water reuse in irrigation, closely monitoring of the water quality parameters of interest is required.

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