Technische Universiteit
Eindhoven
University of Technology

Multidisciplinary project / Eindhoven University of Technology / December 16, 2011

The Chlorine Dilemma

Final Report

/Eindhoven University of Technology
/department of Chemical Engineering and Chemistry

Project leader:	R.G. Kleijnen
Treasurer:	B.G.M. Knoben
Team members:	B.L. Hoofwijk
	D.G.J. Pol
	G.H.L. Heintges
	J.F. De Visser

Client:	Dr. P.J. Nickel
Tutor:	Dr. J.C. Reijenga

Technische Universiteit
Eindhoven
University of Technology

Abstract

Disinfection of water is a crucial step in the treatment of water in order to obtain clean drinking water. Chlorine is widely used as a disinfectant, as it is an effective way of eliminating the vast majority of pathogens in water. However, toxic and/or carcinogenic by-products are formed as a result of drinking water chlorination. The question arises, whether chlorine, being cheap and widely applied, should be used as a disinfectant, or an alternative such as UV-irradiation or ozonation should be emphasized in future decisions regarding drinking water disinfection.

In this report, an extensive ethical and technological reflection on the use of chlorine as a disinfectant in drinking water is performed. Two cases are particularly investigated: the first being the choice of disinfectant in the Netherlands, a country renowned for its high standards in drinking water quality and its progressiveness in the application of novel techniques. In particular a choice has been made between chlorine and UV-irradiation, the latter being the most widely applied technology in the Netherlands as of today.

The second case concerns the choice of disinfectant in Kenya, a third world country dealing with water shortages and especially a lack of safe drinking water. Moreover, the country can serve as an exemplary case for other countries in the same region (Sub-Saharan Africa).

Making use of the ethical cycle, an ethical analysis was performed on both cases. Emphasis has been put on deontology and cost-benefit analysis to be used as ethical frameworks to come to an ethically justified decision. For the Netherlands it followed that UV disinfection supplemented with chlorine disinfection for vulnerable groups such as the ill or the elderly is the best option. It has been found that both disinfection methods each eliminate a slightly different range of micro-organisms and that combination of both techniques would offer the best protection against waterborne pathogens. For the general population though, UV-irradiation provides sufficient protection.

Based on the ethical frameworks, the decision for Kenya has been to promote solar disinfection in rural areas, supplemented with chlorine disinfection where and when solar disinfection is not possible. In urban areas with a developed distribution system, chlorine would be the preferred disinfectant, despite its drawbacks: the reduction in number of diseases as a result of disinfection compensates well for the health risks associated with disinfection by-products.

The results of this study are realistic, both ethically and technically substantiated. The results may also be extrapolated to other comparable countries.

Technische Universiteit Eindhoven University of Technology

Table of Contents

1. Introduction

1.1. Drinking water

Clean drinking water is something that should be available for everyone. Even though water is a crucial requirement for human beings, safe drinking water is still not available for one billion people in the world. The people that do have access to safe drinking water often take this for granted and they seem not to realize sometimes what the luxury of safe and clean water really is. On the other hand, what is the definition of clean drinking water?

Clean drinking water is water that is obtained after several purification steps. One of the final steps in this process is the disinfection of water. A relative cheap chemical used for this disinfection is chlorine. In many countries chlorine is the primary means of disinfection. There are however some remarks about the use of chlorine. Although it does kill waterborne pathogens that are present in the water, its usage also has some negative side-effects. Chlorine can react with organic matter that is also present in the water which results in the production of a variety of possibly toxic disinfection by-products (DBP's). These DBP's have been discovered to be potentially linked with increased rates of miscarriages, bladder cancer and many more illnesses.

There seems to be a good solution to this problem. Chlorine is not the only chemical that can be used for disinfection, because there are some good alternatives. However, these alternatives have other possible (toxic) side-effects. What should be done? Which alternative is best? Is chlorine currently maybe the best option despite the harmful side-effects?

1.2. Project 'Chlorine dilemma'

The above listed questions will hopefully be answered at the end of this project. To do this an ethical analysis of this so called chlorine dilemma will be performed using the ethical cycle as a tool. During the analysis at least one different alternative to chlorine will be considered. Also different countries or regions in the world will be taken into account, because a big difference is expected between these on technical, financial as well as ethical grounds.

The results of this project will contain a detailed description and analysis of some possible disinfection methods for drinking water. The research done during this project about the technical and financial aspects and from an ethical point of view can be used to decide which disinfection method is the best option for a particular country or region in the world.

The original assignment is attached to appendix A.

2. History of water purification and disinfection

2.1. Before 20th century

Purification of water has been around for millennia, starting with the simple boiling of water and particle filtration 2000 years B.C. In 1774 the first synthesis and characterization of chlorine by the Swedish chemist Carl Wilhelm Scheele put the element on the map, however chlorination of drinking water was only first suggested around the year 1800 by Louis-Bernard Guyton de Morveau (France) and William Cumberland Cruikshank (England).

The need for disinfection was only discovered later on when scientists proved that micro-organisms in drinking water could cause diseases. In 1854 the British scientist John Snow discovered that the cholera disease, which was causing problems all over the world, was spread through contaminated water. This changed the future of water treatment. He applied chlorine to purify the contaminated water, and this paved the way for water purification.

Before the discovery it was considered that filtration with a sand filter was enough, because the water had smelled and tasted normal. However, after the discovery that water could spread diseases the conclusion was drawn that good taste and smell alone does not guarantee safe drinking water. It led governments to start installing municipal water filters, and the first government regulation of drinking water was a fact.[**1**]

In the late nineteenth century, municipal water treatment began to take hold in the United States. Because of the growing amount of water treatment facilities around the world, outbreaks of waterborne diseases such as cholera and typhoid rapidly decreased in the early twentieth century. A statistical study of disease rates in cities, held in 2004, uncovered that clean water was the main reason for the rapid declines in urban death rates during the late 1800's and early 1900's. The study concluded that disinfected water was responsible for nearly half of the total mortality reduction in major cities, three-quarters of the infant mortality reduction and nearly two-thirds of the child mortality reduction. The study put forth the impressive claim, that chlorination and filtration reduced typhoid fever by 91% within 5 years, followed by its near-eradication by 1936.[**2**]

2.2. During 20th century

Around the 1900's the first negative effects of the use of chlorine were discovered. These effects could possibly explain the aggravation of respiratory diseases. The use of chlorine as a disinfectant was therefore disputed not long after it was used on larger scale and the search for alternatives was started. In 1902, Belgium started using calcium hypochlorite and ferric chloride, which resulted in both coagulation and disinfection.

Ozone was used as a disinfectant in 1893 in Holland for the first time. As of 1906 ozone was used as a disinfectant in Nice, France. In addition to the search for alternatives people started to use home water filters and shower filters to prevent exposure to chlorine in water. By 1980 over 1100 water treatment facilities were using ozone, most of which were located in Europe. Nowadays more than 2000 water treatment plants throughout the world use ozone as a disinfectant.[**3**]

The purification of drinking water with use of liquefied chlorine gas was developed in 1910 by U.S Army Major Carl Rogers Darnall. Shortly thereafter Major William J.L Lyster used a solution of calcium hypochlorite in a linen bag to treat water. This method, called the Lyster Bag, was standard for the U.S ground forces in the field and camps to disinfect water. The work done by Darnall became the basis for the present day systems of chlorination of municipal water supplies.

The first adaptation of UV radiation for disinfection was in 1910 in Marseille, France. It wouldn't be until much later that it would become a feasible replacement for chlorination of water. The high cost and absence of technology were problems from implementing it as a purification method. By 2002 UV radiation was used in more than 3000 water treatment facilities in Europe.[**4**]

In 1956 chlorine dioxide was introduced as a large scale disinfectant. The advantage using chlorine dioxide is that it minimizes the production of the formation of disinfection by-products (DBP's). However, a disadvantage is the presence of chlorite and chlorate resulting from the ClO_2 treatment. In the Netherlands chlorine dioxide did replace the use of chlorine for a long time until chlorine was banned by law as a primary disinfectant.[**5**]

In 1971 the first discovery of disinfection by products (DBP's) was made in the form of chloroform. The American scientist Bellar discovered traces of chloroform in the drinking water, but no chloroform was found in the Ohio river water which was used for the production of drinking water. When in 1972 the Clean Water Act was introduced in the U.S. the discovery of more DBPs followed soon after. Since 1974 over 600 different DBP's have been discovered, however only a few are monitored intensively, because the average concentration levels of most are far too low to cause any health risks.[**6**]

2.3. Beginning 21st century

There has been an interesting trend over the last decades when it comes down to water disinfection. More and more water treatment facilities are switching from chlorination to other means of disinfection, for example UV radiation, by using ozone as disinfectant or chlorine dioxide. The Netherlands is one of the first countries to put a ban on chlorine as primary disinfectant. By 2003 over 80% of the drinking water was chlorine free and by 2005 all of the drinking water had to be chlorine free.

2.4. Timeline

In Figure 1 a rough overview of the most important discoveries regarding drinking water disinfection is shown in the form of a timeline.

- **1774** • First synthesis of chlorine by the Swedish chemist Carl Wilhelm Scheele.
- **1800** • Disinfectant properties of chlorine are discovered in France and England.
- **1852** • John snow discovers that cholera spreads by drinking contaminated water. Chlorine is used to disinfect the first time.
- **1890's** • Municipal water treatment facilities are becoming more common. Chlorine is used as disinfectant.
- **1900** • Side effects of chlorine discovered, namely the fact that it causes aggravation of respiratory diseases.
- **1902** • Belgium starts to experiment with calcium hypochlorite en ferric chloride.
- **1906** • France starts to experiment with ozone as a disinfectant.
- **1910** • Major Carl R. Darnall invents a way to purify water with liquefied chlorine gas, laying the base for present day chlorination systems.
- **1910** • Major William J.L Lyster invents the later named Lyster bag: a linen bag with hypochlorite to disinfect water on location.
- **1916** • The US starts to experiment with UV as a way of disinfecting water.
- **1956** • Chlorine dioxide is used for the first time on large scale in Brussels.
- **1971** • The first discovery of a DBP in the U.S., namely chloroform.
- **1974** • After the introduction of the clean water act more DBPs were discovered. So far over 600 are known.
- **2005** • The Netherlands became the first country to ban chlorine as primary disinfectant.

Figure 1: Timeline water disinfection

3. Worldwide facts & figures

3.1. Current situation

Water is the most abundant resource on the planet. About 70.9% [**7**] of the total area of the world is covered by water. The total amount of water is estimated at 1.4 billion cubic kilometers [**1**]. That amount of water is sufficient to build three stacks of Olympic swimming pools all the way to the moon.

Yet still not all people in the world have access to safe drinking water. This has much to do with the fact that the vast majority of water on the planet is marine water that contains a high amount of salt (mainly sodium chloride) which makes it unsuitable for drinking, if it is not purified through the tedious process of distillation. Only 0.4% of the earth's water resources are readily available to serve as drinking water [**8**], which makes the problem of fresh water around the globe a lot more evident.

3.2. Water supply and usage

In Table 1 the percentage of inhabitants with a sustainable water supply in different areas of the world is listed. It can be seen that in most urban areas drinking water does not pose a great problem, as percentages are almost all above 90%. Amongst the most critical regions with respect to a sustainable water supply are Sub-Saharan Africa and Oceania. The fact that Sub-Saharan Africa has a major drinking water issue can easily be explained by the great amount of poverty that the countries in this region usually have to deal with. The situation in Oceania on the other hand is a bit odd, as the majority of landmass in this region is represented by Australia, commonly regarded as a developed country. The main reason of the dramatic figure for the rural drinking water supply in this region could be explained by the climate situation in the inlands of Australia, which inhibits the finding and use of a sustainable drinking water source.

If looked then at the water usage per capita per year in Figure 2 it is possible to get a good view of the regions where water supply and its use may be an issue. Analogue to the limited availability of sustainable water sources in Sub-Saharan Africa, it can be seen that also the use of water is amongst the lowest in the world. Quite remarkably, Australia, part of the region with the smallest amount of people in rural areas having access to a sustainable water source, uses more than 1000 m^3 drinking water per capita per year.

Table 1: Percentage of inhabitants with sustainable water supply in 2006 [8][9]

	Total	**Urban**	**Rural**
Developing Countries	84	94	76
Northern Africa	92	96	87
Sub-Saharan Africa	58	81	46
Latin America and Caribbean	92	97	73
Eastern-Asia	88	98	81
Southern-Asia	87	95	84
Southeastern-Asia	86	92	81
Western-Asia	90	95	80
Oceania	50	91	37
Commonwealth of Independent States (CIS)*	94	99	86
CIS Asia	88	98	79
CIS Europe	97	99	91
Developed countries	99	100	97

* Former Soviet Union

Also remarkable is that not all Western countries exhibit the same pattern with respect to their water usage. This may have something to do with the climate, but possibly also with the mentality of inhabitants and regulations in that specific area. It is for instance possible that European legislation forces governments to limit their water usage, but that United States laws are not as strict. More detailed information about laws and directives can be found in appendix B, "Factual analysis situation in Western world".

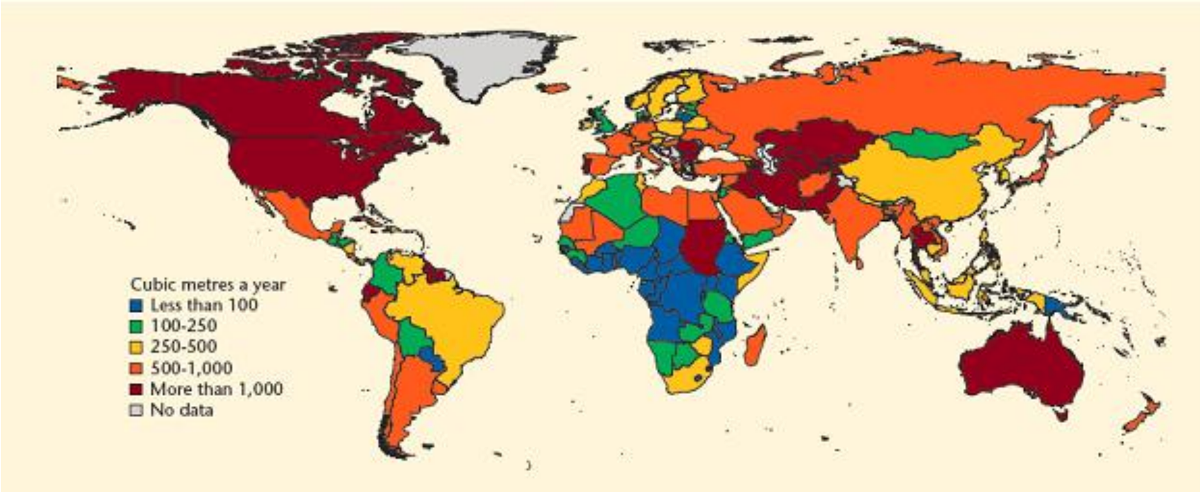

Figure 2: Drinking water usage per capita per year [9]

Drinking water can be obtained from different sources. In Figure 3 these sources are divided into their respective shares, where the shares for drinking water use have been deduced from all uses. It can be seen that groundwater is a main source for drinking water, more than for other uses [**9**]. The large advantage of using groundwater is that it usually is not necessary to disinfect, as harmful micro-organisms are absent in the depths of the earth. It is also clear that desalination of marine water is rarely used as a way of obtaining drinking water, underlining the importance of a sustainable, readily available water source.

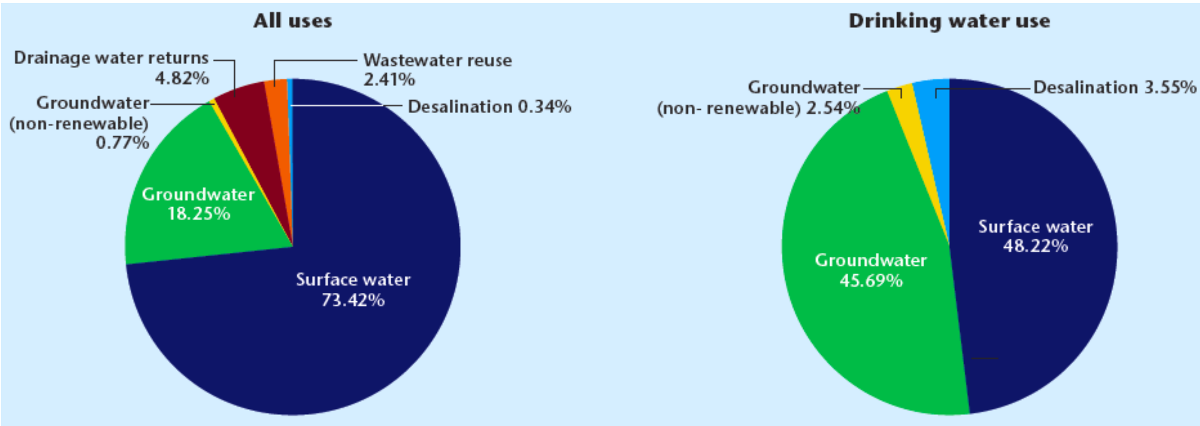

Figure 3: Different sources of drinking water [9]

4. Technical aspects of water disinfection

4.1. Disinfection by chlorination

Chlorine has been found to be very effective in killing waterborne pathogens. In this section the nature of chlorine chemistry and its effect on pathogens will be explained. Moreover, side reactions and the formation of potentially harmful substances will be discussed. The use of chlorine as a disinfectant in industrial applications will be treated in the last section.

4.1.1. Chemistry

Chlorine is usually added to water in the form of chlorine gas, or as a sodium or calcium hypochlorite solution. Chlorine itself hydrolyzes quickly to hydrochloric acid and hypochlorous acid. These compounds may dissociate, dependent on the pH of the solution. The overall reaction scheme is given in Figure 4.

Hydrochloric Acid   **Hypochlorous Acid**

$$Cl_2 + H_2O \leftrightarrow HCl + HOCl$$

$$HCl \updownarrow H^+ + Cl^- \qquad HOCl \updownarrow H^+ + OCl^-$$

Chlorite

Figure 4: Overall reaction scheme

It is found that hypochlorous acid has a specific reactivity that is about 10.000 times higher than that of the hypochlorite-ion. Disinfection will therefore be more effective under acidic conditions: at pH 7.5 the equilibrium lies in the middle, with about 50% of the chlorine in the hypochlorous acid form. At pH <5 the equilibrium is shifted to the hypochlorous acid side, and 100% of the Cl_2 is present in the form of hypochlorous acid.

Hypochlorous acid may react with ammonia to form chloramines. These chloramines have some disinfection potential, but are much slower in reaction than free chlorine. It is important that these so-called combined residuals are present in the water to ensure the long-term disinfection of the water. The free chlorine residuals, the chlorite-ion and especially hypochlorous acid, have a much higher reactivity than chloramines and will therefore be consumed earlier by reaction with organic compounds.

The chemical reactions of chlorine with organic matter are very complex and diverse, but can generally be divided into three reaction types: oxidation, addition and substitution. The majority of reactions with organic matter, about 50-80%, concern oxidation reactions. Chlorination of compounds occurs only in addition or substitution reactions.

In drinking water disinfection, pathogens are very vulnerable to chlorine. Chlorine breaks down the lipids in cell walls and reacts with enzymes and proteins, which renders them unusable. Without functioning enzymes, micro-organisms and pathogens are doomed.

However, not only pathogens are affected by chlorine. There are many other substances present in water as it is found at the surface. The general composition of organic compounds in average river water is displayed in Figure 5. It has been found that chlorine does not react readily with carbohydrates, carboxylic acids and hydrocarbons, so their contribution to the formation of halogenated organic compounds can be neglected. The most important compounds in considering disinfection by-products are humic materials.

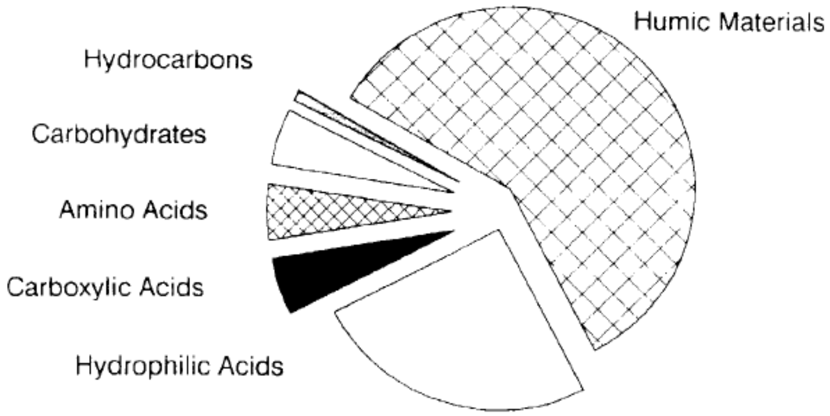

Figure 5: Dissolved organic compounds in average river water [10]

Humic material is a complex collection of different, sometimes polymeric, substances such as lignin, carbohydrates, proteins and fatty acids. It originates from deteriorated plants and other organic material and was one of the first sources associated with the formation of trihalomethanes. A considerable amount of research has since then been put in unveiling the general composition of humic material and in determining its susceptibility to chlorination reactions. It was found that especially phenolic compounds are susceptible to chlorination via a ring rupture mechanism. Different mutagens have been identified that originate via such a mechanism, which is represented in Figure 6.

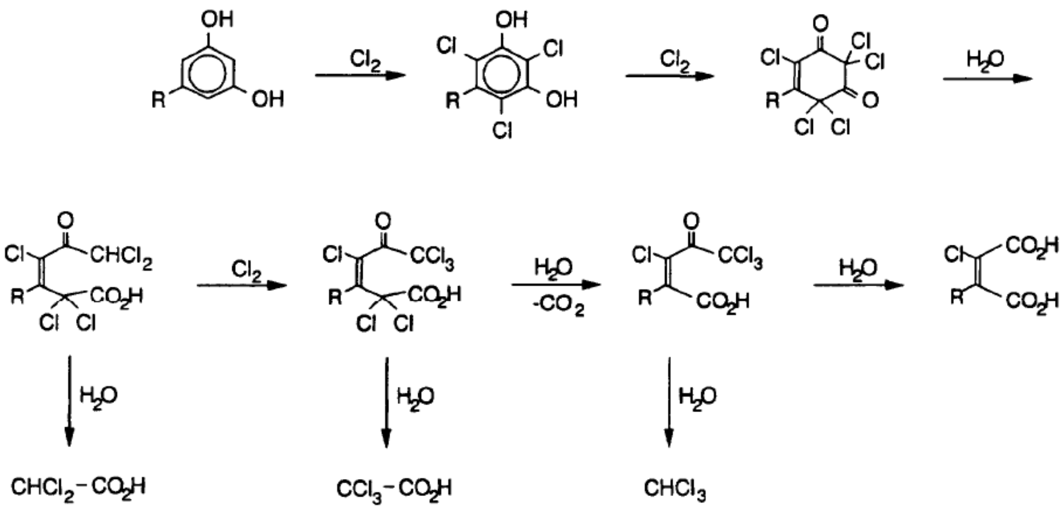

Figure 6: Ring rupture mechanism [10]

It has also been found that amino-acids may be chlorinated to the aforementioned chloramines, but that also aldehydes and nitriles may be formed. Furthermore, chlorination even leads to the degradation of peptides, under the formation nitriles and trihalomethanes. [**10**][**11**][**12**][**13**]

4.1.2.Kinetics

The killing of micro-organisms during disinfection can be considered to be a first order reaction, according to Chick's law. This law can be used to express the death of pathogens as a function of time:

(0.1) $$\frac{dN}{dt} = -kN$$

This can be integrated to give:

$$\ln\frac{N}{N_0} = -kt \qquad (0.2)$$

With N being the concentration of living pathogens at time t, N_o the initial concentration of pathogens and k the rate constant. The rate constant is dependent mostly on temperature, salinity, type of micro-organisms and of course disinfecting material. The rate constant can be redefined to take into account the characteristics of the disinfectant:

$$k = k'C^n \qquad (0.3)$$

With C the concentration of disinfectant, and n an empirical constant known as the coefficient of dilution. The coefficient of dilution is unique for every particular system and can only be determined by measurements. It depends on the type of disinfectant, its concentration and type of micro-organisms present. The dilution coefficient for free chlorine may vary in different systems at least from 0.3 to 4.7.[**14**]

When the natural logarithm of the surviving micro-organisms, $\ln(N/N_0)$, is plotted against time this should result in a straight line with slope $-k'C^n$. Equation 1.2 can thus be rewritten to yield:

$$C^n t = -\frac{1}{k'}\ln\left[\frac{N}{N_0}\right] \qquad (0.4)$$

This is an adaptation of Watson's law. For a desired ratio of N/N_0 the amount of $C^n{\cdot}t$ can be calculated. This equation also stresses the importance of the coefficient of dilution as this may determine whether time or the concentration of a disinfectant is most important. Conversely, if N/N_0 is known it is possible to calculate from known time and concentration the coefficient of dilution of a given system.

Altogether, this Chick-Watson model for the rate of destruction of micro-organisms is widely used to describe the effect and amount of disinfectant needed for a desired amount of disinfection. [**11**]

4.1.3. Application in industry: transport and prices

In large drinking water obtaining and purification stations, chlorine can be delivered in its elemental state, as a liquid in high pressure cylinders. The chlorine is ejected into highly pressurized water using a venturi orifice which creates a vacuum that causes chlorine to be drawn into the water. Storage and transportation of chlorine occurs in pressurized steel cylinders. The largest risk lies in the toxicity of chlorine. Rupture of a cylinder would cause highly toxic chlorine gas to be released into the air, with possibly catastrophic consequences. Because of this it is not remarkable that, in the Netherlands, there has been much protest against the transportation of chlorine via trains. This protest has ultimately led to a ban of chlorine transport via train on a regular basis in 2002. Currently the Dutch government allows such a transport to take place only incidentally. An advantage of chlorine however is still its price: in bulk quantities it only costs around €550,- per metric ton.[**15**]

Another way to add chlorine to drinking water is in the form of a sodium hypochlorite solution or as calcium hypochlorite tablets. These methods are usually applied in smaller-scale environments, such as pools, but there are also drinking water facilities that use this method. The greatest advantage of these chlorine forms is their relative safety with respect to elemental chlorine; they are far less toxic and less difficult to handle, although precautions should still be made. However, both forms are highly corrosive and cannot be stored in just any container. Generally fiber reinforced plastic or HDPE are used.[**15**] The reaction of calcium hypochlorite with organic matter, such as wood, can even create enough heat to set the wood on fire.

Moreover, the price of sodium hypochlorite solution is €130,- per ton. It should be taken into account that there is less free chlorine present in sodium hypochlorite, because only a fraction of its mass can be transformed to free chlorine. Chlorine gas on the other hand has 100% of its mass available as free chlorine. The actual price compared to elemental chlorine is therefore much higher, about €1050,- per metric ton free chlorine. For calcium hypochlorite a similar price can be found. In bulk quantities it costs around €450,- per metric ton, but with generally 60% free chlorine the price per ton free chlorine is €750,-. [**16**][**17**][**18**]

4.2. UV disinfection

An alternative to chlorine for drinking water disinfection is UV disinfection. When ultraviolet light (UV) was first discovered as disinfection method, the problems were that it did not kill all of the bacteria and that the costs for maintaining and installing UV light based reactors were high. However, over the years development in the UV-sector has decreased the costs significantly and optimization of UV-radiation has made this a viable method for water disinfection. Today, after many years of research, it is recognized that the most effective alternative water disinfection process available is UV-irradiation.[**19**] In Table 2 an overview of the advantages and disadvantages compared to the other disinfection techniques is given.

Table 2: (Dis)advantages of different disinfection techniques[20]

	Disinfection techniques						
Criteria	**UV**	**Chlorine**	**Sodium hypochlorite**	**Onsite hypochlorite generation**	**Ozone**	**Chlorine dioxide**	**Chloramines**
Giardia Inactivation	*Excellent*	*Fair*	*Fair*	*Fair*	*Excellent*	*Excellent*	*Poor*
Crypto inactivation	*Excellent*	*Poor*	*Poor*	*Poor*	*Good*	*Excellent*	*Poor*
Virus Inactivation	*Excellent*	*Good*	*Good*	*Good*	*Excellent*	*Very good*	*Fair*
Leaves a residual	*None*	*Good*	*Good*	*Good*	*None*	*Fair*	*Excellent*
Organic DBPs	*None*	*High*	*High*	*High*	*Low*	*Low*	*Low*
Brominated DBPs	*None*	*High*	*High*	*High*	*High*	*None*	*None*
Safety Risk	*Low*	*High*	*Low*	*Low*	*Medium*	*Medium*	*Low*
Complexity	*Low*	*Medium*	*Medium*	*Medium*	*High*	*High*	*Medium*
Capital Cost	*Medium*	*Medium*	*Medium*	*Medium*	*High*	*Medium*	*Medium*
O&M cost	*Medium*	*Low*	*Low*	*Low*	*High*	*Medium*	*Low*

4.2.1. How does it work?

The water that has to be disinfected flows through a disinfection system, which consists of multiple parallel UV reactor trains. These trains consist of multiple reactors. Each reactor has multiple banks and each bank has several modules that consist of multiple UV lamps. Each bank can be turned on or off depending on the water flow and quality. In the end it is the objective to achieve between 99% and 99.99% disinfection.

Ultraviolet radiation does not kill the micro-organisms directly, but it damages their DNA and RNA. By doing this the micro-organism is still able to function, however it cannot use its DNA/RNA anymore to reproduce, causing the population of the organisms to become extinct.

There is also the risk of repair of the DNA damage by using the wrong type of light. For example light with wave lengths between 350 – 450 nanometers can cause photo reactivation, which causes the DNA of the damaged organisms to repair itself.A lot of research regarding UV disinfection has gone into determining the optimal wavelength of the UV-light used for disinfection. Research has shown that this optimum ranges between 250 nm and 270 nm.[**21**]

4.2.2. Disinfection costs

UV disinfection has been a good alternative for chlorination in the last decades. It first started to compete with chlorination in the disinfection of wastewater, because wastewater dumped in open water sources also had to be de-chlorinated. Over the years capital investment costs have declined more, which has made UV a competitor for drinking water disinfection as well. The costs of UV disinfection systems are dependent of manufacturer, the site, the capacity of the plant and other specifications. Operating costs are lower compared to chlorination, because it is a simple to use technique and it involves little to no risks to operators. Therefore no special training is required for the operators and safety measurements are a lot lower than when using chlorine as disinfectant.

Other annual operating and maintenance costs for UV disinfection include power consumption, cleaning chemicals and supplies, miscellaneous equipment repairs (2.5% of total equipment cost), replacement of lamps, ballasts, and sleeves and staffing requirements.[**22**]

4.2.3. Advantages of UV-disinfection

UV disinfection is effective at inactivating most bacteria, viruses, spores, and cysts that are present in the water. What remains is often removed by adding oxidants like peroxides or even ozone.

One of the most important advantages is that it does not produce any known toxic byproducts. Compared to other methods of disinfection it does not form any bromide to bromines or bromates, nor does it change nitrates into nitrites. There is also no production of other DBP’s like HAA’s or THM’s.

Another advantage of UV disinfection is that the effectiveness is relatively insensitive to temperature and pH differences. Also, UV installations require little supervision or maintenance. It has improved safety, minimum service time, low operation costs and maintenance cost, and it adds no chemical taste or smell to the disinfected water.

4.2.4. Disadvantages of UV-disinfection

There are two key disadvantages that have to be taken into account when UV-radiation is used as disinfectant. Probably the most important disadvantage is that UV-light can be scattered and therefore be ineffective in neutralizing micro-organisms. Suspended solids, turbidity, color or soluble organic matter can cause this. Turbidity also limits the penetration depth of the radiation in the water. To limit these problems precautions have to be taken, like filtration of the water and reducing the turbidity.

A second important disadvantage is the absence of any residual disinfectant in the water, which means that unless water is transported through a micro-organism free environment there is a chance of recontamination. This also means that in case of pipe ruptures that disinfecting with chlorine based disinfectant is the only option.

Other disadvantages of UV disinfection are the complicated process of measuring the effectiveness of UV disinfection.

4.3. Ozonation disinfection

A second alternative to chlorine for drinking water disinfection is ozonation disinfection. Ozone (O_3) is a powerful oxidant as it has an oxidation potential of 2.07 V, whereas free chlorine has an oxidation potential of 1.36 V. Although in disinfection the oxidation potential is not the all determining factor, it indicates that ozone can be a promising candidate to replace chlorine. In this section the mechanism of reactions of ozone with different compounds will be discussed, as well as the applicability of ozone as a primary disinfectant for drinking water in larger facilities.

4.3.1. Reaction mechanism

The power of ozone as an oxidizing agent lies in its inherently unstable nature. The molecule is a resonance hybrid and has various resonance structures in which charges are distributed within the molecule in different fashions (see Figure 7). These charge distributions offer ozone the ability to react both as a dipole and as an electrophilic molecule and ensure that ozone can break down complex and potentially harmful organic molecules to less dangerous smaller molecules.

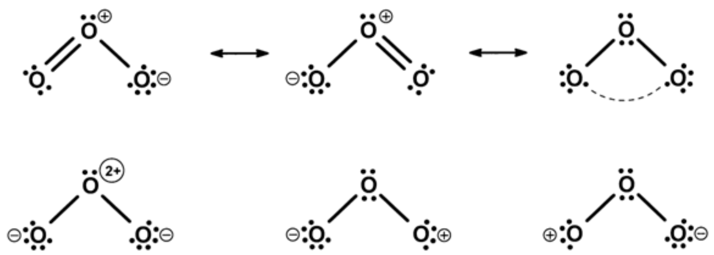

Figure 7: Various resonance structures of ozone

Dipole-mediated attack of ozone generally occurs at ethylic bonds. A primary ozonide is formed in a 1,3-cycloaddition that decomposes into a ketone and hydrogen peroxide or a carboxylic acid and water. Electrophilic attack is the primary mechanism for ozonation of aromatic compounds. The reactivity of ozone with such compounds increases when they contain more electron-rich groups (e.g. -OH, $-NH_2$, etc.). A third reaction mechanism is the reaction of radicals formed due to the decomposition of ozone: as ozone slowly breaks down in solution, various radicals are formed, each with a specific reactivity to organic compounds. Among the most reactive radicals are hydrogen peroxy ($HO_2\cdot$) and hydroxyl ($\cdot OH$). It is assumed that micro-organisms are especially susceptible to these radicals, as they disintegrate the cell walls.[**23**] Multiple sources state that ozone is the most effective disinfectant amongst the commonly used ones. [**13**]

4.3.2. Application

Ozone is an instable compound that rapidly decomposes into the much more stable oxygen. For ozonation of drinking water it is thus required to produce the ozone on-site. Ozone is generated by discharging a high-voltage current in dry air or pure oxygen (much like in nature, where a distinct ozone smell can be discerned after a thunderstorm). This method yields at maximum 3% ozone for air, while yields of 12% are achievable with pure oxygen. [**23**] The ozone is then brought into contact with the water that has to be treated. Because of the rapid decomposition of ozone, in order to uniformly contact the water, contacting needs to occur in a reactor with near plug flow conditions. In Figure 8, a schematic representation of the process is lined out.

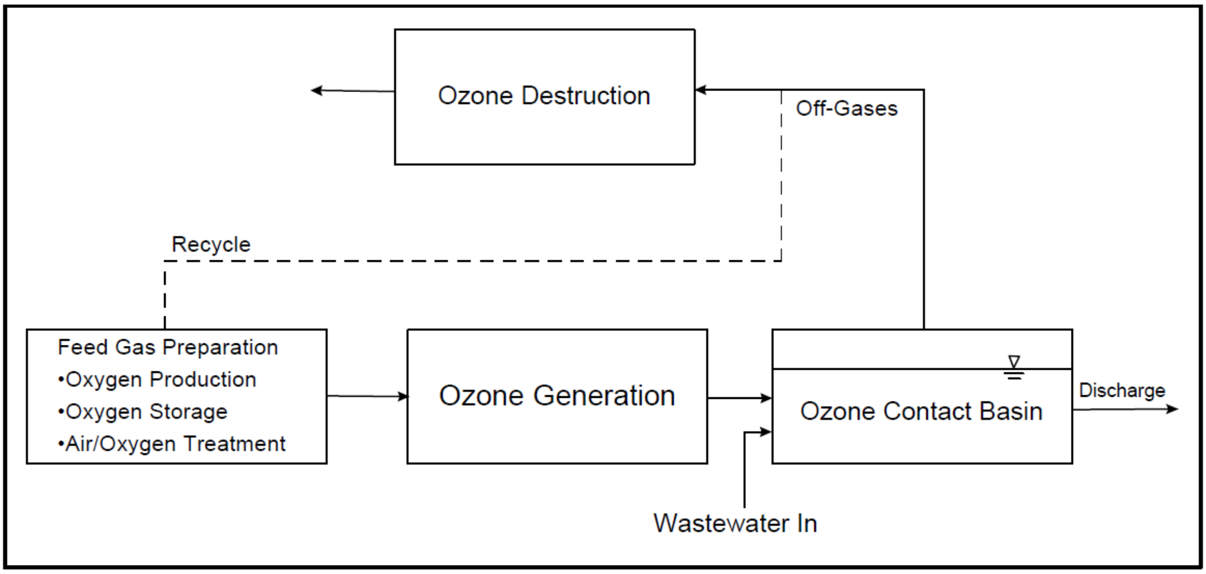

Figure 8: Schematic representation of ozone water treatment [23**]**

To ensure proper disinfection, ozone dosage in water generally lies at 2 to 4 mg/L.[**16**] Naturally, some ozone still remains in the off-gas after contacting. In order to release the off-gas safely into the atmosphere, it has to be run through an ozone destruction unit. When pure oxygen is used as base component it is also possible to use the off-gas as a recycle, thereby preventing the use of a destruction unit.

4.3.3. Costs

Ozone disinfection is one of the more expensive disinfection techniques. The capital investment costs of a disinfection unit using pure oxygen (without the need of a destruction unit) are estimated at €190,000. If air is used as the base component capital costs are lower, as investing in oxygen production and storage is no longer necessary. A destruction unit is required however, bringing the total cost of this type of treatment facility to an estimated €60,000. Operational costs largely involve labor, quoted yearly at €9,000. Next to that, running the facility requires about 90 kW of power (electricity) and replacement costs are estimated at €5,000. With such a facility, about 3.5 million liters of water can be disinfected every day, sufficient for 10,000 households (40,000 people). [**23**]

5. Situation in the Netherlands

5.1. Water supply, usage and disinfection

In the Netherlands, water supply is in the hands of ten private companies, each governing a particular region. The companies are associated in a national body known as VEWIN, which represents the interests of the Dutch water companies both on a national and European level. The companies provide drinking water for the Dutch citizens and industry. A survey is held on a yearly basis to get a view of household water use in the Netherlands. The summary of these results from 2010 is listed in Table 3. It can be seen that the majority of drinking water is not actually used to drink, but to clean.

Table 3: Water usage separated to application in the Netherlands [24]

Bath	2.8
Shower	48.6
Washbasin	5.0
Toilet flushing	33.7
Clothes washing (hand)	1.1
Clothes washing (machine)	14.3
Dishwashing (hand)	3.1
Dishwashing (machine)	3.0
Food preparation	1.4
Coffee and Tea	1.2
Water consumption	0.6
Remaining kitchen tap	5.3
Total	120.1

Figure 9: Water suppliers in the Netherlands [29]

The total amount of water obtained from various sources in the Netherlands lies around 1100 million m^3, which is about 0.03% of the total amount of water used worldwide.[**8**] Efforts have been made over the years to reduce the usage of drinking water, as can be seen in Figure 10. The reduce in usage can be attributed mainly to various technological innovations that limit water usage, such as partial toilet flushing and water-saving shower heads.

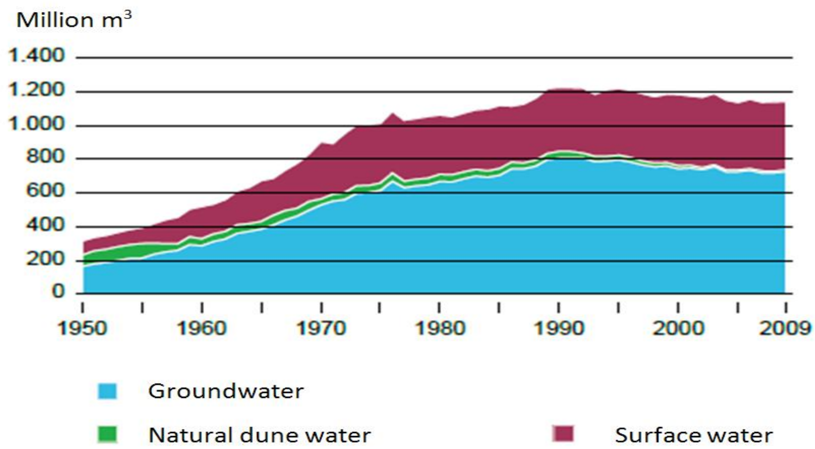

Figure 10: Drinking water usage in the Netherlands to source [25]

Figure 10 also makes a distinction between the water sources in the Netherlands. Groundwater forms the largest source of drinking water in the Netherlands, so it is expected that disinfection is not applied everywhere. A short search on the websites of Dutch water supplying companies was performed on the main sources and their primary means of disinfection. The results of this are shown in Table 4. It generally follows from this table that companies with ground water as their main source usually do not need to disinfect their water, or at least do not mention it on their website. Companies that use surface water as a source do need to disinfect their water and it is found that UV disinfection is primarily used in this case.

Table 4: Dutch drinking water companies, sources and means of disinfection

Company	Region	Main source	Disinfection
Brabant Water	Noord-Brabant	Ground water	-
Dunea	Zuid-Holland	Dune water	-
Evides	Zuid-Holland, Zeeland	Surface, dune, ground water	UV, Ozone, Chlorine-dioxide
Oasen	Zuid-Holland	Riverbank ground water	UV
PWN	Noord-Holland, Utrecht	Surface water	UV + Peroxide
Vitens	Utrecht, Friesland, Gelderland, Flevoland, Overijssel	Ground water	UV (if necessary)
Waterbedrijf Groningen	Groningen	Ground water	-
WMD Water	Drenthe	Ground water	-
WML	Limburg	Ground, surface water	UV
Waternet	Utrecht, Noord-Holland	Surface water	Ozone

It is debated however whether UV disinfection kills all waterborne pathogens. [**26**] Many drinking water companies therefore use not only UV, but various other ways of disinfection, to ensure that their water is safe to drink. The main methods applied in the Netherlands are disinfection using ozone, peroxide disinfection or addition of chlorine dioxide. These methods all have their particular pros and cons, but as this study is focusing on the primary means of disinfection, they will not be treated further.

5.2. Chlorine vs. UV in the Netherlands

The Netherlands is one of the most prominent countries in the world when discussing high drinking water quality. Therefore this country will form a perfect starting point for the rest of the research and analysis during this project. Using a country in which the “chlorine problem” has already “been solved” by using alternatives, allows us to use and implement the experience from and technical results about these alternatives within the ethical analysis. The experience available of the alternatives will make it possible to make a proper comparison between this alternative method and the disinfection using chlorine.

Information about disinfection of drinking water in the Netherlands is sufficient available in contrary to some other western world countries like for example Australia. The combination of availability of information about disinfection methods, the experiences and results of alternatives to chlorine that is already available and the high welfare and quality standards of the Netherlands concerning drinking water, will form the base of a proper ethical analysis of the drinking water situation in the Netherlands.

Because chlorine can be described as a cheap product that can be freely produced it is still primarily used for disinfection, even though there are multiple alternatives at hand. In this chapter it can be seen that, regarding disinfection of water in the Netherlands by water providing companies, almost every company that disinfects their drinking water uses UV-irradiation for this. Because of this, there will probably be enough information available about the technical aspects as well as empiric knowledge and experience about the alternative of UV-irradiation. The alternative method of water disinfection that shall be investigated next to chlorine disinfection will be disinfection by UV-irradiation.

6. Ethical analysis situation in the Netherlands

6.1. Ethical analysis

Ethics is part of theological ethics (moral theology) and philosophical ethics. The fact that ethics has some fundamental elements in philosophy is of importance, as:

- In ethics the quality of thinking (the arguments) of a philosopher is criticized, not his own actions on itself;
- Ethical purpose and objectives are connected with human actions. Therefore, ethics as a normative discipline forms part of practical philosophy;
- Ethical questions cannot be interpreted as free-standing issues, but are more or less related to other disciplines in philosophy, e.g. metaphysics, anthropology, social philosophy, religion philosophy and epistemology.

An ethical analysis of the disinfection of drinking water in the Netherlands as western country was done using the ethical cycle. The ethical cycle is a systematic approach to problem solving that does justice to the complex nature of moral problems and ethical judgment. It provides a structured and disciplined method of addressing moral problems, which helps to guide a sound analysis of these problems. The ethical cycle consists of multiple constructive steps, see Figure 11. The results of all steps of this cycle for the disinfection of drinking water in the Netherlands are presented in this chapter.

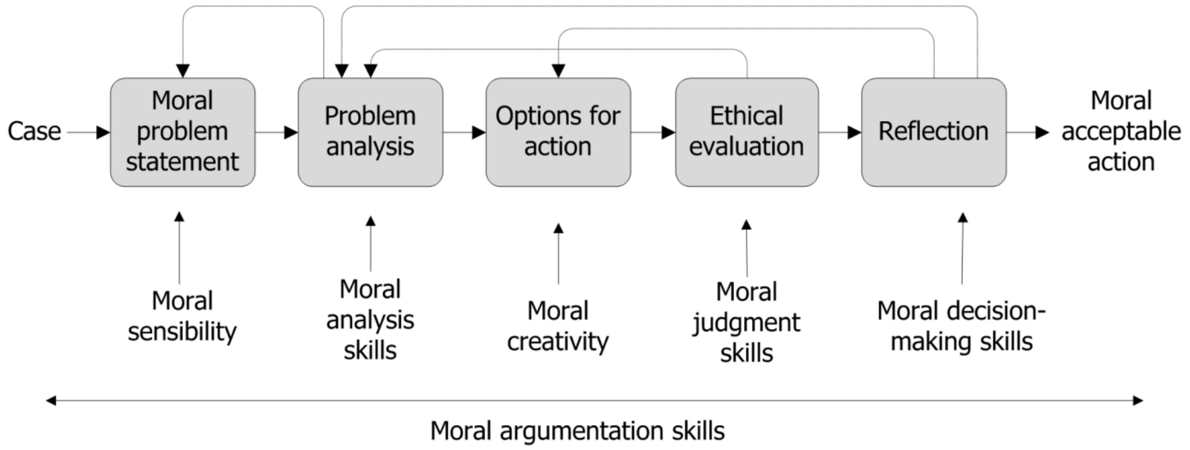

Figure 11: Overview different steps of the ethical cycle [27]

6.2. Moral problem statement

Should chlorine be used as a primary and cheap disinfectant source by governments, even if this means that harmful side-effects like the production of toxic by-products could take place, and knowing that there are feasible alternatives with possibly less harmful side-effects?

6.3. Problem analysis

6.3.1. Stakeholders and their interests

- **<u>Government</u>**

  The major interest that the government has is the wish to be re-elected during the next elections. The government itself doesn't have a great amount of expertise regarding water purification. They use advisory boards to inform them. The government also wants to have a healthy population in their country. This is associated with the wish to reduce health care costs as much as possible. Their major goal however again, is to build up a good reputation so that they will be re-elected the next time.

- **Advisory boards**
  Advisory boards often have a high amount of expertise. Their goal is to do reliable research. There is an aspect of commercial interest, as they wish to be the best in their research area. They are independent organizations that inform the government about issues regarding for example public health and research. The advices they give are often non-binding and are mostly concerning the broad lines of policy and legislation.

- **Water purification companies**
  With the water purification companies there is a large amount of expertise available, especially regarding the technical aspect of water purification. The biggest interest they have is commercial interest. They would like to make money and build up a good reputation so that the company continuity is guaranteed for the future. For this good reputation they want to make a good product. If technological insights require change of the current process, they want this to be as cheap as possible.

- **Insurance companies**
  Regarding water purification the (health)insurance companies have a low amount of expertise. They have a high amount of commercial interest, because they want the cost of the health care to be as low as possible. This will result in the buildup of a good reputation so that the company being is guaranteed for the future. A good reputation is crucial for the existence of an insurance company as consumers have the possibility to switch between different companies when they are unsatisfied.

- **Consumers**
  This is a group with a relative low amount of expertise at both the technical as health consequences aspects. They have the confidence that the water that comes out of their tap is clean, healthy and of the highest quality. Their interests are high water quality, low cost of this water and a good taste of the water. They depend on the water that comes out of their tap as they cannot choose the water that is supplied to them. There is no free choice of favorable water company as there is with the energy market.

- **Environmental groups**
  Environmental groups may sometimes be overprotective for the consumer. One of their interests is to get as much as attention as possible regarding safety aspects, health aspects and the (negative) consequences of different water purification methods. They want to inform the consumer about the environment and they wish for the best quality of water for both the people as the environment. They have a big influence on some parts of the population as they tend to scare them with all negative effects.

- **Health care**
  The health care organizations also have some commercial interest. They mainly want the population to be as healthy as possible and want to have the risk regarding drinking water reduced as much as possible. Their interest is less patients through cleaner water so that they have to make fewer costs for the patients.

- **Media**
  There is a high commercial interest of the media, as they want to sell as much information as possible through newspapers, magazines and other media. They also want to build up a good reputation. They want to inform people with (sometimes so called 'breaking') news, showing often the negative sides of the news. There is a high amount of attention paid to them, which shows the great influence that they have on the society.

- **Chlorine manufacturers**
  Chlorine manufacturers have a high commercial interest. They want the chlorine usage to be as high as possible so that a lot of their product can be sold. The market of water purification is big and they definitely want to remain in this market. Their product is simple and gives them a big profit so they cannot permit themselves to be replaced by another product or technology.

- **UV and ozone technology companies**
  UV and ozone technology companies have a high commercial interest. They want their technology to be implemented in the water purification sector. They want to stimulate UV and ozone technology usage because they think their product is the best available. They tend to be innovative companies as their product is relative new in the market.

- **Competitors on the drinking water market**
  Competitors on the drinking water market are the producers of bottled water. They tend to distinguish themselves from tap water by producing so called 'mineral water' and 'spring water' which they believe is more natural and healthier for the population. Their main interest however is a commercial one, as they want to make as much money with their product. They wish to build up a good reputation so that consumers will be convinced of the quality of bottled water over tap water. The competitors want to make a good product in which distinction is the key word.

6.3.2. Relevant moral values

- Health of the population;
- Safety;
- Clean environment;
- Reliability;
- Freedom of choice;
- Economic welfare;
- Bliss and pleasure.

6.3.3. Relevant facts

In this paragraph the most important relevant facts are mentioned that were used during the ethical analysis. A complete list of all the used facts, including disputed facts, can be found in appendix C.

Regarding water disinfection using chlorine, with adequate pre-treatment, chlorine dosing, contact time and maintenance, this disinfection method effectively destroys many disease-causing bacteria and viruses.[**28**] If a sufficient amount is added, chlorine-based disinfectants are the only disinfectants that provide lasting residual protection to protect the water from waterborne pathogens throughout the distribution system from treatment plant to the consumer's tap.[**2**][**29**] One of the downsides is that chlorine in drinking water might combine with organic matter at the stage of chlorination, i.e. before it reaches in our home plumbing system. What are produced from this chemical process are trihalomethanes (THM's for short), or haloforms. These chlorine by-products are known carcinogens.[**30**]

UV disinfection is very effective at inactivating pathogens at low dosages.[**31**] Unfortunately UV disinfection does not provide a chemical disinfectant residual to protect the water from recontamination or microbial re-growth after treatment.

In the Netherlands physical processes (sedimentation, filtration, etc.) are used in preference of oxidizing agents to produce biostable water. The water is distributed through a pressurized distribution system, preventing ingress of water and thus bacteria and nutrients. The distribution network is kept clean by minimizing particles and preventing precipitation by using high flow velocities. The network is also regularly flushed. This combination of biostable water with a clean distribution network results in the fact that no additional disinfectant has to be used to ensure residual disinfecting properties. Next to that, the Netherlands have to implement the European drinking water directive, but in fact have stricter requirements in their drinking water decree. In 2005 the last chlorine disinfection processes were stopped and replaced by alternatives.

Concerning diseases that can be caused by contaminated water, Legionnaires' disease is one of the most important and dangerous ones. It is caused by *Legionella pneumohilia*, which appears generally in freshwater. Multiplication occurs principally in installations including water cooling towers, whirlpools, showers, nebulizers and distribution systems of drinking water. Atomization of warm water may have potential high risks to public health.[**32**][**33**] The bacteria increase in number on contact related water surfaces, the so called bio film. The growth of *Legionella* in the environment and technical water systems is strongly determined by the formation of biofilm.[**32**] Concentrations of bio film in water pipes depends on the composition of the water, the material of the pipes, hydraulic conditions (flow), presence of amoebae and the temperature of the water.[**32**] The growth of *Legionella pneumophilia* might be limited by the conservation of high (>60ºC) or low (<25ºC) water temperatures.[**32**] An increased risk for catching this disease is for retired people, since the risk of developing Legionnaires' disease from *Legionella* infections increases sharply with age.[**34**]

6.3.4. Disputed, uncertain or unknown facts

Disinfection by chlorine is still the best guarantee of microbiologically safe water.[**2**] However, moderate to heavy consumption of chlorinated tap water by pregnant women has been linked with miscarriage, birth defects, heart problems, cleft palate, and major brain defects. Especially pregnant women in their first three months are at higher risk of miscarrying.[**35**][**36**] The presence of chlorine in tap water has also been linked to the dramatic rise of heart disease. Scientists argue that chlorine is a primary cause of the development of atherosclerosis, or hardening of the arteries. It is also said that the chlorine disinfection byproducts (DBP's) are responsible for the increase in rectal and bladder cancers and that chlorine disinfectant byproducts are one of the most deadly carcinogens in tap water.

Concerning UV disinfection, this type of disinfection does not produce a disinfectant residual. Therefore it can only be used as a primary disinfectant. A secondary disinfectant, such as chlorine, in combination with UV radiation has to be used when treating drinking water with UV disinfection.[**37**]

Regarding diseases caused by contaminated water, legionellae are susceptible to a broad range of disinfectants, including chlorine- and bromine-containing compounds, ozone, heavy metal ions, and ultraviolet light.[**38**][**39**] The Dutch Health Council estimated 50 cases of Legionnaires' disease per million inhabitants.[**40**] The number of registered Legionella patients has increased to more than 300 per year in the Netherlands since the outbreak in Bovenkarspel in 1999.[**41**] The real number of Legionnaires' disease is probably higher than the reported number due to underestimations in diagnostics.[**42**] The mortality of Legionnaires' disease is between 5% and 30%.[**43**]

6.4. Options for actions

1. *Use only chlorine as disinfectant for drinking water.*
2. *Use only UV-technology for disinfection of drinking water.*
3. *Combine chlorine and UV-technology; More specific, use UV-technology to disinfect the water at the water purification plant and add a little chlorine for residual disinfection during transport.*
4. *Do not disinfect the water.*
5. *Use UV disinfection combined with chlorine disinfection for vulnerable groups. In general this means that UV-technology is used for basic disinfection of drinking water. Next to that chlorine disinfection is used in for example hospitals and residential care homes.*
6. *Use chlorine as only disinfectant for drinking water, but also use filters to filter out the chlorine at the tap.*

6.5. Ethical judgment

In this paragraph an ethical judgment was made using the before mentioned facts and stakeholders. The most relevant ethical analyses were found to be the 'cost-benefit analysis' and the analysis using the Kantian approach. The results of some other methods, like the 'intuitive method', 'dominant-value method' and the approach using 'virtue ethics' can be found in appendix D.

6.5.1. Cost-benefit analysis

The objective of this analysis is to find the action which should be taken so that the greatest good is done for as much stakeholders as possible and to reduce the costs to a minimum for the least number of stakeholders. To achieve this aim, the benefits and the costs of each action will be evaluated by using the facts presented in the previous section.

Actions

Action 1: Use chlorine as only disinfectant

The benefits of chlorine over UV are that some pathogens, in particular Legionella, are more efficiently killed, but on the other hand chlorine does not penetrate the biofilm in the pipes and is not fully effective against Legionella. Chlorine also provides residual disinfection and prevents the regrowth of bacteria in the distribution network. The use of biostable water and a clean distribution network would however make this irrelevant.

As soon as chlorine is added to the water disinfection by-products (DBP's) are formed, of which most are carcinogenic. The dangers of these by-products have been researched in numerous studies; however, quantification of the cancer cases caused by DBP's remains difficult.

Quantification of cases of Legionella is also disputed, as are the origins of the infection. Statistics vary from a few hundred cases of Legionella each year in the Netherlands to close to a thousand deaths. Estimates of cancer cases caused by DBP's vary similarly. Therefore, no direct comparison can be made using the number of deaths caused by Legionella or DBP's.

Another factor is the cost of chlorine based disinfectants. Chlorine disinfection is more costly than UV disinfection on small scale; however the difference in cost decreases in larger scale plants. A large contributor to the cost of chlorine is the transportation. This transportation can also pose dangers for the environment should chlorine or chlorine based disinfectants be leaked.

A final remark that can be made is that excessive use of chlorine will make the water taste bad. This is however not a big problem if chlorine concentrations are kept low.

Action 2: Use UV-technology

A drawback of UV disinfection is that some pathogens are not efficiently killed. To kill pathogens like Legionella, a stronger intensity of radiation is required combined with longer exposure times. Another drawback is that this disinfection method does not provide residual disinfection in the distribution network. This is a problem if the network is not clean and the water is not biostable, i.e. it supports bacterial growth. If the distribution network is clean and the water is biostable, no residual disinfection is required and thus UV disinfection can be used.

UV disinfection does not lead to harmful DBP's. Some DBP's are formed, but in very low quantity and these pose no health risks. As mentioned before, UV disinfection is cheaper than chlorine on small scale but the same in cost on larger scale. UV light does not leave traces in the water and thus is neutral in taste.

Action 3: Combine chlorine and UV technology

The benefit of this approach would be that some residual disinfection is still present in the water, thus preventing regrowth of bacteria. As mentioned before, clean pipes and biostable water would render this advantage irrelevant; this would only truly be an advantage when regrowth in the pipes is possible.

Another advantage is that pathogens more resistant to UV disinfection would be killed more efficiently. The main drawback of this approach is that the chlorine will form DBP's in the water (albeit in lower concentrations) which can be harmful to the health of the consumers. Again, the harms of DBP's should be compared with the harms caused by resistant pathogens, but statistics of this are disputed.

This action would increase the cost of water disinfection as two methods are combined. This approach would also require transport of the chlorine and the risks associated with this. The taste of the water would, by using this approach, not change because chlorine is used in very small concentrations.

Action 4: Do not disinfect the water

This approach would be the same approach used 200 years ago. In that period, cholera and typhoid outbreaks occurred regularly and killed a lot of people. It would be fair to say that many more lives would be lost by not disinfecting the water than by presence of DBP's.

Action 5: Use UV disinfection combined with chlorine disinfection for vulnerable groups

In this approach, most of the general public drinks water purified by UV irradiation, while persons at risk of infection receive chlorinated water. This would mean that the general public is not exposed to DBP's and their health risks. At the same time, people who are vulnerable for infections caused by UV resistant bacteria (such as Legionella) would be protected. This would most likely reduce the number of cases of Legionella.

The general public is not exposed to DBP's and the people in the vulnerable groups are not exposed on long term basis to DBP's (people in hospital would be exposed for a few days to a few weeks, elderly people would generally not be exposed long enough to substantially increase the risk of cancer). This means that the health risks posed by DBP's would almost be reduced to zero, while lowering the risk of Legionella substantially.

This approach would entail a somewhat higher cost than disinfection by UV alone. The added cost would however be limited as only a small fraction of the water would be chlorinated. There would however be a larger start-up cost as hospitals and care homes would have to install installations to chlorinate the water.

Action 6: filter out chlorine at the tap

This would have all the benefits of chlorine disinfection, but also the same drawbacks. Studies have shown that chlorine itself does not increase health risks, but the DBP's do. There are no efficient filters to remove the DBP's thus the health risks do not change. The only added advantage over just using chlorine is that the taste of chlorine will be removed. There are large costs associated with this option as these filters will have to be bought and installed.

Stakeholders

Government

The government would most likely choose action 5 as the costs are justified by the decrease of Legionella risk. In this way the government can show to the public that they take actions to increase the safety of the drinking water for everyone.

Advisory boards

Advisory boards would also opt for option 5 as the costs are justified by the gains.

Water purification companies

Water purification companies would choose the cheapest solution while still providing safe and good tasting drinking water. It is likely that they would opt for option 2. If the cost of the chlorination of the water for vulnerable groups is taken by the government or the institutions (hospitals, care homes) there is no difference between option 2 and 5 from their point of view.

Insurance companies

Insurance companies would choose the option that reduces health risks the most. Therefore, option 5 is best for them.

Consumers

Consumers would choose option 5 as health risks are reduced. In addition, the taste of the water would not change for the general public.

Environmental groups

These groups would choose the option that poses the least threats to the environment: the option that does not require transport of dangerous materials. This would be option 2 or 4, but option 4 would be too dangerous for the public health to apply. Option 5 would be also acceptable as transports of disinfectants would be reduced versus option 1, 3 or 6.

Health care

Health care would opt for option 5, as this is the option with the least health risks. Furthermore, implication of option 5 would mean that less people would get sick by drinking water contamination while in health care, thus providing a better reputation for them. If the costs of option 5 would have to be carried by the health care itself, this option would still be the preferred one because of the decrease of health risks.

Media

The media would not have a preferred option, as all the options give them a chance to instigate a public debate.

Chlorine manufacturers

Chlorine manufacturers would definitely choose for option 1 or 6, as this is in their financial interests. If option 5 or 3 would be chosen, they would lose profits made on chlorine disinfectants, but not as much as with option 2 or 4.

UV and ozone technology companies

These companies would prefer option 2, 3 or 5 as this would give them the most opportunities for business.

Competitors on the drinking water market

The competitors would most likely prefer option 1 as this would have the most chance to give a bad taste to the water. This would allow them to make better sales. Other than this they would prefer options 3 or 6 as the concerns about health risks would increase their sales.

Analysis

From the analysis of the stakeholders, it is clear that most stakeholders either prefer option 5, or find that it does not harm their interests much. The biggest stakeholder: ‘the consumers’, and the most influential stakeholder: ‘the government’, both prefer option 5. The only stakeholders whose interests are harmed by this option are environmental groups, chlorine manufacturers and drinking water competitors. The environmental groups and chlorine manufacturers prefer however option 5 over some other options, so their interests are not fully harmed.

It is clear then that option 5 would be the preferred option to implement as this gives the most gains for the largest number of stakeholders.

6.5.2. Deontology (Kantianism)

The Kantian ethics or deontology is a form of ethics based on moral principles. Shortly it says; only act if the underlying principle can be applied as a law for everyone, in all circumstances. People can, by themselves, make an ethical right choice without influences from the outside world. The Kantian ethics shall be used on several options for action consistent with the chlorine dilemma. The outcome of this approach shall be determined by the facts which were presented in the previous section.

Actions

Action 1: Use chlorine as only disinfectant

The use of chlorine as disinfectant for drinking water stops the threats which are present in non-disinfected drinking water. The drinking water is disinfected from storage till the tap of the consumer. According to this, the Kantian approach has no objections against the use of chlorine, but unfortunately, by using chlorine to disinfect, by-products are produced which can be classified as carcinogenic. Having this knowledge the Kantian approach must reject the use of chlorine. This because it isn't acceptable to remove harmful products, while in the same time introducing new harmful products. Even if no by-products would exist, the action cannot be supported because a small amount of chlorine is needed for disinfection until the water comes out of the tap. Consumers are therefore still exposed to chlorine in their drinking water.

Action 2: Use UV-technology

For using UV as disinfectant technology for stopping harmful threats, the ethics of Kant shows no objections. Consumers have access to safe drinking water, and many diseases, such as diarrhea, can be stopped. Looking at the facts of using UV as technology, it is apparent that on the health side no moral principles shall be disputed. This is the main concern why chlorine use should be rejected. Disinfection by-products are present but not harmful DBP's or on levels of concern. The problem of no residual disinfection in the distribution system can be solved using high pressures to transport the water. Harmless drinking water can be made using UV technology in the disinfection phase. Based on this short analysis there can be concluded that no moral problems can exist using the Kantian approach and this type of disinfection can be applied as law for everyone.

Action 3: Combine chlorine and UV-technology

This action is in conflict with the moral principles that are used in the Kantian ethics. The problem lies in the fact that still chlorine is used as a disinfectant and the UV-technology doesn't remove the residual chlorine or its disinfection by-products. Therefore this action should be rejected.

Action 4: Do not disinfect the water

Non-disinfected water comes from a period when many outbreaks of diseases occurred. As time expires mankind develops itself and therefore new knowledge is obtained. It is in this present time not possible to have the same moral principles on this statement as in the past. This leads to the rejection of this action, evaluated by the Kantian approach, because when diseases caused by contaminated drinking water can be stopped, it must be done reasoned by our conscience. Many lives can be spared making drinking water much safer. That is why doing nothing cannot be accepted as a law and conflicts our principles.

Action 5: Use UV disinfection combined with chlorine disinfection for vulnerable groups

The purpose of this action is to protect vulnerable groups, such as elderly people, against diseases as Legionella. Most consumers are not exposed to the chlorine and its DBP's. People in hospitals aren't continually exposed, so the health risks are very minimal. Elderly people would generally not be exposed long enough to substantially increase the risk of cancer. But do these assumptions make it acceptable? Not all people stay for a short time in the hospital or in a retirement home. There are always people who don't match the criteria stated above and maybe exposed for a longer period. Therefore the Kantian ethics still cannot allow chlorine as a disinfection technique for drinking water. It is on the edge of what is morally acceptable, but when people are not generalized it is not possible to use chlorine disinfection for vulnerable groups.

Action 6: Filter out chlorine at the tap

The only difference between action 6 and action 1 is that there is no residual chlorine coming out of our taps. The DBP's aren't removed this way, so the health risks don't decrease. Kantian ethics would reject this action because of the same statements of why chlorine should not be used.

6.6. Reflection

6.6.1. Cost-benefit analysis

The cost benefit analysis was difficult as reliable data on the number of Legionnaires' disease cases and deaths could not be found, and the harmful effects of DBPs could not be quantified. Therefore this analysis was not carried out using hard data and using some assumptions. This makes that the analysis is of lower value, but it still is reliable in a qualitative sense.

6.6.2. Deontology (Kantianism)

When criticizing the drinking water dilemma on a deontologist point of view, the only acceptable action is to use only UV as disinfection. All the other actions still contain chlorine and therefore DBP's which are carcinogenic. Kantian ethics is based on moral principles which suggest it is an easy way to judge the dilemma. When people are pigeonholed this is true, but there are always exceptions. This is in conflict with the moral principles and therefore making a proper decision is harder, because it must be applied as a law for everyone, in every circumstance.

6.7. Choice for moral action

The action that should be taken from an ethical point of view is action number 5. Almost every method of the ethical analysis led to this decision. Even though deontology has some remarks about this action it is not clearly forbidden. All other judgments were found to have a clear preference for action number 5.

Action number 5:

"Use UV disinfection combined with chlorine disinfection for vulnerable groups. In general this means that UV-technology is used for basic disinfection of drinking water. Next to that chlorine disinfection is used in for example hospitals and residential care homes."

Although the cost benefit analysis was difficult because of the lack of reliable data on the number of diseases and deaths, the analysis is still reliable in a qualitative sense. From the analysis of the stakeholders, it is clear that most stakeholders either prefer option 5, or find that it does not harm their interests much. The biggest stakeholder: 'the consumers', and the most influential stakeholder: 'the government', both prefer option 5.

The conclusion of Kantian ethics is that action 5 is on the edge of what is morally acceptable and not clearly forbidden. The purpose of action 5 is to protect vulnerable groups, such as elderly people, against diseases as Legionella. However, Kantian ethics had some remarks regarding the generalization and pigeonholing of people.

Also on an intuitive basis this is the optimal action, because in this case the best result is given with the least amount of work. A remark that can be made is that an intuitive decision is made with an emotional feeling about the elderly and ill people. You want them to have good disinfected water but the risks that this new situation brings with it could have been neglected. Finally, with health chosen as the most dominant value the action that should be taken is also action number 5, as UV-disinfection will give good disinfection to the average consumer while chlorine disinfection gives the best (residual) disinfection for pathogens including Legionella that is wanted for less healthy and elderly people. The determination of the most dominant value and is difficult to do, because this choice is never objective.

7. Situation in Kenya

7.1. General information

Kenya is a third world country located in the east of Africa (see Figure 12). It covers an area of 582,646 square kilometers and can be divided into four geographic regions, namely: Lake Victoria Basin, Rift Valley and Western Highlands, Northern Kenya and Eastern Highlands, and the Coastal Belt.[**44**] Kenya had a Gross Domestic Product (GDP) of 775 USD per capita in 2010.[**45**] Kenya is considered as a water-scarce country with less than 647 cubic meter of water available per capita compared to the international benchmark of 1000 cubic meters per capita.[**46**] The renewable freshwater resources of Kenya are estimated at 20.2 km^3 per year, which corresponds to 647 m^3 per capita per year.

Figure 12: Topographic location of Kenya, surrounded by Sudan, Ethiopia, Somalia, Tanzania, Uganda and the Indian Ocean [47]

Kenya goes through two rain cycles every year from which one runs from March until May and the other from October until December. Presented in Figure 13 is the amount of rainfall in Kenya in mm/year.[**48**]

During the rainy periods, rain is the main source of drinking water for about 52% of the total drinking water supply. In dry periods the rural population relies on springs, rivers and streams for their drinking water. Urban households have water piped into their compound or dwelling (49%) or get water from public taps. The majority lives within 15 minutes of their water source supply. About 22% of the population in Kenya lives in an urbanized area. The main population lives in rural territory. Especially in the rural part, source waters are both heavily faecally contaminated and highly turbid. Although there are no health based rules on turbidity, the WHO suggests that drinking water with a turbidity of 5 NTU (Nephelometric Turbidity Unit) is acceptable to consumers. For adequate disinfection however, the turbidity should be below 0.1 NTU.[**49**][**50**]

When looking at the urban areas, investigations have shown a decline in improved drinking water sources and a slight increase in sources in rural regions. In the urbanized regions 85% of the population has access to safe drinking water. From all the people who live in rural areas, 53% has access to safe drinking water. Figure 14 shows these trends for the last 20 years.[**51**]

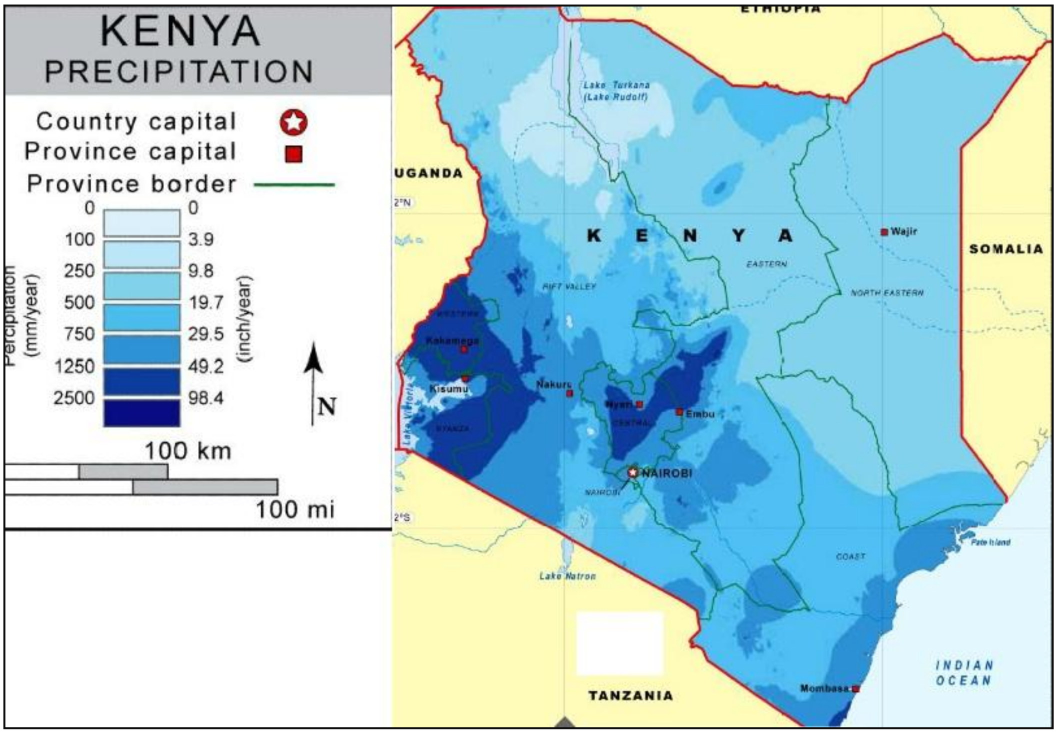

Figure 13: Rainfall in Kenya [48]

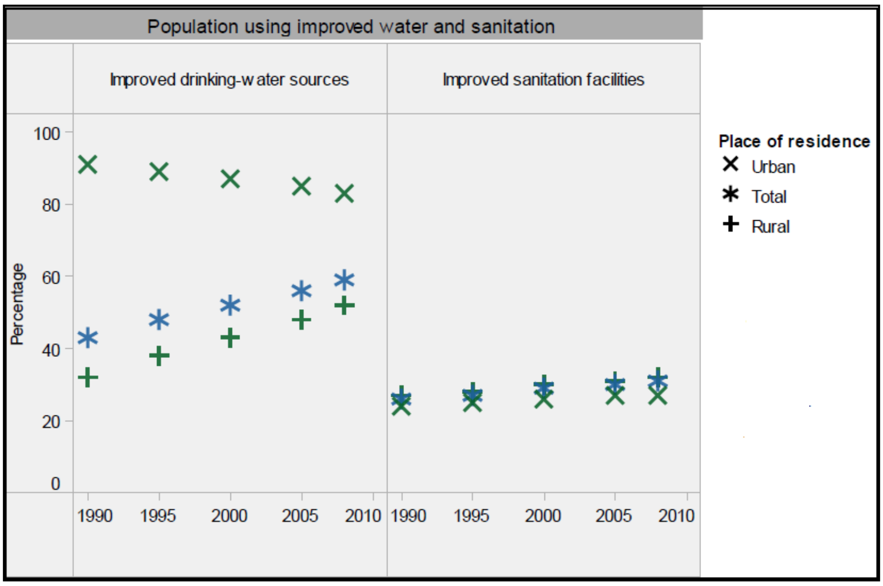

Figure 14: Population using improved water and sanitation in Kenya [51]

Kenya has five basins. The Lake Victoria Basin Drainage area system in Western Kenya is part of the Nile River Basin. The closed Rift Valley Inland Drainage system includes a number of rivers and lakes, including large freshwater lakes such as Lake Turkana, Lake Baringo and Lake Naivasha, rivers such as the Kerio River, as well as a number of salt lakes. The Athi Drainage system, the Tana Drainage system and the Ewaso Ng'iro North Drainage system all flow towards the Indian Ocean.[**52**] (See Figure 15)

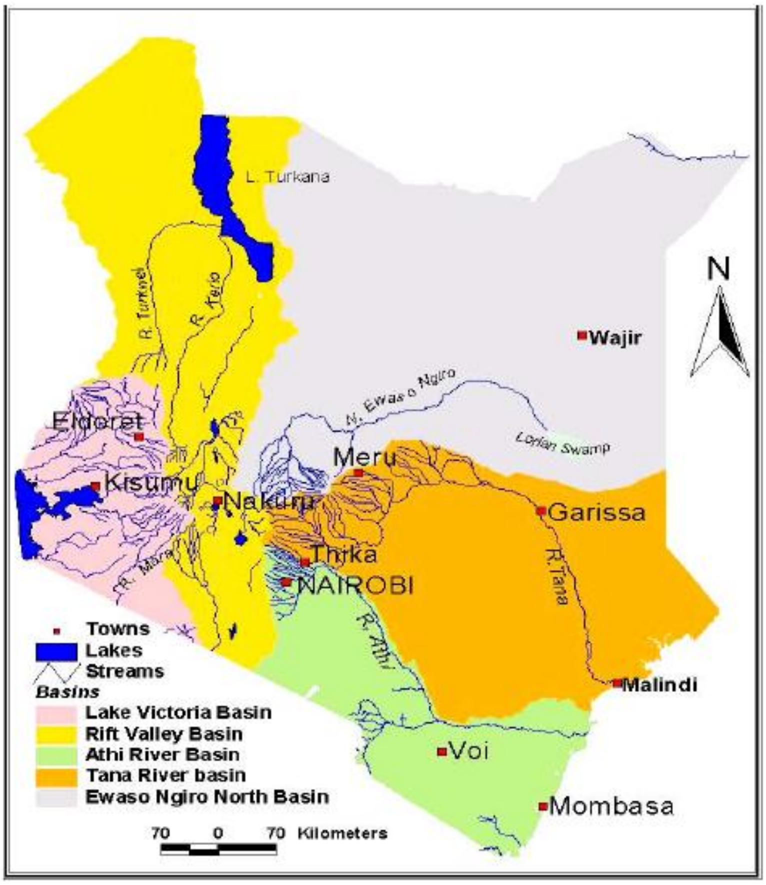

Figure 15: Drainage systems of Kenya [52]

7.2. Disinfection methods

Within Kenya, in contrary to some third world countries, there is a decent amount of knowledge and awareness for disinfecting drinking water. The population is made aware of the importance of safe water for consumption. This results in the use of both basic and more advanced forms of disinfection. Because of Kenya's large rural area and lack of distribution system, the disinfection has to be done on household level, therefore rendering not all techniques suitable. The most viable household water treatment methods in Kenya are listed below:

- Boiling of drinking water;
- Chlorination disinfection;
- Filtration of drinking water;
- Solar disinfection.

More detailed information regarding these disinfection methods, looking at the advantages, disadvantages and the effectiveness of the methods, can be found in chapter 8, relevant facts about disinfection techniques.

8. Ethical analysis situation in Kenya

8.1. Ethical analysis

An ethical analysis of the disinfection of drinking water in Kenya as third world country was done using the ethical cycle. A similar approach using the most relevant ethical frameworks was used as the one that was used when analyzing the situation in the Netherlands (see chapter 6). The results of the different steps of this cycle for the disinfection of drinking water in Kenya are presented in this chapter.

8.2. Moral problem statement

In Kenya, is it necessary to disinfect drinking water for both rural and urban settings or should more money be invested providing infrastructure for a better distribution of drinking water?

8.3. Problem analysis

8.3.1. Stakeholders and their interests

- **Governmental institutions**

  The major interest that the government has is the wish to be re-elected during the next elections. The government also wants to have a healthy population in their country. In Kenya the most important governmental institutions contain the Ministry of Water and Irrigation (MWI), which is the key institution responsible for the water sector in Kenya, and the Ministry of Public Health and Sanitation (MoPHS).[**53**]

  In Kenya the regulation and monitoring of urban and rural water service provision is carried out by the Water Services Regulatory Board (WASREB). WASREB is a non-commercial state corporation established in March 2003 on the basis of the 2002 Water Act. Its functions comprise: issuing of licenses to water services boards and approval of SPAs, developing tariff guidelines and carrying out tariff negotiations, setting standards and developing guidelines for service provision, publishing the results of sector monitoring in the form of comparative reports (such as the Impact Report).[**54**]

- **Non-governmental organizations (NGOs)**

  Kenya also has an active civil society including a number of local NGOs active in water supply and sanitation. Many of them are members of the Kenya Water and Sanitation Civil Society Network (Kewasnet) founded in 2007. One of the larger Kenyan NGOs active in water and sanitation is Maji Na Ufanisi (Water and Development). It is involved in community development and infrastructure construction in urban slums and in small towns, advocates for improved sector governance and carries out research.[**55**]

  Kewasnet monitors service delivery, especially for the poor, and policy implementation on water sector reforms. It also provides information to Kenyans to enable them to be engaged and involved in the management and decision-making mechanisms of the Water and Sanitation Sector. It also promotes a culture of consumer responsibility that pays for supplied services from utility companies, safeguards water services infrastructure and equipment against vandalism by criminals.[**56**]

- **Water service boards and providers**

  With the water service boards and providers there is a large amount of expertise available, especially regarding the technical aspect of water purification and distribution. The biggest interest they have is commercial interest. They would like to make money and build up a good reputation so that the company continuity is guaranteed for the future. If technological insights require change of the current process, they want this to be as cheap as possible.

  In Kenya the responsibility for water and sanitation service provision is in the hands of eight Water Services Boards. Water Services Boards are responsible for asset management, i.e. for the development and rehabilitation of water and sewerage facilities, for investment planning and implementation.[**57**][**58**]

WSBs are not required to provide services directly - they can delegate them to commercially oriented public enterprises, the so called Water Service Providers (WSPs). Service provision is regulated by service provision agreements (SPAs) to ensure compliance with the standards on quality, service levels and performance established by WASREB.[**52**]

- **Small service providers of water**
  Informal small service providers (SSPs) provide water in both rural and urban low income settlements. Some of them sell water from tanker trucks or through jerry cans, often at prices that are five to ten times that of piped water supply. Others are self-help groups, often run by women, who provide piped water supply.[**59**]

- **Consumers**
  This is a group with a relative low amount of expertise at both the technical as health consequences aspects. Their interests are safe water and low costs.

- **Industry, agriculture and energy companies**
  There are different types of water users in Kenya. Next to the consumers, defined as 'population of Kenya that want to have access to (safe) drinking water', there is also the industry, the agriculture section and the energy companies.[**52**] They also need water, in their case as cooling, irrigation or process water. When enough water is available this will normally not be a problem. However, because of the scarcity of water in Kenya, a choice has to be made whether the available water will be provided to the population of Kenya or whether it is sold to the industry, agriculture and energy companies. They both have different interests, causing the governments and water service boards and providers having to make a choice about water provision on moral and financial grounds.

- **Disinfections manufacturers and importers**
  Manufacturers or importers of disinfection materials have a high commercial interest. They want their technology to be implemented in the water purification sector. The usage of their disinfection technique should be as high as possible so that a lot of their product can be sold.

- **Health care**
  The health care organizations also have some commercial interest. They mainly want the population to be as healthy as possible and want to have the risk regarding drinking water reduced as much as possible. Their interest is less patients through cleaner water so that they have to make fewer costs for the patients.

- **Environmental groups / authorities**
  Environmental groups want to inform the consumer about the environment and they wish for the best quality of water for both the people as the environment. One of their interests is to get as much as attention as possible regarding safety aspects, health aspects and the (negative) consequences of different water purification methods. They may sometimes be overprotective for the consumer. They have a big influence on some parts of the population as they tend to scare them with all negative effects.

  The most important party in this case is the National Environment Management Authority (NEMA). Its role is to promote the integration of environmental considerations into government policies, plans, programs and projects. As regards the water sector in particular, NEMA is in charge of formulating water quality regulations.[**60**][**61**]

- **Action Groups**
  The 2002 Water Act also provided for the establishment of an independent Water Appeals Board to settle water related disputes and conflicts.[**61**] The Water Appeals Board was established in 2005 in Nairobi.[**62**] In 2010 Water and Sanitation Action Groups (WAGs) were established consisting of citizen volunteers in

order to provide a forum for dialogue and for feedback from consumers. Consumer complained about inaccurate billing and metering, pipe bursts, illegal connections, poor workmanship on installations, vandalism, overcharging and corruption. Utility staffs were initially suspicious and even hostile. The feedback was done in the form of focus group discussions, public hearings and scheduled meetings between citizen representatives and utility managers. While 63% of the complaints were resolved after 8 months, it remains to be seen if the system will become permanent or will be extended to other cities.[**63**]

- **Media**
  There is a high commercial interest of the media, as they want to sell as much information as possible through newspapers, magazines and other media. They also want to build up a good reputation. They want to inform people with (sometimes so called 'breaking') news, showing often the negative sides of the news. There is a high amount of attention paid to them, which shows the great influence that they have on the society.

- **Neighboring countries and development partners**
  Have interest in shared water resources and efficient use of these resources.

8.3.2. Relevant moral values

- Health of the population;
- Safety;
- Clean environment;
- Reliability;
- Freedom of choice;
- Economic welfare;
- Bliss and pleasure.

8.3.3. Relevant facts

In this paragraph the most important relevant facts are mentioned that were used during the ethical analysis. A complete list of all the used facts, including a differentiation between relevant and disputed facts, can be found in appendix F.

8.3.3.1. Governmental

Kenya is a water scarce country with 647 cubic meter of water per capita. To ensure water supply, the Kenyan government has signed various treaties concerning rivers and lakes with neighboring countries. Efforts in the last years to build more distribution infrastructure, has led to a coverage of 40% and 60% in rural and urban environments respectively.

The Ministry of Water and Irrigation (MWI) is the key institution responsible for the water sector in Kenya. The Ministry is divided into five departments: (i) Administration and Support Services, (ii) Water Services, (iii) Water Resources Management, (iv) Irrigation, Drainage and Water Storage and (v) Land Reclamation.[**53**] The regulation and monitoring of urban and rural water service provision is carried out by the Water Services Regulatory Board (WASREB). WASREB is a non-commercial state corporation established in March 2003 on the basis of the *2002 Water Act*.[**54**] Among other activities, the Kenya Water and Sanitation Civil Society Network (Kewasnet, founded in 2007) monitors service delivery, especially for the poor, and policy implementation on water sector reforms. It also provides information to Kenyans to enable them to be engaged and involved in the management and decision-making mechanisms of the Water and Sanitation Sector. It also promotes a culture of consumer responsibility that pays for supplied services from utility companies and safeguards water services infrastructure and equipment against vandalism by criminals.[**56**]

Responsibility for water and sanitation service provision is in the hands of the Water Services Boards (WSBs). Water Services Boards are responsible for asset management, i.e. for the development and rehabilitation of water and sewerage facilities, for investment planning and implementation.[**57**][**58**] WSBs are not required to provide services directly - they can delegate them to commercially oriented public enterprises, the so called Water Service Providers (WSPs). Service provision has been decentralized to 117 Water Service Providers (WSPs). The provision is regulated by service provision agreements (SPAs) to ensure compliance with the standards on quality, service levels and performance established by WASREB. There are four types of SPAs.[**52**] Informal small service providers (SSPs) provide water in both rural and urban low income settlements. Some of them sell water from tanker trucks or through jerry cans, often at prices that are five to ten times that of piped water supply. Others are self-help groups, often run by women, who provide piped water supply.[**59**]

The 2002 Water Act also provided for the establishment of an independent Water Appeals Board to settle water related disputes and conflicts.[**61**] In 2010, WASREB and local utilities helped to establish Water and Sanitation Action Groups (WAGs) consisting of citizen volunteers in Kisumu, Kakagemam, Nairobi and Mombasa in order to provide a forum for dialogue and for feedback from consumers. Consumers complained about inaccurate billing and metering, pipe bursts, illegal connections, poor workmanship on installations, vandalism, overcharging and corruption. Initially, utility staff was suspicious and even hostile. The feedback was done in the form of focus group discussions, public hearings and scheduled meetings between citizen representatives and utility managers. While 63% of the complaints were resolved after eight months, it remains to be seen if the system will become permanent or whether it will be extended to other cities.[**63**]

Full involvement of the consumers of the water will be encouraged through their participation and they will be prepared for eventual taking over of the schemes. The government will encourage self-sustaining projects by encouraging the beneficiaries to take full control of the water projects at all levels including running and maintenance of the projects. The government will facilitate the taking over management of the various community projects by training personnel from the community in running and maintenance of these projects and gradually pulling out in the running of these projects.[**52**]

8.3.3.2. Water resources

Water resources availability varies significantly in time and between regions due to the sub-tropical climate.[**64**] The total yearly water withdrawal is estimated to be less than 14% of resources.[**65**] Kenya is divided into five drainage basins.[**52**] The water distribution in the basins is highly uneven with the highest water availability in the Lake Victoria Basin (more than 50%) and the lowest in the Athi Drainage system. Only the Tana and Lake Victoria Basins have surplus water resources, while the three other basins face deficits. [**52**]

About 54% of Kenya's water resources are shared with other countries. Through the Lake Victoria Basin, Kenya provides 45% of surface water inflows to L. Victoria and hence to the upper Nile. Kenya also shares a large number of other important surface and groundwater resources with its neighbors, namely Ethiopia, Sudan, Tanzania, and Uganda. Actions that Kenya takes to tap any surplus water through say multipurpose investments, such as hydropower development, expanded irrigation use, catchments conservation and flood control, could bring benefits beyond Kenya. [**52**]

8.3.3.3. Water supply and infrastructure

Water scarcity, which is defined as more than five days without sufficient water supply, still occurs in Kenya. Around 80% of the population lives in rural areas and most of them obtain water for domestic purposes directly from rivers, lakes, dams, streams, and impoundments. They use it directly without treatment.[**52**] Water supply is overseen by the Department for Water Services, whose functions include: formulation of policy and strategies for water and sewerage services, sector co-ordination and monitoring of other water services institutions.[**53**] Kenya has an active civil society including a number of local NGOs active in water supply and sanitation. Many of them are members of the Kenya Water and Sanitation Civil Society Network (Kewasnet).[**55**]

There are 43 sewerage systems in Kenya and waste water treatment plants in 15 towns (total population served: 900,000 inhabitants). The operation capacity of these wastewater treatment plants is estimated at around 16% of design capacity. The main reasons for this inefficiency are: inadequate operation and maintenance and low connection rate to sewers.[**66**] In Kenya, the estimated connection rate of sewerage systems is 19%.[**66**] Of the wastewater that enters the sewer network, only about 60% reaches the treatment plants.[**67**] The most common solution used for wastewater treatment in Kenya is waste stabilization ponds.

Water access has fallen by five percent since 1990 due to the shortage of adequate funding to repair or replace rapidly aging infrastructure.[**68**] Urban households have water piped into their compound or dwelling (49%) or get water from public taps.[**69**] The majority of Kenya's population lives within 15 minutes of their water source supply. However, the present infrastructure is inadequate in places as Bondo, Siaya, Maua, Othaya, Mukurwe-ini and Kitui, as it was constructed in the fifties.[**70**] Next to that, Kenya has not invested in water storage infrastructure to deal with shocks from extreme events.[**70**]

8.3.3.4. Diseases

Regarding diseases through contaminated water in Kenya, there is a high degree of risk for catching infectious diseases spread through contaminated food and water like bacterial and protozoal diarrhea, hepatitis A, typhoid fever and schistosomiasis. [**7**] Cholera is one of the diseases that causes diarrhea and could be spread by contaminated water. From 2000 to 2006, cholera cases were reported each year ranging from 1,157 to 816. [**71**] An average case fatality rate for this disease was estimated at 3.57%. [**71**] During the cholera outbreak in 2009, Kenya reported 11,769 cases including 274 deaths (Case fatality rate = 2.33%). [**71**] The country had not experienced such a high number of cases in the last 10 years. Poor quality water problems remain a serious challenge to Kenyans, because over 40% of the people in Kenya still rely on raw water sources like wells, pans, and springs. [**72**]

It is estimated that 30% of global morbidity from diarrheal diseases is related to contaminated water. [**73**] Several studies in developing countries have shown that household based disinfection of drinking water with sodium hypochlorite or with a flocculant-disinfectant reduces the incidence of diarrhea by 20-48%.[**49**]

8.3.3.5. Disinfection techniques

Chlorine

Chlorination is a well-established means of drinking water disinfection. Chlorine eliminates the vast majority of micro-organisms in drinking water, with the exception of some, more resilient species. Chlorination can be applied both on a large scale in urban areas and on a small scale in rural areas, as it can be added in its gaseous form to a drinking water network or in the form of hypochlorite pills to a bucket of water respectively.

Chlorine is relatively cheap: small scale solutions such as hypochlorite pills cost around €0.50 per kilogram, with which approximately 5000 liters of water can be disinfected. Application of chlorine in a larger, urban environment requires more capital and operational expenditures, though gaseous chlorine is far less costly than hypochlorite: for the same price up to 8 times more water can be disinfected.

An advantage of chlorine is its residual disinfection potential. After adding chlorine to drinking water, residual chlorine that is not used initially prevents regrowth of micro-organisms. This allows for safe storage during an extended period of time. A major disadvantage of chlorine is the inherent formation of possibly toxic or carcinogenic by-products. These products are formed due to the reaction of chlorine with organic matter. Removal of such compounds is a difficult and tedious process and in the case of sanitation of drinking water never applied. Another main disadvantage of chlorine use is that some organisms are resistant to chlorine and will not be reduced. Some of these organisms are related to diarrhea diseases. Table 5 shows the main advantages and disadvantages of chlorine used as disinfection chemical. [**73**]

Table 5: Advantages and disadvantages: chlorination [73]

+	-
+ If correctly applied (in terms of concentration and contact time), chlorine: • is effective against most waterborne pathogens including viruses, with the exception of *Cryptosporidium parvum*, *Cyclospora cayetanensis*, pathogenic environmental mycobacteria species and to a lesser extent *Giardia lamblia and* helminth eggs; • provides a level of free residual chlorine lowering of the risk of microbial recontamination during storage + Inexpensive (with an initial cost of US$8/household (for special container for the water) + annual operating cost of US$3/household). + Proven and safe technology.	- Quality of the water will influence the effectives of microbial inactivation: • particulate, colloidal and dissolved constituents in water will react with and consume chlorine. The efficiency of chlorination is reduced in turbid water (>5 NTU) • pH and temperature of the water influence the effectiveness of chlorine disinfection. - The process must thus be adapted to take account of these factors and the level of free residual chlorine and/or microbial quality must be checked. These operations are hard to achieve at the household level. As a consequence, standard-dose products (SDP) are used. SDP's may not have a 100% disinfecting effect or can give a chlorine taste to the water. - Variable resistance of microorganisms regarding disinfection. - Potential production of disinfection by-products. - Free chlorine residual measuring required. - Cultural resistance to chlorine tasting water: a strong promotional component is thus required. - Dependent on, and with a risk of an interruption of, chlorine generating product if not locally produced.

UV disinfection

Disinfection of drinking water with UV irradiation is widely used as an alternative to chlorination. The process consists of a battery of UV lamps that irradiate a passing water stream with UV-B and UV-C radiation (100 – 300 nm). Especially UV-C radiation has so-called germicidal properties: it directly attacks and breaks down the DNA strands in pathogens present, thereby inactivating them.

Capital costs of larger (urban) scale UV systems are comparable to their chlorine-based counterparts, while operating costs tend to be less, because the UV process is considered safer than the use of chlorine.

A continuous power supply is required to make good use of UV technology. It is also necessary that the turbidity of the water that is to be treated does not exceed a certain value, based on contact time and power of the particular UV lamps. If turbidity is an issue, an additional pre-filtering step is needed. UV-disinfection does not incorporate any residual protection. In fact, UV rays of higher wavelengths than UV-C may even promote repair and regrowth of pathogens. Disinfected water should therefore be drunk immediately after disinfection, or be stored with a compound that provides residual disinfection.

Filtration

One way to filter the water is with the use of ceramic candle filters, because this does not require the addition of chemicals to the water. An advantage for this approach is that the drinking water will contain no chemical taste and odor. Also there is no formation of disinfection by-products.. This method of treatment can be recommended for long-term usage. More advantages and the method’s disadvantages can be found in Table 6. [**73**]

Table 6: Advantages and disadvantages: filtration of drinking water [73]

+	-
+ Highly effective against most waterborne pathogens (bacteria, protozoa, helminth eggs). + Operate consistently regardless of turbidity (but high turbidity leads to quick clogging: 15-20 NTU seems to be a maximum without pretreatment), pH, and temperature. + No addition of chemicals to the water. Therefore absence of formation of toxic disinfection by-products and/or taste and odour. + Easy to use and maintain, minimal instruction or need for behavioural change. + Visual observation of the water quality improvement (turbidity reduction). + High levels of user acceptability. + Sustainable and transferable technology than can lead to local production and commercialisation. In this case, cost are low: US$3 to US$10/household/year. + Insertion of adsorption media in the candle can reduce taste, odour and organic contaminants such as pesticides.	- Uncertain viral performance: additional studies needed. - No residual protection, but due to the configuration of the system, risk for potential microbial recontamination during storage is low. Higher risk if drinking water containers are hand-made. - Filtration effectiveness depends on pore size and the presence/absence of colloidal silver coating. - Relatively high cost if produced in developed countries: initial cost of US$35/household + US$5-10/year/household. Accessibility, affordability and sustainability for household use by the poorest people is thus uncertain. - Low production capacity (20L/day, or 0.5-2L/h, depending on the filter and the turbidity of water). - Breakage is possible. Even if only slightly cracked, filter is unsuitable for the removal of microorganisms. The crack may remain undetected for long periods. - Systems require regular cleaning (scrubbing-boiling) to remove accumulated materials and restore normal flow rate (each week or two weeks). - Candles must be changed (life expectancy of 6 months to 2 years).

Boiling

Boiling water is a basic technique that eliminates all pathogens effectively. In order to boil water an external energy source is necessary. Boiling water cannot be used on a larger scale than household level, due to the energy inefficiency. It also does not provide any residual disinfection. Boiling the drinking water for 1 to 5 minutes is a simple and extremely effective way to remove all waterborne pathogens. Consuming the water on the same day it has been boiled is considered safe. This is a key point in having disinfected drinking water, because storing boiled drinking water for longer than a day cannot be considered safe, as recontamination can occur. An overview of the advantages and disadvantages of this method is listed in Table 7. [**73**]

Table 7: Advantages and disadvantages: boiling drinking water [73]

+	-
+ Effective (if correctly applied in terms of temperature and time) in destroying all classes of waterborne pathogens (viruses, bacteria, bacterial spores, fungi, protozoa, helminth ova). + Can be effectively applied to all waters, including those with high turbidity or dissolved constituents. + 'Rolling' boil = indication (when temperature sensors are not available) of the efficiency of the treatment. + No particular equipment needed (with the exception of the energy source). + No need for highly skilled labour, so low level of training required.	- Consumption of energy (fossil fuels/firewood): problems of availability, cost (50 to 150 US$ a year for 40 L/day -the required volume for a family of 5) and sustainability in a lot of regions. Leading to the risk of incomplete treatment to save money. - No residual protection, leading to a risk of microbial recontamination from sources such as hands, and utensils during storage. Consumption should therefore ideally occur during the same day as treatment - the use of a lid is an asset. - Absence of impact on chemical and other components that can be present in drinking water. - People can be reluctant to boil. In this case, a strong promotional component could be required. - It takes time for the water to cool down: time between preparation and consumption can be long. - Risk of scalding (especially among children). - Boiling seems to affect the taste (but shaking the bottle will improve the taste).

Solar disinfection

Solar disinfection is a very simple and straightforward technique that has emerged in recent years. The basic principle is to fill up plastic PET bottles with contaminated water and laying them in the sun for a minimum of 6 hours. After this period of time the UV radiation of the sun will have eliminated the majority of pathogens. Research has shown that solar disinfection reduces the risk of diarrhea for 26%. Thermal inactivation of micro-organisms occurs at a minimum water temperature of 45 degrees Celsius. Note that it is not proven to fully inactivate all micro-organisms. [**74**]

The technique is said even to work on cloudy days, although the process then takes 2 days to complete. Solar disinfection is particularly useful in rural areas on a small household scale. Requirements are that the plastic bottles are UV transparent, especially in the germicidal range of 100-300 nm. The turbidity of the water may also not exceed a certain value (0.1 NTU is needed for optimal disinfection). Solar disinfection does not incorporate any residual disinfection: disinfected water is to be drunk immediately after disinfection. Whether or not harmful by-products are formed is not known.

8.3.3.6. Research and development

In order to move from the current technological development to higher levels, there is need to involve universities and other tertiary institutions in capacity building programs both in theory, practice and development of standards that are equal or superior to the rest of the world. The country has the necessary human capacity on all areas of the water sector. The creation of a favorable environment and provision of relevant resources is however required to work. [**52**]

Funding of research at the central government is difficult as the government has to choose between the provision of service and research, which may not bring a direct benefit to the consumers in the short-term, particularly where there are limited resources. This has been the situation for the Research Division for the last 15 years. The Sessional Paper No.1 of 1999 on National Policy on Water Resources Management and Development, however, states that "*Water levies and fees will be introduced where necessary and applicable for utilization of water from all public water courses. Such levies/fees will be used in ensuring a health state of the nation's water and will include support for research into technologies suited to our water needs*". [**52**]

The policy encourages collaboration with other research institutions nationally and internationally and other stakeholders in the water sector. It also mentions that financial resources will be increased, particularly for research programs aimed at the development of improved water resources management based on the sector needs.[**52**]

8.4. Options for actions

To be able to answer the moral problem statement, a list of possible options for actions was created. In this case it was found to be more clear for the ethical analysis to divide the possible options for action into two sections. The first section will give answer to the question whether or not disinfection of drinking water has to be stimulated in Kenya, while (if answered positively) the second part will give answer to the best method of disinfection. The first three possible options are listed below.

1. *Do not disinfect drinking water, but invest in infrastructure for distribution of water.*
2. *Disinfect drinking water in urban areas but not in rural areas and invest in infrastructure for better distribution of drinking water in rural areas.*
3. *Disinfect the drinking water everywhere, but do not invest in infrastructure for distribution.*

When this will result in either option 2 or 3, a second list of options for actions is to be analyzed. The second four possible options are shown below.

If disinfection is used, what technique should be used?

- *a) Employ chlorine based disinfectants.*
- *b) Employ solar UV disinfection.*
- *c) Use UV disinfection (with UV-lamps).*
- *d) Cook the water to disinfect it.*

8.5. Ethical judgment

In this paragraph an ethical judgment was made using the before mentioned facts and stakeholders. The most relevant ethical analyses were found to be the 'cost-benefit analysis' and the analysis using the Kantian approach.

8.5.1. Cost-benefit analysis

The objective of this analysis is to find the action which should be taken so that the greatest good is done for as much stakeholders as possible and to reduce the costs to a minimum for the least number of stakeholders. To achieve this aim, the benefits and the costs of each action will be evaluated by using the facts presented in the previous section.

Actions about disinfection

Action 1: Do not disinfect drinking water, but invest in infrastructure for distribution of water

In Kenya, the risk of catching infectious diseases spread through contaminated food and water is high. Examples are bacterial and protozoal diarrhea, hepatitis A, typhoid fever and schistosomiasis. Furthermore, because of improved water disinfection in recent years, cholera outbreaks are now under control. It seems therefore inappropriate to not disinfect the water, as the costs saved will not outweigh the costs caused by the diseases. The cost of disinfection is small compared to the cost of providing distribution. Studies have also shown that disinfecting water will be more efficient in preventing diseases than providing distribution.[**75**] Although water shortage is a serious issue in Kenya, a larger number of people will have a larger benefit from disinfected water than from an increased availability of water in general. Because of all of these reasons, option 1 can be discarded as viable option to apply to the Kenyan case.

Action 2: Disinfect drinking water in urban areas but not in rural areas and invest in infrastructure for better distribution of drinking water in rural areas

Because studies have shown that disinfection is more important than infrastructure to prevent spreading of disease [**75**], option 2 can also be discarded. Furthermore, there are many relatively simple and cheap solutions to sanitation of water on a small scale. Moreover, as inhabitants of urban areas generally already have access to safe drinking water, the greatest reduction of disease occurrences can be achieved in rural areas.

Action 3: Disinfect the drinking water everywhere, but do not invest in infrastructure for distribution

Because of the reasons presented in the previous paragraphs, option 3 is the best as far as preventing most health issues for the least cost: disinfection is cheaper and provides more benefits than better distribution on a short term.

Actions about different techniques

Action a: Employ chlorine based disinfectants

Chlorine will disinfect the water very efficiently, unless the water has a very high turbidity. It can be employed locally by the use of hypochlorite tablets, but it can also be used on a larger scale. The cost of these disinfection agents is low. A large advantage is that chlorine based disinfectants provide residual disinfection. This means that a supply of disinfected water can be stored for longer periods than a day. As stated earlier, safety remains an issue. Chorine, especially stored in its liquid form, is very toxic and should be handled with great care. Investments in safety should therefore also be made, attributing to the total cost of disinfection.

A drawback of chlorine is that not all pathogens are always killed, as proper dosing is sometimes difficult. Furthermore, DBP's can be formed which pose health risks after longer periods. The largest drawback in the small scale application (in areas without proper infrastructure) is that despite the low price, the local population will have to buy these products. The government of course has the option to distribute chlorine tablets free of charge although this may not be possible due to budgetary issues. Therefore, the importance of clean drinking water will have to be made clear through campaigns.

Action b: Employ solar UV disinfection

Solar UV disinfects water rather efficiently. The water should however have a low turbidity (sometimes a filtration step is required). The technique can only be employed locally on a small scale. The main advantage of solar UV disinfection is its low cost. Very little equipment and expertise is needed, i.e. in the simplest cases only a PET bottle filled with water. This will make it easier to convince local populations to use this technique, in fact, there are already initiatives to encourage people to disinfect there water with solar UV.[**76**] Moreover, experimental devices exist which could be produced for 10 USD a piece and which could disinfect up to 40 liters a day.

A major drawback is the fact that, to have an efficient disinfection, no cloud coverage should be present, i.e. the sun should be able to directly irradiate the water for proper and relatively fast disinfection. Once the water is disinfected, it should be consumed within a day to prevent regrowth of bacteria. If PET bottles are being used, a family will have to have roughly 20 to 40 2-liter bottles lying in the sun. This is because a family in Africa uses roughly 40 liters of water a day, and because the water cannot be stored for extended periods of time. This requires thus a large amount of containers in use at any given time.

Action c: Use UV disinfection (with UV-lamps)

UV disinfection can be employed on larger scales, but is somewhat less suited for small scale. The water should have low turbidity for this.

A drawback of UV disinfection is that a stable electric power source is required. This poses a problem in some areas of the country where the power supply is not stable. Solutions to this problem exist, such as using diesel generators, but these are costly.

The water has no residual disinfection, which poses a problem if the water is transported through pipes which are not entirely clean, as is the case in Kenya.

Action d: Cook the water to disinfect it

Cooking the water kills all pathogens and disinfects the water very thoroughly, regardless of turbidity. The technique can only be used on the small scale. The costs are high, with 100 to 150 USD for 40 liters a day annually. The main drawback therefore is the need for fuels and the associated costs.

Advantages are that this technique can always be used and requires virtually no equipment.

Stakeholders

Governmental institutions

In areas where adequate infrastructure exists, the government will most likely choose chlorine as a disinfectant, as this gives residual disinfection when passing through the distribution system. Chlorine based disinfectants are a cheap solution and a lot of people can be helped this way.
In areas where no infrastructure exists, the government can encourage the population to disinfect the water using solar UV when possible, because the population will be easier convinced to use a technique which costs them nothing, or by using chlorine tablets otherwise, as this is cheaper than boiling. This will keep costs low so funds are available for the expansion of distribution.

Non-governmental organizations (NGOs)

These advisory boards will most likely also select chlorine disinfection in areas where infrastructure exists, and solar UV supplemented with chlorine tablets in other areas.

Water service boards and providers

Water providers have commercial interests, so they will choose chlorine based disinfection where infrastructure exists, as this is the cheapest solution. They may promote chlorine tablets in more rural areas as they can sell these tablets to the local population.

Small service providers of water

For these small water providers, especially an improvement in the distribution system will harm their commercial interests. Possibilities for them lie in the distribution of hypochlorite tablets or in the selling of PET bottles.

Consumers

Consumers with access to drinking water infrastructure, i.e. tap water, expect that the water is safe. The easiest way to accomplish this is to use chlorine as disinfectant.
Consumers with no access to infrastructure are being made aware by various organizations of the importance of drinking water disinfection. The cost of this disinfection plays an important role in this consideration, as poverty is a major issue in Kenya. These consumers will therefore choose for solar UV disinfection, as this is the cheapest option, supplemented by chlorine tablets if solar UV cannot be used.

Industry, agriculture and energy companies

The interests of companies competing with consumers for water supply mainly lie in the availability of a healthy workforce. Regardless of which disinfection technique is used, competition with consumers will remain an issue, but properly disinfected water will contribute to the health of employees of the companies and is a large benefit. As for the choice of disinfectant the companies will have a preference for the safest option, with the least side-effects. Solar disinfection would therefore be the best alternative, although boiling also cannot be ruled out.

Disinfections manufacturers and importers

Of course these groups will try their best to maintain their position because of commercial interests. These groups will advocate the use of chlorine and chlorine tablets because, of the choices given, this is the method for which chemicals (which have to be imported and sold) are being used.

Health care

Health care organizations want to have healthy drinking water. All methods, if used correctly, will provide this. A distinction can be made between hospitals and health care organizations “in the field”. Hospitals are assumed to have a stable water supply to rely upon. Such distribution systems require chlorine or UV disinfection. Out in the field, the goal of health care organizations is to provide safe and suitable drinking water to the largest amount of people. Solar disinfection will therefore have their preference, as this is the most accessible technique.

Environmental groups/authorities

Environmental groups will closely monitor the impact of various disinfection alternatives. Using chlorine means that contamination of the environment is a risk. Solar UV necessitates large amounts of PET bottles which will end up in the environment. Finally, boiling means that fossil fuels will have to be burnt, or that trees will have to be felled for use as fuel. The preference of environmental groups will tend to the use of solar UV, provided that no additional PET bottles are produced to facilitate the use of this technology.

Media

The media will have to work with the government to educate people in water disinfection. That being said, they will most likely not have a great preference for one disinfection technique or another.

Neighboring countries and development partners

These countries and partners will not have a preference for one disinfection method or the other, as long as the water is being used responsibly.

Conclusion

Most stakeholders would agree that if infrastructure is present, chlorine disinfection should be used. This is a relatively cheap solution which is the safest to use because of the residual disinfection.

In areas where no infrastructure is present, the best option is more difficult to determine. Solar UV disinfection is a great technique because of the low cost and the easy implementation. However, this cannot always be used (water turbidity, no clear skies). Chlorine disinfection is also a good technique, but it requires more awareness of the importance of clean drinking water to convince the population to buy these tablets. Therefore, it seems best to promote solar UV disinfection whenever possible, supplemented with chlorine tablets in situations and climates where the solar UV technique cannot be used.

8.5.2. Deontology (Kantianism)

A short introduction into Kantian ethics has been given in chapter 6. As with the situation in the Netherlands, the Kantian ethics method has been used to analyze the situation in Kenya as well. The outcome of this approach can be seen below.

Actions about disinfection

Action 1: Don't disinfect drinking water in the whole country

In the principle of universality of Kant, the maxim of this action can be stated as: "if a country has too little ways and means available for drinking water disinfection, there is no possibility at all to disinfect drinking water." The negation of this starting point concerns that with or without capital inadequacy, every country should have possibilities to disinfect their drinking water. This precept can be used as general law more than the given maxim related to action 1, because there will be lower probability for health dangers or aggravation respectively. According to Kantianism this contradiction discomforts action 1 in the principle of universality.

According to the Reciprocity Thesis of Kant, action 1 can be rejected as well. After all, if sufficient financial allocation and expertise (universities, inter-institutional cooperation programs) are present, it doesn't seem logical to decide for a non-disinfectant water system. If this would be the case, government has chosen to offer more or less unsafe drinking water and use the financial allocation rather for energy, industry and agriculture. Consequently, citizens should be informed they are used as appropriation to reach the goals in such a way they are in the position to join in or not. So, citizens should initially have the opportunity to choose for disinfection or not. However, this would implement some forms of utilitarianism as well.

To speak more in terms of the Kantian moral norms, when disinfection of drinking water seems feasible, the Kenyan population has the right to have access to safe drinking water. Hence, this action should be avoided. After all, the decrease of diseases, e.g. diarrhea, gives rise to a higher health grade of the population.

Action 2: Disinfect drinking water in urban areas and not in the rural regions

The maxim in the universality principle of this action can be defined as: "if sufficient ways and means are accessible for disinfection, it would be justified to carry out this in areas with high population densities or areas with higher contamination risks, due to sanitation problems for example." However, in spite of the assumption urban areas have higher risks; everyone has the same right to have access to safe drinking water (negation). This fundamental issue is essential in Kantian ethics, because making a law of the given maxim referred to action 2 induces discrimination on the living areas of citizens, which is conflicting with moral norms. However, it probably saves more lives than the negation statement, but in Kantian ethics this isn't important.

In order to analyze this action again based upon the Reciprocity Thesis, it will be clear that citizens in rural areas should be informed about the disinfection policy concerning urban versus rural areas. In fact, they are used to reach policy goals. If the rural parties concerned are able to choose in a well considered way in order to co-operate, there is no problem. However, if the issue is characterized by no proper agreement, it is ethically unjustified. Obviously, financial interests mainly influence these relations, but they are passed over due to overwhelming complexity.

Action 3: Disinfect drinking water in both urban as rural areas

When again looking at the universality principle the maxim can be described as: "if sufficient ways and means are available, then they should be proportionally divided; e.g. x amount per head." This results in greater investment opportunities for urban areas, but with reference to higher population densities as well as higher contamination risks, it may be justified. The opposite of the maxim can be pointed out as: "ways and means for disinfection should be putting on areas with the highest necessity with regard to disease rates, outdated equipment, et cetera". However, this negation cannot be used as general law in the universality principle, because disinfection policy based on differences of facilities again induces discrimination. Besides, the mismanagement of affairs or bad execution would be rewarded with disinfection investments. This contraction gives convincing evidence that action 3 can be used as general law for developing countries.

According to the Reciprocity Thesis, it seems no party encounter disadvantages of this disinfection decision. Therefore, it seems more or less irrelevant to analyze this action with the help of this Kantian Thesis, unless specific population groups don't want disinfected drinking water. However, this seems very unrealistic due to enhancements of health risks.

Actions about different techniques

Action a: Chlorine disinfection

Chlorine disinfection can be used in both urban as rural parts of Kenya. For example: in rural parts with tablets and in urban regions on a larger scale within the drinking water network. Based on action 3, it is a very good and accessible option to disinfect drinking water. The only problem is to make the population aware about doses of chlorine they have to use when using tablets. This needs a form of education, but the Kantian ethics doesn't consider this in the judgment.

Action b: Solar disinfection

Disinfection by putting clear bottles, containing water, in the sun is not a good option according to the Kantian ethics. It can be suitable for rural regions, but in urban areas it is definitely not an option. The downside of this solar disinfection is the fact that it will not work when weather conditions aren't sunny and during the night. When having enough sunlight available and using the right exposure time, people, mostly in rural regions without cooling equipment, are forced to drink the water at a high temperature. Therefore the Kantian ethics must reject this approach because better alternatives are available.

Action c: UV disinfection

UV disinfection is a good method for disinfecting drinking water in urban water networks. In rural parts of Kenya UV is not an option, because of the costs and requirements, like a power source. Therefore the Kantian ethics has to reject this method concerning the outcome of what action has to be taken.

Action d: Boiling water

Boiling the water is a good technique that can be applied both in rural as in urban areas. It disinfects the water very good and doesn't require a certain water standard like low turbidity. Kantian ethics will have no rejection for using a boiling procedure to disinfect drinking water. However, applying such a procedure on a piped water network is unfeasible and therefore trivial.

8.6. Reflection

8.6.1. Cost-benefit analysis

This cost benefit analysis can be considered reliable. A lot of reliable information was available which made the analysis more thorough. On the subject of infrastructure, good data was more difficult to find and hence in this point this analysis could be improved, albeit unlikely that it could change the final conclusion.

All in all, the result obtained by this analysis is reliable and can be used to support the final conclusion.

8.6.2. Deontology (Kantianism)

As stated before, Kantianism advocates action 3 with chlorine disinfection as the most preferred method. Obviously, a difference between urban and rural can still be made in form of the sort of chlorine disinfection method which can be used (hypochlorite versus chlorine tablets), but that is related to the presence of infrastructure, costs, user friendliness, et cetera. From a deontological point of view, it is important that everyone should have access to a drinking water source in combination with a well applied disinfectant like chlorine.

8.7. Choice for moral action

On the question whether or not water should be disinfected, both ethical frameworks were clear. Kantian ethics stated that not disinfecting the water would be morally unacceptable, and that differentiating between rural and urban areas was not ethical. The cost benefit analysis reached the same conclusion by stating that the costs (both financial and health-wise) of not disinfecting the water would not outweigh the gains.

The first sub question can therefore be answered as such: *"Water should be disinfected in rural and urban areas alike."*

The second ethical question was with regard to the disinfection method used. On this subject, Kantian ethics differed somewhat from the cost benefit analysis. Kantian ethics stated that it would be morally unacceptable to disinfect water differently in rural and urban areas. This makes the Kantian analysis cruder, and less detailed than the cost benefit analysis. The outcome of this analysis, using chlorine as disinfectant, will however still be considered in the final decision.

In urban areas the choice of disinfectant is clear, as both the cost benefit and the Kantian approach indicate that chlorine should be used. In rural areas the choice is more difficult. The Kantian approach indicates that chlorine should be used, while the cost benefit analysis identifies solar UV as the best disinfection method, supplemented by chlorine.

Therefore, the final decision seems to be that chlorine should be used in rural areas as primary disinfectant, but that solar UV must not be discarded altogether, but rather viewed as the next best alternative. In situations where no chlorine is available solar UV can be used, or it can be used to supplement the chlorine disinfected water supply. If the technique of solar UV can be made more practical, this could become the primary choice of disinfectant. Only if both techniques are unavailable, cooking the water can be considered.

9. Conclusions

In this report, the water disinfection with respect to two countries, the Netherlands and Kenya, was discussed. The Netherlands formed a basis for the rest of the research and analysis. It was possible to implement the technical results about specific alternatives as well as some ethical experiences within the ethical cycle of Kenya. The latter can be compared to countries within the Sub-Saharan region in Africa. Not only is the drinking water situation comparable with the situation in Kenya, but also the political, cultural and economical situation in this region is more or less the same. The Netherlands and Kenya differ greatly; the amount of funding available, the prevalence of certain diseases and the presence of water distribution networks were found to influence the choice of disinfection method.

For the Netherlands, it was found that UV disinfection was best, because this technique does not produce DBP's. Matters of concern were diseases which could not be prevented by UV disinfection such as Legionnaires' disease. Therefore, it seemed ethically relevant to make a distinction between people who are vulnerable to these diseases and the general population. It was deemed to be morally correct to provide UV disinfection for the general population and chlorine disinfection for the groups at risk. Generally it seems that if a country has a clean distribution network (like in the Netherlands) UV disinfection is certainly an option. Before implementing this, relevant advisory boards should however look at the consequences of this choice in relation to diseases which are not fully prevented by UV disinfection. In some cases, a solution can be implemented such as stated above.

In Kenya, the number of deaths and illnesses caused by badly disinfected drinking water meant that DBP's became less of a priority. It was found that where distribution infrastructure was established, chlorine disinfection should be used, and that in regions where there was no such infrastructure, the solar UV method was very promising. In parts of the world where no distribution network exists, solar UV disinfection is a technique with many advantages. However, this solar UV disinfection method cannot always be used and should therefore not be regarded as a complete solution. Solar UV can then be supplemented with chlorine tablets, which still seems to be the most effective way to disinfect the water as it provides residual disinfection.

10. Recommendations

Investing the Netherlands has shown that statistics about prevalence and cause of Legionella were often not undisputed. Also the harmful effects of DBP's should be researched further and quantified.

To give a more complete view, a second world country should also be discussed. The generated results may explain in which way this specific country performs better than our undeveloped country (Kenya) and in which way it performs worse than The Netherlands. Furthermore, it was found that Kenya is only representative for the sub-Saharan region. To give a more complete picture of water disinfection in the third world, it would be interesting to find out which connections could be made with undeveloped countries in Asia and South America.

Because of the complexity of the water management in Kenya it would be advisable to perform research to simplify the water management. Kenya has many organizations concerning the drinking water issue, which influences the development of disinfecting drinking water significantly. Besides, further research in the technique of solar UV disinfection is needed to make things more practical as well as its scaling-up possibilities. Innovation of this technique may prevent the use of chlorine, which would be possibly beneficial for Kenya and other third world countries in order to avoid DBP problems / discussions, which are now more or less experienced in developed countries.

Finally, filtration is stated as an option for disinfection in sub-Saharan regions. The advantages and disadvantages are presented in the factual analysis. Because of the disadvantages like costs, it was decided to don't take this technique into account. Further research in this method is needed.

11. References

[1] Lenntech BV Delft. (1998 - 2011) Lenntech - Water Treatment Solutions. [Online]. http://www.lenntech.com

[2] Water Quality and Health Council. (2011) Drinking Water Chlorination. [Online]. http://www.waterandhealth.org/drinkingwater/wp.html

[3] Rob Dunham, Hong He, and Ken Woodard, "Water Disinfection with Ozone," Blacksburg, 1998.

[4] W., R.G. Rice, P. Priouret, et al. Masschelein, "Ultraviolet light in water and wastewater sanitation," *CRC Press*, 2002.

[5] Office of research and development, "Controlling disinfection by-products and microbial contaminants in drinking water.," Washington DC, 2001.

[6] Centers for Disease Control and Prevention (CDC). Disinfection By-Products and the Safe Water System. [Online]. http://www.cdc.gov/safewater/publications_pages/thm.pdf

[7] CIA - The World Factbook. CIA - The World Factbook. [Online]. https://www.cia.gov/library/publications/the-world-factbook/

[8] Vewin (Drinkwaterstatistieken). (2008) Vewin Drinkwaterstatistieken. [Online]. http://www.vewin.nl/SiteCollectionDocuments/Publicaties/Drinkwaterstatistieken%202008/Vewin_Drinkwaterstatistieken2008_lr.pdf

[9] UN WWDR, "The United Nations World Water Development Report 3," Paris / London, 2009.

[10] R. J. B. Peters, Chemical Aspects of Drinking Water Chlorination, 1991.

[11] N. F. Gray, *Water Technology*. London: Arnold, 1999.

[12] Office of Drinking Water Center for Environmental Research Information, "Technologies for Upgrading Existing or Designing New Drinking Water Treatment Facilities," Cincinnati, 1990.

[13] Henri Roques, *Chemical Water Treatment*. New York: VCH Publishers, Inc., 1996.

[14] S.S. Block,.: Lippincott, Williams & Wilkins, 2001, p. 68.

[15] Water Treatment Practices Committee. (2006) Pool Water Treatment Advisory Group. [Online]. http://www.pwtag.org/researchdocs/Used%20Ref%20docs/33%20Sodium%20Hypochlorite%20and%20Chlorine%20Gas.pdf

[16] Environmental Protection Agency, Water Treatment Manuals: Disinfection, 1998.

[17] (2011, Oct.) Alibaba.com - Global trade starts here. [Online]. http://www.alibaba.com/trade/search?SearchText=calcium+hypochlorite&Country=&CatId=8&IndexArea=product_en&fsb=y&viewAllCategory=

[18] (2011, Oct.) Alibaba.com - Global trade starts here. [Online]. http://www.alibaba.com/trade/search?SearchText=sodium+hypochlorite&Country=&IndexArea=produ

ct_en&fsb=y&CatId=8

[19] ITT Water & Wastewater. (2004) Flygt Impeller - Watering the Olympics. [Online]. http://www.ittwww.com/impeller/2434775.asp?newsid=2444197

[20] Hatch Mott MacDonald. Ultraviolet Disinfection (Technology Update). [Online]. http://www.hatchmott.com/documents/adobe/uv%20disinfection_w.pdf

[21] National Drinking Water Clearinghouse. (2000, September) Tech Brief Ultraviolet Disinfection. [Online]. http://www.nesc.wvu.edu/ndwc/pdf/ot/tb/ot_tb_f00.pdf

[22] ETI (Environmental Technology Initiative). Ultraviolet Disinfection - A Technical Overview. [Online]. http://www.nesc.wvu.edu/pdf/WW/publications/eti/UV_Dis_tech.pdf

[23] EPA (Ozone Disinfection). (1999, September) United States Environmental Protection Agency - Ozone Disinfection Technology Fact Sheet. [Online]. http://www.mtnhighwater.com/wp-content/uploads/2010/06/EPA.pdf

[24] TNS Nipo / Vewin, "Watergebruik thuis 2010," Amsterdam, 2011.

[25] Vewin (Kerngegevens drinkwater). (2010) Kerngegevens drinkwater 2010. [Online]. http://www.vewin.nl/SiteCollectionDocuments/Publicaties/Brochure%20kerngegevens%20drinkwater/Kerngegevens%20drinkwater%202009.pdf

[26] Government Engineering, "UV Disinfection of Groundwater," *Government Engineering*, pp. 18-19, 2009 (July/August).

[27] I. van de Poel, A. Pieters L. Royakkers, *Ethiek & Techniek - Morele overwegingen in de ingenieurspraktijk*. Baarn: HBuitgevers, 2004.

[28] Agriculture and Agri-Food Canada. (2011, June) Chlorine Disinfection of Private Water Supplies for Household or Agricultural Uses. [Online]. http://www.epa.gov/ogwdw/disinfection/chloramine/pdfs/Q4.pdf

[29] WEDC (World Health Organisation). Measuring chlorine levels in water supplies. [Online]. http://www.who.int/water_sanitation_health/publications/2011/tn11_chlorine_levels_en.pdf

[30] EnzineMark.com. Chlorine in Drinking Water - How You Can Get Rid of It. [Online]. http://education.ezinemark.com/chlorine-in-drinking-water-how-you-can-get-rid-of-it-4ec8e207a7d.html

[31] EPA. Environmental Protection Agency. [Online]. http://www.epa.gov/ogwdw/disinfection/chloramine/pdfs/Q4.pdf

[32] D. van der Kooij, H. Veenendaal, "Biofilmvorming en groei legionellabacteriën," *VV+*, pp. 198-203, 2007.

[33] RIVM, "Meldingen Infectieziektenwet," *Infectieziekten Bulletin, Vol. 18(1)*, p. 30, 2007.

[34] C.M. Helms, "Is Legionnaires' disease a risk in the elderly?," *Geriatrics 35, No. 6*, pp. 87-94, 1980.

[35] AllFilters.com. 10 Important Facts about Chlorine in Tap Water. [Online]. http://www.allfilters.com/waterfilter/chlorinefacts

[36] Best Water Filter Guide. Chlorine In Drinking Water. [Online]. http://www.best-water-filter-guide.com/chlorine-in-drinking-water.html

[37] E.A. Farren, "Reducing Trihalomethane concentrations by using chloramines as a disinfectant," *Thesis Submitted to the faculty of the Worcester Polytechnic Institute*, p. 10, 2003.

[38] Landeen, L. K., M. T. Yahya, et al, "Efficacy of copper and silver ions and reduced levels of free chlorine in inactivation of Legionella pneumophila," *Appl Environ Microbiol 55(12)*, pp. 3045–50, 1989.

[39] Muraca, P., J. E. Stout, et al, "Comparative assessment of chlorine, heat, ozone, and UV light for killing Legionella pneumophila within a model plumbing system," *Appl Environ Microbiol 53(2)*, pp. 447–53, 1987.

[40] Gezondheidsraad, "Bestrijding van Legionella," *Gezondheidsraad*, 2003.

[41] Versteegh A. et al, "Legionella onder controle?," *H2O (23)*, p. 7, 2008.

[42] J.A.C. Schalk et al, "Legionella in water," *RIVM, Rapport 703719039/2010*, 2010.

[43] Roopal Patel, Matthew R. Moore, and Barry S. Fields, "Legionellosis," *chapter 19*, p. 396, 2009.

[44] Alekal, Pragnya Y. (2005, June) Appropriate water treatment for the Nyanza Province of Kenya. [Online]. http://web.mit.edu/watsan/Docs/Student%20Theses/Kenya/PragnyaAlekal-Thesis%205-18-05.pdf

[45] The World Bank Group. (2011) GPD per capita. [Online]. http://data.worldbank.org/indicator/NY.GDP.PCAP.CD/countries

[46] Water.org. (2011, November) Kenya. [Online]. http://water.org/country/kenya/

[47] Wordtravels.com. (2011) Wordtravels.com. [Online]. www.wordtravels.com

[48] World Trade Press: Best country reports. (2011) Precipitation Map of Kenya. [Online]. http://www.bestcountryreports.com/Precipitation_Map_Kenya.php

[49] Crump JA, Otieno PO, Slutsker L, Keswick BH, Rosen DH, Hoekstra RM, Vulule JM, Luby SP, "Household based treatment of drinking water with flocculant-disinfectant for preventing diarrhoea in areas with turbid source water in rural western Kenya: cluster randomised controlled trial," *BMJ.com*, September 2005.

[50] Wikipedia. (2011, November) Water supply and sanitation in Kenya. [Online]. http://en.wikipedia.org/wiki/Water_supply_and_sanitation_in_Kenya

[51] WHO (World Health Organization). (2011, November) World Health Organization: KENYA. [Online]. http://www.who.int/gho/countries/ken.pdf

[52] Unicef. (2005) Kenya National Water Development Report, UN World Water Assessment Programme. [Online]. www.unicef.org

[53] Ministry of Water and Irrigation, Kenya. (2008, December) Ministrial Strategy plan 2009-2012. [Online]. http://www.water.go.ke/

[54] WASREB. (2009, November) Water Services Regulatory Board Kenya. [Online]. www.wasreb.go.ke

[55] Maji na Ufanisi. (2011, November) Background of Maji na Ufanisi. [Online]. http://www.majinaufanisi.org/

[56] KEWASNET. (2011, November) Kenya Water and Sanitation Network. [Online]. www.kewasnet.org

[57] NEMA Kenya. (2010) National Environment Mangagement Authority. [Online]. http://www.nema.go.ke

[58] Athi Water Services Board. (2010) Athi Water Services Board. [Online]. http://www.awsboard.go.ke/

[59] Ministry of Water and Irrigation, Kenya, "Human right to WSS," *Annual Water Sector Review*, pp. 65-66, 2009.

[60] Ministry of Water and Irrigation, Kenya. (2006) Environmental Management and co-ordination (water quality) regulations, Arrangement of regulations, Water Services Regulatory Board, Legal Notice no. 120. [Online]. http://www.water.go.ke/

[61] Ministry of Water and Irrigation, Kenya. (2010) Water Sector Reform in Kenya and the Human Right to Water. [Online]. http://www.water.go.ke/

[62] Ministry of Water and Irrigation, Kenya, "Ruling on appeals," *WAB, Annual Water Sector*, pp. 32-34, 2009.

[63] Rop, Rosemary, Rose Lukalo-Owino, Alois Muthini, "Lessons for Regulators, Utilities and Citizens in Promoting Accountability and the Human Right to Safe Water and Sanitation Services," *World Water Week, Stockholm*, vol. 302-303, 2011.

[64] Unicef. (2010) Case Study Kenya Part II: Water Availability, UN World Water Assessment Programme. [Online]. www.unicef.org

[65] Aquastat, Country Profile: Kenya, 2010, p.4.

[66] R. Gakubia, U. Pokorski and P. Onyango, "Upscaling Access to Sustainable Sanitation - Kenya," *German Technical Development Cooperation (GTZ), Follow-up Conference of the International Year of Sanitation 2010 (IYS)*, 2010.

[67] Ministry of Water and Irrigation, Kenya, "Annual Water Sector Review 2009," pp. 35-40, 2010.

[68] United States Agency for International Development. Kenya: Water and Sanitation Profile. [Online]. http://pdf.usaid.gov/pdf_docs/PNADO931.pdf

[69] Oxfam GB. (2009, September) Urban Poverty and Vulnerability In Kenya. [Online]. http://www.irinnews.org/pdf/Urban_Poverty_and_Vulnerability_in_Kenya.pdf

[70] African Development Bank. (2011) African Development Bank Project. [Online]. http://www.afdb.org

[71] WHO (World Health Organization). (2010, April) Cholera Country Profile: Kenya. [Online]. http://www.who.int/cholera/countries/KenyaCountryProfile2010.pdf

[72] Ministry of Water and Irrigation, Kenya. (2011, November) World Water Day 2010, Celebrations on 22nd March, 2010 at United Nations Environment Programme, Gigiri Nairobi. [Online]. http://www.water.go.ke/index.php?option=com_content&view=article&id=124:world-water-day-2010-celebrations-on-22nd-march-2010-at-united-nations-environment-programme-gigiri-nairobi&catid=34:ministerspeeches&Itemid=2

[73] Laurent, P. (2005, February) Household drinking water systems and their impact on people with weakened immunity. [Online]. http://www.who.int/household_water/research/HWTS_impacts_on_weakened_immunity.pdf

[74] McGuigan KG, Joyce TM, Conroy RM, Gillespie JB, Elmore-Meegan M. (1998) Solar disinfection of drinking water contained in transparent plastic bottles: characterizing the bacterial inactivation proces. [Online]. http://www.sodis.ca/Research%20Papers/SODIS%20basics%20McGuigan.pdf

[75] WHO (World Health Organisation). (2007) Combating waterborne disease at the household level. [Online]. http://www.who.int/household_water/advocacy/combating_disease/en/index.html

[76] Sodis. (2011) Solare Wasserdesinfektion. [Online]. www.sodis.ch

[77] OCED / Wikipedia. (2007) Wikipedia.org. [Online]. http://en.wikipedia.org/wiki/File:First_Second_and_Third_world_map_2007.jpg

[78] Health Canada. (2006, December) Health Canada: Drinking Water Chlorination. [Online]. http://www.hc-sc.gc.ca/hl-vs/iyh-vsv/environ/chlor-eng.php

[79] The Canadian Water and Wastewater Association (CWWA). (2010) Disinfection and turbidity requirements in other jurisdictions. [Online]. http://www.cwwa.ca/pdf_files/freepub_disinfection_turbidity%20Report.PDF

[80] Vipin Bhardwaj, "Disinfection byproduct and waterborne diseases," *National Environmental Services Center (NESC)*, pp. 34-37, 2004.

[81] EPA - Disinfectants in drinking water. Environmental Protection Agency. [Online]. http://water.epa.gov/drink/contaminants/basicinformation/disinfectants.cfm

[82] David L. Sedlak and Urs von Gunten, "The Chlorine Dilemma," *Science (Vol. 331)*, pp. 42-43, 2011, January 7.

[83] European Commission (Environment). The Drinking Water Directive (DWD), Council Directive 98/83/EC. [Online]. http://ec.europa.eu/environment/water/water-drink/index_en.html

[84] World Health Organisation. Managing water in the home: accelerated health gains from improved water supply. [Online]. http://education.ezinemark.com/chlorine-in-drinking-water-how-you-can-get-rid-of-it-4ec8e207a7d.html

[85] N. Mole, D. Lunt, M. Fielding, "Influence of UV disinfection on by-product formation and the operational

implications," Buckinghamshire, 1997.

[86] Remilekun Yetunde Adedapo. Disinfection By-Product Formation in Drinking Water Treated with Chlorine Following UV Photolysis & UV/H2O2.

[87] den Boer, J.W., Yzerman, E.P., Schellekens, J., Lettinga, K.D., Boshuizen, H.C., Van Steenbergen, J.E., Bosman, A., Van den Hof, S., Van Vliet, H.A., Peeters, M.F., Van Ketel, R.J., Speelman, P., Kool, J.L. en Conyn-Van Spaendonck, M.A., "A large outbreak of Legionnaires' disease at a flower show, the Netherlands, 1999," *Emerging Infectious Diseases 8*, pp. 37-43, 2002.

[88] F. Franchimon, R.C.G.M Loonen, J.E.M.H. van Bronswijk, "The economic acceptability of monochloramine treatmentof potable water in the Netherlands," *Helathy Building Services for the 21st Century*, pp. 29-37, 2009.

[89] Ricketts KD, Joseph CA., "Legionnaires' disease in Europe 2003-2004," *Eurosurveillance*, pp. 256-9, 2005.

[90] Ricketts KD, McNaught B, Joseph CA, "Travel-associated legionnaires' disease in Europe: 2005," *Eurosurveillance*, 2007.

[91] Skaliy, P., T. A. Thompson, et al, "Laboratory studies of disinfectants against Legionella pneumophila," *Appl Environ Microbiol 40(4)*, pp. 697–700, 1980.

[92] Helen Y. Buse et al, "The Journal of Microbiology," *Vol. 49, No. 2*, pp. 200-207, 2011.

[93] Poos et al, "Hoe vaak komen infecties van de onderste luchtwegen voor en hoeveel mensen sterven eraan?," *Nationaal Kompas Volksgezondheid*, 2007.

[94] Amato-Gauci A, Ammon A (red.), "The First European Communicable Disease Epidemiological Report," *European Centre for Disease Prevention and Control*, 2007.

[95] Dijkstra, F., Gageldonk-Lafeber, A.B. van, Brandsema, P., Friesema, I.H.M., Robert-Du Ry van Beest Holle, M., Lubben, I.M. van der, Wilbrink, B., Meijer, A., Hoek, W. van der en Sande, M.A.B. van der, "Jaarrapportage respiratoire infectieziekten 2007/2008," *RIVM briefrapport 210231003/2008*, 2008.

[96] WHO, World Health Organization, "Legionnaires' disease, Europe," *Wkly Epidemiol Rec 2000c; 75*, pp. 347-52, 2009.

[97] P. van Tongeren, *Deugdelijk Leven - Een inleiding in de deugdethiek*. Amsterdam: Uitgeverij SUN, 2003.

[98] United Nations. (2010) The Millennium Development Goals Report. [Online]. http://www.un.org/millenniumgoals/pdf/MDG%20Report%202010%20En%20r15%20-low%20res%2020100615%20-.pdf#page=60

[99] Kelsey E., Miarintsoa R.R., Rakotomalala O., Dunston C.,Quick R.E. Ram P.K., "Bringing safe water to remote populations: an evaluation of a portable point-of-use intervention in rural Madagascar," *Am J Public Health*, pp. 398–400, 2007.

[100] Global Times. (2010, October) Madagascar access to drinking water down 6 percent from 2008: UN. [Online]. http://www.globaltimes.cn/world/africa/2010-10/582715.html

[101] WaterAid. (2002, April) Poverty reduction strategies in Madagascar: Water supply and sanitation. [Online]. http://www.wateraid.org/documents/plugin_documents/madagascarprsp.pdf

[102] United States Agency for International Development. Madagascar: Water and Sanitation Profile. [Online]. http://pdf.usaid.gov/pdf_docs/PNADO933.pdf

[103] WaterWiki.net. Facing the Water Challenges in Cameroon: A WWDR3 Case Study. [Online]. http://waterwiki.net/index.php/Facing_the_Water_Challenges_in_Cameroon:_A_WWDR3_Case_Study

[104] H. Dagdeviren. (2008) Reforming Without Resourcing: The Case of the Urban Water Supply in Zambia. [Online]. http://ideas.repec.org/p/ipc/pbrief/8.html

[105] The National Water Supply and Sanitation Council (NWASCO). [Online]. www.nwasco.org.zm

[106] The Guardian. (2011) Angola. [Online]. www.guardian.co.uk/world/angola

[107] Unicef. (2008) Angola - Statistics. [Online]. www.unicef.org

[108] J.M. Arnal et al., "Design and installation of a decentralized drinking water system based on ultrafiltration in Mozambique," *Desalination 250*, pp. 613-617, 2010.

[109] Unicef. (2007) Water shortages call for greater collaboration between partners and countries, Mozambique. [Online]. www.unicef.org

[110] Aquastat, food and agriculture organization of the United Nations, "Geography, climate and population (Mozambique)," *Water Report, No. 29*, 2005.

[111] L. Konersmann, E. Frank, "Solar Thermal Water Disinfection: Development and implementation of a flow through solar pasteurizer for small communities that produces 500 liter drinking water per day for a 500$ initial investment," *Institut für Solartechnik SPF, University of Applied Science Rapperswil, Oberseestr. 10, CH-8640 Rapperswil, Switzerland*, 2009.

[112] L. Konersmann, E. Frank, "Solar water disinfection: field test results and implementation concepts," *Institut für Solartechnik SPF, University of Applied Science Rapperswil, Oberseestr. 10, CH-8640 Rapperswil, Switzerland*, 2011.

[113] A. Jiménez et al., "Challenges for Water Governance in Rural Water Supply: Lessons learned from Tanzania, Water Resources Development," vol. 26, no. 2, pp. 235-248, 2010.

[114] National Bureau of Statistics, "Household Budget Survey 2007 – Mainland Tanzania," 2009.

[115] Hucks L. & Axwesco F., "WaterAid in Tanzania, East Africa data reconciliation workshop," WaterAid, WHO, UNICEF, 2011.

[116] Ministry of Water and Irrigation, Tanzania, "National Water Sector Development Strategy - 2006 to 2015," 2008.

[117] Ministry of Water and Irrigation, Tanzania, "Water Sector Status Report," 2009.

[118] S.A. Mbogo, "A novel technology to improve drinking water quality using natural treatment methods in

rural Tanzania," *J. Environ. Health.*, vol. 70, no. 7, pp. 46-50, 2008.

[119] Mbuya et al. (2011) Ultraviolet light disinfection of drinking water: an alternative to chlorination, National Water Program (USDA NIFA & Land Grant Colleges and Universities). [Online]. http://www.usawaterquality.org/themes/health/research/ultraviolet.html

[120] SodisAfricaNet. (2007, July) Solar water disinfection - Senegal. [Online]. http://www.sodisafricanet.org/English/text/project%20Senegal%202.htm

[121] Chris Vaught. (2004) Water Treatment and Supply in Kayes, Mali, West Africa: Treatment Processes, Operations, and Economics. [Online]. http://www.cee.mtu.edu/peacecorps/studentfiles/vaught.pdf

[122] Wikipedia. List of countries by GDP (nominal). [Online]. http://en.wikipedia.org/wiki/List_of_countries_by_GDP_(nominal)

[123] Wikipedia. (2011, November) Water supply and sanitation in Senegal. [Online]. http://en.wikipedia.org/wiki/Water_supply_and_sanitation_in_Senegal

[124] AMCOW. Water Supply and Sanitation in Senegal. [Online]. http://www.wsp.org/wsp/sites/wsp.org/files/publications/CSO-senegal.pdf

[125] Runda. (2010) Runda Estate Association website. [Online]. http://www.rundaestate.com/

[126] H.W. Pearson, S.T. Avery, S.W. Mills, P. Njaggah and P. Odiambo, "Performance of the phase II Dandora waste stabilisation ponds: The case for anaerobic ponds," *Water Science and Technology*, vol. 33, no. 7, pp. 91-98, 2010.

[127] Lonely Planet. (2011) Weather in Kenya. [Online]. http://www.lonelyplanet.com/kenya/weather

[128] Maps of World.com. (2011, November) Cholera in Kenya. [Online]. http://www.mapsofworld.com/kenya/health/cholera-in-kenya.html

[129] Maps of World.com. (2011, November) Hepatitis A in Kenya. [Online]. http://www.mapsofworld.com/kenya/health/hepatitis-a-in-kenya.html

[130] Jun Wen Li, Zhong Tao Xin, Xin Wei Wang, Jin Lai Zheng, Fu Huan Chao, "Mechanisms of inactivation of hepatitis A virus in water by chlorine dioxide," *Water Research*, vol. 38, no. 6, pp. 1514-1519, March 2004.

[131] B. Ivanoff, M.M. Levine, "Typhoid fever: continuing challenges from a resilient bacterial foe," *Bulletin de l'Institut Pasteur*, vol. 95, no. 3, pp. 129-142, July / September 1997.

[132] Morteza Abbaszadegan, Michaela N. Hasan, Charles P. Gerba, Peter F. Roessler, Barth R. Wilson, Roy Kuennen, Eric Van Dellen, "The disinfection efficacy of a point-of-use water treatment system against bacterial, viral and protozoan waterborne pathogens," *Water Research*, vol. 31, no. 3, pp. 574-582, March 1997.

[133] SODIS - Solar Cooking. (2011) SODIS - Solar Cooking. [Online]. http://solarcooking.wikia.com/wiki/SODIS

[134] WASREB, "Impact report 2009," pp. 27-31, 2009.

[135] Maps of World.com. (2011, November) Typhoid in Kenya. [Online]. http://www.mapsofworld.com/kenya/health/typhoid-in-kenya.html

[136] D. Schoenen, "Role of disinfection in suppressing the spread of pathogens with drinking water: possibilities and limitations," *Water Research*, vol. 36, no. 15, pp. 3874-3888, September 2002.

[137] HistoryofWaterFilters.com. (2004 - 2010) The Past, Present, and Future of Water Filtration Technology. [Online]. http://www.historyofwaterfilters.com

[138] Tanathi Water Services Board. (2008) Tanathi Water Services Board. [Online]. http://www.tanathi.go.ke/

Appendix A: Original assignment

Projectnummer: 491
Projectinformatie voor: The Chlorine Dilemma – the ethics behind safe drinking water

Beschrijving:

Having access to safe drinking water is essential. The fact that one billion people worldwide do not have this access is an important ethical and technological challenge. Those who do have clean tap water can count their blessings, until they read a very recent article by Sedlak and von Gunten in Science, entitled The Chlorine Dilemma*).

The widespread use of chlorine disinfection seems to have a dark side: it kills waterborne pathogens but also produces toxic by-products when reacting with (more or less) natural organic matter. What to do? There are alternatives to chlorine, but with other apparent side-effects. Should we therefore decide what's best purely on technical (or financial) grounds? This MDP will use an extended approach: an ethical analysis of the Chlorine Dilemma, considering all stakeholders and technical data available.

*) David L. Sedlak and Urs von Gunten, The Chlorine Dilemma, Science 7 January 2011: Vol. 331 no. 6013 pp. 42-43. DOI: 10.1126/science.1196397

Zie verder: http://www.sciencemag.org/content/331/6013/42.summary

Geschikt voor de opleiding(en): BMT N ST TEMA

Trimester: 1 (najaar) 2011-2012

Projectindiener: dr. Philip J. Nickel
Contactadres voor inhoudelijke informatie: dr.ir. Jetse C. Reijenga

Appendix B: Factual analysis situation in Western world

B.1. Definition Western world

The “Western world” is a group of countries that have established a dominant position in the world society. They are strong, powerful and rich countries that have a lot of influence in the world. These countries belong to the top of the world concerning technological prosperity and economic welfare. The term "Western world" is often used along with the term “First World” for pointing out the difference between First World and the Third World (undeveloped countries) (see Figure 16). Countries and regions belonging to the Western world are: North America and Canada, Western Europe including Scandinavia and Turkey, Australia and New Zealand, Brazil, Russia, China and Japan.

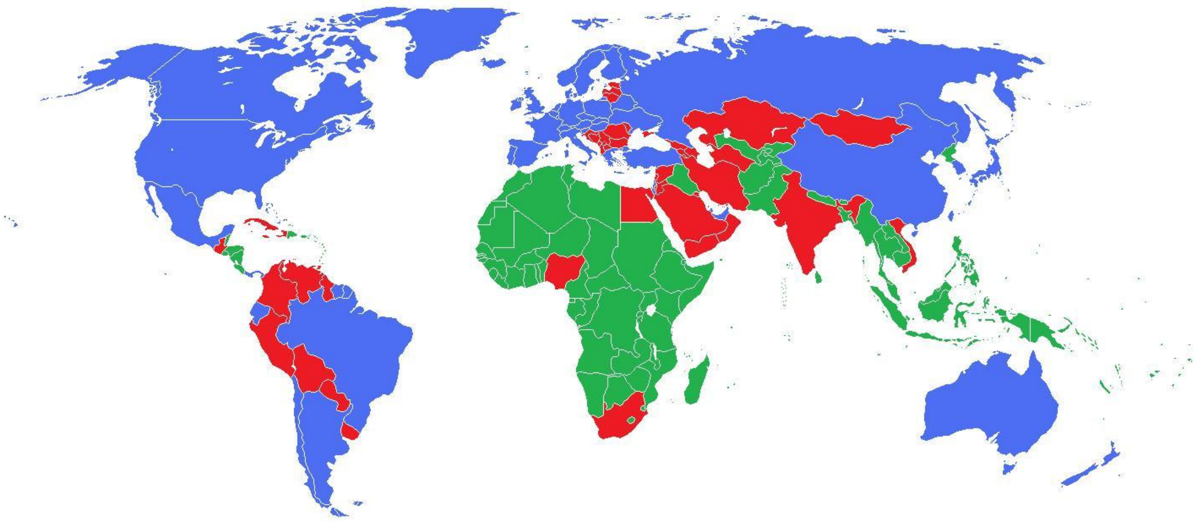

Figure 16: First world (blue), Second world (red) and Third world countries (green) as stated by OCED (2007)[77]

B.2. Current state of water disinfection in the Western world

Within the Western world chlorine is often used as a disinfectant-chemical for water. Chlorine is the first step that springs to mind for water treatment, as it is a well-established, cheap and effective method. Chlorine is currently by far the most commonly used disinfectant in all regions of the world.

B.2.1. Canada

<u>Current situation</u> [**78**]

Most drinking water treatment plants in Canadian provinces use chlorine as a disinfectant. Only the province of Prince Edward Island does not require disinfection because it totally depends on groundwater as drinking water source. The other provinces maintain disinfection residuals in their distribution system. Residuals in the drinking water range from 0.04 to 2.0 mg/L. At these concentrations, taste and odor related to chlorine or its by-products are generally within the range of acceptability.

<u>Rules and directives</u> [**79**][**80**]

In most provinces no maximum chlorine level is established but where it is, a maximum of 4 mg/L is applied. This maximum will keep disinfectant levels low enough to minimize the by-product formation and limit negative health effects. The drinking water is constantly monitored and when out of range the staff will be alerted. As stated above, no numerical value of the chlorine is given as a national directive, but rather a range is given. Drinking water providers should maintain low levels of chlorine ensuring that disinfection has occurred and residuals are still present, thus providing water that is acceptable for the consumer. All provinces require some form of reporting and remedial action when values go out of range. The remedial actions vary from alarms to back-up chlorination in Quebec. Recommended is that all water leaving a plant is tested at least daily for chlorine residuals.

Trihalomethanes are the most common disinfection byproducts. Trihalomethanes are formed in harmful concentrations if the chlorine concentration exceeds 4.0 mg/L. Health Canada has issued a guideline for trihalomethanes and sets the maximum concentration at 0.1 mg/L. An additional guideline for bromodichloromethane, a specific trihalomethane that is harmful at lower concentrations, exists and is set at a maximum concentration of 0.016 mg/L.

Alternatives in use [**78**][**80**]

Canada uses mostly chlorine and chlorine based disinfectants for drinking water treatment. Alternatives, like UV and ozone are used only on a very small scale.

B.2.2. USA

Current situation [**81**]

Most states follow the EPA (Environmental Protection Agency) requirements for chlorine residuals in drinking water. These requirements are for surface water sources only. The range of chlorine residuals in drinking water should not be less than 0.2 mg/L and may not exceed 4 mg/L. Here also the maximum is set to minimize by-product formation and limit health effects. Drinking water is constantly monitored in all states.

Rules and directives [**79**][**80**][**1**]

EPA regulations state that if the residual value goes out of range, the water supplier must notify the state authority as soon as possible. When the level is restored, the state authority must be notified again. As a rule the lowest value must be recorded each day and the water must periodically be tested. Remedial actions differ from state to state but always lead to a correction of water or providing an alternative drinking water. In some states even the public is notified as soon as the values of the drinking water are not in range.

Some rules do not address private wells because they are not subject to EPA regulations. The EPA advises states and homeowners to manage individual wells.

The EPA also issues guidelines on the maximum amount of trihalomethanes in the drinking water. This maximum limit is 0.080 mg/L.

Alternatives in use [**2**]

The USA uses mostly chlorine and chlorine releasing disinfectants to purify its drinking water. More than 80% of the drinking water is chlorinated. Alternatives are beginning to be used however, with chloramines (29% of the drinking water) and chlorine dioxide (8%) as the alternatives of choice. Ozone is used on a small scale (6%), while UV purification is slowly rising in the US. Many water purification plants also use more than one disinfection method to purify the water.

Specific aspects [**82**][**2**]

The government discourages consumers to use bottled water instead of tap water. In many cases, the bottled water does not differ from the tap water.

As the chlorine reacts and the concentration decreases during transport within the distribution network, sometimes the maximum allowed concentration of chlorine is added to the water. This way, the consumers living near water purification plants receive high chlorine concentrations in the drinking water, while consumers at the end of the network still at least have the minimum needed concentration in the drinking water for residual protection.

If chlorine is removed as disinfectant, an alternative substance has to be put in for stopping the lead from the piping system coming into the drinking water.

B.2.3. Western Europe

Current situation [1]

Almost all countries in Western Europe use chlorine as their primary disinfectant chemical. It is used in the form of chlorine gas, calcium hypochlorite or sodium hypochlorite. Drinking water in Europe has to satisfy the European Drinking Water Directives. The water does not directly require that disinfectant residual is present at all times but does set microbiological quality standards. These standards need to be achieved by residual disinfection or by making the water free of pathogenic micro-organisms, viruses and stop bacterial growth. Countries in Europe have different minimum and maximum values for chlorine residues. In Germany for example, health authorities ask for residue free water whereas the UK has no maximum level.

The member states do not have to use disinfectants “as long as they will take any other action needed in order to guarantee the healthiness and purity of water intended for human consumption.”

To guarantee the water quality regularly monitoring is done according to EU regulations.

Rules and directives [79][83]

Countries in Europe have different rules and directives concerning chlorine usage. The rule of the European Union is that where disinfection is required, corrective action must be done to re-assure the concentrations to the right value. For example in France, the distribution of water will be stopped until the problem is solved. In Spain re-testing will take place and the public will be alerted until the concentration is restored.

The EU has issued guidelines for trihalomethanes, with the maximum concentration set at 0.100 mg/L.

Alternatives in use [2]

Many countries in Europe employ alternatives for chlorine. The UK uses mostly chloramines for their water purification. In the Netherlands, UV and ozone are used on a large scale, while chlorine based disinfectants are banned. In France the primary treatment method uses ozone. The alternative ozone prevents the unwanted taste of chlorine to drinking water. Italy and Germany use ozone or chlorine dioxide as primary disinfectant chemical. Great-Britain is one of the rare countries where chloramines are used, although sometimes chloramines are also used in Finland, Sweden and Spain.

Specific aspects [25][1]

In the Netherlands, no disinfection is required. With this so called “Netherlands approach”, the focus is on making the water free of pathogenic micro-organisms, viruses and their indicators. Further focus is on low colony counts through multiple barrier approaches and on reducing the AOC (assimilable organic carbon) levels to the point that bacterial growth in the system is unlikely.

Appendix C: Ethical analysis; facts concerning the Netherlands

C.1. Relevant facts

C.1.1. Chlorine in drinking water and disinfection by-products

- If a sufficient amount is added, chlorine-based disinfectants are the only disinfectants that provide lasting residual protection to protect the water from waterborne pathogens throughout the distribution system from treatment plant to the consumer's tap.[**2**][**29**]

- Disinfection with chlorine takes at least 30 minutes at 18 degrees Celsius or higher. If the temperature drops, the contact time increases. [**29**]

- Sometimes disinfection with chlorine has to be done multiple times, because the initial dose loses its effectiveness over time.[**31**]

- With adequate pre-treatment, chlorine dosing, contact time and maintenance, chlorination effectively destroys many disease-causing bacteria and viruses.[**28**]

- Chlorine is effective against a wide range of disease-causing micro-organisms. Its effectiveness against some organisms requires higher concentrations of chlorine and longer contact times.[**29**]

- Joop Rook, a Dutch researcher, first discovered and warned about disinfection byproducts such as THM's.

- To be more specific regarding cancer, what is happening is that chlorine in drinking water might combine with organic matter at the stage of chlorination, i.e. before it reaches in our home plumbing system. What are produced from this chemical process are trihalomethanes (THM's for short), or haloforms. These chlorine by-products are known carcinogens.[**30**]

C.1.2. UV-disinfection

- UV radiation is not suitable for water with high levels of suspended solids, turbidity, color, or soluble organic matter. These materials can react with UV radiation, and reduce disinfection performance.

- It does not provide a chemical disinfectant residual to protect the water from recontamination or microbial re-growth after treatment.

- No technical database exists on how well UV systems perform for various water quality conditions.

- No standardized mechanism measures, calibrates, or certifies how well equipment works before or after installation.

- The UV lamps require periodic cleaning, especially for systems using submerged lamps, and they have a finite lifespan and must be periodically replaced.

- High dosages are required for *Cryptosporidium* and *Giardia* inactivation. Both species are parasites which harm the intestine and cause diarrhea.[**21**][**84**]

- In the presence of nitrates or nitrites, elevated levels of mutagenic substances are formed from various amino acids on irradiation of water under neutral conditions.[**85**]

- Aromatic hydroxy acids e.g. hydroxybenzoic acid and 3,4-dihydoxy benzoic acid, were formed during UV irradiation of aqueous NOM. These probably originated from the degradation of lipids and tricylglycerols derived from algae and terrestrial plants.[**86**]

- UV radiation did not significantly alter the total concentration or the speciation of the disinfection byproducts.

- At low UV doses, pH values typical of UK water sources, and nitrate concentrations within the regulatory limit, the formation of nitrite is rarely, if ever, likely to exceed 100 μg/L.

- Aldehydes, in particular formaldehyde and acetaldehyde, are formed as a result of the UV irradiation of solutions of humic acid. However, they do not appear to be formed at levels that would be of concern.[**85**]

- A reliable and affordable source of electricity is required to power the UV lamps.[**21**]

- UV disinfection is very effective at inactivating pathogens at low dosages.[**31**]

C.1.3. About the Netherlands

- The Dutch use physical processes (sedimentation, filtration, etc.) in preference of using oxidizing agents to produce biostable water. The water is distributed through a pressurized distribution system, preventing ingress of water and thus bacteria and nutrients. The distribution network is kept clean by minimizing particles and preventing precipitation by using high flow velocities. The network is also regularly flushed. This combination of biostable water with a clean distribution network results in the fact that no additional disinfectant must be applied to ensure residual disinfecting properties.

- The Netherlands have to implement the European drinking water directive, but have stricter requirements in their drinking water decree.

- In 2005 the last chlorine disinfection processes were stopped and replaced by alternatives.

C.1.4. Legionnaires' disease

- The Netherlands realize that *Legionella* might be hazardous concerning public health after an epidemic outbreak in Bovenkarspel in 1999. At least 188 people fall ill and 21 have died.[**87**]

- In 2009 the Netherlands belong to the top five European countries for the incidence of Legionnaires' disease.[**88**]

- An increased risk is the age of retired people, since the risk of developing Legionnaires' disease from *Legionella* infections increases sharply with age.[**34**]

- Legionnaires' disease is caused by *Legionella pneumohilia*, which appears generally in freshwater. Multiplication occurs principally in installations including water cooling towers, whirlpools, showers, nebulizers and distribution systems of drinking water. Atomization of warm water may have potential high risks to public health.[**32**][**33**]

- It is difficult to find the source of infection in the vicinity of patients. This is probably due to failing detection methods as they are not able to detect all *Legionella* bacteria in water samples. The RIVM has developed the '*polymerase chain reaction'* (PCR), which is expected to be valuable concerning source identification. However, further validation is necessary.[**42**]

- Bacteria increase in number on contact related water surfaces, the so called bio film. The growth of *Legionella* in the environment and technical water systems is strongly determined by the formation of biofilm.[**32**]

- Concentrations of bio film in water pipes depends on the composition of the water, the material of the pipes, hydraulic conditions (flow), presence of amoebae and the temperature of the water.[**32**]

- The growth of *Legionella pneumophilia* might be limited by the conservation of high (>60ºC) or low (<25ºC) water temperatures.[**32**]

- Modern heating systems can increase *Legionella* colonization in cold water systems in homes.[**34**]

- Both floor heating and district heating pose an increases risk of *Legionella* growth that may lead to extra cases of Legionnaires' disease.[**88**]

C.2. Disputed, uncertain or unknown facts

C.2.1. Chlorine in drinking water and disinfection by-products

- Moderate to heavy consumption of chlorinated tap water by pregnant women has been linked with miscarriage, birth defects, heart problems, cleft palate, and major brain defects. Especially pregnant women in their first three months are at higher risk of miscarrying.[**35**][**36**]

- The presence of chlorine in tap water has been linked to the dramatic rise of heart disease. Scientists argue that chlorine is a primary cause of the development of atherosclerosis, or hardening of the arteries.

- Studies show chlorinated water is toxic to human intestinal bacteria, the body's natural flora that converts organic compounds in our food into necessary nutrients.

- Chlorine disinfection byproducts (DBP's) are responsible for the increase in rectal and bladder cancers.

- Chlorine disinfectant byproducts are one of the most deadly carcinogens in tap water.

- During the summer, surface water used for drinking water contains more organic material and, as a result, DBP levels are often higher than they are in the fall and other times of the years.

- Because chlorine is a calcium antagonist, long-term consumption of chlorinated water has been linked to loss of calcium in bones. Chlorinated tap water has also been linked to childhood and adult asthma and allergies.[**35**]

- Disinfection by chlorine is still the best guarantee of microbiologically safe water.[**2**]

C.2.2. UV-disinfection

- This type of disinfection does not produce a disinfectant residual. Therefore it can only be used as a primary disinfectant. A secondary disinfectant, such as chlorine, in combination with UV radiation has to be used when treating drinking water with UV disinfection.[**37**]

C.2.3. About the Netherlands

- The Dutch use the best quality water source available to them as they use a lot of microbiologically safe groundwater.

C.2.4. Legionnaires' disease

- The Netherlands, the United Kingdom and France report relatively a large amount of *Legionella* infections caused by foreign journeys. The Netherlands count approximately 50% of foreign related *Legionella* infections which lead to pneumonia. Countries which seem responsible are Spain, Turkey, France and Italy.[**89**][**90**]

- Additionally, legionellae are susceptible to a broad range of disinfectants, including chlorine- and bromine-containing compounds, ozone, heavy metal ions, and ultraviolet light.[**38**][**39**][**91**]

- In spite of the fact that various Legionella species are isolated from non-clinical water settings, there is neither a standard method to determine whether environmental *Legionellae* may be infectious to humans[**92**] nor any known facts about the relevant infectious dose of Legionellae in connection with public health[**42**].

- The availability of a simple and quick method in order to diagnose is one of the most important conditions concerning the increased attention of *Legionella.*[**41**]

- In only 3.5% of 708 *Legionella* incidences the source of infection was verified in the Netherlands. Around one half of these patients (25) were contaminated in hospitals or other care establishment.[**41**]

- Almost 30,000 cases of pneumonia need hospital admission in the Netherlands. The mortality of Legionnaires' disease is assumed to be 1,200 (4%).[**93**][**88**]

- The Dutch Health Council estimated 50 cases of Legionnaires' disease per million inhabitants.[**40**]

- The number of registered *Legionella* patients has increased to more than 300 per year in the Netherlands since the outbreak in Bovenkarspel in 1999.[**41**]

- The real number of Legionnaires' disease is probably higher than the reported number due to underestimations in diagnostics.[**42**]

- The mortality of Legionaires' disease is between 5% and 30%.[**43**]

- In 2006, 446 cases of Legionnaires' disease were reported in the Netherlands.[**33**]

- The incidence of *Legionella* pneumonia has increased in Europe since 1993. Since 2002 the incidence has stabilized to 10 infections per million.[**89**][**94**]

- Despite stricter legislation the number of Legionnaires' disease has increased for the last years.[**95**]

- Presented as a 'figure-fact' is shown in Figure 17 the number of reported Legionella pneunomia cases per million inhabitants in several European countries in 1999, 2003 and 2004.[**96**][**89**]

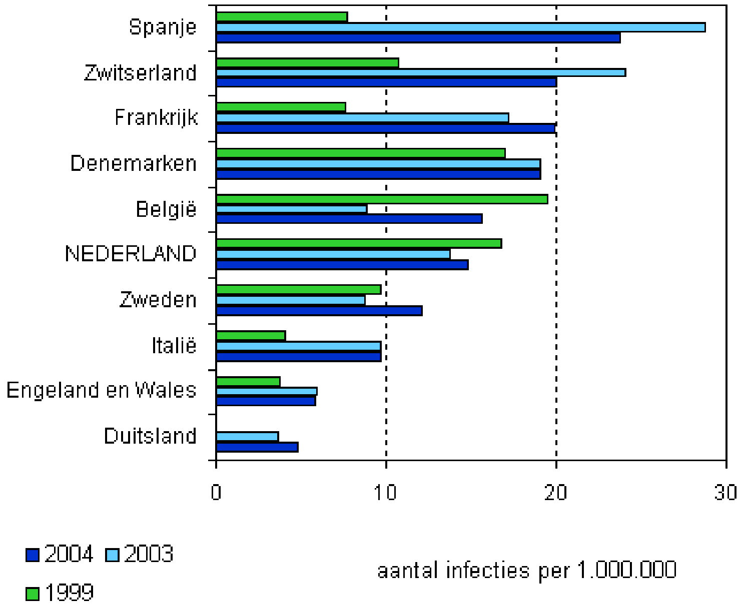

Figure 17: Number of reported Legionella pneunomia cases per million inhabitants in several European countries in 1999, 2003 and 2004.[96][89]

Appendix D: Ethical analysis; ethical judgment about the Netherlands

D.1. Intuition

D.1.1. Ethical judgment

To choose the optimal action that has to be taken, a moral judgment was made based on intuition. From an intuitive point of view the optimal action is action number 5, use UV disinfection combined with chlorine disinfection for vulnerable groups. As said before, in general this means that UV-technology is used for basic disinfection of drinking water. Next to that chlorine disinfection is used in for example hospitals and residential care homes. On intuitive basis this is the optimal action, because in this case the best result is given with the least amount of work. The current situation in the Netherlands is that water purification is mainly done with UV-disinfection. This appears to be a very good technology with very little negative side-effects. There is one clear point of remark that is made often, and that is the fact that UV-disinfection doesn't provide any residual disinfection properties when the drinking water is transported to the customer. The risk of the presence of Legionella species for example, that cause Legionnaires' disease, is still relatively high.

Fortunately Legionnaires' disease is not a deadly illness to everyone. You can get sick from it, but the people that are really sensitive for catching the disease and to whom the illness can be deadly are mainly elderly people and persons with limited health resistance.

Those elderly people and persons with limited health resistance are often found in care homes and hospitals. Intuitively then you can say that the drinking water in those places should be of higher quality than in other places, regarding contaminants that can cause diseases like Legionnaires' disease. Chlorine disinfection would in this case be perfect for extra disinfection. The unpleasant side effect of adding a distinctive chlorine taste to the water is in no contrast to the extra safety it will provide the elderly people and persons with limited health resistance. The chlorine can be added on site at hospitals, care homes and such places to more improve water disinfection.

D.1.2. Reflection

Intuition is not a clear method of decision making. An intuitive decision is a decision about feelings and does not provide good arguments for that decision. In this case the intuitive decision is one that appears to have a big effect in preventing diseases among elderly people and persons with limited health resistance, with a little amount of work. However no strong factual arguments are given regarding the effectiveness of adding chlorine on site at hospitals and care homes. Is there enough time for the chlorine to effectively disinfect the drinking water when used on site? How will the chlorine be transported to the hospitals and the care homes, isn't this dangerous and doesn't this also come with risks? The intuitive decision is made with an emotional feeling about the elderly and ill people. You want them to have good disinfected water but the risks that this new situation brings with it are neglected. The risk of an intuitive decision without good arguments is that it isn't clear if the situation will become better. On first sight it might be, but there has to be taken a closer look.

D.2. Dominant-value method

D.2.1. Ethical judgment

The most dominant value is the health of the population. A healthy population can increase the happiness and economic welfare in the society. Health is one of the most desired values of many people. With health chosen as the most dominant value the action that should be taken is action number 5, use UV disinfection combined with chlorine disinfection for vulnerable groups. UV-disinfection will give good disinfection to the average consumer while chlorine disinfection gives the best (residual) disinfection for pathogens including Legionella that is wanted for less healthy and elderly people.

A clean environment is also an important moral value, but is not seen as the most important one. Next to that, the influence on the environment of the negative side effects of different disinfection technologies seems to be in the same order. Differentiation on this part therefore does not have much effect.

The formation of DBP's however, is an important fact to discuss. Chlorine disinfection will produce DBP's. There are negative health effects of DBP's and UV-disinfection will not produce DBP's. It is clear however that the amount of people that are exposed to DBP's is relatively low because chlorine is used only in hospitals and care homes. Next to that, the exposure time is also relatively low, because the average consumer will not stay in a hospital or a care home his whole life. This reduces the chance for development of diseases like cancer that could be caused by DBP's.

The biggest positive health effects on the population are obtained by using UV disinfection combined with chlorine disinfection for vulnerable groups, and because health of the population is seen as the most dominant value, that is the disinfection method that should be used.

D.2.2. Reflection

The dominant-value method is a difficult method to use. The first crucial step is to determine the most dominant value and this is difficult to do. This choice is never objective, because it often is an intuitive decision and unfortunately intuitive decisions are often debated. Next to that, the other moral values are not taken into account using this method. One of them is chosen as the most important one and the others are totally neglected. There is no combination of the two or three most important values using this method. A different choice of dominant value could have lead to a different action.

D.3. Virtue ethics

D.3.1. Ethical judgment

Background

Virtue ethics is a specific approach in this field. Ethical approaches may be distinguished on several aspects:

- The **principle** in which ethical questions are answered; *teleological ethics* versus *deontological ethics*.
- The **criterion** in which the moral quality of action is determined; *consequential ethics* versus *inclination ethics*
- The interest of **human actions**; *Diskurs-Ethik* (addressed on rational speaking) versus a *theory of moral sentiments* (addressed on moral feelings)
- The **central aspect of morality**; worth ethics versus virtue ethics.

The fundamental question in virtue ethics is as follows: "How do I have to live (individually, socially, generally)? Virtue ethics is not defined in a 'social' way however it doesn't mean virtue ethics may be characterized as egoistic ethics, because:

1. The successfulness of peoples own life cannot be completely distinguished from others, especially the ones in close connection
2. The *praxis* (the purpose is determined in the action by itself) encloses many practical issues, which might be practiced in relation to others.
3. The own life, which is mainly emphasized, could centralize the life of a community as well.

The virtue functions like a connection between norm and value. One the one hand norms may be characterized by objectivity, but they limit their selves in a manner of negativity and minimization which could lead to offence. On the other hand values form a maximum which is quite motivating, but make them subjective as well. Virtue ethics offset to solve moral problems with the help of protocols and behaviour codes.[**97**]

The virtue

People need underlying qualities to optimally realize specific functions. Aristotle distinguishes two sorts of virtues: intellectual virtues (realization of different human intellectual abilities) and character virtues (an attitude which makes a person capable of making right decisions as well as strikes the golden mean). The ethics are based on a human vision, which says that the character of a person (virtues) should be formed by education and training. Following the right examples is essential. It is not all about the improvement of actions, but the formation of feelings as well.

People have to be moral correct, responsible beings in order to live a 'good life'. Aristotle's virtue ethics is teleological: it follows the logic of the purpose (telos). The actions are made in order to achieve this purpose, which is criticized as 'good'. The highest purpose of life according to Aristotle should be bliss. Aristotle brings the right actions in connection with the golden mean. This mean is hardly identified, because no predetermined minimum or maximum exists and the right extent seems to be dependent on the situation. However, two marginal notes should be placed concerning the problem to determine the right mean:

- In virtue ethics it is not about whether to do something or not. It is about the exemplariness of a certain attitude.

Despite Aristotle emphasizes to direct at the relativity of the mean, he is not a relativist at all: in a specific situation the mean should be given by the sensibility of the sensible person.[**27**]

Four special virtues are the so called 'cardinal virtues'. The virtues have such importance that every other virtue is more or less present is one of those: courage, modesty, sensibility and justice.[**97**]

Virtue ethics in 'The Chlorine Dilemma'

Concerning virtue ethics in the question about chlorine in drinking water it is assumed that the government would be the acting stakeholder. Essentially, the characters which would be expected to present in the different situations / actions should be analyzed in order to realize the 'good' behaviour.

The absence of doing anything to disinfect drinking water proves no social responsibility at all if a western country like The Netherlands would proceed to this decision. Besides, there is no awareness of duty, lack of expertise, no compassion and no concern. The only use of chlorine gives the government a naïve nature and a lack of flexibility, because perhaps other methods are available with better (more reliable) performance in connection to some pathogens. Obviously, the government tends to be obstinate and non innovative since chlorine disinfection is relatively old-fashioned in this spirit of times. Moreover, there is again lack of expertise or no notion for detail, because the government is not aware of the dangers of *Legionella, Giardia lambia cyste*, *Cryptosporidium* and DBP's. If there is nevertheless any awareness about these pathogens, the government may be typified by non integrity behaviour and it tells something about the lack of decisiveness as well. The installation of filters at the end of does not change anything about these virtues, because the possible presence of pathogens and DBP's cannot be filtered out at all. However, willingness has to be added to this action as most people of the population do not belong to the risky group and should profit from odourless and tasteless drinking water.

The use of UV gives the government a more innovative character as well as some improvement in expertise since pathogens like *Giardia lambia cyste*, *Cryptosporidium* and the possible carcinogenic organic compounds (DBP's) may be reduced. Therefore, it behaves with more responsibility towards citizens. However, there is still no concern about the absence of any residual disinfectant in the distribution pipes. If chlorine is used after the primary method of UV disinfection, this concern is not absence anymore. On the other hand, DBP's are introduced since excess of chlorine has to be added in order to maintain any residual amount. In this way compromises have to be made: less *Legionella* (UV – chlorine) or less DBP's (UV).

If compromises provoke a decrease in safety, the use of another action gives the government possibly more the name of social responsible. This action, which concerns the basic UV-disinfection in combination with chlorine as residual disinfectant at critical places where *Legionella* outbreaks are likely according to several examinations, would exhibit expertise and notion for detail. After all, the government use practical data (and possibly) recommendation of examination outcomes. Furthermore, this action proves decisiveness as well. When returning to the 'cardinal virtues', it is clear that this action is enclosed by 'modesty' as well. Obviously, only the vulnerable group of the population is treated more effectively in order to prevent infections, the other group could still profit from the advantages of UV-disinfection. This action might be interpreted as 'the golden mean' rule.

D.3.2. Reflection

Normally, consequences are not taken into account when analyzing problems with virtue ethics. The virtues of the acting person of institute form most of the time the mainline. This would give some problems, because using virtues to guarantee the right action might be disputed. However, since the actions of the disinfection problem are more or less the same (apply chlorine, apply UV, apply combination and so on) it was quite difficult to distinguish them with different virtues. Therefore, the virtues are moderately coupled with the consequences. This can be justified, as in the background it is explained why virtue ethics is not an egoistic discipline, especially by the points of *praxis* and centralization of the own life into the community.

Appendix E: Factual analysis situation in Third world

E.1. Definition Third world

The third world is a group of undeveloped countries that have a bad economy and as a result a poor population and limited infrastructure. Often these states are faced with problems such as famine, droughts and other natural disasters. Many of these countries moreover have an instable political climate, resulting in a bad handling of structural problems. Countries and regions belonging to the third world are mostly African countries, with the exception of parts of North Africa and South Africa. There are also undeveloped regions in the southeast of Asia and Central America. This research will be restricted to African countries.

In 2000, a series of millennium goals were adopted by the UN.[**98**] These goals are to be fulfilled by 2015. Goal 7.c says: "Halve, by 2015, the proportion of the population without sustainable access to safe drinking water and basic sanitation". In order to reach this goal, many efforts have been made by governments and NGO's since 2000.

E.2. Current state of water disinfection in the third world

In this overview only third world countries and regions will be discussed which meet the following criteria:

- The countries should not be economically prosperous or have a good infrastructure with regard to water distribution. This means that North African countries, such as Egypt and Morocco, and South Africa will not be investigated.

- The nation or region must have a more or less stable political climate and should not be at war. Only this way it is possible that necessary changes to the drinking water disinfection method could be made. Countries such as the democratic republic of Congo, Côte d'Ivoire and Somalia shall not be considered for this reason.

- The region must not (constantly) suffer from a chronic lack of drinking water, such as (too) frequent droughts, as the water disinfection is the area under investigation. Nations where large parts of the territory consist of desert shall therefore not be considered. Examples for this include Sudan, Chad and Niger.

E.2.1. Madagascar

Madagascar is a poor country with a GDP per person of only 900 USD in 2010 and where 50% of the population lives below the poverty line.[**7**] In the 90's and 00's, health organizations and NGO's managed to raise awareness to the importance of clean drinking water. An estimated 23% of the population lives in urbanized centers where water distribution infrastructure is present. Despite efforts by numerous organizations to improve infrastructure in rural areas, sometimes by stimulating the local population to work on these projects, still only 41% of the population has access to safe drinking water. In urbanized areas 71% of the population has access to drinking water compared to only 21% for the population in rural areas.[**99**]

In places where water is disinfected on a larger scale, mostly chlorine is used. In rural areas, where no infrastructure is present, chlorine based water disinfection tablets are being used to provide safe drinking water. A part of the population however still does not use this because of financial problems or limited awareness. [**100**][**101**]

Madagascar has a water supply of 17.000 m^3 per capita on a yearly basis. Of these resources, in 2000, only 924 m^3 was used. By 2015, to comply with the millennium objectives, almost 13.000 m^3 should be available for each person per year.[**102**]

E.2.2. Cameroon

Cameroon has a slightly more developed drinking water infrastructure than Madagascar with 88% coverage in urbanized areas and 47% in rural areas. The economic situation is better than some other African countries with a GDP per capita in 2010 of 2300 USD. About 48% of the population however remains below the poverty line. Sanitation is not good, and the water provided is not always clean. Poor environmental management and corruption has led to bad exploitation of the country's natural water sources. In spite of all of these problems, in 2006, 70% of the population had access to drinking water.[**103**] Where disinfection is applied, mostly chlorine and chlorine based chemicals are used. Chlorine based tablets are also available to the general population as means of water treatment.

E.2.3. Zambia

The GDP of Zambia is 1500 USD per capita as of 2010. Access to safe drinking water in Zambia is average, with 59% coverage for the urban households and only 43% among the rural population.

According to local government, the biggest problem is that in almost every peri-urban setup the infrastructure for safe drinking water is absent. Furthermore the problem in Zambia isn't the absence of water but the absence of safe drinking water. Due to the low amount of resources available, less than 6% of the actual needed budget is available per year, causing the infrastructure to develop very slowly.[**104**]

The drinking water quality in urban areas was far below the drinking water standards in 2010. About 94% of the samples taken were in compliance with the standards and often the drinking water was polluted by the mines in such a degree that manganese levels were beyond treatable limits. The supply of drinking water in urban regions is intermittent with an average supply of 16 hours per day. The few water treatment plants that do exist in Zambia do not achieve their effluent standards and the capacity of these plants is often outgrown by the population in the region.[**105**]

What can be said about the development of safe drinking water in Zambia is that it's in progress. With the founding of the Ministry and Department of Infrastructure and Support Services, a first step towards safe drinking water was made. A regulator for the drinking water is the National Water Supply and Sanitation Council[**105**] and it is so successful that it can serve as a role model in the region according to German Technical Cooperation. Under guidance of these departments and council's it looks like the MDG for drinking water can be potentially met. In 2006 the percentage of people without drinking water was 40% and the target is 24.5% by 2015.

In Zambia multiple disinfection agents are used. Among these is a household chlorination system and sodium hypochlorite.

E.2.4. Angola

The GDP per capita in Angola is 8200 USD as of 2010. The availability of water in Angola is not a problem. According to the United Nations, Angola has the most rainfall in southern Africa, twice as much water available per capita as Zambia or Mozambique and an estimated ten times more than South Africa. However, according to the government's own figures, only 42% of Angola's 17 million citizens has access to clean water, in a country where water bottling is becoming a major industry.[**106**] Access to safe drinking water in 2008 was available to 40% of the population in rural areas and 75% in urban areas.[**107**]

Angola does take part in the Millenium Development Goals (MDG). However, if nothing were to change in the aproach of reaching these goals, the forecast is that it will come 14% short of the 69% of the population that should have access to clean drinking water.

The primary disinfectant used in Angola is calcium hypochlorite. Other disinfection means are solar radiation and chlorine solutions or tablets.

E.2.5. Mozambique

The main reasons that explain the lack of drinking water in developing countries are the absence of a proper infrastructure and deteriorated distribution networks or interrupted service that encourages stagnancy of water and growth of pathogens.[**108**]

With a Gross Domestic Product (GDP) per capita of 410 USD in 2010[**45**], Mozambique is one of the ten poorest countries of the world, with over 37.8% of the population living with less than 1 USD/day and 78.4% living with less than 2 USD/day. Each person has only 10 liters of water available for daily personal needs. This value is well under the 50 liter minimum water requirement stated by WHO and UNICEF for human domestic use (i.e. drinking, basic personal hygiene, laundry and bathing).[**108**]

To a large extent, Mozambique depends on water resources that originate in neighboring countries. This is where 54 % of the annual surface flow comes from. The country is also characterized by great climatic diversity (subtropical climate), with annual rainfall varying from 400 mm (in the south) to 1800 mm (in the north) and a hydrological network with nine shared rivers.[**109**] The main source of water in Mozambique is surface water. However, groundwater is utilized on a large scale in a number of urban centers for drinking water supply. Hand pump-mounted boreholes and shallow wells are used throughout the country as the main source of drinking water in rural areas.[**110**] In order to improve the access to safe water, most projects are running under the management of UNCIFEF. However, the AQUEPOT project, which is also installed in Mozambique (Ressano Garcia), was developed in the Polytechnic University of Valencia (Spain) It is intended for the installation of decentralized drinking water systems based on membrane technologies as an alternative to the current water management method in developing areas.[**108**] Between 2006 and 2010, a simple solar water disinfection system called SoWaDis with almost no need for maintenance has been developed at the Institute for Solar Technology SPF in Rapperswil (Switzerland). Since 2009, several systems have been installed at various locations in Bangladesh, Mozambique and Tanzania.[**111**][**112**]

Despite the progress made in Mozambique in expanding access to water and sanitation, this is still not sufficient to meet the Millennium Development Goals (MDG). The MDG include a specific target to cut in half, by 2015, the proportion of people that lack access to water and sanitation services.[**113**] Data indicate that only 26% of the population in rural areas had access to improved sources of drinking water (compared with 72% in urban areas). The total coverage was only 43% in the entire country. The MDG target for Mozambique is 68% coverage with improved sources of drinking water by 2015. Despite noteworthy improvement in access to improved sanitation, in comparison with other countries in the region, the report indicates that in 2005 only 19% of the population in the rural areas of Mozambique had access to improved sanitation, compared with 53% in the urban areas, giving a total coverage of 32%. The MDG target for Mozambique is 60% access to improved sanitation by 2015.[**109**]

Table 8: Health and development indicators for Mozambique, Africa, developing and developed Countries[108]

Indicator	Mozambique	Africa (average)	Developing countries (average)	Developed countries (average)
Urban population (%)	35.6	39.2	43.1	78
Population growth rate	1.7	2.2	1.7	0.6
Life expectancy at birth (years)	41.6	50.7	62	78
Child mortality rate (per 1000 births)	152	133.3	79.8	10.2
Access to safe water (%)	43	64.4	78	100
Access to sanitation (%)	32	42.6	52	100
Public expenditure on health as % of GDP (%)	2.9	3.3	1.8	6.3

E.2.6. Tanzania

Tanzania had a GDP per capita of 527 USD in 2010.[**45**] Access to water and sanitation remains low in Tanzania. Slightly more than half the population of Tanzania is estimated to have access to an improved water source, with large differences between urban areas (about 81%) and rural areas (about 46%). In rural areas, access is defined as meaning that households have to travel less than one kilometer to a protected drinking water source in the dry season.[**114**] Each person has approximately 25 liters of water available for daily personal needs.[**115**]

Table 9: Access to water and sanitation in Tanzania (2007)[7]

		Dar es Salaam (6% of population)	*Other urban areas (19% of population)*	*Rural (75 % of population)*	***Total***
Water	**Broad definition**	85%	76%	40%	**52%**
	House connection	8%	13%	1%	**4%**
Sanitation	**All forms, incl. latrines**	97%	97%	90%	**93%**
	Flush toilets	10%	6%	1%	**3%**

Controls of the quality of drinking water fall under the responsibility of local service providers at the point of water production. They refer to the Water Quality Standards established for urban and rural areas in the 1970s.[**116**]

Water quality varies significantly within the country. In the semi-arid regions (including Dodoma, Singida, Tabora, Shinyanga, and Arusha), color and turbidity levels become problematic during the rainy season. Rivers in the fluoride belt (including Arusha, Kilimanjaro, Singida, and Shinyanga regions of the Rift Valley, and extending to the Pangani and Internal Drainage basins) have naturally high fluoride concentrations. The waters of Lakes Tanganyika and Nyasa have overall good water quality except in the vicinity of urban areas where effluent and storm water cause local contamination. The water quality of Lake Victoria is poor as high turbidity and nutrient levels lead to frequent blooms of algae and infestations of water weeds.[**117**]

Conventional water treatment relies on the addition of chemicals such as alum (aluminium sulfate) as coagulants and the addition of chlorine as a bactericide.[**118**] Mbuya et al. state that there is a huge potential for UV light drinking water disinfection systems in rural communities and developing nations. Work is being undertaken to develop and apply low-cost UV disinfection technology to drinking water supplies in Tanzania and South Africa.[**119**]

The main policy implementation instrument is the Water Sector Development Program, whose rural component is the Rural Water Supply and Sanitation Program (RWSSP). The RWSSP, that was officially launched in 2006, establishes targets for the percentage of the population in rural areas who shall have sustainable and equitable access to safe water: (1) 65% by 2010 (goal set by the National Strategy for Growth and Reduction of Poverty, MKUKUTA); (2) at least 74% by mid-2015 (MDGs); and (3) 90% by 2025. [**113**]

E.2.7. Senegal

Senegal has a tropic climate with a well-defined dry and humid season. Most parts of the country have sufficient drinking water available in the form of surface water and ground water. One of these sources is the largest water resource in the country, namely the Senegal River. In its rural areas 82% of Senegal's population has access to safe drinking water. The population in urban areas has for 98% access to safe drinking water. The main disinfection methods that are used in Senegal are chlorine disinfection and solar water disinfection.[**120**][**121**] Before disinfection the water is filtered with sand filters.

The population of Senegal has a GDP of 12,865 million and the prices of drinking water differ from 2.40 USD/m^3 to 1.09 USD/m^3. [**122**][**123**]

The government monitors the drinking water supply that is distributed by private operating companies. Therefore the government provides a framework for all stakeholders that must ensure that the millennium goals are reached. Other support of the state is in the form of on-lending of donor's financing.[**123**] Senegal is on the right track to meet the targets of the millennium goals and predicts to reach the targets before 2015.[**124**]

E.3. Conclusions

The country that will be investigated should not be extremely poor, as this would mean that it would not be representative for other parts of Africa. For this reason, Mozambique, Tanzania and Madagascar are not selected. Cameroon is not selected because of the corruption, as changes in the system would be thwarted. Of the four remaining nations, Kenya seems to be the most representative for other regions in Africa in terms of economy and water provision. Furthermore, most information could be found on Kenya. For these reasons Kenya was selected for further research.

Appendix F: Ethical analysis; facts concerning Kenya

F.1. Relevant facts

F.1.1. Disinfection techniques

F.1.1.1. Chlorine

- If a sufficient amount is added, chlorine-based disinfectants are the only disinfectants that provide lasting residual protection to protect the water from waterborne pathogens throughout the distribution system from treatment plant to the consumer's tap.[**2**][**29**]

- Disinfection with chlorine takes at least 30 minutes at 18 degrees Celsius or higher. If the temperature drops, the contact time increases. [**29**]

- Sometimes disinfection with chlorine has to be done multiple times, because the initial dose loses its effectiveness over time.[**31**]

- With adequate pre-treatment, chlorine dosing, contact time and maintenance, chlorination effectively destroys many disease-causing bacteria and viruses.[**28**]

- Chlorine is effective against a wide range of disease-causing micro-organisms. Its effectiveness against some organisms requires higher concentrations of chlorine and longer contact times.[**29**]

- To be more specific regarding cancer, what is happening is that chlorine in drinking water might combine with organic matter at the stage of chlorination, i.e. before it reaches in our home plumbing system. What are produced from this chemical process are trihalomethanes (THM's for short), or haloforms. These chlorine by-products are known carcinogens.[**30**]

F.1.1.2. UV-disinfection

- UV radiation is not suitable for water with high levels of suspended solids, turbidity, color, or soluble organic matter. These materials can react with UV radiation, and reduce disinfection performance.

- It does not provide a chemical disinfectant residual to protect the water from recontamination or microbial re-growth after treatment.

- No technical database exists on how well UV systems perform for various water quality conditions.

- No standardized mechanism measures, calibrates, or certifies how well equipment works before or after installation.

- The UV lamps require periodic cleaning, especially for systems using submerged lamps, and they have a finite lifespan and must be periodically replaced.

- High dosages are required for *Cryptosporidium* and *Giardia* inactivation. Both species are parasites which harm the intestine and cause diarrhea.[**21**][**84**]

- In the presence of nitrates or nitrites, elevated levels of mutagenic substances are formed from various amino acids on irradiation of water under neutral conditions.[**85**]

- Aromatic hydroxy acids e.g. hydroxybenzoic acid and 3,4-dihydoxy benzoic acid, were formed during UV irradiation of aqueous NOM. These probably originated from the degradation of lipids and tricylglycerols derived from algae and terrestrial plants.[**86**]

- UV radiation did not significantly alter the total concentration or the speciation of the disinfection byproducts.

- At low UV doses, pH values typical of UK water sources, and nitrate concentrations within the regulatory limit, the formation of nitrite is rarely, if ever, likely to exceed 100 µg/L.

- Aldehydes, in particular formaldehyde and acetaldehyde, are formed as a result of the UV irradiation of solutions of humic acid. However, they do not appear to be formed at levels that would be of concern.[**85**]

- A reliable and affordable source of electricity is required to power the UV lamps.[**21**]

- UV disinfection is very effective at inactivating pathogens at low dosages.[**31**]

F.1.1.3. Solar disinfection

- Six hours in the sun, or two days during cloudy days, is sufficient to eliminate various waterborne pathogens in drinking water stored in PET bottles.[**76**]

- Solar disinfection is a simple, yet effective means of disinfection at a household level.

- The scale-up potential of this method is limited.

- Solar disinfection provides no residual protection.

- The type of bottle is a key factor: the bottle should be transparent, unscratched and undamaged. It should also be manufactured from PET, as PET is UV translucent.

- Solar disinfection is recommended by the WHO as a cheap and powerful disinfecting method.[**75**]

F.1.1.4. Boiling

- Boiling of water is an effective means of disinfection and may kill the vast majority of pathogens in a few minutes.

- Boiling is only applicable at household level.

- Boiling does not provide any residual protection.

- An external energy source is needed to be able to boil the water.

F.1.2. Governmental

- Kenya is considered as a water scarce country with less than 647 cubic meter of water available per capita compared to the international benchmark of 1000 cubic meters per capita.

- Kenya is a signatory to various International treaties and other agreements in the field of environment. The Government of Kenya, through the Ministry of Water and Irrigation, has obligation to meet in those treaties relating to Rivers, River Basins, Water Courses and Lakes.

- Kenya has no control over what happens to the shared water resources on the side of its neighboring countries.

- About 46 percent of Kenya's population lives below the poverty line.

- Due to efforts the last year's water coverage has reached 40% and 60% in rural and urban areas respectively. Furthermore, sewerage and basic sanitation coverage of 20% and 55% respectively have been achieved.

- Continued human settlements in water catchment areas and destruction of forests have led to depletion of water resources.

- **Ministries:** MWI co-operates mainly with the Ministry of Public Health and Sanitation (MoPHS) to harmonize the institutional framework for sanitation, Mininstry of Education in the area of school sanitation by participating in Water and Sanitation Program Committees, Ministry of Forestry, Ministry of the Environment and Ministry of Special Programs in order to improve the rehabilitation and maintenance of water towers.[**67**]

- **Private sector:** The private sector plays a limited, but not negligible role in operating water supply systems in Kenya. The biggest interest they have is commercial interest.[**125**]

- **Water Appeals Board:** Since 2005, only three cases have been determined by the Water Appeals Board. Five additional appeals are pending because the Chair has resigned in March 2009 and the terms of two other Board members have not been extended.[**62**]

- Water quality monitoring is being encouraged to check on pollution control. The water Act 2002 has provided deterrent penalties for water pollution in line with the polluters pay principle which is set at a maximum KShs.100.000,- for the first offence and KShs.100.000,- plus a jail term of twelve months to the operator of a polluting enterprise. The legislation of pollutant discharge is scattered across a wide range of statutes.[**52**]

- The Ministry of Water and Irrigation (MWI) is the key institution responsible for the water sector in Kenya. They expect to invest 1.9 billion Euros in water supply and sanitation between 2009 and 2013. The ministry's mission and vision are: [**53**][**50**][**68**]
  - **Mission:**
    To facilitate sustainable management and development of water resources for national development.
  - **Vision:**
    To be a regional leader in the sustainable management and development of water resources.

- Water supply itself is governed by the Water Services Regulatory Board (WASREB). This board regulates tariffs and provides licenses. The average water tariff reported for 2006-2007, by a non commercial state corporation, was 0.46 USD/m^3. This figure is not very indicative because of significant regional variations and because in Kenya a progressive block tariff system is in place for household connections. [**53**][**50**][**68**]

- Kenya is trying to achieve the Millennium Development goals, set for 2015. It will be hard for the government to meet the targets. The population has to be involved to achieve the goals. [**53**][**50**][**68**]

F.1.3. Water supply and infrastructure

- One of the waste stabilization ponds is the Dandora Waste Stabilization Pond System which treats the industrial and domestic sewage from the city of Nairobi and is the largest pond system in Africa.[**126**]

- Water access has fallen by five percent since 1990 due to the shortage of adequate funding to repair or replace rapidly aging infrastructure.[**68**]

- Urban households have water piped into their compound or dwelling (49%) or get water from public taps.[**69**]

- The present infrastructure is inadequate in places as Bondo, Siaya, Maua, Othaya, Mukurwe-ini and Kitui, as it was constructed in the fifties.[**70**]

- Kenya has not invested in water storage infrastructure to deal with shocks from extreme events.[**70**]

- The Rift Valley and Lake Victoria South regions have the highest percentage of citizens without water supply in the country.[**68**]

F.1.4. Water resources

- The renewable freshwater resources of Kenya are estimated at 20.2 km^3 per year, which corresponds to 647 m^3 per capita per year.[**53**]

- At the international level, the Lake Victoria Tripartite agreement set the stage for the Lake Victoria Environment Programme. The Nile Basin initiative provides the basis for cooperation of all riparian countries in the development of the water resources of the Nile Basin. The emphasis is towards the need for equitable sharing of the benefits, the sustainability of water resources, the need to build trust and cooperation between riparian countries and the need for protection of resources.[**52**]

F.1.5. Climate

- The climate of Kenya falls under the sub-tropical climate.[**127**]

- Kenya's diverse geography means that temperature, rainfall and humidity vary widely, but effectively there are four distinct zones.[**127**]

- The hot, rainy plateau of western Kenya has rainfall throughout the year, the heaviest usually during April, when as much as 200mm may be recorded, and the lowest in January, with an average of 40mm. Temperatures range from a minimum of 14°C to 18°C to a maximum of 30°C to 36°C throughout the year.[**127**]

- The temperate Rift Valley and Central Highlands have perhaps the most agreeable climate in the country. Average temperatures vary from a minimum of 10°C to 14°C to a maximum of 22°C to 28°C. Rainfall varies from a minimum of 20mm in July to 200mm in April, falling in essentially two seasons – March to the beginning of June (the 'long rains') and October to the end of November (the 'short rains').[**127**]

- Mt. Kenya and the Aberdare Range are the country's main water catchments, with falls of up to 3000mm per year recorded in these places.[**127**]

- In the semiarid bush lands of northern and eastern Kenya, temperatures vary from highs of up to 40°C during the day to less than 20°C at night. Rainfall in this area is sparse and, when it does occur, is often in the form of violent storms. July is usually the driest month, and November the wettest. The average annual rainfall varies between 250mm and 500mm.[**127**]

- The consistently humid coast region has rainfall averages from 20mm in February to around 300mm in May. Rainfall is dependent on the monsoon, which blows from the northeast from October to April and from the southwest for the rest of the year. The average annual rainfall is between 1000mm and 1250mm (less in drought years). Average temperatures vary little during the year, ranging from 22°C to 30°C.[**127**]

F.1.6. Diseases

- In Kenya there is a high degree of risk for catching infectious diseases spread through contaminated food and water like bacterial and protozoal diarrhea, hepatitis A, typhoid fever and schistosomiasis. [**7**]

- From 2000 to 2006, cholera cases were reported each year ranging from 1,157 to 816. An average case fatality rate was estimated at 3.57%.[**71**]

- During the cholera outbreak in 2009, Kenya reported 11,769 cases including 274 deaths (Case fatality rate = 2.33%). The country had not experienced such a high number of cases in the last 10 years. The peaks occurred during March-April, June and October-November.[**71**]

- 30% of global morbidity from diarrheal diseases is related to contaminated water.[**73**]

- In Kenya, like in many parts of the world, water quality is generally influenced by human related activities including reckless discharge of raw solid and liquid wastes and siltation into the water bodies including rivers, aquifers, dams and lakes. Due to lack of adequate monitoring capacities and poor institutional collaboration, inadequate enforcement mechanisms continue to undermine the effectiveness of these institutions.[**72**]

- Poor quality water problems remain a serious challenge to Kenyans, because over 40% of the people in Kenya still rely on raw water sources like wells, pans, and springs.[**72**]

- Several studies in developing countries have shown that household based disinfection of drinking water with sodium hypochlorite or with a flocculant-disinfectant reduces the incidence of diarrhea by 20-48%.[**49**]

- More than 80% of annual total mortality from diarrheal diseases is among children under 5 years of age.[**73**]

- Around 1.1 billion people in low income countries lack access to improved water sources, and arrhoeal diseases cause an estimated 2.2 million deaths a year.[**49**]

- Persistent and/or chronic diarrhoea is a major cause of morbidity and mortality in AIDS patients and, consequently, an important issue of public health, particularly in sub-Saharan Africa where more than 25 million people are living with HIV. Immunocompromised patients are as vulnerable for diarrhoeal disease as groups with an insufficient immunity system like the very young, the old and the sick.[**73**]

- Since mid 1997, Kenya is suffering from the vital epidemic disease Cholera. According to WHO in 1997 the total number of Cholera cases was 17200 out of which 555 were dead and in 1998 out of 22432, 1237 were dead.[**128**]

- Hepatitis A is a food and water borne disease and is widespread in Kenya. The virus, found in the intestine, comes into the body through water and food contaminated by sewage.[**129**]

- A contamination of the body by the hepatitis A virus gives rise to symptoms like tiredness, jaundice and sometimes fever.[**129**]

- Hepatitis A is a highly contactable disease and the whole of Kenya is a high risk zone. Every traveler visiting Kenya is advised to take precautionary measure against Hepatitis A.[**129**]

- The hepatitis A virus is deactivated by chlorine.[**130**]

- Boiling water kills typhoid fever causing micro-organisms.[**131**]

- The Hepatitis A virus is deactivated by UV irradiation.[**132**]

F.2. Disputed, uncertain or unknown facts

F.2.1. Disinfection techniques

F.2.1.1. Chlorine

- Moderate to heavy consumption of chlorinated tap water by pregnant women has been linked with miscarriage, birth defects, heart problems, cleft palate, and major brain defects. Especially pregnant women in their first three months are at higher risk of miscarrying.[**35**][**36**]

- The presence of chlorine in tap water has been linked to the dramatic rise of heart disease. Scientists argue that chlorine is a primary cause of the development of atherosclerosis, or hardening of the arteries.

- Studies show chlorinated water is toxic to human intestinal bacteria, the body's natural flora that converts organic compounds in our food into necessary nutrients.

- Chlorine disinfection byproducts (DBP's) are responsible for the increase in rectal and bladder cancers.

- Chlorine disinfectant byproducts are one of the most deadly carcinogens in tap water.

- During the summer, surface water used for drinking water contains more organic material and, as a result, DBP levels are often higher than they are in the fall and other times of the years.

- Because chlorine is a calcium antagonist, long-term consumption of chlorinated water has been linked to loss of calcium in bones. Chlorinated tap water has also been linked to childhood and adult asthma and allergies.[**35**]

- Disinfection by chlorine is still the best guarantee of microbiologically safe water.[**2**]

F.2.1.2. UV-disinfection

- This type of disinfection does not produce a disinfectant residual. Therefore it can only be used as a primary disinfectant. A secondary disinfectant, such as chlorine, in combination with UV radiation has to be used when treating drinking water with UV disinfection.[**37**]

F.2.1.3. Solar disinfection

- There are concerns that solar disinfection may cause toxic chemicals in PET bottles that can be released in the water.[**133**]

F.2.2. Governmental

- Reliance on donor funding may undermine long term sustainability of some aspects of water reforms after the external funding ends or if funding is reduced/varied due to changes in the donors' domestic foreign assistance policies.

F.2.3. Water supply and infrastructure

- The Impact Report provides data on continuity of water supply for 55 Water Service Providers in 2006-2007, weighted for distance, waiting time and affordability. The average number of service hours that Kenyan water utilities provide is 14 hours. Only in seven WSPs water supply is continuous (Nyeri, Othaya, Eldoret, Malindi, Meru, Tuuru and Tachaasis). In Nairobi water is provided on average for 16 hours a day and in Mombasa for 6 hours.[**134**]

- The majority of Kenya's population lives within 15 minutes of their water source supply.

- Women spend between 3 to 5 hours per day fetching water. This amounts to about 40% of their working day.[**70**]

F.2.4. Research and development

Several research areas have been identified as follows [**52**]:

1) The application and development of appropriate technology in combination with modern technology in Integrated Water Resources Management and Development.

2) Effective and efficient methods of catchment protection, pollution control, conservation and water use efficiency, and in particular agriculture.

3) Effective water resources management and in particular ground water and water recycling.

4) Efficient methods of disaster preparedness, intervention and recovery, and creation of mechanisms for disbursing of disaster contingency funds to the focal points in order to increase the coping mechanisms of the affected communities.

5) Effective institutional arrangements from the national to the local levels for efficient service delivery systems and control.

6) Interactive communication system backed by reliable and up-to-date data bases.

There are several achievements that have been made, among them[**52**]:

1) Introduction of slow sand filters in some of the rural water supplies.

2) Introduction of de-fluoridation gadgets for use in fluoride prone areas. The gadget uses locally available materials.

3) Improvement of household rainwater harvesting where the first dirty water is collected and disposed of in a tank and clean water is automatically transferred to the main storage tank. This technology is for the rural areas where access to clean water is limited.

4) Improved communication and collaboration with other stakeholders from local to international levels.

F.2.5. Diseases

- Outbreak of Typhoid in three different areas of Kenya in 2005 killed 21 people.[**135**]

- The number of Kenya's cholera cases is decreasing because the outbreak of cholera has come under control.[**128**]

- Typhoid fever may or may not be severe. Severe cases lead to fever, headache, malaise, anorexia and insomnia. Constipation, rather than diarrhea is seen more in adults and older children. If the disease remains untreated then by the third week it may prove fatal.[**135**]

- The typhoid virus affects only human beings. It is transmitted through contaminated food and water. If water sources are polluted then epidemics of typhoid fever can erupt when many people use the same source of drinking water.[**135**]

- Typhoid fever outbreaks are prevented by using chlorine as disinfectant.[**136**]