Environmental Handbook

Documentation on monitoring and evaluating environmental impacts

Environmental Brief

Limiting the number of pathogens in service water and wastewater

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Contents

1. Scope

1.1 Definitions

Wastewater is defined as water whose properties have been changed by domestic, industrial, agricultural or other use and other water discharged with such water in dry weather (**sewage**) and also as water from precipitation which runs off and is collected from built-up and hard-surfaced areas (**rainwater**). Liquids discharged and collected from facilities for the treatment, storage or dumping of waste are also classed as sewage.

Wastewater, whether untreated or after purification in a treatment plant, almost always reaches a **body of water** or is used as service water (from which further requirements result). Bodies of water comprise **surface waters, coastal waters** and **groundwater**. Under adverse circumstances, some of the **microorganisms** or **germs** (including pathogenic bacteria, fungi, viruses and protozoa) contained in wastewater can cause and spread diseases among animals and humans.

Unwanted or dangerous pathogens can be removed by the following means:
- **Disinfection: destruction** of, or considerable **reduction** in the number of, **pathogens causing infectious diseases** to the extent that infection no longer need be feared (Steuer, Lutz-Dettinger, 1987).
- **Sterilisation:** destruction of all microorganisms and their spores (feasible only under special circumstances and rarely necessary).
- **Removal of pathogens:** more precisely the removal of all microorganisms. In most cases, a **reduction in the number of germs** is sufficient which ensures the removal of most infectious microorganisms, making infection very unlikely. This term is usually used synonymously with “disinfection”. (May also be wastewater purification).

1.2 Problems

In the wake of epidemics of typhoid fever and cholera, disinfection of outflows from mechanical-biological sewage treatment plants using chlorinated lime was tried as long as 100 years ago (Salomon, 1906). However, it was only after 1945 that wastewater disinfection became established on a wide scale in certain countries such as the USA and Canada. In most countries, though, even now disinfection is only used in exceptional cases, for example when treating infectious wastewater and for the protection of some bathing waters. Making it a general rule to disinfect all wastewater treatment plant outflows has so far been rejected in many European countries for the following reasons:

- Other discharges of wastewater containing pathogens, such as mixed water discharges from the sewer system or diffuse discharges from municipal or agricultural sources, are not covered.
- Drinking water is mainly recovered from groundwater (for example: Denmark: 99%; Italy: 87%; Germany: 73%; France 64%; in contrast: Great Britain: 28%; USA: 10%).
- The advantages of wastewater disinfection do not justify the cost, because humans rarely come into direct contact with raw sewage, treated wastewater or highly contaminated bodies of water.
- Chlorination of wastewater treatment plant outflows can cause considerable harm to the water biocoenosis and in addition lead to the unwanted formation of organic chlorine compounds.

Nevertheless, with the further development and introduction of more extensive wastewater purification processes in industrialised countries, measures to reduce the number of pathogens in treated wastewater can be expected to gain importance world-wide. In this context, wastewater chlorination as a standard procedure for disinfection will probably be replaced by procedures such as UV irradiation and microfiltration, and in individual cases by wastewater treatment with ozone or hydrogen peroxide.

Difficult conditions prevail in many newly industrialising and developing countries: here, municipal and industrial wastewater is often discharged into bodies of water after only inadequate purification or none at all. Diffuse discharge locations exist almost everywhere, increasing the risk of infection. The extent of direct and indirect human contact with wastewater is considerably greater than in industrialised countries, especially in circumstances where there is uncontrolled wastewater discharge and where contaminated wastewater and surface water is utilised. For reasons of cost, wastewater chlorination has so far been considered to be the disinfection procedure of choice in almost all instances.

2. Environmental impacts and protective measures

2.1 Origin of microorganisms in wastewater

The following microorganisms can be expected to be present in wastewater, especially in developing countries (Bitton, 1994):

Worms and leeches (helminths): animal parasites, which infest human intestines but also other organs. They can be extremely small, but in some cases also up to several meters long (tapeworms). Well known parasites include roundworms (Ascaris), tape worms (Taenia) or liver flukes. The infection is spread in wastewater by helminth eggs.

Protozoa: single-cell organisms, sized between 1.5 and 150 µm. Important as causative agents of some tropical diseases (e.g. amoebic dysentery).

Bacteria: single-cell microorganisms, sized between 0.5 and 5 µm, which multiply by simple cell division. The most significant group of pathogens (e.g. typhoid fever, cholera, salmonellosis).

Viruses: not an actual life form but infectious particles (size 0.02 to 0.4 µm), consisting of a capsule surrounding genetic material. They cause diseases such as hepatitis A.

Fungi: these are relatively insignificant. Can cause skin diseases, for example.

The species composition and density of organisms within the flora and fauna in wastewater depend on the origin and the age of the wastewater. Organisms from the intestinal tract of warm-blooded animals and from soil are predominant in wastewater from human settlements, while soil organisms originate from drainage water. During all phases of the controlled or uncontrolled treatment of wastewater, anaerobic and facultative anaerobic species of bacteria are the predominant flora. It is usual to find a total amount of up to 10^7 bacteria/ml. Worms, viruses and protozoa are found in considerably smaller numbers. In the case of industrial wastewater (with no sanitary wastewater content), the overall number of pathogens and their differentiation depends on the type of production and therefore differs according to the branch of industry.

Human and animal faeces are mainly responsible for the presence of pathogenic microorganisms in municipal wastewater. The total number of germs in human faeces is roughly 10^{12}/g, and the number of faecal coliform bacteria 10^6/g to 10^9/g. Accordingly, depending on the origin, composition and temperature of the wastewater, the inflows to the treatment plants contain a number of microorganisms which can only partly be removed by standard wastewater treatment (Table 1).

Table 1: Ranges of pathogen concentration in sewage treatment plant inflows and outflows in developing and industrialised countries (after EPA, 1986)

Group of organisms	a) Inflow (number/ml)	b) Outflow (number/ml)
Total number of coliform bacteria	10,000 – 1,000,000	500 – 20,000
Faecal coliform bacteria	3,000 – 500,000	100 – 15,000
Faecal streptococci	500 – 50,000	20 – 1,500
Viruses	up to 100	up to 10

The origins of the pathogenic germs discharged into the sewer system vary considerably. In principle, germs causing infectious diseases can be present in all wastewater containing animal or human faeces. This is caused not only by diseased individuals but also by chronic carriers exhibiting no symptoms. In municipal wastewater, discharged faeces and also washing and rinsing water, and in hospital wastewater discharges from isolation wards, laboratories and laundries, are to be classified as potentially infectious. In the case of industrial wastewater, discharges from abattoirs, tanneries and rendering plants are worthy of special mention, as well as - in industrialised countries - wastewater from test and production laboratories and institutes for biotechnology and genetic engineering.

The proportion of water pollution with microorganisms caused by direct discharges from farms and especially from mass-rearing stations is frequently underestimated. Rainwater running off hard-surfaced areas also leads to a considerable increase in the number of germs in bodies of water, as does rainwater running off large areas of agricultural land fertilised with animal slurry or manure. That said, a significant correlation can be found in most cases between the intensity of precipitation, the retention capability of the land surface (plant cover, slope) and the utilisation of the land (type of fertilisation, livestock) on the one hand and the species and numbers of microorganisms swept off the surface on the other.

Also, the addition of pathogenic germs to surface waters from excrement of water fowl, water rats and fish (especially from commercial fish farms) should not be neglected.

Even in unpolluted bodies of water and soils, a great number of microorganism species can be found whose metabolism depends on the utilisation of the inorganic and organic matter present. The great majority of these species, however, are non-pathogenic.

Information on the survival times of selected pathogenic germs is given in Table 2 (see Appendix). In sea water the survival time for viruses is shorter and that for bacteria very much shorter than in other bodies of water; in some cases it amounts to just a few hours.

Even if it is digested, municipal sludge also represents a potential health risk to humans and animals. In addition to pathogenic bacteria and viruses, worm eggs (ascarid eggs, helminth eggs) contained in wastewater enter the sludge. Such worm eggs are sometimes discharged in large quantities into the sewer system from abattoirs on slaughtering days (absolute numbers up to 10^9). Because of their considerable ability to withstand environmental influences, ascarid eggs are used as a measure of accounting for what happens to all other parasite eggs. If ascarid eggs are destroyed, it can be taken for granted that all other worm eggs will be destroyed as well.

2.2 Influence of climate on the development of microorganisms

Temperature and residence time are factors which determine the number of pathogenic microorganisms in water at any given time. Although a specific growth and death rate curve can be determined under laboratory conditions for individual species of organisms, parameters such as the availability of nutrients, pH, salt content and the number of competing organisms influence growth kinetics, such that prognoses as to the number of pathogens at a time x_t vary considerably. For bacteria, the mode of growth is the same in a temperature range between roughly 10 and 40 °C if there is a sufficient supply of nutrients. After an initial adaptation phase (lag phase) the number of bacteria increases exponentially (log phase), followed by a stationary phase and finally by the decline phase. Most bacteria species grow within a temperature range of 30°C, but only a small temperature range actually provides optimum growth conditions for them. For human intestinal bacteria this optimum growth temperature is in the region of 40°C, whereas for psychrophilic bacteria it is around 25 °C (Fig. 1, see Appendix).

Growth and survival of pathogens in water:

- Higher water temperatures lead to a faster increase in the number of pathogens because of increased rates of division in comparison with lower water temperatures.

- Microorganisms living in water can cope better with gradual changes in temperature than with sudden ones.

- In developing countries, where water temperatures are often high, the lifetime of the pathogens is reduced because predators grow equally fast. The high level of UV irradiation reduces lifetime as well.

This means that in tropical countries where water temperatures are constantly high the physical turnover of the entire water biocoenosis is accelerated, so that immediately after contaminated wastewater is discharged into bodies of water the number of mesophilic pathogenic bacteria increases faster than in intermediate latitudes. However, following this increase, higher organisms use the bacteria and protozoa as food at a much faster rate in high temperatures than at low temperatures. This “self-cleaning effect” is the reason why the survival time of pathogens is shorter in the tropics. At higher latitudes however, mesophilic bacteria are often the predominant species in summer, and psychrophilic bacteria in winter. Here, the frequent changeover of water biocoenosis leads, among other effects, to a reduction in the self-cleaning capacity of any given body of water. For this reason, survival times are longer. This effect has also been proved for polio viruses and for the total number of measurable bacteriophages in experiments undertaken in Germany on the elimination of pathogens in water from the outflows of sewage treatment plants (Käss, 1992).

2.3 Microorganisms in wastewater and bodies of water

2.3.1 Wastewater in irrigated agriculture

World-wide, probably far more than 1 million hectares of agricultural land are irrigated with wastewater that has been pretreated in different ways. This constitutes a risk for humans and animals of becoming infected with pathogenic bacteria, viruses, protozoa or worm eggs if no special preventative measures are taken. However, the use of surface waters with a low level of contamination also causes or promotes certain tropical diseases (e.g. bilharziosis, malaria, yellow fever or Dengue fever).

Mechanisms of infection for causative agents of water-borne diseases are:

- Direct contact
- Dissemination as an aerosol
- Ingestion of irrigated agricultural products
- Contact with contaminated bodies of water

The following factors influence the effect of the pathogens:

- Death rate of the microorganisms
- Pathogenicity
- Minimum infectious dose
- Immunisation of the population
- Distance of irrigated areas of land from settlements
- Methods, timing and duration of irrigation
- Hydrogeological conditions

Among these factors, it is mainly the irrigation methods that have a considerable influence on the spread of pathogens. The use of sprinklers leads to the formation of an aerosol (about 0.1 to 1% of the amount of water spread). As a result, pathogens may be transported as far as 750 m with the wind. Using small sprinkler systems, for example in orchards, can reduce direct contact of the fruit with the water. However, if drip irrigation (trickle irrigation) is used, no aerosols are formed and crops growing above ground only come into contact with the wastewater applied when they touch the soil. If the irrigation hoses are laid in the ground or beneath a plastic sheet, any direct contact is avoided. Pathogenic microorganisms are not normally transported upwards through the roots.

Population-wide immunisation programs against water-borne diseases are above all directed against viral infections and some bacterial infections, such as typhoid fever.

The health risk caused by contact with pathogenic organisms in irrigated agriculture can be categorised after Shuval et al. (1986) as follows:

- High risk: worm eggs, (Ancylostoma, Ascaris, Trichuris, Taenia);
- Medium risk: *Cholera Vibrio*, *Salmonella typhosa*, *Shigella*,
- Low risk: enteroviruses.

In sandy soils, transportation of pathogens is limited under normal irrigation conditions; if the sand is interspersed with coarse-textured soils such as gravel and pebbles however, transportation across more than 100 m as far as nearby wells is possible. There is a particular risk of fast vertical pathogen dissemination if shallow soils with low sorption capacity on karst ground are irrigated.

The survival times of selected pathogens in soils and on crops are shown in Table 3. They are shorter than the corresponding survival times in water listed in Table 2 (see Appendix), especially on crops (high levels of solar irradiation and desiccation).

Table 3: Survival times of pathogens in soils and on crops (World Bank, 1986)

Organisms	Survival time (d)	
	In soils	On crops
Viruses		
Enteroviruses[(a)]	<100; normally <20	<60; normally <15
Bacteria		
Faecal coliform	<70; normally <20	<30; normally 15
Salmonella sp.	<70; normally <20	<30; normally <15
vibrio cholerae	<20; normally <10	<5; normally <2
Protozoa		
entamoeba histolytica (spores)	<20; normally <10	<10; normally <2
Helminths		
Eggs of *ascaris lumbriocoides*	several months	<60; normally <30
Hookworm larvae	<90; normally < 30	<30; normally <10
Eggs of *taenia saginata*	several months	<60; normally <30
Eggs of *trichuris trichiura*	several months	<60; normally <30

[(a)] including polio, ECHO and Coxsackie viruses

2.3.2 Surface waters

Even after mechanical and/or biological purification, increased numbers of hygienically relevant microorganisms can be detected in wastewater discharged into surface waters. In the case of faecal coliform bacteria used as indicators, this usually amounts to 10^4 - 10^6 per

100 ml. Such figures are far above those aimed for in the EU directive on the quality of bathing waters, which is the only binding standard for a bacteriological-hygienic evaluation of bodies of water (see 3.1). However, there are no recognised microbiological standards for sewage treatment plant outflows.

As a rule, a higher degree of contamination of bodies of water with microorganisms can be expected after episodes of heavy rain. This is caused by soil swept off the surface of agricultural land, mobilisation of sediments during flooding and especially by pollution from the discharge of mixed water, when untreated wastewater mixed with rainwater is discharged directly into surface water.

After their discharge, the number of pathogens in the surface water is gradually reduced by self-cleaning processes, although a high degree of organic contamination in combination with higher water temperatures can initially lead to an increase in the number of pathogens. The death rate is determined by abiotic factors such as temperature, pH and UV irradiation, but above all by predators which use the pathogens as food ("grazing") and by competition in the form of the indigenous microflora. Some hygienically relevant microorganisms are highly adaptable to changes in environmental conditions because they can change or reduce their metabolism in a short period of time. They find good conditions for survival in fine-textured sediments where pathogen numbers are many times higher than in the flowing water. If the flow and therefore the water turbulence varies, pathogens can be released again from the sediment. This is the reason why the rate of pathogen reduction is subject to considerable variations and difficult to quantify. After wastewater is discharged, the self-cleaning distance for faecal pathogens is 5 to 15 km in relatively cool, flowing water; it is shorter in tropical water flowing at the same velocity.

2.3.3 Groundwater

Causative agents of infectious diseases spread by groundwater are almost without exception bacteria and viruses. Fungi, protozoa and metazoa have virtually no impact on health in higher latitudes, and only a minor impact on health in the tropics and subtropics.

The surface soil constitutes a barrier which reduces the number of pathogens. However, direct discharge into groundwater, for example via invaded wells or gravel pits, poses more problems. After admission of biologically purified wastewater to overflow meadows, it has been shown that a sandy-silty layer with a depth of about 1 m is sufficient to reduce the number of E. coli in the seepage water by 99.9 % given an application of 50 $l/m^2 \cdot d$ to the area. If biologically active humus layers are present this result is even better.

Test results show that pathogens in the groundwater originating from a discharge point for wastewater or landfill leachate do not move as a block of contamination (Knoll, Jung, 1995). Instead, a depot forms at this site from where pathogens are distributed over a lengthy period of time. The initial site of pollution long remains contaminated even after the cessation of discharge. The survival times of indicator pathogens such as Proteus mirabilis, Pseudomonas aeruginosa or E. coli extended to more than 100 days. Matthess et al. (1985, 1991) found that the longest time for these pathogens to be detected in sandy aquifers was 30 days with transportation distances of about 60 m. This short distance can be attributed to filter effects, as the actual survival times of the pathogens are longer.

Most of the bacteria in groundwater – up to 99% or more in sandy biotopes – are situated on the hard surfaces of the loose rock underground. In waters rich in nutrients, they can form slimy "biofilms" on these surfaces. A specific food chain consisting of bacteria $\rightarrow$ protozoa $\rightarrow$ metazoa $\rightarrow$ carnivore metazoa usually results in the elimination of the pathogenic as well as other microorganisms. In any case, groundwater provides highly adverse living conditions for pathogenic organisms.

In sandy-gravelly aquifers, widespread contamination of the groundwater with pathogens beyond the 50 days limit is not to be expected in most cases. In coarse gravel and karst regions however, wide-ranging transportation of pathogens is possible.

Little is known about the occurrence of viruses (bacteriophages) in groundwater; at present, therefore, it is not yet possible to assess their significance with regard to bacterial composition. The hygienically most significant virus spread by water is the causative agent of infectious hepatitis, the hepatitis A virus. This virus is relatively resistant to environmental influences. The same applies to some enteroviruses that are spread in water: poliomyelitis, Coxsackie and ECHO viruses.

2.3.4 Coastal waters

As in other bodies of water, the death rate of pathogens in sea water is mainly influenced by water temperature, insolation, salt content, pH, and the presence of other organisms.

Pathogenic bacteria introduced into coastal waters are eliminated faster than in fresh water, primarily by the indigenous flora of the seawater. Studies have shown that if the number of marine bacteria is 100,000/ml – as is commonly the case – the elimination of coli bacilli takes place up to 1,000 times faster than if there is a small number of marine organisms (Mitchell, 1972). In this context, the way in which the wastewater is introduced is of considerable importance: if there is single-point introduction through a simple wastewater pipe, a high pathogen count is initially found within a small area. Depending on convection and the flow of the seawater in three dimensions, however, this count decreases at a varying rate. If diffusers are used to ensure better spreading of the wastewater discharge, even the initial pathogen count will be significantly lower. In both cases, a hydraulic propagation model should be drawn up to enable a prediction to be made of the pathogen count in space and over time. (For details on the measurement of pathogens when wastewater is discharged into coastal waters with low levels of contamination, see Appendix.)

2.4 Measures for the removal of pathogens from wastewater

2.4.1 Reduction of pathogen counts in wastewater purification

During the treatment of wastewater - in addition to the reduction of organic pollutant loading - the concentration of pathogenic and non-pathogenic microorganisms is lowered. Where treated wastewater is used for irrigation or where the bodies of water into which wastewater is discharged are vulnerable, the pathogen count should be reduced by a factor of about 10^{-4} for faecal bacteria (i.e. a reduction by 99.99%) and by a factor of about 10^{-3} for worm eggs (= 99.9%). In most cases, the pathogen contamination remaining after this reduction can be tolerated (WHO, 1989).

Normal wastewater treatment plants employing state-of-the-art mechanical-biological treatment methods and also purification systems using plants are able to reduce the concentration of pathogenic bacteria at least by 2 powers of ten (i.e. by 99%). Assuming a contamination of the untreated water with 10^8 faecal coliform bacteria/100 ml, for example, this corresponds to 10^5 to 10^6 bacteria/100 ml in the outflow.

Details of the removal of pathogenic organisms during the purification process following the evaluation of several studies are given in Table 4.

Table 4: Reduction of pathogenic microorganisms during different stages of wastewater treatment (as logarithmic exponents) (according to World Bank, 1986)

Stage of treatment	Bacteria	Viruses	Single cell organisms (protozoa)	Helminths
Mechanical primary clarification	0 - 1	0 – 1	0 - 1	0 - 1
Simple biological treatment (septic tanks)	1 - 2	0 – 1	1 - 2	1 - 2
Trickling filter	0 - 2	0 - 1	0 - 1	0 - 1
Activated sludge process	2 - 3	1 - 2	1 - 2	1 - 2
Tertiary ponds (retention time 20 d; 4 units)	4 - 6	2 - 4	4 - 6	4 - 6

This shows that the tertiary ponds downstream of the treatment plant are the units which have by far the greatest effect. In the tertiary ponds, the helminths are eliminated mainly by sedimentation, and the remaining organisms by sedimentation, by natural predators and (especially in regions with high levels of insolation) by destruction through UV rays.

It should be noted that a large proportion of the eliminated pathogens remain in the sludge. It is therefore not practical to use this sludge, in vegetable growing for example, without previous sanitation. The sludge should either be made alkaline by adding lime or be stored for about one year before being used.

The following points should also be noted:

- The direct discharge of wastewater from mixed water relief sewers into bodies of water must be avoided, for example by building stormwater retention tanks and connecting them to the treatment plant.

- At low temperatures, warm industrial wastewater must not be discharged together with untreated sanitary wastewater from the same site, because bacteria such as coliform bacteria, salmonella and enterococci reproduce quickly under these circumstances.

2.4.2 Removal of pathogens from wastewater with disinfectants

The main disinfectants used in the removal of pathogens from wastewater are chlorine (Cl_2) and ozone (O_3); others used less extensively are chlorine dioxide (ClO_2) and chlorine-separating substances such as chlorinated lime (= mixture of CaO and CaOCl) and sodium hypochlorite (NaOCl).

The disinfectant effect of chlorine depends strongly on the pH value: at values between 6 and 8 it is significantly better than at more alkaline values. The actual disinfectant effect is provided by the hypochloric acid (HOCl) formed by the introduction of gaseous chlorine into water. Commonly used metering apparatuses mostly use an injector, through which the gas is introduced into the wastewater using a vacuum. The gas is metered according to the amount of water flowing through and according to the chlorine consumption of the wastewater, which must be determined by advance tests. For a retention time of 15 to 30 minutes in a reaction tank, the amount of chlorine required is between 5 and 20 g/m³ wastewater.

If chlorine dioxide is used as a disinfectant it must be produced directly at the location of its use, for example with the hydrochloric acid/chlorite method. Between 3 and 10 g ClO_2/m^3 wastewater are needed. Only a small amount of haloform substances and chloramines are formed during this process.

In comparison with chlorination, the disinfection of wastewater with ozone is better for the receiving bodies of water. Ozone is a highly reactive gas and cannot be stored or transported over long distances. It is produced directly at its place of intended use by silent electrical discharge in an ozone generator using dried air and pure oxygen. Essential factors for successful disinfection are the metered amount of ozone and the retention time in the reaction tank, in addition to rapid intermixture with the wastewater. Substances in the water which consume ozone and substances with catalytic effects, which speed up the decomposition of ozone, must be taken into consideration when estimating the amount of ozone necessary for disinfection. To ensure a sustained minimum concentration of 0.3 – 0.5 g O_3/m^3 in municipal, biologically treated wastewater for approximately 10 minutes, the amount of ozone employed is usually 10 - 20 g/m³. Preliminary tests on ozone consumption are required in order to run an ozone plant to optimum effect.

Ozone generators consist of a considerable number of paired electrodes (plate or tube generators) arranged inside a steel container. The capacity of such units ranges from a few kg of ozone per hour to more than 100 kg per hour. The power consumption for generating 1 g of ozone ranges from between 10 and 30 Wh if air is used to between 6 and 15 Wh if oxygen is used, depending on the size of the generator.

Frequently, ozone is dissolved in a side flow of the wastewater under high pressure. This is then reunited with the remaining wastewater in a countercurrent arrangement. The excess ozone not consumed during this reaction must be removed using heat or catalysts in a residual ozone elimination unit. The cost of wastewater disinfection with ozone is roughly DM 0.10 to 0.35/m³ wastewater (ATV, 1997). This constitutes a substantial financial burden for developing countries, which is why ozone should be used as a disinfectant only in relatively sensitive areas such as in food processing. Because the plants need inspection, there is no cost advantage in relation to industrialised countries.

2.4.3 Removal of pathogens from wastewater using physical methods

These methods include filtration through granulated media, membrane filtration, UV irradiation, high-temperature treatment and direct insolation using the thin-film method. Of these, only filtration (mentioned in 2.4.1) and UV irradiation have so far gained substantial importance in practice.

When treating small volumes of wastewater, it is also possible to use thermal methods. These are mainly suitable for wastewater containing posing a high risk of infection. Untreated wastewater including suspended matter can also be disinfected in this way. If the potential risk is small, thermal treatment above 70 °C for about 20 minutes is sufficient. Highly infectious wastewater, however, should be treated by sterilisation at temperatures above 121 °C for at least 20 minutes (this corresponds to a pressure of approximately 2 bar).

In the technical UV irradiation of wastewater it is mainly the UV-C spectrum with a wavelength range of 200 to 280 nm which has a microbicidal effect. During this process, the high-energy radiation is absorbed by the DNA of the microorganisms, damaging the proteins of the genetic material and thereby preventing reproduction of the pathogens. Viruses and gram-negative bacteria such as *E. coli* and salmonella are sensitive to UV irradiation; gram-positive bacteria such as staphylococci and streptococci are less sensitive. Fungi and some bacterial spores are relatively resistant to UV irradiation, as are worm eggs and other permanent forms of single-cell and multicellular organisms (ATV, 1997).

UV disinfection should always be applied after the last stage of wastewater treatment in a purification plant. At this stage the light transmission capacity of the wastewater is at its highest, meaning that the lowest UV dose is required. Usually the wastewater that is to be disinfected flows through an open flume with no pressure applied, where the UV radiators are installed horizontally to the direction of flow. Under normal circumstances disinfection can be ensured with a UV dose of 300 to 400 J/m^2. The arrangement and routine operation of the UV unit must ensure that this dose is applied under all operating conditions. Details of the amount of energy (in the form of UV-C radiation) required in respect to different types of wastewater treatment can be found in Table 5 (see Appendix).

The UV radiators used most commonly today are mercury radiation emitters, which differ in terms of UV emission and energy consumption. The wastewater from which the pathogens are to be removed and the UV unit must meet the following requirements (Rudolph, 1993):

- The biologically treated wastewater should have a light transmission capacity (transmittance) of 45% to 70% if at all possible. Below 45% the effectiveness of UV irradiation is limited.
- The amount of turbid matter in the wastewater should be below 20 mg/l.
- To ensure even irradiation, the water flow through the UV chamber should be turbulent. Dead spaces must be avoided, as well as water levels falling below or above the level of the radiators.
- The arrangement of the radiators should ensure a high level of irradiation with the least possible installed electrical power.

It must be possible to check the disinfection performance of a UV unit online at any time during routine operation. Photosensors which measure the intensity of the radiation are used for this reason.

Because water is heated around the radiator tube sleeves, deposits may form, depending on the types and amounts of substances dissolved in the wastewater; when the unit is switched off, biofouling may also occur. In such cases, the reduction in irradiation impairs the disinfectant effect. For this reason, automatic wipers are now part of the standard equipment of an irradiation unit.

In recent years, UV disinfection of wastewater has become more and more important for developing countries as well, as it is a relatively simple method which does not require the use of chemicals. Equipment can be retrofitted to existing wastewater treatment plants. In some countries, for example Great Britain, this method is already established as the standard procedure in such cases where wastewater disinfection is required. UV units are already in use in some developing countries, too. However, relatively well trained operating personnel are a prerequisite.

The operating costs quoted by several authors (electrical power, replacement of UV radiators after about 10,000 h, maintenance) amount to around 0.02 – 0.04 DM/m^3, while the capital costs, depending on requirements, lie between 0.1 and 0.2 DM/m^3.

3. Notes on the analysis and evaluation of environmental impacts

3.1 Sanitary requirements for the use of wastewater and bodies of water

In most industrialised countries no limit values have been stipulated for the discharge of pathogenic microorganisms into bodies of water and the public sewer system because, in contrast with developing countries, no direct use of the water is usually made.

In Germany, sanitary problems relating to wastewater are managed in general terms by the requirements of the Federal Water Act *(Wasserhaushaltsgesetz)* §1 (general duty of care in order to avoid water pollution) and the Federal Epidemics Law *(Bundesseuchengesetz)* §12 (avoidance of health risks posed by pathogens). Disinfection before discharge into bodies of water or the sewer system is only required for wastewater from a few areas of origin:

- Wastewater from genetic engineering units (Genetic Engineering Safety Ordinance, 1990)
- Wastewater from carcass disposal (Carcass Disposal Plants Ordinance, 1976)
- Wastewater from tanneries (Appendix List of the Federal Board of Health according to §10 Federal Epidemics Law, 1994)
- Highly infectious hospital wastewater (among others, DIN 19520: Treatment of Wastewater from Hospitals, 1964)

After discharge into the sewer system, “normal” hospital wastewater should be mixed with municipal wastewater in a ratio of at least 1:100. Special requirements for wastewater from isolation wards in general hospitals can be imposed by the authorities.

Because there is a special risk to humans if they come into direct contact with contaminated water (bathing, water sports), the EU directive on the quality of bathing waters is often used as a guideline or as a standard for quality requirements for the use of bodies of water. The microbiological guide values specified there can be applied to the microbiological wastewater quality requirements (see Table 6, Appendix).

With regard to the use of wastewater in agriculture in warm climates, the WHO recommends that excessively high sanitary requirements should not be applied, especially in the case of bacteria (e.g. California standards of effluent reuse of 1968), but rather that about 1000 faecal coliform bacteria per 100 ml should be allowed depending on the type of wastewater use. This guide value is also recommended for the operation of aquacultures. The unreasonable application of excessively strict bacterial quality standards is rejected in the light of extensive experience in tropical countries. On the contrary, imposing too-demanding requirements would lead to the avoidance of suitable technical measures and to inadequate controls by the responsible authorities. Appropriate water treatment methods are available which, in combination with regulations on the type of irrigation for different crops and the observation of personal hygiene, ensure that only a small potential risk remains.

On the other hand, the risks posed by helminths have so far been underestimated. These organisms should be removed almost totally, especially if the wastewater is used in agriculture in tropical countries. The number of worm eggs to aim for is ≤ 1 per litre. This figure can only be attained by a combination of conventional wastewater purification with long-term retention (> 8 days >) in tertiary ponds or with a combination of aerated oxidation ponds and tertiary ponds.

3.2 Water-borne diseases

Pathogenic microorganisms infect humans and animals with water-borne diseases in the following ways:

- Ingestion of untreated wastewater
- Ingestion of insufficiently treated drinking water
- Ingestion of food contaminated with pathogens from polluted water
- Skin contact with contaminated water

Table 7 summarises the causative agents of important water-borne diseases (according to ATV, 1997).

Table 7: Important pathogens present in wastewater

Pathogen (families)	Diseases
Viruses:	
Hepatitis A virus	Hepatitis A
Adenoviruses	Respiratory diseases Eye infections
Polio viruses	Poliomyelitis, meningitis
Coxsackie virus A, B	Herpangina, meningitis
Bacteria:	
Salmonellae	Typhoid fever, paratyphoid fever, enteritis
Shigellae	Dysentery
E. coli	Enteritis
Vibrios	Cholera, gastroenteritis
Pseudomonas species	Ear and skin infections
Mycobacteria	Tuberculosis, skin granulomas
Staphylococci	Purulent infections
Bacilli	Anthrax
Clostridiae	Gas gangrene
Protozoa:	
Amoebae	Amoebic dysentery
Lambliae	Lamblia dysentery
Trichomonads	Genital infections
Cryptosporidiae	Intestinal infections
Worms and worm eggs:	
Ascarids	Ascariasis
Tape worms	Taeniasis
Thread worms	Oxyuriasis
Schistosomae	Bilharziosis (schistosomiasis)

In tropical and subtropical countries, most serious infections and deaths after infections caused by water-borne pathogens are limited to just a small number of diseases (UN figures for 1986):

- **Diarrhoea:** about 1,500 million infections causing about 4 million deaths in children under 5 years of age
- **Schistosomiasis (bilharziosis):** 900 million infections causing more than 200.000 deaths
- **Roundworm infections:** about 900 million infections causing 200,000 deaths
- **Hookworm infections:** about 900 million infections causing 50,000 deaths
- **Typhoid, paratyphoid fever:** about 1 million infections causing about 25,000 deaths
- **Poliomyelitis:** about 200,000 infections causing about 25,000 deaths

The majority of epidemics caused by bacteria involve cosmopolitan diseases, for which a warm climate is a favourable factor, although not a prerequisite. These include diseases which some time ago were prevalent in Central Europe as well, but which today are usually only endemic in warmer countries (cholera, for example). In addition, there are diseases which, although still present in Europe, have lost their significance there (such as bacterial dysentery, Salmonella enteritis and typhoid fever). By far the most morbidity and mortality in tropical countries is brought about by bacterial intestinal infections (diarrhoea) caused mainly by shigellae, but also by salmonellae and vibrios. It is noteworthy that the infectious dose varies considerably in some cases: often, 10^8 to 10^9 live bacteria are necessary to cause an infection with salmonella, whereas sometimes only 200 cells are sufficient to cause Shigella dysentery.

Cholera is an endemic disease in countries such as India. *Vibrio cholerae* is the main causative agent. People are usually infected by contaminated water and food and often by chronic carriers without symptoms. Under normal sanitary conditions the disease rarely spreads, because a very large number of pathogens is necessary to produce this effect (10^8 to 10^{10}). Long-term experience with this disease shows that simple improvements in personal hygiene and in wastewater disposal can easily control the disease. It is mainly debilitated persons who are affected.

Another category of causative agents of diseases that is almost as important is parasitic worms (helminths), which have a far greater significance in tropical and subtropical countries than in moderate climates. Infections with schistosomes, hook worms and filiform nematodes are very common and can cause epidemics among the population. In warm countries, the skin constitutes an important portal of entry for helminths, as well as the mouth. Infection is mainly brought about by the use of wastewater in agriculture, but also when working in bare feet when cultivating rice. In respect of the use of wastewater in agriculture, the WHO (1989) states the health risks posed by helminths to be significantly greater than the risks posed by bacteria, viruses or single cell organisms. It is very difficult to remove worm eggs by wastewater disinfection, however. This can only be achieved by a sufficient degree of wastewater treatment.

The most common helminthic disease is bilharziosis. It is transmitted by Trematodae (flukes), which can be found in ditches, canals, irrigation systems and reservoirs (for example the Nile delta). A snail is needed as an intermediate host. The following prerequisites must be met: carriers of worm eggs, snail species suitable as intermediate hosts, contamination of the water containing the snails with faeces, water temperature mostly >25 °C, contact with human skin. In order to prevent bilharziosis, no wastewater or faeces should be discharged into bodies of water containing snails.

3.3 Experience with the removal of pathogens from wastewater

In a number of tropical and subtropical countries (such as Jordan, Israel and Mexico) positive experience has been gained with the reduction of the number of pathogens in wastewater using tertiary ponds, connected downstream of a conventional treatment plant or aerated oxidation ponds. The numbers attained have not always been below the WHO guidelines of 1000 faecal coliform bacteria/100 ml. This is barely a problem, however, if personal safety precautions (e.g. wearing wellington boots, avoidance of direct skin contact) are taken in irrigated agriculture and the known irrigation rules are observed. Helminths, which pose particular problems, are reliably destroyed by plants of this type. Studies have shown that a sufficient reduction in the number of enteropathogens ensures that, after discharge into a body of water either in the tropics or in moderate climate regions, they will not multiply to such an extent as to constitute a risk of infection (Rudolph K. et al., 1994).

In Israel, most of the wastewater generated in the country is reused after purification. Treatment with disinfectants is carried out only in special cases. The WHO rules are normally observed; the concentrations of faecal coliform bacteria stipulated in California, i.e. < 20/100 ml, are considered overly strict (Avnimelech, 1992).

In Europe and North America, the removal of pathogens from biologically treated wastewater using UV irradiation has in the meantime become the state of the art. Widespread use is not pushed, because it is questionable if pathogens should be removed from the outflow of a treatment plant purely for precautionary reasons.

There is growing criticism of the disinfection of wastewater with chlorine, for reasons such as the formation of harmful by-products. Although the respective discharge standards in Egypt and Tunisia, for example, stipulate concentrations for coliform pathogens which are barely achievable without disinfection, the figures attained are rarely monitored.

In Saudi Arabia, wastewater from a clinical centre was disinfected with sodium hypochlorite before being used as sprinkling water in the hospital grounds. Although pathogen microorganisms could not be detected immediately afterwards, after a storage time of several days the purified water was found to be heavily recontaminated with pseudomonas species and flavobacteria (Rump, 1999). These bacteria are not considered to be directly pathogenic, but they are feared as so-called “hospitalism germs” in health care institutions in particular.

The use of disinfectants for the removal of pathogens from wastewater can be necessary for sanitary reasons. However, even if used correctly, some of these substances are dangerous for the operating staff of wastewater treatment plants or have negative effects on the environment. Provision must therefore be made for appropriate personal safety and environmental protection measures. Also, bodies of water can be harmed by an excess of disinfectants if disinfected wastewater is discharged into them. Depending on their reaction mechanisms and their toxic limit concentrations, the effect of the substances on organisms living in the water varies. Retention time (persistence) and possible detrimental reactions with substances dissolved in the water must be taken into account in this connection.

Note: The various disinfectants and their effect on the removal of pathogens from wastewater are described in the Appendix.

4. Interaction with other sectors

Points of contact occur mainly in areas of planning and measures aimed at protecting the human environment and preserving or restoring the health of humans and animals. There are connections to other sectors in all areas where raw water for drinking water production is endangered by wastewater pathogens; this applies to the higher ranking planning level such as water industry framework planning as well as to specific objectives in infrastructure or agriculture. The subject of removing pathogens from wastewater is of particular and immediate significance for drinking water treatment in the context of municipal and rural drinking water supply. In terms of its content, it represents a specific addition to the Wastewater Disposal brief.

a) Trans-sectoral planning

- Regional planning
- Water industry framework planning
- Tourism

b) Infrastructure

- Rehabilitation of residential areas
- Health services, hospitals
- Wastewater disposal
- Municipal and rural water supply

c) Agriculture

- Irrigation
- Fishing and aquaculture

5. Summary assessment of environmental relevance

Adequate wastewater purification is the most important prerequisite for avoiding or reducing the incidence of water-borne diseases. Depending on local conditions, the removal of pathogens beyond that achieved by mechanical-biological wastewater treatment measures is only necessary where wastewater from certain sources which poses particular sanitary risks (see 3.1) has to be disinfected at its place of origin or where a body of water receiving wastewater is used in the following ways:

- For the recovery of drinking water
- As bathing water
- As sprinkling water in agriculture for sensitive cultures, e.g. leafy vegetables
- As drinking water for livestock
- For commercial fishery

After a decision has been taken to remove pathogens from wastewater using disinfection, the following points must be considered:

- Mechanical-biological wastewater treatment should be arranged upstream of the disinfection stage.
- UV irradiation should be preferred to methods employing the use of chemicals. However, UV irradiation requires water that is free from turbid matter to a large extent to allow the radiation to take optimum effect.
- Other methods that can possibly be applied include the use of ozone, chlorine dioxide, peracetic acid, hydrogen peroxide (the latter two only if small amounts of wastewater are involved).
- The use of chlorine and chlorine-separating substances for disinfection at the treatment plant outflow must be ruled out because of undesired effects on bodies of water (except in emergencies). In contrast, the chlorination of a side flow of wastewater in order to use it as rinsing or sprinkling water within the treatment plant may make sense.
- If possible, the number of pathogens at the treatment plant outflow should be below the guide values of the EU guidelines for bathing water.

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7. Appendix

7.1 Disinfectants and their effects

7.1.1 Chlorine and chlorine-containing substances

The disinfectants chlorine, chlorine dioxide, hypochlorite and chloramine have a highly toxic effect on almost all water organisms. Chlorinated wastewater which is not passed through a dechlorination stage before being discharged can lead to mass death of fish; 0.05 mg/l of free chlorine in the water is almost always fatal. 0.3 to 0.6 mg/l causes irreversible losses in the plant and animal biomass. This damages the self-cleaning capacity of the body of water and harms the natural predators of the pathogenic microorganisms.

During the disinfection of wastewater with chlorine or sodium hypochlorite, it must be expected that organic chlorine compounds will be formed – even more so than is the case with the chlorination of drinking water. For example, toxic reaction products such as chloramines, slow-evaporating chlorinated hydrocarbons, trihalomethanes and chlorinated phenols can be formed from amino acids or humic acids. As a group, these products are referred to as AOX (= adsorbable organic halogen compounds). If AOX values are high in a body of water, its use for the recovery of drinking water is greatly limited, and the water often has an unappetising smell ("pharmacy smell"). Some persistent organic chlorine compounds accumulate in the food chain and thus lead to lasting environmental damage.

In comparison with the use of chlorine, disinfection using chlorine dioxide carries a lower risk of the formation of harmful substances, and AOX formation is also reduced by more than 90%.

The handling of chlorine, chlorine dioxide and chlorine-separating disinfectants requires strict safety measures because of the toxicity of these substances. Chlorine and chlorine dioxide are gases, with a maximum allowable concentration at the place of work (MAC) of 1.5 mg/l and 1.45 mg/l respectively. Even low concentrations in the breathable air cause breathing difficulties and irritation of the airways, while higher concentrations have a paralysing effect on the central nervous system. Chlorine is usually supplied in pressurised cylinders. The regulations devised in the industrialised countries, such as DIN 19606 and 19607, must be observed during the installation and operation of chlorine gas metering apparatus. Because it is now also common practice in developing countries to use chlorine gas apparatus that operates according to the vacuum principle, the handling of potentially dangerous chlorine has become relatively safe even in developing countries. Chlorine dioxide cannot be stored but must be produced immediately before use, for example from sodium chlorite and hydrochloric acid. The solutions of both of these chemicals are dangerous substances and must be stored and handled in the proper manner.

7.1.2 Oxygen-containing substances

Because of its strong oxidising effect, ozone brings about a breakdown of organic residues in wastewater. Biological treatment of the resulting intermediate products is usually easier than that of the original substances. A further breakdown in the water can therefore lead to oxygen depletion and to a worsening of living conditions for water organisms. In addition, if the ozone dosage is high, the formation of new persistent substances must also be expected, especially in industrial wastewater. As opposed to the effect of chlorine and chlorine-containing substances, there are not normally any disturbances in the body of water after the ozonisation of wastewater: excess ozone reacts with substances in the water only at the discharge site and also rapidly fragments to form oxygen. If bromides are present in the wastewater, however, ozone can lead to the formation of carcinogenic bromate.

In developing countries, ozone and other oxygen-containing disinfectants tend to be used only in exceptional cases. However, they are sometimes used in the treatment of wastewater and service water in food-processing factories, for example.

Special safety requirements apply to the operation of ozone plants. If limit values for gas flow, cooling water temperatures and the high-voltage source are exceeded, alarms and shut-off systems must be installed. The threshold odour concentration for ozone is 0.02 ppm, and the maximum allowable concentration (MAC) for an 8 hour stay at the place of work is 0.1 cm^3/m^3 (this corresponds to 0.2 mg/m^3 or 0.1 ppm); concentrations of 0.5 ppm or more cause symptoms of poisoning in humans. According to OSHA/ASTM, a maximum concentration of 0.3 ppm within 10 minutes must not be exceeded. Continuous measuring of ozone in interior air at the place of work is therefore recommended. Adequate ventilation must be ensured in enclosed spaced (at least a 10-fold change of air per hour). Breathing masks must be available.

Other oxygen-containing disinfectants such as hydrogen peroxide, peracetic acid and potassium permanganate are significantly less toxic for water organisms when compared with chlorine-containing substances. If the volumes of water are small, consideration can be given to using them, also in developing countries. Whereas the first-named substances decompose to form harmless end products, insoluble manganese oxides remain after the reduction of potassium permanganate. Accident prevention regulations must be observed when handling the substances.

7.1.3 Other substances

If the amounts of contaminated water are small, sometimes iodine, bromine or silver compounds are used to reduce the number of pathogens in addition to the disinfectants mentioned above. The alkaline solutions such as caustic soda lye or milk of lime formerly used for wastewater disinfection in the isolation wards of some hospitals have nowadays been replaced by commercially available disinfectants. Such substances are also used to disinfect faecal residues from chemical toilets on building sites. They often contain formaldehyde or quaternary ammonium bases, which can interfere with the biological stage in treatment plants after they are discharged into the sewer system. A detrimental effect on bodies of water is not likely where wastewater collection and treatment is properly regulated. If this is not the case, other disinfection methods should be chosen. A risk of damage to water organisms is only likely if the substances are discharged directly into bodies of water.

7.2 **Fig. 1:** Influence of temperature on the rate of division of bacteria

(image available in printed version only)

7.3 Table 2:

Survival time of pathogens at 20-30 °C in surface water and wastewater (World Bank, 1986)

Organisms	Survival time (d)	Infectious dose
Viruses		low
Enteroviruses[(a)]	<120; normally <50	
Bacteria		medium to high
Faecal coliform	<60; normally <30	
Salmonella sp.	<60; normally <30	
Shigella sp.	<30; normally <10	
vibrio cholerae	<30; normally <10	
Protozoa		low to medium
entamoeba histolytica (spores)	?	
Helminths		low
Ascaris lumbriocoides eggs	?	

[(a)] including polio, ECHO and Coxsackie viruses

Where wastewater is discharged into coastal waters with low levels of contamination, the number of pathogens at a certain distance from the discharge point can be estimated with the following equation:

$$\mathbf{K_x = K_a/V_x \cdot E_{m,s}}$$

K_x Number of pathogens at the distance x from the discharge point
K_a Number of pathogens immediately after the “initial mixing” at the discharge point
V_x Dilution at the distance x from the discharge point
$E_{m,s}$ Elimination of pathogens , caused by exposure to sea water and insolation

The pathogen elimination rate following exposure to seawater for coliform bacteria, for example, is about 0.02/h (at 20 °C) and about 0.045/h for enterococci. The additional elimination effect of insolation can be calculated with consideration for the intensity of insolation and the retention time (Gameson and Gould, 1975) or can be determined empirically.

7.4 **Table 5**: UV-C energy required as a function of the type of wastewater treatment

Treatment	UV transmission, 1/cm	Filterable substances, mg/l	Coliform bacteria CBE/100 ml	UV-C energy, W/m³/h
Mechanical	<50	>30	1×10^7	20
Biological + sedimentation	50-60	20-30	1×10^6	12
Flocculation + sedimentation	60-70	10-20	1×10^5	9
Flocculation + filtration	>70	<10	1×10^4	6

7.5 **Table 6**: EU Directive on the quality of bathing waters of 8.12.1975 (76/160/EEC)

Pathogens	Reference volume	Guide value (number of pathogens)	Limit value (number of pathogens)
Total number of coliform bacteria	100 ml	500 (80)	10,000 (95)
Faecal coliform bacteria	100 ml	100 (80)	2,000 (95)
Streptococcus faecalis	100 ml	100 (90)	
Salmonellae	1 l		0 (95)
Intestinal viruses	PFU/10 l		0 (95)

The numbers in brackets indicate the number of samples, as a percentage, in which the values must not be exceeded. The interval between taking samples is usually 14 days.