Chapter 8
Water Use for Drinking Water and Reuse of Treated Wastewater

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8.1 Introduction

The average annual precipitation is 130 mm in the Zayandeh Rud catchment. Comparing the precipitation values with the average monthly temperatures in the range from 3 to 29°C, the Zayandeh Rud catchment is an arid region. Considering such climatic conditions, it is no surprise that the predominant water withdrawal is taken from the groundwater (57%) and only 43% from surface water (FAO 2015).

The United Nations Environmental Program (UNEP) classified all countries according to their freshwater availability. Thereby the availability of 0 to 1000 m^3 per capita and year is considered "scarcity", from 1000 to 1700 "stress" and 1700 to 2500 "vulnerability" (UNEP 2008). The actual renewable water re-sources in Iran provide 1946 m^3 per capita and year (FAO 2015); hence the country is classified as vulnerable. On top of that water resources are distributed unevenly over the country.

In Iran the predominant amount of water is consumed by the agricultural sector. In 2004 the agricultural water withdrawal amounted to more than 92% whereas more than 50% are gained from groundwater sources. Industrial water consumption is only responsible for slightly more than 1% of the water abstraction while the domestic water withdrawal sums up to more than 6% (FAO 2015). Due to the high water demand and the varying water quality requirements, the agricultural sector can be a suitable consumer of TSE. Subsequently the valuable groundwater resources could be preserved.

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8.2 Water Use

Before TSE is evaluated and recommendations for possible areas of applications are identified, the private water consumption should be looked at. In the following chapter the findings of the private water consumption patterns that have been investigated by water meters in 30 households in Isfahan are presented. The investigation intends to optimize the water consumption and in doing so save valuable fresh water resources.

According to the WHO/UNICEF Joint Monitoring Programme (JMP) for Water Supply and Sanitation close to 95% of the Iranian urban population had access to drinking water sources via house connections in 2011. The figure is 9% lower for the rural population (JMP 2015). The urban population enjoys close to complete coverage of drinking water services. In 2006 the coverage amounted to 99% (FAO 2015).

In Isfahan the drinking water supply is mainly based on surface water. About 80% of the drinking water is withdrawn from rivers or surface water reservoirs. The remaining 20% originate from groundwater sources (Cornel 2005).

Despite the scarcity of fresh water resources there is little information on the water consumption pattern. Further research is required to eventually address target-oriented recommendations for water saving measures.

To overcome this shortcome the water consumption of 30 private households in Isfahan was investigated at various domestic locations. Water meters were installed for two weeks in all of the households. After evaluation of the results, the data sets of 10 households turned out to be complete and reasonable. Accordingly, these data were summarized. The results are given in Tables 8.1 and 8.2.

The total renewable water resources in Iran are different from those in Germany. In Iran 137 billion m^3 and in Germany 154 billion m^3 are available (FAO 2015). In this regard the comparison cannot be seen as best-practice study. The comparison of the average consumption figures of Isfahan to the German values is not adequate due to the data collection in only 10 households in Isfahan. The measurement campaign in Isfahan has a considerable error rate since about 11% of the consumed water could not be attributed.

Therefore, for a comprehensive assessment of the Iranian water consumption pattern further investigation is necessary.

Despite the comparison shortcomings the figures indicate the following profound differences or imprecisions. In spite of limited fresh water resources in Iran, in Isfahan the daily per capita water consumption is about 20 litres higher than in Germany. Still, on a global scale both water consumptions are relatively low.

Table 8.2 shows that the water consumption for showering and bathing are relatively similar. However, there are differences for the toilet flushing. Against the background of exclusive toilet paper usage in Germany, the water consumption for toilet flushing is much higher in Germany. The toilet paper use in conjunction with an increasing spread of water saving technology through push plates in

Table 8.1 Per capita water consumption in Isfahan (Iran) and Germany. Source for German values (BDEW 2015)

	Isfahan–Data of 10 households (randomly chosen, average values) recorded in 2014	Average values of German households of 2014
Daily drinking water consumption per capita [litre]	140	121

Table 8.2 Water consumption of private households in Isfahan (Iran) and Germany

	Isfahan–Data of 10 households (randomly chosen, average values) recorded in 2014	Average values of German households of 2014
Bath room [%]	24	36
Sink/body care [%]	8	
Toilet flushing [%]	16	27
Kitchen (cooking, drinking) [%]	28	4
Laundry [%]	8	12
Dish washer [%]	5	6
Cleaning, gardening, car cleaning [%]	no data	6
Small business [%]	no data	9
Not attributable [%]	11	–
Sum [%]	100	100

Source for German values (BDEW 2015)

Germany gives rise to expectations of lower values than in Iran. Here no explanation can be given; this means further research is necessary.

The water consumption in Isfahan's kitchen is by far higher than in Germany. In Iran homemade food and family gatherings enjoy a high relevance; this might be the reason for a more abundant usage.

This rough comparison illustrates that the water consumption pattern of private households in Isfahan and Germany is similar for the major part of the consumption figures. The only exception is the water consumption in the kitchen. Here the Iranian values are about ten times higher.

Due to the water quantity and quality requirements for safeguarding the livelihood there are various options for reducing the consumption in the kitchen; among them are: repairing trickling water-taps, installation of water-saving fittings, washing of fruits and vegetables in bowls, complete filling of washing machine and dishwasher, etc.

8.3 Reuse of Treated Wastewater in Agriculture

8.3.1 General Conditions in Iran

As outlined above Iran faces an increasing pressure on water resources. In order to tackle this, reuse of TSE can substitute water withdrawal from surface or groundwater. The Iranian Expediency Council supports this measure by the following strategies and policies (Mahmoudian 2004):

- Exploitation of drinking water potential of freshwater prior to its use for other purposes, and allocation of the produced wastewater to the agricultural sector after treatment;
- Replacement of agricultural water rights for withdrawal of freshwater with water rights for TSE in order to ensure future urban water demand;
- Irrigation of green spaces using TSE instead of freshwater being a resource for potable water production;
- Increase of pressure on industries to implement wastewater treatment and recycling facilities (threat of withdrawal of licenses for water abstraction or water supply); and
- Promotion of research projects for the development of reasonable standards for safe and reliable water reuse for agricultural purposes and artificial groundwater recharge (this includes convincing the farmers of advantages regarding the replacement of freshwater by TSE).

In addition to the substitution of freshwater resources, reuse of TSE for agricultural or landscape irrigation provides further benefits: TSE is a reliable perennial water resource containing valuable nutrients that are essential for plant growth, so that application of TSE may also contribute to increased agricultural cost efficiency due to enhanced agricultural productivity and reduced use of chemical fertilizers.

Certain quality standards for the safe application of TSE reuse practices have to be implemented for the protection of field workers and consumers. In case hygienic parameters are exceeded the application of TSE reuse constitutes a serious threat.

In the past Iran hesitated with the bulk usage of TSE. This is underlined by the figures of FAO's database AQUASTAT; in 2003 only 154 million m^3 of TSE were reused (FAO 2015). Until today the figures are only slowly catching up. Tajrishy published figures for reused wastewater of 2010. Therein the reuse is given with 328 million m^3 which is about 40% of the treated wastewater (see Table 8.3).

However, the official figures do not represent the situation on site. The withdrawal of treated effluents for irrigation purposes is widely spread. Aerial photos underline this assumption as in the vicinity of the wastewater treatment plants' (WWTP) effluent channel the area is cultivated and abundantly covered with vegetation. Therefore it seems likely that the unofficial figures for TSE reuse are much higher.

Nevertheless, the TSE reuse quantity in Iran - having more than 78 million inhabitants - is minor. One reason is that in 2010 less than half of Iran's population was connected to the sewer system. In ancient times wastewater was frequently

Table 8.3 Summary of wastewater discharge, collected, treated and reused in Iran in 2010 (Tajrishy 2011)

	In Iran in 2010 [million m^3]
Wastewater produced	3,547
Wastewater collected	1,162
Wastewater treated	820
Wastewater reused	328

Table 8.4 Cumulative wastewater collection network length, number of wastewater treatment plants (WWTPs) and population connected statistics in Iran (Tajrishy 2011)

Year	Length [km]	No. of WWTPs	Population connected
1997	9,978	30	1,959,548
2000	15,654	37	2,327,702
2005	23,473	84	6,001,322
2010	35,500	129	12,977,079

discharged into existent Qanat Systems (also called kareez) or wells (Angelakis et al. 2012). Only in Isfahan the aforementioned method could not be applied and a sewer system was built.

In terms of the sewer system and the wastewater treatment capacity there is room for improvement. The nationwide development over the last years is shown in Table 8.4.

8.3.2 *Wastewater Infrastructure in Isfahan*

Isfahan the third largest city in Iran is located at the Central Plateau at the edge of the Zagros mountain range. The seasonally fluctuating river Zayandeh Rud flows through the city centre. Due to the geological conditions the city was the first one in Iran to be equipped with a modern sewerage system and WWTPs. The implementation of such investment in the infrastructure was done in the late 1960s and early 1970s (Mohajeri and Dierich 2011).

Today nearly all inhabitants are connected to the sewer system in Isfahan; the wastewater production is given as 575,000 m^3/d (Tabatabaei and Najafi 2009). In the latest census 1,756,126 inhabitants were counted (Statistical Centre of Iran 2012). Originally the sewer system was designed as combined system but due to the low precipitation rate, the storm water proportion is virtually irrelevant (Cornel 2005). The urban sewer system discharges the predominant share of wastewater to one of the four treatment plants of Isfahan.

Isfahan's main four treatment plants are (design capacity as population equivalent – PE):

- WWTP Isfahan North (Phase I: 400,000 PE + Phase II: 800,000 PE)
- WWTP Isfahan South (800,000 PE)

Fig. 8.1 View from the digesters of WWTP Isfahan North

- WWTP Isfahan East (250,000 PE)
- WWTP Shahin Shahr (260,000 PE)

The Isfahan Water and Wastewater Company (IWWC) is responsible for the collection and treatment of wastewater, whereas the TSE reuse for irrigation purposes is within the Esfahan Regional Water Board's (ESRW) field of responsibility.

The project work concentrated on the WWTP Isfahan North (see Fig. 8.1). Therefore the following investigation on TSE reuse is based on these effluents. The plant's treatment aim is carbon removal only.

The first construction phase of WWTP Isfahan North, commissioned in 1987, has a design capacity of 400,000 PE corresponding to about 70,000 m^3/d (Cornel 2005). In recent years, the average hydraulic load was 64,000 m^3/d.

Following the first treatment step consisting of screening, grit separation, and primary clarification in two circular clarifiers, there is a biological stage with two separate aeration tanks. At the time of the project implementation the tanks were equipped with rotary brush aerators. In the meantime the aeration system has been changed to subsurface disk diffusers. For the secondary clarification there are two sedimentation tanks. Finally there is a chlorine contact tank, however, no operational and controlled disinfection stage. Subsequently the TSE is discharged into a concrete channel outside of the WWTP that leads to the Zayandeh Rud.

The excess sludge is thickened, digested and dewatered and eventually used in agriculture.

The second construction phase, commissioned in 2008, has a design capacity of 800,000 PE. In recent years the average hydraulic load amounted to 70,000 m^3/d.

The treatment is carried out based on a two-stage activated sludge process (A–B process). The first treatment step consists of coarse screening, grit separation and fine screening. The biological stage consists of two rectangular tanks of stage A being aerated with centrifugal surface aerators, then four intermediate clarifiers preventing the release of A-sludge and stage B with two rectangular tanks equipped with centrifugal surface aerators. The final clarification takes place in four sedimentation tanks. Before TSE is released into the aforementioned concrete channel the supernatant undergoes disinfection but the disinfection management is weak. On a temporary basis bleach solution (sodium hypochlorite) is added. A proper control mechanism is not in place.

The excess sludge is thickened, digested and dewatered and eventually used in agriculture.

The central conclusion of the process analysis underlines the fact that there is a high degree of optimization potential for the treatment process. For instance, the mixed liquor suspended solids (MLSS) and the sludge age are too high, the removal of floatable matter is unsatisfactory and the sedimentation rate of the clarifiers are insufficient thus there is still a relatively high concentration of total suspended solids (TSS) in the TSE. The average data of monthly mean concentrations 2010–2011 amount to 118 mg TSS/l in the first phase. Similarly the BOD_5 removal of the first phase is insufficient; the average data of monthly mean concentrations 2010–2011 is 104 mg/l.

The TSE values of the second phase point in the same direction. The average data of monthly mean concentrations of 2012 was measured with 93 mg TSS/l and the BOD_5 in the effluent showed 82 mg/l as average data of monthly mean concentrations of 2012.

As conclusion, the TSE of both phases contains relatively high TSS and BOD_5 concentrations, which represent a significant constraint in terms of effluent reuse. Besides the loss of biomass due to insufficiently separated activated sludge from the liquid phase, increased TSS concentrations affect the efficiency of disinfection processes due to possible shielding of microorganisms by particulate matter.

For the efficient operation of disinfection processes, TSS concentrations of secondary effluent should be constantly kept below 20 mg TSS/l, and preferably lower (DWA-M 205 2013); (Metcalf and Eddy Inc 2003) – the lower, the better the disinfection efficiency. With regard to effluent disinfection by UV radiation, it has been shown that even a significant increase in radiation intensity does not improve the disinfection efficiency in case of increased TSS concentrations, i.e. >20 mg TSS/l (Metcalf and Eddy Inc 2003). Concerning chemical disinfection processes, abundance of particles also results in significantly increased demands in terms of the disinfectant dosage due to quenching of disinfectants by particles. Thus, suspended solids do not only reduce the disinfection efficiency, but also increase the disinfectant consumption. Moreover, high concentrations of organic matter result in the increased formation of harmful disinfection by-products.

In addition to the impact on disinfection processes, high TSS concentrations may lead to deposits or blockage of certain irrigation systems (e.g. drip irrigation and subsurface irrigation). Therefore, the reliable reduction of the TSS concentrations of TSE generated at WWTP Isfahan North is of major importance with regard to any agricultural reuse scheme.

In large WWTPs being appropriately designed and operated, TSS concentrations can commonly be kept below the target value (20 mg TSS/l). In case of increased and/or significantly varying TSS concentrations, additional filtration of secondary effluent may be required in order to ensure sufficiently low TSS contents prior to disinfection. However, the dimensioning of filtration processes is also strongly depending on the TSS concentrations of the effluent to be filtered. Therefore, it is strongly recommended to focus on the minimisation and stabilisation of the secondary effluent's TSS concentration by operational measures prior to designing any tertiary filtration stage for the WWTP Isfahan North.

8.3.3 Iranian Limits for Wastewater Reuse

Despite the aforementioned advantages that have been recognized by the Iranian government, the country lacks a policy for wastewater reuse. In 1994 the "Effluent Discharge Standard" was developed by the Department of the Environment (Bahri 2008). The standard is only applicable for discharge of treated wastewater into receiving surface water bodies, into absorption wells and for irrigation purposes in agriculture (Iranian Department of Environment 1998). In this context, surface waters are defined as seasonal or permanent rivers, natural or artificial lakes and lagoons. The term absorption well refers to ditches or trenches having the capacity for the infiltration of water into the ground. The limit values are given in Table 8.5 is. Being limited to these three reuse options, the standard does not represent a complete wastewater reuse policy.

Concerning the key question of the present project of TSE reuse options in agriculture the "Effluent Discharge Standard" forms the basis.

Compliance with the effluent standards specified in Table 8.5 is under the supervision of the Department of Environment. Amongst others, the following specifications associated with these effluent standards are to be considered:

- Measurements for the control of compliance with the standards shall be on the basis of combined samples, i.e. 24-hour samples which have been prepared of individual samples being taken at intervals of maximum 4 h.
- The effluent shall be free of odour, foam, and floating matter. The colour and turbidity of the effluent shall not visibly change the natural appearance of receiving and local water bodies.
- Discharge of TSE into absorption wells or trenches is prohibited if the distance between their base and the groundwater table is less than 3 m.
- Polluting industries must treat their effluents up to a standard level according to engineering principles and the use of an appropriate and economic technology.

Table 8.5 Iranian Standard for discharge and reuse of treated sewage effluent (Iranian Department of Environment 1998)

Parameter	Unit	Discharge into surface waters	Discharge into absorption wells	Reuse for agricultural irrigation
Silver	mg/l	1	0.1	0.1
Aluminium	mg/l	5	5	5
Arsenic	mg/l	0.1	0.1	0.1
Boron	mg/l	2	1	1
Barium	mg/l	5	1	1
Beryllium	mg/l	0.1	1	0.5
Calcium	mg/l	75	–	–
Cadmium	mg/l	0.1	0.1	0.05
Free Chlorine	mg/l	1	1	0.2
Chloride	mg/l	600[a]	600[b]	600
Formaldehyde	mg/l	1	1	1
Phenol	mg/l	1	negligible	1
Cyanide	mg/l	0.5	0.1	0.1
Cobalt	mg/l	1	1	0.05
Chrome(VI)	mg/l	0.5	1	1
Chrome(III)	mg/l	2	2	2
Copper	mg/l	1	1	0.2
Fluoride	mg/l	2.5	2	2
Iron	mg/l	3	3	3
Mercury	mg/l	negligible	negligible	Negligible
Lithium	mg/l	2.5	2.5	2.5
Magnesium	mg/l	100	100	100
Manganese	mg/l	1	1	1
Molybdenum	mg/l	0.01	0.01	0.01
Nickel	mg/l	2	2	2
Ammonia	mg/l	2.5	1	–
Nitrite	mg/l	10	10	–
Nitrate	mg/l	50	10	–
Phosphate-P	mg/l	6	6	–
Lead	mg/l	1	1	1
Selenium	mg/l	1	0.1	0.1
Sulphide	mg/l	3	3	3
Sulphite	mg/l	1	1	1
Sulphate	mg/l	400[c]	400[d]	500
Vanadium	mg/l	0.1	0.1	0.1
Zinc	mg/l	2	2	2
Oil & grease	mg/l	10	10	10
Detergent	mg/l	1.5	0.5	0.5
BOD_5	mg/l	30 (instant 50)	30 (instant 50)	100
COD	mg/l	60 (instant 100)	60 (instant 100)	200

(continued)

Table 8.5 (continued)

Parameter	Unit	Discharge into surface waters	Discharge into absorption wells	Reuse for agricultural irrigation
Dissolved oxygen	mg/l	≥2	–	≥2
Total dissolved solids (TDS)	mg/l	–[a]	–[b]	–
Total suspended solids (TSS)	mg/l	40 (instant 60)	–	100
pH		6.5–8.5	5–9	6–8.5
Radioactive materials	mg/l	0	0	0
Turbidity	NTU	50	–	50
Colour		75	75	75
Temperature	°C	–[e]	–	–
Faecal coliforms	MPN/100 ml	400	400	400
Total coliforms	MPN/100 ml	1000	1000	1000
Nematode eggs	eggs/l	–	–	–[f]

[a]Discharge of amounts above those specified in the table shall be allowed only if the effluent will not affect the concentrations of chloride, sulphate, and dissolved solids in receiving water bodies by more than 10% over a radius of 200 m.
[b]Discharge of amounts above those specified in the table shall be allowed only if the concentrations of chloride, sulphate, and dissolved solids in receiving water bodies will not be increased by more than 10%.
[c]Discharge of amounts above those specified in the table shall be allowed only if the effluent will not affect the concentrations of chloride, sulphate, and dissolved solids in receiving water bodies by more than 10% over a radius of 200 m.
[d]Discharge of amounts above those specified in the table shall be allowed only if the concentrations of chloride, sulphate, and dissolved solids in receiving water bodies will not be increased by more than 10%.
[e]Temperature shall not affect the temperature of the receiving water body by more than 3 °C over a radius of 200 m.
[f]The number of nematode eggs should be ≤1 egg/l if the effluent is to be used for irrigation of crops eaten uncooked.

- Sludge and other solid materials produced by wastewater treatment plants must be treated to an appropriate level before discharge and such an action shall not lead to the pollution of the environment.

In Table 8.5 the parameters faecal and total coliforms as well as nematode eggs refer to microbiological standards. Bacteria such as faecal coliforms and total coliforms present an epidemic risk in case of TSE reuse for irrigational purposes. On a global scale the Iranian limit values are to be seen in the mid-range.

While the occurrence of coliform bacteria gives information about the hygienic properties of TSE, the predominant health risks for consumers and farm workers related to irrigation using TSE are usually associated with intestinal parasites.

These show a substantial resistance against chemical disinfection and have a long resilience under environmental conditions (WHO 2006).

8.3.4 WHO Limit Values for Water Reuse

In the current WHO Guidelines for wastewater use in agriculture an integrated approach combining various options for achieving the water quality required for agricultural irrigation is promoted (WHO 2006). This approach is to some extend in contrast to the Iranian regulation. Besides the production of TSE by more or less technological wastewater treatment processes, the WHO approach includes a differentiation regarding the crops to be irrigated. Moreover, the contribution of different irrigation techniques for the reduction of the risk of crop contamination is considered, as well as appropriate health and safety measures for the protection of field workers and consumers.

With regard to produce restriction, crops which are usually eaten raw are distinguished from crops being only consumed after further processing (e.g. wheat) or cooking (e.g. rice, potatoes) and non-food crops (e.g. cotton, fodder plants). Crops being eaten raw, including vegetable and salad crops (e.g. root crops, lettuce), require irrigation water of high quality in terms of pathogen contents, i.e. water suitable for unrestricted irrigation. TSE having a lower quality should only be reused for restricted irrigation, i.e. for crops being processed before consumption.

However, the above mentioned WHO Guideline follows the concept of health-based targets, which means achieving a certain reduction of health risks related to effluent reuse. As a result of this approach, an overall pathogen reduction of 6 log-units is suggested for unrestricted irrigation of leafy vegetables (e.g. lettuce) and of 7 log-units for unrestricted irrigation of root vegetables being consumed raw (e.g. onions). The reduction of coliform bacteria (e.g. *Escherichia coli*) is considered as a practicable measure for pathogen reduction (WHO 2006).

Whilst the focus of the formerly suggested WHO limits was only on the TSE quality, the now required 6- to 7-log-unit pathogen reduction may be achieved by a combination of different options. This approach is illustrated in Fig. 8.2. For instance, the relatively high requirements for unrestricted irrigation of leafy vegetables are fulfilled in case of conventional irrigation (flood, furrow, or sprinkler irrigation) using treated effluent after 3-log-unit pathogen reduction (being equivalent to 104 thermo tolerant coliforms/100 ml) if the irrigation is stopped 1–2 weeks prior to harvesting and if the produce is sufficiently washed by the consumers (example B in Fig. 8.2). However, the same result can be achieved with a lower degree of wastewater treatment, but effluent application via surface drip irrigation, provided that the crops are high-growing and do not get in contact with the soil (example C in Fig. 8.2). In case of low-growing crops, additional pathogen removal by wastewater treatment prior to surface drip irrigation has to be ensured (example D in Fig. 8.2).

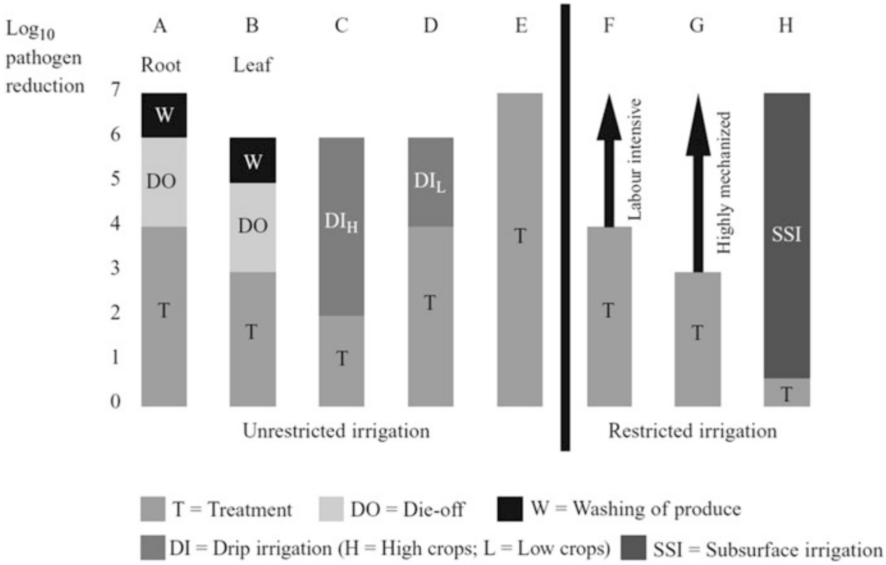

Fig. 8.2 Examples for options for the reduction of viral, bacterial and protozoan pathogens by different combinations of health protection measures (WHO 2006)

In addition to the concentrations of pathogenic bacteria, viruses, and protozoa, which are usually measured by a bacterial indicator parameter (e.g. *E. coli*), helminth eggs contained in effluents are another issue of concern. Regardless of whether the effluent is reused for unrestricted or restricted irrigation, the content of helminth eggs should be <1 egg/l according to the WHO Guideline. In case of possible contact of children with TSE due to playing in the fields, the concentration should be <0.1 egg/l (WHO 2006).

With regard to the Iranian Effluent Discharge Standard, there is no distinction in terms of different effluent qualities for unrestricted and restricted irrigation, except for the limit concerning helminth eggs (<1 egg/l), which is only to be considered for the irrigation of crops being eaten raw (i.e. unrestricted irrigation).

8.3.5 Recommendations for WWTP Isfahan North

Disinfection of the plant's effluent is reasonable and necessary because the TSE deriving from both phases of WWTP Isfahan North is used for agricultural irrigation, so that disinfection contributes to the protection of farm workers and consumers against microbial infections. However, the plant's disinfection conditions are critically assessed for the following reasons:

- The disinfection efficiency is likely to be limited due to high TSS concentrations. Microorganisms being embedded in suspended particles may be shielded against the impact of disinfectants and survive, which may result in bacterial regrowth in TSE.

- High BOD_5 concentrations result in the excessive consumption of free chlorine, thus requiring high chlorine doses for achieving sufficient disinfection efficiency. Moreover, the reaction of chlorine with organic matter results in the formation of potentially harmful disinfection by-products.
- Chlorine-based disinfection is generally less efficient in plants without nitrification due to the formation of chloramines, which provide also some disinfection potential, but require much longer contact times for achieving disinfection efficiencies being comparable to free chlorine.
- There is no management and control strategy in place to supervise the dosage and efficiency. Accordingly there is no information on the effectiveness and possible remaining risks for field workers and/or consumers.
- There are no devices for controlled mixing of the bleach solution into the secondary effluent. Rapid mixing of the disinfectant into the water is highly important in terms of disinfection efficiency.
- Chlorination is not effective against helminth eggs and parasites (especially Cryptosporidium).

Bearing in mind the aforementioned arguments, the most suitable disinfection technology for Isfahan was assessed. The assessment was based on the technologies: maturation ponds, ultraviolet radiation, membrane filtration, chlorination, ozonation, peracetic acid or performic acid. The advantages and disadvantages were carefully weighed and verified for their applicability in Isfahan.

The result is that only a few seem to be appropriate for the implementation at WWTP Isfahan North. Eventually, the disinfection by membrane causes high investment and operation costs. The application of chlorine seems to be not feasible due to the missing nitrification stage. The disinfection by ozonation and peracetic acid forms high risks for the operating staff due to in-situ storage, preparation and application. The recommendable stage for Isfahan is UV disinfection. A clear benefit of the UV disinfection facility is the simple and transparent operation. Furthermore the low labour requirements are favourable, i.e. routine work such as supervision, documentation and cleaning of UV-lamps.

In any case, necessary treatment process improvements at the WWTP Isfahan North in particular for the secondary effluent, need to be implemented before the application is feasible and reasonable. According to latest operational data the permanent achievement of 20 mg TSS/l in the supernatant is highly questionable. Additional treatment stages such as rapid filtration or micro screening have to be introduced. Here the permeate's target value should be 5 mg TSS/l.

Supposing the operation of the WWTP is optimized and the TSE is in line with the Iranian limit values, the reuse in agriculture as irrigation water is a favourable option. But to be well on the way to TSE reuse additional aspects have to be kept in mind. At one side the wastewater is a reliable year-round water resource while irrigation water is required seasonally, so storage becomes an issue which is discussed below. On the other side, the way of irrigation is crucial to the health of the field workers, as outlined above, and has a significant influence on the quality of the final field product.

In Isfahan Province the surface irrigation, including flood and furrow irrigation is the predominant agricultural irrigation technique. In case of hygienically insufficient water quality, the application of surface irrigation involves a high health risk not only for fieldworkers due to direct contact with irrigation water, particularly if protective clothing (e.g., boots, shoes and gloves) is not worn but also to humans living in the irrigated area in general. The latter can suffer from inappropriate constructed and managed irrigation schemes that can provide ideal conditions for the proliferation of bugs that are the basis for vector-borne diseases. Consequently, the population's health is threatened by malaria, bilharzia, dengue and dengue haemorrhagic fever, liver fluke infections, filariasis and onchocerciasis (Feyen and Badji 1993) when the climatic conditions are suitable.

The design of the irrigation scheme has to consider at least the following aspects. In order to minimize the health impacts, straight and lined channels without vegetation lead to faster flows reducing breeding sites. The channels have to be drained in case of no irrigation. Generally covered channels are favourable; however, due to higher construction costs these are often omitted.

The risk for crop contamination with pathogens due to contact with irrigation water is high, in particular for low-growing crops. Therefore, especially flood irrigation implicates increased health risks for consumers if crops being eaten raw are irrigated with insufficiently treated sewage effluent.

Another aspect to be considered is the irrigation efficiency, i.e. the ratio of water needed by the crop to water applied to the field. This ratio is comparatively low in case of surface irrigation systems because of water losses due to evaporation and seepage beyond the root zone. The increase of the irrigation efficiency is considered to be of particular importance in Isfahan due to limited water resources available and a high water demand for agricultural irrigation.

Taking into account the aforementioned aspects, it becomes evident that surface irrigation is not the optimum irrigation technique in Isfahan Province when considering water scarcity and TSE reuse. Here irrigation technics such as drip irrigation are favourable.

Drip irrigation has been widely used in the Middle East for a long time and is not only beneficial regarding irrigation efficiency and salinity control, but also in terms of the reduction of epidemic risks related to effluent reuse. The salt movement is radial along the point of irrigation and salt accumulates between drip points. However, an increased TSE quality regarding suspended solids is required in order to avoid clogging of the emitter system.

Discussing the reuse potential, the storage of TSE is also one important issue. Wastewater is available relatively constantly throughout the year. In contrast thereto irrigation water is required only during the irrigation period. The excess TSE being generated during the non-irrigation period is suggested to be taken into consideration to avoid any significant loss of this valuable water resource.

Storage of TSE in tanks above ground would require the construction of enormous tank capacities and lead to enormous evaporation losses, so that this option is not further considered. However, seasonal aquifer recharge by infiltration of TSE may be an alternative for temporary storage of large quantities of TSE during the non-irrigation period. However, it has to be pointed out that the current treatment process at WWTP Isfahan North including carbon removal only, but no nitrification/denitrification does not fulfil the Iranian standard's requirements on effluent quality for aquifer recharge (cf. Table 8.5).

The comparison of the operational data with the Iranian standard shows that carbon, nitrogen and coliform parameters are well above the limit. Under these conditions the aquifer recharge is not permitted.

Supposing the WWTP is extended by additional treatment steps and the TSE is in line with the Iranian standard's values, the aquifer recharge is a favourable option for groundwater recharge respectively temporary storage of irrigation water during non-irrigation periods i.e. in winter when temperatures are relatively low. Therefore, evaporation and correlated water losses due to large surface areas are considered to be of minor importance for infiltration ponds.

It has to be further considered that infiltration rates may be lower in winter due to the water's increased viscosity. Furthermore a slower drying and recovery of the infiltration capacity has to be anticipated. The biological activity and the associated reduction of the infiltration rates due to bio-clogging of the ponds' bottom may be less intense in winter (Bouwer 2002). To enhance the infiltration capacity injection wells might be considered, however, high TSE quality and intensive maintenance are required in order to avoid clogging.

Detailed knowledge of the hydrogeological conditions at possible infiltration sites and the surrounding areas are mandatory. Surface infiltration requires sufficient vertical soil permeability from the bottom of the infiltration basin to the top of the aquifer. Moreover, detailed information is required in terms of the storage capacities and groundwater flow conditions at the respective sites in order to be able to make reliable predictions regarding the expected dispersion and transport of infiltrated TSE and its influence on natural groundwater resources.

An initial investigation revealed that the area around WWTP Isfahan North belongs to the Borkhar aquifer. According to data provided by the Iranian partners, the electrical conductivity in Borkhar aquifer is in the range of 2000 to 3000 μS/cm, i.e. the groundwater is affected by increased salinity. In the long term, irrigation and/or groundwater recharge using TSE may further affect the quality of soil and groundwater in terms of salinity. Therefore, attention has to be paid to the TSEs salinity and to its effects on soil and groundwater quality, also considering irrigation management. According to today's status the recharge into the Borkhar aquifer has to be seen critically but additional hydrological data is necessary and field tests are required to come to a final recommendation.

8.4 Conclusions

The first section of this chapter compares the private water use in Isfahan to Germany. Obviously the project's result is relatively similar to the German water consumption. Nevertheless, Germany with abundant water resources has a daily per capita consumption around the hundred twenties while Iran with water vulnerability consumes twenty litres more per day and capita. Based on this rough comparison, the implementation of water saving technology in private households is recommended.

In the second section of this chapter the reuse of TSE of the WWTP Isfahan North is investigated and appropriate and safe reuse options in the agricultural sector are discussed. Today, TSE reuse is implemented due to growing scarcity of water resources and increasing water demands. Frequently, the replacement of agricultural water rights for withdrawal of freshwater by water rights for TSE is implemented in order to safeguard future water resources for human consumption.

In the case of WWTP Isfahan Nord the secondary effluent contains high TSS and BOD_5 concentrations which represent a significant constraint in terms of effluent reuse. High TSS concentrations negatively affect the efficiency of disinfection processes due to the shielding of microorganisms by particulate matter against radiation or chemical disinfectants. Provided that the necessary improvements of the secondary effluent are implemented, UV disinfection for Isfahan is the most recommended solution.

Surface irrigation is not the optimum technique in Isfahan Province considering water scarcity and reuse of TSE. A sustainable irrigation management is to be established that e.g. foresees techniques that are adapted to the crop culture with regard to survival time of the pathogens.

It seems to be advisable to consider temporary storage of TSE for the non-growing period. Due to the climatic conditions in Isfahan covered or underground facilities might represent a feasible option.

Based on the previously mentioned conditions it is strongly recommended to optimize the treatment process of the WWTP Isfahan North in order to reduce the BOD_5 and TSS concentrations in the effluent, implement a sustainable disinfection stage and achieve a high quality TSE to be suitable for reuse in agriculture.

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