ISSN 2664-4169 (Print) & ISSN 2664-7923 (Online)
South Asian Research Journal of Biology and Applied Biosciences
Abbreviated Key Title: South Asian Res J Bio Appl Biosci

| Volume-4 | Issue-2 | May-Jun -2022 | **DOI: 10.36346/sarjbab.2022.v04i02.003**

Review Article

Critical Assessment of Treated Wastewater and Their Reuse for Irrigation in Iraq

T. Noor[1*], and Entkhab M. A. Alanisi[2]

[1]Department of Biology Science, Mustansiriyah University, POX 46079, Baghdad, Iraq, thananoor20@uomustansiriyah.edu.iq
[2]Department of Biology Science, Mustansiriyah University, POX 46079, Baghdad, Iraq, entkhab80@uomustansiriyah.edu.iq

***Corresponding Author:** T. Noor
Department of Biology Science, Mustansiriyah University, POX 46079, Baghdad, Iraq

Article History
Received: 19.04.2022
Accepted: 04.06.2022
Published: 12.06.2022

Abstract: Rustumihia is one of the biggest WWTP (Waste Water Treatment Plant) based in Baghdad the capital of Iraq. The effluent treated wastewater, were used for irrigation by the farmers nearby the Rustumihia WWTP. The growth of Iraqi population and limited development in the infrastructure to the treatment plants in Iraq like old Rustumihia project. There is a need to assess the treated effluents water that is used for irrigation. Wastewater considered as a key alternative water resource as it can be used in agriculture field to reimburse shortages in water need. In developed countries like Iraq, the irrigation by using wastewater has a long history. Continues lagging in WWTP maintenance and its infrastructure could cause many problems for the treated effluent that has its own effect on health and environment aspects. Therefore, by applying a strong management practices, for example advanced and appropriate treated and irrigated knowledge, can be used later to gain significant advantages in the same time minimizing health risks. This article discussed the treated wastewater used by farmers nearby Rustumihia treatment plant and focus on the challenges linked with wastewater irrigation.

Keywords: Rustumihia plant, treated wastewater, irrigation.

1 INTRODUCTION

1-1 BACKGROUND

A major priority must be given to the treated wastewater which is released back into the environment in order to remove pollutants that can be diagnosed as an environmental health danger. Local authorities (*i.e.,* city and county councils) are responsible for the management of wastewater collection and infrastructure treatment. The Ministry of Environment and Water Resources is the main body which is accountable for regulating and authorising the discharged wastewater from the water services.

The authorisation system purpose is to block or reduce contaminants by wastewater discharges. In developing countries like (Iraq, Jordan, Egypt, Palestine, *etc.*) wastewater treatment iscritical as a consequence of the distinctive discharge of contaminated effluents from agricultural, industrial, and local municipal/sewage activities (Jayyousi *et al.,* 2004; Abdulrazza, 2013 and Massoud, 2014). Due to improper discharge of liquid and solid waste into the surface water and land, water contaminants are considered as a major critical environmental issue. Domestic wastewater, agricultural residues, chemicals and industrial effluents are categorised as the most significant sewage disposal issues (Abdul Karim, 2013). Furthermore, the continued disposable waste, the primarily industrial and domestic wastewater that goes straight away into the rivers is one of the basic causes of river pollution. Most of the WWTPs are operated and designed to decrease the contaminant loads to a level that the environment can handle. Thus, it is important to evaluate the environmental influence of the present wastewater treatment facilities (Massoud, 2014 and Massoud *et al.,* 2019).

As such, the urban drainage system should be considered as a fundamental infrastructure designed to eliminate both rainwater and wastewater from the city in an attempt to reduce unhygienic circumstances and to avoid any excessive

Citation: T. Noor & Entkhab M. A. Alanisi (2022) Critical Assessment of Treated Wastewater and Their Reuse for Irrigation in Iraq. *South Asian Res J Bio Appl Biosci, 4*(2), 51-63.

destruction caused by flooding (Adila, 2011). In 1981, Haist and Partners designed the Rustumihia wastewater plant. Rustumihia is one of the oldest wastewater treatment plants in Baghdad/Iraq which supply public health services to more third of whole Baghdad population habitant (Aenab and Singh, 2015). It is located in the southeastern part of Baghdad and its 2 kilometers away from the closest resident population area. The nature of the land for this sanitation project was an agricultural type (Abdul Hameed *et al*, 2010) Through Rustumihia, All the treated waste was disposed with automatic ways into Diyala river stream. The effluents quality was based on the Iraqi standards of effluent wastes disposal into the receiving waters (AbdulKarim, 2013). AL-Samawi, (2008) studied Al-Rustumihia WWTP efficiency performance before and after rehabilitation in order to confirm the rehabilitated work efficiency. His results displayed that the Rustumihia WWTP effluent discharge into Diyala River did not meet the Iraqi effluent standards. On the other hand, all biological processing results clarify an obvious biological concern. All the results revealed distinctly that the rehabilitated program had no considerable effect on ameliorating the actual state of negligence.

(Aenab and Singh 2015), estimated the performance and effectiveness of the sewage treatment plants in Baghdad for both Al-Risafa and Al-Karkh sides. All the calculations were carried out on the average basement and the peak capacity of each plant according to the population growth rates with three values in Baghdad for the period between 2005 and 2025. The study demonstrated that the treatment efficiency deficit ratio would reach 273% in the next coming fifteen years in Rustumihia WWTP. Moreover, at Al-Karkh sewage treatment plant, the situation is more complicated as the shortage in the treatment adequacy will reach 700%. It is important to understand the main concentrations, the variation range of the chemical parameters and the ratios that are used to elucidate the wastewater quality to maintain warranty for the suited design and size of the treatment facilities.

Image captured by Google earth 2010 for Rustumihia WWTP

1-2 The importance Quality parameters in the agricultural use of wastewaters

According to Aziz and Aws (2012), a new regulation, No. 25 for the year 1967, was issued by the Iraqi government regarding the protection of stream and water tanks from pollution. The legalization prohibits any kind of wastewater discharge into the main water body without requesting a particular permit issued by the health administration. This law controlled the quantity and quality of discharged wastewater into the natural sources.

Table 1: Quality standard for water sources according to Regulation 25, issued by the Iraqi government (Aziz and Aws 2012)

Constituents		Units	Con. Level
1	Colour	-	Normal
2	Temperature	-	-
3	Suspended solid	-	-
4	PH	-	6.5-6.8
5	Dissolved Oxygen	Mg/L	More than 5
6	BOD_5	“	Less than 3
7	COD (Cr_2O_7method)	“	-
8	Cyanide CN^-	“	0.02
9	Fluoride F^-	“	0.02 or more as naturally present
10	Free chlorine	“	Trace
11	Chloride	“	200 or more as naturally present
12	Phenol	“	0.005
13	Sulphate	“	200 or more as naturally present
14	Nitrate(No_3)	“	15

Constituents		Units	Con. Level
15	Phosphate (PO_4)	“	0.4
16	Ammonium (NH_4)	“	1.0
17	DDT	“	N.L.
18	Lead(pb)	“	0.05
19	Arsenic AS	“	0.05
20	Copper Cu	“	0.05
21	Nickel Ni	“	0.1
22	Selenium Se	“	0.01
23	Mercury Hg	“	0.001
24	Cadmium Cd	“	0.005
25	Zinc Zn	Mg/L	0.5
26	Chromium Cr	“	0.05
27	Aluminum Al	“	0.1
28	Barium Ba	“	1.0
29	Boron B	“	1.0
30	Cobalt Co	“	0.05
31	Iron Fe	“	0.3
32	Manganese Mn	“	0.1
33	Silver Ag	“	0.01
34	Total hydrocarbons and their compounds	For detail refer to regulation No.25	-
35	Sulfide S	-	-
36	Ammonia N as NH_3	-	-
37	Ammonia gas (NaS free NH_3)	-	-
38	Sulphur dioxide (So_2)	-	-
39	Petroleum Alcohol	-	-
40	Calcium Carbide (CaC)	-	-
41	Organic Solvents	-	-
42	Benzene	-	-
43	Chlorobenzene	-	-
44	TNT	-	-
45	Bromine	-	-

Major amounts of wastewater usually come from an urban area that has sewer networks. The sewage composition depends on the urban area characteristics. The treatment process is mainly affected by the suspended solids, phosphorus, ammonia, $BOD_{5,}$ and organic nitrogen. In fact, domestic wastewater sewage is infected with viruses, protozoa, pathogenic organisms, helminths eggs, and bacteria. Baghdad city has three main sewage treatment plants:

1. The old Rustamiyah treatment plant, design capacity (175,000) $m^3/\ d^{-1}$.
2. Karkh treatment plant, design capacity (205,000) $m^3/\ d^{-1}$.
3. New Rustamiyah treatment plant, design capacity (300,000) $m^3/\ d^{-1}$.

In Iraq, the treated sewage waste is about (580) million m^3. The estimated water that is used for agriculture is (15000) m^3/ha, which helps to irrigate around (38666) ha.

Table 2: Treatment plants in Baghdad and some pollutant concentrations mg/L

Project name	BOD_5	COD	TDS	S.S	PO_4	SO_4	NH_3	NO_3
Karkh sewage	15	86	26	44	36	9.5	1.8	-
	22	95	34	43	31	7.8	1.4	-
	17	81	21	51	30	8.6	1.6	
Old Rustumihia sewage	50	92	1766	99	3.2	-	-	-
	55	97	1734	100	2.9	-	-	-
	58	94	1801	87	2.6	-	-	-
New Rustumihia sewage	35	146	2507	20	7.9	-	-	-
	38	143	2201	19	8.3	-	-	-
	43	138	2224	23	8.6	-	-	-

1-3 Parameters of agricultural significance

Generally, flood and watering cans, the so-called furrow irrigation, are the main means used by farmers to irrigate the peri-urban and urban (Martijin and Redwood, 2005; Drechsel *et al*., 2006; Keraita *et al*., 2010 and Massoud *et al.*, 2019). Farmers should be advised when choosing irrigation methods via extension services to maintain the quality of the supplied water (Amponsah *et al.*, 2016). The opportunitiesfor harvest contamination with health risk issues like pathogens are quite high during the irrigation process; there are environmental implications and potential health risks (Alegbeleye and Sant'Ana, 2020). Certainly, the choice does not only rely on water affordability but also on water quality, labor availability, tenure security and other output factors. Predominantly, suitable water hoses are not obtainable and they usually are much expensiveto afford. The lowest cost method is the flood irrigation if the topography is convenientor laborers can afford a pump. On the other hand, water use efficiency is considered the least successful where it is not a restriction factor. A higher level of health protection could be provided by furrow irrigation. However, there has to be special requirements such as land levelling and suitable topography.

Certain irrigation methods that spread water on the crop surface like irrigation with watering cans and sprinklers are not recommendeddespite the fact that fragile vegetable beds, usually favour them; the least cost effective irrigation methods are cans in contrast with the sprinklers which have medium water use efficiency and medium to high cost in addition to a pump and hose care should be exercised when using sprinklers irrigation method such as irrigating at night and not irrigating during windy conditions(Qadir *et al.*, 2010).

Some field attemptsregarding sorghum and forage crops particularly in Tunisia revealed that contamination is bacterial; it develpoed after irrigation method with secondary treated wastewaterdiversified according to the type of crop, season, weather, bacterial species, and the number of the days after cessation of irrigation as they used cessation of irrigation, prior to harvest to permit natural and habitat pathogen die-off (Gaaloul N., 2011). In conducted field trials on lettuce in Ghana, cessation led to the loss of fresh weight. However, 4-5 days without irrigation would increase food security making it safer, about 25% of a yield loss was not convenient enough to farmers. A cessation of 2 days would be a compromise with higher adoption potential, with 10% of a yield reduction (Keratita *et al.*, 2007 and Drechsel *et al.*, 2008).

Partially treated wastewater or untreated wastewater has many risks when used in agriculture. These risks can be brought down through integrating both factors: non-treatment options and waste water treatment (WHO, 2006) which involve: (1) controllinghuman exposure, (2) improving water quality, (3) managing the farm level wastewater, and (4) intervening harvest and post-harvest. In many developing countries like Iraq, Jordan, Lybia ….etc. wastewater quality used for irrigation could be improved initially by improving the primary treatment of wastewater (Alegbeleye and Sant'Ana, 2020).

In some areas, secondary treatment can be implemented at a sensible cost, using methods like waste stabilisation ponds, infiltration-percolation, constructed wetlands, and up-flow anaerobic sludge blanket reactors (Sarma, 2020). It is important to aim at standards which can be implemented in the local context. One of theWHO (2006) guidelines, provide integral choices for human exposure control and wastewater treatment.Storing treated wastewater in tanks ameliorates microbiological quality and supplies peak equalisationcapabilities, which boost the accuracy of supply and enhance the rate of reuse. In the King Talal Reservoir, the Amman-Zarqa Basin of Jordan, the fecal coliform levels were reduced in the water downstream of the dam by long detention times. However, it was not initially planned for that aim (Grabow and McCorinck, 2007 and Al Omari, 2020).

In another developing country, Morocco, particularly in Drarga, the most untreated wastewater is discharged, polluting drinking water providers. An institutional participant including urban water users, local water management stakeholders, and agriculture user groups was established to confirm maintenance and sustainability of the reclaimed and reused program (Nehren *et al.*, 2020). An obligatory fee was imposed on domestic water providers; it appliedcost-recovery mechanisms on others. (Qadir *et al.*, 2010 and Aenab and Singh, 2015). Deep percolation can exclude microorganisms and recharge groundwater; the supplied soil attribute issuitable, and the processes are duly managed.

A key component involves suitably maintaining adequate microbiological populations, appropriate flooding and drying cycles, and retaining sufficient distance and transient time between leakagebasins and water providing wells (Asano and Cotruvo, 2004 and Nehren *et al.*, 2020). Whereas in developed countries which have adopted certain policies to maintain high water quality and to organise wastewater use, the unreasonablestandards usually make implementation hard to achieve or the process may become an expensive target only to be realized in the long term. In accordance with the technical, local, social, economic, and cultural contexts, meaningful criteria need to be established. Furthermore, enhancing the water quality demands new approaches to wastewater management in cities, subdividing cities into manageable units following Bangkok as an inspiring example, which made possible successes step-wise (Okadera *et al.*, 2020).

More than a quarter of the national vegetable production in Pakistan is irrigated with wastewater (Ensink *et al.*, 2004 and Mahmood, A. and Malik, 2014). In Ghana, informal irrigation that includes diluted wastewater comes from streams and rivers occupying about 11,500 ha which is larger than reported extent of formal irrigation (Keraita *et al.*, 2012). Around 260.000 ha in Mexico are irrigated mostly with untreated wastewater (Castro, 2004). The farmers in most of these cases irrigate lands with untreated, diluted, or slightly treated wastewater. Farmers and their family who have direct exposure to untreated wastewater face many health risks factors like bacteria, parasitic worms, and viruses.

The wastewater used for irrigation has a major negative influence on the environmental health conditions (Jahany and Rezapour,2020 and Wu, 2020). Environmental and health aspects are precisely sensitive issues and they are crucial. Sewage water must not be accepted; it should not be used to substitute standard or probably other non-standard water sources for irrigation processes unless it is safely applied and adequately addressed (Alsharhan and Rizk, 2020 and Yaser and Safie, 2020). The most important achieved goals of water reuse in agriculture are to supply sufficient amount of high-quality water to growers and to adhere to food health safety (Wu, 2020). Consequently, in developed countries, the water quality objective is usually determined via public institutions bearing in mind the required wastewater treatment factors and health risks.

There are specifically integrated programmes for the reuse of reclaimed water in developed countries. These programmes are sophisticated; they are set by a specialized government body and they involve policies to enhance the supervision on wastewater before it is used in agriculture. Afterwards, the irrigated crops and products are offered for sale and human consuming. California is considered one of the first pioneer States that exerted the necessary efforts to promote treated wastewater and reuse it in the agriculture field. The first publicised regulation of reused water was in 1918 (Asano and Levine, 1996). At present, around 1.5% of the municipal water in the United States is reused in agriculture. Furthermore, the amount of the reused municipal wastewater by California residents is around 656 million cubic meters per year. The integrated reused wastewater programs in other developed countries, such as Israel have allowed that wastewater accounts for 20% of water incomes which is used in the agriculture (Brooks *et al.*, 2020 and Miarov *et al.*, 2020).

The quality of municipal water provider determines the water excellence generated from treated wastewater, the degree of treatment for the received wastewater and the compositions of the wastes added through use. To control wastewater quality, data are regularly collected, measured and recorded at the main treatment plant specifically for treated sewage disposal or discharge necessities regarding the total contamination limitations, for example, chemical oxygen demand (COD), biochemical oxygen demand (BOD), suspended solids (SS). These factors are the main concerns for water contamination management (Bharagava and Saxena, 2020 and Qi *et al.*, 2020). Nonetheless, there are specific chemical compounds and elements which have a direct effect on soil permeability or plant growth; they exist in the water used for irrigation in landscape and agriculture(Saxena *et al.*, 2020). Due attention must be given to some characteristics which are not recorded or measured via treatment agencies as part of their regular monitoring programmed for water quality. Thus, all the data collected from a treated wastewater irrigation system are necessary; they are used when samples of those selected factors are analysed; theydefine the conviviality of the treated water that is used for landscape irrigation and agriculture (Alsharhan and Rizk, 2020). In order to assess water quality that is used for irrigation, there is a list of laboratory limitations that need to be implemented as illustrated in Table three below (Ayers and Westcot 1989).

Table 3: Laboratory determinations needed to evaluate common irrigation water quality problems (Ayers and Westcot 1989)

Parameter	Symbol	Unit
Salinity		
Electrical conductivity	ECw	dS/m
Total dissolved solids	TDS	mg/l
Cations and anions		
Calcium	Ca2+	mg/l
Magnesium	Mg2+	mg/l
Sodium	Na+	mg/l
Carbonate	CO32−	mg/l
Bicarbonate	HCO3−	mg/l
Chloride	Cl−	mg/l
Sulphate	SO4−	mg/l
Miscellaneous		
Boron	B	mg/l
Hydrogen ion activity	Ph	unit
Sodium adsorption ratio	SAR	Dimensionless

The treated municipal wastewater that is used for irrigation depends on Ayers and Westcot (1989) which is considered a valid basic reference till now. Later on, other different styles are used; they present more advanced water quality guidelines that emphasise the control needed to effectively use a certain quality of water for irrigation. The guideline style is frequently used a lot in estimating irrigation water quality; it is clarified in Table 4 below (Asano *et al.*, 2007). According to Pedrero *et al.*, (2010), the potential restrictions in use shown in beloware somewhat arbitrary since water quality changes occur gradually and there is no clear-cut break point. It is also important to realise that it is not applicable covering all local situations when planning to organise water quality guidelines.

Table 4: Guidelines for interpreting water quality for irrigation (Asano *et al.*, 2007)

Potential irrigation problem	Units	Degree of restriction on use		
		None	Moderate	Severe
Salinity				
ECw	dS/m	≤0.7	0.7–3.0	≥3.0
TDS	mg/l	450	450–2000	2000
Permeability (effects of infiltration rate of water into the soil. Evaluate using ECw and SAR together)				
	SAR = 0–3	ECw ≥ 0.7	ECw 0.7–0.2	ECw ≤ 0.2
	SAR = 3–6	ECw ≥ 1.2	ECw 1.2–0.3	ECw ≤ 0.3
	SAR = 6–12	ECw ≥ 1.9	ECw 1.9–0.5	ECw ≤ 0.5
	SAR = 12–20	ECw ≥ 2.9	ECw 2.9–1.3	ECw ≤ 1.3
	SAR = 20–40	ECw ≥ 5.0	ECw 5.0–2.9	ECw ≤ 2.9
Specific ion toxicity				
Sodium (Na)				
Surface irrigation	mg/l	≤3	3–9	≥9
Sprinkler irrigation	mg/l	≤70	>70	
Chloride (Cl)				
Surface irrigation	mg/l	≤140	140–350	≥350
Sprinkler irrigation	mg/l	≤100	>100	
Boron (B)				
Surface–sprinkler irrigation	mg/l	≤0.7	0.7–3	≥3
Miscellaneous effects				
Nitrogen(Total N)	mg/l	≤5	5–30	≥30
Bicarbonate(overhead sprinkling only)	mg/l	≤90	90–500	≥500
Residual chlorine (overhead sprinkler only)	mg/l	≤1	1–5	≥5
pH		Normal range 6.5–8.4		

1-4 Wastewater quality guidelines for agricultural use

More than 70% of fresh water is used worldwide for agriculture irrigation purposes (Sterner *etal.*,2020); some Arab countries like Iraq, Saudi Arabia, Jordan, Lebanon, Palestine, Egypt, UEA, Qatar, and Libya are considered as water–stressed countries because they impose a critical encumbrance on water supplies. In order to alleviate this stress on water resources, many researchers try to find surrogate solutions to enhance and develop the local market for sewage water to cover all agriculture irrigation needs (Alsharhan and Rizk *et al.*, 2020 and Li *et al.*, 2020). Despite the intensive endeavor to enhance and develop wastewater and to reuse it as a surrogate water resource for irrigation in the agriculture field, all attempts are still not commonly convenient in some developing countries like Saudi Arabia especially from the low reuse rate perspective (Drewes *et al.*, 2012; Khanpae *et al.*, 2020 and Zekri and Al-Maamari, 2020).

The lack of understanding of the wastewater treatment plants efficacy in eliminating pollutants leads to the aversion to reuse treated wastewater. In developingcountries, there is general knowledge among the local public regarding the inefficient treatment processes in the WWTPs; that results in thedeficient removal of microbial contaminants (e.g faecal indicators and pathogens) (El-Zanfaly. 2015 and Khanpae *et al.*, 2020). The badly treated wastewater has a negative effect on people who have direct exposure to it during vocational contact and on the irrigation field. Public consumers will be affected by insufficiently treated wastewater as they are indirectly exposed to it via consumption of the polluted produced food. In order to encourage people to use treated wastewater, it is necessary first to apply systematic monitoring efforts towards effective treatment of local WWTP, and to estimate any possible microbial risk contamination resulting from using retreated wastewater. Conventional water quality parameters aregenerally used to assess treatment effects that involved the abundance of coli form and heterotrophic bacterial counts (Cabral, 2010; Mara, 2013).

1-5 Water quality guidelines for maximum crop production

In many countries all over the world, excreta and sludge which is the land application of wastewater is considered as a common practice with an old classic tradition. Animal excrements have been used by farmers in China as fertilisers for centuries. Mediterranean civilisations and northern European used sewage sludge and wastewater just as manure. For example, in Valencia Huertas and Milanese Marcasites, the wastewater was reused for a long time in the 14th and 15th centuries, respectively (Tadesse, 2014).

The agriculture field in many North American and European cities was the main receptor for all disposal wastewater before wastewater treatment technology was developed to ban the contaminants of other water bodies. In some countries like Paris, the use of a certain partially extent degree for treated wastewater was widespread until the 1950s (Jimenez *et al.*, 2010). Wastewater has been used as an exporter of crop food nutrients over the last ten decades especially in developing countries, for example, Egypt, Peru, China, Lebanon, Mexico, India, Vietnam, and Morocco (Jimenez and Asano, 2008 and Kog, 2020) Consequently, crop production and land application continued using untreated wastewater in the agriculture field for centuries (Keraita *et al.*, 2008 and Abdelhafez *et al.*, 2020). Nevertheless, over the years, untreated wastewater for irrigation in developed countries becomes less popular as a result of the massive improvement of treatment technologies and commoncautions raising awareness of health risk and environmental issues related directly to this practice.

On the other hand, in the Middle East and in some developed countries, the lack of physical and financial resources required to treat wastewater led to the uncontrolled and unplanned wastewater use, besides, the context of urbanization, and the socio-economic situation. The Comprehensive Assessment of Water Management in Agriculture conducted a study that covered more than 53 cities from the developed countries; the study considered the main drivers of treated wastewater in agriculture particularly in the irrigation field (Raschid-Sally and Jayakody, 2009):

1. The contamination of water bodies, soils, and traditional irrigation water sources caused by shortages in developed countries capacities to control wastewater treatment.
2. Deficiency of surrogate (obtainable or harmless, similarly trustworthy, cheaper) water exporter in the physical environment.
3. The demand for urban food and market motivations favoring food production in the in the closeness of cities, where water exporter is generally contaminated.

Furthermore, the level of the household regarding the influence of the socio-economic factors directly affects the quality of wastewater; for example, low education and poverty in developing countries, where inadequate job chances and lack knowledge for health risk consciousness coexist (Jimenez *et al.*, 2010; Coelho *et al.*, 2020). The reused wastewater under such circumstances can represent a willing opportunity to enhance food supply and cash crop production. The population is the end user for all the produced food derived from irrigation by treated wastewater and they gauge its advantages. It is hard to modify people life performance particularly when these changes are connected to historical water rights or cost. This might be changed by decreasing the accessibility of freshwater resources, be it for physical or economic reasons.

One of the important factors that drive farmers to use treated wastewater for irrigation is the inherited recognition for the nutrient value of sludge and raw wastewater. Nonetheless, in most of the developed countries, recycling and reusing water are progressively seen as a responded method to actual water shortage (involving drought control and management in addition to climate change) water reorganizations from irrigation means in agriculture field to other uses and also as a cost-effective answer to expensive inter-basin transfers. These strict standards of the environment are considered as an additional factor affecting wastewater recycling, which makes sludge and land application of treated wastewater unavoidable together and economically more practical. The reuse of agricultural drivers of excreta and sludge is more connected to removal issues than to the actual intention of claiming components.

On the other hand, many farmers count them as a worthy fortune that is close to farmyard manure. This advantageous use is progressively increasing; it is driven by the intention of the closed loops of nutrients that confirm the improvement in soil fertility by returning all nutrients to agricultural land. In most cultures, excreta and sludge were historically considered as harmful substances and shame objects to be used in any field spatially in agriculture. For this reason, the reuse of treated wastewater rather than sludge and excreta is more acceptable by farmers (LeBlanc *et al.*, 2009 and Kehrein *et al.*, 2020). Some Asian countries were the oldest references that used excreta in aquaculture to increase fish production (World Health Organization, 2006, Botta *et al.*, 2020).

In the last two decades, because of the densely populated areas that produce huge quantities of sludge and excreta within a limited stockpiling space, it is not possible for the environment to naturally assimilate and control the sludge, which became an important issue, especially for the developed countries (Haque, 2020). In fact, controlling excreta is a hard task especially when there is a shortage of social people support. Most people favor to avoid what might occur to excreta after discharging it off into latrines; they felt annoyed if it is brought back to their thinking, be it in developing or developed countries (Jimenez *et al.,* 2010 and Ahmadi *et al.,* 2020). Although, from all the information that wasrevealed above, an effort was made as shown in Table five below to display a widespread image of the current use of wastewater, excreta and sludge across the world employing the best leading obtainable data.

Table 5: Some characteristics from countries using wastewater for irrigation (Jimenez *et al.*, 2010)

Use of wastewater for irrigation	Total number of countries	GDP per capita for the 50% of the countries (in US$)	Sanitation coverage for the 50% of the countries (in %)
Untreated	23	880-4800	15-65
Treated and untreated	20	1170-7800	41-91
Treated	20	4313-19800	87-100

1-6 Health protection measures in aquacultural use of wastewater

Numerous authors have exerted efforts to supply a guideline for health protection measures for waste water claim and use (e.g. Helmecke *et al.,* 2020). However, none of these has beenstandardised or taken up globally. In spite of explaining wastewater reuse, the expressions indirect, direct, unplanned, and planned are repeated commonly. These are described here with examples:

- Direct use of untreated wastewater indicates the use of raw sewage which is disposed from WWTP; it is used for crop production where it is directly disposed of on the land.
- Indirect use of untreated sewage points to the concept of normally diluted wastewater (or contaminated stream water) which is used for irrigation purposes. This is widespread especially the downstream of urban centres where most of the treatment services are inadequate. In fact, farmers might realise that the challenge comes from the quality of water that they used to use.
- Direct use of reclaimed wastewater designates the use of treated water that has been moved from the treatment stage to the use stage without the interference of the drainage to waters.

Planned water reuse signals the awareness and managed use of wastewater both raw (direct) and diluted (indirect). Most of the indirect use occurred without previous planning and this could be explained by using low-quality water.

Usually, in dry climates, the direct use of wastewater takes place especially when water sources are rare. Treated, untreated or moderately treated sewage water is used directly in agriculture (for irrigation purposes) without diluting or mixing them. The direct use of treated wastewater is widespread as a planned technique in developing countries including some larger parts of North African and the Middle East area (Alsharhan and Rizk 2020). However, the unplanned action can also take place in dry seasons; for example, when the wastewater is carried by streams, like the River Musi in India. However, diluted wastewater that is used in agriculture (indirect use) is significantly more often used than its direct use and that happens even more in special climates like the wetter climates. In these conditions, partially/insufficiently treated or untreated wastewater from urban areas is disposed of directly into drains, tributaries of the larger water bodies and small streams with fresh water and storm water usually mixed; both were diluted wastewater (or contaminated surface water). Afterwards, it was used by most traditional users who are farmers.

The shortage of satisfactory sanitation and waste outlet infrastructure in large cities is one of the direct and crucial reasons of such contamination and use (Schellenberg *et al*., 2020 and Visanji *et al.*, 2020). This is not exclusive to Middle Eastern countries (the low–income ones) because of the deficiency in collecting and treating sewage water covering all treatment aspects. However, that also happens in developed countries (fast-growing economies); for example, Brazil, China and some of North Africa area. Despite the huge progress in wastewater treatment investments, the generated wastewater in the city of Beijing is half treated and the untreated wastewater is disposed of into water streams as the farmers used downstream (Al Omari, 2020; Alsharhan and Rizk, 2020). In addition, in some middle eastern countries like Palestine and Lebanon, the nearby rivers, seas, and *valleys* are the end discharge point for all the wastewater which is collected from sewer localities, also on open land escape where it seeps into the ground with no or slight treatment (Alsharhan and Rizk, 2020; Brooks*et al.,* 2020 and Coelho *et al.,* 2020).

Despite the (EU) regulations which are considered too harsh and strict, some countries like Spain, Portugal, and Italy used untreated wastewater that is discharged of into rivers streams; later this water is used for irrigation purposes particularly in hot seasons like summer when the river flow is little (Alsharhan and Rizk, 2020)**.**

Recently, the level of wastewater treatment has been increasing due to efforts made by some countries to meet EU legislations which initiated this practice; the use of untreated wastewater being reduced. In Turkey, because of the lack of satisfactory treatment and insufficient sewerage facilities, a huge amount of domestic wastewater is disposed into rivers and used later for irrigation (Nas *et al*., 2020). In some countries, irrigation infrastructure was built to transfer fresh water, groundwater or surface water which is recently used for wastewater during a specific time. The fresh water that is used for irrigation is supplemented by pumped wastewater into irrigation canals. For example, in Vietnam, the generated wastewater from Hanoi and other cities along the Red River Delta is driven into irrigation canals at a specific time of the year to enhance the quantity of irrigation water (Van Thanh *et al.*, 2020).

In contrast, in some other cities like Haroonabad in Pakistan and Hyderabad in India, wastewater may be the only water flowing in the canals especially at the tail end of the irrigation system or through in the dry season (Schellenberg *et al.*, 2020 and Haque, 2020). In Jordan, the domestic wastewater of the capital Amman is mainly treated in the As-Samra WWTP which is located in the southern part of Jordan Valley, the treated water is merged again with surface run-off from *valleys* before it is tentatively kept in the countries major reservoir with 75 million cubic meters storing capacity. Unfortunately, because the wastewater flow is increased, the detention time of the water in the reservoir is reduced from ten months to a few months.

First of all, diseases should be made known as they are connected to the pathogen nature inside the wastewater; consequently, this will change locally according to the pattern of the local public health. Secondly, farmers are not the only people who are facing the risks of these diseases. In fact, diseases can be detected in four different groups: crop handlers, regular customers of crops or milk and meat coming from cattle grazing on contaminated fields, workers in agriculture fields and their families and people who are living close to the areas where wastewater, excreta or sludge is found. Within these groups, the elderly and children are considered the most susceptible sections. Thirdly, there is a difference in the observed responses according to the developed and developing countries. This is due to pathogen concentrations and distributions that these groups are exposed to, which are very different because of the living circumstances and their resistance level to diseases between developed and developing countries (Orsini*et al.*, 2013 and Khanpae *et al.*, 2020). In fact, the food safety statistics are uncertain because of the low laboratory standards in most developing countries.

The crops are mainly contaminated with pathogens via direct contact. However, some cases of uptake by plants have been recorded (Massoud *et al.*, 2019 and Wu, 2020). In addition to pathogens, sludge and wastewater can also be a provenance of the high level of the organic toxic compound and heavy metals (Mahmood and Malik, 2014; Alegbeleye and Sant'Ana, 2020).

Pollution happens, in the case of organic chemicals and some metals, through soil absorbance, which substantially relies on the location (potential pollution sources), conditions of the environment (specifically the soil), bio-availability (in the case of some pollutants), type of agricultural and plant practices (irrigation method and quantity of water applied) (Mahmood and Malik ,2014 and Brooks *et al*., 2020).

There is comparatively good awareness of the admissible quantities of heavy metals that soil and crops can be exposed to when sludge, wastewater or biosolids are utilised in soil (Lente *et al.*, 2014). Additionally, for developing and developed countries both, heavy metals content in wastewater, sludge and excreta from domestic origin are commonly quite low to permit their usage for crop fertilisation (Orsini *et al.*, 2013 and Abdelhafez *et al.*, 2020). Nonetheless, constantly there are cases where caution needs to be taken; for instance, near mining or tanneries areas (Brooks *et al.*, 2020). The risks stemming from direct pesticide usage is in common much higher than the risks coming from organic components that exist in wastewater in contrast with the health risks; the pathogenic, pesticide levels of vegetables weredeemed to be less important, even if they are high, in the context of a developing country (Wu, 2020). As pointed out above, wastewater usage, excreta and biosolids define risks rather than benefits. Considerably, the experts recommend treating wastewater, excreta and sludge 'properly'and simply prohibiting such unsafe practice.

CONCLUSION

In this article we reviewed the maintenance lack for the infrastructure of Rustumihia wastewater treatment plant. The disposed effluent from Rustumihia WWTP was used directly in irrigation by nearby farmers close to the WWTP. Therefore, a supreme degree of awareness and commitment is required by the farmers who are using this treated wastewater in agriculture as the use of the effluents will be reflected directly on people health as well as the environment. An integrated approach should be applied that includes cooperation between the government body and farmers representative in order to maintain the benefits and minimize the health risks. Iraqi farmers have a lack of knowledge for the long-term effects of the reuse of treated wastewater in irrigation. Ministry of water resources need to establish a clear policy for the reuse of treated wastewater and follow up the farmers with the new updates of world health organization and their guidelines for interpreting water quality that is used for irrigation. Hence, this could be implemented via training groups of skilled laboratory employees at various stages who are specialist to look for research work on wastewater reuse and focus on finding alternative methods to eliminate hazardous on environment and human health. Emphasize on increasing the awareness of the wastewater that is used for domestic or portable purposes by following the required standers for drinking water. In the other hand there are many fields that we can invest the treated wastewater in it like, cooling the pipes of boiler in industrial uses, municipal uses for gardens, street cleaning and watering of road sides etc.

ACKNOWLEDGMENTS

The authors would like to thank MUSTANSIRIYAH UNIVERSITY (www. uomustansiriyah.edu.iq) Baghdad Iraq for its providing support in the current work.

REFERENCES

- AbdulRazzak, A. M. (2013). Performance evaluation of Al-Rustamiya wastewater treatment plant. *Journal of Engineering*, *19*(4), 429-38.
- Abdelhafez, A. A., Metwalley, S. M., & Abbas, H. H. (2020). Irrigation: Water Resources, Types and Common Problems in Egypt. In *Technological and Modern Irrigation Environment in Egypt* (15-34). Springer, Cham.
- Abdul Hameed M Jawad, A., Haider S, A., & Bahram K, M. (2010). Application of water quality index for assessment of Dokan lake ecosystem, Kurdistan region, Iraq. *Journal of Water Resource and protection*, *2010*.
- Adila, S. (2011). The role of the municipality in wastewater management in Bahawalpor city. *Management of Environmental Quality*, 22, 282-291.
- Aenab, A. M., & Singh, S. K. (2015). Critical assessment of river water quality and wastewater treatment plant (WWTP). *International Journal*, *3*(1), 405-411.
- Ahmadi, A., Esmaeilion, F., Esmaeilion, A., Ehyaei, M. A., & Silveira, J. L. (2020). Benefits and limitations of waste-to-energy conversion in Iran. *Renewable Energy Research and Application*, *1*(1), 27-45.
- Al Omari, H. (2020). *Water Management in Jordan and its Impact on Water Scarcity* (Doctoral dissertation, Université d'Ottawa/University of Ottawa).
- Alegbeleye, O. O., & Sant'Ana, A. S. (2020). Manure-borne pathogens as an important source of water contamination: An update on the dynamics of pathogen survival/transport as well as practical risk mitigation strategies. *International Journal of Hygiene and Environmental Health*, *227*, 113524.
- Alsharhan, A. S., & Rizk, Z. E. (2020). Overview on Global Water Resources. In *Water Resources and Integrated Management of the United Arab Emirates* (17-61). Springer. Cham.
- Alsharhan, A. S., & Rizk, Z. E. (2020). Treated Wastewater: Quality Concerns and Potential Uses. In *Water Resources and Integrated Management of the United Arab Emirates* (471-497). Springer Cham.
- Al-Samawi, H. A. (2008). Evaluation of Al- Rustamiya 3rd extension wastewater treatment plant efficiency and its environmental effect using remote sensing data. M.Sc Thesis-Building and Construction Engineering Department, University of Technology, Baghdad, Iraq.
- Amponsah, O., Håkan, V., Schou, T. W., Braimah, I., & Abaidoo, R. C. (2016). The impact of farmers' participation in field trials in creating awareness and stimulating compliance with the World Health Organization's farm-based multiple-barrier approach. *Environment, development and sustainability*, *18*(4), 1059-1079.
- Asano, T., & Cotruvo, J. A. (2004). Groundwater recharge with reclaimed municipal wastewater: health and regulatory considerations. *Water research*, *38*(8), 1941-1951.
- Asano, T., & Levine, A. D. (1996). Wastewater reclamation, recycling and reuse: past, present, and future. *Water science and technology*, *33*(10-11), 1-14.
- Asano, T., Burton, F., Leverenz, H., Tsuchihashi, R., & Tchobanoglous, G. (2007). *Water Reuse*. McGraw Hill. New York. U.S.A.
- Ayers, R. S., & Westcot, D. W. (1989). Water quality for agriculture. FAO Irrigation and drainage paper 29 Rev. 1. Food and Agricultural Organization. Rome. http://www.scirp.org/(S(lz5mqp453edsnp55rrgjct55))/reference/ReferencesPapers.aspx?ReferenceID=1949433
- Aziz, A. M., & Aws, A. (2012). Waste water production treatment and use in Iraq. Country report by Ministry of Water Resources, Iraq. (Report). http://www.ais.unwater.org/ais/pluginfile.php/356/mod_page/content/114/Iraq_WasteWaterProduction.pdf.
- Bharagava, R. N., & Saxena, G. (2020). Progresses in Bioremediation Technologies for Industrial Waste Treatment and Management: Challenges and Future Prospects. In *Bioremediation of Industrial Waste for Environmental Safety* (531-538). Springer, Singapore.
- Boamponsem, G. A., Kumi, M., & Debrah, I. (2012). Heavy metals accumulation in cabbage, lettuce and carrot irrigated with wastewater from Nagodi mining site in Ghana. *Int J Sci Technol Res*, *1*(11), 124-129.
- Botta, R., Asche, F., Borsum, J. S., & Camp, E. V. (2020). A review of global oyster aquaculture production and consumption. *Marine Policy*, *117*, 103952.
- Brooks, D. B., Trottier, J., & Giordano, G. (2020). Supporting Palestinian Agriculture. In *Transboundary Water Issues in Israel, Palestine, and the Jordan River Basin* (63-70). Springer Singapore.
- Cabral, J. P. (2010). Water microbiology. Bacterial pathogens and water. *International journal of environmental research and public health*, *7*(10), 3657-3703.

- Castro, J. E. (2004). Urban water and the politics of citizenship: the case of the Mexico City Metropolitan Area during the 1980s and 1990s. *Environment and Planning A*, *36*(2), 327-346.
- Coelho, S. T., Recalde, M. Y., Mani, S. K., & Stafford, W. H. (2020). Overview of Developing Countries. In *Municipal Solid Waste Energy Conversion in Developing Countries* (9-61) Elsevier.
- Cui, Q., Liu, H., Yang, H. W., Lu, Y., Chen, Z., & Hu, H. Y. (2020). Bacterial removal performance and community changes during advanced treatment process: A case study at a full-scale water reclamation plant. *Science of the Total Environment*, *705*, 135811.
- Drechsel, P., Graefe, S., Sonou, M., & Cofie, O. O. (2006). Informal irrigation in urban West Africa: An overview. 102. IWMI. http://www.iwmi.cgiar.org/Publications/IWMI_Research_Reports/PDF/PUB141/RR141.pdf.
- Drechsel, P., Keraita, B., Amoah, P., Abaidoo, R. C., Raschid-Sally, L., & Bahri, A. (2008). Reducing health risks from wastewater use in urban and peri-urban sub-Saharan Africa: applying the 2006 WHO guidelines. *Water Science and Technology*, *57*(9), 1461-1466.
- Drewes, J. E., Patricio Roa Garduño, C., & Amy, G. L. (2012). Water reuse in the Kingdom of Saudi Arabia–status, prospects and research needs. *Water Science and Technology: Water Supply*, *12*(6), 926-936.
- Ensink, J. H., Mahmood, T., Van der Hoek, W., Raschid-Sally, L., & Amerasinghe, F. P. (2004). A nationwide assessment of wastewater use in Pakistan: an obscure activity or a vitally important one?. *Water policy*, *6*(3), 197-206.
- El-Zanfaly, H. T. (2015). Wastewater reuse in agriculture: A way to develop the economies of arid regions of the developing countries. *J Environ Prot Sustain Dev*, *1*(3), 144-158.
- Gaaloul, N. (2011). Water resources and management in Tunisia. *International Journal of Water*, *6*(1-2), 92-116.
- Grabow, G. L., & McCornick, P. G. (2007). Planning for water allocation and water quality using a spreadsheet-based model. *Journal of Water Resources Planning and Management*, *133*(6), 560-564.
- Haque, N. (2020). Mapping prospects and challenges of managing sludge from effluent treatment in Bangladesh. *Journal of Cleaner Production*, *259*, 120898.
- Helmecke, M., Fries, E., & Schulte, C. (2020). Regulating water reuse for agricultural irrigation: risks related to organic micro-contaminants. *Environmental Sciences Europe*, *32*(1), 1-10.
- Jahany, M., & Rezapour, S. (2020). Assessment of the quality indices of soils irrigated with treated wastewater in a calcareous semi-arid environment. *Ecological Indicators*, *109*, 105800.
- Jayyousi, A., Jarrar, A., McKee, M., & Kaluarachchi, J. (2004). Development of water supply and demand in Palestine. In *Critical Transitions in Water and Environmental Resources Management* (pp. 1-8).
- Jimenez, B., & Asano, T. (2008). Water Reclamation and Reuse around the World. In: Jimenez, B., & Asano, T. Eds. Water Reuse: An International Survey of Current Practice, Issues and Needs, IWA Publishing, London, p 648.
- Jiménez, B., Drechsel, P., Koné, D., Bahri, A., Raschid-Sally, L., & Qadir, M. (2010). Wastewater, sludge and excreta use in developing countries: an overview. *Wastewater irrigation and health: assessing and mitigating risk in low-income countries*, 3-29.
- Kehrein, P., Van Loosdrecht, M., Osseweijer, P., Garfí, M., Dewulf, J., & Posada, J. (2020). A critical review of resource recovery from municipal wastewater treatment plants–market supply potentials, technologies and bottlenecks. *Environmental Science: Water Research & Technology*, *6*(4), 877-910.
- Keraita, B., Konradsen, F., & Drechsel, P. (2010). Farm-based Measures for Reducing Microbiological Health Risks for Consumers from Informal Wastewater-Irrigated Agriculture. In Drechsel, P., Scott, C. A., Raschid-Sally, L., Redwood, M., & Bahri, A. (Eds), *Wastewater Irrigation and Health: Assessing and Mitigating Risk in Low-income Countries.* Earthscan, 189-207.
- Keraita, B., Konradsen, F., Drechsel, P., & Abaidoo, R. C. (2007). Reducing microbial contamination on wastewater-irrigated lettuce by cessation of irrigation before harvesting. *Tropical medicine & international health*, *12*, 8-14.
- Keraita, B., Abaidoo, R. C., Beernaerts, I., Koo-Oshima, S., Amoah, P., Drechsel, P., & Konradsen, F. (2012). Safe re-use practices in wastewater-irrigated urban vegetable farming in Ghana. *Journal of Agriculture, Food Systems, and Community Development*, *2*(4), 147-158.
- Khanpae, M., Karami, E., Maleksaeidi, H., & Keshavarz, M. (2020). Farmers' attitude towards using treated wastewater for irrigation: The question of sustainability. *Journal of Cleaner Production*, *243*, 118541.
- Kog, Y. C. (2020). Water reclamation and reuse in Singapore. *Journal of Environmental Engineering*, *146*(4), 03120001.
- LeBlanc, R. J., Matthews, P., & Richard, R. P. (Eds), (2009). Global Atlas of Excreta, Wastewater Sludge, and Biosolids Management: Moving Forward the Sustainable and Welcome Uses of a Global Resource.
- Lente, I., Ofosu-Anim, J., Brimah, A. K., & Atiemo, S. (2014). Heavy metal pollution of vegetable crops irrigated with wastewater 41 Heavy Metal Pollution of Vegetable Crops Irrigated with Wastewater in Accra, Ghana. *West African Journal of Applied Ecology*, *22*(1), 41-58.

- Li, Y., Feukam Nzudie, H. L., Zhao, X., & Wang, H. (2020). Pattern of Physical and Virtual Water Flows: The Impact to Water Quantity Stress Among China's Provinces. In *Addressing the Uneven Distribution of Water Quantity and Quality Endowment* (pp. 23-31). Springer, Singapore.
- Mahmood, A., & Malik, R. N. (2014). Human health risk assessment of heavy metals via consumption of contaminated vegetables collected from different irrigation sources in Lahore, Pakistan. *Arabian Journal of Chemistry*, *7*(1), 91-99.
- Mara D. 2013. Domestic Wastewater Treatment in Developing Countries. Routledge, London, U. K.
- Martijn, E. J., & Redwood, M. (2005). Wastewater irrigation in developing countries—limitations for farmers to adopt appropriate practices. *Irrigation and Drainage: The journal of the International Commission on Irrigation and Drainage*, *54*(S1), S63-S70.
- Massoud, M. A., Terkawi, M., & Nakkash, R. (2019). Water reuse as an incentive to promote sustainable agriculture in Lebanon: Stakeholders' perspectives. *Integrated Environmental Assessment and Management*, *15*(3), 412-421.
- Massoud, M. (2014). Wastewater Management and Reuse: Motivations, Challenges and Opportunities in Developing countries. 2nd Arab-American Frontiers of Science, Engineering, and Medicine Symposium, Muscat 13-15 December 2014.
- Miarov, O., Tal, A., & Avisar, D. (2020). A critical evaluation of comparative regulatory strategies for monitoring pharmaceuticals in recycled wastewater. *Journal of Environmental Management*, *254*, 109794.
- Nas, B., Uyanik, S., Aygün, A., Doğan, S., Erul, G., Nas, K. B., ... & Dolu, T. (2020). Wastewater reuse in Turkey: from present status to future potential. *Water Supply*, *20*(1), 73-82.
- Nehren, U., Lichtenberg, S., Mertin, H., Dennig, N., Alaoui, A. E., Zgou, H., ... & Raedig, C. (2020). The Atlas Workshops of Agdz, Morocco: A Model Region for a Scientific–Artistic Dialogue. In *Stewardship of Future Drylands and Climate Change in the Global South* (pp. 253-278). Springer, Cham.
- Okadera, T., Syutsubo, K., Yoochatchaval, W., Ebie, Y., & Kubota, R. (2020). Water volume-and bod-based flow analysis for domestic wastewater treatment using wastewater inventories of Bangkok, Thailand. *Journal of Water and Environment Technology*, *18*(2), 71-79.
- Orsini, F., Kahane, R., Nono-Womdim, R., & Gianquinto, G. (2013). Urban agriculture in the developing world: a review. *Agronomy for sustainable development*, *33*(4), 695-720.
- Puengrang, P., Suraraksa, B., Prommeenate, P., Boonapatcharoen, N., Cheevadhanarak, S., Tanticharoen, M., & Kusonmano, K. (2020). Diverse microbial community profiles of propionate-degrading cultures derived from different sludge sources of anaerobic wastewater treatment plants. *Microorganisms*, *8*(2), 277.
- Pedrero, F., Kalavrouziotis, I., Alarcón, J. J., Koukoulakis, P., & Asano, T. (2010). Use of treated municipal wastewater in irrigated agriculture—Review of some practices in Spain and Greece. *Agricultural Water Management*, *97*(9), 1233-1241.
- Qadir, M., Wichelns, D., Raschid-Sally, L., McCornick, P. G., Drechsel, P., Bahri, A., & Minhas, P. S. (2010). The challenges of wastewater irrigation in developing countries. *Agricultural water management*, *97*(4), 561-568.
- Qi, M., Yang, Y., Zhang, X., Zhang, X., Wang, M., Zhang, W., ... & Tong, Y. (2020). Pollution reduction and operating cost analysis of municipal wastewater treatment in China and implication for future wastewater management. *Journal of Cleaner Production*, *253*, 120003.
- Raschid-Sally, L., & Jayakody, P. (2009). *Drivers and characteristics of wastewater agriculture in developing countries: Results from a global assessment* (Vol. 127). IWMI.
- Sarma, J. (2020). Filtration and chemical treatment of waterborne pathogens. In *Waterborne Pathogens* (105-122). Butterworth-Heinemann.
- Saxena, G., Purchase, D., & Bharagava, R. N. (2020). Environmental hazards and toxicity profile of organic and inorganic pollutants of tannery wastewater and bioremediation approaches. In *Bioremediation of Industrial Waste for Environmental Safety,* (381-398). Springer. Singapore.
- Schellenberg, T., Subramanian, V., Ganeshan, G., Tompkins, D., & Pradeep, R. (2020). Wastewater discharge standards in the evolving context of urban sustainability–The case of India. *Frontiers in Environmental Science*, *8*, 30.
- Sterner, R. W., Keeler, B., Polasky, S., Poudel, R., Rhude, K., & Rogers, M. (2020). Ecosystem services of Earth's largest freshwater lakes. *Ecosystem Services*, *41*, 101046.
- Tadesse, A. (2014). Using Industrial Barley Washed-out Wastewater for Irrigation.
- Van Thanh, T., Thao, N. T. P., Hieu, T. T., Braunegg, S., Schnitzer, H., Braunegg, G., ... & Le, S. (2020). An integrated eco-system for pollution prevention and greening the production chain of small-scale rice-paper production–A case study from Vietnam. *Journal of Cleaner Production*, *245*, 118785.
- Visanji, Z., Sadr, S. M., Johns, M. B., Savic, D., & Memon, F. A. (2020). Optimising wastewater treatment solutions for the removal of contaminants of emerging concern (CECs): a case study for application in India. *Journal of Hydroinformatics*, *22*(1), 93-110.
- Wu, B. (2020). Human health hazards of wastewater. In *High-Risk Pollutants in Wastewater* (125-139). Elsevier.

- World Health Organization. (2006). Guidelines for the safe use of wastewater, excreta and greywater. *Science of the Total Environment*, 382, 391-392.
- Yaser, A. Z., & Safie, N. N. (2020). Sewage Treatment in Campus for Recycling Purpose: A Review. In *Green Engineering for Campus Sustainability* (207-243). Springer, Singapore.
- Clemens, M., Khurelbaatar, G., Merz, R., Siebert, C., van Afferden, M., & Rödiger, T. (2020). Groundwater protection under water scarcity; from regional risk assessment to local wastewater treatment solutions in Jordan. *Science of the Total Environment*, *706*, 136066.
- Zekri, S., & Al-Maamari, A. (2020). An Overview of the Water Sector in MENA Region. *Water Policies in MENA Countries*, 1-17.