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Effects of wastewater irrigation on groundwater quality: An overview

Abrahan Mora[1,a], Juan Antonio Torres-Martínez[2], Mariana V. Capparelli[3], Andrith Zabala[1] and Jürgen Mahlknecht[2,a]

Abstract
The use of wastewater/reclaimed water for agriculture and landscape irrigation is a common worldwide practice that improves crop productivity and enhances the climatic resilience due to the sustainable use of water. Nevertheless, this activity deteriorates the groundwater quality in areas where it is applied, posing potential risks to ecological safety and human health. This manuscript offers a short overview of the chemical and microbiological pollutants threatening the groundwater quality in zones subjected to intensive and long-term wastewater irrigation, describing the main processes involved in the transport of certain contaminants from the topsoil to the saturated zone.

Addresses
[1] Escuela de Ingeniería y Ciencias, Tecnológico de Monterrey, Campus Puebla, Atlixcáyotl 5718, Puebla de Zaragoza, 72453, Puebla, Mexico
[2] Escuela de Ingeniería y Ciencias, Tecnológico de Monterrey, Campus Monterrey, Eugenio Garza Sada 2501, Monterrey, 64849, Nuevo León, Mexico
[3] Instituto de Ciencias del Mar y Limnología – Estación El Carmen, Universidad Nacional Autónoma de México, Ciudad del Carmen, 24157, Mexico

Corresponding author: Mora, Abrahan (abrahanmora@tec.mx)
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Introduction

Wastewater irrigation (WWI) has been a standard practice to attend the water scarcity issue and increase in turn the food production [1]. Global estimates from 2017 suggest that about 35.9 Mha of irrigated croplands worldwide depend on urban wastewater flows, being China, India, Pakistan, Mexico, and Iran the countries with the highest estimates of wastewater-dependent croplands [2]. Nevertheless, recent studies have estimated an irrigation potential of undiluted wastewater at 42 Mha, considering updated values of wastewater production (380×10^9 m^3 yr^{-1}) [3]. Table 1 shows several examples of direct and indirect use of raw/treated wastewater for irrigation in both developed and developing countries.

Despite the use of raw/treated wastewater for crop irrigation has further increased as the wastewater production has been increased [12], this practice leads to threats such as the bioaccumulation and biomagnification of metals and organic pollutants in crops, shifts in the physicochemical properties of soils, contamination of groundwater resources, and health hazards, among others [13,14]. Regarding the groundwater quality issue, major ions and trace elements [15,16], organic contaminants [17], virus, heterotrophic bacteria [18] and polyethylene, polypropylene, and polystyrene micro-nano-particles contained in wastewater may infiltrate into shallow aquifers [19,20]. This infiltration deteriorates the groundwater quality, posing a potential risk for ecological communities in groundwater receptors and affecting the health of local populations using this water for domestic purpose [21]. Hence, the objective of this short review is to identify the main chemical and microbiological agents and related processes threatening groundwater resources in areas where intensive and/or long-term WWI has been applied. Overall, Figure 1 summarizes the main pollutants found in shallow aquifers of croplands irrigated by treated and untreated wastewater.

Salinity and metals

Salinization of groundwater is one of the most severe impacts caused by WWI. This practice accumulates considerable quantities of salts in soils due to the high load of salts in wastewater. These salts are leached beyond the root areas and the vadose zone, infiltrating into the aquifers and altering the chemistry of groundwater [15,22]. Recent studies have demonstrated that the total dissolved solid (TDS) concentrations in groundwater may

Table 1

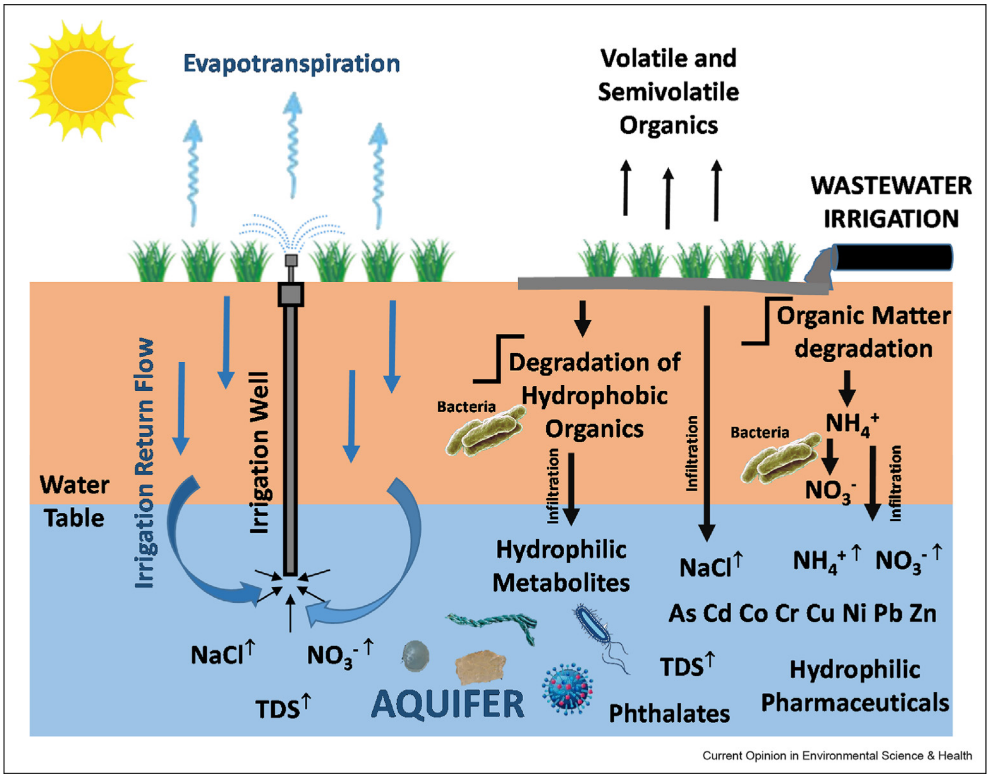
Examples of direct and indirect use of raw and treated wastewater for cropland irrigation in both developed and developing countries.

Country	Example of raw/treated wastewater irrigation	Sources and conditions	Impact	Reference
Pakistan	Eighty percentage of the cities with a population higher than 10,000 inhabitants use their untreated wastewater directly for soil irrigation. About 25% of the wastewater generated in Pakistan is used for soil irrigation	Raw or poorly treated urban and industrial wastewater is directly used or mixed with stream and river waters for crop irrigation	Groundwater contamination Soils contamination Changes in the physical and chemical characteristics of soils Metal accumulation in food crops	[4]
Mexico	Seventy percentage of the wastewater (50 m^3 s^{-1}) generated in Mexico City (20 million inhabitants) is used to irrigate 80,000 ha in the Mezquital Valley	Untreated wastewater with and without dilution. Primary treatment is performed in wastewater reservoirs	Groundwater contamination Soils and crops contaminated with toxic metals High prevalence of diarrheal disease in children	[5,6]
Mexico	Both treated and untreated wastewater coming from the fourth largest metropolitan area of Mexico (Puebla–Tlaxcala) is used for irrigation	Industrial and urban wastewater is mixed with river waters for crop irrigation	Groundwater pollution Gastrointestinal diseases High risk of suffering cancerous diseases in children High risk for developing non-cancerous diseases in adults and children	[7]
China	An irrigation district comprising an area of 789 km^2 in Beijing has been irrigated with reclaimed wastewater since 2003	Undiluted treated wastewater is used for the irrigation of crops such as cucumber, eggplant, wheat, and long bean	Accumulation of pharmaceuticals and personal care products in several crops	[8]
India	Ninety percentage of the wastewater generated by the Hyderabad City (6.8 million inhabitants) is used for irrigating 12,000 ha of croplands	Untreated and poorly treated wastewater (industrial and urban) is mixed with river water to irrigate peri-urban and rural areas	Itchy skin, skin rashes, foot cracks, joint pain, and fever in farmers using wastewater for irrigation	[9]
Iran	The use of undiluted treated or partially treated wastewater for crop production is a common scene in Iran. However, the indirect use of raw wastewater mixed with storm water—stream water—polluted river water for irrigation is very common downstream of urban centers with inadequate treatment facilities		Lack of alternative water resources, limited capacity of cities to treat their wastewater, the socio-economic situation (among others) lead the conditions for unplanned and uncontrolled wastewater use and associated health problems	[10]
Australia	Two billion m^3 of municipal wastewater is treated per year. Overall, agriculture uses 82% of all recycled water in the country			[11]

increase up to 4-fold regarding background levels in zones exposed to long-term WWI, where several species such as chloride are even much more concentrated in groundwater than in wastewater due to the NaCl accumulation in soils [23]. WWI practices may also increase the groundwater sodicity by the NaCl lixiviation and the reverse cation exchange process (dissolved Ca is exchanged by Na on surfaces of the aquifer matrix) [24,25]. Additionally, groundwater–wastewater integrated irrigation systems may exacerbate both salinity and sodicity due to the evaporative effect of the return flows (Figure 1) [15]. Overall, the rising salinity and sodicity may shift groundwater type from Ca–Mg–HCO_3 to Na–Cl [23]. Indeed, if groundwater is also used for irrigation in integrated systems, the excessive sodicity may deteriorate the soil structure and affect the plant growth [24]. Thus, water classification schemes have been developed to restrict water for irrigation use, based on the parameters salinity and sodicity.

Because positive metal ions have a strong affinity to the negative hydroxyl groups of organic matter and clays, the metals contained in wastewater may accumulate in topsoil and subsoil horizons of wastewater-irrigated

Figure 1



Processes controlling the presence and abundance of chemical and microbiological species that degrade the groundwater quality in areas subjected to wastewater irrigation (this figure is based on the research carried out in this review).

areas [26]. Hence, some investigations have reported that WWI does not lead to groundwater pollution by metals [25]. Conversely, current works have demonstrated that elements such as As, Cd, Cr, and Pb can migrate to deep soils in areas subjected to long-term WWI, reaching and contaminating shallow aquifers [26,27]. This may result from increased salinity in the soil systems, because metals such as Cd, Hg, and Pb may be leached from wastewater-irrigated soils to groundwater under elevated soil salinity (between 2% and 5%) [28,29]. Although several metals can migrate through the soil column, their infiltration into the aquifers may depend on many factors such as soil grain-size and soil chemistry, low values of unsaturated zone thickness (water-table levels generally lower than 8 m), and the hydrogeological structure of aquifers, among others [27,30,31]. Additionally, some wastewater characteristics such as pH, salinity, and the content of metals and dissolved organic matter may limit/promote the transport of metals to the saturated zone. In fact, some studies report metal contamination (As, Cd, Co, Cr, Cu, Ni, Pb, and Zn) in groundwater affected by WWI, whereby the concentrations of the above-mentioned elements exceed the permissible limits established in national standards and international guidelines for agricultural and/or drinking purposes [30–33].

Nitrogen inorganic species

Groundwater nitrogen contamination in wastewater-irrigated areas is one of the most relevant issues of concern because high nitrate concentrations in groundwater may cause serious human health threats (such as methemoglobinemia in bottle-fed infants) and disrupt multiple water-related environmental services [34,35]. During WWI, nitrogen enters the system in form of organic matter contained in the sewage. Thus, the organic matter is degraded/oxidized by bacteria in the upper soil horizons and ammonium (NH_4^+) is released from organic nitrogen. Subsequently, part of NH_4^+ is volatilized as ammonia (NH_3) and the rest percolates to lower soil horizons, where heterotrophic nitrification occurs under the influence of nitrifying bacteria [36]. Unreacted NH_4^+ together with nitrite (NO_2^-) and nitrate (NO_3^-) infiltrates into shallow aquifers and their permanence will depend on factors such as pH, dissolved oxygen and dissolved organic carbon (DOC) concentrations, NO_3^-/NO_2^- ratios, the redox potential of the system and the presence of selected N-transforming bacterial communities such as nitrifying, denitrifying and ammonifying bacteria, among others [36−40].

Studies have highlighted the key role of N-transforming bacteria in the dynamics of N-inorganic species in aquifers affected by WWI. Overall, both NO_3^- and NH_4^+ are the most abundant N-inorganic species due to their relatively high stability under oxidizing or reducing conditions, respectively; whereas NO_2^- concentrations remain low in these systems (values below 1.5 mg/L of NO_2^-) due to the instability of this ion [36,37,41,42]. Nitrifying bacteria convert NH_4^+ to NO_2^- and NO_2^- to NO_3^- under oxidizing conditions [36,38]. Otherwise, bacteria-assisted NO_3^- denitrification occurs during strong reducing conditions and high DOC/NO_3^- ratios (heterotrophic denitrification) [38]. Autotrophic denitrification may also occur when bacteria denitrify using reduced inorganic compounds (manganese, iron or sulfides), which act as electron donors [39]. In both denitrification cases, NO_3^- is reduced to gaseous nitrous oxide (N_2O) or nitrogen (N_2). Additionally, recently discovered bacteria-induced processes such as denitrifying anaerobic methane oxidation (DAMO) and anaerobic ammonium oxidation (ANAMMOX) have also been found to regulate the concentration of N-inorganic species in aquifer systems affected by WWI, transforming NO_2^- and NH_4^+ to inert molecular N_2 [37]. In fact, the ANAMMOX has been considered the major N-sink process in aquifer systems worldwide [40].

Overall, the groundwater of lands subjected to WWI may reach concentrations of up to 202 mg/L of NO_3−N [41] and 5.2 mg/L of NH_4^+−N in specific areas where denitrifier organisms dominate [36]. Thus, this may pose a serious threat to groundwater consumers and the environment because both nitrates and ammonium may cause eutrophication in groundwater-dependent water bodies. The groundwater NO_3^- may be exacerbated in groundwater−wastewater irrigation systems due to the effect of the irrigation return flow [43].

Anthropogenic organics

Organic micropollutants such as pharmaceutically active compounds, personal care products, prescription and illicit drugs, industrial organic additives, deodorants, and fossil-fuel compounds, among others, are present in raw wastewater because these are released to sewage systems from point and non-point sources [14,17,44]. These compounds may remain in reclaimed water because conventional wastewater treatment plants (WWTPs) exhibit limitations in removing many of these compounds during the treatment cycle [45].

When raw or treated wastewater is used for irrigation, volatile and semivolatile organics mainly become volatilized during the wastewater storage and irrigation processes [17], whereas most of the organic compounds reaching the topsoil and subsoil horizons are adsorbed onto mineral and organic soil-surface structures, being subjected to biological and/or chemical degradation afterwards [46,47]. However, the most hydrophilic and hard-to-degrade compounds can potentially reach the shallow aquifers, enhancing groundwater contamination. Table 2 shows recent studies indicating the most detected organic compounds in groundwater of areas irrigated with different wastewater types. It is observed that the concentrations of these organics in groundwater are between one and two orders of magnitude lower than those of irrigated water, suggesting that soil-sorption/degradation processes amend the levels of organic contaminants during infiltration. However, in the study performed in lands irrigated with treated wastewater in Wendeburg (Germany), the concentrations of sulfamethoxazole and carbamazepine in groundwater were higher than those found in treated wastewater. This may be due to the use of a mixture of digested sludge and treated wastewater in these croplands [48]. The anti-epileptic drug carbamazepine and the antibiotic sulfamethoxazole seem to be the most common pharmaceuticals in groundwater subjected to WWI. These are commonly present in WWTP effluents because they persist through the wastewater treatment [49]. Additionally, although carbamazepine (log K_{OW} of 2.45) is moderately hydrophobic compared to sulfamethoxazole (log K_{OW} 0.89), both compounds show low affinity to soil-sorption sites and present a strong environmental persistence. All these characteristics make both pharmaceuticals behave almost conservatively during transport, which explains their presence in aquifer systems [50].

Other organics such as caffeine (stimulant), acesulfame (artificial sweetener), and DEET (insect repellent) are abundant in reclaimed water, wastewater and greywater and may also reach groundwater during infiltration. Acesulfame is one of the most useful wastewater tracers in water bodies due to its ionic nature, high hydrophilicity (log K_{OW} −1.33), and high environmental persistence [49]. Similarly, DEET is ubiquitous in wastewater-affected sub-surface environments due to its strong recalcitrance to degradation, despite its moderate hydrophobic nature (log K_{OW} 2.02) [55,57]. Otherwise, although caffeine has shown efficient removal rates during the wastewater treatment [49,53] and a quick degradation during the water infiltration [50], its elevated concentrations in raw wastewater (up to 250 μg/L) and high hydrophilicity (log K_{OW} −0.07) make this natural stimulant moving rapidly through the soil profile, sometimes reaching groundwater [55]. Additionally to these compounds, hydrophilic decomposition products (metabolites) of the organics degraded in the soil horizons may also reach the saturated zone, increasing the risk of contamination with

Table 2

Most detected organic compounds in groundwater of areas irrigated with different wastewater types and their range of concentrations in irrigation water and groundwater.

Location	Irrigation water type	Compounds	Irrigation water range (ng/L)	Detection frequency in groundwater (%)	Groundwater range (ng/L)	Reference
Gran Canaria Island (Spain)	Reclaimed water	Nicotine	132.6 ± 9.0	85.7	<39.4–113.6	[51]
		Caffeine	116.1 ± 6.8	71.4	<2.9–44.9	
		Atenolol	208.7 ± 17.6	50	<12.4–67.7	
La Plana de Castellón (Spain)	Reclaimed water	Bezafibrate	780–1219	92.8	<1.3–12	[52]
		Carbamazepine	84–97	71.4	<0.2–1.9	
		Primidone	57–151	64.3	<1.1–7.5	
		Sulfamethoxazole	115–140	57.1	<0.5–6.1	
		Acetaminophen	44–106	50	<1.1–63	
Pennsylvania (USA)	Reclaimed water	Sulfamethoxazole	$<100–317 \times 10^3$	40	<100–27,410	[53]
		Caffeine	$<100–258 \times 10^3$	32	<100–14,150	
		Naproxen	$<100–347 \times 10^5$	19	<100–98,390	
Area of Oued Souhil (Tunisia)	Reclaimed water	Triclozan	~90	50	<20–289	[54]
		Carbamazepine	690	41.6	<20–155	
		Sulfamethoxazole	~200	33.3	<20–46	
Enoggera Catchment (Australia)	Greywater	DEET	1200–1800	95	<5–12,000	[55]
		Caffeine	$2.4 \times 10^5–13 \times 10^5$	90	<20–140	
		Acesulfame	350–610	90	<5–340	
West Bank (Palestinian territories)	Treated greywater	Azithromycin	0.3–5.1	16.7	0.3–27.6	[56]
		Ciprofloxacin	0.4–87.4	33.3	0.4–70.5	
		Penicillin G	0.7–63.1	8.3	0.7–42	
		Sulfamethoxazole	0.5–18.1	0	<1.02	
		Caffeine	40.4–190,000	100	23.8–953.4	
Wendeburg (Germany)	Treated wastewater	Sulfamethoxazole	61.9–85.4	–	98.2–406.9	[48]
		Carbamazepine	43.4–107.2	–	168.5–272.3	
Mezquital Valley (Mexico)	Raw wastewater	Bis-2-(Ethylhexyl) Phthalate	570–62,300	100	120–1830	[17]
		Dibutylphthalate	290–71,600	100	170–420	
		DEET	32.7–2500	95.2	<0.4–5280	
		Sulfamethoxazole	<1.3–6570	85.7	<1.3–46.6	
		Carbamazepine	17.2–370	47.6	<1.8–99.7	

potentially hazardous organic micro-pollutants [17]. In addition to these compounds, there is a large number of antibiotics and other anthropogenic organics contained in manure and sewer sludge used as crop fertilizers in agricultural lands, which also contaminate groundwater resources [58,59]. Surely, these compounds are also abundant in wastewater compartments and may also occur in groundwater of lands subjected to WWI.

Unlike other anthropogenic organics such as pharmaceuticals and personal care products, the phthalate esters have been poorly addressed in groundwater of croplands irrigated with wastewater. Because these endocrine disruptors cannot be efficiently removed through the wastewater treatment process, they are abundant in reclaimed water and raw wastewater used for irrigation [17,60]. These compounds are rapidly retained by soils because of their high hydrophobicity, although their transport toward deeper horizons depends on the physicochemical characteristics of soils such as temperature, grain-size distribution, mineralogical composition, exchangeable ion capacity, and organic matter content [61]. Studies performed in wastewater-irrigated soils demonstrated that the soil-phthalate hydrophobic interactions may result weak and phthalates may be desorbed and lixiviated to groundwater when a strong complexing carrier phase such as dissolved organic matter is present [62]. In fact, a recent study performed in Mexico (Table 1) found elevated levels of bis-2-ethylhexyl phthalate and dibutyl phthalate in groundwater derived from untreated WWI, wherein the former showed concentrations higher than the value of 0.32 μg/L defined by U.S. guidelines for safe drinking water [63]. The authors suggested that the presence of both high molecular weight phthalates in groundwater is due to their high environmental persistence [17].

Plastic pollution

Microplastics (MPs, particles <5 mm) and nanoplastics (NPs, particles between 1 and 1000 nm) in the environment have raised attention in recent decades due to their slow degradation and potential risks to the ecosystems [64]. Owing to some plastic microparticles such as facial cleanser microbeads and synthetic clothing fibers (among others) are released to the sewage system during household activities, both raw wastewater and greywater may contain important levels of MPs and NPs. However, given that WWTPs are not designed to specifically remove plastic material [65], household plastics may drain through the sewage system to agricultural lands, affecting irrigated soils. However, research till the date on MP pollution in groundwater of areas subjected to WWI is still limited. A recent study performed in groundwater of agricultural lands in Victoria (Australia) found MPs in all groundwater samples with abundances that varied from 16 to 97 items/L, being the microparticles of polyethylene and polyvinyl chloride the most detected [66]. This study suggested that the most probable way for groundwater MP contamination was the MP permeation through the soils.

Although the permeation of MPs through soils seems to be restricted, there is consistent evidence suggesting the vertical migration of MPs from soils to groundwater [19,20,67,68]. Some factors such as composition and properties of soils (sandy, silty, and clayey), the characteristics of MPs and NPs and the co-presence of other substances have been shown to impact on the transport behavior of plastic particles in porous media [19,69]. Densities and surface properties of NPs and MPs can condition their mobility in porous media; however, their additives may also be a key factor controlling transport [69]. For example, the presence of the plasticizer diethylhexyl phthalate restricted the transport of NP particles on gibbsite-coated sands due to this plasticizer caused chemical heterogeneity, which promoted the NP deposition [70]. Additionally, other substances such as surfactants, black carbon, and colloids may be adsorbed onto available sorption sites on porous media, affecting the MPs deposition/mobility [69]. An interesting issue is the transport behavior of MPs in soils under the presence of organic matter. Due to the characteristics of the raw wastewater, its high content of dissolved organic matter may play an important role in the transport of MPs and NPs through the soil column in croplands subjected to WWI. For example, natural organic matter has been found to cover the porous media and the surface of MPs and NPs, increasing the electronegativity in both the mineral surface and the plastic surface. This prevents the deposition of the plastic particles in the media by repulsive forces, increasing their mobility and transport [69,71]. Therefore, the study of the transport of MPs and NPs through soils irrigated with raw wastewater with high content of organic matter is an important issue of concern that should be addressed.

Finally, it is important to point out the role of the MPs in the transport of other contaminants to groundwater systems. Both MPs and NPs may act as a vector of various pollutants including metals, pharmaceutical and personal care products, hydrophobic organic contaminants, plasticizers, and pathogen organisms through combination and sorption [68,69]. Therefore, owing to all of these contaminant are abundant in treated and raw wastewater, MPs might be an important carrier phase of absorbed pollutants from irrigated lands to aquifers. Moreover, recent works have shown that these plastic particles shift the sorption behavior of pesticides in soils, increasing the pesticide mobility to groundwater systems [68]. Thus, studies should be carried out to understand the role of the MP and NP particles in the migration of heavy metals, microbiological agents, personal care products, antibiotics, and other organic and inorganic pollutants through the soil column in agricultural lands.

Microbiological agents

The microbiological contamination is another issue of concern in groundwater of areas subjected to raw WWI. Groundwater of these areas has shown values of total coliforms (TC) and fecal coliforms (FC) above the limits of national standards and international guidelines, indicating possible contamination with pathogens. For example, values of TC and FC of up to 750 and 150 colony-forming unit (CFU)/100 mL, respectively, have been measured in groundwater of mixed wastewater-irrigated sites in the Nile River Delta, Egypt [72]. Similarly, values of TC, FC, and enterococci of up to 404, 53 and 370 CFU/100 mL, respectively, have been reported in groundwater of lands irrigated by raw wastewater in Mexico [73]. This study also reports the detection of rotavirus, enterovirus, and astrovirus in raw wastewater, although those enteric viruses were not detected in groundwater. This may be the result of a significant attenuative capacity of the aquifer matrix with regard to microbial transport. However, the transport of viruses and other pathogens may be promoted in shallow/fractured aquifers, conditions that may cause serious microbiological hazards to groundwater [18].

Conclusions

This short review highlights the main aspects regarding the chemical and microbiological contamination of groundwater in agricultural lands subjected to WWI. Overall, this practice (WWI) increases the levels of salinity and sodicity in groundwater and may incorporate several toxic metals to soils, mainly if raw wastewater is used for irrigation. Once inside upper soil layers, several metals such as As, Cd, Cr, and Pb may infiltrate through the soil column, reaching shallow aquifers. Nitrate was identified as one of the most common contaminants in groundwater of areas subjected to WWI practices. Owing to its toxicity at elevated concentrations and eutrophication effects on groundwater receptors, the study of this compound and its transformations in aquifer systems is an issue of concern that deserves further attention in areas irrigated with treated or untreated wastewater.

Regarding the anthropogenic organics, the antibiotic sulfamethoxazole and the antiepileptic drug carbamazepine seem to be the most studied and detected compounds in aquifer systems impacted by WWI practices. This peculiarity is led by their worldwide use in the treatment of related diseases, their high environmental persistence and their low affinity to soil-sorption sites. It is noteworthy to mention that although antibiotics, personal care products, sweeteners, and other persistent organics have been assessed in aquifers of urban, rural, industrial and agricultural areas around the world, the study of the abundance of these compounds in aquifers of croplands recharged by wastewater is still limited. Numerous soil column experiments simulate the transport of these contaminants using wastewater as a source [74,75]; nevertheless, more *on site* studies are needed in order to understand the processes governing the mobility of old and new organic contaminants and their metabolites in wastewater-irrigated soils under real conditions.

Another interesting issue regarding the groundwater derived from WWI practices is the acquisition of antibiotic resistance genes by bacteria. Even though the study of antibiotic resistance has been mainly focused on soils subjected to WWI [76], only two recent works have pointed out that treated WWI promotes the dissemination of antibiotic resistant genes into subsoil pore-water and groundwater, maintaining the bacterial load [48,77]. Hence, this topic deserves special concerns in the near future. Thus, more field investigations about the antibiotic resilience in the groundwater microbial communities of wastewater-irrigated areas are needed.

Owing to MP and NP contamination is a recent issue of concern, there are limited studies regarding the assessment of plastic particles in aquifer systems, especially in wastewater irrigated areas. However, both observational and experimental evidence confirm the migration of these plastic particles through the soil column. In addition, experimental studies have demonstrate that this migration is enhanced in presence of organic matter. Therefore, future efforts should be directed to the assessment of MP contamination in groundwater resources affected by WWI in agricultural lands and the study of the MP and NP transport in soils irrigated by raw wastewater.

Finally, although WWI leads some benefits such as water shortage solutions, bioavailable nutrient sources for crops and nutrient reuse (which diminishes the eutrophication of surface waters), this practice may lead serious contamination problems in groundwater systems. Therefore, it is necessary to perform risk-cost-benefit analyses of the use of wastewater in croplands, mainly in regions irrigated with untreated wastewater, in order to change the sources used for irrigation and/or implement better strategies to prevent groundwater pollution. Strong management strategies may include the application of treatment technologies for the elimination of contaminants in wastewater maintaining the nutrient levels and the use of suitable irrigation technologies. The implementation of these high-priority-actions can lead substantial benefits in crop productivity, carrying out a more efficient use of water resources and minimizing risks of groundwater pollution.

Credit author statement

Abrahan Mora: Conceptualization, Methodology, Writing—Original draft, Visualization. **Juan Antonio Torres-Martínez**: Writing—Original draft. **Mariana V. Capparelli**: Writing—Original draft. **Andrith Zabala:** Writing—Review & Editing. **Jürgen Mahlknecht**: Writing—Review & Editing, Supervision.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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* of special interest
* * of outstanding interest

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