Comparative Study of the Egyptian Code for Reusing Treated Wastewater for Agriculture

Ahmed Khaled Abdella Ahmed[a*,] Moussa Shalaby[a], Osama Negim[b], Talaat Abdel-Wahed[a]

[a] Civil Engineering Department, Faculty of Engineering, Sohag University, Sohag, Egypt

[b] Soil and Water Department, Faculty of Agriculture, Sohag University, Sohag, Egypt

Abstract

Egypt's limited water resources and rising water demand are critical to the country's economy and food security. This predicament encouraged the development of non-traditional water resources in order to bridge the gap between supply and demand for water. treated wastewater (TWW) reuse for irrigation is a viable alternative for closing this gap and conserving traditional water resources for residential and urban usage. TWW is a valuable source of nutrients in most wastewater treatment technologies, and it can improve the physicochemical properties of light-textured soils in the long run. Pathogens and the accumulation of harmful chemical substances, on the other hand, are the principal problems that can prevent TWW reuse in agriculture. This study compares Egyptian treated wastewater quality parameters for irrigation with those of other countries throughout the world, focusing on the environmental and health risks associated with the use of treated wastewater. Finally, the acceptable health parameters of treated wastewater for agricultural purposes were reviewed to preserve the health of the Egyptians.

1. INTRODUCTION

Water is a vital resource for the development of countries and the formation of permanent communities. Nonetheless, in many countries, water demand outstrips supply, resulting in freshwater scarcity [1, 2]. Conventional surface irrigation is the primary user of freshwater, resulting in a water crisis in arid and semi-arid regions such as Egypt [2]. As a result, it is critical to implement sustainable water management plans and seek alternative water supply plans such as water conservation, water reuse, and desalination of seawater and brackish groundwater [3]. Many countries consider the reuse of treated wastewater as an alternative source of irrigation and a valuable asset for agriculture [4, 5]. Wastewater reuse is an excellent way to manage water scarcity while also protecting high-quality fresh water and lowering environmental pollution [6, 8]. In Egypt, treated wastewater is the only source of new water as other sources become scarce. As a result, Egypt has taken the lead in terms of integrated drainage water management. In 2014, Egypt's Ministry of Water Resources and Irrigation announced that treated wastewater is required to mitigate the risk of a water shortage [9].

Even though treated wastewater is a rich source of nutrients in most wastewater treatment technologies for soil and plants, it has several drawbacks [10]. Microbial infections, the accumulation of harmful heavy metals, and a rise in soil salinity are the most severe consequences of reusing treated wastewater for agricultural use [11]. As a result, infections impact human health in addition to bacterial diseases of the consumers of this water's irrigated crops [12, 13]. As a result, the treated wastewater's quality must be assessed before it is used to irrigate agricultural land [14]. Egypt enacted laws, legalizations, and regulations to protect the health of these crops' consumers as well as to assure the safe reuse of treated wastewater. The Egyptian code for wastewater reuse (no.501/2015) for irrigation is the most recent Egyptian regulation [15]. The purpose of this study is to examine the existing Egyptian code for wastewater reuse for irrigation, with an emphasis on health restrictions, in comparison to the regulations of other countries and organizations. The overall goal in Egypt is to maximize the benefits of treated wastewater.

---

* Corresponding author: ahmed_khaled@eng.sohag.edu.eg

Different wastewater treatment technologies have been used in Egypt through 412 wastewater treatment plants [16, 17]. Some of these technologies are passively aerated biological filters, constructed wetlands, oxidation ponds, up-flow anaerobic sludge blanket, membrane bioreactors, up-flow anaerobic bio-filter reactor, and activated sludge [17, 18]. Egypt has employed wastewater reuse for agriculture since 1911, when untreated and partially treated wastewater was reused for irrigation at the Algabal Al-Asfar farm in the Eastern Desert, 25 kilometers northeast of Cairo [19].

Different countries have different regulations, guidelines, and biological and microbiological quality restrictions for irrigation uses. Also, even some countries that have the same quality parameters vary significantly in the threshold levels for those parameters [20]. The differences extend to include the states of the same country like the United States. But these differences have negative effects on wastewater reuse acceptance and cause uncertainty between farmers and stakeholders. As a result, the implementation of agricultural water reuse is being slowed [21]. Also, at the international level, these differences make countries pose more restrictive conditions and obstacles on global trade of food crops (FC) irrigated by treated wastewater.

1.1. Definitions and terminologies

It's crucial to know the distinction between regulations and guidelines. Guidelines are advisory, voluntary, and non-enforceable, whereas regulations are legally adopted, enforceable, and mandatory. However, guidelines can be included in water reuse licenses and therefore become enforceable obligations [22]. The term "water quality guidelines" refers to a set of management goals based on water quality standards that are suggested but not required by law to be followed. The safe reuse of TWW as agricultural water has been suggested by organizations and governments (e.g., the WHO, the US EPA, and Australia). Greece and the United States set state-based water quality standards, which are the actual restrictions that are controlled by law [23].

1.2. Treated wastewater quality standards for irrigation

The quality of treated wastewater for irrigation can be divided into three categories: health controls, agronomic controls, and physicochemical controls, each of which includes a variety of other branching criteria [24, 25]. This study examines the health controls.

2. HEALTH CONTROLS

The most concerning matter about using agricultural irrigation with treated wastewater is the public health of all the people who are subjected to this water including farmers, workers, consumers, and people who live next to these farms that use the TWW. Accordingly, all regulations and standards have addressed this issue in the form of microbial and chemical water quality controls.

2.1. Microbiological constituents in the treated wastewater

The most common issue in TWW irrigation is the possibility of communicable diseases transfer by pathogenic organisms. Enteric pathogens, such as enteric bacteria, protozoa, helminths, and viruses, are the most common microorganisms linked to waterborne disease. Microorganisms were first recognized as agents of waterborne disease in the 1860s during a cholera outbreak in England when German bacteriologist Theodor Escherich isolated organisms from a cholera patient's stools and discovered that they were similar to those found in the intestinal tracts of all healthy people. And these organisms are named for Escherichia coli or E. coli [22].

2.1.1. Main types of enteric microorganisms
- Bacteria are minute organisms that range in size from 0.2 to 10 um. Shigella, Salmonella, E. coli, Yersinia enterocolitica, Campylobacter jejuni, and other bacteria are among them.
- Protozoa: Single-celled organisms without a cell wall are known as protozoa. Giardia lamblia,
- Cryptosporidium parvum, and Entamoeba histolytica are all major pathogenic protozoa.
- Helminths are a group of mostly parasitic worms like A. lumbricoides and S. mansoni.
- Viruses are host-specific obligatory intracellular parasitic parasites that can only replicate within a host cell. Like Hepatitis A, Noroviruses and Other Caliciviruses, Rotaviruses, Enteroviruses, and Adenoviruses.

2.1.2. Indicator organisms
Monitoring all possible microbial constituents especially viruses in the treated wastewater is a nearly impossible matter. as it is impractical and takes a lot of time for analysis. As a result, the notion of indicator organisms has been recognized for monitoring microbiological constituents. And there are some conditions of the ideal indicator organism like [26]:
- When there is fecal contamination, the indicator organism must be detected.
- The number of indicator organisms cannot be less than that of the pathogenic organism being studied.

- The indicator organism survival characteristics in the treatment process must be the same or greater than those for the target pathogenic organisms …and so on.

The different countries' regulations and standards for the treated wastewater quality take different indicator organisms to monitor the microbiological constituents for safe use of the treated wastewater. For example, faecal coliforms are a sign of faecal contamination and the health hazards that come with it. Total coliform is considered more stringent than fecal coliform. Additional indicator species included in the regulations include thermo-tolerant Coliforms, Clostridium perfringens, E.coli, Enterococci, Klebsiella spp., Fecal Streptococci, Bacteroides, F-RNA Bacteriophages, Somatic Coliphages, Nematodes, P.Aeruginosa, and A hydrophila [27].

2.1.3. Major approaches of microbial water quality

One of the most challenges of irrigating with treated wastewater is the high cost to conform to high microbiological standards so there are a variety of techniques for creating microbiological guidelines for the use of treated wastewater. The different approaches have different outcomes as their objectives:[28]

- The absence of fecal indicator bacteria to an acceptable limit in the treated wastewater (restricted microbial regulation).

  The benefit of this approach is that it eliminates the need to keep track of all harmful germs. The negative is that it is overly rigorous and expensive. This is acceptable in industrialized countries, but countries with high rates of endemic enteric infections as a result of poor sanitation and hygiene are unwilling to pay such a high price. The regulations and standards which are established by different countries using this approach are shown in Table (1)

- In the exposed population, there are no increased cases of enteric infections (unrestricted microbial regulation).

  The benefit of this approach is that the health risk assessment is done by examining the infection between people who have been exposed to treated wastewater, but the downside is that it is only valid for the time and place when the health risk assessment was done. Moreover, conducting these epidemiological studies is not always easy. The regulations and standards established by different countries using this approach are shown in Table (2)

- Epidemiological research and quantitative microbiological risk assessment are used to determine the risk to human health (QMRA).

  In defining the authorized microbe limits, a procedure for calculating the risk of exposure to microorganisms is used. This approach is dependent on the irrigation method and crop type, and it considers risk reduction due to the complete agricultural process, from irrigation to pre-consumption cleaning.

2.1.4. Egypt regulation compared with other countries

In general, Table 1 and Table 2 show that countries have different organism indicators for the same treated wastewater reuse category. Also, countries and organizations have different thresholds for the same indicator and reuse category. This incompatibility leaves a bad impression on encouraging the use of treated wastewater for different fields.

TABLE 1. RESTRICTIVE AGRICULTURAL WASTEWATER REUSE REGULATIONS AND GUIDELINES.

Country, state, organization	Reuse Categories	Required Microbial Quality (CFU[†] or E. coli) /100 mL) (Monitoring)
US EPA[‡] [29]	Crops for human consumption	FCB[§] (daily): 0 (AVG[**] of the prior 7 days), 14 (max[††])
	P.F.C[‡‡]/ N.F.C[§§]	FCB (daily): 200 (AVG of the prior 7 days), 800 (max)
ISO[***] [30]	A: treated wastewater of very high grade; irrigation of food crops	TTCS[†††]: 10, 100 (max)

[†] Colony Forming Units

[‡] United States Environmental Protection Agency

[§] Fecal Coliform Bacteria

[**] average

[††] maximum

[‡‡] Processed food crops

[§§] non-food crops

[***] International Organization for Standardization

[†††] Thermo-tolerant coliforms

	consumed uncooked in unrestricted agricultural and residential settings	
	B: high quality treated wastewater; Irrigation of processed food crops is restricted in cities and agriculture.	TTCS: 200, 1000 (max)
	C: treated wastewater of good quality; agricultural irrigation of non-food crops	TTCS: 1000 IN‡‡‡: 1 Egg/L (AVG)
	D: treated wastewater of moderate quality; restricted irrigation(R) of seeded and industrial crops	IN: 1 Egg/L (AVG), 5 Egg/L (max)
	E: widely treated wastewater;	IN: 1 Egg/L (AVG), 5 Egg/L (max)
CA§§§ (British Columbia) [31]	R****	FCB (weekly): 200
	U.R††††	FCB (daily): 2.2
CA (Atlantic Canada) [32]	R	E.C‡‡‡‡ (two times each month): 200
	U.R	E.C (two times each month): 2
US (Georgia) [33]	P.F.C/N.F.C	FCB (Daily): 23 (The geometric average for the month), 46 (The geometric average of the week): 100
	A: Crops for human consumption, unrestricted irrigation	FCB: 0 (7-day CON§§§§ sampling, AVG), 14 (Max)
US (Massachusetts) [34]	B: pastureland for dairy cows, unprocessed food crops (no contact with the crop's edible section), restricted	FCB: 14 (7-day continuous sampling, AVG), 100 (Max)
	C: orchard and vineyard (no contact with the crop's edible section), processed food crops	FCB: 200 (AVG)
US (Pennsylvania) [35]	Crops for human consumption	FCB (2/week): 2.2 (Mean for the month), 23 (Max)
	Non-food/processed food crops	FCB (Weekly): 200 (Mean for the month), 800 (Max)
	Agglomerations > 2000 p.e*****	E.C (1/15 Days): 5 IN: 0
	Agglomerations < 2000 p.e. all crops	FCB: 5, 15 (Max) IN: 0
Cyprus [29]	Agglomerations < 2000 p.e. unlimited access and vegetables eaten cooked (potatoes, beetroots, Colocasia)	FCB: 50, 100 (Max) IN: 0
	Agglomerations < 2000 p.e. limited access and crops for human consumption	FCB: 1000, 5,000 (Max) IN: 0
	Agglomerations < 2000 p.e. fodder crops	FCB: 1000, 5,000 (Max) IN: 0
Italy [36]	Not Specified	E.C: 10
Greece [37, 38]	R	E.C (Weekly): 200 (Median)

---

‡‡‡ Intestinal nematodes
§§§ Canada
**** Restricted irrigation
†††† Unrestricted irrigation
‡‡‡‡ Escherichia. Coli
§§§§ Continuous
***** Population equivalents

	U.R	E.C (4/Week): 5 (80% of samples), 50 (95% of samples) methods
	A:	E.C (Weekly): 10 IN (2/Month): 1 Egg/L
European Commission [39]	B:	E.C (Weekly): 100 IN (2/Month): 1 Egg/L
	C:	E.C (2/Month): 1000 IN (2/Month): 1 Egg/L
	D:	E.C (2/Month): 10,000 IN (2/Month): 1 Egg/L
Israel [40-42]	Not Specified	FCB: 10
	A: cooked vegetables, parks, playgrounds roadsides in the city	E.C or FCB: 100 IN: 1 Egg/L
Jordan [43]	B: fruit trees	E.C or FCB: 1000
	C: crops used in industry	NS
	D: flowers	E.C or FCB: 1.1
Kuwait [44]	Not Specified	TC[†††††]: 400 FCB: 20
Saudi Arabia [45]	R	TTCS: 1000 IN: 1
	U.R	TTCS: 2.2 IN: 1

TABLE 2. LESS RESTRICTIVE AGRICULTURAL WASTEWATER REUSE REGULATIONS AND GUIDELINES.

Country, state, organization	Reuse Categories	Required Microbial Quality (CFU or E. coli) /100 mL) (Monitoring)
FAO[‡‡‡‡‡] [46]	A: Irrigation of non-processed food crops, sports fields, public parks	FCB: 1000, 200 (In case of fruit trees) IN: 1 Egg/L
	B: irrigation of fodder crops, industrial crops, cereal crops, pasture, and trees	IN: 1 Egg/L
	C: irrigation of crops in category B using drip irrigation if workers and the general public are not exposed	Not Specified
WHO[§§§§§] [47]	R	E.C: 10,000 (Labour), 100,000 (Highly automated) IN: 1 Egg/L
	U.R (localized irrigation)	E.C: 1000 (Low-growing), 100,000 (High-growing) IN: 1 Egg/L
	U.R	E.C: 1000 (Root crops), 10,000 (Leaf crops) IN: 1 Egg/L
US (Nebraska) [48]	U.R	FCB: 200 (The GM[******] of the last 30 days), 400 (Only ten percent of the samples are used.)
US (South Dakota) [49]	Crops for human consumption	TC: 200
US (Wyoming) [50]	Crops for human consumption	FCB: 200

[†††††] Total Coliforms
[‡‡‡‡‡] Food and Agriculture Organization of the United Nations
[§§§§§] World Health Organization
[******] geometric mean

	P.F.C/N.F.C	FCB: 1000
Mexico [51, 52]	Not Specified	FCB: 2,000 (AVG for the day), 1000 (AVG for the month)
France [53]	A: unrestricted Irrigation of all crops, even those that are accessible to the public.	Enterococci (Weekly): ≥ 4 Logs E.C(Weekly): 250
	B: all crops, except those consumed raw or green spaces open to the public	Enterococci (1/15 days): ≥ 3 Logs E.C (1/15 days): 10,000
	C: various ornamental crops, bushes, grains; drip-irrigated horticultural crops, controlled-access forests	Enterococci (Monthly): ≥ 2 Logs E.C (Monthly): 100,000
	D: inaccessible woodlands	Enterococci: ≥ 2 Logs
Spain [54]	2.1	E.C (Weekly): 100 IN: 1 Egg/10L
	2.2 (A) irrigation of processed food crops (B) Irrigation of grazing land for dairy or meat animals (C) aquaculture	E.C (Weekly): 1000 IN: 1 Egg/10L
	2.3: (A) drip irrigation of tree crops (B) Irrigation of decorative flowers, nurseries, and greenhouses (c) irrigation of industrial non-food crops	E.C (Weekly): 10,000 IN: 1 Egg/10L
Egypt [15]	A: 1.1 Green spaces for educational facilities and public and private parks 1.2 Fruit crops that are eaten fresh without peeling	E.C (3 times weekly): 20 IN: 1 Egg/1L
	B: 2.1 Dry cereal crops, as well as raw and cooked vegetables 2.2 Fruit crops are sustainable and deciduous such as citrus fruits, mangoes, and pomegranates 2.3 Medicinal plant crops such as anise and fenugreek	E.C (3 times weekly): 100
	C: 3.1 Dry cereal crops, fruit crops, and medicinal plant crops included in group B provided that the spray irrigation method is not used. 3.2 Non-food seeds 3.3 All kinds of seedlings 3.4 Roses and all kinds of ornamental plants 3.5 Trees, afforestation of highways [55-58] and green belts 3.6 All forage crops 3.7 Forage crops, legumes 3.8 Kinds of berries used in silk production 3.9 All seedlings and ornamental trees	E.C (Weekly): 1000

	D: 4.1 Plants that produce solid biomass 4.2 Plants that produce liquid biomass 4.3 All non-food crops to produce glucose and its derivatives 4.4 Woody trees	Not Specified
Spain [54]	(A) irrigation of processed food crops (B) Irrigation of grazing land for dairy or meat animals (C) aquaculture	E.C (Weekly): 1000 IN: 1 Egg/10L
China [59]	fiber	FCB: 40,000 IN: 2
	Corn oil crops grown in dry fields	FCB: 40,000 IN: 2
	Grain harvested from paddy fields	FCB: 20,000 IN: 2
	Vegetable	FCB: 20,000 IN: 2
Portugal [60]	A: vegetables consumed raw	FCB: 100
	B: public parks and gardens, sports fields, and public woods	FCB: 200
	C: Cooking veggies, fodder crops, vineyards, and orchards	FCB: 1000
Oman [61]	A: uncooked vegetables and fruits	FCB: 200 IN: 1 Egg/L
	B: processed vegetables and fruits	FCB: 1000 IN: 1 Egg/L

‡‡‡‡‡Food and Agriculture Organization of the United Nations
§§§§§ World Health Organization
****** geometric mean

Egypt follows the second approach of treated wastewater quality standards, depending on the 2006 guidelines of the World Health Organization (WHO) [15]. Egyptian organisms' indicators for the microbiological constituents are E. coli and Intestinal Nematodes as shown in Figs. (1,2, 3, and 4). These indicators are less restrictive than total coliform or even fecal coliform because the quantity of E. coli is always less than the total number of coliforms. The Egyptian code (501-2015) classifies treated wastewater reuse into four categories. The threshold of indicator organisms is different from one category to another. Egypt's threshold for E. Coli for the first category to some extent is great when compared with other countries as shown in Fig. (1). Egypt only takes Intestinal Nematodes for the first category as 1 egg/l.

In general, the microbiological characteristics and limits in the existing rules and guidelines for using treated wastewater for irrigation are inadequate to guarantee human health safety.[62]. While antibiotic-resistant bacteria (ARBs) and antibiotic resistance genes (ARGs) are becoming more widely recognized as emerging pollutants, current water reuse rules and guidelines do not sufficiently address these issues [63].
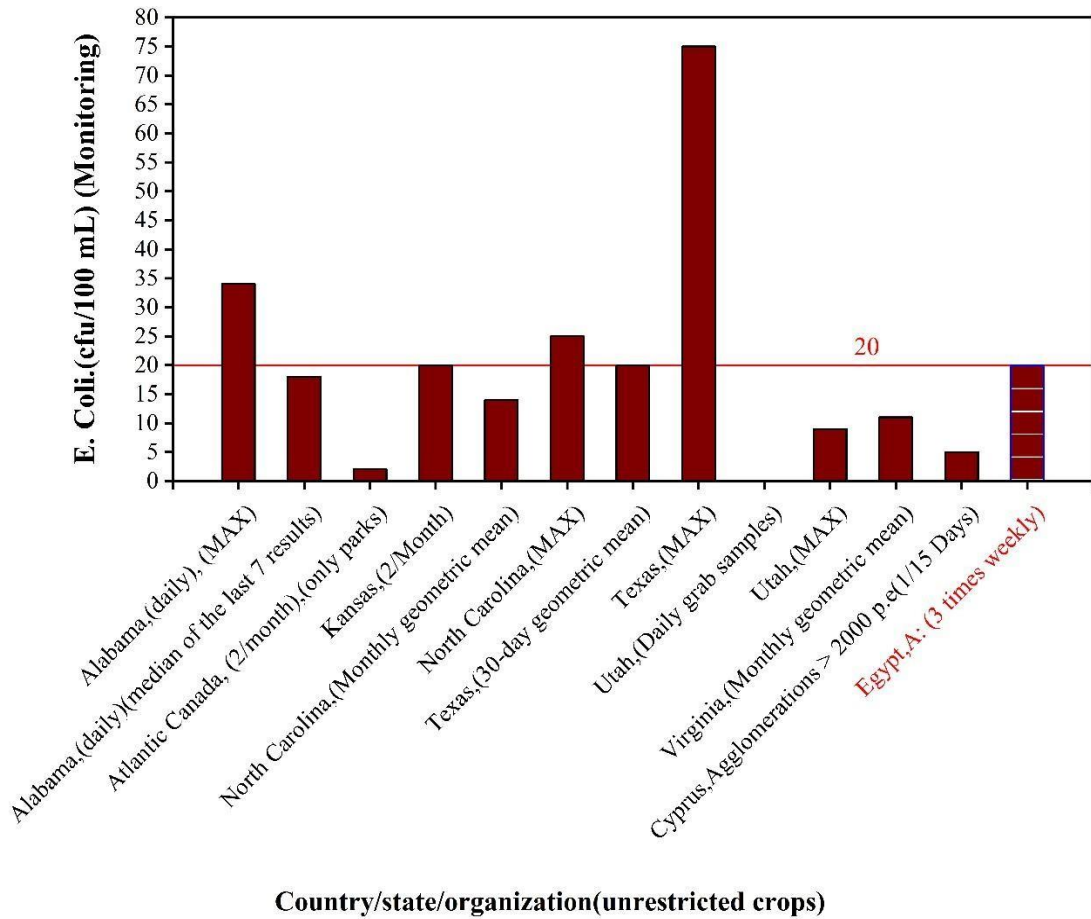
Country/state/organization(unrestricted crops)

Fig. 1. Required microbial quality for unrestricted crops: Escherichia. Coli (cfu/100 mL) (Monitoring)

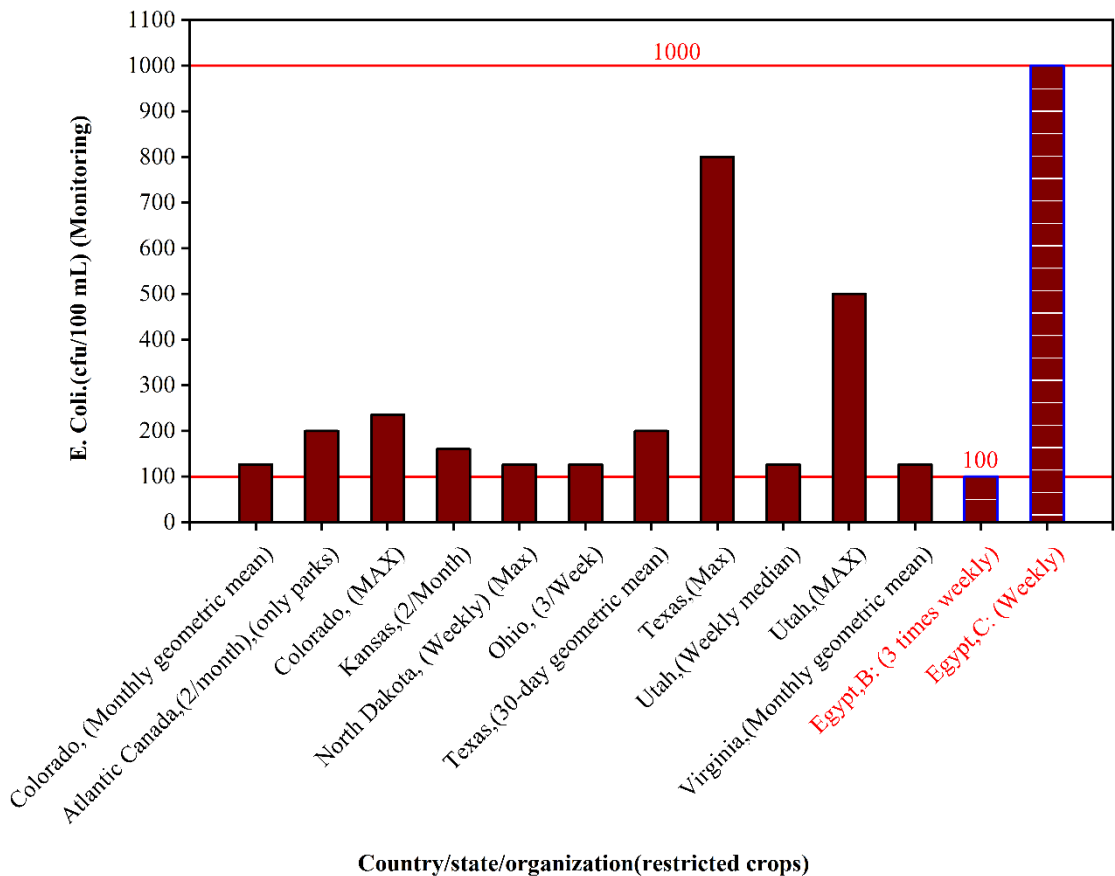**Country/state/organization(restricted crops)**

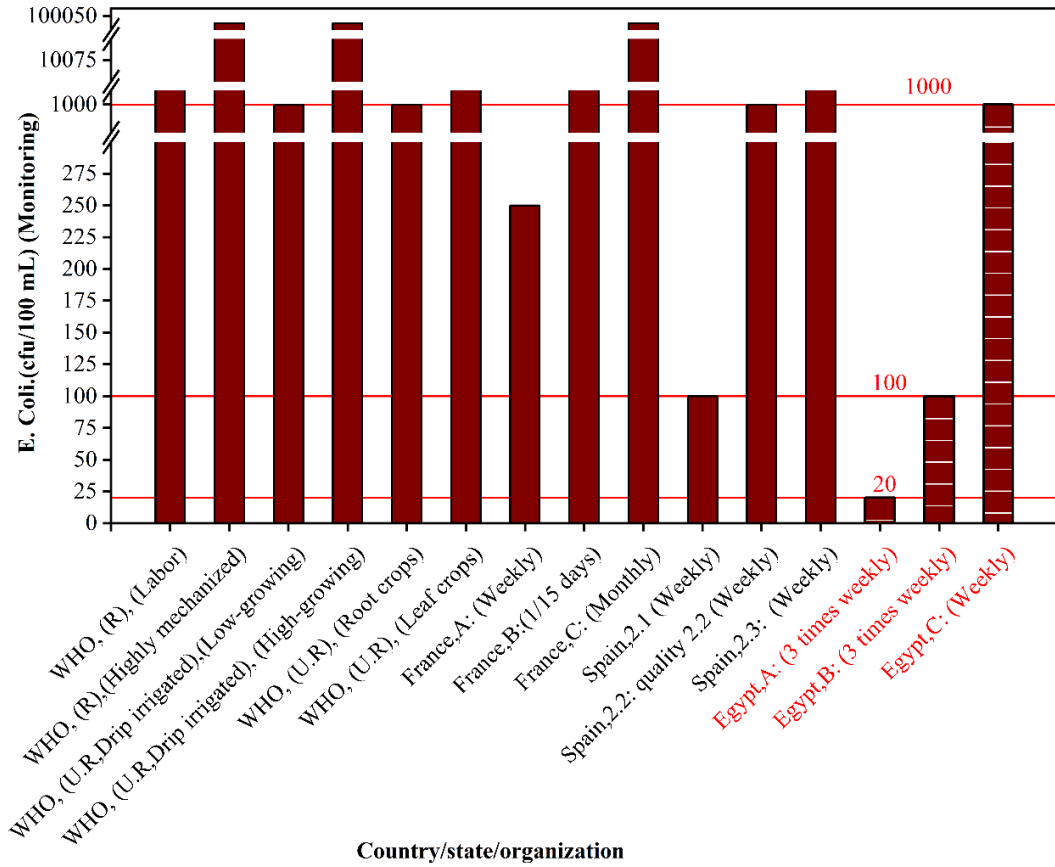Fig. 2. Required microbial quality for restricted crops: Escherichia. Coli (cfu/100 mL) (Monitoring)

Fig. 3. Required microbial quality for less restrictive regulations: Escherichia. Coli (cfu/100 mL) (Monitoring).
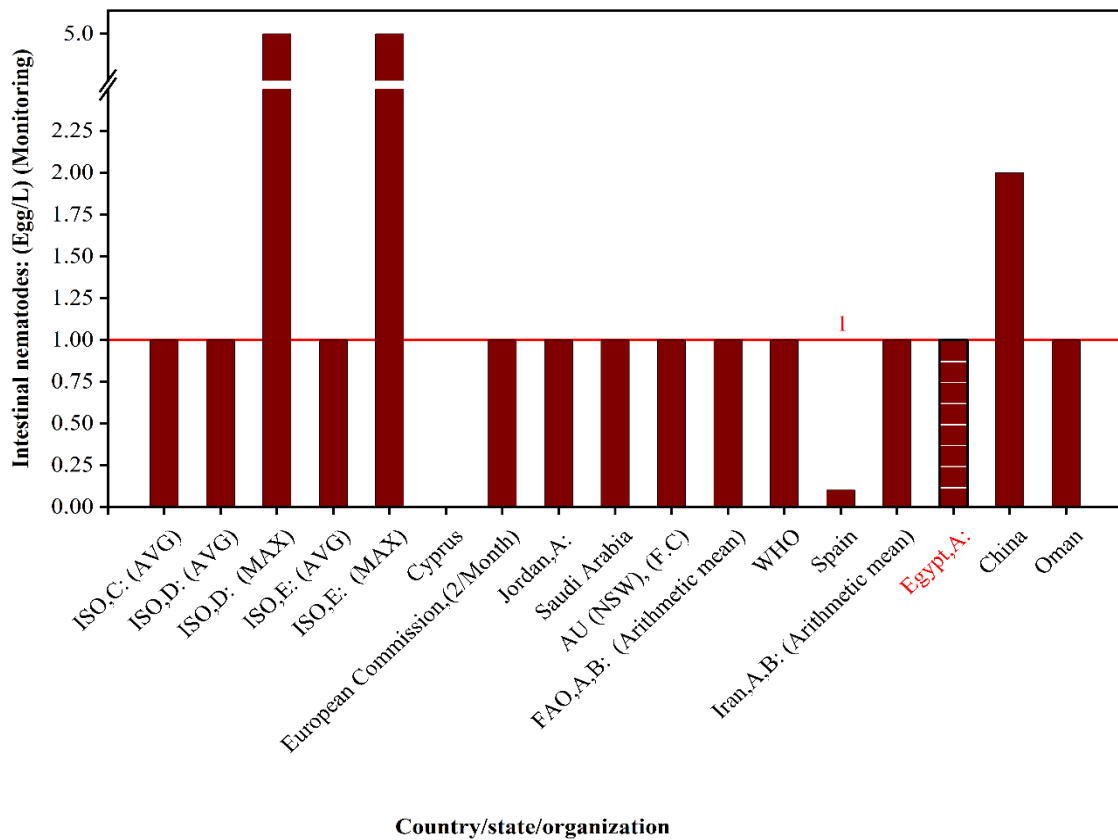

Fig. 4. Required microbial quality: Intestinal nematodes (Egg/L) (Monitoring)

2.2. Chemical components in the treated wastewater

The chemical components in the treated wastewater are very important and crucial in evaluating the possible health risks regarding its application for agriculture irrigation. Chemical constituents include metals, pharmaceuticals, trace elements, personal care products, and endocrine-disrupting compounds (EDCs). These chemical elements have been shown to block, stimulate, or inhibit natural hormones in animal endocrine systems, as well as produce detrimental consequences in humans, according to researchers. [22, 64].

Figs. (5, 6, 7, and 8) show a general comparison of these constituents' thresholds between Egypt and other countries.

Egypt doesn't consider Silver (Ag), Copernicium (Cn), Tin (Sn), Cyanide (CN−), Barium (Ba), Uranium(U), Benzene(C6H6), Methanol(CH3OH), Acrolein(C3H4O), Pentachlorophenol(C6HCl5O), Total aldehydes, Tetrachloroethylene(C2Cl4), Benzo(a)pyrene(C20H12), Chlorinated biocides, Total Chlorinated solvents, Total trihalomethanes, Total Aromatic solvents, Total organic Nitrogen solvents, Total surfactants, Chlorinated biocides, Phosphorated pesticides, Linear alkylate sulfuric, and Trichloracetic aldehyde in its regulation. Figs. (5, 6, 7, and 8) show that there are big differences between Egypt's thresholds and other countries for some elements such as Iron (Fe), Lead (Pb), and zinc (Zn).
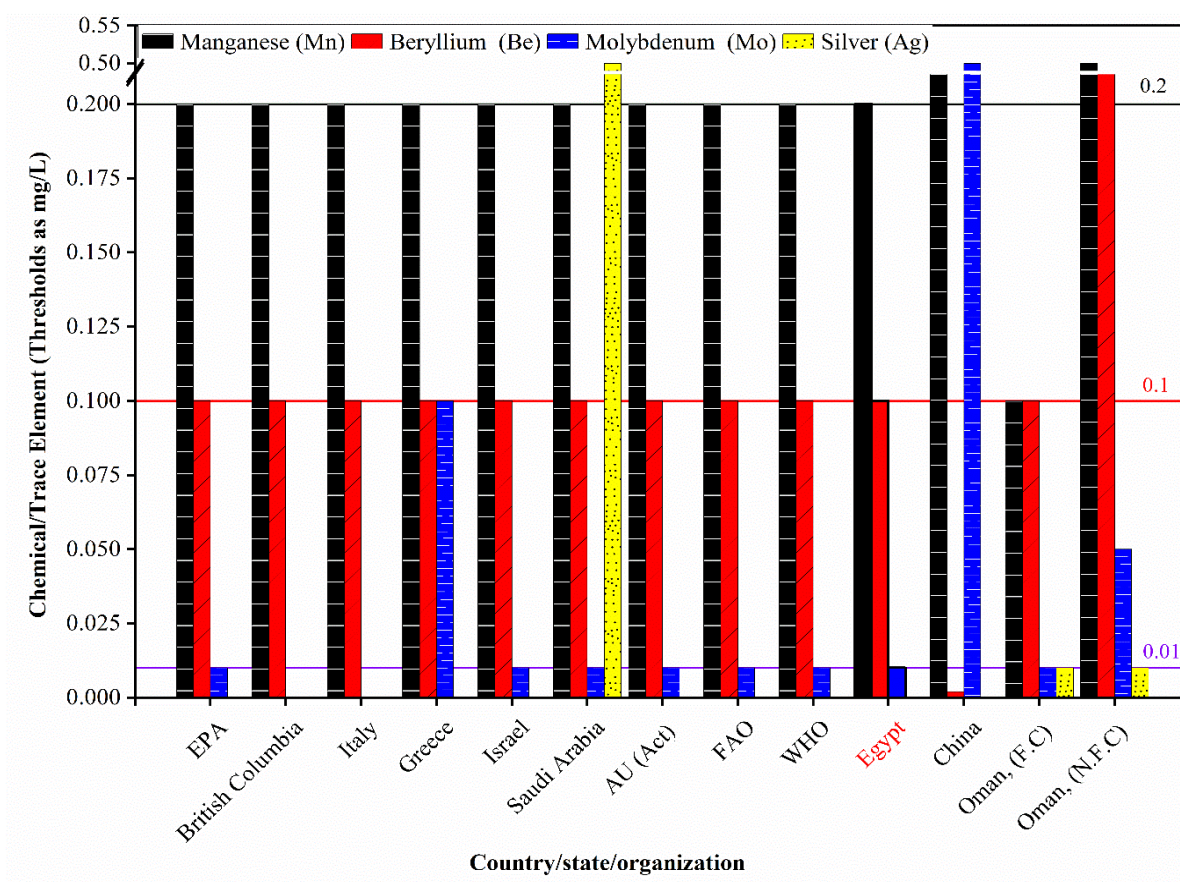

Fig. 5. Threshold values for (Manganese, Beryllium, Molybdenum, and Silver) in the reuse of agricultural wastewater regulations.
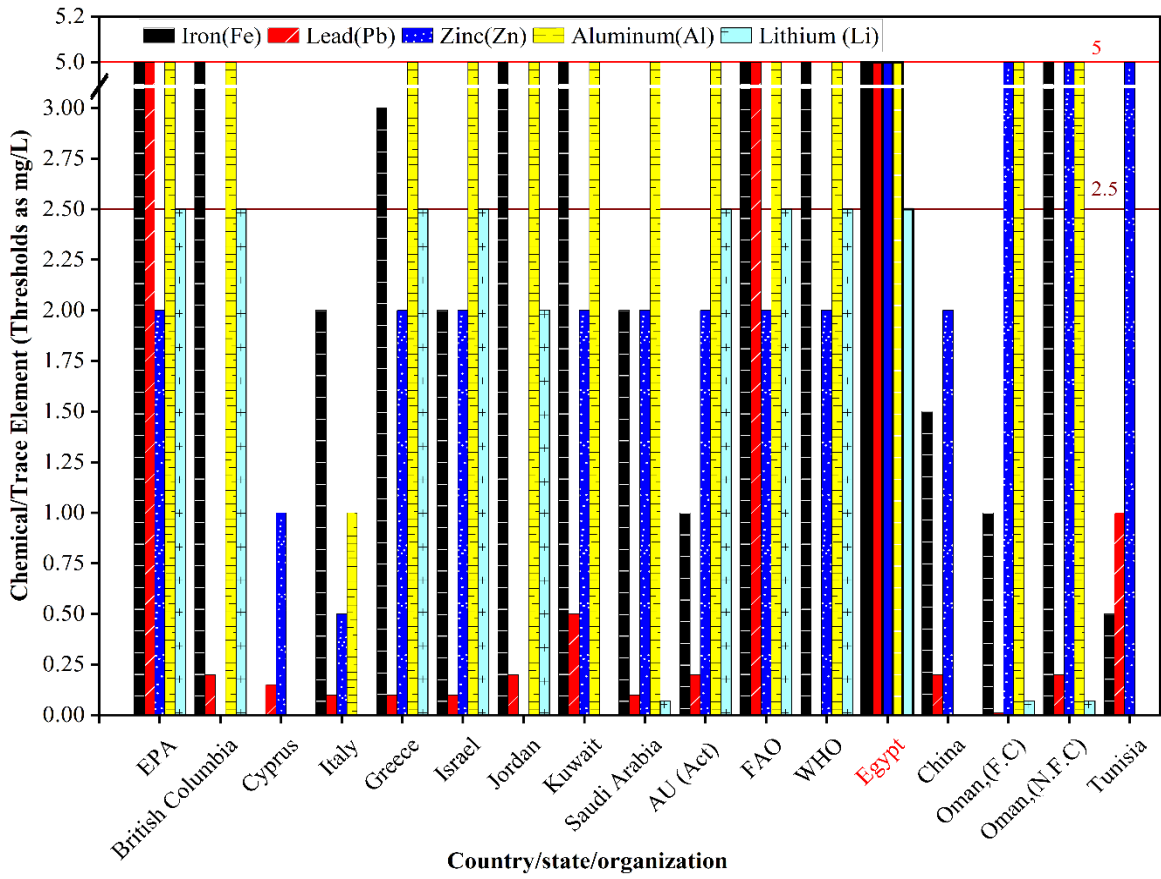
Fig. 6. Threshold values for (Iron, Lead, Zinc, Aluminum, and Lithium) in the reuse of agricultural wastewater regulations
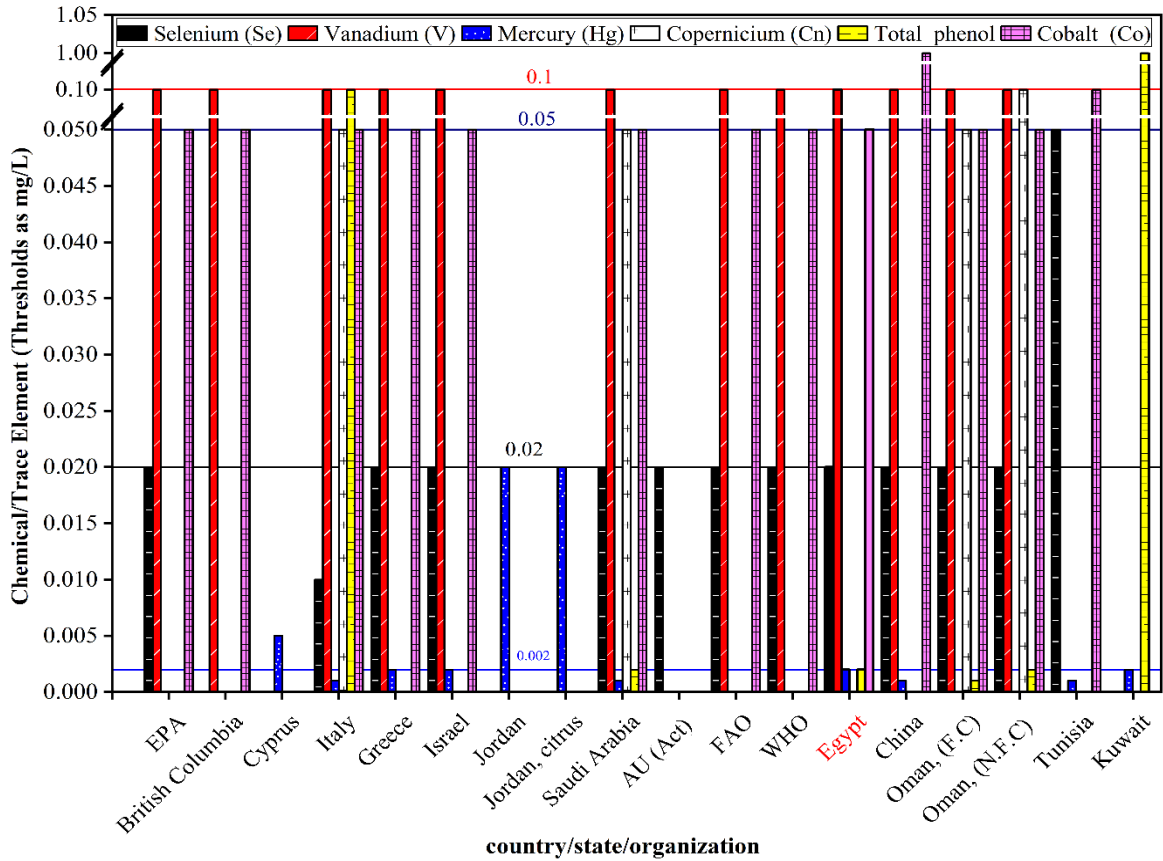

Fig. 7. Threshold values for (Selenium, Vanadium, Mercury, Copernicium, Total phenol, and Cobalt) in the reuse of agricultural wastewater regulations.
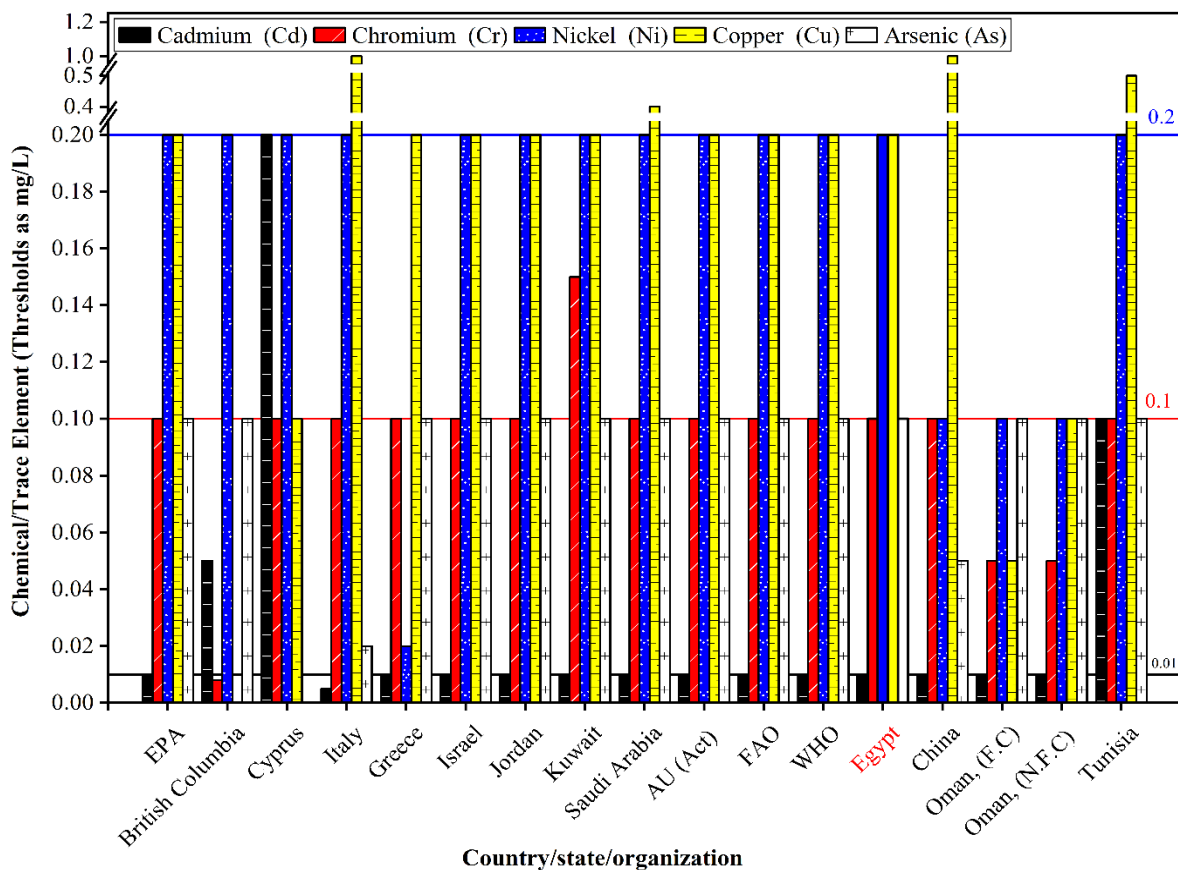
Fig. 8. Threshold values for (Cadmium, Chromium, Nickel, Copper, and Arsenic) in the reuse of agricultural wastewater regulations.

3. CONCLUSION

The current state of wastewater treatment technology allows for the production of water of any quality. The key concern, however, is the constituents that must be eliminated from the water, as well as the threshold limit for other components, in order to ensure that wastewater is safely treated and reused for irrigation. As a result, various organizations and governments created rules and legislations for the reuse of treated wastewater. The existing Egyptian code for wastewater reuse for irrigation (no.501/2015) was compared to international health regulations in this study (microbiological and chemical constituents). The primary goal of this comparison is to assess and identify the differences between existing Egyptian rules and international standards. To summary, the findings demonstrate that Egypt's thresholds for numerous treated wastewater parameters, such as E. coli, intestinal nematodes, iron, lead, zinc, and other contaminants, are higher than those of other countries and organizations. Furthermore, Egypt ignores several critical criteria such as emerging worry containments such as atenolol, caffeine, carbamazepine, sucralose, and so on. Many metals, such as silver (Ag), copernicium (Cn), tin (Sn), cyanide (CN), barium (Ba), uranium (U), benzene (C6H6), are not included in the Egyptian code. This incompatibility casts doubt on the utilization of treated wastewater for agricultural purposes. Egypt eventually intends to optimize the use of wastewater, particularly in agriculture, while guaranteeing that there are no negative consequences on Egyptians' public health or the long-term viability of soil use. As a result, extensive research into the effects of treated wastewater parameters, which Egypt either ignores or ignores in proportion to other countries, is advised.

References

[1] Y. Xiao, et al., "Groundwater circulation and hydrogeochemical evolution in Nomhon of Qaidam Basin, northwest China", Journal of Earth System Science, Vol.126, No. 2, pp. 1-16, 2017.

[2] Hussain, M.I., et al., "Sustainable use and management of non-conventional water resources for rehabilitation of marginal lands in arid and semiarid environments", Agricultural Water Management, Vol. 221, pp. 462-476, 2019.

[3] S. Eslamian, "Urban water reuse handbook", CRC Press, 2019.

[4] C. Becerra-Castro, et al., "Wastewater reuse in irrigation: A microbiological perspective on implications in soil fertility and human and environmental health", Environment International, Vol. 75, pp. 117-135, 2015.

[5] Ghernaout, "Water Reuse (WR): The Ultimate and Vital Solution for Water Supply Issues", Vol. 3, No. 4, 36, 2017.

[6] O. Al-Jayyousi, "Greywater reuse: towards sustainable water management. " Desalination, Vol. 156, No. 1, pp. 181-192, 2003.

[7] H. Al-Hamaiedh, & M. Bino, "Effect of treated grey water reuse in irrigation on soil and plants," Desalination, Vol. 256, No. 1, pp. 115-119, 2010.

[8] T. Abdel-Wahed, & N. Rashwan, "Application of Cement Dust and OPC as Mineral Filler in the binder Hot Mix Asphalt", LJMU International Conference on; Asphalt, Pavement Engineering and Infrastructure, Liverpool, UK, Vol. 15, ISBN 978-0-9571804-8-2, 2016.

[9] T.A. Elbana, N. Bakr, & M. Elbana, "Reuse of treated wastewater in Egypt: challenges and opportunities, in Unconventional Water Resources and Agriculture in Egypt", pp. 429-453. 2017

[10] I. Papadopoulos, "Wastewater management for agriculture protection in the Near East Region", Technical Bulletin, FAO, Regional Office for the Near East Cairo, Egypt, 1995.

[11] E. Shakir, Z. Zahraw, & A. Al-Obaidy, "Environmental and health risks associated with reuse of wastewater for irrigation", Egyptian Journal of Petroleum, Vol. 26, No. 1, pp. 95-102,2017.

[12] C.A. Scott, et al., "Wastewater irrigation and health: challenges and outlook for mitigating risks in low- income countries", In Wastewater Irrigation and Health, Routledge, pp. 407-420, 2009

[13] R. Mitchell, "Health guidelines for the use of wastewater in agriculture and aquaculture: Report of a WHO Scientific Group, Technical Report Series No. 778", World Health Organization, Geneva, 1992.

[14] J. Xu, et al., "Impact of long-term reclaimed wastewater irrigation on agricultural soils: A preliminary assessment. Journal of Hazardous Materials", Vol. 183, No.1, pp. 780-786, 2010.

[15] Egyptian code of practice for the use of treated municipal wastewater for agricultural purposes. The Ministry of Housing Utilities and Urban Communities (in Arabic), 2015.

[16] R. Wahaab, A. Salah, & T. Grischek, "Water quality changes during the initial operating phase of riverbank filtration sites in upper Egypt", Vol. 11, No. 6,1258, 2019.

[17] M.S Hellal, et al., "Technologies for wastewater treatment and reuse in Egypt: Prospective and future challenges", In Handbook of Advanced Approaches Towards Pollution Prevention and Control, pp. 275-310, 2021.

[18] P. Reymond, et al., "Scaling up small scale wastewater treatment systems in low-and middle-income countries: An analysis of challenges and ways forward through the case of Egypt", Vol.52, pp. 13-21, 2018.

[19] Q. Mahmood, et al., "Natural treatment systems as sustainable ecotechnologies for the developing countries", 2013.

[20] F. Shoushtarian, & M. Negahban-Azar, "Worldwide regulations and guidelines for agricultural water reuse: a critical review", Vol. 12, No. 4, 971, 2020.

[21] S. Eslaman, "Urban water reuse handbook", CRC Press, 2016.

[22] Metcalf, et al., "Water reuse", McGraw-Hill Professional Publishing, 2007.

[23] H. Jeong, H. Kim, & T. Jang, "Irrigation water quality standards for indirect wastewater reuse in agriculture: a contribution toward sustainable wastewater reuse in South Korea", Water, Vol. 8, No. 4, 169, 2016.

[24] V. Lazarova, & A. Bahri, "Water reuse for irrigation: agriculture, landscapes, and turf grass", CRC press, 2004.

[25] M. El-Rawy, et al., "Forecasting effluent and performance of wastewater treatment plant using different machine learning techniques". Vol. 44, 02380, 2021.

[26] L. Coen, et al., "Ecosystem services related to oyster restoration", Vol. 341, pp. 303-307, 2007.

[27] Metcalf, et al., "Wastewater engineering: treatment and reuse", McGraw Hill, 2003.

[28] U. Blumenthal, et al., "Guidelines for the microbiological quality of treated wastewater used in agriculture: recommendations for revising WHO guidelines", Vol. 78, pp. 1104-1116, 2000.

[29] United States. Environmental Protection Agency. Office of Wastewater Management. Municipal Support Division, National Risk Management Research Laboratory (US). Technology Transfer, and Support Division. Guidelines for water reuse. US Environmental Protection Agency, 2004.

[30] ISO 16075-2:2015, Guidelines for treated wastewater use for irrigation projects — Part 2: Development of the project, https://www.iso.org/cms/render/live/en/sites/isoorg/contents/data/standard/06/27/62758.html.

[31] B. Columbia, "Irrigation Management Guide - Province of British Columbia", 2020.

[32] A. Island, "Atlantic Canada Wastewater Guidelines Manual", Government of Prince Edward Island, 2016.

[33] R. Mines, et al., "Performance assessment of major wastewater treatment plants (WWTPs) in the state of Georgia", Vol. 41, No. 10, pp. 2175-2198, 2006.

[34] C. Standards, "Reclaimed Water Permit Program and Standard, 2020.

[35] F. Brenner, & J. Mondok, "Nonpoint Source Pollution Potential in An Agricultural Watershed in Northwestern Pennsylvania 1", JAWRA Journal of the American Water Resources Association, Vol. 31, No. 6, pp. 1101- 1112, 1995.

[36] Barbagallo, S., et al., "Wastewater reuse in Italy", Vol. 43, No. 10, pp. 43-50, 2001.

[37] A. Angelakis, et al., "The Necessity for Establishment of Greek Regulations on Wastewater Reclamation and Reuse", Report for the Ministry of Public Works and Environment and Hellenic Union of Municipal Enterprises for Water Supply and Sewage, Larissa-Greece,110, 2000.

[38] A. Ilias, A. Panoras, & A. Angelakis, "Wastewater recycling in Greece: The case of Thessaloniki", Vol.6, No. 5, pp. 2876-2892, 2014.

[39] L. Alcalde-Sanz, & B. M. Gawlik, "Minimum quality requirements for water reuse in agricultural irrigation and aquifer recharge", Towards a legal instrument on water reuse at EU level, 2017.

[40] Y. Inbar, "New standards for treated wastewater reuse in Israel, in Wastewater reuse–Risk assessment" , decision-making and environmental security, pp. 291-296, 2007.

[41] D. Lavee, M. Ritov, & N. Becker, "Is desalination the most sustainable alternative for water- shortage mitigation in Israel?", International Journal of Sustainable Economy, Vol. 3, No. 4, pp. 410-424, 2011.

[42] A. Aharoni, & H. Cikurel, "Mekorot's research activity in technological improvements for the production of unrestricted irrigation quality effluents", Desalination, Vol. 187, No.1-3, pp. 347-360, 2006.

[43] World Health Organization, "A compendium of standards for wastewater reuse in the Eastern Mediterranean Region", No. WHO-EM/CEH/142/E, 2006.

[44] A. Abusam, & A. Shahalam, "Wastewater reuse in Kuwait: Opportunities and constraints", WIT Transactions on Ecology and the Environment, Vol. 179, pp. 745-754, 2013.

[45] A. Al-Jasser, "Saudi wastewater reuse standards for agricultural irrigation: Riyadh treatment plants effluent compliance", Journal of King Saud University-Engineering Sciences, Vol. 23, No.1, pp. 1-8, 2011.

[46] M. Pescod, "Wastewater quality guidelines for agriculture use", Wastewater treatment and use in agriculture, FAO, 1992.

[47] World Health Organization, "WHO guidelines for the safe use of wastewater excreta and greywater", Vol. 1, 2006.

[48] D. Heineman, "Nebraska Department of Environmental Quality Title 128– Nebraska Hazardous Waste Regulations", 2014.

[49] Resources, "Plans and Specifications - South Dakota Department of Environment and Natural Resources", https://denr.sd.gov/plansprg.aspx, 2021.

[50] Wyoming Administrative Rules, "Environmental Quality, Dept. of Water Quality", Ch 21: Reuse of Treated Water, https://rules.wyo.gov/DownloadFile.aspx?source_id=8701&source_type_id=81&doc_type_id=110&include_meta_data=Y&file_type=pdf&filename=8701.pdf&token=01115924318323105519016919393045 , 2021.

[51] Wastewater reuse for Agricultural Irrigation and Its Impact on Health - Cepis. 2021 [cited 2021; Available from: http://cepis.org.pe/wastewater-reuse-agricultural-irrigation.

[52] A. Peasey, et al., "A review of policy and standards for wastewater reuse in agriculture: a Latin American perspective" well study, Task, 68, 2000.

[53] N. Paranychianakis, et al., "Water reuse in EU states: necessity for uniform criteria to mitigate human and environmental risks", Vol. 45, No. 13, pp. 1409-1468, 2015.

[54] R. Iglesias, et al. "Water reuse in Spain: data overview and costs estimation of suitable treatment trains." Desalination, Vol. 263, No. 1-3, pp. 1-10, 2010.

[55] A. Megahid, H. Younis, T. Abdel-Wahed, & E. Abdel-Sabour, "Utilization of Industrial Waste Material in Highway Construction," JES. Journal of Engineering Sciences, Vol. 48, No. 3, pp. 373-382, 2020. DOI: 10.21608/JESAUN.2020.107604

[56] T. Abdel-Wahed, A. Othman, & N. Rashwan, "Utilization of Waste Iron Slag on Hot Mix Asphalt Concrete Mixtures", Structural Engineering and Mechanics, 2015.

[57] G. Moussa, A. Abdel-Raheem, & T. Abdel-Wahed, "Investigating the moisture susceptibility of asphalt mixtures modified with high-density polyethylene", JES. Journal of Engineering Sciences, Vol. 48, No. 5, pp. 765-782, 2020. DOI: 10.21608/jesaun.2020.39052.1001.

[58] G. Moussa, A. Abdel-Raheem, & T. Abdel-Wahed, "Effect of Nanoclay Particles on the Performance of High-Density Polyethylene-Modified Asphalt Concrete Mixture", Polymers, Vol. 13, No. 3, 434, 2021. https://doi.org/10.3390/polym13030434.

[59] S. Lyu, et al., "Wastewater reclamation and reuse in China: opportunities and challenges", Vol. 39, pp. 86-96, 2016.

[60] do Monte, M.H.F.M., "Guidelines for good practice of water reuse for irrigation: Portuguese standard NP 4434", Wastewater Reuse–Risk Assessment, Decision-Making and Environmental Security, pp. 253-265, 2007.

[61] Oman. Ministerial Decision No. 145 of 1993 issuing the Regulations on waste water reuse and discharge. 1993 10/22/2020]; Available from: https://www.ecolex.org/details/legislation/ministerial-decision-no- 145-of-1993-issuing-the-regulations-on-waste-water-reuse-and-discharge-lex-faoc044940/.

[62] M.E. Verbyla, et al., "Managing Microbial Risks from Indirect Wastewater Reuse for Irrigation in Urbanizing Watersheds", Environmental Science & Technology, Vol. 50, No.13, pp. 6803-6813, 2016.

[63] P. Hong, et al., "Reusing treated wastewater: consideration of the safety aspects associated with antibiotic-resistant bacteria and antibiotic resistance genes", Vol. 10, No. 3, 244, 2018.

[64] A.K Abdella, and M.H. Abdel-Aa, "Iron Removal from Ground Water through Expanded Polystyrene Filter", Vol. 9, No. 3, pp. 657-666, 2021.