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

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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.

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Keywords: Treated wastewater reuse; Egyptian standards; Agriculture; Irrigation; Microbial hazards.

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, 7]. 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 [8].

Despite the fact that treated wastewater is a rich source of nutrients in most wastewater treatment technologies for soil and plants, it has a number of drawbacks[9]. Microbial infections, the accumulation of harmful heavy metals, and a rise in soil salinity are the most severe consequences of using treated wastewater for agricultural use[10]. As a result, infections impact human health in addition to bacterial diseases of the consumers of this water's irrigated crops[11, 12]. As a result, the treated wastewater's quality must be assessed before it is used to irrigate agricultural land[13]. 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[14]. 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.

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Different wastewater treatment technologies have been used in Egypt through 412 wastewater treatment plants [15, 16]. 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 [16, 17]. 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 kilometres northeast of Cairo [18].

1.1. Regulations and guidelines among countries and their effects:

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 [19]. 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 [20]. 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.

1.2. 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 [21]. 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 [22].

1.3. 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 [23, 24]. 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 [21].

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:[25]

- 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[26].

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:[27]

- 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.

<table>
<thead>
<tr>
<th>Country, state, organization</th>
<th>Reuse Categories</th>
<th>Required Microbial Quality (CFU† or E. coli)/100 mL) (Monitoring)</th>
</tr>
</thead>
<tbody>
<tr>
<td>US EPA‡ [28]</td>
<td>Crops for human consumption</td>
<td><strong>FCB‡ (daily): 0 (AVG‡ of the prior 7 days),</strong> 14 (max††)</td>
</tr>
<tr>
<td></td>
<td>P.F.C§/N.F.C§§</td>
<td>FCB (daily): 200 (AVG of the prior 7 days), 800 (max)</td>
</tr>
<tr>
<td></td>
<td>A: treated wastewater of very high grade; irrigation of food crops consumed uncooked in unrestricted agricultural and residential settings</td>
<td>TTCS†††: 10, 100 (max)</td>
</tr>
<tr>
<td></td>
<td>B: high quality treated wastewater; Irrigation of processed food crops is restricted in cities and agriculture.</td>
<td>TTCS: 200, 1000 (max)</td>
</tr>
<tr>
<td>ISO*** [29]</td>
<td>C: treated wastewater of good quality; agricultural irrigation of non-food crops</td>
<td>TTCS: 1000</td>
</tr>
<tr>
<td></td>
<td>D: treated wastewater of moderate quality; restricted irrigation (R) of seeded and industrial crops</td>
<td>IN: 1 Egg/L (AVG), 5 Egg/L (max)</td>
</tr>
<tr>
<td>CA §§ (British Columbia) [30]</td>
<td>E: widely treated wastewater;</td>
<td>FCB (weekly): 200</td>
</tr>
<tr>
<td></td>
<td>R****</td>
<td>FCB (daily): 2.2</td>
</tr>
<tr>
<td></td>
<td>U.R††††</td>
<td>E.C†††† (two times each month): 200</td>
</tr>
<tr>
<td>CA (Atlantic Canada) [31]</td>
<td>R R</td>
<td>E.C (two times each month): 2</td>
</tr>
<tr>
<td></td>
<td>U.R</td>
<td>FCB (Daily): 23 (The geometric average for the month), 46 (The geometric average of the week): 100</td>
</tr>
<tr>
<td>US (Georgia) [32]</td>
<td>P.F.C/N.F.C</td>
<td>FCB: 0 (7-day CON§§§§ sampling, AVG), 14 (Max)</td>
</tr>
<tr>
<td></td>
<td>A: Crops for human consumption, unrestricted irrigation</td>
<td></td>
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<tr>
<td></td>
<td>B: pasture land for dairy cows, unprocessed food crops (no contact with the crop’s edible section), restricted</td>
<td>FCB: 14 (7-day continuous sampling, AVG), 100 (Max)</td>
</tr>
<tr>
<td>US (Massachusetts) [33]</td>
<td>C: orchard and vineyard (no contact with the crop’s edible section), processed food crops</td>
<td>FCB: 200 (AVG)</td>
</tr>
<tr>
<td></td>
<td>Crops for human consumption</td>
<td>FCB (2/week): 2.2 (Mean for the month), 23 (Max)</td>
</tr>
<tr>
<td>US (Pennsylvania) [34]</td>
<td>Non-food/processed food crops</td>
<td>FCB (Weekly): 200 (Mean for the month),</td>
</tr>
</tbody>
</table>

† 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
¶¶ Intestinal nematodes
§§§ Canada
**** Restricted irrigation
†††† Unrestricted irrigation
##### Escherichia. Coli
§§§§ continuous
Agglomerations > 2000 p.e.

800 (Max)

E.C (1/15 Days): 5
IN: 0

FCB: 5,
15 (Max)
IN: 0

Agglomerations < 2000 p.e. all crops

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,
5000 (Max)
IN: 0

Agglomerations < 2000 p.e. fodder crops

FCB: 1000,
5000 (Max)
IN: 0

Cyprus [28]

Not Specified

E.C: 10

R
E.C (Weekly): 200 (Median)

Greece [36, 37]

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

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

European Commission [38]

Not Specified

FCB: 10

Israel [39-41]

A: cooked vegetables, parks, playgrounds roadsides in the city
E.C or FCB: 100
IN: 1 Egg/L

B: fruit trees
E.C or FCB: 1000
NS

Jordan [42]

C: crops used in industry

D: flowers
E.C or FCB: 1.1

Kuwait [43]

Not Specified

TO: 400
FCB: 20
TTCS: 1000
IN: 1

Saudi Arabia [44]

TTCS: 2.2
IN: 1

***** Population equivalents.
††††† Total Coliforms
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<td>A: Irrigation of non-processed food crops, sports fields, public parks</td>
<td>FCB: 1000, 200 (In case of fruit trees) IN: 1 Egg/L</td>
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<tr>
<td>B: irrigation of fodder crops, industrial crops, cereal crops, pasture, and trees</td>
<td>IN: 1 Egg/L</td>
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<td>C: irrigation of crops in category B using drip irrigation if workers and the general public are not exposed</td>
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- Food and Agriculture Organization of the United Nations
- World Health Organization
- Geometric mean

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crops, controlled-access forests
E.C (Monthly): 100,000
D: inaccessible woodlands
Enterococci: ≥ 2 Logs

2.1

2.2:
(A) irrigation of processed food crops
(B) Irrigation of grazing land for dairy or meat animals
(C) aquaculture

E.C (Weekly): 100
IN: 1 Egg/10L

Spain [53]

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

1.1 Green spaces for educational facilities and public and private parks
1.2 Fruit crops that are eaten fresh without peeling

Egypt [14, 54]

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): 20
IN: 1 Egg/1L

3.1 Dry cereal crops, fruit crops, and medicinal plant crops included in group B provided that the spray irrigation method is not used.

C:
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] 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

D:
4.1 Plants that produce solid biomass
4.2 Plants that produce liquid biomass 4.3 All non-food crops for the production of glucose and its derivatives
4.4 Woody trees

Not Specified

fiber

China [56]

Corn oil crops grown in dry fields
FCB: 40,000
IN: 2

Grain harvested from paddy fields
FCB: 20,000
IN: 2

Vegetable

A: vegetables consumed raw
FCB: 100

Portugal [57]

B: public parks and gardens, sports fields, and public woods
FCB: 200

C: Cooking veggies, fodder crops, vineyards, and orchards
FCB: 1000

A: uncooked vegetables and fruits
FCB: 200
Egypt follows the second approach of treated wastewater quality standards, depending on the 2006 guidelines of the World Health Organization [14]. 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 [59]. 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 [60].

**Fig. 1. Required microbial quality for unrestricted crops: Escherichia. Coli (cfu/100 mL) (Monitoring)**
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 [21, 61].

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, Aluminium, 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

18. Mahmood, Q., et al., Natural treatment systems as sustainable ecotechnologies for the developing


