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Egyptian Reuse Standards of Treated Wastewater for Irrigation: A Comparative Study of Physico-Chemical and Agronomic Controls

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KEYWORDS:
Treated wastewater reuse; Egyptian Standards; Agriculture; Irrigation.

***Abstract*—One of the most important issues and challenges nowadays in Egypt is how to provide enough water for current and future needs. The great population growth, agricultural consumption, climate change, limited freshwater resources, and welfare lifestyle require more water. All these factors push the Egyptian policy to search for additional water resources. One of the considerable water resources is the treated wastewater that has been used in irrigation under some restrictions. However, the use of treated wastewater for agricultural irrigation may have negative health effects if its properties were deviated from the allowable standards. This study considers Egyptian standards, regulations, and limitations for using treated wastewater in agricultural irrigation, in comparison to other nations around the world. The study discusses the related treated wastewater quality parameters for irrigation, including physio-chemical controls and agronomic controls. The results revealed that the Egyptian code (ECP 501/2015) is highly compatible with the regulations of other countries, but there are some differences. These differences are allowable because (ECP 501/2015) prohibited the use of treated wastewater in irrigating raw vegetable crops. Finally, the acceptable chemical, physical, and agronomic properties of treated wastewater for agricultural applications in Egypt have to be more studied to make the best use of treated wastewater.**

I. INTRODUCTION

MANY countries throughout the world view treated wastewater as an alternative source for reducing the burden on freshwater supplies [1, 2]. The use of treated wastewater for agricultural irrigation is spread over all the world [3, 4]. The percentage of people who consume food grown with sewage is 10% of the total population [5, 6].

The area of cultivated land with wastewater (raw or treated) is about 20 million hectares (equivalent to 7% of the cultivated area), located in 50 countries, which means that 200 million farmers are exposed to wastewater [7].

Egypt has regarded treated wastewater as one of its most valuable water resources. The treated wastewater is used in Egypt in all possible applications, especially agricultural

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irrigation. The purpose of using treated wastewater in agricultural irrigation can be summarized as follows [8]:

A. Preserving the Egyptian natural water resources.
B. Protect the environment from pollution.
C. Protect the public health of Egyptians.

Egypt divides treated municipal wastewater reuse in agriculture into two categories: direct and indirect [8]. In the direct reuse, the treated wastewater is directly used from the treatment plants for irrigation and land reclamation. Indirect reuse is by collecting the mixed effluent from treatment plants with water from agricultural drains. This study discusses the use of processed wastewater for irrigation directly and its potential risks on:

1. The Egyptian crops which irrigated with treated wastewater.
2. The health of agricultural products, consumers, farmers, and the environment.
3. The chemical and physical properties of the Egyptian soil and its sustainability.

Many Organizations have enacted standards or guidelines for safe treated wastewater reuse such as the United States Environmental Protection Agency (US EPA) [9], International Organization for Standardization (ISO) [10], European Commission [11], Food and Agriculture Organization of the United Nations (FAO) [12], and World Health Organization (WHO) [5]. Also many united states such as Alabama [13], Arizona [14], California [15, 16], Colorado [17], Delaware [18], Florida [19], Georgia [20], Hawaii [21], Idaho [22], Indiana [23], Kansas [24], Maryland [25], Massachusetts [26], Minnesota [27], Montana [28], Nevada [29], New Jersey [30], North Carolina [31], North Dakota [32], Ohio [33], Oklahoma [34], Oregon [35], Pennsylvania [36], Rhode Island [37], Texas [38], Utah [39], Virginia [40], Washington [41], Nebraska [42], South Dakota [43], and Wyoming [44]. Also many Canadian states such as British Columbia [45], Atlantic Canada [46], Saskatchewan [47], and Alberta [48]. Also many Australian provinces [49] such as Northern Territory(NT), Tasmania(TAS), Queensland(QLD), Western Australia(WA), Victoria(VIC), New South Wales(NSW), Australian Capital Territory(ACT), and The Australian guidelines for water recycling(AGWR). Also many other countries such as Cyprus [9], Italy [50], Greece [51, 52], Israel [53-55], Jordan [56], Kuwait [57], Saudi Arabia [58], Mexico [59, 60], France [61], Spain [62], China [63], Palestine [64], Portugal [65], and Oman [66]. Egypt also updated the Egyptian code for the agricultural use of treated wastewater (ECP 501 – 2015) in 2015. This study inspects the current Egyptian code for treated wastewater reuse and compares it with other countries to evaluate and enhance the reuse of treated wastewater.

II. Treated Wastewater Quality Standards for Irrigation

As shown in Fig. 1, the quality of treated wastewater for direct irrigation (without mixing with fresh water as mentioned in the MWRI laws) can be divided into three categories: health controls, agronomic controls, and physicochemical controls, each of which includes a variety of other branching criteria [67]. This study examines both Physico-chemical and agronomic controls.

A. The Egyptian code of the reuse of treated wastewater for agricultural purposes (ECP 501-2015)

The (ECP 501-2015) prohibited the usage of raw municipal wastewater (not treated) for agricultural use. This code also prohibited to use treated wastewater – whatever the level of treatment is – in irrigating vegetables crops eaten raw. Whereas, the treated wastewater has been classified into four categories (A, B, C, and D) according to the treatment level. Each of these categories is devoted to irrigate specific crops as shown in Table I. In addition, as indicated in Table II, the Egyptian code reported physico-chemical and agronomic control thresholds for the treated wastewater categories [8].

TABLE I
Plants and Crops Permitted for Irrigation by Treated Wastewater [8]

Grade of Treatment	Agricultural Group	Description
A *(2 Groups)*	Group 1-1: Green landscapes in Educational establishments, public and private parks	All types of grass and fence plants and all kinds of flowers
	Group 1-2: Fruit Crops	Fruits that are eaten fresh without peeling, such as: apples, apricots, peaches, grapes, etc.
B *(3 Groups)*	Group 2-1: Dry grains crops, cooked & processed vegetables	All Kinds of Vegetables (manufactured) and strategic dry crops of all types such as wheat - corn - barley - rice - beans - lentils – sesame
	Group 2-2: Fruit Crops	Fruit trees with sustained and deciduous leaves such as: Citrus fruits - olive - palm - mango - pecan – pomegranate for the purpose of drying
	Group 2-3: Medicinal Plants	Anise - hibiscus - Cummins - Marjoram - Ammi - Fenugreek - moat - fennel - Chamomile – sage herb
C *(9 Groups)*	Group 3-1: Dry grain crops, fruits, medicinal plants contained group (B)	Same species in addition to sunflower plant providing that spray irrigation is not used.
	Group 3-2: Non-food seeds	All seeds of propagation for major food crops such as wheat, corn and all kinds of vegetables' seeds
	Group 3-3: All types of seedlings, which are then transplanted in permanent fields	Seedlings of Olive - pomegranate - citrus - bananas - palm - figs - mango - apples – pears
	Group 3-4: Roses and Cut flowers	Roses farmyard – Rosa Canina - bulbs such as Algeladiols, bird of paradise and all kinds of ornamental plants.
	Group 3-5: Trees suitable for planting in highways and green belts	Alcazurina - camphor - oleander – tamarisk - types of ornamental palms.
	Group 3-6: All types of fiber crops	Such as cotton - linen - Jute - kenaf.

(Continued on the next page)

TABLE II: continued

Grade of Treatment	Agricultural Group	Description
C *(9 Groups)*	Group 3-7: Grassy forage crops and leguminous crops	Sorghum types and kinds of shamrock
	Group 3-8: Mulberry to produce silkworm silk	All kinds of Berries
	Group 3-9: All plants and ornamental trees nurseries	Such as Ficus décor - Ficus Natda - Ambassndr – Acacia
D *(4 groups)*	Group 4-1: Solid biomass crops	All crops that are converted into charcoal such as: willow, poplar and moringa
	Group 4-2: Liquid biomass crops	All crops for the production of bio-diesel fuel and energy oils such as: soybean - rapeseed - Jojoba - and Jatropha - Castor.
	Group 4-3: Crops to produce cellulose	All non-food crops for the production of glucose and its derivatives like ethanol and acetic acid - ethanol – Generation
	Group 4-4: Timber trees	All trees for timber production such as Alcaaa - camphor - and mahogany

TABLE II

PHYSICO-CHEMICAL AND AGRONOMIC CONTROL THRESHOLDS FOR THE TREATED WASTEWATER CATEGORIES [8]

Parameter	Unit	Degree of Treatment			
		Grade A	**Grade B**	**Grade C**	**Grade D**
pH	---	undefined			
EC	dS/m	undefined			
TDS	(mg/L)	2000			
TSS		15	30	50	300
Turbidity	NTU	5	undefined	undefined	undefined
SAR	---	6-9			
Na^+	(mg/L)	230			
Cl^-		undefined			
HCO_3^-		400			
SO_4^{2-}		500			
NO_3^-		undefined			
PO_4^{3-}		30			
COD		undefined			
BOD_5		15	30	80	350

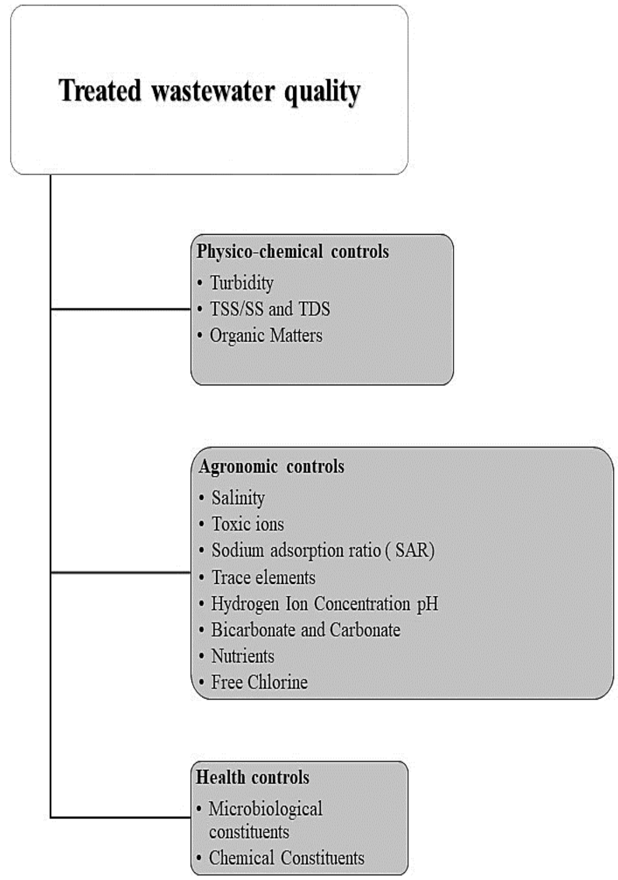


Fig. 1. Treated wastewater quality parameters for irrigation application.

III. AGRONOMIC CONTROLS

Agronomic parameters include both pH, SAR, salinity, toxic ions, trace elements, free chlorine, nutrients, carbonate, and bicarbonate. They are very important for using the treated wastewater for agricultural irrigation. Where it has impacts on both the crop's quality and the yield of the crops and the sustainability of lands irrigated with this water quality.

A. Hydrogen Ion Concentration pH

pH is the measurement of water acidity. It's the easiest parameter to be determined in the water and a very important water quality parameter for agriculture. It's thought to be a sign of toxic ions. The pH of irrigation water should be between 6.5 and 8.5. If irrigation water contains a harmful ion or has a pH outside of the typical range, it may produce a nutritional imbalance. Water of low pH is highly corrosive, potentially corroding pipelines, sprinklers, and control equipment quickly [68, 69]. Low pH levels alter heavy metal mobility in the soil, allowing them to be absorbed by crops and contaminating water sources [70].

Fig. 2 shows a general comparison of the pH values in the countries and organizations which consider the pH threshold in their regulation. Egypt doesn't consider the pH range in their code (ECP 501-2015).

B. Salinity

One of the most critical quality characteristics for treated municipal wastewater reuse in agriculture is salinity. This is because salts in the soil or water diminish the amount of water available to the crop, lowering output. Also, resulting in specific ion toxicity [70, 71]. Salinity is frequently measured using total dissolved solids (mg/L) or electric conductivity (dS/m). Also, there is a relationship between TDS and EC in case of EC less than 8 dS/m as indicated in the following equation [67]

$$TDS(mg/L) = EC(ds/m) \times 640 \quad (1)$$

Egypt considers the total dissolved solids as an indicator of salinity with max. of 2000 mg/l. As shown in Fig. 3, this value appears to be acceptable when compared to countries that impose similar severe restrictions on the reuse of treated wastewater.

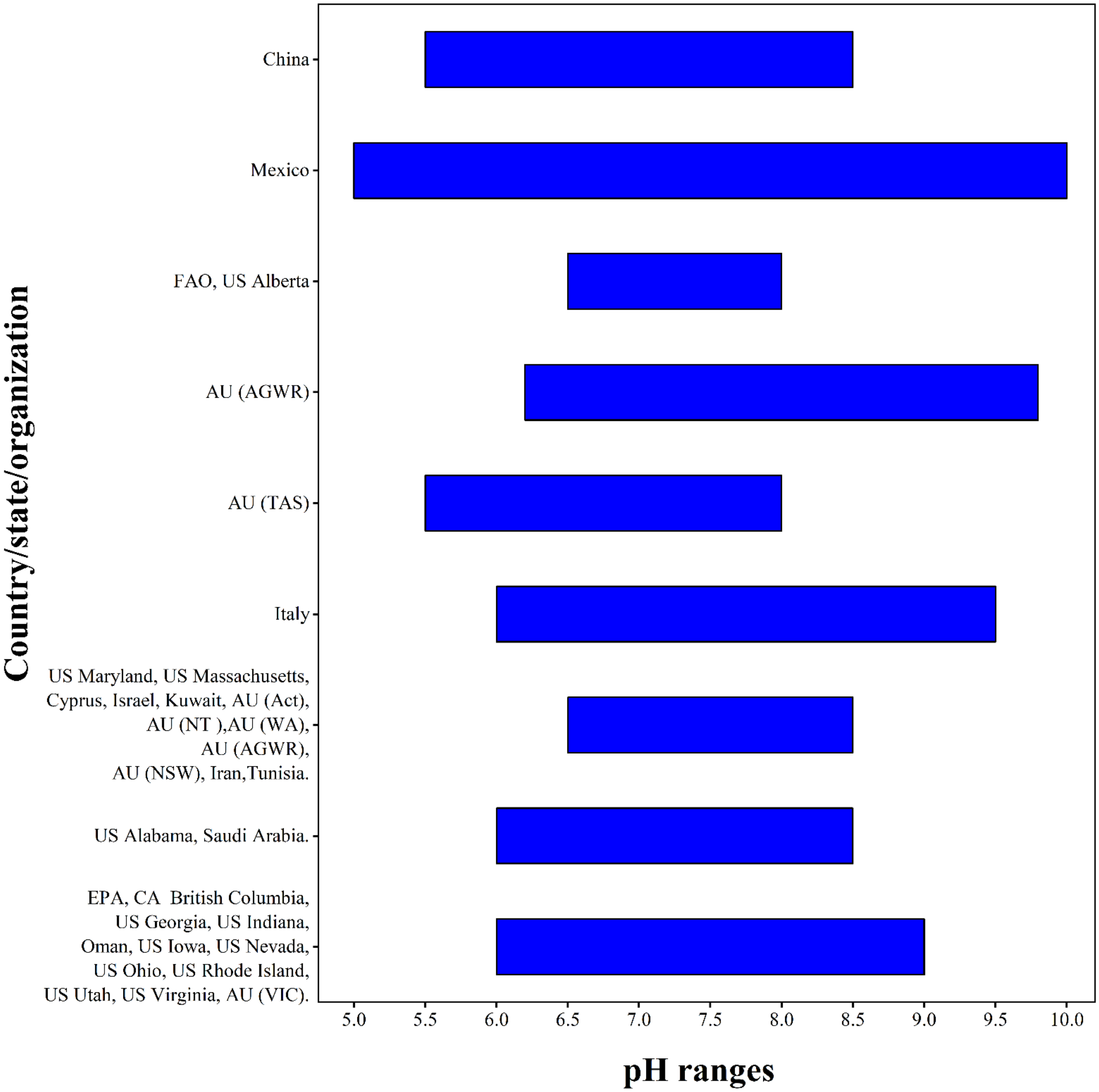


Fig. 2. pH ranges in the treated municipal wastewater reuse regulations [8, 9, 13, 20, 23, 25, 26, 29, 33, 37, 39, 40, 45, 49, 50, 53-55, 57-60, 66, 72-75].

C. *Micronutrients and Nutrients*

Nitrogen (N), Phosphorus (P), Potassium (K), Zinc (Zn), and Sulfur (S) are all key nutrients and micronutrients for plant growth [71]. Although nitrogen is essential for crops, too much of it can cause problems such as growth stimulation, maturity delays, and poor quality. In coastal locations or lakes, it can also lead to groundwater contamination and eutrophication [76]. Moreover, applying excess nitrogen for the long-term leads to the weakness of stalks, stems, and branches of the crops [67]. Phosphorous is also important for crop growth but excess amounts can increase the rate of eutrophication. Potassium increases the growth rate of algae and bacteria, leading to clogging problems for spray irrigation and drip irrigation [71]. Although zinc is necessary for plant growth, larger quantities limit root growth, cause growth inhibition and toxicity symptoms [76].

Most countries and organizations consider nitrogen whether it is organic nitrogen, total nitrogen, nitrate, ammonium, or ammonia as shown in Fig. 4. But Egypt doesn't consider it in its regulation. For phosphate, Egypt's threshold is 30 mg/l and this is a large value compared with Italy (2 mg/l) or Cyprus (10 mg/l).

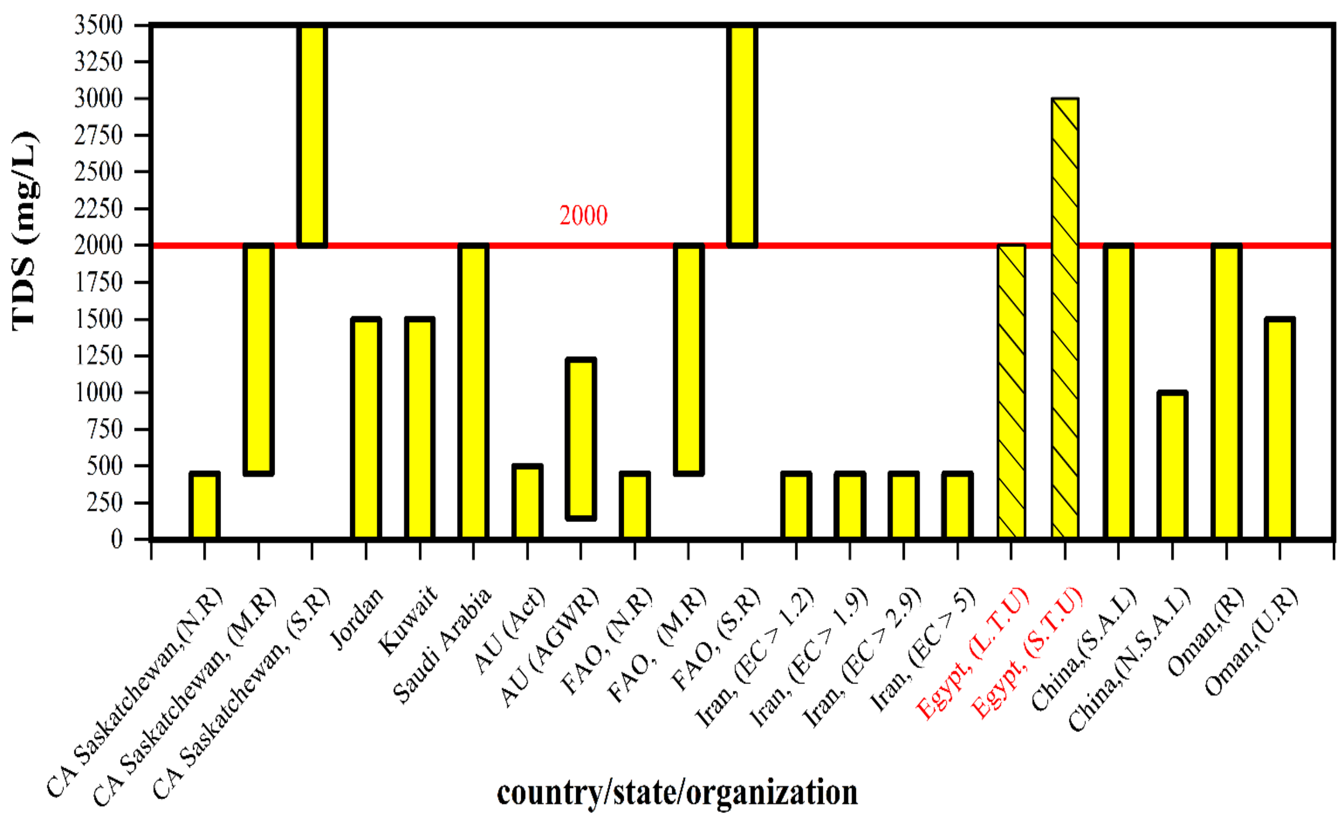
D. *Sodium Adsorption Ratio (SAR)*

Sodium is a very crucial ion in irrigation treated wastewater quality. Excessive sodium in irrigation water causes soil dispersion and structural breakdown, resulting in a reduction of water and air infiltration into the soil, soil crusting, poor seeding emergence, lack of aeration, plant and root diseases, weed and mosquito control problems. But it's worth noting that all of the aforementioned effects occur only when sodium exceeds calcium by a ratio greater than the sodium adsorption ratio (SAR), which is provided in (2). Also, low salinity water makes the matter worse [78-80].

$$SAR = \frac{Na^{+}}{\sqrt{\frac{Ca^{+2}+Mg^{+2}}{2}}} \qquad (2)$$

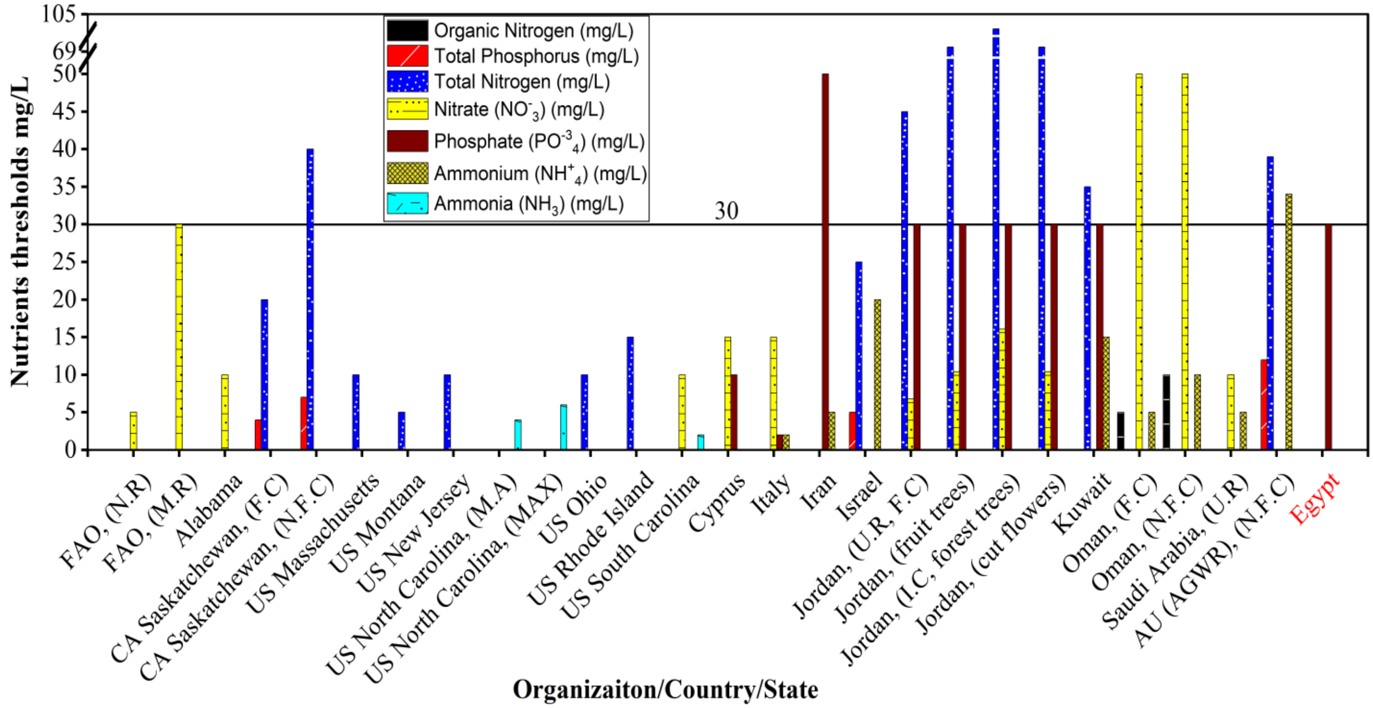
Where Na = sodium in milliequivalent per liter, Ca = calcium in milliequivalent per liter, and Mg = magnesium in milliequivalent per liter.

Egypt's threshold for SAR is 6-9 regardless of the salinity threshold. As shown in Fig. 5, the Canada threshold depends on the category use of the treated wastewater and the Iran threshold for SAR depends on the salinity threshold. So, Egypt needs to relate the SAR threshold with the category reuse of the treated wastewater and the salinity threshold. Moreover, the value from 6 to 9 is somewhat large compared with countries such as Israel.



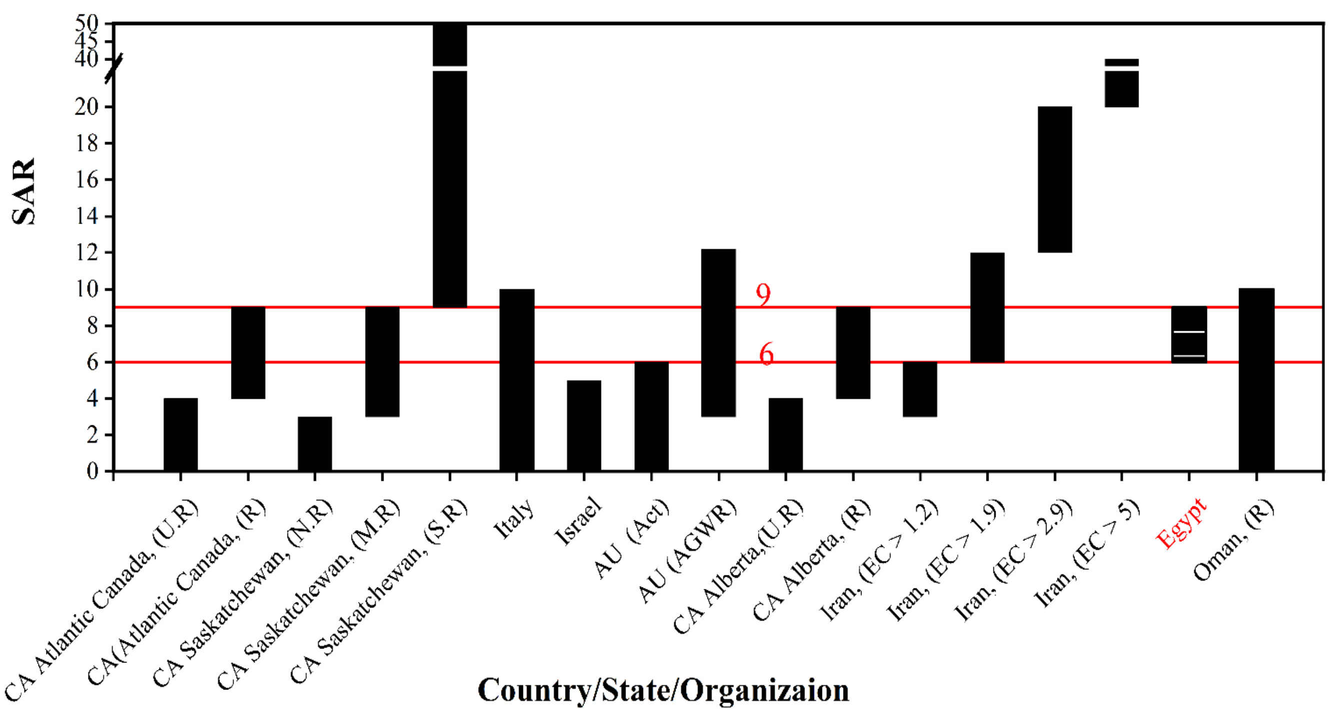
Abbreviations:
N.R: No restriction for treated wastewater reuse, M.R: Moderate restriction for treated wastewater reuse, S.R: Severe restriction for treated wastewater reuse, EC: Electrical conductivity, L.T.U: Long-term use, S.T.U: Short-term use, S.A.L: Saline-alkali land, N.S.A.L: Non-saline-alkali land, R: Restricted irrigation, U.R: Unrestricted irrigation.

Fig. 3. Salinity (total dissolved solids TDS) thresholds in the treated municipal wastewater reuse regulations [8, 12, 47, 49, 56-58, 63, 66, 73, 77].



Abbreviations:
N.R: No restriction for treated wastewater reuse, M.R: Moderate restriction for treated wastewater reuse, F.C: Food crops, N.F.C: Non-food crops, MA: Monthly average, MAX: Maximum, U.R: Unrestricted irrigation, I.C: Industrial crops.

Fig. 4. Nutrient thresholds in the treated municipal wastewater reuse regulations [8, 9, 12, 13, 26, 28, 30, 31, 33, 37, 47, 50, 53-58, 66, 73, 76, 77].



Abbreviations:
R: Restricted irrigation, U.R: Unrestricted irrigation, N.R: No restriction for treated wastewater reuse, M.R: Moderate restriction for treated wastewater reuse, S.R: Severe restriction for treated wastewater reuse, EC: Electrical conductivity.

Fig. 5. Treated municipal wastewater reuse regulations' SAR thresholds **[8, 46-50, 53-55, 66, 73, 77].**

E. Toxic Ions (Chloride, Sodium, and Boron)

Toxicity occurs when specific ions, most commonly chloride, sodium, and boron, are taken up by the soil-water and build in the leaves during water transpiration to the point that the plants are damaged. The main components of plants through which sodium and chloride can be absorbed are the roots and leaves. These ions are useful at low concentrations, despite their possible detrimental influence. Because not all crops are equally susceptible to poisonous ions, the degree of damage caused by these ions is dependent on time, concentration, crop sensitivity, and crop water use [67, 79, 81].

1) Chloride

When the chloride content in the crop surpasses the tolerance limit, damage signs such as leaf burn or leaf tissue drying appear. Also, the salty taste of the crops resulting from the accumulation of chloride affects the crop's market negatively [79, 82]. Although many countries realize how dangerous chloride affects the crops as shown in Fig. 6, Egypt does not consider it in its regulation.

2) Sodium

Leaf burn, scorch, and dead tissue around the outside edges of leaves are all indications of sodium toxicity in plants. It increases osmotic stress and kills crop cells, but it's worth noting that sodium toxicity can be adjusted or lessened if there's enough calcium in the soil [79, 83]. Egypt's threshold for sodium ions is 230 mg/l. Egypt's threshold is a nearly large value when compared with other countries and organizations as shown in Fig. 7 such as Iran (70 mg/l) and Israel (150 mg/l).

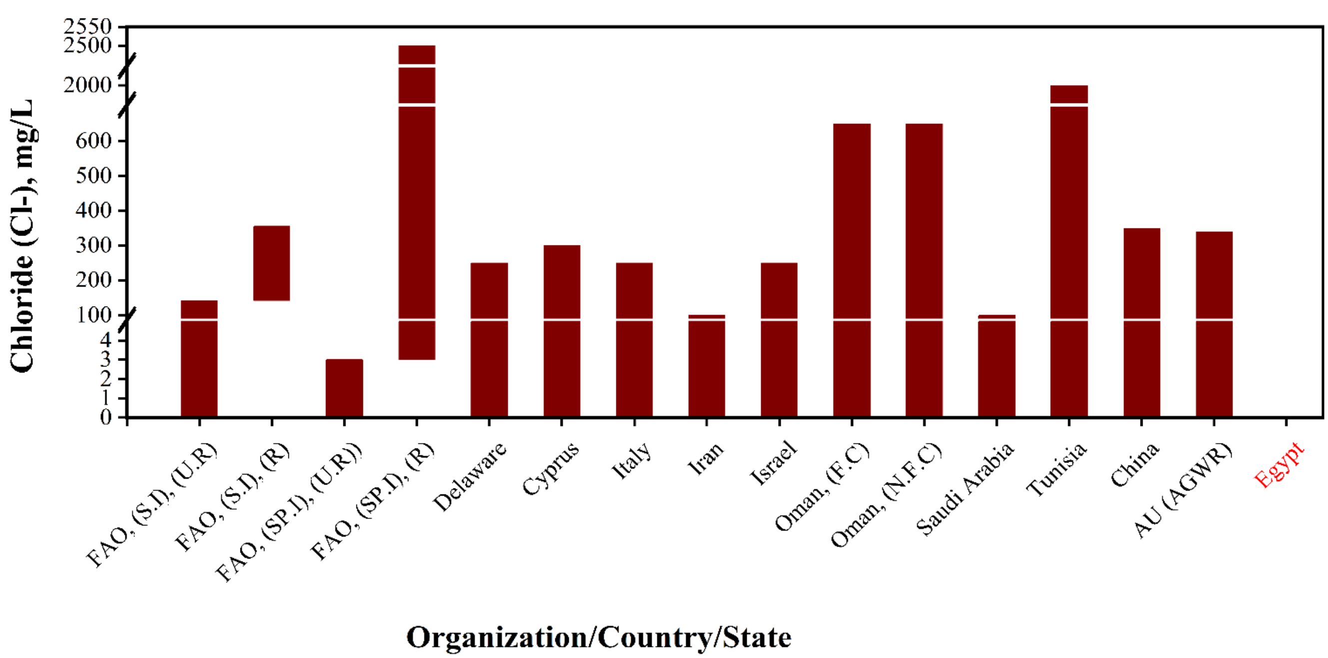
3) Boron

Boron is a necessary mineral for plant growth, yet an excessive amount of it is hazardous to plants. Boron poisoning manifests itself in older leaves as yellowing, staining, or drying of leaf tissue at the tips and edges [79]. Egypt's threshold for Boron is 1 mg/l. It's the same as Cyprus, Italy, China, and Oman for the food crops category when compared with other countries and organizations as shown in Fig. 8. But all of EPA (0.75 mg/l), Iran (0.7 mg/l), Israel (0.4 mg/l), Saudi Arabia (0.5 mg/l) thresholds for Boron are less than Egypt. However, it's acceptable because 1 mg/l of Boron is required for crop growth [67].

F. Carbonate and bicarbonate

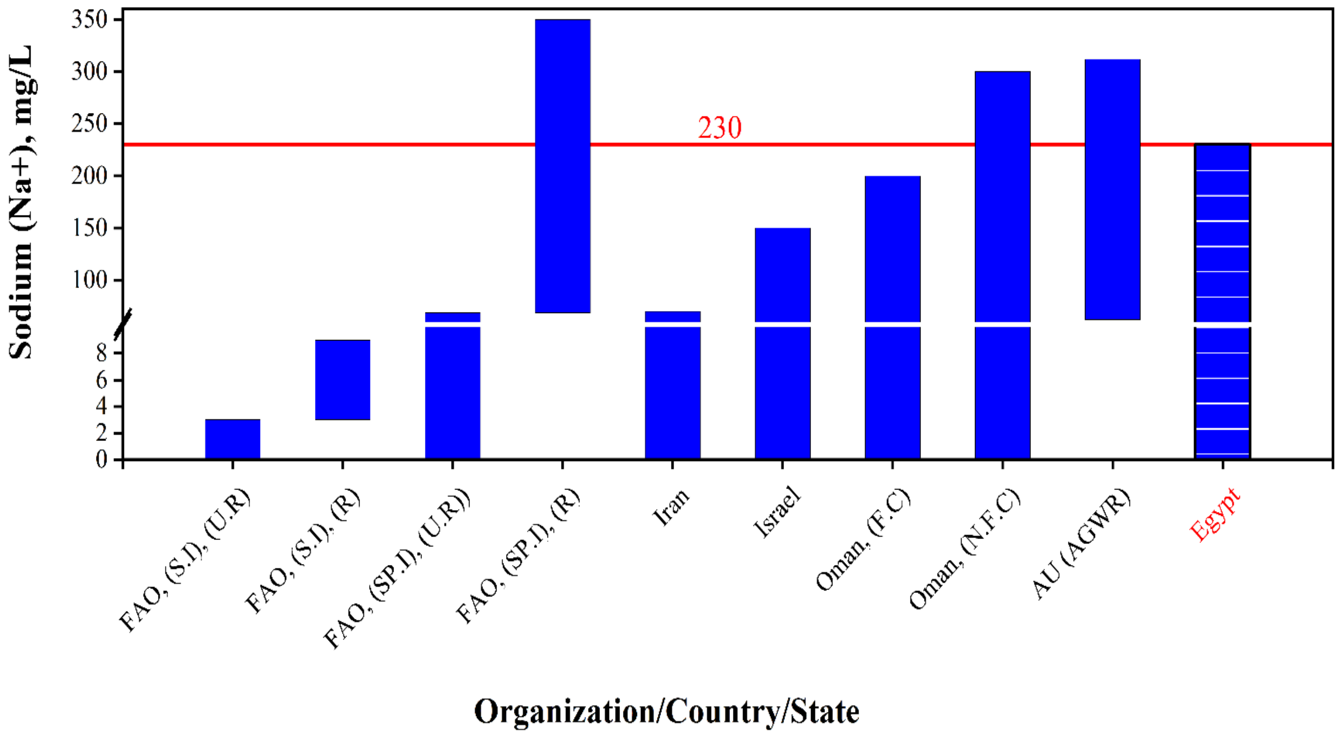
Although bicarbonate and carbonate are not poisonous to plants, they can have differing effects on them. High Bicarbonate levels in combination with Carbonate increase soil pH and may have an impact on soil permeability. When Bicarbonate ions combine chemically with elements like Calcium or Magnesium, they precipitate as Calcium Carbonate or Magnesium Carbonate, causing an increase in SAR due to a decrease in dissolved Calcium concentration. Also, there is another crucial issue related to the excess amount of Carbonate and Bicarbonate ions in the irrigation water is white lime deposits on plant leaves when using the overhead sprinkler irrigating method. Furthermore, these white patches detract from the aesthetic quality of the plants as well as their marketability. Moreover, these deposits choke irrigation accessories such as spray nozzles and drip emitters, causing them to malfunction [67, 76]. Finally, in some crops, a high concentration of HCO_3 ions in the nutritional medium resulted in a significant reduction in the dry weight of the roots and shoots [83] and can induce iron chlorosis in sunflower [84].

As shown in Fig. 9, Egypt is among very few countries and organizations that consider the bicarbonate ions threshold in its regulation, which is considered as a significant advantage of the (ECP 501/2015). Egypt's threshold for bicarbonate is 400 mg/l as same as Jordan. But Iran 90 mg/l and FAO (91.5 mg/l) have lower thresholds.



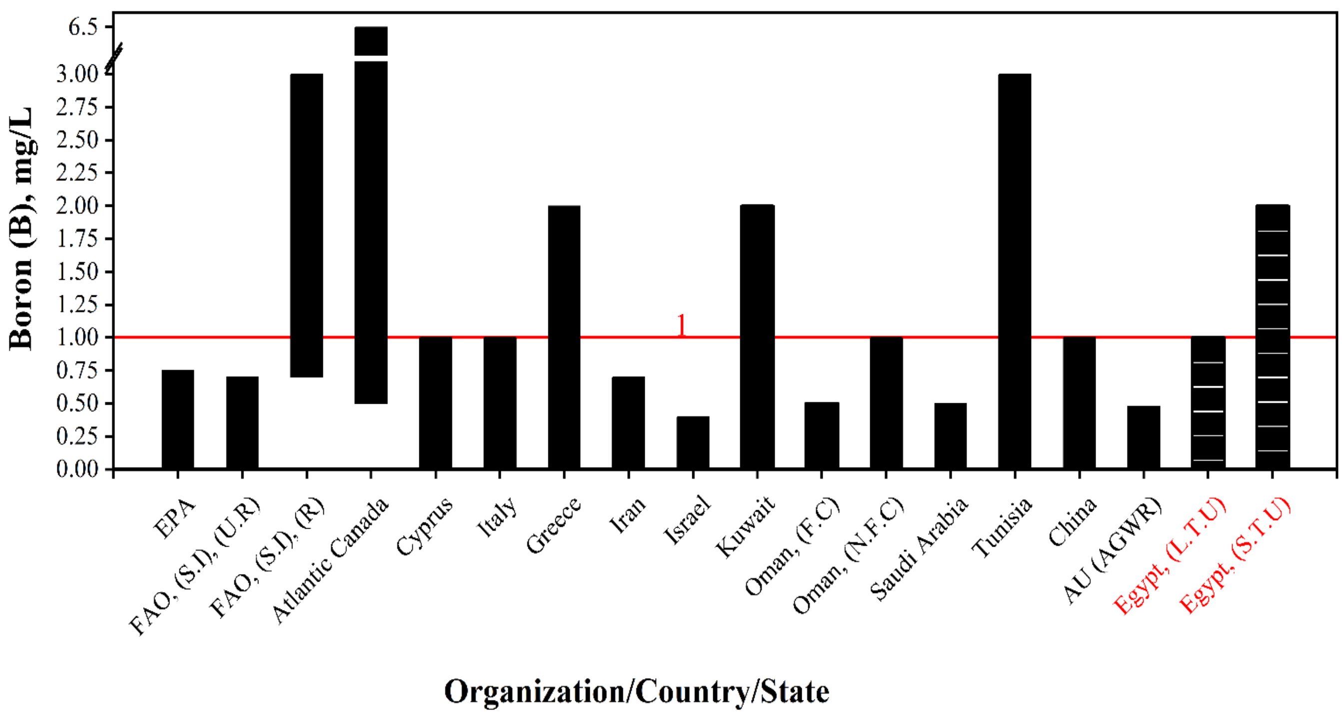
Abbreviations:
S.I: Surface irrigation, SP.I: Sprinkler irrigation, R: Restricted irrigation, U.R: Unrestricted irrigation, F.C: Food crops, N.F.C: Non-food crops.

Fig. 6. Chloride thresholds in treated municipal wastewater reuse regulations [8, 9, 12, 18, 50, 53-55, 58, 63, 66, 74, 75, 77].



Abbreviations:
S.I: Surface irrigation, SP.I: Sprinkler irrigation, R: Restricted irrigation, U.R: Unrestricted irrigation, F.C: Food crops, N.F.C: Non-food crops.

Fig. 7. Sodium thresholds in treated municipal wastewater reuse regulations [8, 9, 53-55, 66, 73, 77].



Abbreviations:
S.I: Surface irrigation, SP.I: Sprinkler irrigation, R: Restricted irrigation, U.R: Unrestricted irrigation, F.C: Food crops, N.F.C: Non-food crops, L.T.U: Long-term use, S.T.U: Short-term use.

Fig. 8. Boron thresholds in treated municipal wastewater reuse regulations [8, 9, 12, 46, 50-55, 57, 58, 63, 66, 73-75, 77].

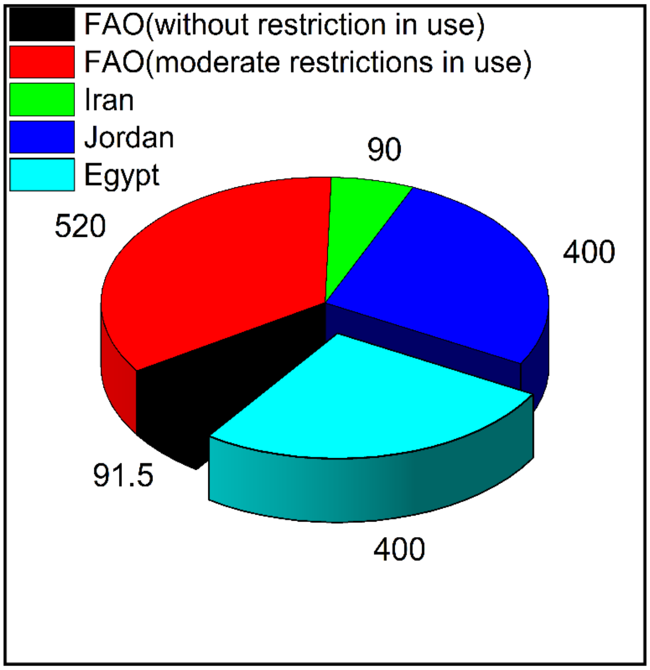


Fig. 9. Bicarbonate (mg/L) thresholds in treated municipal wastewater reuse regulations [8, 12, 56, 77].

G. *Free Chlorine*

Chlorine is used in wastewater treatment plants to disinfect the wastewater [85]. The amount of chlorine used is sufficient to ensure that some free chorine remains in the treated wastewater, protecting it from pathogen recontamination in the storage and supplying systems. It is unlikely to harm plants if the residual free chlorine concentration is less than 1 mg/l. However, even at low doses of roughly 0.5 mg/l, some sensitive plants are severely harmed. The symptoms of chlorine on the sensitive plants are chlorosis, plant growth decrease, leaf discoloration, etc. [67, 83, 84, 86]. Although many countries realize how dangerous the free chorine affects the crops as shown in Fig. 10, Egypt does not consider it in its regulation.

IV. PHYSICO-CHEMICAL CONTROLS

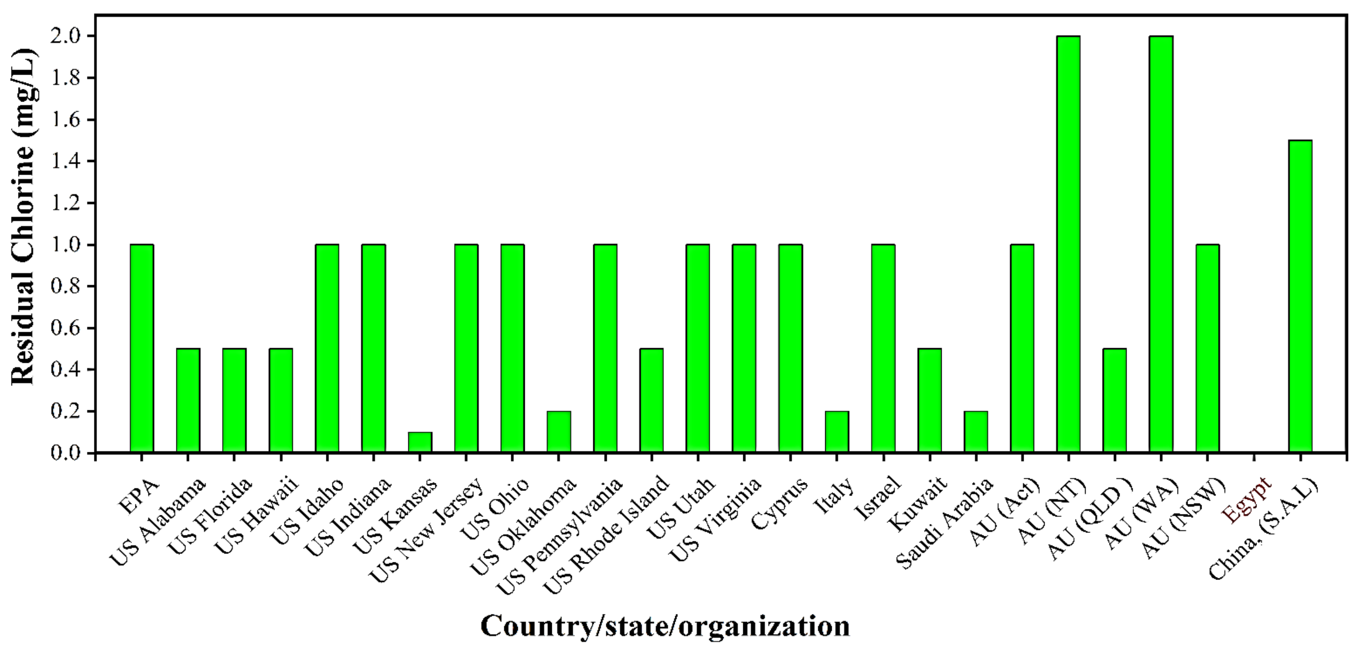
Physico-chemical parameters include turbidity, TSS and TDS, and organic matters. They are essential for the use of treated wastewater for agricultural irrigation.

A. *Turbidity*

Turbidity is a crucial parameter for the health of both plants, crops, and humans. The most important impact of turbidity is that solids and soil particles enclose the germs and organisms resulting in obstruction of the wastewater disinfection [87].

Fig. 11 demonstrates the turbidity thresholds for various countries and organizations, with suspended solids being used in most countries that don't have a turbidity standard. The turbidity threshold depends on the category reuse of the treated wastewater. The used measuring unit of the turbidity is NTU (Nephelometric Turbidity Units).

Egypt considers turbidity threshold only for category reuse (A) as 5 NTU and with daily monitoring. While other countries and organizations set 2 NTU regarding the first category of treated wastewater reuse as shown in Fig. 11. Moreover, Egypt does not determine the maximum value of the turbidity threshold just the daily average value. Of note is that the average value for Egypt (5 NTU) is considered maximum value for different organizations and countries such as EPA (Food crops), ISO (A category reuse), US Arizona (Food crops), US Delaware (All types), US Utah (Food crops), Saudi Arabia (Unrestricted), and Australia



Abbreviations:
S.A.L: Saline-alkali land.

Fig. 10. Residual Chlorine thresholds in treated municipal wastewater reuse regulations [8, 9, 13, 19, 21-24, 30, 33, 34, 36, 37, 39, 40, 49, 50, 53-55, 57, 58, 63].

B. TSS (Total Suspended Solids)/ (SS)

Total suspended solids (TSS or SS) and total dissolved solids (TDS) are the two components of total solids (TS). A filtration technique is used to separate them from each other [87-89]. Total Dissolved Solids (TDS) are the total number of mobile charged ions, such as minerals, salts, or metals, dissolved in a given volume of water, and are measured in milligrams per liter (mg/L). Total suspended solids (TSS) refer to all particles suspended in water that aren't filtered. In sanitary wastewater and many types of industrial wastewater, suspended particles are present. They are also an important element for the reuse of treated wastewater for irrigation in agriculture. They could obstruct irrigation water distribution lines and emitters, causing irrigation systems harm [5, 87, 90, 91].

Fig. 12 shows the total suspends thresholds for different countries and organizations. The TSS threshold depends on the category reuse of the treated wastewater and there are different monitor times for checking TSS. According to the (ECP 501/2015) classification for treated wastewater reuse for agriculture, the Egyptian threshold for category A is 15 mg/l, while the EPA, ISO, Florida, Indiana, and North Carolina thresholds for the same category are 5 mg/l, as shown in Fig. 12 (b) Cluster 2. The thresholds for the same category in Italy, Hawaii, Greece, the European Commission, and Israel are 10 mg/l. Of note is both of Israel and Italy threshold is constant regardless of the category of the treated wastewater. Egypt thresholds for both of B, C, D categories are 30,50,300 respectively. And, as demonstrated in Fig. 12, Egypt's thresholds are rather high when compared to other countries in almost the same categories

C. Organic Matter

Organic matter is a very important parameter for the treated wastewater quality for agricultural irrigation. As it is not only negatively altering the water’s odor and color, but also is considered a nutrient for microbes, and negatively causes many diverse effects during the disinfection process [84]. The quality of treated wastewater is measured using indices of biological oxygen demand (BOD), carbonaceous oxygen demand (CBOD), and chemical oxygen demand (COD). The organic matter thresholds for several countries and organizations are depicted in Fig. 13.

The threshold depends on the category reuse of the treated wastewater. Egypt considers the BOD_5 as an indicator for organic matter and their thresholds are 15,30,80, and 350 mg/l for A, B, C, and D category reuse, respectively. As shown in Fig. 13, Egypt's threshold for the first category A is 15 mg/l, but other organizations and nations have lower limits, such as ISO (5 mg/l), Hawaii (5 mg/l), Texas (5 mg/l), Greece (10 mg/l), Saudi Arabia (10 mg/l), and so on. The same as with the other groups. In comparison to other countries in the same category, Egypt has a high threshold. Of note is that the highest BOD_5 thresholds are issued by Egypt (D: Category reuse) as 350 mg/L.

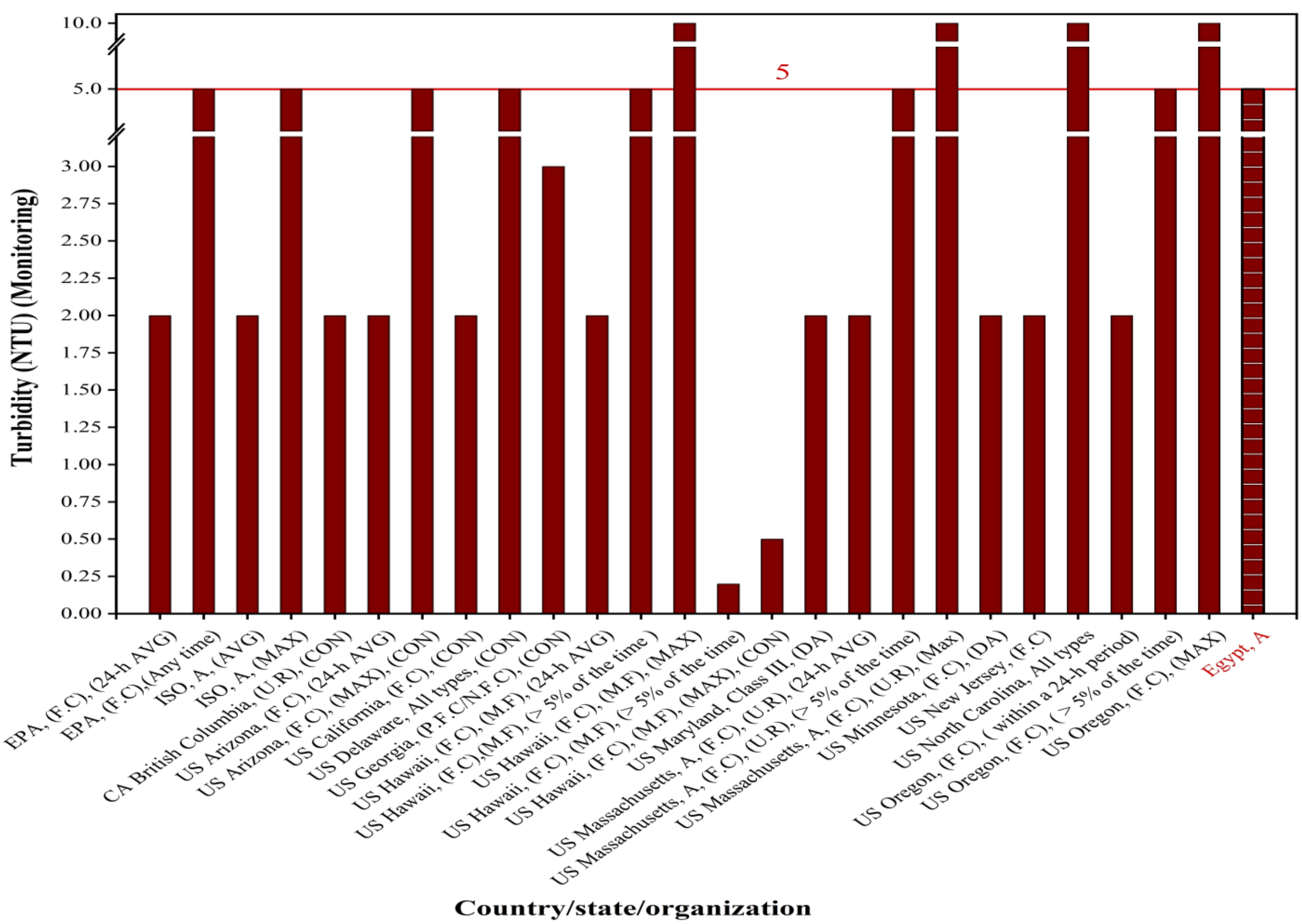


Fig. 11. (a) Cluster 1

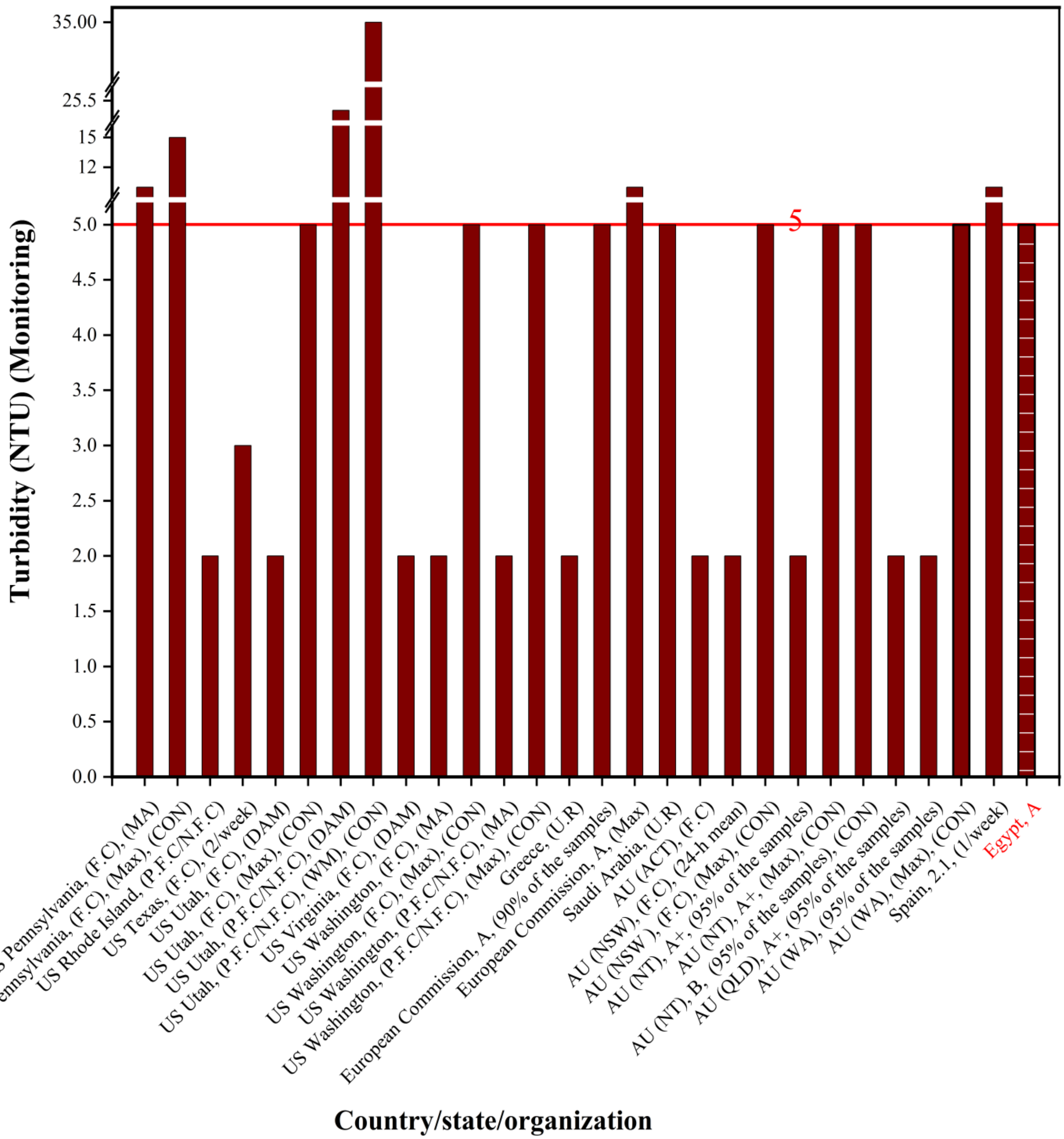


Fig. 11. (b) Cluster 2

Abbreviations:

MAX: Maximum , AVG: Average, CON: Continuous, DA: Daily average, DAM: Daily arithmetic mean, WM: Weekly mean, F.C: Food crops, N.F.C: Non-food crops, P.F.C: Processed food crops, M.F: Media filtration, R: Restricted irrigation, U.R: Unrestricted irrigation.

Fig. 11.(a & b) Turbidity thresholds in treated municipal wastewater reuse regulations [8-11, 14-16, 18, 20, 21, 25-27, 30, 31, 35-41, 45, 49, 51, 52, 58, 62].

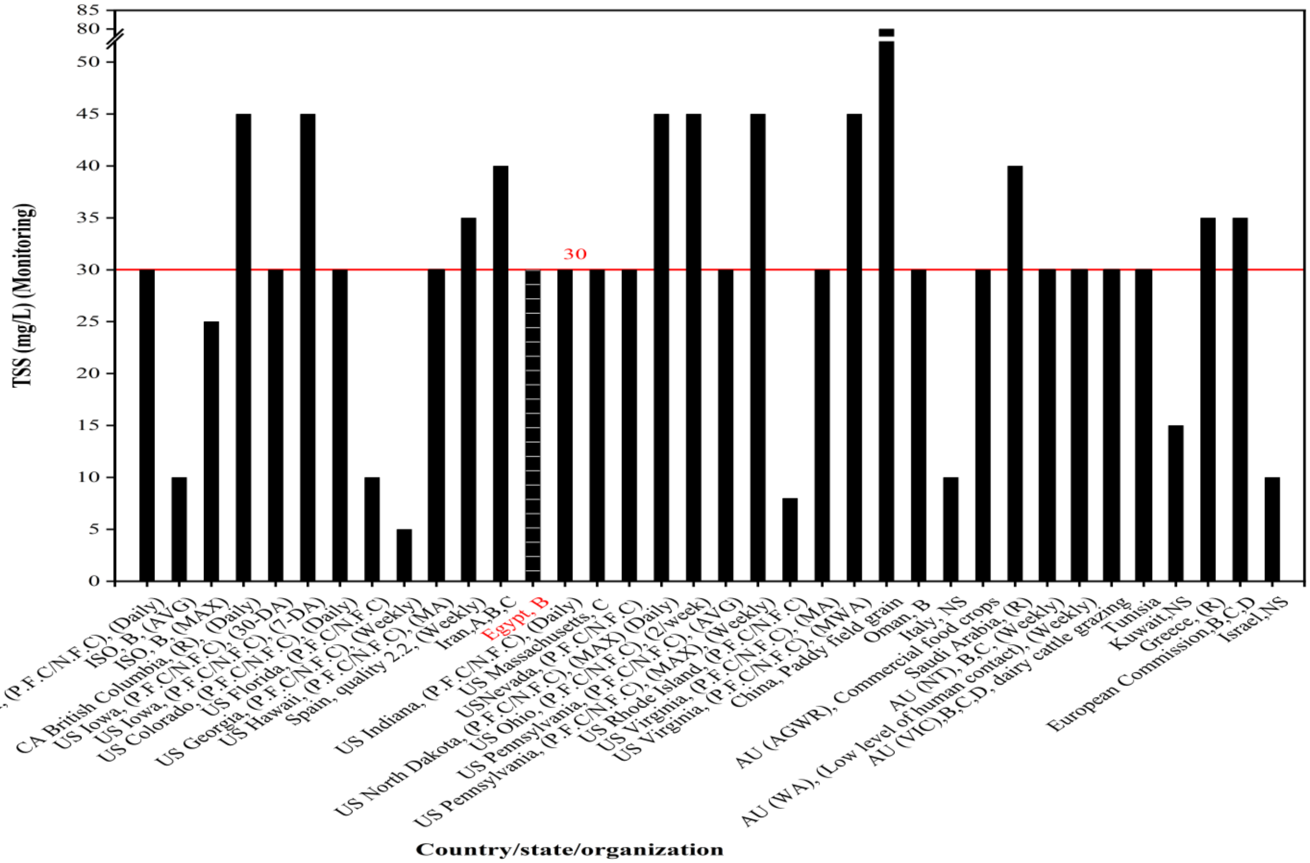


Fig. 12. (a) Cluster 1

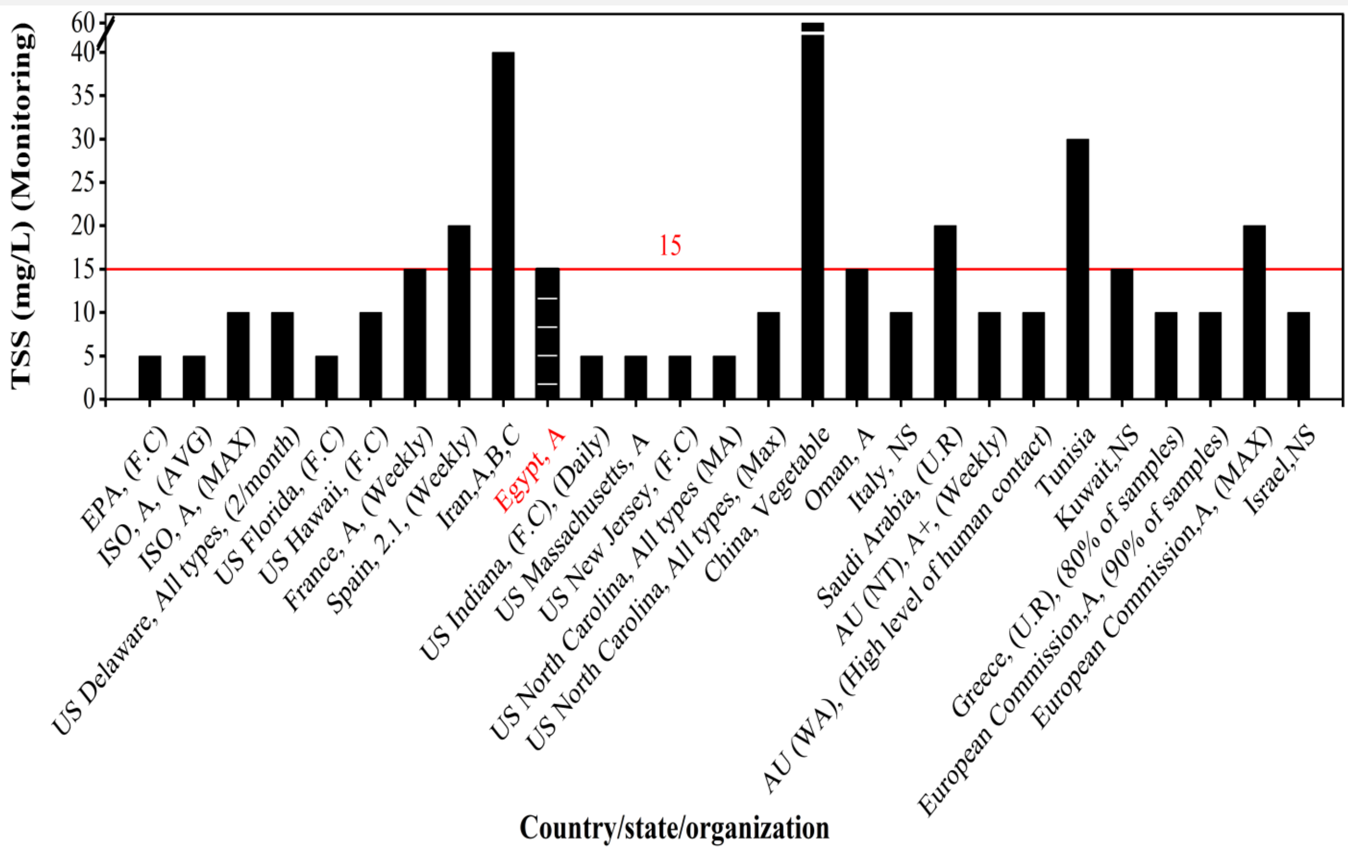


Fig. 12. (b) Cluster 2

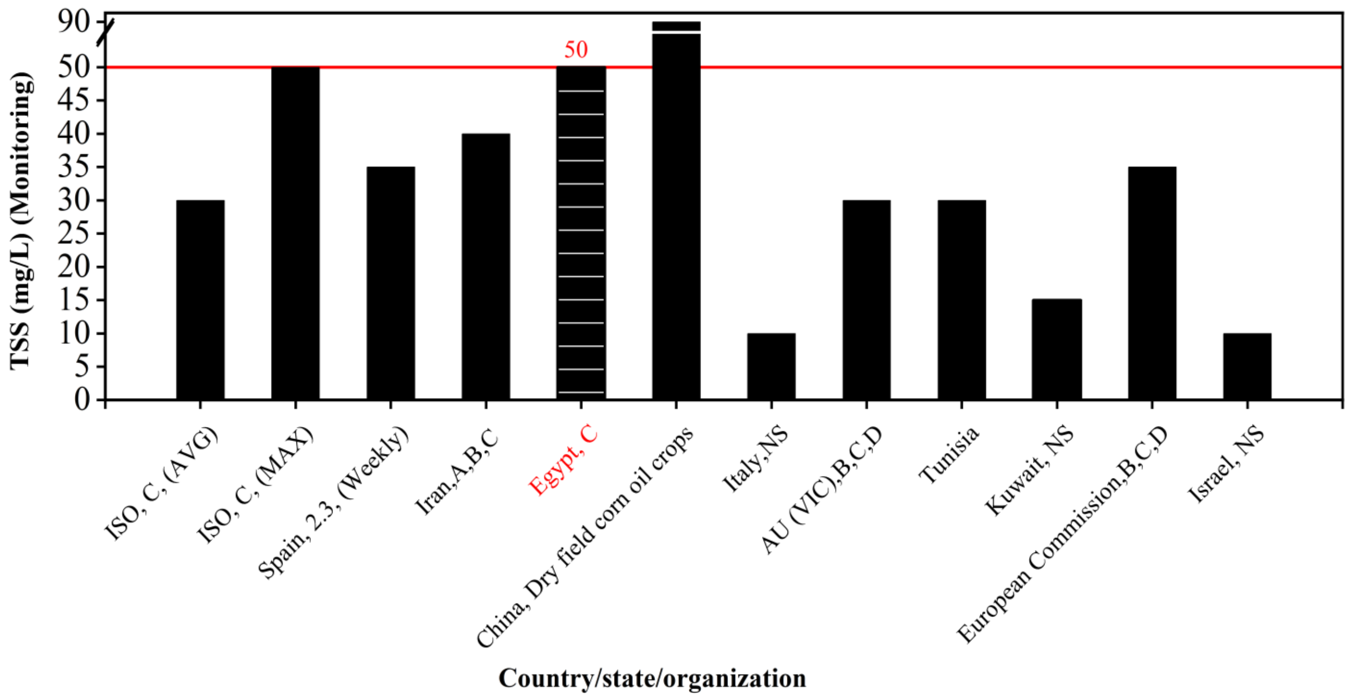


Fig. 12. (c) Cluster 3

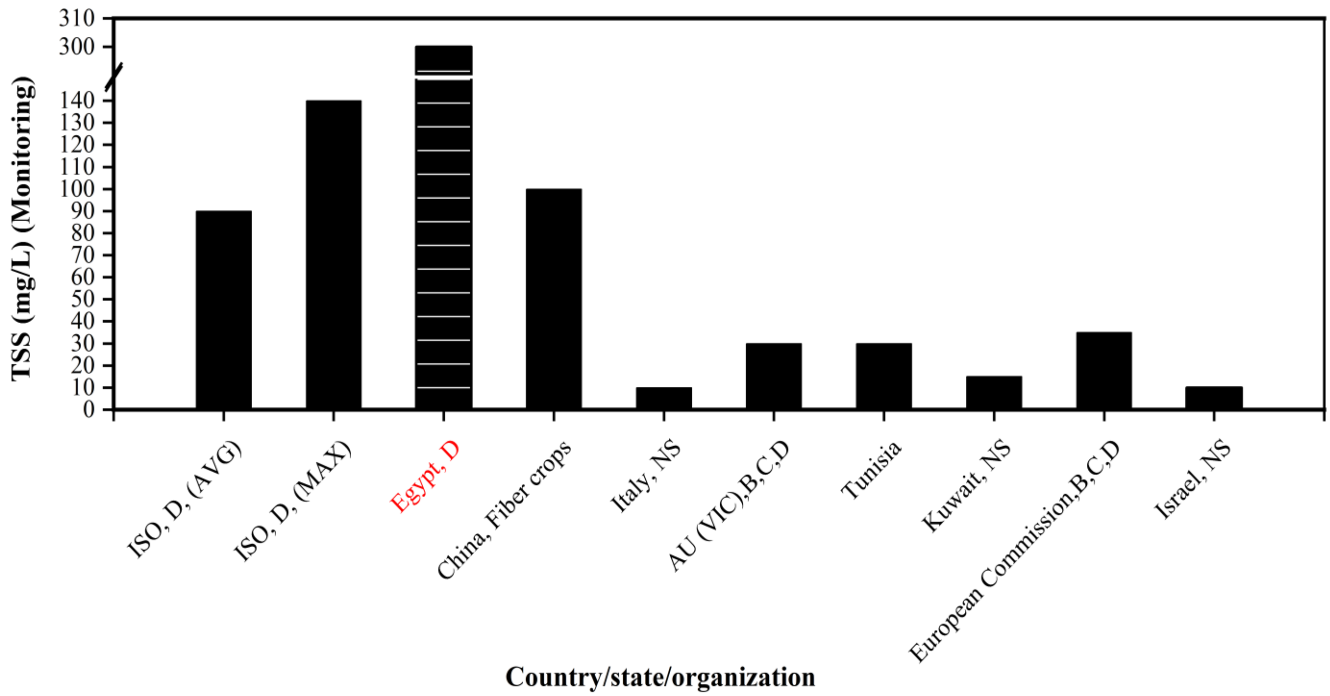


Fig. 12. (d) Cluster 4

Abbreviations:

MAX: Maximum , AVG: Average, CON: Continuous, DA: Daily average, DAM: Daily arithmetic mean, WM: Weekly mean, MWA: Maximum weekly average, NS: Not Specific, F.C: Food crops, N.F.C: Non-food crops, P.F.C: Processed food crops, M.F: Media filtration, R: Restricted irrigation, U.R: Unrestricted irrigation.

Fig. 12. (a, b, c &d) TSS/SS thresholds in treated municipal wastewater reuse regulations [8-11, 13, 17-21, 23, 26, 29-33, 36, 37, 40, 45, 49-58, 61-63, 66, 72-75, 77].

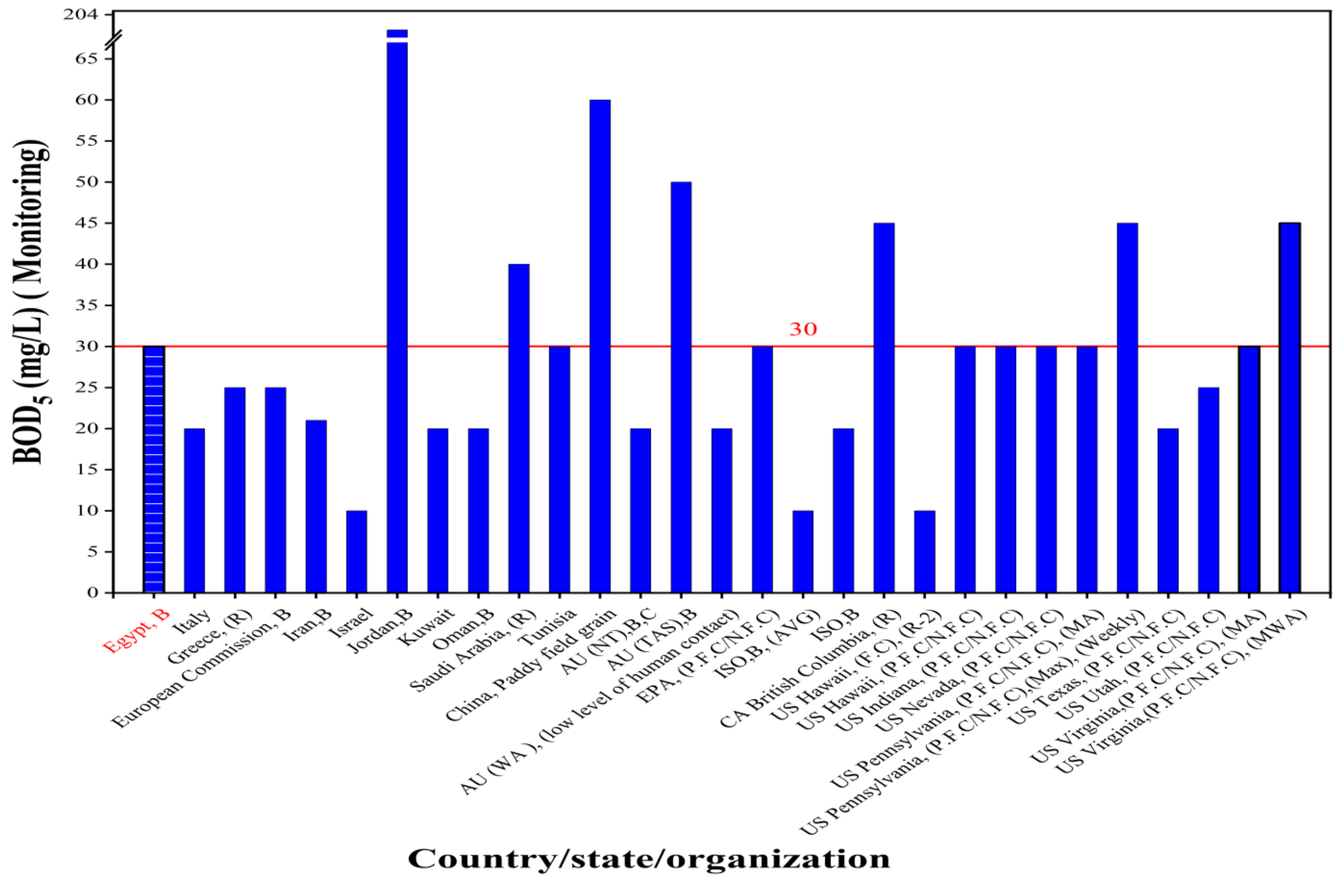


Fig. 13. (a) Cluster 1

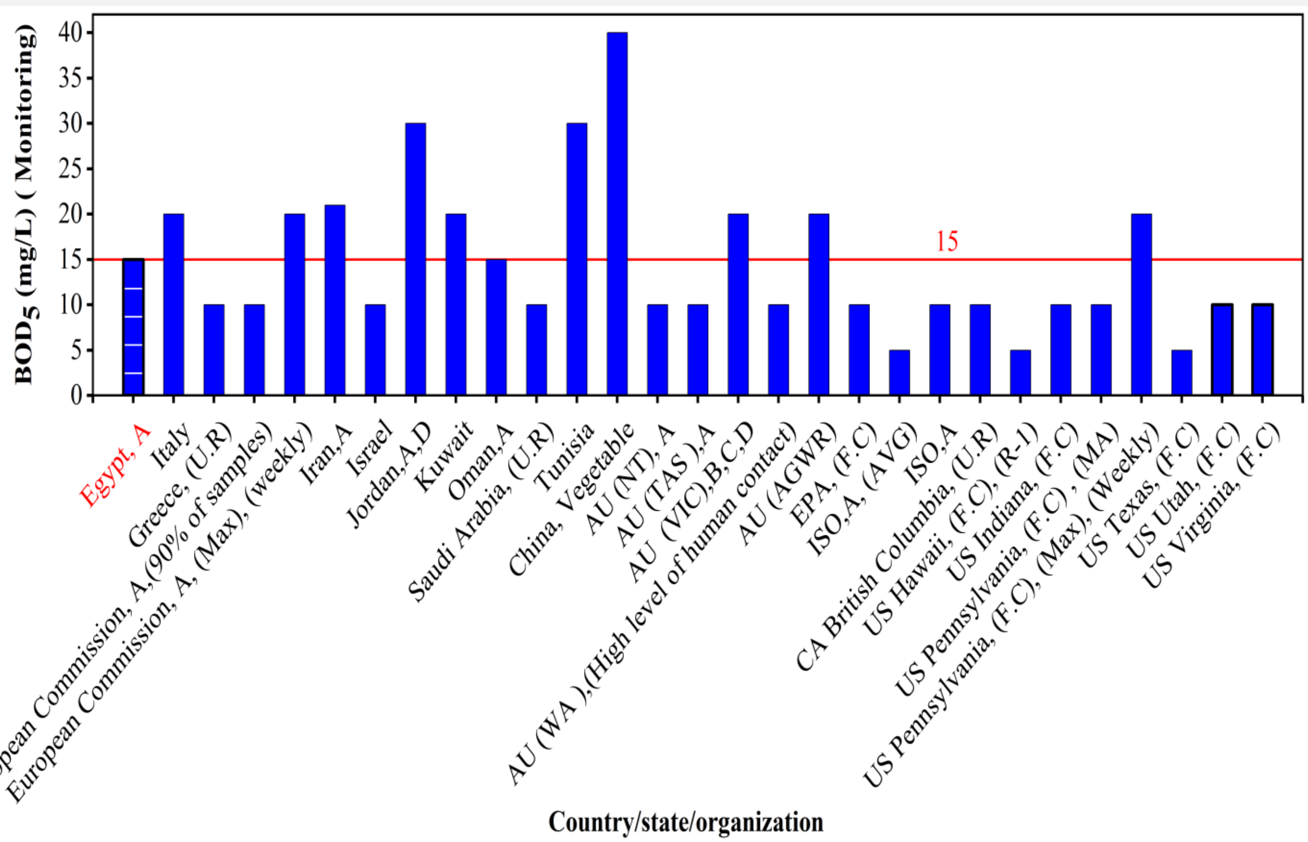


Fig. 13. (b) Cluster 2

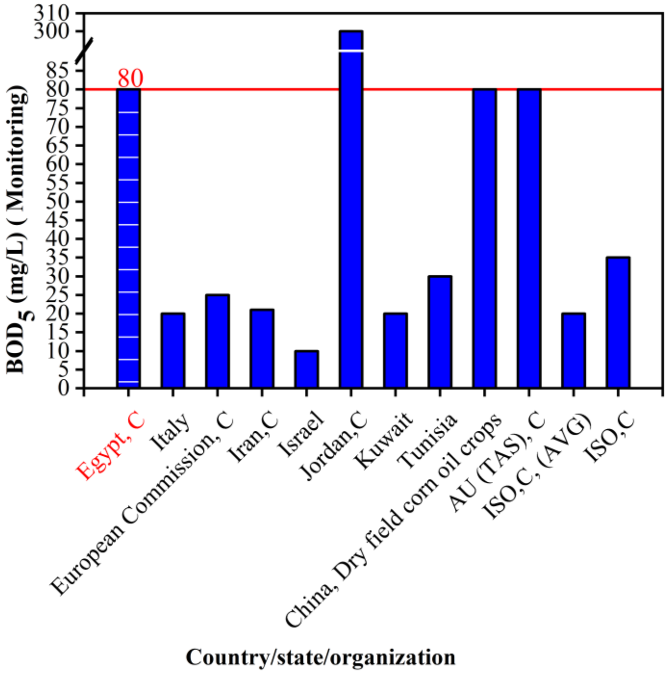


Fig. 13. (c) Cluster 3

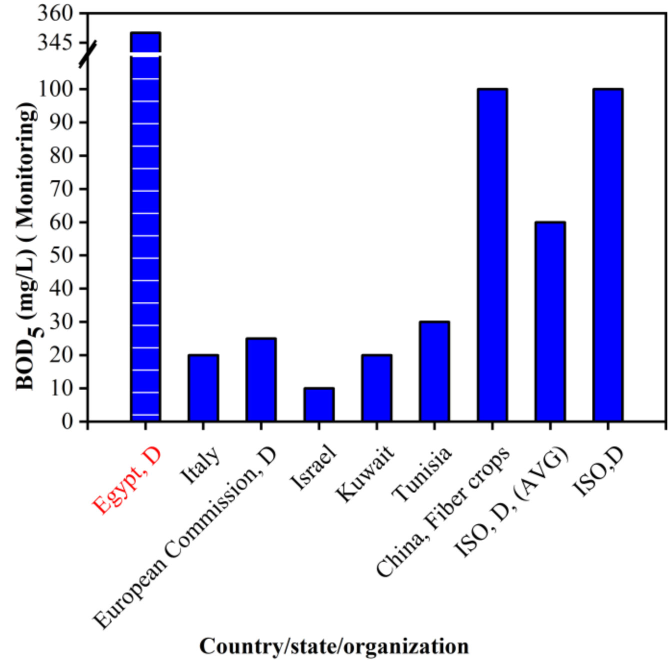


Fig. 13. (d) Cluster 4

Abbreviations:
MAX: Maximum , AVG: Average, CON: Continuous, DA: Daily average, DAM: Daily arithmetic mean, WM: Weekly mean, MWA: Maximum weekly average, NS: Not Specific, F.C: Food crops, N.F.C: Non-food crops, P.F.C: Processed food crops, M.F: Media filtration, R: Restricted irrigation, U.R: Unrestricted irrigation.

Fig. 13. (a, b, c &d) BOD_5 thresholds in treated municipal wastewater reuse regulations [8-11, 18, 20, 21, 23, 25, 26, 29, 31, 32, 34, 36-41, 45, 49-58, 63, 66, 73-77, 92].

V. Conclusion

The (ECP 501-2015) prohibited to use of treated wastewater – whatever the level of treatment is – in irrigating vegetable crops eaten raw. So the main purpose of this work is to optimize the use of treated wastewater to include all the treated wastewater reuse categories in Egypt without any harmful impacts on:

1) The quality of crops irrigated with that water.
2) The sustainable use of irrigated lands with that water.

In doing so, this review has compared the latest Egyptian regulation for treated wastewater reuse in agriculture with other countries worldwide and international organizations regarding both agronomic controls (salinity, toxic ions, SAR, pH, carbonate, nutrients, and free chlorine), and Physico-chemical controls (turbidity, TSS, and organic matters). To summarize, the results show that (ECP 501/2015) is highly compatible with the regulations of other countries for the same category reuse of the treated wastewater. Eventually, this review provides important information for the development of a strategy for the use of treated wastewater in irrigation for all uses in Egypt, especially with recent advancements in wastewater treatment technologies, which allow for the production of almost any water quality.

Authors Contribution

Ahmed Khaled and Moussa Shalaby conceived the outline picture of the presented idea. They also collected, discussed and developed all needed data.

All authors drafted, verified, and discussed the article data.

Ahmed Khaled and Talaat Abdel-Wahed supervised and critically revised the paper. They encouraged Moussa to investigate the main points and supervised the discussion of this work.

All the authors contributed to get the final manuscript.

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TITLE ARABIC:

المعايير المصرية لإعادة استخدام مياه الصرف الصحي المعالجة للري: دراسة مقارنة للضوابط الفيزيائية والكيميائية والزراعية

ARABIC ABSTRACT:

من أهم القضايا والتحديات في الوقت الحاضر في مصر هو كيفية توفير ما يكفي من المياه للاحتياجات الحالية والمستقبلية. يتطلب النمو السكاني الكبير والاستهلاك الزراعي وتغير المناخ وموارد المياه العذبة المحدودة ونمط حياة الرفاهية المزيد من المياه. كل هذه العوامل تدفع بالسياسة المصرية للبحث عن موارد مائية إضافية. و تعتبر مياه الصرف الصحي المعالجة من الموارد المائية التي تم استخدامها في الري في ظل بعض القيود. ومع ذلك ، فإن استخدام مياه الصرف الصحي المعالجة للري الزراعي قد يكون له آثار صحية سلبية إذا تجاوزت خصائصها المعايير المسموح بها. تتناول هذه الدراسة المعايير واللوائح والقيود المصرية لاستخدام مياه الصرف الصحي المعالجة في الري الزراعي ، مقارنة بالدول الأخرى حول العالم. تناقش الدراسة معايير جودة مياه الصرف الصحي المعالجة للري ، بما في ذلك الضوابط الفيزيائية والكيميائية والضوابط الزراعية. أظهرت النتائج أن الكود المصري (ECP 501/2015) متوافق بدرجة كبيرة مع لوائح الدول الأخرى ، لكن هناك بعض الاختلافات. هذه الاختلافات مسموح بها لأن الكود المصري حظر استخدام مياه الصرف الصحي المعالجة في ري محاصيل الخضروات التي تؤكل نيئة. أخيرًا ، يجب إجراء المزيد من الدراسات على الخصائص الكيميائية والفيزيائية والزراعية المقبولة لمياه الصرف الصحي المعالجة للتطبيقات الزراعية في مصر لتحقيق أفضل استخدام لمياه الصرف الصحي المعالجة.