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Wastewater Reuse for Irrigation Agriculture in Morocco: Influence of Regulation on Feasible Implementation

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Abstract: Morocco is a water-scarce developing country with a growing marketable agro-food industry, where untreated or insufficiently treated wastewater represents less than 1% of the irrigation water and treated wastewater reuse is virtually nil. The Government of Morocco is planning to increase the volume of treated wastewater reuse for irrigation agriculture under the current permissive regulation to alleviate the pressure on conventional water sources. However, the reuse of insufficiently treated wastewater implies environmental and human health risks besides the degradation of land and renewable natural resources. This paper shows the feasibility of increasing wastewater reuse for irrigation agriculture in Morocco and how the existing permissive regulation must be improved to force more efficient technologies aimed at ensuring the export of agricultural goods to the most restrictive international markets. The results show how the quality standards of Moroccan regulation are below that of their equivalents in developed countries, as well as in most of the consulted developing countries. After verifying that tertiary treatment is financially feasible, the updated regulation must also consider climatic water scarcity and the locally low cultural perception of environmental and human health risks in order to design optimal solutions.

Keywords: wastewater reuse; irrigation agriculture; international quality standards; regulation improvement; tertiary treatment; natural resources degradation; Morocco

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1. Introduction

The Mediterranean area is one of the regions of the world where the sustainability of conventional water sources is most hazarded, as reflected in near-future scenarios of climate change, population growth and migrations, expansion of urbanized areas, agriculture, and pollution [1–3]. Both southern Europe and northern Africa must deal with the challenges posed by rising water demand due to growing demographic pressure and the increasing irregularity of precipitation patterns. For instance, near-future climate scenarios indicate that precipitation will decline by between 10% and 30% during dry seasons [4], increasing the length of non-recharge periods to aquifers [5,6] and decreasing the water quantities held in reservoirs [7,8].

Even though the challenge of meeting water demand is similar throughout the Mediterranean area [9–11], solutions differ between the developed southern European countries and the developing northern African countries. Two complementary strategies to meet the growth in water demand are typically adopted as (i) implementation of sustainable management policies for conventional water sources, and (ii) production of additional non-conventional water sources. Whereas the southern European countries can combine the two strategies, some northern African countries find it difficult to do so due to legal, economic, and cultural constraints [1,12–14].

In northern African countries, the development of non-conventional water sources to cope with increasing urban and agricultural demand is a desirable target. In many densely populated, irrigated drylands, the use of non-conventional water sources such as wastewater reuse [15–17] and desalination of seawater, brackish groundwater, and reclaimed wastewater [18–21] represents a partial solution to cope with water quantity and quality requirements, generally making use of subsidizing energy policies [22]. Where there are permanent effluents from medium to large urban areas, wastewater reuse must be a priority for the environment and human health.

Morocco is a developing country whose water scarcity—induced by global climatic driving forces and the overdevelopment of conventional water sources—prevents it from meeting the increasing urban and agricultural demand. Morocco is one of the northern African countries with the lowest rate of wastewater reuse for irrigation agriculture [14]. The World Bank predicted wastewater volume to increase from 666 Mm^3 in 2014 to 900 Mm^3 in 2020 [23,24], whereas the treated fraction was still considerably lower—around 38 Mm^3—in 2017 [25]. Official reports have focused preferentially on the positive consequences of wastewater reuse. However, the scientific literature has also reported some negative consequences for water, soil, and crops, due to the prolonged use of untreated or inadequately treated wastewater under permissive Moroccan regulations [26–33]. With the aim of promoting sustainable water policies, the Government of Morocco is planning to increase the volume of treated wastewater reuse for irrigation agriculture. However, the international markets where most of Morocco's agricultural production is exported have more restrictive regulations and problems associated with the quality of the imported products could occur in the near future.

Regarding the production of treated wastewater, two questions arise: Will the quantity and quality of reused wastewater increase according to the greater urban water usage and irrigation water demand foreseen in the near future? Can the Moroccan economy and society withstand the current treatment technology and discharge policy when facing this growth in water demand? Morocco has a wide improvement margin in this matter relative to similarly water-scarce southern European countries and some northern African countries. For instance, in 2010 the production of tertiary-treated wastewater was 347 Mm^3 in Spain, 233 Mm^3 in Italy [34,35], and 240 Mm^3 in Tunisia [14], i.e., 37-, 24-, and 25-fold, respectively, the secondary-treated wastewater reused in Morocco. Regarding agricultural water demand, Moroccan policy has been based on large reservoirs to supply official irrigable areas and the growing populations are attracted to them as a result. Successive plans to develop new irrigation areas have provoked the degradation of surface watercourses and groundwater bodies [28,33]. A new question arises: how can Morocco increase treated wastewater production for irrigation agriculture in order to alleviate the pressure on conventional water sources while safeguarding the emergent agro-food industry? A revision of the Moroccan regulations aimed at resolving deficiencies affecting the agro-food industry, environment, and human health is needed.

This paper explores the feasibility of expanding the use of wastewater for irrigation agriculture in Morocco. Given that regulations ultimately determine technical solutions and social habits, the Moroccan regulations for treated wastewater reuse for irrigation agriculture are compared to their equivalents from other regions of the world with similar climates, but different economic and cultural contexts. This comparison is aimed at identifying technological deficits in the field of wastewater treatment and reuse to meet the most restrictive standards of the international destination markets. This regulation overview is needed for future hazard analysis and critical control points [36] aimed at designing reliable decision support tools [37].

2. The Moroccan Framework

2.1. Geography, Climate, Irrigation Agriculture, and Water Demand

Morocco is located between latitudes 28 °N and 36 °N and has a surface of 446,550 km^2 (Figure 1). The orography is dominated by the Atlas (in the East and South) and Rif (in the North) mountain ranges, which exceed 4000 m and 2500 m elevation, respectively, highlands (plateaus) exceeding 1000 m elevation and coastal plains (Figure 1a). In the northern and central regions, the largest rivers flow from mountain ranges to the Atlantic Ocean and the Mediterranean Sea, surrounded by highlands and mountains that exceed 2000 m in elevation [38]. The southern and eastern regions occupy the northern and eastern borders of the Sahara Desert [12].

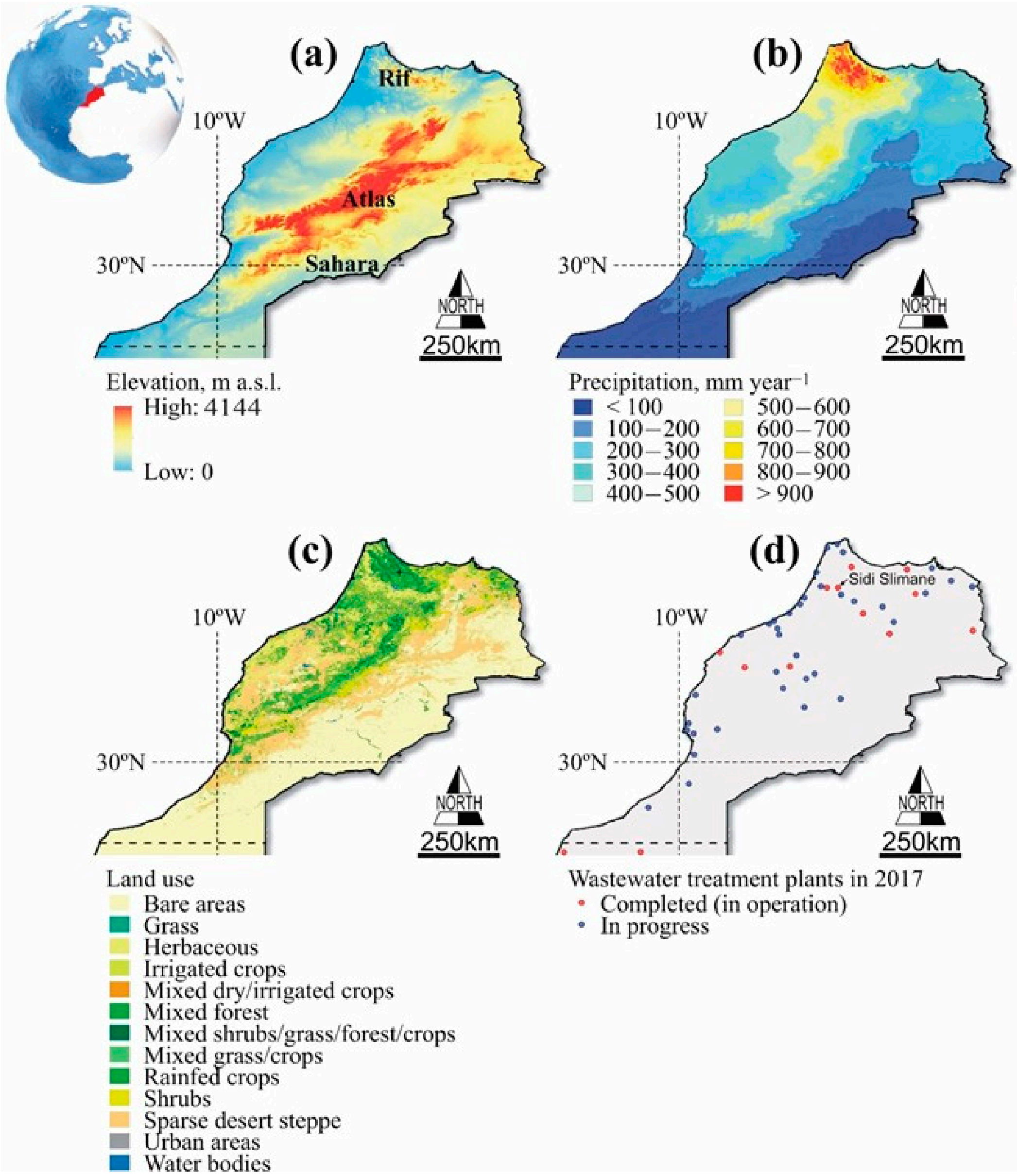

Figure 1. (**a**) Elevation, (**b**) precipitation, (**c**) land use, and (**d**) wastewater treatment plants in Morocco. The three first maps were modified from Gourfi et al. [38], whereas the latter was created from the PWNOW database (accessed on January 2017).

According to the Köppen classification [39], climates in Morocco can be classified as temperate Mediterranean (CSa, CSb) and semiarid (BSh, BSk) in northern and western regions, desert (BWh, BWk) in southern and eastern regions and dry-summer subarctic (Dsc) in mountain ranges. This climatic distribution determines different precipitation regimes, from less than 100 mm per year in southern and eastern regions to more than 900 mm per year in northern and western regions (Figure 1b), thus favoring the most water abundance and highest population density in these last regions [40,41]. The Food and Agriculture Organization estimated total renewable water resources to be 29 km^3 year^{-1}—around 60% surface water and 40% groundwater—but only 22 km^3 year^{-1} are considered to be technically manageable [42]. Mountain ranges and the Sahara Desert are sparsely inhabited areas because the climates are respectively very cold and very hot for human activities, including irrigation agriculture.

Morocco is a great producer and exporter of agricultural goods. In 2019, the agro-food industry contributed 15% to the country's gross domestic product and employed more than 33% of the active population, making this sector one of the biggest sources of foreign exchange for the country [42]. Since Morocco's independence in 1956, successive development plans have promoted new irrigation areas, growing from 900 km^2 in 1961 to almost 14,000 km^2 in 2014 [42], i.e., around 3.1% of the country (Figure 1c). These areas are located in the northern and western coastal areas, the valleys of the largest rivers, and low-lying areas of the highlands where water is more abundant and mild temperatures rarely produce frosts. In southern and eastern regions, irrigated crops are concentrated in sparse river valleys and oases [1,12,38].

Irrigation agriculture's water demand increased from 500 Mm^3 in 1961 to 13,500 Mm^3 in 2014, 70% being surface water, 30% groundwater, and less than 0.1% non-conventional sources including wastewater reuse [42]. Around 80% of the total Moroccan irrigated crop products are exported in the form of citrus, tomatoes, and vegetables. In recent years, the profit earned through irrigation agriculture has noticeably increased, thus leading to the transformation of further bare areas and previously rainfed crops into irrigable surfaces. This land transformation has stimulated the overdevelopment of conventional water sources, mostly groundwater, and may produce degradation of land and natural resources [43,44].

2.2. Wastewater Treatment and Reuse Regulations

The first wastewater treatment regulation was set by the National Master Plan for Liquid Sanitation 'Schéma Directeur National de l'Assainissement Liquide' in 1998 [45]. The National Rural Sanitation Programme Project 'Projet du programme national d'assanissementen milieu rural' [46] updated this regulation in 2013. Legal parameters for wastewater treatment have progressively been framed into the Law of Waters of 1995 [47] and the above National Plans [45,46]. The Potable Water National Office (PWNO) 'Office National de l'Eau Potable', which became the Water and Electricity National Office-Water Branch (PWNOW) or 'PWNO-Branche eau' in 2015, is the agency in charge of this process.

The Moroccan regulation establishing quality standards for wastewater reuse for irrigation agriculture was enacted in 2002 [48]. A significant impulse occurred in the 2010s, when the country advanced towards a marketable agriculture economy, and subsequent water quantity and quality problems arose. In 2006, new legislation was enacted to establish quantity and quality standards for wastewater spills, such as a decree regulating leakages, flows, spills, and direct or indirect discharge to surface water and/or groundwater bodies [49] and an order fixing specific limits for domestic discharge [50].

2.3. Wastewater Reuse Experiences

Official initiatives promoted by the PWNOW state that wastewater reuse is essential for coping with the growing Moroccan water deficit. In 2017, the PWNOW, through the National Sanitation Plan Dashboard, informed about 49 projects concerned with wastewater treatment plants, 13 completed (in operation), and 36 in progress (Figure 1d). Most of these projects used secondary treatments through lagooning (e.g., Ouarzazate city), aerated lagooning (e.g., Benslimane city), and infiltration (e.g., Bensergao and Drarga cities) techniques to jointly treat domestic, industrial, and municipal wastewater. The PWNOW is also studying how to implement separate treatment lines and additional distribution systems to irrigate the agricultural areas around medium-sized cities such as Al Hoceima, Imzouren, Bni Bouayach, Targuist, Guelmim, and Tiznit. According to Mahi [51], the predominant lagooning-based technology promoted by the PWNOW is useful for irrigation agriculture under the present Moroccan quality standards, even though only 8% of wastewater is treated following this regulation and a smaller fraction is reused for this purpose [14]. As a result, less than 1% of the irrigated surface uses untreated or inadequately treated wastewater and less than 0.1% uses treated wastewater [23,24,42]. Tertiary treated wastewater is rarely used for irrigation agriculture.

The scientific literature has covered both the positive and negative consequences of wastewater reuse. The positive consequence is the alleviation of the Moroccan water deficit even though the reuse rate is quite low. Regarding the negative consequence, Kadmiri et al. [32] have highlighted the impacts of pollutants—due to untreated or inadequately treated wastewater—on water, domestic animals (mammals), soil (salinization and microbiological reduction), and crops. Bihadasen et al. [26], Bourouache et al. [27], and El Moussaoui et al. [29–31] have studied the effects on soils perennially irrigated with inadequately treated wastewater. Tests conducted by Tahri et al. [52] at the Tétouan city pilot station have yielded acceptable quality levels for effluents under current Moroccan standards. Baroud et al. [53], Belarbi et al. [54], and Ouelhazi et al. [55] have reported similar findings in analogous case studies. Latrach et al. [56] have proven that a combination of multi-soil layering and sand filter techniques is sufficient to meet Moroccan quality standards but insufficient for the quality standards of some international markets to where most of the agricultural production is exported.

3. Basis for Comparing Regulations

When wastewater produced under permissive standards is reused for irrigation agriculture, quality problems affecting crops typically occur. Acceptable levels of pollutant agricultural products are ultimately determined by the destination market and, the higher the standards set by the destination market, the more likely it can be that the treatments currently applied in the country of origin will be rendered insufficient. Any rejection of Morocco's agricultural products by the destination markets would endanger its economy.

The regulations and experiences of Morocco's trading partners have continued to evolve since its own regulations were enacted. This is the case in the European Union (EU) countries, where the volume of treated wastewater produced increased noticeably after the European Wastewater Directive was enacted [57] and the new regulation for wastewater treatment and reuse for irrigation agriculture [58] expanded. The adopted technical solutions attending to the particular climate, orography, economy, and social habits of each EU country may guide technical development in Morocco to meet more restrictive standards.

For instance, southern Spain is a water-scarce territory with a similar orography and climate to northern Morocco [34,38], as can be deduced from the Köppen climate classification [39], thus enabling comparisons (Figure 2). Four populous urban areas in northern Morocco (M) and southern Spain (S) with equivalent climate and orography enable the identification of different technological and cultural contexts via legal standards as the main cause of divergence: Sidi Yahya del Gharb (M)—Seville (S) for low-elevation, hot-dry summer, Atlantic sub-humid; Fès (M)—Granada (S) for medium-elevation, hot-dry summer, continental wet semiarid; Nador (M)—Almería (S) for low-elevation, hot-dry summer, Mediterranean dry semiarid; and Tétouan (M)—Estepona (S) for low-elevation, hot-dry summer, Mediterranean wet semiarid. As deduced, climate and orography do not imply a differential for a given treatment and reuse technology whereas lower technological development and cultural perception of the environmental and human health risks determine the more permissive wastewater treatment and reuse regulations in Morocco.

The Moroccan regulations for wastewater reuse for irrigation agriculture [48] and their equivalents from developed and developing regions were compared in order to determine differences in quality standards. The developed regions included: (1) the EU [58], to which Morocco exports a large fraction of its agricultural production; (2) Spain [59], as a southern EU country with trade links to Morocco and a similar climate and orography; (3) California [60], Texas [61], and Florida [62] in the United States of America (USA), due to trade links to Morocco and a similar climate and orography; (4) Israel [63], due to its recent trade links and similar climate and orography; and (5) Japan [64], which does not have a similar climate. The developing regions included: (1) the World Health Organization (WHO) regulation [65] adopted by most of these countries; and (2) South Africa [66], as another emergent African country with a similar climate, orography, and export rate of agricultural goods to international markets.

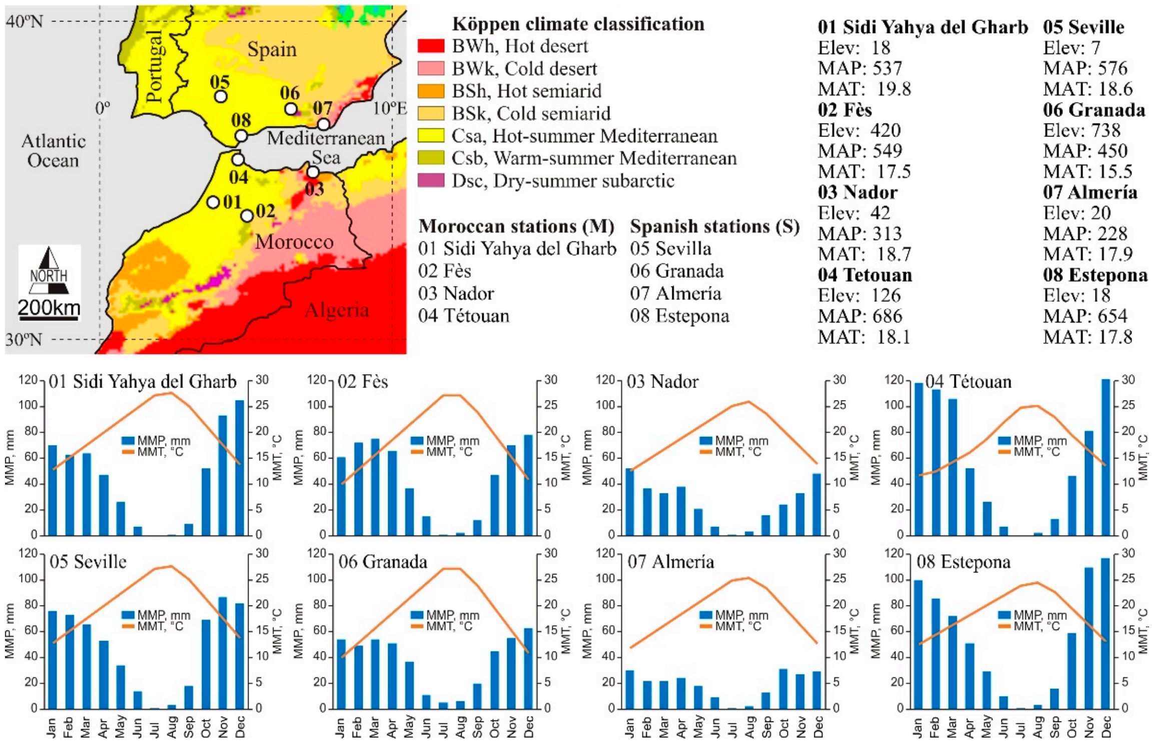

Figure 2. Four climatic and orographic equivalences between populous urban areas in northern Morocco (M) and southern Spain (S) for: low-elevation, hot-dry summer, Atlantic sub-humid in Sidi Yahya del Gharb (M) and Seville (S); medium-elevation, hot-dry summer, continental wet semiarid in Fès (M) and Granada (S); low-elevation, hot-dry summer, Mediterranean dry semiarid in Nador (M) and Almería (S); and low-elevation, hot-dry summer, Mediterranean wet semiarid in Tétouan (M) and Estepona (S). Mean monthly precipitation (MMP) in mm and mean monthly daily temperature (MMT) in °C after data compiled from the Climate-Data.Org website [https://es.climate-data.org/], accessed on January 2021. Urban areas 01 to 08 are placed over the Köppen climate classification map [39]. Elev = elevation, m above sea level (m a.s.l.); MAP = mean annual precipitation in mm; MAT = mean annual daily temperature in °C.

4. Results

4.1. Moroccan and EU Wastewater Treatment Regulations

The Moroccan [49,50] and EU [57] wastewater treatment regulations manifest significant differences in terms of the magnitude of some quality standards (Table 1). The Moroccan standards are higher (more permissive) than the EU ones for BOD5 (4.8-fold), chemical oxygen demand (COD) (2-fold), and SS (2.5–4.3-fold). These values are applicable at the stage of raising standards from a previously deficient state. The Moroccan regulation does not report values for total P and total N, thus limiting comparisons. It is important to remember that Moroccan quality standards can be met by using secondary treatment whereas tertiary treatment is required to meet the EU quality standards. This implies different costs. The financial feasibility of tertiary treatment facilities in a typical Moroccan plant is analyzed later.

Table 1. Some quality standards of the Moroccan and European Union (EU) wastewater treatment regulations.

Parameter	Morocco [1]	EU [2]
BDO_5 (mg/L O_2)	120	25
CDO (mg/L O_2)	250	125
SS (mg/L) > 10,000 eq-innh	150	35
SS (mg/L) < 10,000 eq-innh	150	60
Total P (mg/L) 10,000–100,000 eq-innh	nd	2
Total P (mg/L) > 100,000 eq-innh	nd	1
Total N (mg/L) 10,000–100,000 eq-innh	nd	15
Total N (mg/L) > 100,000 eq-innh	nd	10

[1] After the Moroccan regulation [49,50]. [2] After the EU regulation [57]. nd—-No data.

4.2. Moroccan, Spanish, and EU Regulations for Treated Wastewater Reuse for Irrigation Agriculture

The microbiological, metal, and chemical quality standards of the Moroccan [48], Spanish [59], and EU [58] regulations for treated wastewater reuse for irrigation agriculture are in Table 2. Note that the Spanish regulation continues to govern while transposing the EU regulation into Spanish legislation. In the three regulations, the standards for metals coincide, which is indicative of the serious health risks they pose. As regards the microbiological standards, the Moroccan regulation is (i) more permissive for faecal coliforms than the Spanish (10-fold higher) and EU (and 100-fold higher) regulations; (ii) less permissive for nematodes, whose removal requires better filtration of wastewater before reuse; and (iii) more permissive for SS than the Spanish (50–100-fold higher) and EU (50-fold higher) regulations for gravitational irrigation and 2.8–5-fold higher than the Spanish regulation for sprinkler and localized irrigation. Regarding microbiological parameters, the EU regulation considers Escherichia coli a more reliable fecal indicator than fecal coliforms. The Moroccan regulation could include this indicator. The Moroccan regulation enables more volume of wastewater reuse but of less quality, especially for chemical standards such as sodium, chlorine, and boron, the former two favoring water and soil degradation, the latter affecting crops.

Table 2. Some quality standards of the Moroccan, Spanish, and new EU regulations for treated wastewater reuse for irrigation agriculture.

Parameter	Morocco [1]	Spain [2]	EU [3]
Microbiological			
Intestinal nematodes. Use wq A [4]	0	1 egg/10 L	
Intestinal nematodes. Use wq B [5]	0	1 egg/10 L	
Intestinal nematodes. Use wq C [6]	Any object	1 egg/10 L	
Faecal coliforms (U/100 mL). Use wq A	<1000	100	10
Faecal coliforms (U/100 mL). Use wq B	nr	1000	100
Faecal coliforms (U/100 mL). Use wq C	Any object	10,000	1000
Salmonella	Absent in 5 L		
Cholerica Vibrion	Absent in 0.45 L		
Pathogenic parasites	Absent		
Eggs, parasites, cysts	Absent		
Anklylostomides larvae	Absent		
Schistosoma hoematobium fluococercaires	Absent		
Metal (mg/L)			
Mercury	0.001		
Cadmium	0.01	0.01	
Arsenic	0.1	0.1	
Chrome	0.1	0.1	
Lead	2		

Table 2. *Cont.*

Parameter	Morocco [1]	Spain [2]	EU [3]
Copper	0.2	0.2	
Zinc	2		
Selenium	0.02	0.02	
Fluorine	1		
Cyanides	1		
Phenols	3		
Aluminium	5		
Beryllium	0.1	0.1	
Cobalt	0.05	0.05	
Iron	5		
Lithium	2.5		
Manganese	0.2	0.2	
Molybdenum	0.01	0.01	
Nickel	0.2	0.2	
Vanadium	0.1	0.1	
Chemical			
Salinity (mg/L)	7680		
Electrical conductivity (mS/cm at 25 °C)	3–12	3	
Infiltration SAR 0–3 CE	<0.2		
Infiltration SAR 3–6 CE	<0.3		
Infiltration SAR 6–12 CE	<0.5		
Infiltration SAR 12–20 CE	<1.3		
Infiltration SAR 20–40 CE	3		
Sodium. SAR Surface irrigation	9	6	
Sodium (mg/L). Sprinkler irrigation	69	6	
Chlorine (mg/L). Surface irrigation	350		
Chlorine (mg/L). Sprinkler irrigation	105		
Boron (mg/L)	3	0.5	
Temperature (°C)	35		
pH	6.5–8.4		
BOD_5 (mg/L). wq A			10
BOD_5 (mg/L). wq < A			25
SS (mg/L). wq A			35
SS (mg/L). Gravitational irrigation.	2000	20–35	
SS (mg/L). Sprinkler and localized irrigation	100	20–35	
N–NO_3 (mg/L)	30		
Bicarbonate (mg/L). Sprinkler irrigation	518		
Sulphate (mg/L)	250		

[1] After the Moroccan regulation [48]. [2] After the Spanish regulation [59]. [3] After the new EU regulation [58]. [4] Water quality (wq) A—All food crops, including root crops consumed raw and food crops where the edible part is in direct contact with reclaimed water. [5] Water quality (wq) B—Food crops consumed raw where the edible part is produced above ground and is not in direct contact with reclaimed water, processed food crops, and non-food crops, including crops for feeding animals devoted to producing milk and meat. [6] Water quality (wq) C—like B, but dripping irrigation only. nr—No recommendation.

4.3. Moroccan and Other International Regulations for Treated Wastewater Reuse for Irrigation Agriculture

Table 3 shows some quality standards of Moroccan and other international regulations for treated wastewater reuse for irrigation agriculture. It is perceived that depending on the economic, political, and social development of the country, the regulations are evolving and, with it, the technological development in wastewater treatment, which is becoming increasingly demanding. Some of the Moroccan standards are higher than the WHO counterparts [65]. Secondary treatment is required to meet the WHO quality standards. The difference for intestinal nematodes is necessarily less permissive for wastewater reuse. Moreover, the WHO has published two additional guidelines [67] for (i) the safe use of sewage, excreta, and greywater; and (ii) sanitation safety planning, manual for safe use and wastewater disposal, greywater and excreta. This normative state at the use of excreta and greywater for agricultural irrigation is increasingly considered a method combining water and nutrient recycling. These guidelines implicitly set procedures to assess and manage human health risks.

Table 3. Some quality standards of the Moroccan and other selected countries' regulations for treated wastewater reuse for irrigation agriculture.

Parameter	Morocco [1]	Spain [2]	EU [3]	WHO [4]	California [5]	Texas [6]	Florida [7]	Israel [8]	South Africa [9]	Japan [10]
Microbiological										
Faecal coliforms (U/100 mL). Use wq A [11]	<1000	100	10	<1000	<2.2	<75		250	<1000	
Faecal coliforms (U/100 mL). Use wq B [12]	nr	1000	100	nr	<23	<800		250	-	<50
Faecal coliforms (U/100 mL). Use wq C [13]	na	10,000	1000	na		-	<200	-	<1000	<1000
Intestinal nematodes. Use wq A [11]	0			<1 egg/L						
Intestinal nematodes. Use wq B [12]	0			<1 egg/L						
Intestinal nematodes. Use wq C [13]	na			na						
BOD_5 (mg/L)	120	0	25			10–20	20	35–60	10–20	<10
SS (mg/L)	2000	20–35	35–60					20–50	10–20	

[1] After the Moroccan regulation [48]. [2] After the Spanish regulation [59]. [3] After the new EU regulation [58]. [4] After the WHO regulation [65]. [5] After the Californian regulation [60]. [6] After the Texan regulation [61]. [7] After the Floridian regulation [62]. [8] After the Israeli regulation [63]. [9] After the South African regulation [66]. [10] After the Japanese regulation [64]. [11] Water quality (wq) A as in Table 2. [12] Water quality (wq) B as in Table 2. [13] Water quality (wq) C as in Table 2. Nr—-No recommendation. Na—-No applicable.

Regarding their equivalents from California [60], Texas [61], and Florida [62] in the USA, the quality standards of the Moroccan regulation [48] are more permissive (Table 3), especially for faecal coliforms and BOD_5. These states use tertiary treatment to meet quality standards. The quality standards of the Moroccan regulation [48] are also more permissive than their equivalents from Israel [63], South Africa [66], and Japan [64] (Table 3). These three countries use tertiary treatment to meet quality standards.

As a graphical summary, Figure 3 shows the differences between the Moroccan and other regulations for treated wastewater reuse irrigation through (i) five basic quality standards used as evaluation criteria (total coliforms, water quality A; total coliforms, water quality B; total coliforms, water quality C; biochemical oxygen demand (BOD_5); and suspended solids (SS)); and (ii) an ordinal score rank from 1 to 4 (1 indicating that regulation does not include the criterion, 2 indicating that regulation includes the criterion with a relatively permissive threshold or without legal force, 3 indicating that regulation includes the criterion as average threshold, and 4 indicating that regulation includes the criterion with a very restrictive level). This qualitative analysis is similar to that implemented by Rodríguez-Luna et al. [68] to compare environmental regulations from different countries, by Baroud et al. [53] to compare equivalent wastewater quality standards, and by Cave et al. [69] for good practices in Environment Impact Assessment. Except for SS, the Moroccan quality standards are more permissive than their equivalents in the selected regulations.

4.4. *Financial Feasibility of Tertiary Treatment Facilities*

A typical Moroccan wastewater plant was selected to demonstrate the financial feasibility of installing a tertiary treatment line. Sidi Slimane is a medium-sized city of around 93,000 inhabitants [70] in northern Morocco (Figure 1d). The PWMOW has completed a secondary-based wastewater treatment plant through lagooning technology to comply with Moroccan regulations (Figure 4). Raw wastewater is pre-treated prior to its reaching the anaerobic/facultative lagoons, and it is then recirculated between lagoons based on operability and led to a recovering channel after the required days of treatment. Finally, the effluent is discharged to the Baht River and the sludge is removed from the drying beds. The cost of this facility is around 3.42 million USD (Figure 4a). In other areas, a similar secondary-treated wastewater effluent produced in analogous plants is directly reused for irrigation agriculture.

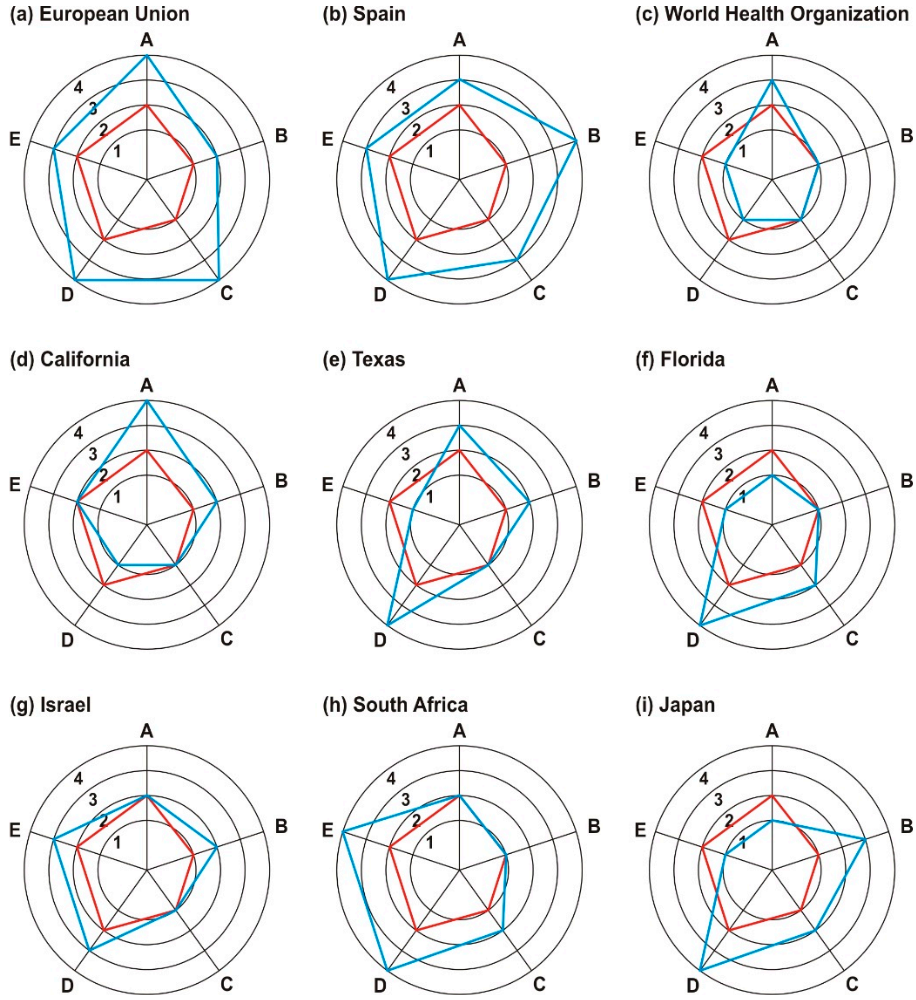

Figure 3. Comparison of the Moroccan (**a**) (red polygons) and other eight (**b**–**i**) international regulations (blue polygons) for treated wastewater reuse for irrigation agriculture. The comparison used five basic quality standards as evaluation criteria (A—total coliforms, water quality A; B—total coliforms, water quality B; C—total coliforms, water quality C; D—BOD_5; and E—SS) and an ordinal score ranking from 1 to 4 (1—regulation includes the criterion, 2—regulation includes the criterion with a relatively permissive threshold or without legal force, 3—regulation includes the criterion as average threshold, and 4—regulation includes the criterion with a very restrictive level).

About 50% of the secondary-treated wastewater effluent, i.e., 10,000 m^3 day^{-1}, could be further treated with tertiary technology (Figure 4b). The cost of this treatment unit is about 1.5 million USD for 12-h operating (833 m^3 h^{-1}), to which the cost of the additional 200–250 KWh electrical power must be added. The price of the tertiary treated wastewater would be 0.06 USD per m^3 due to electrical supply and 0.08 USD per m^3 more for chemical reagents and personnel expenses. The currently increasing energy prices could slightly modify these expenses.

As deduced, the additional expense for tertiary treatment lines is not prohibitive and can be assumed in those cases that pose a special risk to the environment and human health. Note that financial feasibility does not mean economic feasibility because the economic analysis must include the financial expense (investment and other fixed and variable costs) as well as benefits (most of them are short-term intangibles) for the environment, human health, and positive international image for business.

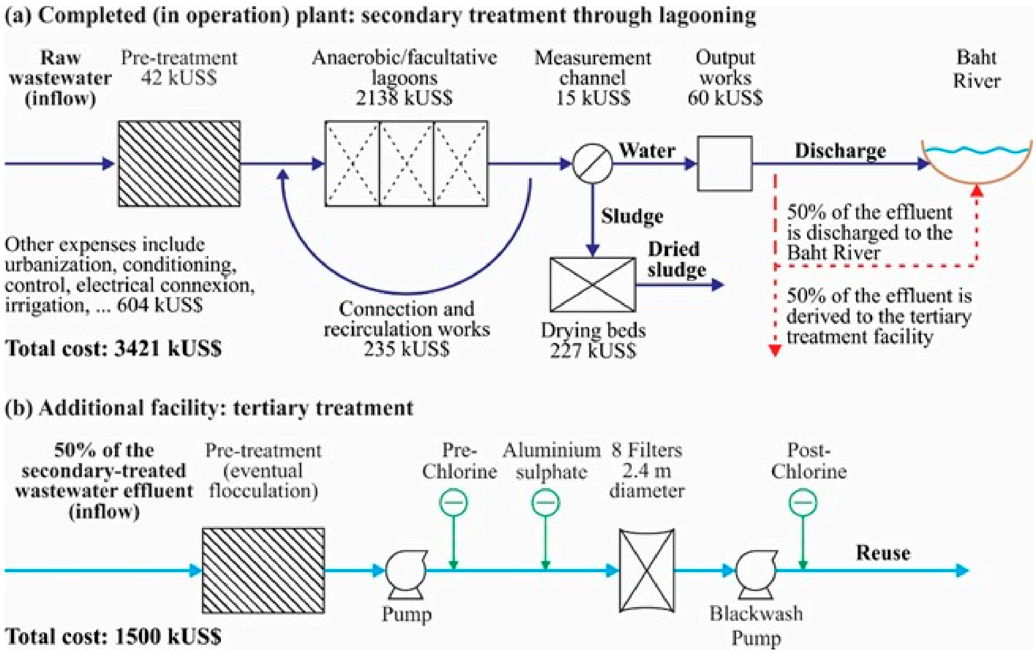

Figure 4. Basic operational scheme of the Sidi Slimane city wastewater treatment plant, showing (**a**) the completed (in operation) unit for secondary treatment through lagooning to meet standards of the Moroccan regulation and (**b**) an additional unit for tertiary treatment to meet the most restrictive standards of the international destination markets. Expenses are expressed in USD.

5. Discussion

5.1. Feasibility of New Treatment Technologies

International agencies have set treated wastewater reuse as a target in order to reduce stress on conventional water sources, tackle environmental problems, and reinforce the primary sector of the economy in developing countries [13]. Their relatively low technological development makes these countries dependent on the more restrictive regulations of the international destination markets. As described above, a more efficient wastewater treatment technology to meet international standards is not unaffordable, but the current immature, permissive regulations of these countries may limit its implementation. Optimal technical solutions should be framed into regulations based on a country's particular climatic, economic and cultural context, in parallel with proper political decision-making. As an emerging country, Morocco's financial feasibility is sufficient to implement more efficient treatment technologies. However, the Moroccan policies focused only on water scarcity and technical efficiency could exacerbate the dimensions of poverty or inequality [71].

Official information about completed (in operation) and in-progress treatment plants is key to discussing the feasibility of new wastewater treatment technologies in Morocco (Figure 5). To this end, the PWNOW database was accessed on January 2017 and 49 projects (13 completed and 36 in progress) in different cities (Figure 5a) were compiled. The basic interpretative criteria were (i) inhabitants as a proxy of the volume of managed wastewater (Figure 5b) and (ii) implemented treatment technology (Figure 5c).

Active sludge was preferably used in larger and medium-sized cities such as Casablanca (2.95 million inhabitants), Tangier (1.97 million), Rabat (0.32 million), Tétouan (0.32 million), and even Nador (0.16 million). Lagooning was predominant in small and medium-sized cities such as Meknès (0.63 million), Berrechid (0.14 million), Taourit (0.10 million), and Sidi Slimane (0.09 million) (Figure 5b,c). The preferable use of active sludge and lagooning was justified by the warm climate in most of the coastal and central cities, the variability in SS, the relatively lower cost, and the higher land availability for wetlands [51]. In medium-sized cities in mountainous areas with a cool winter climate, bacterial beds were mostly implemented. Tertiary treatment was operative in only six cities, but it will soon be adopted in larger cities such as Rabat and Marrakech, although the projected treatment volume remains very low. Meanwhile, most of the new plants that the PWNOW is projecting will continue to use secondary treatment through lagooning with forced aeration at most. In Rabat, the consequences of the inadequately treated wastewater spills reaching aquifers comprise a rising groundwater level and the deterioration of the foundations of some world cultural heritage monuments [72].

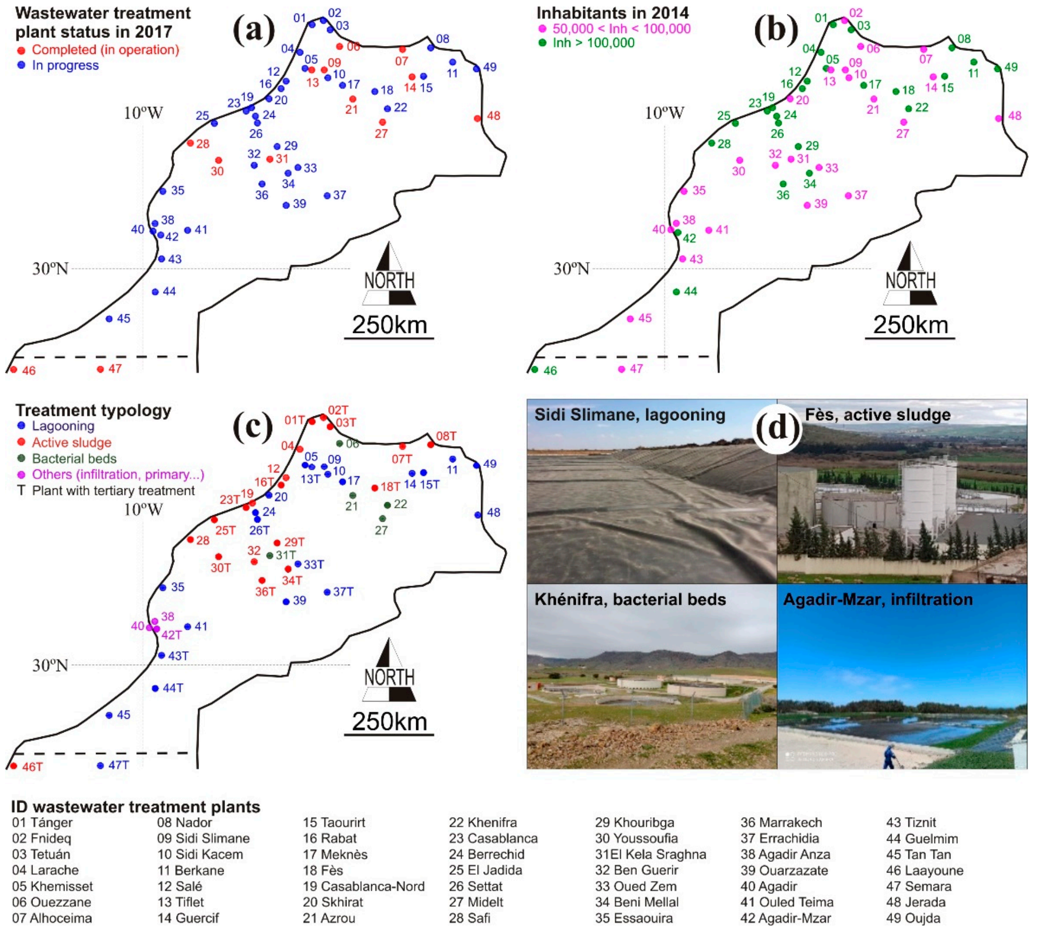

Figure 5. Urban wastewater treatment plants in Morocco after the PWNOW database (accessed on January 2017). (**a**) Completed (in operation) and in-progress treatment plants, as in Figure 1d. (**b**) Classification of treatment plants attending to inhabitants reported by the High Commission for Planning of Morocco [70]. (**c**) Classification of the treatment plants attending to the implemented treatment technology, identifying also those plants with operative tertiary treatment. (**d**) Photos showing the typology of some treatment plants.

Some developing countries with similar climatic and socio-economic contexts have reported similar issues and incomplete solutions [13,14,73–75]. Other emerging countries such as Jordan [9] and Tunisia [14] have proposed decentralization, choosing the optimal treatment technology (including lagoon/wetland and anaerobic digester) and using zero-discharge technologies as the keys to short-term success, while awaiting mature policies aimed at implementing systematic tertiary treatments.

5.2. Normative Trends in Moroccan Regulation

An updated Moroccan regulation should consider new protocols for wastewater treatment adapted to climate, orography, population density, and raw water used for urban supply, within new sustainable water policies to avoid collateral impacts. For instance, under the current efficient irrigation strategy typically used for irrigation agriculture, more water inevitably implies that bare lands and areas devoted to rainfed crops will transform into new irrigable surfaces aimed at marketable crops. Degradation of land and natural resources leading to increasing desertification is expected, as documented in other north African countries [76]. In the case of enacting a more restrictive regulation, which is also desirable for the durable international trading of agricultural goods, tertiary treatment of representative fractions of wastewater should be mandatory [14,56]. If the current, permissive regulation persists, secondary treatments or combinations of different techniques to meet the quality standards of the destination markets are already essential [9,14].

As shown in previous sections, climate, orography, and export rate of agricultural goods do not determine the quality standards policy. On the contrary, standards depend on the technological and cultural development of the country, as can be deduced from the similarly restrictive regulations in the EU, USA, Israel, and Japan (Figure 3). Therefore, it is crucial to know the standards assigned by the destination markets to different vegetables before designing official protocols to remove specific pollutants that affect production, even when wastewater means a fraction of the total irrigation water endowment. Protocols must clarify wastewater treatment's operational costs and reuse profitability in order to estimate the cost of the entire treatment and reuse system. The food production policy of Morocco (the producer) should involve long-term agreements with international markets (the consumers) for sustainable, durable trading.

The important trade link between Morocco and the EU requires special attention. The first Moroccan wastewater treatment regulation [45] was enacted when the first EU equivalent [57] was already known. Subsequent Moroccan regulations [49,50] have adopted neither the more restrictive standards of the EU nor analogous others. The fact that Morocco chose different standards is probably owing to the influence of technological and economic sectors that were willing to try basic treatment technologies. This means that regulations dictate the acceptable technological framework, and therefore the specific technical issues used in daily practices. Morocco is currently planning to increase the use of wastewater for irrigation agriculture, but the more restrictive EU regulation (Figure 3) may bring problems in the future. Below, some additional rationales for an updated regulation are discussed.

As shown in previous sections, the permissive Moroccan standards for sodium, chlorine, and boron may bring negative consequences for water, soil, and crops. As is the case in Spain and other southern EU countries, the hydrogeological features of Morocco may constrain the use of groundwater from some boron-rich geological formations for urban supply. Disinfection by-products to remove organic matter, desalination to reduce sodium and chlorine, post-treatment for boron removal, and alkalinity correction may be necessary actions before using wastewater for irrigation agriculture. The new regulatory framework should also consider these protocols under the currently increasing energy prices framework.

Another example showing the need for a new regulation arises from the combination of multi-soil layering and sand filter techniques tested by Latrach et al. [56]. This basic combination provided effluents containing 10 EXP 5.49 total coliforms/100 mL. This figure is valid under the Moroccan quality standards for irrigation water quality categories B and C of the EU regulation, i.e., food crops produced above ground without direct contact with reclaimed water. However, this same figure surpasses irrigation water quality category A of the EU regulation, i.e., food crops, including root crops, in direct contact with reclaimed water. This means that some vegetables, especially tubercles, may not pass the EU's quality controls.

Advanced oxidation can be an alternative treatment aimed at lowering the pollutant load of effluents, as proven in other regions with more restrictive legislations and similar climates to Morocco. Solarization and biosolarization are also of interest to mineralize organic matter and some pollutants in regions with insolation higher than 3000 h per year [77].

The new idea proposed by this article is to analyze the technologies installed for wastewater treatment in relation to the development of the regulations, analyzing both environmental and socio-economic characteristics.

The updated Moroccan regulation should be aimed at lowering environmental and human health risks. In terms of ensuring earnings based on the durable international trading of agricultural goods, the quality standards of the most restrictive international destination markets must be used as a guide. This is in the vein of WHO calls [78] on water treatment for better health, environments, economies, and societies.

6. Conclusions

In Morocco, climate change and degradation of land and natural resources—in particular, water resources—can hasten desertification. New methods of water resources management are needed to establish higher standards for non-conventional water sources that finally enter natural systems. In particular, treated wastewater reuse for irrigation agriculture would benefit from an updated regulation that promoted tertiary treatments aimed at reducing near-future agro-economic, environmental, and human health risks. The regulation should also promote larger, treated, wastewater reuse, since the current low rate depends more on the cultural context than technological or economic issues. The comparison of the Moroccan regulation to some equivalent international ones has revealed how quality standards mostly depend on each country's cultural and technological context. Developed countries highly aware of the environmental and human health risks use efficient technologies for wastewater treatment and reuse adapted to their particular climatic and orographic settings. This is not the case in Morocco, where secondary treatment through lagooning technology predominates in a cultural context of lower perception of the environmental and human health risks. This technology is well suited to the permissive Moroccan regulation but may limit the exportation of some agricultural goods to more restrictive international markets.

For suitable applications, two concomitant problems must be eliminated. In terms of the environmental and human health risks, more efficient treatment technology aimed at reducing the load of pollutants is needed. In terms of ensuring incomes based on the durable international trading of agricultural goods, the EU (the largest importer of Moroccan agricultural goods) quality standards may be used as a guide. So, systematic tertiary treatments via an updated regulation are needed. This paper demonstrates how tertiary treatments are financially feasible.

In Morocco, water scarcity and irrigation agriculture profit show a positive relationship that is nevertheless unsustainable in the long term. The development of intensive agriculture has progressively decreased the quality of the used natural water sources. More efficient wastewater treatments for reuse via updated regulations are required to prevent increased pollution. This regulation could be part of a first-order regulation to cope with water quantity and quality requirements as a national target.

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