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Review Article

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The effects of irrigation with treated wastewater on crops and human populations: A Review

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Abstract The use of treated urban wastewater as a resource for irrigation water is a practice widely employed in arid and semi-arid regions of the world but also one that is expected to become more diffuse due to the reduction of water resources and the climax in the competition for water. Researchers' interests are, thus, focused on investigating the effects of the method under question on the crops on which it is applied. This review presents the main research findings on the topic with a special reference to research carried out in Greece. The general conclusion of the present review is that the use of treated urban wastewater in irrigation can have beneficial effects on most crop yields, provided that quality characteristics of both treated wastewater and crops are sufficiently monitored.

Keywords Water reuse, Agriculture, Greece, Contaminants

1. Introduction

The Mediterranean Sea basin contains just 2% of the global water reserves, while the population in the area corresponds to about 7% of the world population. The aforementioned water reserves are distributed unevenly and are found concentrated primarily in northern countries. As a result, water scarcity is a limiting factor for a variety of activities and especially for crop cultivation, which is the basic consumer of fresh water resources worldwide [1-2]. Due to the uneven spatial distribution which characterizes the availability and the quantity of the water reserves, but also due to the intensive use that water resources are under, the reuse of treated water, over the last decades, has become an attractive proposal towards the reduction of the quantity of water that is abstracted from natural reserves. The use of treated wastewater in crop irrigation could cover part of the demand for fresh water, especially in Mediterranean countries and other arid and semi-arid regions that face an increasing water scarcity [3-5].

Both wastewater treatment and the use of treated wastewater in crop irrigation differ among Mediterranean countries. Northern countries process about 90 % of their wastewater but use only a small percentage of the treated wastewater for irrigation. Southern countries, on the other hand, which have lower water reserves, process a small percentage of their wastewater but tend to use a large percentage of fully but also minimally treated wastewater for crop irrigation [6].

Technological progress has enabled the treatment of wastewater to such a level, that most qualitative requirements are satisfied and the treated wastewater is suitable for various uses, such as the irrigation of crops and parks [3].

In technologically developed countries, on the other hand, like Israel, full-scale programs for the reuse of wastewater have created a framework for the reuse of 65% of wastewater for irrigation [7]. Water reuse is also used in other technologically advanced countries, such as the USA, France, Spain, Great Britain, Belgium and Cyprus [8]. In California, USA about 894 million tons of recycled water were used in 2009, a quantity that is estimated to rise to 1.540 million tons in 2015 and 1.880 million tons in 2020 [9]. The corresponding numbers for Beijing were about 680 million tons in 2010, a quantity that corresponds to 20% of the city's water needs. Furthermore, it was estimated that in 2015 the reuse of water in Beijing will exceed 1.000 million tons [10].

It is also important to point out that the use of treated wastewater can be successfully combined both with conventional treatment methods and with natural-system treatment methods, such as with the method of constructed wetlands [11].

This review aims to present and synthesize the findings of studies and publications on the effects that the use of treated urban wastewater in crop irrigation and other areas has on the qualitative characteristics of crops, on soil properties, on the environment and on the human population. It is one of only a few papers of this kind on this particular subject and one of very few which focus on case studies in Greece.

The scope of the present paper is, precisely, the investigation of the impact of the use of treated wastewater on crops and human population, since it constitutes a method that is widely diffuse in many parts of the world and which can contribute in the rational use of water resources in regions where they are limited.

After the present introduction, this paper presents the conditions necessary for the use of treated urban wastewater on crops, its advantages, its potential negative aspects, its implementation in Greece and ends with conclusions and proposals for further research on the subject.

2. Conditions for the use of treated urban wastewater on agriculture

There are official documents in various countries around the world which specify the qualitative characteristics that treated wastewater destined for irrigation should have.

In Greece, Ministerial Decision 145116/2011 (Government Gazette 354/B/03.08.2011)[12] specifies the required qualitative characteristics of treated wastewater that is destined for irrigation, the crops on which it can be applied and the type of irrigation that is allowed to be used. On the same document, a distinction is made between two types of irrigation, on the basis of the kind of crops irrigated, the irrigation system and the accessibility of the irrigated area to the public. The two types of irrigation distinguished are: a) limited irrigation, concerning exclusively crops whose products are destined either for industrial use, post-processing consumption, or that are not destined for human consumption at all, and b) unlimited irrigation, concerning crops whose products are destined for raw consumption and floricultural crops.

Water's suitability or unsuitability for application to each crop can be determined from the determination of a series of chemical and microbiological parameters, always taking into account the requirements and the resistance of the crop under question to specific environmental factors. Indicatively, some of the parameters required to assess the suitability of a water sample for irrigation are: its electrical conductivity (EC), the total dissolved solids (TDS), valuable anions and cations such as calcium (Ca^{2+}), magnesium (Mg^{2+}), sodium (Na^{+}), the pH, the sodium absorption ratio (SAR) and the concentration of heavy metals.

3. Advantages of using treated urban wastewater in crop irrigation

The use of treated urban wastewater for the irrigation of agricultural crops, green areas and recreation spaces presents several advantages such as water saving, the protection of the environment and economic benefits.

Firstly, the reuse of treated wastewater, particularly in agricultural applications is a practical solution to the problem of limited water resources [13-15].

Additionally, reuse of treated wastewater protects aquatic ecosystems, as the channeling of untreated sewage waters in aquatic ecosystems would cause eutrophication and algae growth [14].

As far as the cost of urban wastewater treatment is concerned, that depends on the processing method applied. However, in any case, urban wastewater treatment is economically more advantageous than other treatment methods employed for the production of water, like desalting, for instance [16].

The use of treated wastewater for agricultural crop irrigation has also been found to be advantageous for soil structure and fertility. According to Kiziloglu et al. (2007)[17] , treated wastewater has a high nutrient content, condition that can act beneficially for plant growth, reduce the need for the use of fertilizers and increase crop yield on poor soils. Various studies show that irrigation with treated urban wastewater increases the soil's concentration in elements associated with plant growth, such as nitrogen (N), phosphorus (P), iron (Fe), manganese (Mn), potassium (K), calcium (Ca), magnesium (Mg), zinc (Zn), boron (B), molybdenum (Mo) and other elements [6, 13, 17-25].

Cirelli et al. (2012) [26] report a yield increase of about 20% in tomato cultivations irrigated with treated urban wastewater, while Akponikpè et al. (2011) [18] report higher yield in eggplant cultivations on an average of 40%. Rusan et al. (2007) [27] report significantly higher biomass production after irrigating fodder plant crops with treated urban wastewater, while Zema et al. (2012) [28] report increased biomass production in the cultivation of energy plants.

The total nitrogen content in the outflow of secondary wastewater treatment is usually 10 to 20 mg L-1 [4, 18, 21], while the ratio of ammonium ions, nitrates and organic nitrogen depends on the degree of treatment. Nitrogen compounds are usually not removed during the treatment of wastewater, so the treated effluent supplies plants with a significant amount of nutrients and reduces requirements in fertilizer. Furthermore, most of the nitrogen and phosphorus quantity is found in forms easily assimilable by plants. Yi et al. (2011) reported that in 2010 30 million tons of treated wastewater were used for crop irrigation in Beijing, resulting in saving 4000 tons of nitrogen, 500 tons of phosphorus and in decreasing fertilizer needs by a percentage of 10-50% [29-30].

In case, however, that the treated wastewater is intended for other uses, such as industrial cooling, an additional treatment stage should intervene for the removal of nutrients that can lead to microbial growth and damage to equipment [16].

Irrigation with treated urban wastewater appears to increase the organic soil matter [13, 17, 22, 31]. In addition, it provides the soil with useful microorganisms [13, 18].

Irrigation with recycled water can contribute to the sustainability of the soil, especially in cases of poor urban lands [32]. The use of recycled water in California and Beijing improved the biological activity of the irrigated soils. On account of the nutrients present in the treated wastewater used for irrigation, enzymatic activity of soils improves, including the recycling of nutrients and of the microbial biomass of the soil [21, 33-34].

Comparing areas irrigated with treated and fresh water, soil microbial biomass increased by 60.14 % and 14.21 % in urban green areas and farming fields, respectively. Furthermore, an enhancement in the activity of five soil enzymes (urease, alkaline phosphatase, invertase, dehydrogenase and catalase) was observed in the surface soil layer (0-20 cm) in percentages of 36.73% and 7.40% higher, in urban green areas and fields respectively [34]. Similar experiments in five different areas of Southern California, irrigated with treated urban wastewater for a long period, showed a doubling or tripling of the activity of 17 soil enzymes associated with the cycles of carbon, nitrogen, phosphorus and sulfur [33].

Regarding the use of recycled water for the irrigation of green areas, it is reported that through it there are economic advantages as well as an enrichment of the soil with high quantities of nitrogen, phosphorus and several trace elements [30, 35].

It becomes obvious, then, that the use of treated wastewater in agriculture is a practice with a high number of advantages, which, with the adherence to certain rules, guidelines and quality standards can assist in the establishment of safe and sustainable food cultivations [13].

4. Negative effects of using treated urban wastewater on crops

The use of treated wastewater for crop irrigation contains potentially negative effects on the environment and on public health.

One such risk to human health is the increase of the resistance of soil bacteria to antibiotics. Gatica and Cytryn, after reviewing numerous relevant studies, concluded that the use of treated wastewater for crop irrigation does not seem to have an effect on soil microflora, but further research should be carried out in order to investigate the horizontal gene transfer from antibiotic-resistant bacteria found in treated effluent to soil bacteria, so that a definitive conclusion on the topic can be made [32].

In regard to the environmental impacts, the degradation of soil quality, due to the increase in salinity and soil acidification (reduction of soil pH) [6, 17, 36] as well as the increase of soil hydrophobicity are reported [37, 38].

The use of treated wastewater on crops also contains some risks to public health, on account of the presence of pathogenic microorganisms, heavy metals and other potentially harmful substances in it. For example, the presence of viruses, protozoa and pathogenic bacteria could cause gastroenteritis, dysentery or typhoid fever, respectively [39].

An analysis of the main risk factors is made next:

Salts: The salinity level in treated urban wastewater is usually 1.5 to 2 times higher in comparison to drinking water. Furthermore, higher counts on the rates of sodium ions (Na^+), chloride (Cl^-) and bicarbonate (HCO_3^-) have been observed, condition which may pose danger to plants and the soil [16]. The irrigation of particular crops, such as maize, rice and industrial tomato, with high salinity water may, also, result in a yield reduction, that can approach 25% for corn [40].

Many studies demonstrate the effect of increased salinity on soil quality and on the development of cultivated plants. Generally, irrigation with recycled water can lead to intolerable salinity levels for most green-area and crop plants, especially in heavy soils [41].

Additionally, irrigation with treated urban wastewater can lead to serious problems in soil infiltration, due to the high sodium concentrations in comparison to the calcium and magnesium ion concentrations, which result in an increase of the Sodium Adsorption Relation (SAR) parameter [42]. It is reported, for example, that golf courses in the USA that were irrigated with recycled water showed higher electric conductivity values of the saturation extract (ECe) of about 187% and higher SAR values of about 481% [23].

The deposition of salts in the soil is influenced by many factors, such as the quality of the reused water, the irrigation method, the soil's properties and the plant's characteristics [23, 41]. Therefore, the risk of soil salinization varies depending on the characteristics of the reused water. Moreover, in some sensitive species, the contact of the foliage with chlorine and sodium ions may have toxic effects if the spray irrigation method is used.

Heavy metals: Heavy metals such as the arsenic (As), cadmium (Cd), copper (Cu), chromium (Cr), nickel (Ni), lead (Pb) and zinc (Zn) can be found in urban waste, but they can be removed to a large extent during sewage treatment. As a result, the concentrations of these elements in treated wastewater are insignificant and similar to those of fresh water [16].

Several studies have proved, however, the accumulation of heavy metals, like cadmium, nickel, chromium and lead in the soil and plants, when they are irrigated with treated urban wastewater [43-44]. According to Gupta et al. (2010), the presence of cadmium and chromium should raise even greater concern, as they accumulate in plant tissues, thus exposing consumers to risk. Kalavrouziotis and Drakatos studied the ability of some Mediterranean forest species to accumulate heavy metals from treated urban wastewater in their tissues and concluded that the tolerance of forest species in heavy metals from treated wastewater varies depending on the type of plant and this variable should, also, be taken into consideration during irrigation with treated wastewater so that toxicity is avoided [43, 45].

Nutrients: The presence of high amounts of specific nutrients can cause a nutrient imbalance (such as the lack of phosphorus or potassium, for example) and a contamination of the groundwater with nitrates [13]. For example, the presence of high amounts of nitrogen in reused irrigation water renders it unsuitable for rice irrigation. In addition, excessive amounts of nitrogen result in extended vegetative growth at the expense of fruit yield maturation [46].

Contaminants: Many organic contaminants have been detected in soils irrigated with treated urban wastewater, such as polycyclic aromatic hydrocarbons, polychlorinated biphenyls and organochlorinated insecticides [47]. In addition, a cause for concern has also been the presence of pollutants, such as chemical substances that affect the endocrine system, pharmaceuticals and personal care products (PPCPs) which originate from drugs, veterinary drugs, fragrances and cosmetics. Many researchers believe that the presence of these substances will have an impact on soil and on human health [47]. Additionally, there is the risk of the potential impact of the aforementioned substances on ecosystems, with the increase of the environment's resistance to antibiotics being the most important risk of all [32].

Pathogens: Several studies have reported large populations of Total Coliforms (TC) and coliforms of intestinal origin in crop cultures that have been irrigated with treated urban wastewater [18, 25, 26] while other researchers have, also, detected pathogens of the genera *Salmonella, Streptococci, Clostridium, Shigell,* and *Vibrio spp.* [22]. Moreover, the presence of viruses, protozoa and helminthes, all of which are pathogenic for humans, has also been reported [48-53]. Mavridou et al., (2015) [39] reviewed the hazards of wastewater used for crop irrigation, based on bacterial indices, viruses and protozoa, and concluded that the hazard of wastewater is a function of its initial load, while its reduction extent varies depending on the treatment they undergo and on the number and type of the initial microbial load. Disinfection of wastewater by chlorination, ozonation or ultraviolet radiation has proved to have satisfactory results against microbial agents [48].

The evidence so far indicates that the spread of diseases due to irrigation with treated urban wastewater is rare, but has not been eliminated yet. In fact, it has been found to depend on various factors, beyond the microbiological quality of the treated wastewater, such as the type of plant in question, the irrigation method and the harvesting practices applied as well as a series of environmental factors (such as moisture and temperature) [16].

5. The use of treated urban wastewater for irrigation of crops in Greece

Greece is characterized by areas with a high water demand and limited water availability. Crop irrigation accounts for 86% of the total water demand and is followed by 11% for urban use, 2% for energy use and 1% for industrial use. Irrigation is predominant in the region of Thessaly, which presents a lack of water resources and in eastern Central Greece, while urban water use is predominant in Attica [8]. Reused water could significantly contribute to the irrigation of Thessaly and other regions of the country, it could cover the industrial needs in Western Macedonia as well as the firefighting needs throughout the country in summer months. Furthermore, studies on the qualitative characteristics of treated urban wastewater conducted in the country have showed that its use to cover part of the irrigation needs is, indeed, possible [40, 49-50].

Panoras et al., (2006b) [40] estimated the organic and inorganic load of the treated water effluent produced in the metropolitan area of Thessaloniki in order to investigate its use for crop irrigation in the Chalastra–Kalohori area, where crop cultures primarily include rice, and secondarily corn, cotton, sugar beet, alfalfa and industrial tomato, and concluded that the parameters determined render it appropriate for irrigation purposes. However, the high electrical conductivity value that was measured, which is directly related to the total concentration of salts in the water, urges for a rational use of the effluent as an irrigation resource [51].

Tsangarakis et al. (2004) [50] in a research on pilot wastewater treatment units in Crete observed that the treated effluent contained low concentrations of heavy metals, a characteristic they attributed to the absence of industrial units and the small population in the installation areas, and, also, relatively low electrical conductivity and total dissolved solids values.

Other Greek researchers have examined the effects of irrigation with treated urban wastewater on the characteristics of the growth of Mediterranean forest species and other crops [40, 52].

Successful small-scale water-reuse programs in Greece have been implemented in the past in Thessaloniki, Halkida, Crete and other areas [8]. For example, in the Chalastra – Kalohori region, 160,000 cubic meters of wastewater were channeled from the Wastewater Treatment Plant (WWTP) of Thessaloniki to a 12,000-acre cultivation area, following the appropriate treatment.

National legislation defined the conditions for the disposal of treated wastewater for irrigation from the WWTP of Thessaloniki with J.M.D. 141937 (2005), whereas the qualitative characteristics of wastewater destined for irrigation, the crops which may be used and the type of irrigation that may be applied are defined by Ministerial Decision 145116/2011 (Government Gazette 354/B/03.08.2011) [12].

7. Conclusion

This review attempted to synthesize the research findings of studies and research papers relative to the effects (positive and negative) of crop irrigation with treated urban wastewater.

The majority of the studies included in the present review show that irrigation with treated urban wastewater can have particularly beneficial effects on crops and especially on the increase of production (mainly through the increase in product yield).

However, specific limit values must be designated for the quality parameters of both wastewater and cultivated species – mainly in countries where there are no similar regulations- and actions should be taken so that the regular monitoring of the applied wastewater is ensured, something that will help to avoid the accumulation of pathogens and other substances in the soil and in crops.

It would be important for researchers to further investigate the maximum limits of the concentration values of heavy metals and other toxic substances that can be accumulated in soils and crops, so that the irrigation with treated urban wastewater can be planned in the long term for each crop and soil type.

In any cases, the effects of irrigation water produced through urban wastewater treatment are closely related to its qualitative characteristics prior to the application on a crop, or, in other words, the treatment it was subjected to previously. In addition, wastewater treatment does not always ensure the successful removal of all biological and chemical contaminants, which results in the transfer of organic matter and active substances in the soil environment (plants and soil), thus affecting, in various ways, both the soil's qualities and the ecosystem.

Therefore, it is important that wastewater be treated in equipped wastewater treatment plants, especially as far as non-technologically advanced countries are concerned, in order to reduce the harmful effects that irrigation with untreated urban wastewater can cause.

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