Essay

Potential use of wastewater in agriculture

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Abstract

The contamination of water, air, soil and food is a collateral consequence of the activities that man has developed to live and improve his quality of life. The development of the human being, its continuous growth since the time of the industrial revolution has left damage and degradation in natural resources. In its demographic, scientific and technological growth, human beings have not made sufficient efforts to sustainably preserve natural resources. Among these resources, water is one of the most essential and vital for all forms of life, but every day the resource is scarcer in a healthy way. Due to multiple factors associated with population growth, urbanization and industrialization, all equally direct and indirect causes of climate change. Treating and using wastewater is challenging because that is often the only option farmers have. Thus, these waters represent a valuable resource, both from an economic and environmental point of view (conservation of water resources, recycling of nutrients). Currently, about 80% of wastewater is disposed of without treatment and is used for agricultural irrigation, representing a significant sanitary problem (due to the presence of pathogenic and toxic elements).

Keywords: risks, treatments, use in agriculture, wastewater.

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The use of wastewater in agriculture should involve more 'treated' wastewater. However, there are still many regions of the world and even Mexico that use wastewater without any type of treatment. This can have negative consequences on degradation and contamination in the medium and long term of the soils where it is used (Petousi *et al*., 2019). Unfortunately, for many farmers in marginalized areas, the only water resource available to them (Woldetsadik *et al*., 2018). Unfortunately, it is also true that there are very few countries in the world where there are reliable and updated records of the volumes and surfaces irrigated with wastewater. That makes it difficult to make improvements in the potential use of this type of water.

Meeting the general needs of human beings is becoming more and more complex due to the lack of balance in our ecosystem. At present, humanity in a global way is going through a series of crises that are aggravated by the excessive increase in the human population since the time of the Industrial Revolution (Fang and Jawitz, 2019). The number of inhabitants of the world and the need to satisfy every one of their requirements makes it increasingly difficult to use natural resources in a healthy and sustainable way. The current crises are medical, industrial, economic and largely related to climate change (Ossebaard and Lachman, 2020). These crises occupy dimensions where causes and effects are intertwined. However, this document focuses on reflecting on the water resource.

The main use of water worldwide is in agriculture (Boretti and Rosa, 2019). High-quality water is increasingly scarce (Vasilyev and Domashenko, 2018). Therefore, water resources must be used sustainably and one of the proposals to achieve this has been wastewater (Jaramillo and Restrepo, 2017). The availability of water resources and the way they are used are essential to improve food security around the world, considering it the most precious resource and the most disputed (Larsen *et al*., 2016). Globally, freshwater reserves have been estimated to be approximately 35 000 000 km^3 (Gleick and Palaniappan, 2010). UNESCO (2016) mentions that exclusively from groundwater resources it is possible to satisfy the basic daily water needs of 2.5 billion people and represents 43% of all water used for irrigation.

Water use has been increasing around the world by about 1% per year since the 1980s (Junguo *et al*., 2016). The steady increase has been mainly due to increasing demand in developing countries and emerging economies (although per capita water use in most of these countries remains below water use in developed countries, simply are reaching).

This growth is driven by a combination of population growth, socioeconomic development, and evolving consumption patterns (Sun *et al*., 2016). 80 million people a year implies a demand for fresh water of approximately 64 billion cubic meters per year. Most of the population growth will occur in developing countries, mainly in regions with water stress and in areas with limited access to safe drinking water and adequate sanitation services (Huang *et al*., 2016) (Table 1).

Table 1. Distribution of water, population and the main river basins in the adapted world UNESCO (2016).

Continent	Distribution		River basins
North America	15%	River basins	Yukon
			Mackenzie
			Nelson
	8%	Human consumption	Misisipi
			St. Lawrence
South America	26%	River basins	Amazon
	6%	Human consumption	Silver
Africa	11%	River basins	Niger
			Chad Lake
			Congo
	13%	Human consumption	Nile
			Zambesi
			Orange
Europe	8%	River basins	Volga
	13%	Human consumption	Danube
Asia	36%	River basins	Ob
			Yenisei
			Lena
			Kolyma
			Amur
	60%	Human consumption	Ganges and Brahmaputra
			Yangze
			Huan He
			Indus
			Eufrates and Tigris
Oceania	5%	River basins	Murray Darling
	<1%	Human consumption	

Globally, the rate of groundwater depletion has doubled and by 2050, global water demand is estimated to continue to increase 20-30% above the current level. Therefore, 40% of the world's population will live under severe water stress (Burek *et al*., 2016; Kölbel *et al*., 2018), including nearly the entire population of the Middle East and South Asia and significant parts of North Africa and China. Levels of water scarcity will continue to increase as water demand grows and the effects of climate change intensify (Khalid *et al*., 2018).

Currently, 20% of the world's aquifers are being overexploited and their decrease in availability and quality is evident (Carrard *et al*., 2019), an example of this is the Yellow River basin in China (Yin *et al*., 2017) and the Pacific northwest of the United States of America (Jager *et al*., 2019). Such decreases affect the availability of water for the extraction of water from farmers, industry and domestic supplies, as well as for current uses, such as power generation, navigation, fishing, recreational and last but not least. importantly, the environment (Jago-on *et al*., 2017).

Importantly, the overexploitation of freshwater resources has largely resulted from the growth in agricultural demand (including irrigation, livestock and aquaculture). Agriculture is the largest consumer of water, since it represents 70% of the annual water withdrawals worldwide, mainly for the production of food, fibers and for the processing of agricultural products (Weinzettel and Pfister, 2019). On the other hand, industry (including power generation) accounts for 19% and households 12% (Bijl *et al*., 2016). Therefore, the share of agriculture in total water use is likely to decrease in comparison with other industries, but it will remain the largest user overall for decades to come.

With the rise of intensive agriculture and emphasizing that it is one of the largest users of water globally, it is essential to find sustainable solutions. Therefore, the growth of global hydrological monitoring and data collection activities remains a major challenge. In addition to strengthening global monitoring networks. This may require exploring the potential of new technologies (Tauro *et al*., 2018).

In this regard, the reuse of treated wastewater in agriculture is an option that is increasingly being studied and adopted in regions with water scarcity (Jaramillo and Restrepo, 2017). Hanseok *et al*. (2016). suggest that more than 10% of the world's population consumes agricultural products grown by irrigation with wastewater.

Wastewater can be a source of raw materials such as nutrients or certain metals (ie. industrial wastewater). In addition, they contribute to reducing the energy required in the extraction of these raw materials for use as fertilizers (Wang *et al*., 2018). The combination of increasing demand for water, especially in agriculture, and declining availability of clean water is driving increasing use of unconventional water sources, such as urban effluents.

The use of these effluents in agriculture can be planned, with treated water and with safe irrigation habits. This should be done with care and knowledge, as it can be a dangerous practice for farmers and consumers when used untreated in a direct (undiluted) or indirect way (diluted wastewater) (Mateo-Sagasta *et al*., 2015).

Production, treatment and reuse of wastewater

Every year 380 billion m^3 (380 trillion liters) of wastewater is produced worldwide, estimates suggest that global wastewater production is expected to reach 470 billion m^3 by the end of 2030, which represents a 24% increase over current wastewater production and in 2050 it will reach 574 billion m^3, 51% more than the current level (Qadir *et al*., 2020)

Today more than 3 300 water reclamation facilities have been created worldwide, in Japan (about 1 800) and the United States of America (about 800). Australia and the European Union have 450 and 230 projects respectively. The Mediterranean area and the Middle East have around 100 plants, Latin America 50 and Sub-Saharan Africa 20, with varying degrees of treatment and for various applications. Among such applications are agricultural irrigation, urban design, recreational uses, industrial processing and refrigeration, indirect production of drinking water, and as groundwater recharge (Table 2) (Intriago *et al*., 2018).

Table 2. Municipal water reuse systems, by field of application.

Use categories	Applications
Urban	Irrigation of public parks, sports facilities, private gardens, roadsides; street cleaning; fire protection systems; vehicle washing; toilet flush; air conditioners; dust control.
Agricultural	Non-commercially processed food crops; commercially processed food crops; pasture for milking animals; forage; use fiber; seed crops; ornamental flowers; orchards; hydroponic cultivation; aquaculture; greenhouses; viticulture.
Industrial	Water processing; cooling water; recirculating cooling towers; wash water; washing aggregate; manufacture of concrete; soil compaction dust control.
Recreational	Irrigation of golf courses; recreational reservoirs with or without public access (eg, fishing, boating, bathing); aesthetic reservoirs without public access; make snow.
Environmental	Aquifer recharge; wetlands; marshes; current surge; wildlife habitat; forestry.
Potable	Recharge of aquifers for the use of drinking water; increased supplies of surface drinking water; treatment up to the quality of drinking water.

A diverse range of economic, institutional, ecological, technological and sociological factors drive water reuse in developed and developing countries (Nadja *et al*., 2016). Despite this, there are common problems such as increasing population and demand for food, water shortages and concerns about environmental pollution. All of these factors make reclaimed water a potentially valuable resource.

A clear example is China, a country facing increasing pressure on its freshwater supply. It is among the 13 countries with the lowest water availability in the world and China's per capita water availability is about a quarter of the world average (Lyu *et al*., 2016; Wang *et al*., 2017). Most of the available water is concentrated in the south, leaving northern and western China to experience perpetual droughts. With population growth, accelerated industrialization and urbanization and global climate change, the water crisis in China is worsening and this shortage has become a major obstacle restricting China's economic development (Zhang *et al*., 2020).

The development of wastewater use in China began using municipal wastewater to irrigate agricultural land in the 1940s, considering it the emerging stage where the water quality was poor and this period lasts until 1985 (Zhang *et al*., 2020). However, China currently has ambitious plans to promote wastewater reuse and make reclaimed water a key element of national water resource management scheme (Lyu *et al*., 2016). As the world's largest developing country, sewage is massively discharged each year in order to meet the needs of life and economic development in China. For example, in 2015 73.530 billion tons of wastewater was treated (Zhang and Ma *et al*., 2020).

In Europe, most of the reuse systems are in the coastal and island areas of the semi-arid Mediterranean regions and in highly urbanized areas (Parisi *et al*., 2018). Water scarcity is a common problem in the Mediterranean region with varied rainfall, sometimes below 400 hm per year in southern parts of Spain, Italy, Greece, Malta and Israel. Sometimes, water resources can reach a level of chronic water scarcity of 1 000 m^3 per inhabitant per year.

The great distances between water resources and users also produce serious water deficits at regional and local level and water shortages can be worsened by the arrival of tourists in high season in summer to the Mediterranean coasts, as well as population growth, drought and possible effects related to climate change (Burak and Margat, 2016).

The European Union included reclaimed water as part of the circular economy, considering it an alternative water resource to combat drought and water scarcity. However, the cornerstone in the implementation of reclaimed water for irrigation is the development of the ‘EU-2020/741 regulation, minimum requirements for the reuse of wastewater’ (Mesa and Berbel, 2020).

Although reclaimed water is a relatively small part of the total water supply, in some countries it plays an important role, especially for agriculture. For example, in Kuwait, where reused water represents up to 35% of total water extraction (Saeed *et al*., 2017). The United Nations has estimated that in agriculture at least 20 million hectares of arable land in 50 countries are irrigated with raw or partially treated wastewater, diluted or not, which represents around 10% of total irrigated land (Thebo *et al*., 2017).

In Latin America and the Caribbean, agriculture is the largest user of water (Miralles and Muñoz, 2018). According to Mahlknecht *et al*. (2020). It is estimated that, at the regional level, 73% of water extraction is attributed to agriculture, of the total irrigated area in Latin America and the Caribbean, it is estimated that approximately 10% is within urban spaces, more than 30 % within a 10 km perimeter around cities and almost 50% within a 20 km radius.

Furthermore, irrigated productions near cities are more intensive, with more crop rotation per year. Although municipal wastewater production is not always monitored and published on a regular basis (Hernandez *et al*., 2017). It is estimated that at least 30 km^3 are generated each year. This is a conservative figure since some data is not up-to-date and information is lacking for some countries with a relevant population size such as Honduras or Haiti. As expected from the size of their populations, only Brazil and Mexico together already produce more than half of the wastewater generated in all of Latin America and the Caribbean (Machado *et al*., 2016).

Potential for the use of wastewater in agriculture

The global demand for agricultural water is continually increasing as a result of population growth and human prosperity. Competition for high-quality water resources is particularly fierce in arid and semi-arid regions with water scarcity, where irrigation is essential for the expansion and success of agriculture. The need to treat and eliminate greater amounts of wastewater, the greater demand for irrigation water, on the other hand, indicates the importance of an efficient and sustainable use of the recovered water waste (Grant *et al*., 2012).

In general, wastewater contains substantial amounts of beneficial nutrients such as N, P, and K that can promote plant growth and performance and reduce the demand for chemical fertilizers (Jung *et al*., 2014). In addition to containing important micronutrients such as Fe and Zn (Pereira *et al*., 2012). Therefore, the careful use of wastewater can reduce the application of fertilizers and therefore environmental and economic costs, in addition to reducing the content of toxic elements such as heavy metals, which cause problems for agricultural production (Raveh and Ben-Gal, 2016; Turlej and Banas, 2018).

The content of these metals in irrigation water can lead to degradation of the physical and chemical properties of the soil (Assouline *et al*., 2015). The excessive accumulation of heavy metals in agricultural soils through wastewater irrigation can not only result in soil contamination, it also leads to high absorption of heavy metals in crops, and therefore affects the quality and safety of food (Muchuweti *et al*., 2006).

On the other hand, the use of wastewater, depending on the level of its treatment, can carry pathogens (viruses, bacteria and protozoa) and present a health risk when applied incorrectly in agriculture (Chahal *et al*., 2016). Okereke *et al.* (2016) evaluated the quality of effluents from an urban wastewater treatment facility in West Africa and found its possible negative impact on public health due to a series of water quality parameters, such as turbidity, oxygen dissolved and density of microbial contaminants that are considered critical factors contributing to numerous outbreaks of waterborne diseases.

Similar research has been conducted in other regions that has demonstrated the health impact of wastewater irrigation. An interesting study is carried out by Ajibade and Ifeanyin (2017) in the suburbs in eastern Cape South Africa, where high contamination of vegetables by *E. coli*, *Shigella*, *Salmonella* and *Vibrio* spp. which have been the predominant water-related pathogens, while it has been reported that certain clonal strains of these pathogens can survive conventional wastewater treatment processes related to inefficient performance, poor design, lack of experience, inefficient monitoring and documentation. poor compliance with processes in wastewater treatment facilities.

An investigation carried out in Dinapur, a tropical city in India, demonstrated the high microbiological contamination of vegetables, due to irrigation with partially treated wastewater and the potential risk that this derived for the health of consumers (Khalid *et al*., 2018). Dickin *et al*. (2016), studied the health implications due to the reuse of wastewater in the irrigation of vegetables, finding that there are appreciable risks to health (Table 3).

Table 3. Chemical and biological risks associated with the use of untreated wastewater in agriculture (Jaramillo and Restrepo, 2017).

Type of risk		Pathogen
Biological	Bacteria	*E. coli*, *Vibrio cholerae*, *Salmonella* spp., *Shigella* spp.
	Helminths	Ascaris, Ancylostoma, *Tenia* spp.
	Protozoa	Intestinal Giardia, Crysptospridium, *Entamoeba* spp.
	Virus	Hepatitis A and E, Adenovirus, Rotavirus, Norovirus
	Schistosoma	Blood flukes
Chemical	Substance of health concern	
	Heavy metals	Arsenic, cadmium, mercury
	Hydrocarbons	Dioxins, Furans, PCB
	Pesticides	Aldrin, DDT

Recent studies have identified wastewater treatment plants as potential sources of anthropogenic greenhouse gas emissions such as: carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O), which contribute to climate change and air pollution (Soler *et al*., 2016). Worldwide, most developing countries focus efforts to improve the performance of wastewater treatment plants and obtain a good quality effluent; however, new challenges have now been generated aimed at ensuring the sustainability of wastewater in terms of its economic viability and environmental impact (Campos *et al*., 2016).

Conclusions

Scientific research, development and innovation are essential to harness wastewater as a valuable resource for agricultural production. Technical solutions aimed at improving the use of reclaimed water, can help mitigate the negative effects of water scarcity worldwide and improve the quality of life for all and in particular for groups in vulnerable and disadvantaged situations, require further development.

The collection of data and documentation can generate new knowledge that helps to better understand the productive use of wastewater in agriculture, a valid alternative as long as its risks are evaluated and the necessary measures to protect health and the environment are taken.

Cited literature

Ajibade, A. M. and Ifeanyin, O. A. 2017. Ecological and public health implications of the discharge of multidrug-resistant bacteria and physicochemical contaminants from treated wastewater effluents in the Eastern Cape, South Africa. Rev. Water. 9(8):562-580. https://doi.org/10.3390/w9080562.

Assouline, S.; Russo, D. and Silber, A. 2015. Balancing water scarcity and quality for sustainable irrigated agriculture. Water Resour. Res. 51(5):3419-3436.

Bijl, L. D.; Bogaart, P. W.; Kram, T.; Vries, J. M. B. and Vuuren, P. D. 2016. Long-term water demand for electricity, industry and households. Environ. Sci. Policy. 55(2016):75-86.

Boretti, A. and Rosa, L. 2019. Reassessing the projections of the World Water Development Report. Clean Water. 15(2):1-6. https://doi.org/10.1038/s41545-019-0039-9.

Burak, S. and Margat, J. 2016. Water management in the Mediterranean Region: concepts and policies. Water Resour. Manage. 30(15):5779-5797. https://doi.org/10.1007/s11269-016-1389-4.

Burek, P.; Satoh, Y.; Fischer, G.; Kahil, M. T.; Scherzer, A.; Tramberend, S.; Nava, L. F.; Wada, Y.; Eisner, S.; Flörke, M.; Hanasaki, N.; Magnuszewski, P.; Cosgrove, B. and Wiberg, D. 2016. Water futures and solution: fast track initiative (Final Report). IIASA Working Paper. Laxenburg, Austria, International Institute for Applied Systems Analysis (IIASA). 23-26 pp.

Campos, J. L.; Valenzuela, H. D.; Pedrouso, A.; Val del Río, A.; Belmonte, M. and Mosquera, C. A. 2016. Greenhouse gases emissions from wastewater treatment plants: minimization, treatment, and prevention. J. Chem. 1(9):1-12.

Carrard, N.; Foster, T. and Willetts, J. 2019. groundwater as a source of drinking water in southeast Asia and the Pacific: A multi-country review of current reliance and resource concerns. Water. 11(8):1605-1625. https://doi.org/10.3390/w11081605.

Chahal, C.; Van den, A. B.; Young, X. F.; Franco, C.; Blackbeard, J. and Mon, P. 2016. Pathogen and particle associations in wastewater: significance and implications for treatment and disinfection processes. Adv. Appl. Microbiol. 97(1):64-110.

Dickin, S. K.; Corinne, J.; Schuster, W.; Manzoor, Q. and Katherine, P. 2016. A review of health risks and pathways for exposure to wastewater use in agriculture. Environ. Health Perspectives. 124(7):900-909.

Fang, Y. and Jawitz, J. W. 2019. The evolution of human population distance to water in the USA from 1790 to 2010. Nature Communications. 10(430):1-8. https://doi.org/10.1038/s41467-019-08366-z.

Gleick, P. H. and Palaniappan, M. 2010. Peak water limits to freshwater withdrawal and use. Journal Proceedings of the National Academy of Sciences of the United States of America. 107(25):11155-11162.

Grant S. B.; Saphores, J.; Feldman, D.; Hamilton, D. L.; Fletcher, A. J.; Cook, T. D.; Stewardson, P. L. M.; Sanders, B. F.; Levin, L. A. and Ambrose, R. F. 2012. Taking the 'waste' out of 'wastewater' for human water security and ecosystem sustainability. Science. 337(6095):681-686.

Hanseok, J.; Hakkwan, K. and Taeil, J. 2016. Irrigation water quality standards for indirect wastewater reuse in agriculture: a contribution toward sustainable wastewater reuse in South Korea. Water. 8(5):169-187. https://doi.org/10.3390/w8040169.

Hernández, P. F.; Margni, M.; Noyola, A.; Guereca, H. L. and Bulle C. 2017. Assessing wastewater treatment in Latin America and the Caribbean: enhancing life cycle assessment interpretation by regionalization and impact assessment sensibility. J. Cleaner Production. 142(4):2140-2153.

Huang, J.; Yu, H.; Guan, X.; Wang, G. and Guo, R. 2016. Accelerated dryland expansion under climate change. Nature Climate Change. 6(2):166-171.

Intriago, J. C.; Lopez, G. F.; Allende, A.; Vivaldi, G. A.; Camposeo, S.; Nicol, E. N.; Alarcon, J. J. and Salcedo F. P. 2018. Agricultural reuse of municipal wastewater through an integral water reclamation management. J. Environ. Manag. 213(1):135-141.

Jager, I. H.; Efroymson, A. R. and Baskaran, M. L. 2019. Avoiding conflicts between future freshwater algae production and water scarcity in the United States at the energy-water nexus. Water. 11(4):836-856. https://doi.org/10.3390/w11040836.

Jago-on, B. K.; Siringan, P. F.; Balangue, T. R.; Taniguchi, M.; Reyes, Y. K.; Lloren, R.; Peña, M. A. and Bagalihog, E. 2017. Hot spring resort development in Laguna Province, Philippines: Challenges in water use regulation. J. Hydrology: Regional Studies. 11(1):96-106.

Jaramillo, M. F. and Restrepo, I. 2017. Wastewater reuse in agriculture: a review about its limitations and benefits. Sustainability. 9(2):1734-1753. https://doi.org/10.3390/su9101734.

Jung, K.; Jang, T.; Jeong, H. and Park, S. 2014. Assessment of growth and yield components of rice irrigated with reclaimed wastewater. Agric. Water Manag. 138(1):17-25.

Junguo, L.; Hong, Y.; Simon, N. G.; Matti, K.; Martina, F.; Stephan, P.; Naota, H.; Yoshihide, W.; Xinxin, Z.; Chunmiao, Z.; Alcamo, J. and Taikan, O. 2016. Water scarcity assessments in the past, present, and future. Earth's Future. 5(6):545-559. https://doi.org/10.1002/2016EF000518.

Khalid, S.; Shahid, M.; Irshad, N. B.; Sarwar, T.; Haidar, A. S. and Khan, N. N. 2018. A review of environmental contamination and health risk assessment of wastewater use for crop irrigation with a focus on low and high-income countries. Inter. J. Environ. Res. Public Health. 15(5):895-910. https://doi.org/10.3390/ijerph15050895.

Kölbel, J.; Strong, C.; Noe, C. and Reig, P. 2018. Mapping public water management by Harmonizing and sharing corporate water risk information. Nota Técnica. Instituto Mundial de Investigación (WRI). 20 p. www.wri.org/publication/mapping-public-water.

Larsen, T. A.; Hoffmann, S.; Luthi, C.; Truffer, B. and Maurer, M. 2016. Emerging solutions to the water challenges of an urbanizing world. Science. 352(6288):928-933.

Lyu, S.; Chen, W.; Zhang, W.; Fan, Y. and Jiao, W. 2016. Wastewater reclamation and reuse in China: opportunities and challenges. J. Environ. Sci. 23(10):1585-1593.

Machado, A. I.; Beretta, M.; Fragoso, R. and Duarte, E. 2016. Overview of the state of the art of constructed wetlands for decentralized wastewater management in Brazil. J. Environ. Management. 187(1):560-570. https://doi.org/ 10.1016/j.jenvman.2016.11.015.

Mahlknecht, J.; Gonzalez, B. R. and Loge, F. J. 2020. Water-energy-food security: a nexus perspective of the current situation in Latin America and the Caribbean. Energy. 194(3):1-17. https://doi.org/10.1016/j.energy.2019.116824.

Mateo-Sagasta, J.; Raschid-Sally, L. and Thebo, A. 2015. global wastewater and sludge production, treatment and use en drechsel. (Eds). Wastewater: economic asset in an urbanizing world. wastewater. Amsterdam. 3-14 pp. Doi: 10.1007/978-94-017-9545-6_2.

Mesa, P. E. and Berbel, J. 2020. Analysis of barriers and opportunities for reclaimed wastewater use for agriculture in Europe. Water. 12(8):1-14. https://doi.org/10.3390/w12082308.

Miralles, W. F. and Muñoz, C. R. 2018. An analysis of the water-energy-food nexus in Latin America and the Caribbean Region: Identifying synergies and tradeoffs through integrated assessment modeling. Inter. J. Eng. Sci. 7(1):8-24.

Muchuweti, M.; Birkett, J. W.; Chinyanga, E.; Zvauya, R.; Scrimshaw, M. D. and Lester, J. N. 2006. Heavy metal content of vegetables irrigated with mixture of wastewater and sewage sludge in Zimbabwe: implications for human health. Agric. Ecosys. Environ. 112(1):41-48.

Nadja, C.; Kunz, M. F.; Ingold, K. and. Hering, J. G. 2016. Drivers for and against municipal wastewater recycling: a review. Water Sci. Technol. 73(2):251-259. https://doi.org/10.2166/wst.2015.496.

Okereke, J. N.; Ogidi, I. and Obasi, K. O. 2016. Environmental and health impact of industrial wastewater effluents in Nigeria - A review. Inter. J. Adv. Res. Biol. Sci. 3(6):55-67.

Ossebaard, H. C. and Lachman, P. 2020. Climate change, environmental sustainability and health care quality. Inter. J. Quality in Health Care. 00(00):1-3. https://doi.org/10.1093/intqhc/mzaa036.

Parisi, A.; Monno, V. and Fidelibus, M. D. 2018. Cascading vulnerability scenarios in the management of groundwater depletion and salinization in semi-arid areas. Inter. J. Disaster Risk Reduction. 30(1):292-305. https://doi.org/ 10.1016/j.ijdrr.2018.03.004.

Pereira, B.; He Z.; Stoffella, P. J.; Montes, C. R.; Melfi, A. J. and Baligar, V. C. 2012. Nutrients and nonessential elements in soil after 11 years of wastewater irrigation. J. Environ. Quality. 41(3):920-927.

Petousi, G.; Daskalakis, M. S.; Fountoulakis, D.; Lydakis, L.; Fletcher, E. I.; Stentiford, T. and Manios, T. 2019. Effects of treated wastewater irrigation on the establishment of young grapevines. Sci. Total Env. 658(1):485-492. https://doi.org/10.1016/j.scitotenv. 2018.12.065.

Qadir, M.; Drechse, P.; Jiménez, C. B.; Younggy, K.; Pramanik, A.; Mehta, P. and Olaniyan, O. 2020. Global and regional potential of wastewater as a water, nutrient and energy source. Natural Res. Forum. 44(12):40-51. https://doi.org/ 10.1111/1477-8947.12187.

Raveh, E. and Ben-Gal, A. 2016. Irrigation with water containing salts: evidence from a macro-data national case study in Israel. Agric. Water Manag. 170(3):176-179.

Saeed, T.; Al-Jandal, N.; Abusam, A.; Taqi, H.; Al-Khabbaz, A. and Zafar, J. 2017. Sources and levels of endocrine disrupting compounds (EDCs) in Kuwait's coastal areas. Marine Pollution Bulletin. 118(2):407-412.

Soler, J. A.; Stevens, B. and Hoekstra, M. 2016. Importance of abiotic hydroxylamine conversion on nitrous oxide emissions during nitritation of reject water. Chem. Eng. J. 287(1):720-726.

Sun, S.; Wanga, Y.; Liu, J.; Cai, H.; Wub, P.; Geng, Q. and Xu, L. 2016. Sustainability assessment of regional water resources under the DPSIR framework. J. Hydrol. 532(1):140-148.

Tauro, F.; Selker, J.; Van de Giesen, N.; Abrate, T.; Uijlenhoet, R.; Porfiri, M.; Manfreda, S.; Caylor, K.; Moramarco, T.; Benveniste, J.; Ciraolo, G.; Estes, L.; Domeneghetti, A.; Perks, M. T.; Corbari, C.; Rabiei, E.; Ravazzani, G.; Bogena, H.; Harfouche, A.; Brocca, L.; Maltese, A.; Wickert, A.; Tarpanelli, A.; Good, S., Lopez-Alcala, J. M.; Petroselli, A.; Cudennec, C.; Blume, T.; Hut, R. and Grimaldi, S. 2018. Measurements y observations in the XXI century (MOXXI): Innovation and multi-disciplinarity to sense the hydrological cycle. Rev. Cienc. Hidrológicas. 63(2):169-196. https://doi.org/10.1080/02626667.2017. 1420191.

Thebo, A. L.; Drechsel, P.; Lambin, E. F. and Nelson, K. L. 2017. A global, spatially-explicit assessment of irrigated croplands influenced by urban wastewater flows. Environmental Research Letters. 12(7):1-12. https://doi.org/10.1088/1748-9326/aa75d1.

Turlej, T. and Banaś, M. 2018. Sustainable management of sewage sludge. E3S Web of Conferences. 49(8):1-8. https://doi.org/ 10.1051/e3sconf/20184900120.

UNESCO. 2016. Informe de las Naciones Unidas sobre el desarrollo de los recursos hídricos en el mundo 2016: agua y empleo. http://www.unesco.org/new/es/natural-sciences/environment /water/wwap/wwdr/.

Vasilyev, S. and Domashenko, Y. 2018. Agroecological substantiation for the use of treated wastewater for irrigation of agricultural land. J. Ecol. Eng. 19(1):48-54. https://doi.org/ 10.12911/22998993/79567.

Wang, X. J.; Zhang, J. Y.; Gao, J.; Shahid, S.; Xia, X. H.; Geng, Z. and Tang, L. 2017. The new concept of water resources management in China: ensuring water security in changing environment. Environ. Develop. Sustainability. 20(4):897-909. https://doi.org/10.1007/s10668-017-9918-8.

Wang, X.; Daigger, G.; Lee, D. J.; Liu, J.; Ren, N. Q.; Qu, J.; Liu, G. and Butler, D. 2018a. Evolving wastewater infrastructure paradigm to enhance harmony with nature. J. Sci. Adv. 4(8):1-10.

Weinzettel, J. and Pfister, S. 2019. International trade of global scarce water use in agriculture: Modeling on watershed level with monthly resolution. Ecol. Econ. 159(3):301-311. https://doi.org/10.3929/ethz-b-000325571.

Woldetsadik, D.; Drechsel, P.; Keraita, B.; Itanna, F. and Gebrekidan, H. 2018. Farmers' perceptions on irrigation water contamination, health risks and risk management measures in prominent wastewater-irrigated vegetable farming sites of Addis Ababa, Ethiopia. Environ. Systems Decisions. 38(4):52-64.

Yin, Y.; Tang, Q.; Liu, X. and Zhang, X. 2017. Water scarcity under various socio-economic pathways and its potential effects on food production in the Yellow River basin. Hydrol Earth System Sci. 21(2):791-804.

Zhang, J. and Ma, L. 2020. Environmental sustainability assessment of a new sewage treatment plant in China based on infrastructure construction and operation phases energy analysis. Water. 12(2):484-507. https://doi.org/10.3390/w12020484.