



A Review of Wastewater Pollution, Its Impacts, and Treatment Challenges in Pakistan

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Abstract

Global freshwater resources are under unprecedented strain, with water demands already surpassing supplies in regions inhabited by over 40% of the world's population. This scarcity is exacerbated by the widespread deterioration of water quality due to pollution from industrial discharge, municipal sewage, and agricultural runoff. Wastewater is a significant source of this pollution, containing harmful pathogens, organic matter, and toxic heavy metals that pose severe risks to human health and ecosystem integrity. In Pakistan, the situation is critical; the country faces severe physical water scarcity and rampant water pollution, with less than 10% of its municipal wastewater receiving any treatment. This review synthesizes the current state of knowledge regarding the composition and sources of wastewater in Pakistan, its detrimental impacts on human health—particularly through the contamination of the food chain—and the associated challenges in wastewater treatment. The analysis highlights the extensive use of untreated wastewater in agriculture due to its perennial availability and nutrient content, a practice that offers short-term economic benefits but leads to long-term consequences, including the accumulation of heavy metals in soils and crops. Finally, the review discusses the potential of constructed wetlands as a sustainable, low-cost treatment technology suited to the economic and technical constraints of Pakistan, offering a viable alternative to energy-intensive conventional treatment methods.

1. Introduction

The unequal global distribution of freshwater resources and population densities has created a scenario where water demands exceed supplies in many parts of the world, impacting the lifestyle and development opportunities of billions (Qadir et al., 2007a). It is projected that up to 60% of the global population may experience physical water scarcity in the near future (Rijsberman, 2006). Access to safe and clean water is fundamental to human health (Iqbal et al., 2019), yet water often acts as a carrier for pathogenic organisms—including viruses, protozoa, and bacteria—that cause illness (Coleman et al., 2013; Ali et al., 2017). The deterioration of water quality, driven by point sources like industrial discharge and non-point sources such as

agricultural runoff and urban stormwater, is a major concern exacerbated by population growth, urbanization, and industrialization (Sánchez et al., 2015; Tran et al., 2015).

Wastewater is a significant conduit for various pollutants, including toxic heavy metals (Ping et al., 2011). Food consumption is the primary pathway for human exposure to these metals, surpassing inhalation and dermal contact (Loutfy et al., 2006). Heavy metal contamination is linked to a spectrum of disorders, including genomic instability, endocrine disruption, neurotoxicity, carcinogenicity, and immunological problems (Dyer, 2007). Specific metals like cadmium (Cd) and lead (Pb) are known to cause mutagenesis, teratogenesis, and carcinogenesis, with high concentrations in food crops linked to gastrointestinal cancers (Khan et al., 2013). Lead exposure is also associated

with elevated blood pressure, renal dysfunction, and impaired haemoglobin synthesis. Other metals like manganese are implicated in neurological disorders such as Parkinson's disease, while nickel (Ni) can cause cancer, skin rashes, and respiratory illness at high concentrations (Harmanescu et al., 2011). Dietary chromium (Cr) intakes have been directly correlated with breast cancer mortalities in international studies (Pasha et al., 2010).

Pakistan exemplifies the challenges faced by many developing nations, grappling with both severe water quantity and quality issues. Water availability is predicted to fall below 700 m³ per capita, a level far below the international water scarcity threshold (Martin et al., 2006). Water pollution, largely from untreated municipal and industrial effluent, contributes to a high prevalence of waterborne diseases (Azizullah et al., 2011). An estimated 7.57×10^6 m³ of municipal sewage is discharged daily into surface waters, with less than 10% receiving any treatment (Martin et al., 2006). The use of wastewater for irrigation, driven by its constant availability and nutrient content, leads to the accumulation of heavy metals like Ni, Cu, Cd, Cr, Pb, As, Hg, and Zn in agricultural soils, introducing them into the food chain and posing a significant threat to public health (Balkhair and Ashraf, 2016; Islam et al., 2017). The safe disposal and treatment of this contaminated water remain a global challenge, necessitating sustainable solutions. Constructed wetlands (CWs) have emerged as a viable, low-cost option for wastewater treatment, capable of handling various effluent types with minimal operational and maintenance requirements (Vymazal, 2019).

2. Composition of Wastewater

Wastewater can be characterized by its physicochemical and biological constituents, which collectively determine its pollution load and environmental impact. The main contaminants include suspended and dissolved solids, organic matter measured as biological oxygen demand (BOD) and chemical oxygen demand (COD), nutrients (particularly nitrogen and phosphorus), heavy metals, and a wide array of pathogenic microorganisms. The specific composition varies significantly based on the source—whether municipal, industrial, or agricultural—but invariably poses risks to receiving water bodies and public health when discharged untreated (Figure 1).

3. Types and Sources of Wastewater in Pakistan

Water pollution in Pakistan is predominantly anthropogenic, stemming from the indiscriminate disposal of industrial, municipal, and domestic wastes into water channels, rivers, and lakes (Hammer, 1986; Kahlowan and Majeed, 2003). It is estimated that over 90% of raw sewage and 70% of untreated industrial wastes are dumped directly into surface waters (Anonymous, 2010).

Industrial pollution is a major contributor. Of the 6634 registered industries in Pakistan, 1228 are classified as highly polluting (Sial et al., 2006). Sectors such as textiles,

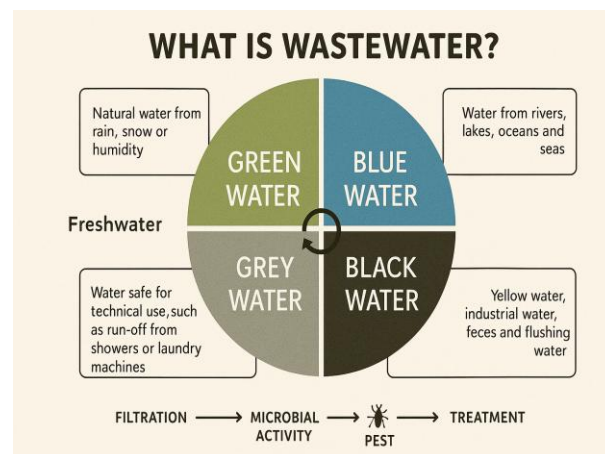


Figure 1: Schematic overview of composting pathways and mechanisms involved in waste transformation and stabilization. The diagram illustrates the major processes occurring during composting, including feedstock preparation, microbial degradation, and thermophilic and maturation phases. Organic waste is aerobically decomposed through microbial oxidation, leading to CO₂ release, humus formation, and pathogen reduction. Key mechanisms include enzymatic hydrolysis (cellulase, ligninase, and protease activity), nitrification–denitrification, humification, and stabilization of organic matter. Reactor zones (aeration unit, thermophilic chamber, and curing section) facilitate controlled temperature, oxygen supply, and moisture regulation, enhancing microbial efficiency and reducing greenhouse gas emissions.

pharmaceuticals, petrochemicals, leather tanning, and fertilizers discharge wastewater laden with organic load, nitrates, nitrites, and toxic metals including arsenic, lead, mercury, chromium, and cadmium (Ali et al., 1996; Sial et al., 2006; Ullah et al., 2009). Most industries dispose of their effluent directly into nearby drains and rivers. For instance, River Kabul receives approximately 80,000 m³ of industrial effluent daily, and even the capital, Islamabad, discharges untreated waste from its industrial estates into the Sawan River (Mian et al., 1998; MOE-PAK, 2005a). A staggering 99% of industrial wastewater is estimated to be untreated before discharge (MOE-PAK, 2005a), resulting in about 40 billion liters of effluent polluting water bodies daily (Saleemi, 1993).

Municipal and domestic wastes pose an equally grave threat. Sewerage collection systems cover less than 50% of urban areas, and only about 8% of the collected wastewater is effectively treated (WB-SCEA, 2006; WWF, 2007). Consequently, an estimated 7.57 billion liters of raw sewage are discharged to surface waters daily (WB-SCEA, 2006). These combined discharges from industry and municipalities not only introduce toxic chemicals but also cause severe bacteriological contamination, elevating parameters like

BOD, COD, TDS, and TSS, thereby rendering water unfit for consumption and ecosystem health.

4. Wastewater Generation and Contaminated Sites

The link between industrial growth and water pollution is evident in fast-growing economies. In countries like China and India, industrial water use and concomitant wastewater discharge have surged dramatically (Pandey, 2005; Shalizi and Zmarak, 2006). In Pakistan, industrial pollution is increasing at a rapid pace, significantly impairing surface and groundwater quality around major urban centers and impacting human health and productivity (Aftab et al., 2000).

5. The Use of Wastewater in Low and High-Income Countries

Wastewater is used for irrigation on millions of hectares worldwide, supporting the livelihoods of an estimated 200 million farmers (Jiménez and Asano, 2008b; Raschid-Sally and Jayakody, 2008). However, a stark disparity exists in treatment levels between income groups. High-income countries treat about 70% of generated wastewater, while upper-middle-income, lower-middle-income, and low-income countries treat only 38%, 28%, and 8%, respectively (Sato et al., 2013). In Pakistan and other developing nations, untreated wastewater is a vital, year-round resource for urban and peri-urban agriculture, offering reliable irrigation and cost savings on fertilizers (Scott et al., 2000; Buechler et al., 2006). Studies indicate that farmers using wastewater can earn significantly more than those using freshwater, highlighting its economic importance despite the associated health risks (Saravanan et al., 2011).

6. Potential Impacts of Wastewater Irrigation on Environment and Health

The reuse of wastewater in agriculture presents a paradox: it enables food production and nutrient recycling but introduces health risks from pathogens, antibiotic-resistant bacteria, and toxic chemicals (Contreras et al., 2017). The absence of treatment in most cases exacerbates these risks, contributing to diarrheal diseases, which remain a leading cause of death in children under five globally (Liu et al., 2012).

In Pakistan, the contamination of drinking water with industrial and municipal waste, coupled with inadequate disinfection, is a primary cause of waterborne diseases such as hepatitis, cholera, dysentery, and typhoid (Hashmi et al., 2009a; Aziz, 2005). These diseases account for a significant portion of hospital patients and one-third of all deaths in the country (WB-SCEA, 2006). The health effects are not uniform; agricultural workers, crop handlers, consumers, and nearby communities—especially children and the elderly—face varying levels of risk from exposure to pathogens and chemicals in wastewater (WHO, 2005).

7. Health Risk Assessment from Food Chain Contamination

Irrigating crops with wastewater introduces a direct pathway for contaminants to enter the human food chain. The health risks depend on the type of crop and the level of contamination. While some crops like cotton or dried fruits pose a lower risk, vegetables consumed raw present a significant health hazard (Shakir et al., 2017). Furthermore, the long-term irrigation with wastewater can lead to groundwater contamination through the leaching of pollutants like chlorides, creating a cumulative and persistent environmental threat (Babiker et al., 2004).

Risk assessment has evolved to quantify these dangers using indices such as the degree of contamination (Cdeg), enrichment factor (EF), bioaccumulation factor (BAF), translocation factor (TrF), hazard quotient (HQ), and estimated daily intake (EDI) (Antoniadis et al., 2017; Shahid et al., 2018). These tools are crucial for understanding the transfer of metals from soil to plants and for evaluating the potential non-carcinogenic and carcinogenic risks to human populations.

8. Wastewater Treatment in Pakistan: Challenges and a Sustainable Alternative

The discovery of emerging pollutants, including toxic heavy metals, micro-pollutants, and pharmaceuticals, is challenging the efficacy of conventional treatment technologies (Zhuang et al., 2015; Xiao et al., 2017). The increasing volume and complexity of wastewater, combined with stringent discharge limits, underscores the need for robust and affordable treatment solutions (Liu et al., 2015). In this context, Constructed Wetlands (CWs) represent a promising natural treatment technology. CWs are engineered systems that mimic natural wetland processes to remove pollutants. They are characterized by lower operational and maintenance costs compared to conventional systems like activated sludge (Wang et al., 2017; Vymazal, 2019). The effectiveness of CWs depends on factors such as wastewater biodegradability and hydraulic loading rates. Systems can be hampered by a lack of biodegradable organics or by loadings that exceed their natural treatment capacity (Kadlec and Wallace, 2008; Dan et al., 2011; Saeed and Sun, 2017a). For a country like Pakistan, facing technical and financial constraints in wastewater management, CWs offer a viable, sustainable pathway to mitigate pollution and protect precious water resources.

9. Conclusion

Pakistan stands at a critical juncture, facing an acute water crisis defined by both scarcity and severe pollution. The widespread discharge of untreated industrial and municipal wastewater has dire consequences for environmental health and human well-being, particularly through the contamination of the food chain via agricultural irrigation. While the use of wastewater provides short-term agricultural benefits, the long-term accumulation of heavy metals and pathogens in the ecosystem poses a significant and growing public health threat. Addressing this challenge requires a paradigm shift in water management. Conventional treatment methods are often economically unfeasible.

Therefore, the adoption of sustainable, low-cost technologies like Constructed Wetlands is not just an option but a necessity. Future efforts must focus on implementing such nature-based solutions, strengthening regulatory enforcement, and promoting safe water reuse practices to secure water for Pakistan's future.

10. Future Recommendations

Based on the comprehensive review of wastewater pollution in Pakistan, the following strategic recommendations are proposed to address the escalating water crisis and its associated health and environmental impacts:

10.1. Policy and Institutional Framework

Strengthen enforcement of the National Environmental Quality Standards (NEQs) through robust monitoring systems and stringent penalties for non-compliance. Develop a national wastewater management policy that prioritizes water reuse and recycling in agriculture. Establish cross-sectoral coordination mechanisms between water, health, agriculture, and industrial sectors. Implement the "polluter pays" principle to generate funds for wastewater treatment infrastructure

10.2. Technological Interventions

Promote decentralized constructed wetland systems for peri-urban and rural areas, tailored to local conditions. Develop hybrid wetland systems combining different macrophytes and flow regimes for enhanced heavy metal removal. Implement pilot-scale studies to optimize wetland designs for specific industrial effluents (textile, tannery, pharmaceutical). Integrate advanced primary treatment with constructed wetlands to handle high organic loads

10.3. Agricultural Management

Implement crop restriction policies for wastewater-irrigated areas, prohibiting leafy vegetables for raw consumption. Promote drip irrigation and other application methods that minimize crop contamination. Develop soil amendment strategies using biochar and compost to immobilize heavy metals. Establish farmer training programs on safe wastewater irrigation practices

10.4. Research and Development Priorities

Conduct longitudinal studies on heavy metal accumulation in soil-crop systems under continuous wastewater irrigation. Investigate the fate and removal mechanisms of emerging contaminants in constructed wetlands. Develop local databases on wastewater quality parameters for different regions and seasons. Research cost-effective pre-treatment options to enhance wetland performance and lifespan

10.5. Public Health Protection

Establish regular monitoring of heavy metals in commonly consumed wastewater-irrigated crops. Implement health surveillance systems in high-risk communities using

wastewater for irrigation. Develop public awareness campaigns on safe food preparation from wastewater-irrigated crops. Promote point-of-use water treatment technologies in areas affected by groundwater contamination

10.6. Economic and Financial Strategies

Explore public-private partnerships for construction and maintenance of treatment wetlands. Develop micro-credit schemes for farmers to adopt safer irrigation technologies. Implement economic incentives for industries that pre-treat their wastewater. Establish water pricing policies that encourage wastewater treatment and reuse

10.7. Capacity Building and Awareness

Train technical staff in design, operation, and maintenance of constructed wetland systems. Incorporate wastewater management and safe reuse in agricultural extension services. Develop educational programs on water conservation and pollution prevention. Strengthen laboratory capabilities for water quality monitoring at district levels

10.8. Climate Resilience

Design treatment systems with climate adaptability, considering temperature variations and extreme weather events. Develop water storage strategies to optimize wastewater use during dry periods. Implement watershed management approaches to reduce non-point source pollution. Promote water-efficient crops in wastewater irrigation zones to maximize productivity

The successful implementation of these recommendations requires a coordinated approach involving government agencies, research institutions, private sector, and local communities. By adopting appropriate technologies like constructed wetlands and implementing comprehensive management strategies, Pakistan can transform its wastewater challenge into an opportunity for water security, environmental protection, and sustainable agricultural development.

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14. Authors Contribution:

Hamna Bashir and Rehman Eman: Writing Original Draft; Naila Ghafoor: Supervision, Writing reviews and corrections.

15. SDGs Addressed

SDG 6 (Clean Water and Sanitation) by addressing water scarcity and promoting sustainable wastewater treatment, and SDG 2 (Zero Hunger) by ensuring safer agricultural practices and food security. Other strongly connected goals include SDG 3 (Good Health and Well-being) through reducing waterborne diseases and SDG 12 (Responsible Consumption and Production) via sustainable water resource management.

16. References

- Aftab, Z., C.L. Ali, A. Khan, A. Robinson and I. Irshad. 2000. Industrial policy and the environment in pakistan. United Nations Industrial Development Organization (UNIDO) Report. Industrial Policy and Environment (NC/PAK/97/018).
- Alcamo, J., T. Henrichs and T. Rösch. 2017. World water in 2025: Global modeling and scenario analysis for the world commission on water for the 21st century.
- Alcamo, J., T. Henrichs and T. Rösch. 2017. World water in 2025: Global modeling and scenario analysis for the world commission on water for the 21st century.
- Ali, J., N. Ali, S.U.U. Jamil, H. Waseem, K. Khan and G. Pan. 2017. Insight into eco-friendly fabrication of silver nanoparticles by pseudomonas aeruginosa and its potential impacts. *Journal of Environmental Chemical Engineering*. 5:3266-3272.
- Angelakis, A., M.M. Do Monte, L. Bontoux and T. Asano. 1999. The status of wastewater reuse practice in the mediterranean basin: Need for guidelines. *Water research*. 33:2201-2217.
- Antoniadis, V., E. Levizou, S.M. Shaheen, Y.S. Ok, A. Sebastian, C. Baum, M.N.V. Prasad, W.W. Wenzel and J. Rinklebe. 2017. Trace elements in the soil-plant interface: Phytoavailability, translocation, and phytoremediation—a review. *Earth-Science Reviews*. 171:621-645.
- Awan, A., C. Arslan, M. Azam Khan, N. Nazir, U. Awan, A. Ali and U. Liaqat. 2012. Industrial waste water management in district gujranwala of pakistan-current status and future suggestions. Vol. 49.
- Aziz, J. 2005. Management of source and drinking-water quality in pakistan.
- Azizullah, A., M.N.K. Khattak, P. Richter and D.-P. Häder. 2011. Water pollution in pakistan and its impact on public health—a review. *Environment international*. 37:479-497.
- Babiker, I.S., M.A. Mohamed, H. Terao, K. Kato and K. Ohta. 2004. Assessment of groundwater contamination by nitrate leaching from intensive vegetable cultivation using geographical information system. *Environment International*. 29:1009-1017.
- Balkhair, K.S. and M.A. Ashraf. 2016. Field accumulation risks of heavy metals in soil and vegetable crop irrigated with sewage water in western region of saudi arabia. *Saudi journal of biological sciences*. 23:S32-S44.
- Buechler, S., G.D. Mekala and B. Keraita. 2006. Wastewater use for urban and peri-urban agriculture. *Cities farming for the future, Urban agriculture for sustainable cities*, in: Veenhuizen R. van (Ed.), RUAF Foundation, IDRC and IIRR. 9:243-273.
- Buechler, S., G.D. Mekala and B. Keraita. 2006. Wastewater use for urban and peri-urban agriculture. *Cities farming for the future, Urban agriculture for sustainable cities*, in: Veenhuizen R. van (Ed.), RUAF Foundation, IDRC and IIRR. 9:243-273.
- Chandran, S., V. Niranjana and J. Benny. 2012. Accumulation of heavy metals in wastewater irrigated crops in madurai, india. *J. Environ. Res. Develop.*, 6 (3), 432. 438:
- Coleman, B.L., M. Louie, M.I. Salvadori, S.A. McEwen, N. Neumann, K. Sibley, R.J. Irwin, F.B. Jamieson, D. Daignault and A. Majury. 2013. Contamination of canadian private drinking water sources with antimicrobial resistant escherichia coli. *Water research*. 47:3026-3036.
- Contreras, J.D., R. Meza, C. Siebe, S. Rodríguez-Dozal, Y.A. López-Vidal, G. Castillo-Rojas, R.I. Amieva, S.G. Solano-Gálvez, M. Mazari-Hiriart, M.A. Silva-Magaña, N. Vázquez-Salvador, I. Rosas Pérez, L. Martínez Romero, E. Salinas Cortez, H. Riojas-Rodríguez and J.N.S. Eisenberg. 2017. Health risks from exposure to untreated wastewater used for irrigation in the mezquital valley, mexico: A 25-year update. *Water Research*. 123:834-850.
- Cui, Q., T. Fang, Y. Huang, P. Dong and H. Wang. 2017. Evaluation of bacterial pathogen diversity, abundance and health risks in urban recreational water by amplicon next-generation sequencing and quantitative pcr. *Journal of Environmental Sciences*. 57:137-149.
- Dan, T.H., N.H. Chiem and H. Brix. 2011. Treatment of high-strength wastewater in tropical constructed wetlands planted with sesbania sesban: Horizontal subsurface flow versus vertical downflow. *Ecological Engineering*. 37:711-720.
- Dyer, C.A. 2007. Heavy metals as endocrine-disrupting chemicals. In *Endocrine-disrupting chemicals*: Springer, 111-133.
- EPA, P. 1997. Pakistan environmental protection act, 1997. Government of Pakistan, Ministry of Environment. 25p.
- Fang, L., L. Li, Z. Qu, H. Xu, J. Xu and N. Yan. 2018. A novel method for the sequential removal and separation of multiple heavy metals from wastewater. *Journal of hazardous materials*. 342:617-624.
- Firdous, S., W. Jin, N. Shahid, Z.A. Bhatti, A. Iqbal, U. Abbasi, Q. Mahmood and A. Ali. 2018. The

- performance of microbial fuel cells treating vegetable oil industrial wastewater. *Environmental Technology & Innovation*. 10:143-151.
- Fund, W.W. 2007. Pakistan's waters at risk: Water & health related issues in pakistan & key recommendations: WWF Lahore.
- Fund, W.W. 2007. Pakistan's waters at risk: Water & health related issues in pakistan & key recommendations: WWF Lahore.
- Fund, W.W. 2007. Pakistan's waters at risk: Water & health related issues in pakistan & key recommendations: WWF Lahore.
- Gude, V.G. 2016. Wastewater treatment in microbial fuel cells—an overview. *Journal of cleaner production*. 122:287-307.
- Hammer, M.J. 1986. Water and wastewater technology.
- Harmanescu, M., L.M. Alda, D.M. Bordean, I. Gogoasa and I. Gergen. 2011. Heavy metals health risk assessment for population via consumption of vegetables grown in old mining area; a case study: Banat county, romania. *Chemistry Central Journal*. 5:64.
- Hashmi, I., S. Farooq and S. Qaiser. 2009. Chlorination and water quality monitoring within a public drinking water supply in rawalpindi cantt (westridge and tench) area, pakistan. *Environmental monitoring and assessment*. 158:393.
- Huang, J., F. Yuan, G. Zeng, X. Li, Y. Gu, L. Shi, W. Liu and Y. Shi. 2017. Influence of ph on heavy metal speciation and removal from wastewater using micellar-enhanced ultrafiltration. *Chemosphere*. 173:199-206.
- Iqbal, M.S., M.M.M. Islam and N. Hofstra. 2019. The impact of socio-economic development and climate change on e. Coli loads and concentrations in kabul river, pakistan. *Science of The Total Environment*. 650:1935-1943.
- Islam, M.A., D. Romić, M.A. Akber and M. Romić. 2017. Trace metals accumulation in soil irrigated with polluted water and assessment of human health risk from vegetable consumption in bangladesh. *Environmental geochemistry and health*. 1-27.
- Jiménez, B. 2006. Irrigation in developing countries using wastewater. *International Review for Environmental Strategies*. 6:229-250.
- Jiménez, B. 2006. Irrigation in developing countries using wastewater. *International Review for Environmental Strategies*. 6:229-250.
- Jiménez, B. and T. Asano. 2008. Water reclamation and reuse around the world. *Water reuse: An international survey of current practice, issues and needs*. 20:3.
- Kadlec, R.H. and S. Wallace. 2008. *Treatment wetlands*: CRC press.
- Kadlec, R.H. and S. Wallace. 2008. *Treatment wetlands*: CRC press.
- Kahlow, M.A. and A. Majeed. 2003. Water-resources situation in pakistan: Challenges and future strategies. *Water Resources in the South: present scenario and future prospects*. 20:
- Khan, K., Y. Lu, M.A. Saeed, H. Bilal, H. Sher, H. Khan, J. Ali, P. Wang, H. Uwizeyimana, Y. Baninla, Q. Li, Z. Liu, J. Nawab, Y. Zhou, C. Su and R. Liang. 2018. Prevalent fecal contamination in drinking water resources and potential health risks in swat, pakistan. *Journal of Environmental Sciences*. 72:1-12.
- Khan, M.U., R.N. Malik and S. Muhammad. 2013. Human health risk from heavy metal via food crops consumption with wastewater irrigation practices in pakistan. *Chemosphere*. 93:2230-2238.
- Kim, D.-G., T.T. Nhung and S.-O. Ko. 2016. Enhanced adsorption of heavy metals with biogenic manganese oxide immobilized on zeolite. *KSCE Journal of Civil Engineering*. 20:2189-2196.
- Kirby, M., M. Mainuddin, T. Khaliq and M. Cheema. 2017. Agricultural production, water use and food availability in pakistan: Historical trends, and projections to 2050. *Agricultural Water Management*. 179:34-46.
- Liu, G., N. Wang, J. Zhou, A. Wang, J. Wang, R. Jin and H. Lv. 2015. Microbial preparation of magnetite/reduced graphene oxide nanocomposites for the removal of organic dyes from aqueous solutions. *RSC Advances*. 5:95857-95865.
- Liu, L., H.L. Johnson, S. Cousens, J. Perin, S. Scott, J.E. Lawn, I. Rudan, H. Campbell, R. Cibulskis and M. Li. 2012. Global, regional, and national causes of child mortality: An updated systematic analysis for 2010 with time trends since 2000. *The Lancet*. 379:2151-2161.
- Loutfy, N., M. Fuerhacker, P. Tundo, S. Raccanelli, A. El Dien and M.T. Ahmed. 2006. Dietary intake of dioxins and dioxin-like pcbs, due to the consumption of dairy products, fish/seafood and meat from ismailia city, egypt. *Science of the total environment*. 370:1-8.
- Martin, P., J. Nishida, J. Afzal, S. Akbar, R. Damania and D. Hanrahan. 2006. *Pakistan strategic country environmental assessment*. South Asia Region, World Bank. 1:
- Mehmood, A., M. Aslam Mirza, M. Aziz Choudhary, K.-H. Kim, W. Raza, N. Raza, S. Soo Lee, M. Zhang, J.-H. Lee and M. Sarfraz. 2019. Spatial distribution of heavy metals in crops in a wastewater irrigated zone and health risk assessment. *Environmental Research*. 168:382-388.
- Mian, Z., T. Ahmed and A. Rashid. 1998. Accumulation of heavy metals in water of river sawan due to effluents in industrial area. *Proc. of Int. Sym. on Agro-Environmental issues and Future Strategies: Towards 21st Century*. UA Faisalabad, Pakistan.

- Ministry of Land, I. and T.o. Japan. 2003. Water resources of Japan.
- Pandey, R. 2005. Estimating sectoral and geographical industrial pollution inventories in India: Implications for using effluent charge versus regulation. *The Journal of Development Studies*. 41:33-61.
- Pasha, Q., S.A. Malik, N. Shaheen and M.H. Shah. 2010. Investigation of trace metals in the blood plasma and scalp hair of gastrointestinal cancer patients in comparison with controls. *Clinica Chimica Acta*. 411:531-539.
- Ping, L., H.-J. Zhao, L.-L. Wang, Z.-H. Liu, J.-L. Wei, Y.-Q. Wang, L.-H. Jiang, D. Liang and Y.-F. Zhang. 2011. Analysis of heavy metal sources for vegetable soils from Shandong province, China. *Agricultural Sciences in China*. 10:109-119.
- Qadir, M., B.R. Sharma, A. Bruggeman, R. Choukr-Allah and F. Karajeh. 2007. Non-conventional water resources and opportunities for water augmentation to achieve food security in water scarce countries. *Agricultural water management*. 87:2-22.
- Raschid-Sally, L. and P. Jayakody. 2009. Drivers and characteristics of wastewater agriculture in developing countries: Results from a global assessment. Vol. 127: IWMI.
- Reinsch, M. and D. Pearce. Pakistan-country water resources assistance strategy: Water economy running dry.
- Rijsberman, F.R. 2006. Water scarcity: Fact or fiction? *Agricultural water management*. 80:5-22.
- Saeed, T. and G. Sun. 2017. A comprehensive review on nutrients and organics removal from different wastewaters employing subsurface flow constructed wetlands. *Critical Reviews in Environmental Science and Technology*. 47:203-288.
- Saleem, M., J. Iqbal and M.H. Shah. 2014. Dissolved concentrations, sources, and risk evaluation of selected metals in surface water from Mangla Lake, Pakistan. *The Scientific World Journal*. 2014.
- Saleem, M., J. Iqbal and M.H. Shah. 2016. Spatio-temporal variability and pollution assessment of selected metals in freshwater sediments, Pakistan. *CLEAN–Soil, Air, Water*. 44:402-410.
- Saleemi, M. 1993. Environmental assessment and management of irrigation and drainage scheme for sustainable agriculture growth. EPA, Lahore, Pakistan.
- Sánchez, A., E. Cohim and R. Kalid. 2015. A review on physicochemical and microbiological contamination of roof-harvested rainwater in urban areas. *Sustainability of Water Quality and Ecology*. 6:119-137.
- Saravanan, V.S., P.P. Mollinga and J.J. Bogardi. 2011. Global change, wastewater and health in fast growing economies. *Current Opinion in Environmental Sustainability*. 3:461-466.
- Sato, T., M. Qadir, S. Yamamoto, T. Endo and A. Zahoor. 2013. Global, regional, and country level need for data on wastewater generation, treatment, and use. *Agricultural Water Management*. 130:1-13.
- Sato, T., M. Qadir, S. Yamamoto, T. Endo and A. Zahoor. 2013. Global, regional, and country level need for data on wastewater generation, treatment, and use. *Agricultural Water Management*. 130:1-13.
- Sato, T., M. Qadir, S. Yamamoto, T. Endo and A. Zahoor. 2013. Global, regional, and country level need for data on wastewater generation, treatment, and use. *Agricultural Water Management*. 130:1-13.
- Sato, T., M. Qadir, S. Yamamoto, T. Endo and A. Zahoor. 2013. Global, regional, and country level need for data on wastewater generation, treatment, and use. *Agricultural Water Management*. 130:1-13.
- SCEA, W. Pakistan strategic country environmental assessment. Main report: Report.
- SCEA, W. Pakistan strategic country environmental assessment. Main report: Report.
- SCEA, W. Pakistan strategic country environmental assessment. Main report: Report.
- Scott, C.A., N.I. Faruqui and L. Raschid-Sally. 2004. Wastewater use in irrigated agriculture: Management challenges in developing countries. Wastewater use in irrigated agriculture: confronting the livelihood and environmental realities. Oxfordshire: CABI Publishing.
- Scott, C.A., J.A. Zarazúa and G. Levine. 2000. Urban-wastewater reuse for crop production in the water-short Guanajuato river basin, Mexico. Vol. 41: IWMI.
- Shahid, M., M. Khalid, C. Dumat, S. Khalid, N.K. Niazi, M. Imran, I. Bibi, I. Ahmad, H.M. Hammad and R.A. Tabassum. 2018. Arsenic level and risk assessment of groundwater in Vehari, Punjab province, Pakistan. *Exposure and Health*. 10:229-239.
- Shakir, E., Z. Zahraw and A.H.M.J. Al-Obaidy. 2017. Environmental and health risks associated with reuse of wastewater for irrigation. *Egyptian Journal of Petroleum*. 26:95-102.
- Shalizi, Z. 2006. Addressing China's growing water shortages and associated social and environmental consequences: The World Bank.
- Sial, R., M. Chaudhary, S. Abbas, M. Latif and A. Khan. 2006. Quality of effluents from Hattar industrial estate. *Journal of Zhejiang University SCIENCE B*. 7:974-980.
- Sial, R., M. Chaudhary, S. Abbas, M. Latif and A. Khan. 2006. Quality of effluents from Hattar industrial estate. *Journal of Zhejiang University SCIENCE B*. 7:974-980.
- Tran, N.H., K.Y.-H. Gin and H.H. Ngo. 2015. Fecal pollution source tracking toolbox for identification, evaluation and characterization of fecal contamination in receiving urban surface waters and

- groundwater. *Science of the total environment*. 538:38-57.
- Turan, V., S.A. Khan, R. Mahmood ur, M. Iqbal, P.M.A. Ramzani and M. Fatima. 2018. Promoting the productivity and quality of brinjal aligned with heavy metals immobilization in a wastewater irrigated heavy metal polluted soil with biochar and chitosan. *Ecotoxicology and Environmental Safety*. 161:409-419.
- Ullah, H., N. Khan, F. Ali, Z. Shah and Q. Ullah. 2018. Health risk of heavy metals from vegetables irrigated with sewage water in peri-urban of dera ismail khan, pakistan. *International Journal of Environmental Science and Technology*. 15:309-322.
- Ullah, R., R.N. Malik and A. Qadir. 2009. Assessment of groundwater contamination in an industrial city, sialkot, pakistan. *African Journal of Environmental Science and Technology*. 3:
- Vymazal, J. 2019. Constructed wetlands for wastewater treatment☆. In *Encyclopedia of ecology* (second edition), edited by B. Fath. Oxford: Elsevier, 14-21.
- Wang, M., D.Q. Zhang, J.W. Dong and S.K. Tan. 2017. Constructed wetlands for wastewater treatment in cold climate—a review. *Journal of Environmental Sciences*. 57:293-311.
- WHO. 2005. Guidelines for the safe use of wastewater in agriculture: World Health Organization Geneva.
- Xiao, X., Q.-Y. Liu, X.-R. Lu, T.-T. Li, X.-L. Feng, Q. Li, Z.-Y. Liu and Y.-J. Feng. 2017. Self-assembly of complex hollow cus nano/micro shell by an electrochemically active bacterium *Shewanella oneidensis* mr-1. *International Biodeterioration & Biodegradation*. 116:10-16.
- Yan, X., M. Liu, J. Zhong, J. Guo and W. Wu. 2018. How human activities affect heavy metal contamination of soil and sediment in a long-term reclaimed area of the Liaohe river delta, north China. *Sustainability*. 10:338.
- Zhou, H., H. Pan, J. Xu, W. Xu and L. Liu. 2016. Acclimation of a marine microbial consortium for efficient Mn (II) oxidation and manganese containing particle production. *Journal of Hazardous Materials*. 304:434-440.
- Zhuang, W.-Q., J.P. Fitts, C.M. Ajo-Franklin, S. Maes, L. Alvarez-Cohen and T. Hennebel. 2015. Recovery of critical metals using biometallurgy. *Current Opinion in Biotechnology*. 33:327-335.
- Zia, M.H., M.J. Watts, A. Niaz, D.R. Middleton and A.W. Kim. 2017. Health risk assessment of potentially harmful elements and dietary minerals from vegetables irrigated with untreated wastewater, Pakistan. *Environmental Geochemistry and Health*. 39:707-728.

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