Health Effects Associated with Wastewater Treatment, Reuse, and Disposal

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ABSTRACT: A review of the literature published in 2015 on topics relating to public and environmental health risks associated with wastewater treatment, reuse, and disposal is presented. This review is divided into the following sections: wastewater management, microbial hazards, chemical hazards, wastewater treatment, wastewater reuse, agricultural reuse in different regions, greywater reuse, wastewater disposal, hospital wastewater, industrial wastewater, and sludge and biosolids.

KEYWORDS: environmental health, public health, risk assessment, sewage, toxicity, wastewater, water reuse.

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Wastewater Management

Al-Khatib et al. (2015) performed a case study analysis that concluded municipal wastewater management in developing countries would continue to be a prevalent issue affecting public health and social well-being. They recommended the addition of health and hazardous waste awareness programs to create an educational foundation about waste generation in developing countries. Bradford-Hartke et al. (2015) compared the environmental benefits and burdens of phosphorus recovery in four centralized and two decentralized municipal wastewater systems using life cycle assessment. In overall summary, selection of an appropriate phosphorus recovery method should be considered both local conditions and other environmental impacts, in addition to eutrophication and mineral depletion. Lam et al. (2015) reviewed 27 studies from three electronic databases, Web of Science, CAB Direct and PubMed, relevant to the sewage and excreta management practices in Southeast Asia and evaluated potential public health risks of this practice. The results indicated that parasitic infection, diarrhea, epilepsy, bacterial infection and skin infection were potential

occupational health risks of sewage and excreta management practice by consuming contaminated fruits, vegetables, or fish.

The association between extreme rainfall and rate of emergency room visits for gastrointestinal illness was investigated by comparing regions with and without combined sewer overflows impacting drinking water sources in Massachusetts (Jagai et al., 2015). The study results showed different associations between heavy rainfall and rate of emergency room visits among regions, and the research found that only the region with drinking water impacted by combined sewer overflows demonstrated an increased cumulative risk for the rate of emergency room visits for gastrointestinal illness after extreme rainfall with the cumulative risk of rate of 1.13. Jiang et al. (2015) reviewed the human and environmental health risks and benefits associated with rainwater harvesting and stormwater use using the techniques of quantitative microbial risk assessment (QMRA). Li, Qu et al. (2015) conducted a review of the literature published in 2014 on topics relating to public and environmental health risks related to sewage disposal, reuse and treatment. The topics covered included chemical and microbial hazards, wastewater management, wastewater reuse, wastewater treatment plants (WWTPs), sludge and biosolids, and wastewater disposal.

Daley et al. (2015) carried out a qualitative case study to identify and understand residents' perceptions of the functionality of current water and wastewater sanitation systems in one vulnerable context that of a remote Arctic aboriginal community in Coral Harbour, Nunavut, Canada. This study emphasized the argument for inclusion of social, cultural, and economic variables in such decisions, particularly in remote and economically challenged communities in Canada or elsewhere around the world. Marcogliese et al. (2015) conducted a case study on the effects of a major municipal effluent on the St. Lawrence River, which is the second largest waterway in North America and receives the treated wastewater mostly from the City of Montreal WWTP. They described some major findings of the intensive researches over the last decades, such as the determination of the fate of contaminants, bioaccumulation in fish and invertebrates and eco-toxicological measurements of aquatic animal heath, and found that the impacts of the effluents from the WWTP are both toxicological and ecological on aquatic organisms.

Microbial Hazards

Bacteria. Al-Badaii and Shuhaimi-Othman (2015) performed an experiment to investigate the cause and prevalence of antibiotic resistant bacteria in the Semenyih River, Malaysia. Their results suggested that antibiotic resistant bacteria might be attributed to a decrease in water quality due to rural sewage and untreated wastewater entering the Semenyih River. Nishiyama et al. (2015) screened the sewage and urban river water samples from Miyazaki, Japan by the minimum inhibitory concentration test using the vancomycin-supplemented membrane-*Enterococcus* indoxyl-β-D-glucoside agar to assess the risk to human health caused by vancomycin-resistant enterococci in the aquatic environment. They observed the distribution of *Enterococcus faecium* and *E.*

faecalis in the water samples collected. Teklehaimanot et al. (2015) investigated the potential health risks and prevalence of enteropathogenic bacteria, such as *Salmonella typhimurium*, *Shigella dysenteriae* and *Vibrio cholera*, in the effluents and receiving waters of three selected South African wastewater treatment works. Their study revealed that the effluents as well as the receiving waters might lead to a potential health risk to the surrounding communities. Osuolale and Okoh (2015) evaluated the physicochemical and microbiological qualities of the final effluents of two WWTPs in the Eastern Cape Province of South Africa over a period of 12 months. They found that the both WWTPs showed the presence of *Escherichia coli* in counts ranging between 0 and 1.86×10^4 colony forming units (cfu)/100 mL and *Vibrio* counts ranging between 0 and 9.93×10^3 cfu/100 mL, indicating both of them have latent health risks to human and other organisms. Jacob et al. (2015) investigated the health risk associated with waterborne pathogens in three large rivers in France based on a two-year monitoring program. *Clostridium perfringens*, *Cryptosporidium parvum* oocysts, *Giardia duodenalis* cysts were found in one of the rivers where major agricultural activities were present, while adenovirus were found at the highest concentration in two other rivers.

Parasites. Analysis of helminth eggs as a health risk indicator for wastewater effluent was examined by Ajonina et al. (2015). Their analysis provided a correlation between helminth eggs and microbial indicators such that additional pathogen monitoring should be considered for a WWTP outflow. Hatam-Nahavandi et al. (2015) studied the removal efficiency of *Cryptosporidium* and *Giardia* in five municipal and domestic WWTPs in Tehran, Iran. The removal efficiency ranged from 76.7% to 92.1% for cysts and 48.9% to 90.8% for oocysts, showing the limited capability of conventional WTTPs to remove (oo)cysts.

Szczotko et al. (2015) assessed the prevalence of protozoan species, *Cryptosporidium* and *Giardia*, in selected swimming areas in Masovian Voivodeship, Poland and determined the microbiological parameters (*E. coli*, Enterococci) and the spore content of sulfite-reducing Clostridia. The results of their study suggested that the agricultural contamination and unregulated processes of wastewater management at farms near the swimming area could be the source of protozoa and to improve health security of the nearby population, the extension of the routine microbiological testing methodology of recreational water by the sanitary indicators should be implemented. The first molecular survey to detect *Cyclospora* in water, vegetables, soil and humans was conducted in southern Italy (Giangaspero et al., 2015). Of the 213 samples tested, *Cyclospora* was detected in 15.5%, suggesting that those vegetables, soil and irrigation water might be contaminated, which could result in a threat to public health, and should be monitored by health authorities.

Viruses. A study was conducted to assess the presence of Merkel cell polyomavirus (MCPPyV), a newly discovered, potentially oncogenic human virus, in urban sewage samples collected at WWTPs in Italy (Di Bonito et al., 2015). By testing 131 raw sewage samples from 21 WWTPs in nine Italian regions, high concentrations of MCPyV were found in all the WWTPs under study,

suggesting a wide circulation of the virus which might need further study upon its transmission. Rusinol et al. (2015) performed a research on the seasonality and viral dissemination in a river catchment located in a typical Mediterranean climate region. In addition to the river water samples, untreated and treated wastewater from a WWTP was also analyzed. Results indicated that the concentrations of human viruses, including human adenovirus, MCPyV, human hepatitis E virus and JC polyomavirus, became high during the low precipitation period. Prevost et al. (2015) carried out a survey to monitor enteric viruses twice a month in Seine River, its tributaries, and the major WWTP effluents in the Paris agglomeration, France. Results showed that there was a close relationship between the health status of inhabitants and the enteric viral contamination of WWTP effluents, as well as the surface water contamination.

Chemical Hazards

Heavy Metals. A study was performed to examine spinach's (*Spinacia olevacea)* ability to grow, root length and germination rates in a variety of soils contaminated with heavy metals (Alia et al., 2015). It was found that cadmium and lead contamination caused the highest toxicity levels in the spinach. Amreeva et al. (2015) examined mercury levels in many different mediums throughout Central Kazakhstan including ambient air, snow, water, bed silt, and regional foods. High levels of mercury derived from industrial activities were detected in all studied objects throughout Central Kazakhstan.

Devarajan et al. (2015) carried out a study of sediments receiving untreated and urban effluent waters from the city of Tiruchirappalli, Tamil Nadu, India for potential environmental and human health risks. The results revealed that the variation of toxic metal levels, such as chromium, copper, zinc, lead, and manganese, and toxicity in sediment composition related to both the type of hospital and the sampling period and illustrated that the method of elimination of hospital and urban effluents led to the pollution of water resources and might place aquatic organism and human health at risk. Yang, Duan et al. (2015) reported the recent trend in heavy metal pollution and associated health risks in the Wei River in the Shaanxi region of China. The monthly heavy metal pollution index values declined gradually with time, which indicated the effective implementation of pollution control strategies in the region including wastewater treatment.

Pharmaceuticals and Personal Care Products. Residues from cytostatic drugs, used in chemotherapy, are often discharged to surface water due to incomplete elimination in WWTPs. Franquet-Griell et al. (2015) compiled total consumption of cytostatic drugs to calculate the predicted environmental concentrations and determine the occurrence and risk of these drugs in aquatic environments. Only two of the 132 cytostatic drugs analyzed had a predicted environmental concentration higher than 10 ng/L, and all calculated risk quotients showed no significant risk. Lutterbeck et al. (2015) investigated the toxic effects of four anti-cancer drugs, including cyclophosphamide, methotrexate, 5-fluorouracil, and imatinib, using a plant assay with *Allium cepa* in the

context of the treated wastewater reuse for agricultural reuse.

The effects in male fish after trophic exposure to the anti-inflammatory drugs diclofenac and dexamethasone in wastewater was studied by Guiloski et al. (2015). The results suggested that the drugs had a negative impact on aquatic organisms, including reduction of testosterone levels and causation of oxidative stress. Gavrilescu et al. (2015) investigated the impact of emerging chemical and biological micropollutants that often occurred in wastewater with respect to monitoring, ecological risks, and remediation to demonstrate the need for research into new treatment technologies. Mottaleb et al. (2015) studied the transformation and bioaccumulation of pharmaceuticals and personal care products and other organic wastewater contaminants. They found that some of the compounds could be biologically transformed to breakdown products forming adducts suited for monitoring biomarkers of exposure, and some could affect swimming behavior in fathead minnow (*Pimephale promelas*) and interfere with thyroid axis in zebra fish (*Danio rerio*).

A quantitative probabilistic ecotoxicological assessment of all of the predicted and probable transformation products of the pharmaceuticals (3 beta-blockers: atenolol, metoprolol, and propranolol; and 5 selective serotonin reuptake inhibitors: citalopram, fluoxetine, fluvoxamine, paroxetine, and sertraline) was presented by Brown et al. (2015). They recommended the developing analytical methods that could isolate and quantify human metabolites and transformation products at environmentally relevant concentrations to confirm these predictions. Pereira et al. (2015) reported the recent status of the prevalence of pharmaceuticals in Portuguese wastewater and discussed the seasonal occurrence, removal and ecotoxicological risks. Chen, Wang et al. (2015) presented a study to investigate the accumulation of triclosan in the surface sediments near the outfalls of the five major municipal waste water treatment plants of Nanjing, China, as well as the evaluation of its potential ecological risk. They concluded that triclosan released from municipal waste water treatment plants could accumulate in the surface sediments nearby and might pose an undermined risk to aquatic organisms.

Other Trace Organics. Benzotriazoles are rapidly becoming a more significant environmental pollutant due to their high levels of toxicity and ability to enter water supplies. Alotabi et al. (2015) focused their review on assessing contemporary detection methods and the occurrence of benzotriazoles in the environment. Li, Cao et al. (2015) evaluated the estrogenic activity and reproductive toxicity of organic extracts from municipal wastewater and treated water in China. The results proved that the organic extracts in the water samples contained two major classes of compounds, benzenes and phthalates and the estrogenic activity of organic extracts from the secondary and tertiary effluents was below that of the raw wastewater, and the secondary effluent would bring some potential hazards on animals while the tertiary effluent was relatively safe. Petrie et al. (2015) published a review paper regarding emerging contaminants in wastewaters and the environment, identified understudied areas of emerging contaminant research in wastewaters and the environment,

and recommended directions for the future monitoring. Thodmaidi et al. (2015) estimated the ecological threat associated with emerging pollutants detected in wastewater in Greece by collecting toxicity data after literature review or using ECOSAR and risk quotients to calculate for treated wastewater and 25 Greek rivers for three different aquatic organisms (fish, daphnia magna and algae). According to their results, the class of emerging contaminants that present the greatest threat was endocrine disrupters and they suggested future national monitoring programs should include specific micro-contaminants that seemed to possess environment risk to surface water. Winid (2015) investigated the occurrence of polybrominated diphenyl ethers (PBDEs) in waters based on available data of PBDE levels in surface waters, soils, and sediments. This investigation revealed that the environmental threats of PBDEs contamination in natural waters might occur in Poland.

Nanoparticles. Gonzalez-Estrella et al. (2015) evaluated the toxicity of elemental copper nanoparticles to glucose fermentation, syntrophic propionate oxidation and denitrification in biological wastewater treatment processes. The results showed that elemental copper nanoparticles were toxic to all microbial processes studied, and that the inhibitory impact was mainly due to the release of copper(II) ions associated with the dissolution of the nanoparticles. Ozmen et al. (2015) assessed the toxicity of two selected xenobiotics, bisphenol A and atrazine after photocatalytic degradation using nano-sized, manganese-doped titanium dioxide. Results showed that the manganese-doped titanium dioxide nanoparticles did not cause significant lethality in *Xenopus laevis* embryos and tadpoles; however, unfiltered samples posed lethality in zebrafish.

Nogueira et al. (2015a) investigated the ecotoxicity of solid residuals resulting from the treatment of three effluents (olive oil mill, kraft pulp mill, and mining drainage) using two nanomaterials, including titanium dioxide and iron(III) oxide (Fe_2O_3). They found that the solid residues could pose adverse effects on *Chironomus riparius*, although the effects depend on the type of effluent treated, as well as on the organic and inorganic compounds attached to the nanomaterials. In a related study, Nogueira et al. (2015b) assessed the ecotoxicity of nickel oxide (100 and 10-20 nm), Fe_2O_3 (85 × 425 nm), and titanium dioxide (< 25 nm), to a series of aquatic organisms. They found that freshwater species were more sensitive than marine species and that the nickel oxide with a diameter of 100 nm was the most toxic, followed by the smaller diameter nickel oxide, titanium dioxide and Fe_2O_3.

Wastewater Treatment

Treatment Plant. A study to assess endotoxin exposure among sewage treatment plant workers and its effect on across-shift changes in respiratory airflow was carried out (Cyprowski et al., 2015). It was concluded that relatively low levels of endotoxin among sewage treatment plant workers might cause small, but significant across-shift declines in forced expiratory volume in one second and that certain respiratory protection should be provided. Rangamani et al. (2015) investigated the health problems of sanitation workers in a town in Karnataka, India. They

identified a number of issues in current health and safety of sanitation workers in the area and suggested provision of an adequate health-monitoring and healthcare system for the workers. Shiota et al. (2015) collected the dust from five fluid-bed wastewater sludge incinerators classified by particle size. The average fine particulate matter ($PM_{2.5}$) level was 0.00014-4.8 mg/m^3 and the total predicted amount of $PM_{2.5}$ emissions from wastewater sludge incinerators for all plants in Japan would be 1.0-8.9 tons per year.

Impact of Treatment on Toxicity. Surujlal-Naicker et al. (2015) studied the toxicity of estrogenic hormones and the removal of toxicity in full-scale WWTPs using the marine bacterium, *Vibrio fischeri* to determine if there was a correlation between the hormones and the toxicity in the effluents. The results of this study revealed that the toxicity of the influent could be reduced to a certain extent in the biological treatment and that the residual estrogen contents as well as the toxicity could be reduced in certain WWTPs as well. Zhang, Sun et al. (2015) reported that the acute toxicity to *Scenedesmus obliquus* could be reduced in municipal WWTPs in northeast China. The results indicated that while the conventional activated sludge treatment could completely remove the algal growth stimulation effect, the sequencing batch reactor and conventional activated sludge techniques could remove the toxicity to cell membrane integrity and partially reduce the acute toxicity on superoxide dismutase.

Lee, Kwon et al. (2015) used pure and surface-modified clay balls as adsorbents for nutrients removal and evaluated the toxicity of tested adsorbents. The maximum phosphate adsorption capacities were found to be 8.869 and 0.084 mg/g of the surface-modified and pure clay ball and the cytotoxicity test showed a little cytotoxic effect of the modified adsorbents on the human cells. Lassonde et al. (2015) conducted a study with an organ culture system to confirm that ozone could remove four parent estrogenic compounds and eliminate the negative effects on testis growth, higher rates of apoptosis, when exposed to the municipal wastewater effluent containing 17β-estradiol treated with ozone. Singh et al. (2015) used a real-time flow-through exposure system to evaluate the innate immunity of goldfish exposed to a recycled water, and ultraviolet/hydrogen peroxide-treated recycled water. Obvious down-regulation was detected in cytokine gene expression in kidney, liver and spleen of fish and the effects were found to be related to changes in the profile of xenobiotics in the reuse water during various seasons, while applying high doses of ultraviolet/hydrogen peroxide could not remove the xenobiotics completely.

Wastewater Reuse

Paranychianakis et al. (2015) investigated the evolution of reuse criteria worldwide and addressed emerging issues related to ecological and public health risks that had not addressed adequately in existing criteria. They specifically focused on European Union (EU) countries and found that the criteria enacted in Greece, Italy, and Spain would probably inhibit the development of water reuse projects and increase the costs. The knowledge of urban water cycle and water reuse perceptions of students in a university community in Canada was studied

by Velasquez and Yanful (2015). They found that people were more likely to accept reclaimed wastewater for applications that did not involve drinking or close personal contact and that the concerns people had were about the presence of chemicals such as pharmaceuticals from reclaimed water and the long-term effects on exposure to these contaminants. Soller et al. (2015) performed two hypothetical direct potable reuse case studies by a quantitative relative risk assessment to predict the possibility and severity of risk to the environment expose to a risk agent. The results indicated that how quantitative relative risk assessment could be used to inform certain water supply decisions relating to industrial wastewater treatment, pretreatment/source control, advanced treatment and drinking water treatment for direct potable reuse. Yang, Liu et al. (2015) evaluated the toxicities of chlorinated saline wastewater and chlorinated fresh wastewater effluents from toilet flushing to the marine organisms. The results showed that the chlorinated freshwater wastewater effluents were more toxic to marine species than chlorinated saline wastewater effluents were, due to the low salinity and organic matters contained in the freshwater, and the researchers also suggested the use of seawater in lieu of freshwater for toilet flushing might mitigate the acute effect to marine organisms.

Agricultural Reuse

South Asia. Health risk of heavy metals through consumption of market food crops that were wastewater irrigated in the Sialkot and Gujranwala districts in Pakistan was investigated (Khan, Malik et al., 2015). The concentrations of lead and cadmium in all crops and the concentration of chromium in most vegetables exceeded the recommended limits of the Food and Agriculture Organization of the World Health Organization (WHO/FAO) and the health risk index was greater than one in *Triticum aestivum* for lead intake in Gujranwala and lead and cadmium intake in Sialkot. Khan, Bibi et al. (2015) evaluated the magnitude and health risk of heavy metal and metalloid pollutants in soils and sponge gourd (*Luffa cylindrica* L.) at two sites in Sargodha, Pakistan irrigated with wastewater. The study found that the metal and metalloid levels in the soils were below maximum permissible limits and that the health risk index was greater than one due to manganese, molybdenum, lead, cadmium, copper, arsenic, nickel, and zinc, while it was less than one due to iron, selenium, and cobalt. Ahmad et al. (2015) investigated the difference in heavy metal contamination in Pakistan from two irrigation sources; canal and wastewater. It was found from their study that wastewater irrigation led to more elevated levels of heavy metals such as cadmium, molybdenum, and lead in the crops.

Khan, Khan et al. (2015) studied the heavy metal accumulation in wastewater irrigated soils, vegetables and fodder crops in the periphery of District Dera Ismail Khan, Pakistan during 2009-2010. The investigation indicated that cadmium, copper, lead, and zinc were excessively accumulated, beyond permissible limits, in a majority of tested vegetables and fodder crops, and chromium, nickel, manganese, and iron were below permissible limits in the vegetables and fodder crops. Ashfaq et al. (2015) studied the heavy metal uptake by pumpkin *Cucurbita maxima*

produced in soil irrigated with sewage effluent in peri-urban areas of Sargodha City, Pakistan. This study indicated that the consumption of contaminated pumpkins might pose a health risk due to the presence of some heavy metals. Khan, Firdos et al. (2015) assessed heavy metals accumulation in varieties of wheat irrigated with municipal sewage water.

The extent of heavy metal contamination in vegetables grown on soil irrigated with untreated sewage water for the last four decades in suburban Peshawar, Pakistan was investigated by Ullah and Khan (2015). The concentrations of heavy metals in soil and sewage water have exceeded the maximum permissible limits of the WHO. Noureen et al. (2015) performed a study to assess the effect of wastewater irrigation on the concentrations of lead and cadmium among brassica, spinach, radish and coriander in Haripur area of Pakistan. It was found that the higher lead concentration in wastewater enhanced its level in both soil and plants of the respective field as compared to cadmium, and both metals in vegetables exceeded the maximum permissible limits of the WHO.

Saldias et al. (2015) looked into the policy and regulation of sewage reuse for agriculture in the City of Hyderabad, India. Results showed that the wastewater reused for agriculture was practiced indirectly and unplanned, thus developing the institutional setup and identify the restraints ambient development of a formal practice were suggested to fully benefit from the reuse practice while reducing the possible adverse effects on public health and the environment. Chopra and Pathak (2015) carried a study on accumulation of heavy metals in the vegetables including *Beta vulgaris*, *Phaseolus vulgaris*, *Spinacia oleracea*, and *Brassica oleracea* grown in the wastewater-irrigated soil near Bindal river, Dehradum India, and found the maximum accumulation of metals for lead, copper, zinc, nickel, cadmium, and chromium. It was concluded that the long-term wastewater irrigation caused accumulation of heavy metals in vegetables sold in Dehradun City, which might result in potential health risks to consumers.

Minhas et al. (2015) conducted an eight-year field experiment comparing food grain, agro-forestry, fodder and vegetable production systems and quantified responses to fertilizers when irrigated with sewage vis-à-vis groundwater. Although they found that the sewage proved as a resource for improving crop productivity, sustainability and saving fertilizer costs, pathogenic contamination (aerobic bacterial plate counts $5.0 \times 10^5 - 4.2 \times 10^8$ cfu/g and *E. coli* $< 2 \times 10^2 - 7 \times 10^5$) might cause health risks and would need to be regulated. Varkey et al. (2015) investigated the effects of application of domestic sewage water on physical, chemical and biological properties of soils at three sites in Gabbur, Mavanur and Katnur Villages near Hubli city in North Karnataka, India for over four decades. More organic carbon content, nutrients, sulfur, copper, boron, as well as bacteria, fungi and actinomycetes were found in sewage irrigated soils.

Western Asia and Middle East. Aydin et al. (2015) conducted a study to identify heavy metal accumulation in soils in Konya, Turkey from wastewater irrigation over 40-years. By examining wheat's ability to uptake these heavy metals, they were able to conclude that

lead posed the greatest threat to wheat contamination in the Konya soils. Asgari and Cornelis (2015) investigated the heavy metal accumulation in wheat and corn and health risks associated with the irrigation of farmland using treated municipal wastewater in Esfahan, Iran. Among the heavy metals analyzed, the concentrations of cadmium and chromium were found to be above the permissible limits determined by the United States Environmental Protection Agency (US EPA) and the health risk indices were high, particularly for the wheat grain. Naseri et al. (2015) investigated the concentrations of some heavy metals such as cadmium, lead, chromium, nickel and cobalt in domestic cultivated and imported rice sold in the Shiraz, Iran markets, and found that the average levels for lead and cadmium in domestic cultivated and imported rice were significantly higher than allowable limits set by the WHO/FAO.

East Asia. A field study was conducted in seven parks in Beijing, China with different histories of reclaimed water irrigation and twenty soil attributes were analyzed to evaluate the effects of reclaimed water irrigation on the soil health conditions (Chen, Lu et al., 2015). They found that the soil health conditions were improved with reclaimed water irrigation. Gao, Liu et al. (2015) compared soil samples from wastewater-irrigated and groundwater-irrigated areas to compare the hepatotoxicity and nephrotoxicity of organic contaminants in wastewater-irrigated soils. The study's results showed that the toxicity present in the wastewater-irrigated soils could cause changes of liver functions in mice and DNA damage of hepatocytes in rats, and could lead to oxidative damages of kidney and liver. Liu et al. (2015) reported the significant genotoxicity of wastewater samples collected from the Dongming discharging river in Shijiazhuang city, China and evaluated the suitability of the wastewater for irrigation. The authors suggested potential harmful effects of such practice on the local resident.

Lu et al. (2015) presented a comprehensive map of both water and soil pollution risks on food safety in China and suggested complete policies addressing the water and soil pollution for implementation of food safety using a holistic approach. Gao, Liang et al. (2015) investigated the long term effect on soil irrigated by river water that received treated wastewater in arid and semi-arid regions of China and compared with the soils irrigated by groundwater. They showed that the long term irrigation with the affected river waters had increased microbial activity and had a beneficial effect on soil microbial microbiological characteristics. Long-term river water irrigation was also shown to pose a potential risk to human health due to accumulation of heavy metals including mercury, cadmium, arsenic, lead, copper, chromium, and zinc. Liang et al. (2015) investigated the toxicity of soil irrigated with gray sewage and treated domestic sewage. The results showed that the soil quality was not affected by the treated sewage except for the heavy metal accumulation, while the soil quality significantly changed in terms of heavy metal accumulation, toxicity and genotoxicity with the grey sewage irrigation.

The concentration and distribution of six major phthalate esters in 39 wastewater-irrigated agricultural soil samples was investigated in the Wangyang River basin in

Hebei Province, China (Zhang, Liang et al., 2015). The study found the total concentrations of the six phthalate esters ranged from 0.191 μg/g dw to 0.457 μg/g dw with di(2-ethylhexyl) phthalate and di-*n*-butyl phthalate the dominant species, and suggested dense anthropogenic activities and random garbage disposal were possible sources of these phthalate esters. In order to evaluate the effects of coal mining wastewater irrigation on soil enzymes, physiological properties of wheat and potential risks of heavy metal contamination to wheat crop, Ma et al. (2015) conducted a series of pot experiments with three mining wastewaters, including leachate of coal gangue, coal-washing wastewater and precipitated coal-washing wastewater. They found that all three wastewaters exhibited significant toxicity in terms of the activities of soil enzymes, root activity and net photosynthetic rate of wheat, as well as the grain yield and the accumulation of heavy metals (including chromium, lead, copper, and zinc) in wheat grain. Massaquoi et al. (2015) evaluated the health risk and accumulation of heavy metals due to three years of post-wastewater irrigation in soils, vegetables and farmers' hair in China. They concluded the persistence of heavy metals in soils and plants previously irrigated with wastewater, although high metal concentrations in farmers' hair samples was not related to soil metal concentrations.

Wang, Liu et al. (2015) assessed the heavy metal concentrations in soils and fruits and their possible human risk in apple orchards of Liaodong Peninsula, a well-known fruit-producing area of China. The results showed that all the orchard soils were with low pollution index values (smaller than one) for cadmium and zinc, while some of the samples exceeded the allowable levels of chromium and copper. Wang, Zeng et al. (2015) studied the ecological risks of heavy metals such as cadmium, copper, lead, zinc, chromium, arsenic, and mercury through crops (wheat and rice) grown in the Tianjin sewage irrigation area in northern China, and discovered that continuous application of wastewater had led to accumulation of heavy metals in the soil, and cadmium, zinc, and mercury were the main pollutants.

Physicochemical properties and microbial risks of soils and vegetables (Pakchoi) irrigated with rural domestic wastewater in China were studied (Yang, Kong et al., 2015). Significantly increased nitrate content and pathogenic bacteria were found in soils and edible parts of investigated vegetables irrigated with raw sewage, while soils and plants irrigated with treated wastewater were not found different from those irrigated using tap water. Zeng et al. (2015) evaluated health risks of heavy metals, namely zinc, copper, chromium, nickel, lead, and cadmium, through dietary intake of wheat in Tianjin, China. The study found that accumulated cadmium and zinc concentrations in 54.5% and 18.25% soil samples exceeded the permissible limits in China, and the risk assessment of heavy metals through wheat consumption found that 36.4% hazard index values for adults and 63.6% hazard index values for children exceeded one.

Heavy metals concentrations in soil and vegetables irrigated with domestic WWTP effluent in Republic of Korea were investigated (Kim et al., 2015). The monitoring results showed decreased concentrations of copper, cadmium, and lead in soil and increased

concentration of zinc in soil during the irrigation period, but all tested metal concentrations were below the soil pollution standards of the Republic of Korea. Based on the risk assessment, the consumption of vegetables grown with domestic wastewater was considered safe.

Africa. Antwi-Agyei et al. (2015) studied the consumer risk of contaminated agricultural products due to wastewater irrigation in Accra, Ghana. The study revealed that more than 80% of produce samples were contaminated with *E. coli* and that the key risk factors were found to be the irrigation water and soil at the farm. Akoto et al. (2015) investigated the ability of lettuce to uptake heavy metals from wastewater irrigation. Their study concluded that the high levels of heavy metals in the wastewater irrigation could be easily transferred to soils and lettuce which might pose a health risk to crop consumers. Cherfi et al. (2015) conducted a performance survey on the urban WWTP of the city of Boumerdes, Algeria in order to assess the potential of reuse of its treated water. From this study, no adverse effects on resident's health were found from consumption of vegetables irrigated with treated wastewaters. Malan et al. (2015) performed a study to evaluate the extent of heavy metal contamination in the Philippi horticultural area in the Western Cape Province, South Africa. Toxic heavy metals were found in the soils during the summer cropping season and in the crops produced in winter.

Americas. Lara-Viveros et al. (2015) determined the concentration of cadmium and lead in soil and different plants, including one alfalfa, tow sunflowers and two maize which accept sewage irrigation in the Mezquital Valley, Hidalgo, Mexico. The results showed that both cadmium and lead in maize were lower than those observed in soil, sunflowers contained lowest levels of the two metals, while the cadmium concentration was found to be higher in alfalfa (0.07 mg/kg) than that in soil (0.03 mg/kg). Malafaia et al. (2015) conducted a 13-week study on the possible physical and biochemical damage in Swiss mice fed with corn produced in soil containing tannery sludge vermicompost and irrigated with domestic sewage wastewater. Since no changes were found in body weight of the animals, and various physical parameters of the animals were stable, they preliminarily concluded that the corn produced in this way was innocuous to animals, but further studies would be needed to investigate other variables not measured in this study.

Europe. Petousi et al. (2015) performed a three-year monitoring study of salts, nutrients, micro-elements, heavy metals, toxic-pollutants and pathogens in soil and leaves of olive trees that were irrigated with three types of water: secondary treated wastewater, tertiary treated wastewater and tap water in Crete, Greece. Results showed increasing concentrations of nutrients (primarily phosphorus and potassium), sodium, magnesium, calcium and boron in soils two years after the application of both types of treated wastewater in comparison to tap water; however, no effects on soil concentrations were found. Sales-Ortells et al. (2015) investigated the health risk by consuming the lettuces irrigated with tertiary effluent containing norovirus in Catalonia, Spain. Results showed that the risk of disease would be highly related to the levels of norovirus in the treated water and the lettuce

consumption and recommended to achieve 4.3 log removal of the norovirus in the tertiary wastewater.

Others. Becerra-Castro et al. (2015) critically reviewed possible effects of raw wastewater irrigation on soil microbiota and human and environment health. Grattan et al. (2015) assessed ground waters and recycled municipal wastewaters with high concentrations of boron and salts as potential water sources for irrigation of *Citrus* spp. The results suggested that existing boron tolerance guidelines for oranges (0.5-0.75 mg/L in the soil solution) should not be modified, and that the maximum boron concentration in the irrigation water fell between 0.3 and 0.5 mg/L over the long term.

Rastetter and Gerhardt (2015) investigated the toxic potential of using various wastewater sludge as fertilizer in agriculture by a series of tests using *Eisenia fetida*, *Lemna minor*, *Gammarus fossarum*, as well as by the analysis of nutrients, organic pollutants and heavy metals. It was found that the dewatered sludge samples were toxic on *G. fossarum* and *L. minor* under laboratory conditions, while it was assumed that under the field condition, the acute toxicity of the sludge samples might be much lower due to lower dosing, adsorption and dilution. Mishra et al. (2015) investigated the toxic metal absorption in radish crop and soil treated with sewage sludge in research plot in Allahabad Agricultural Institute, Deemed University, Allahabad, India. It was found that suffering the irreversible problems of cumulative loading of trace elements and in any type of soil in long term effect could be inevitable since the heavy metals could be passed to higher levels in the processes by successive applications of municipal sewage sludge of agronomic rates.

Greywater Reuse

Busgang et al. (2015) carried out an epidemiological study for the assessment of health risks associated with greywater reuse for irrigation in arid regions. There was no difference in the prevalence of water-related diseases between control and graywater users, and the authors postulated that QMRA was conservative and could safely be used toward the establishment of regulations governing graywater reuse. The health risks and presence of organic micropollutants in greywater as a potential source for potable water was investigated by Etchepare and van der Hoek (2015). Of the 280 micropollutants that had been detected in greywater, fourteen compounds were identified to pose an appreciable concern to human health. The findings would be helpful to define the methods and goals of treatment in future greywater reclamation plants for potable water production.

Shamabadi et al. (2015) investigated and designed an onsite grey water reuse system at Hazrat-e-Masoumeh University, Qom, Iran. Trickling filters with suspended plastic media, a settling tank and a chlorination system were applied. It was the first report of building an onsite grey water treatment system in an Iranian University. In order to test grey-water quality and its effects on soil nutrient content following four successive growing seasons, Mzini and Winter (2015) performed an experimental field study in the vicinity of the Umtata Dam, northwest of the town of Umtata, South Africa. The analyses results

showed that average sodium (16 mg/L) and chloride (15 mg/L) ions were considerably higher for grey-water than other treatments; however, they both were lower than the 100 mg/L limit per the South African Water Quality Guidelines.

Katukiza et al. (2015) investigated grey water characteristics and loads in an urban slum in Uganda. The analysis results showed that the chemical oxygen demand was 9,225 ± 1,200 mg/L in laundry grey water, 71,250 ± 1,011 mg/L in kitchen grey water and 4,675 ± 750 mg/L in bathroom grey water and that the maximum concentrations of *E. coli* and total coliform in the bathroom grey water were 2.05×10^7 cfu/100 mL and 1.75×10^8 cfu/100 mL, respectively, while the maximum concentration of *Salmonella* spp. in the laundry grey water was 7.32×10^6 cfu/100 mL.

Wastewater Disposal

Impact on the Coastal Environment. Cabral-Oliveira et al. (2015) studied the accumulation of trace elements, including copper, zinc, lead, nickel, cobalt, cadmium, iron, manganese, and arsenic, in edible rocky shore species: mollusks (*Mytilus galloprovincialis*, *Patella ulyssiponensis*, and *Phorcus lineatus*) based on the comparison between one sewage-impacted area and two reference areas. From this study, it was discovered that the concentrations of trace elements in the soft tissues of the selected mollusks could be affected by the presence of sewage discharges, and the sewage pollution increased the concentrations of arsenic in the mollusk species, emphasizing its potential damaging effects on natural systems and edible species. Trabalon et al. (2015) investigated the synthetic musks in samples of 10 widely consumed fish and shellfish species from Tarragona (Catalonia, Spain). The results suggested that the concentrations of musks in fish and shellfish should not pose human health risks for the adult population living in Tarragona.

Krumhansl et al. (2015) monitored the sewage quality of five arctic communities and evaluated its effect on marine benthic invertebrates. Minimal impacts were detected to benthic communities for their evenness, density, diversity, species richness, and some differences in species composition in four out of the five communities, where the population was <2,000 people and variation occurred in the other community depending on the effluent quality and quantity. Rodrigues, Feijo-Oliveira et al. (2015) evaluated the impacts of wastewater on the metabolism of the Antarctic fishes *Notothenia coriiceps* and *N. rossii* in the Brazilian Antarctic Station Comandante Ferraz, King George Island and Admiralty Bay. The two species of Antarctic fish presented different metabolic responses to the wastewater and *N. coriiceps* exhibited greater susceptibility to the toxicity of the pollutants.

Maranho, DelValls et al. (2015) studied the potential risk of wastewater discharge to benthic biota at the Bay of Cadiz, Spain. They proposed a methodology to use marine clams *Ruditapes philippinarum* to assess the risk. In a related study, Maranho, Garrido-Perez et al. (2015) investigated the adverse effects of WWTPs on sediment quality at the Bay of Cadiz using a battery of acute bioassays and chemical analysis. They chose five

sites directly affected by WWTPs effluents and one control site, and found that the Bay of Cadiz was contaminated by polycyclic aromatic hydrocarbons, metals, detergents and pharmaceutical products. Results also showed that acute toxicity and chemical contamination differed significantly across the five sites with seasonal variations. Ezekwe and Edoghotu (2015) investigated the water quality of the Andoni River estuary in the eastern Niger Delta of Nigeria. The study found that the sampled sites did not meet international standards for nitrate, heavy metals and hydrocarbons, generally had dissolved oxygen concentration below 5 mg/L and that 20% of the sampled sites had turbidity levels above recommended standards for estuarine ecosystems. This study concluded that the whole river system had a declining capacity to support fish and aquatic grass habitats due to pollution from hydrocarbon sources, erosion of contaminated sediments, discharge from human waste, and long distance river pollution. Tayeb et al. (2015) investigated the effects of industrial and urban effluents on the coastal marine environment in Oran, Algeria. A follow-up research showed that consideration needed to be given at the higher ecological impart from the concentrations of oil and grease released into the bionetwork and the results revealed that most beaches in Oran were under the national environmental standard limit as well.

Li, Chen et al. (2015) evaluated the genotoxicity and embryotoxicity of sediments from Yangtze River estuary which suffered from abundant sewage from the coastal cities using *Danio rerio* embryos. Results presented that the *Danio rerio* embryos exhibited an increasing death rate, abnormal development, lower hatching rate and heart rate after exposing to the sediment 96 hours and obvious genotoxicity was detected in the samples. Falkenberg and Styan (2015) addressed the concern that the wastewater discharge of desalination plants might result in unique impacts on the biota and surrounding environment that could not be predicted using existing plants. To address this concern, three recent Australian case studies that had conducted toxicity assessments using whole effluent prior to the construction of the desalination plant were reviewed. Although the whole effluent toxicity assessments were limited by time available for testing, this method showed significant benefits and could be used to better forecast the impacts of proposed desalination plants on a case-by-case basis.

Impact on Surface Water. Rodrigues, da Silva et al. (2015) analyzed the water quality of stream Campo Alegre influenced by the WWTP from the City of Santa Helena de Goias, Brazil and compared the treated water, upstream and downstream water quality in dry and wet climatic periods. Results showed that the stream was deteriorated by the treated wastewater, especially during the dry period with respect to the pathogenic microorganisms. Sibanda et al. (2015) summarized a series of public and environmental health problems in South Africa due to the increasing discharge of sewage effluents. Those problems included thinning of riverine macroinvertebrate diversity, massive fish mortalities, microbial community structures transferred to waterborne pathogens, increased levels of endocrine-disrupting

compounds and elevated bioaccumulation of metals in edible plant parts.

In order to evaluate surface water and the sediment quality of rivers connected to WWTPs with different treatment technologies, fish embryo tests with *Danio rerio* were conducted by using native water and sediment samples collected upstream and downstream of four WWTPs in Southern Germany (Thellmann et al., 2015). They found the higher embryotoxic potentials in water and sediments collected downstream of the WWTPs equipped with sand filtration than in the water sample from downstream of both WWTPs upgraded with a powdered activated carbon stage. Popovic et al. (2015) evaluated the impact of treated wastewater on the health status of fish living downstream, microbiological contamination and antimicrobial resistance, fish tissue structure, blood biochemistry, oxidative stress, genotoxic effects, as well as multi-xenobiotic resistance mechanism using two organismic biosensors, namely Prussian carp *Carassius gibelio* and earthworm *Eisenia fetida*. They found a substantial increase in plasma values of urea, total proteins, albumins and triglycerides and a weighty decrease in the activity of plasma superoxide dismutase in carp from the effluent-receiving canal.

Tabet et al. (2015) examined the mutagenicity and genotoxicity of urban wastewater of the City of Guelma in Algeria between April 2012 and April 2013 in order to assess the water pollution and its effect upon human health and river biotic communities. A decrease in the percentage of cells in prophase and an increase in the telophase were observed with a significant decrease in mitotic index and anaphase bridges, disturbed anaphase-telophase cells, vagrants and stickiness in anaphase-telophase cells were the main observed aberrations. Manzano et al. (2015) evaluated the genotoxicity of surface waters impacted by domestic and industrial wastewaters using the hepatoma tissue culture comet assay in Sao Paulo, Brazil.

Luminescent bacteria and zebrafish embryos were used as bioassay tools to assess the ecotoxicity of surface water from the Huangpu River, China (Zhang, Li et al., 2015). It was found the river water samples inhibited *Vibrio qinghaiensis* sp. Q67 with inhibition rates 0-34.6±4.82%, increased the lethal rates and caused morphological abnormalities of zebrafish embryos, and that the toxicity was higher in winter than in summer and higher in the river sections impact by anthropogenic activities.

Hospital Wastewater

Fekadu et al. (2015) conducted a cross-sectional study on hospital wastewater, to determine if partially metabolized and residual quantities of antimicrobials present in hospital wastewater could result in exposed bacteria developing a resistance to biocides. The study concluded that effluents from the two hospitals tested contained antibiotic-resistant bacteria, which might pose a threat to public health. Kern et al. (2015) studied the ecotoxicity and genotoxicity of hospital laundry wastewaters from a regional hospital located in Rio Pardo Valley, Reo Grande do Sul, Brazil. The results indicated significant toxicity of these hospital effluents and warranted more work to develop proper treatment methods.

Li and Lin (2015) conducted a study to investigate the acute toxicity of hospital effluents containing pharmaceuticals using several vertebrates and *Cyprinus carpi* and the impact of solar irradiation. Their results revealed that the solar irradiation for five days had increased the fish toxicity. Sharma et al. (2015) analyzed the mutagenic and genotoxic potential of sewages from three large hospitals in Jaipur, India by SOS chromotest and *Salmonella* fluctuation assay. Results found a high genotoxic potential of untreated water, while slight genotoxicity was detected in the treated water.

Antibiotic contamination of hospital wastewater in seven hospitals in Bangkok, Thailand was studied by Hamjinda et al. (2015). Of the 19 antibiotics that were detected, norfloxacin appeared in the highest concentration (12 μg/L), although most of the toxicity was reduced after treatment leaving only slight toxicity on some test species which may be due to chlorination. Neri-Cruz et al. (2015) conducted a study to investigate the oxidative stress in the common carp *Cyprinus carpio* induced by a hospital wastewater in Mexico. They found significant increases in hydroperoxide content, malondialdehyde content and protein carbonyl content in exposed specimens, mostly in gill, liver and brain. In addition, the activities of the antioxidant enzymes superoxide dismutase and catalase were also increased in liver and brain. Rani et al. (2015) investigated the influence of geochemical factors and microbiome structure in dental wastewater on mercury methylation. They found that the concentrations of total mercury, methyl mercury and heavy metals were high in dental wastewater and that there were significant correlations between the bacterial community, mercury levels and geochemical factors including pH and the predicted total amount (not fraction) of neutral mercury-sulfide species.

Industrial Wastewater

Tannery and Textile. Investigation of tannery wastewater affecting local fish biosystems in East Calcutta wetlands in West Bengal, India was performed by Aich et al. (2015). It was concluded that the exposure to tannery wastewater had increased fish stress enzyme activity affecting hormonal and reproductive processes within the local aquatic biosystems. The toxicity of tannery and textile effluents was evaluated by a battery of toxicological bioassays and toxicological indices (Huang et al., 2015). The results indicated the reduction rates of toxicity in tannery and textile effluents were 36.8% and 23.2%, respectively based on the potential ecotoxic effects probe, and the major toxicant of textile effluent was non-polar organic pollutants, filterable compounds, heavy metals, oxidizing substances and volatile compounds. Sorsa et al. (2015) evaluated the heavy metal concentrations and physicochemical characteristics of treated water along the discharge route from Hawassa Textile Factory, Ethiopia. Data illustrated that physicochemical parameters (total dissolved solids, pH, conductivity and phosphate) in the effluent samples at the two sampling sites were over national/international discharge limits, while the heavy metal levels were below acceptable ranges of the provisional discharge limits. However, long-term accumulation would be a threat to public and environment.

Idel-Aouad et al. (2015) studied Fenton and Fenton-like processes in homogeneous and heterogeneous phases in the mineralization and decolorization of the dye Acid Red 14. The treated solutions were analyzed with the Microtox assay and it showed that the toxicity intrinsic to the chemicals used in the process was lower than that of the degradation products in the treated dye solution. Iqbal et al. (2015) evaluated the performance of gamma radiation treatment for detoxification of pollutants in textile wastewater. The study indicated that the cytotoxicity reduction was 39.56% in human red blood cells, 49.65% in sheep red blood cells, and 79.63% in brine shrimp, and that the mild mutagenicity in untreated wastewater was removed to not detected level after gamma radiation. Punzi et al. (2015) conducted a study on the combined anaerobic-ozonation process for the treatment of textile wastewater containing azo dyes. They found that both untreated and biologically treated textile effluents had mutagenic effects; however, no mutagenicity was detected in the effluents subjected to a longer exposure to ozone.

Agri-Food. Julien and Safferman (2015) evaluated the impact of food processing wastewater organic and hydraulic loading on metal mobilization within the soil during land-application treatments. This study demonstrated excessive organic loading mobilized naturally occurring metals in the soil and metals being applied with the wastewater and recommended a waste application frequency of twice a day to improve the treatment effectiveness. Rusan et al. (2015) conducted a research about the phytotoxicity of olive mill sewage treated by various technologies, including solar Fenton oxidation, microfiltration followed by reverse osmosis process, microfiltration followed by nanofiltration, aerobic biological technology in a Jacto Reactor, and dilution with various ratio of tap water, on seed germination of barley (*Hordeum vulgare* L.). The results indicated that the phytotoxicity significantly decreased by all the techniques tested except for the dilution with tap water less than two times.

Oil and Gas. Chemicals used and/or produced by oil and gas operations were investigated for endocrine-disrupting activities and reproductive and developmental outcomes in male mice after prenatal exposure (Kassotis et al., 2015). Twenty-three commonly-used chemicals were found to activate or inhibit endocrine-disrupting activities, synergistically, additively, or antagonistically, and the prenatal exposure of male mice to a mixture of chemicals at 3, 30, and 300 μg/kg·d caused decreased sperm counts and increased testes, body, heart, and thymus weights and increased serum testosterone. Mrdjen and Lee (2015) reviewed the potential impacts of high-volume hydraulic fracturing operations on surface water and public health. They indicated the exposure to surface water contaminated with the chemicals used in the high-volume hydraulic fracturing might increase cancer risk and turbidity of water, which might lead to pathogen survival in the surface water. Zhang, Hammack et al. (2015) investigated the fate of radium 226 in three Marcellus Shale flowback water storage impoundments in southwestern Pennsylvania. The sampling results revealed that radium 226 concentration in storage impoundments increased during the reuse of flowback water and the concentration in the bottom sludge

increased from <10 pCi/g in fresh sludge to several hundred pCi/g in aged sludge, and the radiation dose equivalent was found below the National Research Council limit.

Gupta et al. (2015) studied the genotoxic potential of a refinery wastewater (Mathura Refinery, Uttar Pradesh, India) using in vitro tests, including plasmid nicking assay, single cell gel electrophoresis, and S1 nuclease assay. It was found that the wastewater led to formation of comets with abnormal tail lengths and proportions, had a genotoxic and potentially damaging effect on DNA, and interacted with calf thymus DNA. Marques et al. (2015) reported the positive effect of the electroflocculation treatment to reduce a toxic effect of oilfield produced water on seed germination, seedling development, and biomass production of sunflower. Steliga et al. (2015) examined the toxicity variations during treatment of wastewater containing petroleum hydrocarbons from an oil plant. Total petroleum hydrocarbons decreased to 49.7 mg/L after the pretreatment and decreased by 89% during the biological treatment, while phenols, xylene and polycyclic aromatic hydrocarbons were removed by 69%, 62% and 46% at the same time and the treated water became non-toxic after the whole treatment.

Pulp and Paper. Dey et al. (2015) reported toxic effects of bleached sulfite pulp mill effluents in fish (*Heteropneustes fossilis*) gills, with optical, scanning electron, and transmission electromicroscope. Based on the analysis, adverse effects include dilation, curling, displacement, degeneration, deposition and severe congestion were found in the grill structures. Ding et al. (2015) carried out a preliminary investigation on the bioaccumulation and the ecotoxic effects of the pulp and paper wastewater for irrigating reed fields, by using the standardized polyurethane foam unit method. It was suggested that this standardized method might guide the control of the pulp and paper wastewater irrigating within the reed fields ecological systems. Dsikowitzky et al. (2015) performed non-target screening analyses of wastewaters from five different paper production sites, including an extended analysis of one facility, for the identification of volatile non-polar to semi-polar organic contaminants. Their findings implied that the paper industry discharges posed a risk to the populations of sensitive macroinvertebrates. Kaur and Dua (2015) investigated the fish toxicity of wastewater from two sites in Tung Dhab drain in the state of Punjab, India. It was found that the wastewater near a paper mill was more toxic to a freshwater fish *Channa punctatus* than other effluents based on their 96 h toxicity study.

Mining. Laliberte (2015) conducted a study on reducing the toxicity of gold-mine effluent by biodegrading the ammonia, cyanides, cyanates and thiocyanates with aerated moving bed biofilm reactors and precipitating the copper. The results showed that both the treatment process and treated effluent were stable between 4 and 25°C, with no obvious changes in the treated water quality. Nawab et al. (2015) conducted a study to evaluate the lead and cadmium concentrations in the soil and medicinal and fodder plants grown in chromite mining-affected areas, Northern Pakistan. The concentrations of lead and

cadmium in most of the plant species grown in surrounding areas of mines were higher than their maximum allowable limits set by the WHO/FAO for herbal (10 and 0.3 mg/kg, respectively) and edible (0.3 and 0.2 mg/kg, respectively) plants.

A geochemistry study of mercury was conducted by Marrugo-Negrete et al. (2015) to evaluate the speciation and bioavailability of mercury in sediments of two tropical swamps contaminated by artisanal and small-scale gold mining wastewater. The percentage of the bioavailability fraction was found to be elevated by up to 15%, meaning a potential risk to the aquatic environment and human health. Estrogenic activities and potential xenoestrogens were studied in a coking WWTP from different stages (Zhao et al., 2015). The potencies of estrogenic activities in influent, primary effluent, anaerobic effluent and final effluent were found to be 1,136 ± 269, 1,417 ± 320, 959 ± 69, and 0.87 ng/L of 17β-estradiol equivalent, respectively, indicating complete removal of estrogenic activities from the coking wastewater, and the study also found that the potential xenoestrogens were the derivatives of indenol, naphthalenol, indol, acridinone, fluorenone, and carbazole.

Other Industrial Effluents. In order to evaluate the toxicity of wastewater samples and aircraft de-icing/anti-icing fluids, Mohiley et al. (2015) conducted two bio-tests on the samples collected from a regional airport: the *Lemna* growth inhibition test and the luminescent bacteria test. They found that aquatic plants and marine bacteria showed higher sensitivity towards the fluid than to the wastewater samples, and the fluid and wastewater samples were more toxic towards *Lemna gibba* L. than *V. fischeri*. Geric et al. (2015) evaluated the impact of wastewater generated from washing boat hulls on marine systems. The wastewater contained copper, zinc, vanadium, chromium, iron, and lead, as well as several organic contaminants that exceeded the maximum allowable values by up to 96 times, and it was shown that electrochemical/ozonation treatment of the wastewater could greatly decrease contaminants and remove the wastewater's cyto/genotoxicity. Mori et al. (2015) evaluated the aquatic eco-toxicity of chemicals from the manufacturing processes of thin film transistor liquid crystal displays using a battery of four selected acute toxicity bioassays. Low toxicity of tetramethylammonium hydroxide was detected in the 72 h-algal growth inhibition test (*Pseudokirchneriellia subcapitata*, EC_{50} = 360 mg/L) and the Microtox test (*Vibrio fischeri*, IC_{50} = 6.4 g/L); however the 24 h-micro-crustacean immobilization and the 96 h-fish mortality tests showed high toxicity (*Daphnia magna*, EC_{50} = 32 mg/L and *Oryzias latipes*, LC_{50} = 154 mg/L).

da Rocha et al. (2015) evaluated the water quality in the Agua Boa stream, in Dourados, Mato Grosso do Sul, Brazil, that has been affected by industrial and agricultural wastewater based on five sets of water samples collected between 2012 and 2013 from three locations within the stream. There was *E. coli* and antibiotic-resistant *Pseudomonas* spp. strains and high concentrations of organic matter, hardness and iron, and an agricultural insecticide residues (thiamethoxam), which called attention to respect the normative national and international standards and supervision upon the situation from

governmental agencies. Miao et al. (2015) reviewed the current status of industrial water pollution in China to provide a better understanding of the background and extent of this serious environmental problem and to prevent and mitigate this issue. Hemachandra and Pathiratne (2015) assessed the toxicity of copper, cadmium and chromium using the *Allium cepa* bioassay, and compared with the established limits of industrial discharge to surface waters. It was found that copper(II) displayed the highest root growth inhibition, followed by cadmium(II) and chromium(VI), and suggested the regulatory limits of industrial effluent discharge be reviewed.

Noel and Rajan (2015) reviewed and discussed the global issues related to the reuse of effluents from mining, textiles, and chemical industries for agricultural irrigation. The discussion topics included potential benefits and possible health risks. Lee, Park et al. (2015) conducted a survey of the occurrence and removal of toxic metals and hazardous chemicals in 27 industrial sewage treatment plants in Korea. Levels of benzene, mercury, 1,1-dichloroethylene, and arsenic in influents to the WWTPs were above the effluent limits for indirect dischargers in industrial complex and average removal rates of volatile organic compounds, metals, selenium and 1,4-dioxane were 70%, 60%, 30% and 18%, respectively, which indicated that managing concerning non-conventional pollutants at each WWTPs is better than establishing a unified limits for all WWTPs. Kannangara and Pathiratne (2015) investigated the toxicity of industrial effluents that were causing negative impacts on the Dandugan Oya, a water canal located in the Western Province of Sri Lanka, using a plant-based bioassay with onion (*Allium cepa*).

Sludge and Biosolids

Concentrations of seven heavy metals, including cadmium, chromium, copper, mercury, nickel, lead, and zinc, were analyzed in the sludge wasted from Ankara Central Wastewater Treatment Plant in Turkey and non-cancer health risks due to child ingestion were evaluated (Kendir et al., 2015). All heavy metal concentrations were found at or below the Turkish regulation limits and cumulative non-cancer health risks associated with child ingesting were within the acceptable level suggested by the US EPA, although lead had the most contribution to the cumulative non-cancer health risks in 2012. Braguglia et al. (2015) conducted an EU project on the quality assessment of digested sludge produced by advanced stabilization processes such as thermophilic digestion integrated with thermal hydrolysis pretreatment, sonication before mesophilic/thermophilic digestion, and sequential anaerobic/aerobic digestion, with the stability index improved by adding aerobic posttreatment or by operating dual-stage process but not by pretreatment integration. It was discovered that all the digested sludge exhibited toxicity to the soil bacterium *Arthrobacter globiformist* at concentrations about factor 100 higher than the usual application rate of sludge to soil in Europe.

Chen, Zhao et al. (2015) carried out a study in sludge toxicity determined by the inhibition of luminescence in the bacterium *Photobacterium phosphoreum*, which were formed during either

acclimating or shocking starting processes with high concentration of *N*,*N*-dimethylformamide. It was found in the results that toxic substances accumulated in the sludge through various factors, including secretions from two types of sludge under *N*,*N*-dimethylformamide stress conditions. A study of the bio-accessibility of PBDEs in sewage sludge from Shanghai, China was conducted using a 3-compartment model and a 6-d Tenax extraction (Meng et al., 2015). The ratio between 6-h Tenax and Soxhlet concentrations, indicating the bio-accessibility, was found to be lower in the sludge generated from industrial wastewater treatment than those from facilities that treated mostly domestic wastewater. Pulicharla et al. (2015) studied the stability and toxicity of chlortetracycline and its metal complexes in wastewater sludge. It was found that the chlortetracycline-metal complexes were more toxic than the chlortetracycline itself for *Bacillus thuringiensis*.

Chen, Unrine et al. (2015) carried out a study on the toxicogenomic responses of a model legume *Medicago truncatlula* to aged biosolids containing a mixture of nanomaterials, including titanium dioxide, silver, and zinc oxide, from a pilot WWTP. From this study, the results indicated that the inhibition of nodulation in the engineered nanoparticle treatment was primarily due to phytotoxicity, likely caused by enhanced bioavailability of zinc ions. Bourioug et al. (2015) investigated the effects of sewage sludge amendment on snail growth and the metal transfer in the soil-plant-snail food chain was traced. There was no apparent toxic effect due to trace metal accumulation in snails while the snail growth was significantly stimulated at high rates of sludge application due to enhanced nutritional content of lettuce leaves exposed to sewage sludge.

Concluding Remarks

As with the articles written in the past years, this year's literature review featured over 160 peer-reviewed research papers dealing with many different aspects of municipal and industrial wastewater treatment, reuse and disposal. Those studies covered in this review were conducted in the countries all over the world, including Asia, Africa, Middle East, Europe, Northern and Southern Americas, as well as in the Arctic and Antarctica, which suggests the global importance of the health issues related to wastewater treatment, reuse and disposal. In particular, the potential impacts of agricultural reuse of untreated and treated wastewater on public and environmental health have attracted growing interests in the South and East Asian countries, including Pakistan, India, and China, as well as in other arid and semi-arid regions in the world. As readily-available water resources, such as surface water and groundwater, are becoming scarcer and scarcer in these regions, wastewater reuse will continue to be an important option not only for agriculture, but also for other uses, such as industrial process water, recreational water, and potable water. Although not many research papers covered in this year's literature review discussed the health effects associated with potable reuse of municipal wastewater, this topic will likely become one of the hot topics in the near future. In addition to wastewater reuse, the impacts of municipal and industrial wastewater discharges on both freshwater and marine environments will continue to be a

very important subject. More research would be needed to better understand the extent of exiting pollutions, and to control and protect the sensitive aquatic environment and precious water resources from degradation.

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