Health Effects Associated with Wastewater Treatment, Reuse, and Disposal

Yao Jin[1], Xiaoyan Qu[1,2], Yuan Li[1,2], Ruoren Yu[1], Keisuke Ikehata[1*]

ABSTRACT: A review of the literature published in 2013 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 reuse, wastewater treatment plants, wastewater disposal, and sludge and biosolids.

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

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Wastewater Management

Verbyla et al. (2013b) performed a study on wastewater infrastructures for small cities in an urbanizing world by evaluating two wastewater treatment systems in Bolivia to investigate their resource recovery potential where one employed an upflow anaerobic sludge blanket reactor and polishing ponds, the other had three stabilization ponds. They suggested that small cities in the region would better allocate their resources wisely when designing wastewater treatment facilities and should pay more attention to removing pathogenic microorganisms to reclaim water and nutrients. Jin et al. (2013) published a literature review on topics relating to public and environmental health risks associated with wastewater treatment, reuse, and disposal. The review paper covered the following topics: water and wastewater management, microbial hazards, chemical hazards, wastewater reuse, wastewater treatment plants, wastewater disposal, and sludge and biosolids.

Chemical Hazards

Pharmaceuticals and Personal Care Products. A study on the occurrence of 14 endocrine disrupting compounds, pharmaceuticals and personal care products in wastewater treatment plants in southern California was

[1]Pacific Advanced Civil Engineering, Inc., 17520 Newhope Street, Suite 200, Fountain Valley, CA 92708; [*]Corresponding Author: Tel. 714-481-0662; Fax: 714-481-7299; e-mail: kikehata@pacewater.com

[2]Department of Civil & Environmental Engineering, University of California, Irvine, Irvine, CA 92697

conducted by Yu, Wu et al. (2013). The authors found that the significant risk quotients of sludge samples for estrone, octylphenol and carbamazepine that indicated a serious ecotoxicological and human health risk while effluents did not pose an immediate ecological risk. Wang, Huang et al. (2013) investigated the stereoisomeric profiling of pharmaceuticals ibuprofen and iopromide in wastewater and receiving surface water of the Pearl River Delta, South China. The results indicated that pharmaceuticals in the mainstream Pearl River were mainly from discharge of treated wastewater, while in the tributary rivers and urban canals, direct discharge of untreated wastewater accounted for a considerable contribution.

Lim et al. (2013) monitored the veterinary medicines in livestock wastewater treatment plants and analyzed their hazard to ecosystems in Korea. The results proved that chlortetracycline, oxytetracycline, acetylsalicylic acid, and disinfectants were prevailing in the livestock wastewater treatment plants influents and expected introductory concentration, predicted exposure concentration and hazard quotient revealed that the livestock wastewater treatment plants were an ecological hazard. A study was conducted to identify the pharmaceutical and personal care products that can be transferred from irrigation water to vegetables when reclaimed water was used (Wu et al., 2013). While roots had a significant accumulation of triclocarban, fluoxetine, triclosan, and diazepam, meprobamate, primidone, carbamazepine, dilantin, and diuron were found in leaves at high concentrations; however, none caused severe risks to human health. Zhang, Huang et al. (2013) performed a study on the trace organic pollutants in the municipal wastewater effluents through exposing male mice to the effluent samples for 90 days. Injuries were found in the mice liver and kidney and perturbations of metabolism, including lipid, nucleotide, amino acid, and energy metabolism were also found in the exposed mice.

Zhang, Brar et al. (2013) reviewed the transfer of fragrance materials to the environment including water and their fate in water, wastewater, wastewater sludge, and soil. The authors suggested that the bio-accumulated fragrance materials could be toxic to human beings and more research on the toxicity would be needed. Keen and Linden (2013) studied the evolution antibiotic activity during UV/H_2O_2 advanced oxidation and photolysis in wastewater effluent. They demonstrated that, during the high dose wastewater disinfection, photosensitized processes could produce anti-bacterially active transformation products through the degradation of some common antibiotics.

Lai et al. (2013) adopted the method of measuring the illicit drug metabolites in raw wastewater to assess drug use patterns in Hong Kong over nine days during April 2011. They found that the level of the drugs were relatively steady during the measuring period; ketamine, whose estimated consumption was 1,400 to 1,600 mg/day/1,000 people, was the predominant drug followed by methamphetamine, cocaine and 3,4-methylendioxymethamphetamine (MDMA).

Other Trace Organics. Rocha-Gutierrez et al. (2013) investigated concentrations and removal of polybromodiphenyl ethers (PBDEs) in wastewater treatment plants along the United States and Mexico

border. Key findings of the study included, 1) BDE-47, BDE-99 and BDE-100 were the most dominant of the 27 PBDEs, 2) PBDEs concentrations ranged from 30.2 to 342 ng/L in influents, not detected to 209 ng/L in effluents, and not detected to 1,303 ng/g in sludge, 3) primary treatment removed 41% to 73% of PBDEs and secondary and tertiary treatment removed 84% to 100% of PBDEs and, 4) ambient temperature has no influence on the PBDEs concentrations.

Calderon-Preciado et al. (2013) assessed the organic microcontaminant levels in various crops irrigated with groundwater and reclaimed water, either secondary or tertiary effluent. Results showed that the microcontaminant content in lettuce, carrots, and green beans were as high as 571 ng/g (fresh weight) with tributyl phosphate and butylated hydroxyanisole being present at the highest concentrations. Li, Lv et al. (2013) analyzed the treatment effect of a treatment train consisting of coagulation, sedimentation, ozonation, biological sand filtration, and granular activated carbon on phthalic acid esters in secondary effluent of municipal wastewater treatment plant and estimated the health risk. They found that the quality of effluent met the requirement of the ornamental scenic environment water, and the health risks of dibutyl phthalate and diisooctyl phthalate in effluent were at the range of 1.99×10^{-12} to 2.15×10^{-12}/annum and 1.48×10^{-11} to 1.85×10^{-11}/annum, respectively, lower than the acceptable maximum risk level (1.0×10^{-6}/annum).

Genotoxicity. Swaileh et al. (2013) applied randomly amplified polymorphic DNA to evaluate the potential genotoxicity of wastewater to albino rats. Results confirmed the genotoxicity of raw and treated wastewater in rats *in vivo*, which showed the treatment processes did not remove the mutagens present in raw wastewater completely. Yu, Dong et al. (2013) investigated the genotoxic activity of water samples extracted by diethyl ether from Songhua River in China. The samples analysis results indicated the genotoxic activity with a mutagenic potency, caused by 104 identified compounds in winter samples and 88 in summer samples. Vasquez et al. (2013) performed a chronic ecotoxicity assessment using representative bacteria of marine and terrestrial ecosystems and a cytostatic and genotoxic evaluation using hepatoma cell line. They found that UV irradiation in several treatment processes might produce genotoxic by products, thus in some related practical applications, the residence time during treatment should get more attention.

Microbial Hazards

Bacteria. Petit et al. (2013) compared a panel of *Pseudomonas aeruginosa* strains isolated from wastewater treatment lagoons to evaluate the contribution of lagoon treatment to the dissemination of clinically relevant *P. aeruginosa*. The results indicated the ability of some genotypes to migrate and persist over time in wastewater treatment lagoons, and some matches to the community-acquired infections. Pitkanen (2013) reviewed the detection methods of *Campylobacter* spp. in drinking and environmental waters. Effectiveness of *Campylobacter* culturing is limited due to time-consuming steps, non-quantitative results, and limitation of culturable forms, and therefore molecular methods, such as quantitative polymerase chain reaction (qPCR), isothermal

amplification and high-throughput sequencing, are promoted to develop for environmental *Campylobacter* research. Schets et al. (2013) investigated the occurrence of *Coxiella burnetii* at sewage water treatment plants in the Netherlands which might have caused a health risk of Q-fever for workers or neighboring residents during 2007 and 2010. However, low levels of *C. burnetti* DNA found in the wastewater during the decline of the Q fever outbreak in 2011 showed a low health risk for human beings.

Ibekwe et al. (2013) applied 454 high-throughput pyrosequencing to identify pathogenic bacteria's DNA sequences with the samples of mixed urban watershed, including surface water, and sediment collected from 19 sites. The highest number of potential pathogens was found in urban runoff water (7.94%), followed by agricultural runoff sediment (6.52%), and park sediment (6.00%). Igbinosa et al. (2013) performed a study on the detection and distribution of putative virulence associated genes in *Aeromonas* species from Kat River and Fort Beaufort wastewater treatment plant in the Eastern Cape Province of South Africa. They found that virulence genes were distributed as follows: in freshwater, lip (67%), aer (43%), alt (33%), fla (62%), ast (10%), and hlyA (86%); in wastewater, lip (92%), aer (21%), alt (54%), fla (83%), ast (29%), and hlyA (88%). McLellan et al. (2013) characterized microbial communities in the wastewater treatment plant influent samples from 12 cities in the United States to reflect the distribution of human fecal Lachnospiraceae across the country. Their result suggested that a microbial indicator based on *Blautia* spp. might have the capacity to discriminate between different fecal pollution sources to improve the environmental and public health.

A study on human bacterial pathogens in two wastewater treatment plants in Hong Kong by a high-throughput shotgun sequencing technique was conducted by Cai and Zhang (2013). The authors found that pathogenic bacteria made up 0.06% to 3.2% of total bacteria population, which were detected in both activated sludge and effluent and that *Mycobacterium tuberculosis*-like species were possibly another threat to human health. Zhang, Wang et al. (2013) investigated the distribution of *Salmonella* spp. and proportion of *Salmonella typhi* in both raw and treated wastewater. The results indicated that *Salmonella* spp. was detective at a level of ranging from 10^3 to 10^6 copies per 100 mL where less than 5% were *S. typhi*, and *S. typhi* were decreased by 1 log unit and 0.5 log units, respectively, through municipal wastewater treatment process.

In order to understand the risks of chlorination arising from the potential selection of pathogenic bacteria, Li, Zhen et al. (2013) investigated the inactivation, reactivation, and regrowth rates of indigenous bacteria in reclaimed water after chlorine disinfection of a municipal wastewater treatment plant. The results showed that the chlorination induced the selection of chlorine-resistant pathogenic bacteria, and the regrowth of pathogenic bacteria could impact public health via wastewater reuse.

Antibiotic Resistant Bacteria. Pruden et al. (2013) investigated management opportunities to reduce the release of antibiotics and antibiotic resistance determinants, aiming at extending the useful life span of

current and future antibiotics. Nutrient management, runoff control, infrastructure upgrades, and communication to engage stakeholders and promote action were identified as effective options, of which most could be at little cost and some were interactive with current policies and goals. Reinthaler et al. (2013) compared antibiotic resistance patterns of *Escherichia coli* strains isolated from the environment (including sewage sludge) and from human patients in 2000 and 2009. The results showed both parallel and independent developments of resistance patterns in human and environmental sources, and multi-resistant *E. coli* strains isolated from both sources increased over time. Luczkiewicz et al. (2013) tested the sensitivity of *E. coli* and *Enterococcus* spp. isolated from a sewage treatment plant to erythromycin and to trimethoprim/ sulfamethoxazole respectively. In *Enterococcus* spp., erythromycin-resistance was prevalent with 41% of isolates, while in *E. coli*, sulfamethoxazole-resistant isolates established with a less amount of 11%. Chen and Zhang (2013) examined the occurrence and removal of several antibiotic resistance genes including four tetracycline resistance genes and two sulfonamide resistance genes in both municipal and rural wastewater treatment systems in eastern China. The analysis showed that antibiotic resistant genes were removed at one to three orders of magnitude in municipal wastewater treatment systems while a smaller removal was observed in rural wastewater treatment systems.

Bouki et al. (2013) reviewed the available data on the detection and fate of antibiotic resistant bacteria in wastewater treatment plants. The results revealed that antibiotic resistant bacteria and genes had been widely detected in the raw and treated wastewater as well as in surface water and that wastewater treatment plants contributed to the widespread occurrences of antibiotic resistant bacteria. Rizzo et al. (2013) reviewed the existing understandings of the roles of urban wastewater treatment plants on the spread of antibiotic resistant bacteria and genes into the environment. Key findings of the review included, 1) advanced treatment technologies were considered to be a key method to control the antibiotic resistant bacteria spread into the environment, 2) risk assessment is needed to accurately estimate the acceptable antibiotic resistant bacteria level in treated effluents and, 3) factors and mechanisms driving development and selection of antibiotic resistance in biological treatment processes should be better understood. Marti et al. (2013) investigated the effect of the wastewater treatment plant discharges on the occurrence of antibiotic resistance genes, such as qnrS, bla TEM, bla CTX-M, and bla SHV, and bacterial community composition in a receiving river. Results suggested that the wastewater treatment plant effluents might have caused the prevalence of antibiotic resistance genes in the biofilm and sediments, and disturbed the bacterial communities in the receiving river.

Yang et al. (2013) performed a study focusing on the transfer of RP4 plasmid, which carries antibiotic resistance genes, among microbial communities in a membrane bioreactor. The activated sludge was found to have a transfer rate of 2.76×10^{-5} per recipient, which was faster than those in wastewater and bacterial sludge reported earlier, and posed a threat to human health. Zhang,

Lv et al. (2013) examined the occurrence and variations of antibiotic resistance genes in the Jiulong River, China, based on 16 comprehensive samples during both low and high flow periods. Nine antibiotic resistance gene families were detected, which could possibly have originated from sewage discharge along the river.

In order to evaluate the long-term effects of antibiotic exposure on soil microbial populations, Topp et al. (2013) established a series of field plots in 1999 and applied a mixture of sulfamethazine, tylosin, and chlortetracycline to the plots. The authors found that accelerated biodegradation of antibiotics in the soil matrices would have weaken environmental exposure to antibiotics, and suggested more investigations in latent risks of antibiotic resistance development in the environmental matrices. Schreiber and Kistemann (2013) studied the occurrence of antibiotic resistance among autochthonous aquatic environmental bacteria in the catchment area of the River Swist in Germany and focused on the resistance of environmental Rhodospirillaceae to antibiotics used in human medicine. They found that the detected resistances were developed rather than inherent.

Guo et al. (2013) performed research about the microbial selectivity of UV treatment on antibiotic-resistant heterotrophic bacteria in secondary effluents of a municipal wastewater treatment plant. The results indicated that UV disinfection led to augmentation of bacteria with resistance to sulfadiazine, vancomycin, rifampicin, tetracycline and chloramphenicol, while the proportions of cephalexin-, erythromycin-, gentamicin- and ciprofloxacin-resistance bacteria in the wastewater decreased. Korzeniewska and Harnisz (2013) investigated the possible presence of extended-spectrum-beta-lactamase (ESBL)-positive Enterobacteriaceae in municipal sewage and their emission to the ambient air and the river receiving effluent from the wastewater treatment plant. They concluded that the municipal sewage may be a reservoir of antibiotic-resistant microorganisms and plasmid-mediated antibiotic resistance genes despite the treatment.

Varela and Manaia (2013) reviewed the human health implications of clinically relevant bacteria in wastewater habitats. They found that the treatment processes might fail to remove the antibiotic resistant bacteria, genes encoding virulence or antimicrobial resistance efficiently, which revealed the necessity of more detailed research on the long-term effects of wastewater discharges, especially wastewater reuse.

Parasites. A study was conducted by monitoring the occurrence of *Giardia* cysts at multiple stages of a wastewater treatment plant in Hamburg, Germany (Ajonina et al., 2013). Key findings included *Giardia* cysts occurred in all sampled stages at concentrations ranging from 50 to 7,548 cysts/L, the treatment plant had an overall removal efficiency of 78% of cysts, and the cysts prevailed most, in both influents and effluents, during fall and winter. Willis et al. (2013) reviewed the historical and present occurrence of *Cryptosporidium* and *Giardia* in shellfish in various water bodies throughout Canada. The authors identified human sewage overflow as one of the contamination sources and pointed out current monitoring and depuration standards should be improved to effectively eliminate the risks caused by harmful protozoan parasites.

Hachich et al. (2013) conducted a study on analyzing enteroviruses, protozoa, and viable *Ascaris* sp. eggs in 24 raw and 24 treated effluents from four wastewater treatment plants in Sao Paulo State, Brazil. They concluded that quantitative microbial risk assessment studies should be conducted to establish pathogen quantitative criteria for a future Brazilian regulation for water reuse. Verbyla et al. (2013a) conducted a study about *Taenia* eggs in a stabilization pond system with poor hydraulics with concerns for human cysticercosis by comparing the removal of *Taenia* and *Ascaris* eggs in a wastewater stabilization pond system consisting of three ponds in series using computational fluid dynamic modeling. They indicated that the theoretical hydraulic retention time of a pond is not always a good substitute for helminth egg removal.

Tonani et al. (2013) analyzed the persistence of *Giardia*, *Cryptosporidium*, rotavirus, and adenovirus in treated sewage in Sao Paulo State, Brazil. They found a remarkable decrease in the concentrations of *Giardia*, rotavirus and adenovirus ($p < 0.05$) and a tendency of decrease in the concentration of *Cryptosporidium* densities, without statistical significance. Although their concentrations decreased after the sewage treatment, the residual loads observed in treated sewage could reach the watercourses, which may cause a public health risk. Moon et al. (2013) described the first outbreak of cryptosporidiosis in Seoul, Korea. They found the drinking water was contaminated with *Cryptosporidium parvum* and that a possible contamination source was a sewage leak from old sewer pipelines.

Viruses. A 2011-2012 report was published on the acute flaccid paralysis surveillance performance indicators supplemented by sewage sample testing, which is a part of the Global Polio Eradication Initiative established by the World Health Assembly (Anon, 2013). Among 19 countries affected by polio, 12 and 13 countries met national performance indicator targets for the years of 2011 and 2012, respectively, and seven and nine countries had 80% or more of the population living in areas meeting the performance indicators in 2011 and 2012, respectively. Hovi et al. (2013) conducted a study on the characteristics of an environmentally monitored prolonged type 2 vaccine derived poliovirus shedding episode that stopped without interference. They found that individuals with prolonged poliovirus infection are not as rare as suggested by the studies on immune deficient patients known to the health care systems, and genetic divergence of vaccine derived poliovirus strains may remain extensive during year's long replication in humans. Klement et al. (2013) reported the outcome of an 11-year program monitoring sewage water and acute flaccid paralysis cases as part of the World Health Organization strategy for polio eradication in the Slovak Republic from 2001 to 2011. The detection of poliovirus in the study area declined from 66% to 30% during 2001 and 2005 and then diminished thereafter.

Lodder, Rutjes et al. (2013) performed a molecular analysis of Aichi virus in sewage and surface water from 1987 to 2000 and from 2009 to 2012 in Netherlands. Their data showed that Aichi virus had been spreading and genotype B dominated in the Netherlands. Lodder, Wuite et al. (2013) studied the human

parechoviruses by an environmental surveillance program including the molecular analyses of sewage samples collected from 15 different locations, including schools and municipalities in the Netherlands. The parechoviruses spreading in the studied population were reaching a higher level than an estimated value, suggesting the infection had gone beyond younger school children. Pellegrinelli et al. (2013) carried out a study of environmental surveillance of culturable human enteroviruses in Milan, Italy, from 2006 to 2010, by isolation of poliovirus and nonpolio enteroviruses from 321 wastewater samples collected from three wastewater treatment plants. Culturable human enteroviruses were isolated from 80% of samples; of which all belonged to the human enterovirus-B group and coxsachievirus type B5 and echovirus 6 were circulating most intensely, while coxsachievirus type B4 was predominant in 2010.

Pereira et al. (2013) performed a cross-sectional study on the prevalence of hepatitis C virus in the urban population of Brazil. They found that the lack of sewage disposal was one of the important risk factors associated with hepatitis C virus infections. Yugo and Meng (2013) reviewed the hepatitis E virus transmission from various environmental sources. Infectious hepatitis E virus was found in sewage water and partially treated water, as well as animal feces, contaminated shellfish and produce. Masclaux et al. (2013) investigated the occurrence of hepatitis E virus, human adenovirus-40, norovirus genogroup II, and porcine adenovirus in the influent and effluent from wastewater treatment plants in Switzerland. The authors found the possible environmental circulation of certain hepatitis E virus genotypes in the region.

Rodriguez et al. (2013) developed and calibrated an infectivity assay incorporating cell culture and real-time polymerase chain reaction (RT-PCR) for rapid detection and semi-quantification of human adenovirus in sewage. They observed a linear relationship between viral mRNA concentrations and infectious units of 10^7 to 10^1 infectious units per assay, and estimated human adenoviruses concentrations in sewage samples ranging from 10^2 to 10^3 mRNA-infectious units/L, of which most were from human adenovirus species F. Haramoto et al. (2013) examined the prevalence and genetic diversity of klassevirus in wastewater in Japan using RT-PCR. More klassevirus was found in raw sewage (50%) than secondary effluent (29%). The authors found the high nucleotide sequence similarities of 94.7% to 100% and 93.2% to 100% in the 2C and 3D regions, respectively, representing the presence of a single klassevirus strain. Human caliciviruses in wastewater from various sized communities in five provinces of South Africa were investigated by Murray et al. (2013a). They found many norovirus and sapovirus genotypes in wastewater, showing a high genetic diversity of caliciviruses in South Africa. Murray et al. (2013b) employed the competitive internal amplification control to detect sapoviruses in wastewater in South Africa. Their result revealed that sapoviruses existed at high concentrations in wastewaters in certain provinces of South Africa, indicating the widespread occurrence of potentially hazardous sapoviruses in the region.

Fumian et al. (2013) performed a study on DNA and RNA virus levels in wastewater samples from Rio de Janeiro, Brazil. All influent samples were found to contain human adenovirus and polyomavirus JC with a level ranging from 10^6 to 10^5 genome copies per liter and a high level of rotavirus species A was disseminated widely. Hewitt et al. (2013) evaluated human adenovirus and human polyomavirus as the indicators of human sewage contamination in the aquatic environment using qPCR assays. They found that detecting human adenovirus and human polyomavirus by qPCR was appropriate for evaluating water quality and that their detection can aid in regulating pollution sources, thus providing useful information for health risk assessments.

Wong et al. (2013) characterized human enteric viruses in community wastewaters through cell culture, combined with multiple target microarrays and PCR assays. The study showed that key viral pathogens were detected more frequently during winter than summer and RNA viruses including astroviruses and enteroviruses were found more than DNA viruses which consisted of adenoviruses, particularly type 41 and BK polyomavirus.

Wastewater Reuse

Agricultural Reuse. Aiello et al. (2013) assessed the health risk associated with the agricultural reuse of treated municipal wastewater in eastern Sicily, Italy. An experiment spanning from 2004 to 2009 indicated the achievement of a median infection risk of rotavirus, *Campylobacter*, and *Cryptosporidium* for lettuce irrigation under unrestricted irrigation approach with treated wastewater from a constructed wetland system. Amin et al. (2013) studied the accumulation of heavy metals (Cu, Ni, Zn, Cr, Fe, Mn, Co, and Pb) green vegetables grown on wastewater irrigated soil in Mardan, Pakistan. Manganese was found to be accumulated in the edible parts of onions *Allium cepa* at 28.05 mg/kg, and accumulation of all other tested metals were found to be significantly higher in the wastewater irrigated vegetables than in the well water irrigated ones and published permissible limits, revealing that consumers of vegetables irrigated with wastewater may ingest excessive heavy metals resulting in high risk of health problems. Zhang, Luo et al. (2013) studied the pollutant partitioning in the soil influenced by two pollution sources including wastewater irrigation and smelter dust. With a soil size fraction of 1 μm or less, a higher metals enrichment factor associated with wastewater irrigation was observed, indicating potential human health risk.

Arunakumara et al. (2013) reviewed that currently reported major anthropogenic sources of metal contamination, such as agrochemicals, wastewater irrigation, sewage sludge application, livestock manures, mining and fly ash, in Asia. Despite the fact that the metal contents in rice grains were lower than most other parts of the plant and within the published permissible limits, this review suggested preventive and remedial measures be enforced due to a higher potential of human exposure to heavy metals via the consumption of rice. Avci (2013) reviewed heavy metals concentrations in crops irrigated with municipal and industrial wastewater and associated human health risks in Gaziantep, Turkey. Heavy metals concentration in both soils and plants were verified to

excess recommended maximum tolerable levels, and further research on metal bioaccumulation, chemical speciation, and the impacts on human health was suggested as the conclusion of this review. Avci and Deveci (2013) analyzed trace elements concentrations in edible portions of several plants grown in wastewater irrigated soils, and found 0.03 to 0.66 mg Co/kg, 0.1 to 3.2 mg Mo/kg, and 8 to 148 mg Zn/kg in corn, mint and vegetables, and 0.01 to 0.05 mg Cd/kg, 2.0 to 5.5 mg Cr/kg, 6 to 47 mg Cu/kg, 0.6 to 6.7 mg Ni/kg, and 0.2 to 3.5 mg Pb/kg in corn and mint. It was concluded that metals high bioaccumulation in plants and animals were caused by anthropogenic activities like wastewater irrigation, in addition to the regional geochemistry in Gaziantep, Turkey. Ul Hassan et al. (2013) assessed the accumulation of heavy metals in wheat plants irrigated with contaminated wastewater. They found that the concentrations of most of the metals were detected above the threshold limits for irrigation water and food set by international regulations, with a decreasing order of Zn>Fe>Mn>Cu>Pb>Cd>Ni>Cr in samples from the areas irrigated using municipal wastewater. Grains were found to accumulate in chromium, nickel, and iron, which exceeded recommended the dietary limits.

Zhang, Yang et al. (2013) assessed the concentrations and health risk of 16 polycyclic aromatic hydrocarbons (PAHs) in soil profiles in a wastewater irrigation area in Hunpu, China. Most of the PAHs in the bottom soil layer were from wastewater and petroleum production and the total PAHs concentrations varied between 7.88 and 2,231 μg/kg, in which phenanthrene was the most prevailing compound. Su et al. (2013) investigated the areas that had experienced nitrate pollution and assessed the health risk of nitrate contamination in groundwater in northeast China. The results revealed that these areas practicing agricultural sewage irrigation had high health risks and children's health risks were stronger than those of adults.

Baghapour et al. (2013) measured 20 physicochemical and three microbial parameters of Shiraz wastewater treatment plant effluent, Iran, and used Canadian Water Quality Index to evaluate the effluent quality for irrigation purpose. The results indicated the physicochemical effluent quality (index of 87 in warm and cold months, and 85 for all seasons) meets the standards for irrigation, but if fecal coliform, helminthes egg, and total coliform were applied to the index value, the effluent quality could barely acceptable for irrigation (index of 67 in warm and cold months, and 64 for all seasons). Pavione et al. (2013) used a quantitative microbial risk assessment model to estimate infection risks associated with consumption of raw crops irrigated with waste stabilization pond effluents. Irrigation with effluents containing 10^3 to 10^4 *E. coli* per 100 mL caused rotavirus infection risks of 10^{-3} per person per year in low-growing crops and 10^{-4} per person per year in high-growing crops, and the risk estimates were highly affected by effluent quality and pathogens reduction before consumption of crops. Silverman et al. (2013) sampled and analyzed wastewater samples for quantification of human norovirus GII, human adenovirus and fecal indicator organisms in Accra, Ghana where untreated wastewater is used for irrigation. *E. coli* concentrations exceeding limits of the World Health

Organization in all samples and human viruses detected in 16 out of 20 samples suggested that wastewater should not be reused in agriculture.

Pham-Duc et al. (2013) statistically studied the risk of helminth infections associated with the agricultural use of wastewater and human excreta in Hanam province, Vietnam. The results revealed that close contact with wastewater polluted Nhue River water increased the risk of *Ascaris lumbricoides* infections, the use of human excreta for fertilizer increased the risk of *Trichuris trichiura* infections, and people performing agricultural activities with lower educational level also presented higher risk of helminth infections. The effects of wastewater irrigation on soil and crop were assessed by Castro et al. (2013). Growth parameters including dry and fresh weights, average height and diameter were found to be higher with treated wastewater irrigation and pathogenic microorganisms were present in both plants and soil in two plots.

The effect of wastewater irrigation on soil structural and chemical behaviors was assessed by Dakoure et al. (2013) in a case study at a sewage treatment plant in Kossodo, Ouagadougou, Burkina Faso. Soil structural damages and black alkali formation at the surface were observed on the soil irrigated with wastewater. Forslund et al. (2013) investigated *E. coli* and helminth eggs in the treated wastewater, soil irrigated with the treated wastewater, and processing tomatoes on the soil in Italy. The tomatoes and soil showed no detection of *E. coli* and low concentration of *E. coli* as 95 cfu/g, respectively, but accidental soil ingestion even irrigated with free of *E. coli* water was found to pose a health risk. Son et al. (2013) conducted a literature review on microbial and toxic chemical risk analysis procedure to evaluate the rice paddy fields irrigated with reclaimed wastewater in South Korea.

Miscellaneous. Faul et al. (2013) examined several important parameters for both sewage and reclaimed drinking water at the Gammams Sewage Treatment Plant, Namibia, including estradiol, estrone, testosterone, acetylcholinesterase inhibition, cytotoxicity, and inflammatory activity. The results showed that all of the parameters were non-detective after treatment. Agidi et al. (2013) used human-specific immunomagnetic separation/adenosine triphosphate bioluminescence (IMS/ATP) for the first time to test fecal contaminants (*Bacteroides fragilis*, *E. coli*, and *Enterococcus* spp.) for the reclaimed wastewater of on-site wastewater treatment and reuse systems. The test results were found to be correlated with qPCR and were also validated with culture-based methods, revealing that the newly developed IMS/ATP was a timely and cost-effective way to detect fecal pollutants in wastewater prior to reuse. Agullo-Barcelo et al. (2013) studied the use of *E. coli*, somatic coliphages and spores of sulfite-reducing clostridia as alternative indicators for monitoring *Cryptosporidium* total or infectious oocysts in reclaimed water. Analytical results showed that *E. coli* was not useful to predict presence/absence of *Cryptosporidium* infectious oocysts unless somatic coliphages data were used together, and spores of sulfite-reducing clostridia showed high correlation values with *Cryptosporidium* total oocysts. A quantitative study on the antibiotic resistance genes occurrence in three recycled water distribution systems in

the western United States was conducted by Fahrenfeld et al. (2013). Multiple antibiotic resistance genes, along with two pathogens, namely, Lmip and gadAB genes, were found in the distribution and one kind of antibiotic resistance genes with resistance to sulfonamides showed an increased level in soil with continuous recycled water irrigation.

Wastewater Treatment Plants

Li, Han et al. (2013) investigated the airborne bacteria emissions from oxidation ditch with rotating aeration brushes at a municipal wastewater treatment plant in Beijing, China over a three-month period (April, May, and June). They found that the total microbial concentration, observed near the rotating brushes (from 931 ± 129 to 3,952 ± 730 cfu/m^3), was highest in June with concentration decreasing as distance and height increased. Li, Yang et al. (2013) performed a study on the emission characteristics of microbial aerosols from the widely used municipal sewage treatment plants in Xi'an, China during summer using an Andersen six-stage impactor and the culture method to control the concentrations and size distributions of airborne viable bacteria, fungi, and actinomycetes. They concluded that airborne actinomycetes emitted from municipal sewage treatment plants might have a more important impact on public health and urban air quality than bacteria and fungi. Li, Zhang et al. (2013) conducted research about the dispersion and risk assessment of bacterial aerosols emitted from rotating-brush aerator during summer in a wastewater treatment plant of Xi'an, China. They found that both mean bacterial concentrations at ground level and the exposure hazard quotient decreased rapidly with downwind distance and that the inhalation route is the main exposure pathway of microbial aerosol intake for surrounding people. The health risks of microbial aerosols associated with rotating-brush aeration for children are much higher than those for adults. Malakootian et al. (2013) investigated the bacterial-aerosol emission from an activated sludge wastewater treatment plant with surface aerators from November 2009 to July 2010 and assessed the health effects among the plant's staff. The results proved that most workers from sewage treatment plant suffered with fatigue, dizziness, eye irritation and abdominal pain because of the bacterial-aerosols.

Wastewater Disposal

Angerville et al. (2013) developed a specific ecotoxicological risk assessment methodology for the management of discharge of combined sewer overflows in peri-urban rivers. The methodology was adapted to a river assessment, showing the water column has moderate risk to organisms, and benthic and hyporheic zones have a major risk for organisms. The assessment of heterotrophic bacteria resistant to tetracycline and ampicillin was conducted in the lower Hudson River Estuary in New York City (Young et al., 2013). The results indicated that the level of antibiotic-resistant bacteria were associated with the level of *Enterococcus*, which implied the contamination by the wet weather sewage overflow. Tetreault et al. (2013) performed a study on fish community responses to multiple municipal wastewater inputs in a watershed, aiming at

assessing the potential cumulative impacts of municipal wastewater effluent discharges in the Grand River on the health status of a sentinel species and the fish community downstream of two municipal wastewater effluent discharges. They successfully demonstrated the cumulative impact of urban development, including multiple outfalls of treated wastewater effluents, on nutrients, pharmaceuticals and personal care products to aquatic systems.

Rouse (2013) surveyed the wastewater treatment facilities in the Federated States of Micronesia and revealed a lack of sustainability of the treatment systems that could result in environmental and public health problems. Key issues identified by the survey included, 1) lack of quantity and composition data of wastewater influent and quality data of treated effluent, 2) direct discharge of raw sewage into the ocean and inappropriate sludge handling practices, 3) lack of management of septic tanks and, 4) ineffective treatment solutions of wastewater from industrial and agricultural sources. Hardisty et al. (2013) studied the options for treatment and discharge of wastewater in regional Western Australia from the perspective of overall sustainability and social net benefit, during which six technical treatment-disposal options were evaluated at a test site, and all of them met the fundamental criterion of protecting human health. They revealed that moving from the identified socially optimal level of treatment to tertiary levels of treatment would lead to a net loss of society equivalent to several hundred million dollars.

Salama et al. (2013) characterized the raw sewage from the city of El Jadida, Morocco with respect to physicochemical and bacteriological parameters. The analysis showed significant environmental and public health risks associated with the untreated wastewater disposal into the ocean, including 588 to 805 mg/L of five-day biological oxygen demand, 691 to 1,512 mg/L of chemical oxygen demand, 524 to 1,067 mg/L of suspended solids, 2.80×10^5 to 2.24×10^6 cfu/100 mL of fecal coliform, 1.94×10^5 to 4.04×10^6 cfu/100 mL of fecal staphylococci, and 2.36×10^5 cfu/100 mL of the spore of sulfite-reducing anaerobes in the wastewater. Ye et al. (2013) conducted research to identify the possible sources of bacteria in the drinking water of ten rural districts in Beijing, China, where groundwater is used as a source water. It is found that the groundwater well locations that were adjacent to sewage ditches and polluting industries had elevated total bacterial counts and the north area of Beijing was determined as the most contaminated area with maximum levels of 88,000 cfu/mL of total bacterial counts, 1,600 MPN/100 mL of total coliforms, and 1,600 MPN/100 mL of *E. coli*.

Impacts on Recreational Waters and Aquatic Organisms. Eichmiller et al. (2013) conducted research on the distribution of genetic markers of fecal bacteria in a lake by analyzing water, sand, and sediment samples from a harbor site in Lake Superior, which accepted treated wastewater discharge, during warm months in 2010 and 2011. The results indicated sand and sediment potentially provided a reproducing place for genetic markers, especially Entero1 and AllBac. Hokajarvi et al. (2013) investigated the impact of thermo-tolerant *Campylobacter* spp. and adenoviruses occurrences in Finnish bathing waters and treated sewage effluents originating from 17

locations in the summers of 2006 and 2007. The low water temperature in Finland might enhance the prevalence of *Campylobacter* in bathing waters. This study showed that the observed common existence of these pathogens in bathing waters and sewage effluents might cause a public health risk.

Uyaguari et al. (2013) performed research about the abundance of genetic agents, class 1-3 integrons in South Carolina estuarine ecosystems under high and low levels of anthropogenic influence, including sewage discharge, by comparing the distribution of three integron classes throughout a coastal estuarine ecosystem. They found that although all three integron classes were present, the relative abundance was different; with class 2 integrons considerably raised in areas of high anthropogenic input and class 1 integrons low input. Vidal-Dorsch et al. (2013) investigated the genomic and phenotypic response of hornyhead turbot exposed to municipal wastewater effluents. They observed the alteration in gene expression (versus controls) in fish exposed to both effluent types and found that although no concentration-dependent patterns of response to effluent exposure were detected, considerable spearman correlations were found between the expression of 22 genes and molecular and/or higher biological responses. Wang, Liu et al. (2013) conducted a study of ten-month exposure to wastewater treatment plants effluent in high-back crucian carp during various life stages to explore the adverse effects of endocrine disrupting chemicals in wastewater on fish health. Results indicated that the carp in early-life-stage were more sensitive to waste water treatment plants effluent exposure. Maceda-Veiga et al. (2013) compared the metal concentration and pathological responses of *Squalius laietanus* exposed to sewage flow in the Ripoll River, Spain with *Barbus meridionalis* which was studied previously. *S. laietanus* showed fewer pathological responses than *B. meridionalis* which stored high mercury and copper predominately in muscle and liver and mercury, copper and lead concentrations in fish tissues exceeded the standard of European and Spanish regulations.

Industrial Wastewater. Ribeiro et al. (2013) studied toxicity and physicochemical characteristics of nitrocellulose production wastewater using *Daphnia similis*, *Danio rerio*, *E. coli*, *Pseudomonas putida* and *Pseudokirchneriella subcapitata* in toxicity assays. The wastewater presented acute and chronic toxicity, with nitration effluent being the least toxic, delignification and bleaching effluents being the most toxic, and the effluents total dissolved solids were not compliant with Brazilian legislation. Wang, Zhang et al. (2013) conducted a study about the occurrence, diversity and abundance of antibiotic resistance genes and mobile genetic elements in aerobic and anaerobic sludge of a full-scale tannery wastewater treatment plant. The results emphasized the prevalence of antibiotic resistance genes and mobile genetic elements in tannery wastewater treatment plant, which could be the major public health risks.

Zhu et al. (2013) investigated the induced genotoxicity by coking wastewater on mice *in vivo* by monitoring micronuclei frequencies in polychromatic erythrocytes of mouse bone marrow. The results showed that coking wastewater could cause genetic damage on

mice and the potential genotoxic risk to human beings was suggested.

Wang, Chen et al. (2013) studied the health risks of thallium in contaminated arable soils and food crops irrigated with wastewater from a sulfuric acid plant in western Guangdong province, China. They found that the content of thallium in the edible plant portions of crops ranged from 1.2 mg/kg to 104.8 mg/kg, which is beyond the recommended permissible limits for food crops, and daily intake of metals values of Tl for both adults and children were greater than the reference oral dose limit recommended by the United States Environmental Protection Agency.

Radioactive Effluent and Sludge. Tsushima et al. (2013) conducted the leachate tests with radioactive incinerator ash, cement solidification incinerator ash, and dewatered sewage sludge cake, in order to understand the possible problems associated with the landfill disposal of contaminated sewage sludge in eastern Japan. They found that the presence of calcium ions and strong alkali in the water that contacted with the incinerator ash increased leaching of cesium, and the capacity of pit soil to absorb radioactive cesium was assessed to be at least 3.0 Bq/g (dry). A study of the radioactivity in effluents and sludge generated at 11 wastewater treatment plants in Spain was performed by Montana et al. (2013). The radiological characterization of the effluent and sludge from the wastewater treatment plants proved that there was not a significant radiological risk on human health.

Hospital Effluent. Picao et al. (2013) identified antimicrobial resistant bacteria, *Klebsiella pneumonia*e, carbapenemase-producing *Aeromonas* spp., *Kluyvera* spp., and other Enterobacteriaceae in hospital sewage and throughout the wastewater treatment plant receiving it. The presence of *K. pneumoniae* and carbapenemase producers indicated the species adaptability to the aquatic environments and the evolution of antimicrobial resistance from hospitals to the environment. A study was performed to investigate the predominance of ESBL-producing *E. coli* in raw hospital wastewater and two sewage treatment plants in Queensland, Australia (Gundogdu et al., 2013). The study revealed that certain ESBL-producing *E. coli* strains were more prevalent in hospital wastewaters than in sewage, implying the significant public health importance of hospital wastewater. Korzeniewska et al. (2013) collected 395 *E. coli* strains from sewage and environmental samples and investigated their antibiotic susceptibility and the presence of bla gene encoding TEM, CTX, OXA, and SHV. They concluded that presumably the preliminary disinfection of hospital sewage before inflow into the sewage system might curtail the spreading of antibiotic-resistant bacteria to the environment. Thompson et al. (2013) performed research about the antibiotic resistant *Staphylococcus aureus* in hospital wastewaters and their transport to sewage treatment plants. They found the existence of methicillin-resistant *S. aureus* strains in untreated hospital wastewaters, their conveyance to the sewage treatment plant, and their occurrence in the final effluent after chlorination, which brings the necessity to investigate the load of methicillin-resistant *S. aureus* in hospitals' wastewaters. Zhang, Qiu et al. (2013) analyzed 99 water samples from various water resources in Beijing,

China to assess the level of New Delhi metallo-beta-lactamase 1-producing bacteria. Only the sewage from the four comprehensive hospitals was found to contain a higher isolation of New Delhi metallo-beta-lactamase 1-producing bacteria *Acinetobacter baumannii*.

Harris et al. (2013) developed a Monte Carlo simulation model to predict the fate of ciprofloxacin in hospital effluent after wastewater treatment, in addition to modeling resistance formation potential, hazard quotient and swimmer exposure. They concluded that the release of hospital effluent into the environment might lead to concentrations of ciprofloxacin, which are of low toxicity concern but may be conductive to resistance formation and allow for the dissemination of resistance. Sharma et al. (2013) evaluated the genotoxic and cytotoxic potential of wastewaters from hospitals and clinical diagnostic centers in Jaipur, India. Data confirmed that the wastewaters from hospitals and clinical diagnostic centers did consist of genotoxic and cytotoxic components. Kargar et al. (2013) conducted a study of first molecular detection of group A rotavirus to evaluate the efficiency of rotavirus removal in urban and hospital sewage treatment plants in Shiraz, Iran. They found that the high prevalence of rotaviruses in urban and hospital sewage systems emphasized the significance of environmental surveillance as a tool to find new genotypes and study the epidemiology of rotaviruses circulating in the community.

Sludge and Biosolids

Bastos et al. (2013) quantified a variety of helminth eggs in sewage sludge in metropolitan wastewater treatment plants in Brazil, and found the eggs of *Ascaris* sp. to be the most prevalent in the samples. The study revealed application of sewage sludge in agriculture will cause public health problems, according to standards established by Brazilian regulations. De Giudici et al. (2013) performed a microbial risk assessment on waste management activities, including composting and sewage sludge application. The authors pointed out that the applicable risk levels for the neighboring community were unavailable and more research was recommended on the transfer from waste to exposure media. Sypula et al. (2013) studied the effects of solar drying process on sanitation indicators in sewage sludge and potential as a technique for fertilizer production. The product of solar drying of sludge contained large concentrations of indicator bacteria such as *E. coli* and *Enterococcus* spp., as well as *Ascaris suum* eggs and might pose a health risk to public health and the environment.

Manea et al. (2013) assessed the environmental risks of wastewater sludge disposal and reuse considering different kinds of risk factors such as heavy metals, nutrients, type of irrigation systems, and climate conditions. Results showed a low content of heavy metal and the macronutrients, including potassium and phosphorus, in the sludge samples, which confirmed that the wastewater sludge would not pose a high environmental risk if it is used in a controlled manner.

Mensah et al. (2013) studied the effect of the use of sawdust as a bulking agent on the microbial quality of biosolids produced from raw fecal sludge. There was significant reduction in bacteria content and helminth eggs

in the biosolids when sawdust was added and dewatered, making the raw fecal sludge safe for farmers. Sreesai et al. (2013) evaluated the potential agricultural application of digested sewage sludge with respect to the levels of plant nutrients, heavy metals, parasites and fecal coliform bacteria in Bangkok, Thailand. The results confirmed that digested sewage sludge had high fertilizing values for organic matter (19.01 ± 0.09%), total nitrogen (2.17 ± 0.07%), total phosphorus (2.06 ± 0.06%) and total potassium (1.16 ± 0.22%), but it was contaminated with human pathogens, indicating that fresh sewage sludge should not be applied to land directly unless the pathogen concentration was reduced.

An assessment of the emission and human inhalation exposure of PBDEs from land-applied sewage sludge was conducted by Ziemba et al. (2013). The authors found that the aerosolized PBDE-47, -99, -153, and -209 maximum daily inhalation dosages from sewage sludge application were 137, 27, 1.9 and 81 pg/day, respectively, which contributed insignificant amounts to human exposure.

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