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Evaluation of Hospital Wastewater Treatment Using Sewage Treatment Plant for Heavy Metals, Radionuclides, and Some Pharmaceuticals: A Case Study

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ARTICLE HISTORY

ABSTRACT

This is the first study in Oman to evaluate the efficiency of a sewage treatment plant (STP) for hospital wastewater (HWW) treatment for heavy metals, radionuclides, and some selected pharmaceuticals. A sewage treatment plant (STP) at Sultan Qaboos University (SQU) receives HWW, from Sultan Qaboos University Hospital (SQUH), and municipal wastewater from non-medical facilities at SQU. Representative samples of HWW (before mixing with municipal wastewater at STP), STP-treated wastewater (TWW), and STP mixing sludge, were collected and analyzed. A method for analyzing pharmaceuticals including metformin, atenolol, chlorpheniramine, triprolidine, diphenhydramine, and citalopram was developed and validated using LC-MS-MS. HWW and TWW show low concentrations of heavy metals. Radionuclides found in HWW include Cs^{137}, K^{40}, Ra^{226}, Th^{234}, I^{131}, Tl^{208}, Zn^{65} Ac^{228}, Sb^{125}, Bi^{124} and Be^7. Diphenhydramine (2.24 μg/L), chlorpheniramine (0.293 μg/L) and atenolol (0.0260 μg/L) were found in HWW. Heavy metals, radionuclides, and pharmaceuticals were found less in TWW than in HWW. STP sewage sludge showed higher levels of these pollutants than HWW or TWW. Concentrations of diphenhydramine, chlorpheniramine, and citalopram were 137, 0.950, and 169 μg/kg, respectively in dried sewage sludge. The study confirms the ineffectiveness of STP treatment to completely remediate HWW. HWW should be considered hazardous and requires physico-chemical treatment before mixing with municipal wastewater.

Keywords: Hospital, pharmaceuticals, radionuclides, heavy metals, wastewater.

تقييم معالجة مياه الصرف الصحي بالمستشفى باستخدام محطة معالجة مياه الصرف الصحي للمعادن الثقيلة والنويدات المشعة وبعض الأدوية: دراسة حالة

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الملخص: هذه هي الدراسة الأولى في سلطنة عمان لتقييم كفاءة محطة معالجة مياه الصرف الصحي (STP) لمعالجة مياه الصرف الصحي بالمستشفى (HWW) للمعادن الثقيلة والنويدات المشعة وبعض الأدوية المختارة. تستقبل محطة معالجة مياه الصرف الصحي بجامعة السلطان قابوس (SQU) مياه الصرف الصحي من مستشفى جامعة السلطان قابوس ، ومياه صرف البلدية من المرافق غير الطبية في جامعة السلطان قابوس. تم جمع وتحليل عينات ممثلة من مياه صرف المستشفى (قبل خلطها مع مياه الصرف الصحي البلدية في STP) ، وكذلك مياه الصرف الصحي المعالجة (TWW) STP ، وحمأة الصرف الصحي الناتجة من محطة المعالجة (STP). تم تطوير طريقة لتحليل المستحضرات الصيدلانية بما في ذلك الميتفورمين ، والأتينولول ، والكلورفينيرامين ، والتريبروليدين ، والديفينهيدرامين ، والسيتالوبرام والتحقق من وجودها باستخدام LC-MS-MS. وأظهرت الدراسة أن مياه صرف المستشفى (HWW) والمياه الناتجة من محطة المعالجة (TWW) تحتوي علي تركيزات منخفضة من المعادن الثقيلة. تشتمل النويدات المشعة الموجودة في HWW على Cs^{137} و K^{40} و Ra^{226} و Th^{234} و I^{131} و Tl^{208} و Zn^{65} Ac228 و Sb^{125} و Bi^{124} و Be^7. وتم العثور على ديفينهيدرامين (2.24 ميكروغرام / لتر) وكلورفينيرامين (0.293 ميكروغرام / لتر) وأتينولول (0.0260 ميكروغرام / لتر) في HWW. وتم العثور على المعادن الثقيلة والنويدات المشعة والمستحضرات الصيدلانية أقل في TWW مما كانت عليه في HWW. وأظهرت حمأة الصرف الصحي من STP مستويات أعلى من هذه الملوثات من HWW أو TWW. كانت تركيزات الدايفينهيدرامين والكلورفينيرامين والسيتالوبرام 137 و 0.950 و 169 ميكروجرام / كجم على التوالي في حمأة الصرف الصحي المجففة. تؤكد الدراسة عدم فعالية علاج STP لعلاج HWW تمامًا. واقترحت الدراسة اعتبار مياه المستشفيات خطرة حيث تتطلب علاج قبل امتزاجها بالصرف الصحي.
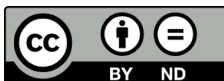
1. Introduction

Hospital waste water (HWW) is considered highly toxic as it contains microorganisms, pharmaceuticals, heavy metals, radionuclides, halogenated organic compounds, disinfectants, pigments, dyes, genotoxins, cytotoxins, and drug metabolites, some of which are environmentally persistent and pose a direct threat to the environmental and public health [1, 2]. HWW contains heavy metals from feces, medicine, and food supplements ingested by patients, as well as cleaning agents, paints, utensils, and equipment wear [3]. Silver is used in X-ray film development, while manganese, gadolinium, and iron are involved in diagnostic magnetic resonance imaging (MRI). Some heavy metals are used for medical treatment purposes such as zinc, tungsten polyoxoanions, cisplatin, and boron [3]. Metals such as iron, copper, cobalt, manganese, zinc, and chromium are essential micronutrients, however, they become toxic at excessive levels [4]. However, non-essential elements, such as mercury, lead, and cadmium are directly toxic to humans, animals, and plants. Levels of Pb, Ni Al, Cd, Fe, Hg, Zn, Mn, and Cr were detected in HWW [4-6].

Nuclear medicine uses gamma-emitting radioisotopes in hospitals for diagnosis (e.g. nuclear imaging) and treatment (e.g. radiopharmaceuticals). Radiopharmaceuticals (radioisotopes attached to a pharmaceutical), when ingested by the patients, are absorbed by a specific organ or diseased tissues, and then detected by a gamma camera [7, 8]. Radioisotopes that are used in medical applications include Be^7, TC^{99m}, I^{131}, I^{123}, Cs^{137}, Sm^{153}, $Rn^{222,}$ and Ra^{226} are detected in HWW [9]. Radiopharmaceuticals have been increasingly used in hospitals in recent years. During radioactive dose preparation and within a few hours after application, radioisotopes are released to hospital sewers from the patient's body via urination. Radiation discharge in the environment depends upon the type of radionuclide, the type of treatment, the metabolism of radiopharmaceuticals inside the body, and whether the treatment is in-patient or out-patient [10]. Health problems such as cancer, birth defects, and sterilization can arise from radiation contamination. In addition, it can also sterilize the soil and contribute to water and air pollution [10]. Other studies showed that wastewater treatment plants (WWTP) failed to completely remove I^{131} and Tc^{99m} [11,12].

Pharmaceuticals have been frequently reported to be present in wastewater, surface water, and groundwater as they escape from wastewater treatment plants [13-15]. German wastewater treatment plants contained over 30 different drugs, according to Ternes [13]. In another study, in Brazil, Canada, and Germany, many drugs have been detected in surface and ground waters [16]. Rodriguez-Mozaz *et al*. [17] analyzed antibiotics in treated effluent in wastewater treatment plants in seven European countries. They found that seventeen antibiotics were found in high concentrations in Ireland, Portugal, and Spain, while lower concentrations were found in Norway, Finland, Germany, and Cyprus [17]. In Colombia, acetaminophen, diclofenac, azithromycin, ciprofloxacin, sulfamethoxazole, losartan, metoprolol, and omeprazole were present in all samples at concentrations from one up to some hundreds of µg/L [18]. In Nigeria, levels of drugs were found in the Odo Iya Alaro River water [19]. A well-known adverse effect of drugs on living species is the feminization of male fish. Over the last several decades, genetic mutation and cancer have been associated with genotoxic substances released in HWW [20]. HWW pollutants can develop antibiotic-resisting bacteria causing a biological imbalance in the aquatic ecosystem [1]. HWW pollutants accumulated in soil due to the usage of contaminated sludge as fertilizer [21] and levels of pharmaceuticals were found in plants such as barley, cucumber, and lettuce [22].

In Oman, it is common to use STP-treated water and sewage generated for parks' irrigation, and as fertilizer for soil, respectively. In this study, HWW from the sewer system of SQUH, STP-treated water (TWW), and generated sewage sludge from STP, which receives HWW from SQUH, were analyzed for heavy metals, radioisotopes, and some pharmaceuticals.

2. Materials and methods

2.1 Materials

Pure samples of metformin, atenolol, chlorpheniramine, triprolidine, diphenhydramine, and citalopram were provided by the National Pharmaceutical Industries Company (NPI), Al Rusayl,

Muscat. The rest of the chemicals used, purchased from Sigma-Aldrich, were of HPLC grade.

2.1.1 Sample collection

HWW of SQUH and municipal wastewater from non-medical facilities at SQU were received in a sewage treatment plant (STP). Before being mixed with municipal water, HWW samples were collected from the two outlets of the sewer system of SQUH during working days and were mixed in equal volumes to produce representative samples. HWW samples were sealed immediately after collection and kept under ice during transport to the lab. Samples of TWW were collected from the STP outlet of treated water. Both HWW and TWW samples were filtered using a 0.45 μm microfilter to remove suspended solids. The samples were stored in a freezer and defrosted to room temperature before conducting the analytical procedure. Five different batches of dry sewage sludge were collected at different times from STP at SQU. Sample collection of HWW, and TWW was carried out on Tuesdays every week in the period between 3 and 29 September 2016 making 4 representative samples. The sewage sludge samples were allowed to dry at 55°C until constant weight was achieved. Dry sludge was kept in a desiccator to cool, then ground to powder and stored in well-closed polyethylene jars. Sewage sludge samples (5 representative samples) were collected on Tuesdays every week in the period between the 3rd of September to the 3rd of October 2016.

2.1.2 General characterization

The pH of HWW and TWW was analyzed using a calibrated pH meter. Chemical oxygen demand (COD) was analyzed using a multi-analyte photometer (Chemetrics, USA) using a COD kit after digestion in a digester block. Total dissolved solids (TDS) was measured using YSI professional plus apparatus (USA). Total suspended solids (TSS) were analyzed following a standard method using a microfilter of 0.45 μm under vacuum [23]. Biochemical oxygen demand (BOD_5) was analyzed following a standard method [24]. Total organic carbon (TOC), inorganic carbon (IC), and total carbon (TC) were analyzed using the GE Sievers InnovOx TOC analyzer (GE, USA).

The sludge pH was determined following a standard method [25]. To measure the pH of sewage sludge, 1 g of dried sludge powder was mixed with 25 mL of CO_2-free MLQ water and was left for 1 hour under constant stirring. The pH of the sludge slurry was determined using a calibrated pH meter.

2.1.3 Analysis of heavy metals and radionuclides

After collection, homogenizing, and filtration, portions from the representative samples of HWW or TWW were acidified to pH 2 using HNO_3 to prevent bacterial growth and avoid possible adsorption metals on the container's walls. Metal concentrations were analyzed via inductively coupled plasma-mass spectrometry (ICP-MS), Aroura M90, Bruker, USA. For STP sludge, 5 g of the dried sludge was mixed with 50 mL (50 % HNO_3). The mixture was heated at 80°C to almost dryness and was allowed to cool at room temperature. The residual liquid was filtered through sintered Glass Gooch (G3) under vacuum and the residue was washed with MLQ water. Filtrate and washings were transferred to a volumetric flask. The volume was completed to the mark using MLQ water and metals were analyzed.

For the analysis of radioactivity, the acidified HWW or TWW was transferred to Marinelli beakers of 1 L capacity. The dry powder of sewage sludge was sieved through a 1000 mm sieve for particle homogeneity. Five hundred grams of the ground sludge was transferred to a Marinelli beaker (500 mL capacity). Both samples of HWW and sludge were sealed to prevent Rn^{220} and Rn^{222} from escaping in case they were emitted during analysis. The samples were left for 4 weeks so that equilibrium takes place between Ra^{226} and its short progenies [26]. The analysis was carried out using a calibrated high-purity germanium detector (HPGe) with background subtraction.

2.1.4 Analysis of pharmaceuticals

2.1.4.1 Drug recovery and matrix effect

For the drug recovery study, two standard mixtures (10 μg/L and 100 μg/L) of the six pharmaceuticals (metformin, atenolol, chlorpheniramine, triprolidine, diphenhydramine, and citalopram) were allowed to pass through a solid phase cartridge (Hypersep retain polymeric PEP cartridge, Thermo Scientific Company). Before the extraction process, the cartridge was conditioned by passing 5 mL methanol followed by 5 mL MLQ water through the cartridge. Mixtures of standards were allowed to pass through the cartridge at a rate of 1 mL/min. 15 mL of absolute methanol was used as an eluent with an elution rate of 1 mL/min. Eluate was collected in a clean dry glass vial and was allowed to evaporate by a stream of nitrogen till dryness. The residue was dissolved in methanol (5 mL) and was immediately analyzed using LC-MS-MS (LCMS-8040, Shimadzu, Japan). The recovery was calculated via the comparison of the peak areas for analytes before and after the solid phase extraction process following Equation 1.

$$\text{Recovery (\%)} = (A/B) \times 100 \qquad \text{(Eq. 1)}$$

where, B and A are the peak areas of the standard solution before and after extraction, respectively [27].

To study the matrix effect (ME), the process involves the extraction of two sets of samples; one set

contains the analyte in tap water (post-extraction sample), while the other set contains the analyte in a solvent (standard solution). Each set of samples was prepared using the same concentration of the analyte and was processed in the same way. Equation 2 can be used to calculate the level of enhancement or suppression caused by the matrix effect(s) [27].

2.1.4.2 Preconcentration of drugs from HWW, TWW, and Sewage sludge

After conditioning the Hypersep retain polymeric PEP cartridge with 5 mL methanol and 5 mL MLQ water, representative samples (200 mL) of HWW and TWW were allowed to pass through the cartridge following the same procedure mentioned above in the recovery study. For the analysis of pharmaceuticals in sewage sludge, a representative sample was made from the five powder sludge samples by mixing 5 g from each, and the samples were then homogenized. 5 g of the homogenized sludge sample was mixed with 150 mL methanol in a round bottom flask. The organic materials were extracted in methanol using Soxhlet

extraction for four hours. The solvent mixture was collected and allowed to almost dry using a rotary evaporator under vacuum. Residual methanol extract was collected in a glass vial and the round bottom flask was washed with a few millilitres of absolute methanol. Methanol extract and washings were mixed in the glass vial and the sample was dried with a nitrogen stream. The residue was dissolved in 5 mL methanol and the sample was filtered using a 0.45 μm microfilter before analysis using LC-MS-MS.

2.1.4.3 Analysis of drugs using LC-MS-MS

The detection, identification, and quantification of the six pharmaceuticals were performed by a liquid chromatographic system coupled to a triple quadruple tandem mass spectrometer equipped with an electrospray ionization (ESI) source. The column that has been used in this project is Poroshell 120 EC -C18 column (3.0 ID × 100 mm length, 2.70 μm) from Agilent Technologies (PC18) and an oven set to 25°C. For gradient use, solvents A (0.1 % formic acid in water) and solvent B (100% acetonitrile) were used as the mobile phase. For best separation of the six drugs, the gradient program was set as follows: 2.5 min (5 % B); 2.5-5.50 min (29 % B); 5.50-9.50 min (32 % B);

9.50-10.50 min (32 % B); 10.50-10.60 min (32 % B); 10.50-13-50 min (5 % B) and 13.50-15 min (5 % B) to equilibrate for next injection (total run time was 15 min). The flow rate of the solvent was 0.30 mL/min with an injection volume of 5 μl. Desolvation line temperature, heat block temperature, and the cell temperature were set as 250°C, 400°C, and 40 °C, respectively, of positive mode. To optimize the conditions for analysis, 4.5 kV was used as the capillary voltage, 230 kPa as the collision-induced dissociation (CID) gas pressure, and 10 msec as the dwell time. The flow rate of the nebulizing and drying gases was 3 L/min. and 15 L/min., respectively.

3. Results and Discussion

3.1 Description of STP operation at SQU Campus

The wastewater effluents received from SQUH and non-medical areas at the university were allowed to pass through screening bars to remove large solid objects, followed by grit removal and fat skimming unit. The wastewater is transferred to a settling tank (primary clarifier) where coagulant(s)/flocculent(s) are added to facilitate the aggregation of small particles and their precipitation. The water is then transferred to an aeration/activated sludge tank, where

biological degradation of dissolved organic material takes place, followed by settling in the secondary clarifier tank. The clear water is transferred to an activated carbon large column as a tertiary treatment and eventually, the water is subjected to disinfection using chlorine. The sludge from both the primary and secondary clarifiers is collected and left to dry in a drying bed.

3.2 General characterization of HWW, TWW, and sewage sludge

In general, water consumption in hospitals ranges between 200-1200 L/day [28]. At SQUH, over 3 years

between 2014-2017, the average water consumption is 890 L/day/bed, with an expected equal amount of

HWW to be generated. General analysis was carried out 4 times for HWW and TWW. As presented in Table 1 the pH of all water samples tested lies within the pH range of natural water and the maximum allowed limits for water reuse in Oman [29,30]. HWW contains much higher levels of TSS, COD, BOD, TOC, IC, TC, and turbidity than TWW. TSS in TWW is slightly higher than the maximum allowed levels for

water reuse in Oman, Table 1 [29]. COD values have tremendously decreased from 745 mg/L (before treatment) to 2.1 mg/L (after treatment) which is very low compared with the maximum allowed COD limit for water reuse in Oman. TDS did not show much variation in both HWW and TWW with both values falling within accepted limits for water reuse in Oman (Table 1).

3.3 Heavy metal analysis

HWW shows higher levels of metals than TWW for B, Al, P, Sr, Ni, Co, and Cd. However, the concentrations of Mg, Fe, Cu, and Zn in HWW show slightly higher levels than HWW for these elements, and this might be related to their presence in municipal wastewater that is mixed with HWW at STP. Co, Cd, and Ni in HWW, and Co and Ni in TWW appear slightly higher than the maximum allowed limits for water reuse (Table 2). Metal ions in HWW may chelate with organic moieties present in water even after treatment such as pharmaceuticals. Some pharmaceuticals acquire functional groups that are capable of chelation with heavy metals in water such

as azo, carboxylic acid, amine, alcohol, amide, and phenolic groups [3,31]. The sewage sludge generated from STP shows much higher levels of heavy metals than in HWW or TWW (Table 2). These metals are expected to be captured onto the sewage sludge via adsorption, ion exchange, and chelation [32].

The maximum allowed limits of heavy metals in soil in Oman were set only for Cu (1000 mg/Kg), Zn (3000 mg/Kg), Cd (20 mg/Kg), and Ni (300 mg/Kg) [29]. As shown in Table 2, the levels of these four metals present in the sewage sludge are less than the maximum allowed limits in the soil for agricultural use in Oman.

Table 1. General characterization of HWW and TWW.

Water	Values	pH	TSS (mg/L)	TDS (mg/L)	TOC (mg/L)	IC (mg/L)	TC (mg/L)	COD (mg/L)	BOD (mg/L)	Turbidity (NTU)
HWW*	Average range	6.78 6.2-7.2	955 754-1103	744.5 634-884	82.0 65-96	19.9 15.4-24	101.5 80.4 -120	744.5 664-834	202 170-230	43.9 35-51.3
	RSD (%)	6.41	15.42	14.28	15.96	21.58	16.68	10.33	21.2	15.69
TWW*	Average range	7.43 6.8-7.8	62.5 21-87	837.5 729-951	5.38 2.3-7.5	12.5 8.3-14.3	18.32 10.6-21.8	2.1 0.005-3.4	5.3 4.5-6.1	2.45 1-3.2
	RSD (%)	5.86	46.2	11.65	40.9	23.3	28.9	69.9	17.6	40.34
Maximum allowed limits for water reuse (Oman) [29]	A†	6-9	15	1500	NA	NA	NA	150	15	NA
	B††	6-9	30	2000	NA	NA	NA	200	20	NA

* 4 water samples, A† Agricultural areas or water bodies with public access. B††Areas with no public access, NA (Not applicable) [29].

3.4 Radionuclides analysis

Natural radiation provides about 88 % of the annual radiation dose to the population, however, medical procedures contribute most of the remaining 12 % [8]. In this study, radionuclides that were found in both HWW and TWW include Cs[137], K[40], Ra[226], Th[234], I[131], Ac[228], Sb[125], Tl[208], Bi[124], Zn[65,] and Be[7] (Table 3) except for Cs[137] and Zn[65], they were not detected in TWW. Radioactivity was found to be at

higher levels in HWW than in TWW. The levels of radioactivity in sewage sludge are larger than HWW or TWW (Table 3). The radioactive ions are mostly adsorbed onto the sewage sludge during the treatment process. I[131] was not detected in any of the sludge samples, and this could be related to its volatilization during the drying process.

Montaña *et al.* [33] detected radioactivity in influents, effluents, and sewage sludge generated from wastewater treatment plants in Spain. Sewage sludge was found to contain high levels of K^{40} and Be^7 but less amounts of I^{131}. Jiménez *et al.* [34] found that the radionuclides of U^{238} (36.4-102.4 Bq/kg), Ra^{226} (10.1-21.0 Bq/kg), Pb^{210} (25.2-69.2 Bq/kg), Ra^{228} (15.5-28.2 Bq/kg), Ra^{224} (15.5-28.2 Bq/kg), K^{40} (113.3-271.7 Bq/kg) and I^{131} (748-771.3 Bq/kg) were found in sewage sludge from a wastewater treatment plant that received HWW. Gamma activities in the range of 24 - 250 bq/Kg were found by Puhakainen [35] in sludge samples generated from a wastewater treatment plant in Finland and such radiation level was related to the use of medical applications and industrial processes.

Table 2. Analysis of heavy metals in HWW, TWW, and Sewage sludge.

Metal	Maximum allowed limits in wastewater in Oman (mg/L) [29] A†	B†	HWW* (mg/L) Average	Range	RSD (%)	TWW water*(mg/L) Average	Range	RSD (%)	Sewage Sludge (mg/kg)** Average	Range	RSD (%)
B	0.5	1	0.078	0.054 – 0.096	22.6	0.066	0.05 – 0.07	14.74	21.0	19.3 – 21.5	4.62
Mg	150	150	0.075	0.055 – 0.074	13.6	1.552	1.43-1.67	6.82	46.0	27.8 – 65.3	29.63
Al	5	5	0.020	0.016 – 0.022	14.0	0.015	0.01 – 0.02	11.70	16.1	9.8 – 19.1	23.06
P	30	30	0.51	0.274 – 0.680	35.87	0.30	0.20 – 0.38	26.94	36.0	27.3 – 49.1	20.92
Fe	1	5	0.025	0.002 – 0.003	9.24	0.022	0.02- 0.03	21.85	26.0	15.4 – 31.6	24.25
Cu	0.5	1	0.0040	0.002 – 0.006	47.80	0.025	0.02 – 0.03	16.9	0.73	0.58- 0.98	61.92
Zn	5	5	0.015	0.005 – 0.022	48.38	0.010	0.009- 0.011	9.82	5.12	3.8 – 5.9	15.70
Sr	NA	NA	0.062	0.061 – 0.064	1.996	0.061	0.02 -0.09	47.1	1.20	<0.005 -1.2	18.30
Ni	0.1	0.1	0.19	0.14 – 0.220	19.11	0.076	0.05- 0.10	24.97	55.5	37.2 – 81.9	35.17
Co	0.05	0.05	0.12	0.087 – 0.154	22.36	0.054	0.04 – 0.063	16.24	23.8	19.8 – 26.6	13.16
Cd	0.01	0.01	0.088	0.079 – 0.094	7.22	0.050	0.022- 0.067	39.29	18.4	15.7 – 19.6	9.10

(*4 samples analyzed from HWW and TWW. **5 samples of sewage sludge). NA (Not applicable)
A† refers to agricultural areas or water bodies with public access. Vegetables or fruit can be eaten without boiling.
B† refers to areas with no public access.

The concern about the environmental and health impact of radionuclides released in HWW is globally growing. In Sweden, the Swedish radiological authority conducted studies to monitor the levels of radioactivity released in HWW [36]. Results show that a few of those radionuclides (P^{32}, Y^{90}, Tc^{99m}, In^{111}, I^{123}, $I^{131,}$ and Tl^{201}) that were used in hospitals for radiotherapy and radio-diagnostics could be of potential risk. Sewage workers are exposed to Tc^{99m}, I^{123}, I^{131}, $In^{111,}$ and Tl^{201} while the public is exposed to I^{131} in drinking water, and P^{32}, Y^{90}, $In^{111,}$ and I^{131} in fish consumption. The half-life time of radionuclides is the time required for half of the radioactive element to decay. However, the hazardous lifetime of a radioactive element is almost 10 to 20 half-lives, and it is the time required for a radioactive element to decay to about a thousandth or millionth of its original radiation. Thus, there is no actual safe level [37, 38]. Common medical radioactive waste includes Te^{99m} with a half-life of 6 hours while hazardous life of 2.5-5 days, Ga^{67} with a half-life of 78 hours and hazardous life of 1-2 months, and I^{131} with a half-life of 8 days and hazardous life of 80-160 days [37, 38]. Khan *et al.* [38] recommended that the radioactive waste is stored away for a minimum period of 10 half-lives when after decay only 0.1 % of the initial activity remains. The guidance levels recommended by WHO for the radioactivity in water are 10 bq/L for I^{131} and Cs^{137}, and 1 bq/L for Th^{232} and Ra^{226} [39]. Based on these values, the radioactivity of I^{131} and Cs^{137} in HWW and TWW are less than the WHO limits, however, Th^{232} and Ra^{226} levels are higher in both HWW and TWW than these guidance levels. The STP treatment proved ineffective for the removal of the radionuclides from the wastewater showing ~31.6 % radioactivity removal from HWW.

The radium equivalent activity [40] of the dry sewage sludge generated from the STP treatment plant was calculated using Eq. (3).

Ra_{eq} (bq/kg) = A_{Ra} + 1.43 A_{Th} + 0.077A_K (Eq. 3)

where A_{Ra} , A_{Th} and A_K are the specific activity concentrations of Ra^{226}, Th^{232} and K^{40} in bq/kg, respectively. The radium equivalent activity for the different samples of sewage sludge was found to be 96.4 bq/kg which is lower than the upper permissible limit of Ra_{eq} in soil (370 bq/kg) [40]. However, using contaminated radioactive sludge in agricultural soil can lead to the accumulation of radioactivity in the soil which can transfer to plants.

In a recent study where wastewater from four hospitals were analyzed in Kuwait, the analysis showed all the wastewater from the four hospitals contained high levels of Tc^{99m} (0.14-14.151 bq/L), I^{131} (13.56-27.1 bq/L), and low levels of K^{40} (0.45-0.86 bq/L) [41].

The high RSD values of the analytical results of heavy metals, radioactivities, and other parameters of HWW, TWW, and sewage sludge are related to the variation in sampling and analysis. As mentioned earlier, the representative samples were collected every Tuesday in different weeks. Thus, HWW sample composition depends on the hospital activities and rate of water consumption. For TWW, the sample composition depends also on the varying activities in the hospital and the non-medical facilities on Campus. The variation in the values is not only related to the analysis but also due to sampling. This principle is emphasized in environmental analysis not only because of a varying environment [42] but also due to their low concentrations [43]. Similar results of large standard deviation for environmental samples analysis were reported before for heavy metals in HWW [44] and other pollutants in groundwater [45].

Table 3. Radioactivity in HWW, TWW, and Sewage sludge.

Radionuclides	HWW (bq/L)			TWW (bq/L)			Sewage sludge (bq/Kg)		
	Average	Range	RSD (%)	Average	Range	RSD (%)	Average	Range	RSD (%)
Cs^{137}	0.0320	0.023-0.040	45.3	ND	ND	ND	0.163	0.122-0.213	25.1 %
I^{131}	0.120	0.0450 – 0.123	47.3	0.0540	0.023-0.067	32.2	ND	ND	ND
Th^{232}	37.2	27.3-45.3	30.2	26.5	22.3-29.3	18.7	47.8	35.6-73.0	28.3
Tl^{208}	4.10	3.03-6.43	1.30	1.45	1.40 – 2.32	44.8	35.7	23.4-45.7	44.3
Ac^{228}	4.11	2.51-5.34	38.3	3.52	3.10-3.73	13.2	91.9	67.5 - 119	20.3
Ra^{226}	8.30	6.34 – 11.3	37.1	6.48	5.54-7.34	17.4	21.8	10.8-26.1	26.7
Sb^{125}	1.60	1.30-1.80	21.2	0.180	0.140-0.210	23.3	42.9	34.0- 56.1	19.6
Be^7	2.23	1.94- 2.45	15.4	1.24	1.01-1.34	18.8	2.13	1.34-2.30	27.4
Bi^{124}	0.360	0.230-0.434	41.2	0.220	0.15-0.270	33.7	3.23	2.43-4.20	33.5
K^{40}	2.43	1.84-2.66	22.8	1.74	1.52-1.85	13.5	81.2	65.7 – 93.4	11.4
Zn^{65}	0.0430	0.0310-0.0500	28.7	ND	ND	ND	0.182	0.160-0.210	23.6

3.5 Pharmaceutical Analysis

Based on the method developed, as mentioned earlier, the drugs showed good separation in the chromatogram (Figure 1) with the chromatographic parameters, LOD, and LOQ presented in Table 4.
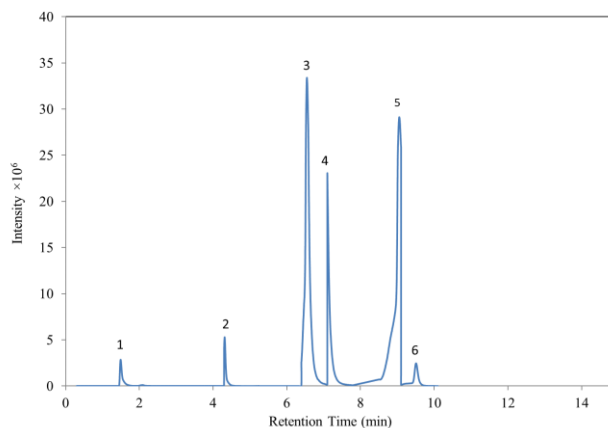

Figure 1. Chromatogram of pharmaceuticals (1: Metformin, 2: Atenolol, 3: Chlorpheniramine, 4: Tripolidine, 5: Diphenhydramine, 6: Citalopram).

All the recovery percentages were higher than 80.5 % except for metformin which shows a low percentage of recovery in both concentrations of drug mixtures (15.08 % for 10 µg/L and 9.81% for 100 µg/L, Table 5). All the recovery percentages were higher than 80.5 % except for metformin which shows a low percentage of recovery in both concentrations of drug mixtures (15.08 % for 10 µg/L and 9.81% for 100 µg/L, Table 5). The low recovery of metformin is due to its polar nature. Thus, metformin is not fully retained by the solid phase and an extent of the compound elutes with water providing less loading. The other five compounds show good recovery as they are less polar or non-polar compared to metformin. To study the matrix effect of the target compounds, two samples of tap water were injected into the LC-MS-MS. The first sample is tap water without drug spiking. The second sample is tap water spiked with a mixture of 6 drugs at two concentrations (10, 100 µg/L). Tap water was taken in this study as a pure or blank sample. The chromatogram of non-spiked tap water shows no peaks during the run. The percentage of matrix effect falls between 88.70 and 99.9864 (Table 5) indicating less effect of the matrix on compound ionization. Representative samples of HWW, TWW, and sewage sludge were analyzed 3 times for the pharmaceuticals under investigation using the developed method. Average and standard deviation values were calculated, Table 6. Diphenhydramine and chlorpheniramine are found in all samples with different concentrations following the order: Sludge >> HWW > TWW. The large contents of both drugs present in the sewage sludge are related to their adsorption onto the sludge surface. Chlorpheniramine in sewage sludge was found to be higher by 3.25 folds than HWW, while diphenhydramine was higher in sludge by 61.5 folds than HWW. Citalopram was found only in the sludge sample with an average of 168.15 µg/kg, however, atenolol was found only in HWW with an average of 0.0264 µg/L. The unavailability of metformin in the samples tested could be related to its very low recovery on the solid

phase and it will be tested soon in another study. TWW shows less concentration of drugs than HWW and this can be related to their adsorption onto the sludge and also to the dilution by mixing municipal water with HWW at STP. Radjenović et.al [46] found that the most abundant pharmaceutical in sewage water was acetaminophen (7.1-11.4 µg/L), ibuprofen (14.6-31.3 µg/L), gemfibrozil (2.0-5.9 µg/L), ofloxacin (0.89-31.7 µg/L), atenolol (0.84-2.8 µg/L, bezafibrate (1.9-29.8 µg/L), hydrochlorothiazide (2.3-4.8 µg/L) and glibenclamide (0.12-15.9 µg/L). In a recent study, levels of antibiotics were found in effluents from wastewater treatment plants in some European countries. For example, ciprofloxacin was found to be 231.4 -457.3 ng/L in Portugal, 200.3 ng/L in Spain, 252.3-259.8 ng/L in Cyprus, 234.0-259.8 ng/L in Ireland, 43.8-230.6 ng/L in Germany, 38.4-43.2 ng/L in Finland and 159.2 ng/L in Norway. Other antibiotics were also found in treated effluents [17]. Several pharmaceuticals including ofloxacin, ibuprofen, diclofenac, azithromycin, and ketoprofen were detected in sewage sludge at concentrations up to 454.7, 741.1, 380.7, 299.6, and 336.3 µg/kg on dry weight, respectively [46]. Other Studies have shown that pharmaceuticals that are more commonly found in the environment include sulfonamides (0.02-0.58 µg/L), ciprofloxacin (6-60 µg/L), acetaminophen (10-23.33 µg/L), diclofenac (0.01-510 µg/L), naproxen (0.5-7.84 µg/L), ibuprofen (0.49-990 µg/L), ketoprofen (0.13-3 µg/L), propranolol (0.05 µg/L) and clofibric acid (0.47-170 µg/L) in addition to others [47,48]. According to Peng *et al.* [49], the maximum concentrations of ibuprofen and clofibric acid in water samples from the Pearl River Delta were 1.42 and 0.248 µg/L, respectively. In a study of hospital wastewater in Kuwait, a high concentration of paracetamol (580 µg/L) was found [41]. The analysis in this paper targeted the above-mentioned six drugs. However, other drugs could be available in HWW, TWW and Sewage sludge will be investigated in the future.

Table 4. The chromatographic parameters, LOD, and LOQ for the analysis of pharmaceuticals.

Compound	Peak number	Adjusted retention time (min.)	Relative retention	Plate number (N×10⁴)	Retention factor	Resolution	LOD (µg/L)	LOQ (µg/L)	Linear range (µg/L)
Metformin	1	0.300	1.18	0.480	1.93	5.57	0.614	2.05	10-200
Atenolol	2	1.18	3.93	6.60	2.39	8.68	0.610	2.05	10-200
Chlorpheniramine	3	5.06	1.79	1.72	4.29	4.91	0.280	1.73	10-200
Tripolidine	4	5.62	1.12	4.60	4.76	5.39	4.25	14.2	100-500
Diphenhydramine	5	7.57	1.35	3.00	6.41	3.76	0.820	2.73	10-200
Citalopram	6	8.02	1.06	2.20	6.80	1.03	10.9	36.3	40-200

Table 5. Recovery data and matrix effect at 10 μg/L and 100 μg/L.

Drug	Drug concentration (μg/L)	Recovery (%)	Matrix effect (%)
Citalopram	10	90.3	88.8
	100	90.6	99.0
Chlorpheniramine	10	98.2	99.3
	100	92.1	99.99
Atenolol	10	80.6	96.3
	100	81.8	99.6
Metformin	10	15.9	88.9
	100	9.82	94.7
Triprolidine	10	101	99.6
	100	96.9	100.0
Diphenhydramine	10	83.6	99.8
	100	92.7	100.0

3.6 Evaluation of STP treatment of hospital wastewater

It is evident, from the current study, that pharmaceuticals (chlorpheniramine, diphenhydramine, and atenolol) and radionuclides (Cs^{137}, K^{40}, Ra^{226}, Th^{234}, I^{131}, Tl^{208}, Ac^{228}, Sb^{125}, Be^7, $Bi^{124,}$ and Zn^{65}) are available in HWW. Treated wastewater (TWW) from STP also includes pharmaceuticals (chlorpheniramine, diphenhydramine), and radionuclides (K^{40}, Ra^{226}, Th^{234}, Ac^{228}, Sb^{125} $Tl^{208,}$ and Be^7), however in less concentrations and radioactivity, respectively, than HWW. The low level of radioactivity and pharmaceuticals in TWW can be related to their adsorption on the sewage sludge, the dilution factor as HWW is mixed with other municipal water in STP, and probably an extent of degradation for the pharmaceuticals in the treatment process. Due to the presence of some persistent substances, such as pharmaceuticals, in HWW and TWW, there is an expected error in BOD values. This is because these persisting substances could sicken the bacteria, and this can affect the level of dissolved oxygen consumption. STP sewage sludge accumulates larger concentrations of pharmaceuticals (chlorpheniramine, diphenhydramine, and Citalopram), more radioactivity (Cs^{137}, K^{40}, Ra^{226}, Th^{234}, Ac^{228}, $Sb^{125,}$ and Be^7), and higher levels of heavy metals than HWW. For example, diphenhydramine, $K^{40,}$ and Cd are 61.5 folds, 33.4 folds, and 211 folds higher in STP sludge than in HWW.

The sewage sludge generated from STP, which receives HWW, is considered toxic and must not be used as a fertilizer for agricultural lands unless treated. Treated wastewater is still contaminated by pharmaceuticals, radionuclides, and heavy metals. Therefore, the study recommends a primary stage of physicochemical treatment for HWW before its mixing with municipal wastewater for further treatment. Figure 2 represents the evaluation of STP treatment of hospital wastewater as most of the pollutants move from treated water to sewage sludge.

Table 6. Analysis of pharmaceuticals in HWW, TWW, and sewage sludge*.

Real sample	Values	Diphenhydramine	Chlorpheniramine	Citalopram	Atenolol
HWW	Average (μg/L)	2.24	0.293	-	0.026
	RSD (%)	12.0	142	-	26.9
Sewage Sludge	Average (μg/kg)	138	0.953	169	-
	RSD (%)	94.5	66.5	76.4	-
TWW	Average (μg/L)	0.958	0.0810	-	-
	RSD (%)	8.46	71.6	-	-

Currently, the STP at SQU is closed and HWW is directed to a membrane bioreactor technology unit for wastewater treatment which will be evaluated in the future.

4. Conclusions

Hospital wastewater, in this study, contains heavy metals, radioisotopes, and pharmaceuticals. Heavy metals did not show much variation between HWW and TWW because of their presence in non-medical wastewater from the residential area at the university campus. The HWW should be considered as hazardous wastewater and effective legislation for its treatment and control is required.

radionuclides; Cs^{137}, K^{40}, Ra^{226}, Th^{234}, I^{131}, Tl^{208}, Zn^{65} Ac^{228}, Sb^{125}, Bi^{124} and Be^7 were found in HWW, but Cs^{137} and Zn^{65} were not found in TWW. However, in sewage sludge, all radionuclides were present except I^{131}. Some pharmaceuticals were found to escape the STP treatment and were found in TWW. Pharmaceuticals, heavy metals, and radionuclides were found in larger concentrations in the

sewage sludge than in HWW or TWW. The study emphasizes their escape from the STP treatment posing danger to public health and the environment. Thus, a physicochemical process is needed to treat HWW before

being mixed with municipal wastewater for further treatment. Contaminated sewage sludge should not be used in agriculture as fertilizer unless clarified from HWW contaminants.
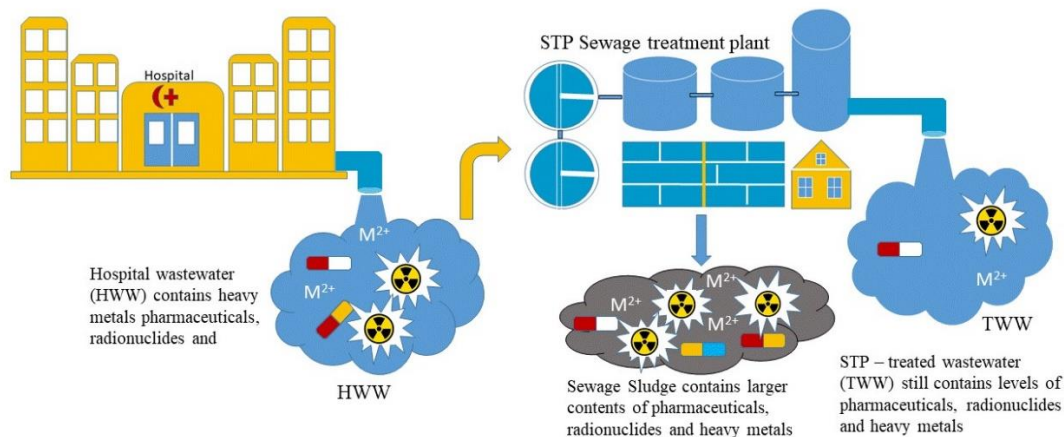

Figure 2. Evaluation of hospital wastewater treatment in a sewage treatment plant (STP).

Conflict of interest

The authors declare no conflict of interest.

Acknowledgment

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