

Performance of Wastewater Treatment Plants in Iraq: Life Cycle Assessment Approach

Isam Alyaseri¹

¹(Isam Alyaseri, Ph.D., Assistant Professor, Department of Civil Engineering, Al-Muthanna University, Al-Samawah 72001, Iraq, and Visiting Assistant Professor, Department of Civil Engineering, Southern Illinois University Edwardsville, Edwardsville, IL 62026-180)

Abstract: Natural water system in Iraq is facing massive destruction and quality degradation mainly due to absence of an effective protection regulations against direct discharge of pollutants, and inefficient wastewater treatment at Iraq's sewage treatment plants. Alsamawah City is the center of AlMuthanna Province in Southern Iraq. The wastewater treatment plant that serves the city is facing major problems related to improper design and/or implementation of structural plan, lack of professional operators, power shortage, and lack of maintenance. An environmental evaluation of the plant was conducted. The plant was not able to reduce the tested contaminants properly, and failed to comply with standards. Effluent average concentration of oil and grease, TSS, CL-, NH₃, COD, and H₂S was 42.0, 5.4, 3.5, 1.6, 1.2, and 1.2 times higher than the local standards, respectively. It complies only at the events when a contaminant is originally had low concentration in the raw sewage. In most sampling events the results show that wastewater was leaving plant with little to no treatment, turning the plant into the top point source polluter in the province. To quantify and show decision makers the damages occurred due to improper treatment at the plant, life cycle assessment methodology (endpoint approach) was used. Annual damages from Alsamawah WWTP are 7.3 (± 0.8) years loss in human life, 2.5×10^{-2} ($\pm 2.9 \times 10^{-3}$) species loss in the area, and $\$1.1 \times 10^7$ ($\pm 1.2 \times 10^6$) more expenses needed for future generations for resources.

Keywords: wastewater treatment, life cycle assessment, developing countries, Iraq

I. Introduction

1.1 Wastewater Treatment in Iraq

The purpose of wastewater treatment is to remove or reduce contaminants in water that impose threats to human and environment if discharged to surface and/or ground waters without proper treatment. While developed countries are continuing working on setting more efficient treatment processes in the WWTPs or establishing new technologies to meet the increasing demand for water, the developing countries are still straggling to establish the required infrastructure for treatment. Although the damage from lack of such infrastructure is obvious, the public concern still limited due to lack of governmental programs that explain the environmental problems for public and the influence of crisis and political conflicts in these countries. Current outreach programs in these countries are still limited and not operative. Increases in water pollution, concomitant with water scarcity may limit economic development and lead to the commonness of poverty, hunger and disease.

Problem of improper wastewater treatment is acute in countries suffering crisis like Iraq. Decades of wars and sanctions in Iraq combined with limited environmental awareness in both public and governmental representatives, have highly contributed to the destruction of Iraq's national water system. According to the United Nations report [1], six million people have no access to clean water and more than 500,000 Iraqi children access their water from a river or creek and that over 200,000 access their water from an open wells. In the first six months of 2010, there were over 360,000 diarrhea cases as a result of polluted drinking water and a lack of hygiene awareness among local communities, particularly vulnerable groups such as women and children. The report showed that "Every day at least 250,000 tonnes of raw sewage is pumped into the Tigris river threatening unprotected water sources and the entire water distribution system" [1].

Currently, the lack of permanent governmental programs for environment protection, lack of expenses, unavailability of professionals, engineers, and skilled operators, unprofessional design and treatment of most of existing plants, and lack of public awareness about the danger of direct discharge of wastewater to water courses had led to serious deficiencies in operations in the country's wastewater treatment plants. Most of these plants were not designed based on a proper local data and were constructed by inexperienced companies. In addition to the improper design and implementation, the mechanical and electrical equipment at these plants have suffered from lack of spare parts and no preventative maintenance due to lack of expenses and trained operators. In many cases untreated raw sewage is directly discharged into Rivers, endangering the health of residents and downstream populations.

Many studies performed to evaluate the wastewater treatment in Iraq [2, 3, 4, 5]. Al-Rawi and Altayar, evaluated the wastewater treatment operations of a plant in the City of Al-Mosul. They concluded that the absence of an experienced operators and the lack of dissolved oxygen are the main reason for the deficiency in treating organic contents [6]. Alsaqqar et al., evaluated the performance of a WWTP in Al-Diwaniya, one of the cities in the southern Iraq. The study indicated many operational problems that render the level of BOD₅, COD, TSS and NO₃ exceeded the disposal limitations [7].

1.2 Wastewater Treatment Evaluation Using Life Cycle Assessment Methodology

Roeleveld et al., showed that the minimization of pollutants discharge and sludge production is more important than minimization of energy consumption when the sustainability of the WWTP has to be improved [8]. If the processes in the wastewater treatment plant (WWTP) did not reduce pollutants properly, damages would be occurred on receiving water and human health. Assessment of damages or impacts can be achieved through the use of life cycle assessment (LCA) methodology [9]. ISO 14044 defined LCA as a method for assessing the environmental impacts associated with a product or a process [10]. LCA methodology becomes more and more common in recent years [11].

Although the use of LCA on wastewater management was covered by many studies during the last few years [12, 13, 14, 15, 16, 17], there is still a need for more studies due to variation in spatial and temporal conditions on each case study, along with the difference in environmental concerns from one place to another. In developing countries, such studies can help evaluating the damages due to improper treatment. They also can help environment protection activists to rise the public awareness about the wastewater contamination.

1.3 Goal and Scope of the Study

Objective of this study is to enlighten public and decision makers about the damages occurred due to wicked planning and operations on wastewater treatment plants using one example in the City of Alsamawah southern Iraq. The study aim to evaluate the environmental performance of the existing wastewater treatment train in the plant using the life cycle assessment methodology.

II. Materials And Methods

2.1 Life Cycle Impact Assessment Method

To describe the impacts, LCA studies use a life cycle impact assessment (LCIA) method [18]. These methods are based on two approaches; the midpoint and the endpoint. The midpoint approach uses the categories that lay in the middle of the cause-effect chain. Examples of these midpoint categories are global warming that is measured in kg CO₂ eq., acidification measured in H⁺ moles eq., and ozone layer depletion measured in kg CFC-11 eq., while the endpoint approach is changing the midpoint impact categories to more specific damage categories on human, ecosystem, and resources. Damages on human are calculated based on the equivalent cancer cases. Damages on ecosystem are evaluated by estimating the fraction of species affected by the nutrients and toxics introduced to environment, and the damages on resources are evaluated based on the calculation of surplus energy or expenses needed by future generation to extract the resources they need due to the current use of resources by our generation.

Changing a unit of substance released from a process or product into equivalent cancer cases in human, disappearance for some species in environment, or surplus expenses needed by future generation, on the endpoint level, needs to facilitate more structured and informed weighting process than the midpoint level. Besides the transparency difficulty, data availability represents one of the biggest constraints that are limiting the use of endpoint approach but, with the increasing interest in LCA methodology and increasing in the number of epidemiological and environmental studies [19], the link between the inventory and potential end damages on human, ecosystem, and resources for most categories becomes available [20].

Although the midpoint approach is easier to perform (less data and assumptions required), it has complications in understanding impacts. It is hard for the public to understand the impacts cause by one kilogram of NO_x emitted to air in a highly populated area, or the impacts of one kilogram of PO₄ emitted to a lake. Endpoint approach gives public, decision makers, and regulatory agencies easier understanding for the final damages [21]. Also, it is more useful for the environmental activists to use results from endpoint approach to explain their concerns to the society especially where and when the public understanding about the environmental problem is limited.

2.2 The Selection of Life Cycle Impact Assessment Method

Examples of methods using endpoint approach now are Eco-indicator 99, IMPACT 2002₊, and ReCiPe 2008 [22, 23, 24, 20]. ReCiPe 2008 method is a newer version of Eco-indicator 99. It converts the life cycle inventory (LCI) into disability years in human, a percentage of decreased biodiversity over an area during a

certain period in environment, or energy needed by future generations due to the depletion in resources. The method also estimates the overall impacts in a single score (point, Pt or millipoint, mPt).

ReCiPe 2008 contains two sets of impact categories with related sets of characterization factors. At the midpoint level, the impact categories are: climate change (CC), ozone depletion (OD), terrestrial acidification (TA), freshwater eutrophication (FE), marine eutrophication (ME), human toxicity (HT), photochemical oxidant formation (POF), particulate matter formation (PMF), terrestrial ecotoxicity (TET), freshwater ecotoxicity (FET), marine ecotoxicity (MET), ionizing radiation (IR), agricultural land occupation (ALO), urban land occupation (ULO), natural land transformation (NLT), water depletion (WD), mineral resource depletion (MRD), and fossil fuel depletion (FD). These midpoint impact categories are further converted and aggregated into three endpoint categories: damage to human health (HH), damage to ecosystem diversity (ED), and damage to resource availability (RA). The ReCiPe method used in this study was based on a Hierarchist perspective. World characterization and normalization factors in ReCiPe were used on which enable the method to be used outside Europe. There are no local normalization factors available for the country of study area.

2.3 System Boundaries

LCA influenced by the selection of system boundaries [25]. Parameters or phases with small contributions are avoided when possible [26, 27, 28]. The boundaries of the system start at the point where the wastewater is entering the sewer system. The functional unit was defined as one cubic meter of raw wastewater. The system boundaries include the phases of construction and operations. Construction materials include production, manufacturing and end of life phases. Electricity used for operations were included. Minor consumable materials (such as offices supplies, monitoring devices, etc.) and labor were not included in this study. Since no sludge was transported yet from the plant, the transportation of end product (sludge) to the point of end disposal was not included. Land occupied by processes was included. No chemicals are used to enhance settling. Maintenance was not included due to the lack of maintenance.

2.4 Inventory Analysis

A life cycle inventory (LCI) was performed by collecting inventory data from the case study (Al-Samawah WWTP). The consumption of electricity was obtained from plant records (0.142 kWh/ m³ of raw sewage). This consumption is less than 0.279 kwh/m³ (10 kBtu/gallon/day) which is the median reported by [29] for energy use in the wastewater treatment plants. The plant facing many problem such as the power shortage. The average supply of power to the plant is only 16 to 20 hours a day from national grid. Emissions to river of biochemical oxygen demand (BOD₅), chemical oxygen demand (COD), total suspended solids (TSS), phosphates (PO₄), Nitrates (NO₃), ammonia (NH₃), chlorides (CL), oil and grease (O&G), and hydrogen sulfide (H₂S) were taken from the laboratory analysis in the plant. Other emissions to air and water were taken from Ecoinvent database. Sewer and WWTP infrastructure burdens were adopted from Ecoinvent database as well. No chemicals or natural gas are used in the plant.

2.5 Case Study Description: Al-Samawah Wastewater Treatment Plant

Al-Samawah WWTP was designed to treat 37000 m³/day. It receives wastewater from residential, commercial, and industrial areas in Al-Samawa City southern Iraq. The actual estimated flow rate is 5.2 MGD (20000 m³/day). The plant consists of grit removal and secondary treatment processes. The preliminary stage consists of a bar rack screen and two grit chambers for grit removal. The grit chambers were not designed properly as the wastewater are not confined for enough retention time to allow grit settling. From grit chambers, the wastewater is moved to an aeration basins. For unknown reason, no primary treatment exist in the plant. The secondary treatment process is an activated sludge process consist of four aeration basins and four secondary clarifiers. Floated surface aerators (propeller type) are used to provide air to aeration tanks.

Prior to discharge to Al-Samawah River, effluent from the secondary clarifiers flows into a chlorine chamber for disinfection. For unknown reason, no de-chlorination unit was designed for the plant. Wasted sludge is taken from the secondary clarifiers and is pumped into two gravity thickeners where the supernatant is pumped back to the distribution chamber and the settled sludge is pumped to the drying beds. The construction works in the plant was done by 2012. Since that time, the plant was facing major problems in complying with the discharging standards. Bar screens are not maintained properly and solids are filling the grit chambers, aeration tanks, and the secondary clarifiers. Solids drying beds were not filled since 2012.

III. Results And Discussion

3.1 Data Analysis

Table 1 shows the data of 11 contaminants obtained from plant's laboratory from October 2012 to January 2015. The average suspended solids concentrations in the discharged wastewater was 325 mg/L. Among 89 sampling events, only one was below the 30 mg/L standard. The average reduction in suspended

solids was limited to 10% indicating high deficiency in the plant's processes. The deficiency is mainly related to inefficient grit removal, lack of primary treatment, and bypassing of wastewater directly to the aeration tanks during the time when screw pumps are malfunctioning. Recently, solids entering the plant are either discharged to the river or accumulated in plant's basins. Consequently, grits and suspended solids are accumulated in the aeration tanks and secondary clarifiers, clogging some piping, and creating some anaerobic conditions.

Table 1. Influent and Effluent Concentrations for Ten Contaminants Measured in Al-Samawah- WWTP Lab.

Parameter, mg/L	Date	# of Tests	Range	Average	St. Deviation	Iraq's Standards
BOD ₅	Influent	69	10-230	103.9	45.9	
	Effluent	64	5-105	35.8	18.5	40
COD	Influent	81	20-380	217.4	65.6	
	Effluent	80	12-188	117.6	32.5	100
TSS	Influent	79	20-2040	455.2	274.9	
	Effluent	89	20-540	324.5	113.6	30-60
TDS	Influent	71	1240-9020	5701	1869	
	Effluent	79	1280-7800	5717	1515	-
SO ₄	Influent	76	57-3884	1267	566	
	Effluent	76	92-3872	1355	526	-
PO ₄ ⁻³	Influent	85	0.02-1.07	0.3	0.2	
	Effluent	83	0.01-0.30	0.1	0.1	3.0
NO ₃	Influent	69	3-50	13.3	9.2	
	Effluent	70	1-46	11.7	10.4	50
CL	Influent	89	222-3937	2104	857	
	Effluent	89	222-3365	2086	738	600
NH ₃	Influent	58	0.5-32.8	15.3	7.0	
	Effluent	53	0.7-43.6	16.2	7.9	10.0
O&G	Influent	42	38-560	220	165	
	Effluent	38	18-480	168	144	4.0
H ₂ S	Influent	70	3.4-51.0	23.1	11.1	
	Effluent	28	0.4-10.6	3.8	2.6	3.0

Among 64 sampling events for the effluent BOD₅ concentration, 16 samples (25%) exceeded the 40 mg/L level. The plant was able to reduce the concentration of BOD₅ from 103.9 mg/L in the raw wastewater to 35.8 mg/L in the discharged wastewater. Since the plant receiving around 50% of the designed flow rate, the reduction in BOD₅ was achievable due to long retention time at the aeration tank. Most non-compliance to the standards was occurred during the years 2013 through 2015 most likely due to accumulation of solids short period after the facility was started in 2012. Another reason is the insufficient aeration provided to wastewater in the aeration tank due to impairment in some mechanical aerators. No measurement of dissolved oxygen (DO) or specific oxygen uptake rate (SOUR) are available in the plant. Among 80 sampling events for the COD concentration in effluent, only eleven (13.8%) were lower than the 100 mg/L standard. Among these eleven samples, six of them had initially low COD concentration in the raw wastewater.

For ammonia concentration, comparison between 54 influent vs. effluent samples, shows an average of zero reduction. In spite of lack of testing equipment, it is obvious that the lack of enough oxygen is responsible for the absence of nitrification process. Ammonia normally requires 3 to 4 times the aerobic capacity required for BOD removal. Despite the long retention time, aeration tanks provide low aeration due to power off problem and the frequent faulty of some of the mechanical aerators.

Table 1 shows that the average of TDS was 5717 mg/L (SD=1515 mg/L). This high concentration of TDS can cause extreme damage to the aquatic life and to the source of drinking water in the area. Although, wastewater treatment plants have no limits for discharging their effluent with high TDS to streams, this case study indicate the need for such limits to protect aquatic life and drinking water sources. One approach for setting limits for TDS may base on the water quality suitable for drinking. American standard for TDS in drinking water is limited to 500 mg/L, while the WHO standard is 1000 mg/L. For example in 2010, The Environmental Quality Board in the State of Pennsylvania in the U.S. set a new wastewater treatment requirements for TDS. The goal of the regulation was to ensure that the concentration of TDS in Pennsylvania's streams does not exceed the water quality criterion of 500 mg/L [30]. Data from office of environment protection in the City of Al-Samawah indicated that Al-Samawah River already exceeded these levels. The average concentration of TDS in the river for August and September, 2015 was 3050 mg/L representing 300% exceedance for WHO standards and 600% for American standards indicating serious environmental problem introduced to the river.

Table 1 shows that the average concentration of H₂S in the raw sewage was 23.1 mg/L indicating high septic condition and odor pollution. In addition to odor problems, this levels of H₂S in the sewer system may cause health risks to operators, and deteriorate the structural reliability of sewer system [31]. During the processes in the plant, the average concentration of H₂S are reduced to an average of 3.8 mg/L in the discharged

wastewater. This average is higher than the taste and odor thresholds [32]. Iraq’s standards for hydrogen sulfide is 3 mg/L. Among 28 effluent samples tested in the plant, only 15 samples were below this standards.

The average concentration of sulfates was 1355 mg/L in the discharged wastewater and is shown in the table. Currently, no limits are imposed for sulfate level in the discharging wastewater to streams. As for drinking water, the level of sulfate is limited to 400 mg/L by Iraqi’s standards and WHO, and 250 mg/L by American secondary standards. The average concentration of sulfate in the discharged wastewater did exceeded the two criterions. This may bring detrimental effects on downstream farmers whom using this water for multiple purposes (may include drinking and cattle feeding).

The table also shows that the chloride concentration was 2085 mg/L in the discharged wastewater. The range was 222 mg/L to 3365 mg/L and the lower bound of this range is very close to 230 mg/L. 230 mg/L is the chronic water quality criteria for chloride set by USEPA [33]. The level of oil and grease may reach to as high as 480 mg/L as can be seen in the table. For 38 sampling events for oil and grease, none was comply with the local discharging limit (4 mg/L).

Most contaminants tested in the plant, does exceed the local maximum contamination limits for effluent, imposing high risk to human, animals, and aquatic life downstream. No action been made for correction so far.

3.2 Life Cycle Analysis

Using ReCipe method, the impacts and damages due to the processes were computed for the treatment of one cubic meter of raw sewage at Alsamawah WWTP. Four major groups of contributors to damage are shown in Fig. 1. The figure shows that damage on the human health is higher than the other damage categories (total of 29.5 mPt).

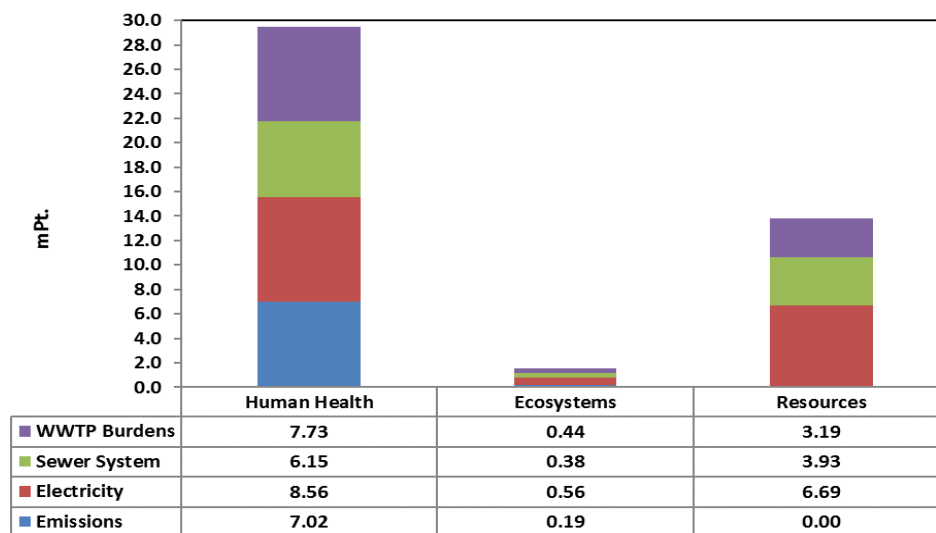


Fig 1 Weighted Damage Assessment Due to Treatment of One Cubic Meter of Raw Sewage at Alsamawah WWTP (Method: ReCiPe point (H) V1.05/World ReCiPe H/A/Weighting).

The Figure indicates that the impacts on human health are coming from electricity (8.56 mPt), WWTP burdens (7.73 mPt.), emissions to air and water (7.02 mPt), and sewer system (6.15 mPt). The damages to resources mainly comes from electricity (6.69 mPt). Electricity also is the most significant contributor for the damage to the ecosystem. The results shows the need for an energy conservation and emission reduction in any correction or proposed alternative. Table 2 shows the damages on different categories due to treatment.

Table 2: Analysis of Existing Treatment in Alsamawah WWTP in the Impact Assessment, Damage Assessment, and Single Score Levels Using ReCipe Method (CI: 95%).

Impact Category	Unit	Damage
Agricultural land occupation	Species.yr	5.4×10^{-11} ($\pm 1.42 \times 10^{-11}$)
Climate change ecosystems	Species.yr	3.06×10^{-9} ($\pm 3.84 \times 10^{-10}$)
Climate change human health	DALY	5.40×10^{-7} ($\pm 6.79 \times 10^{-8}$)
Fossil depletion	\$	1.52 (± 0.16)
Freshwater eco-toxicity	Species.yr	1.16×10^{-12} ($\pm 5.51 \times 10^{-13}$)
Freshwater eutrophication	Species.yr	2.63×10^{-11} ($\pm 1.55 \times 10^{-11}$)
Human toxicity	DALY	1.57×10^{-7} ($\pm 4.42 \times 10^{-8}$)
Ionizing radiation	DALY	4.92×10^{-10} ($\pm 5.44 \times 10^{-10}$)
Marine eco-toxicity	Species.yr	3.96×10^{-15} ($\pm 1.66 \times 10^{-15}$)

Metal depletion	\$	6.21×10^{-3} ($\pm 2.01 \times 10^{-3}$)
Natural land transformation	Species.yr	9.44×10^{-11} ($\pm 3.00 \times 10^{-11}$)
Ozone depletion	DALY	6.84×10^{-11} ($\pm 8.95 \times 10^{-12}$)
Particulate matter formation	DALY	2.98×10^{-7} ($\pm 3.08 \times 10^{-8}$)
Photochemical oxidant formation	DALY	7.15×10^{-11} ($\pm 7.74 \times 10^{-12}$)
Terrestrial acidification	Species.yr	2.17×10^{-11} ($\pm 2.97 \times 10^{-12}$)
Terrestrial eco-toxicity	Species.yr	2.43×10^{-11} ($\pm 9.14 \times 10^{-12}$)
Urban land occupation	Species.yr	1.11×10^{-10} ($\pm 1.45 \times 10^{-11}$)
Damage Assessment		
Human health	DALY	9.95×10^{-7} ($\pm 1.05 \times 10^{-7}$)
Ecosystem quality	Species.yr	3.39×10^{-9} ($\pm 4.03 \times 10^{-10}$)
Resources	\$	1.53 (± 0.16)
Single Score		
Total	mPt.	44.9 (± 4.39)

As for impact categories, Fig 2 shows the impact on the 17 categories. Climate change, fossil depletion, particulate matter formation, and human toxicity were the significant contributors to the damage. Major impact from processes was related to climate change human health (5.4×10^{-7} DALY equal to 15.4 mPt) (Table 1). The second highest impact is related to fossil depletion (\$1.44 equal to 13.0 mPt), while the third highest impact is on particulate matter formation (2.98×10^{-7} DALY equal to 8.9 mPt) which is mainly related to emissions from electricity used in the plant. The figure shows that the emissions are the major contributor to the human toxicity and particulate matter formation, and shows the importance to improve treatment in the plant.

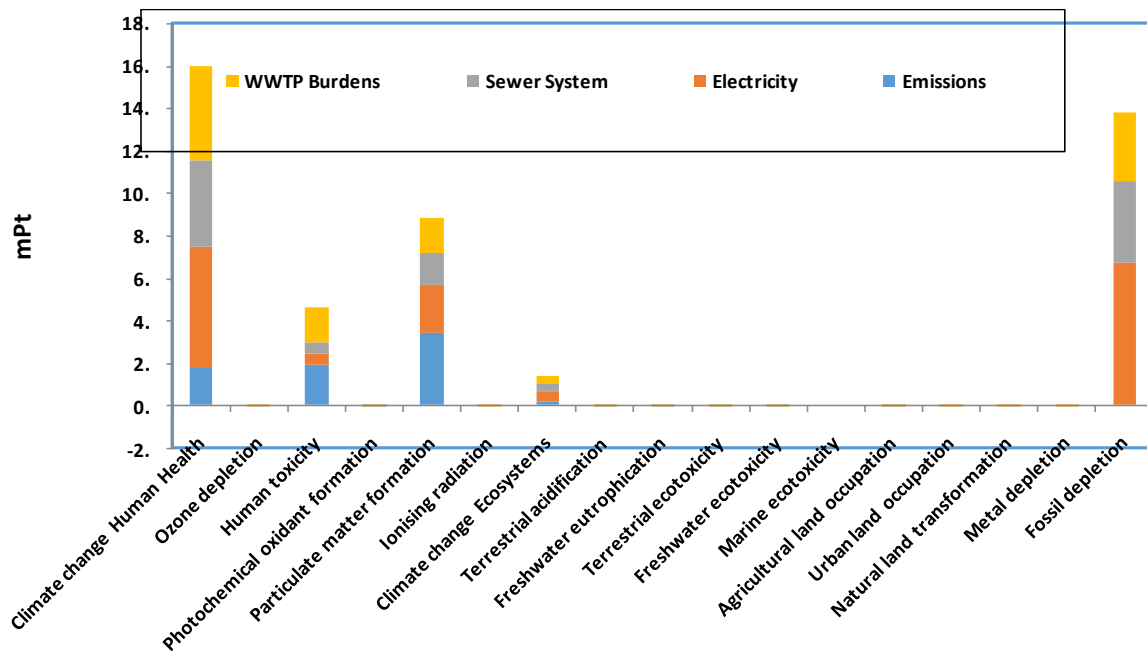


Fig 2 Weighted Impact Assessment Due to Treatment of One Cubic Meter of Raw Sewage at Alsamawah WWTP (Method: ReCiPe Endpoint (H) V1.05/World ReCiPe H/A/Weighting)

Climate change or global warming, particulate matter formation, and human toxicity are of the most common categories in wastewater treatment analysis. Corominas et al., showed that among 45 studies reviewed on wastewater treatment, 38 of them considered global warming potential but none of them analyzed the particulate matter formation or human toxicity potentials [34]. Employing weighting of ReCiPe Method shows the need to pay attention to these categories as well. Fig 2 shows that particulate matter formation and carcinogens cause human toxicity both have an impact that cannot be neglected.

Figures 1 and 2 show significant contribution from construction materials of wastewater treatment plant. These results are not consistent with the studies that neglected the environmental impacts related to construction of the facilities [27, 12, 26]. The Figures show that the environmental impacts of the construction phase of wastewater treatment processes are not negligible. However, the size of the plant is highly affect the contribution of construction materials or construction phase. Impacts from construction materials in small plant (like 5 MGD or less) usually significant as showed by Hong et al. [28]. The Figure shows no contribution from

chemicals since the plant used none. No sludge was taken from the plant since operations started so no impacts from transportation to farms as well.

The average annual cubic meter of wastewater treated by the plant is 20,000 m³. Using ReCipe method which supports the analysis of environmental burdens from the treatment processes in terms of the final damages to human health, eco-system, and resources, total annual damages can be calculated. The annual damage to human health was an average of 7.3 DALYs. This damage is relatively high when compare to plants with high flow rate (the plant receives only 5.2 MGD). This number of DALYs is relate only to the process of treatment and do not indicate the losses of human life due to spreading of pathogens. The annual species lost due to processes is 0.025, and the annual surplus expenses needed to extract resources in the future is an average of $\$1.11 \times 10^{+7}$.

IV. Conclusions And Recommendation

Like many other WWTPs in the country, the WWTP in Alsamawah, Iraq needs high efforts to overcome its inefficiencies. Although high energy and burdens for WWTP and sewer system were used, the plant was not able to reduce contaminants such as COD, TSS, oil and grease, or nutrients, and failed to comply with local regulations. Electricity and burdens from constructing WWTP and its sewer system turned out to be the main contributors to the performance of the treatment process in the WWTP. Analysis of treatment showed that most damages are related to climate change, depletion in resources, and human toxicity. In this case study (flow of 5.2 MGD), construction phase had significant contribution to environmental burdens.

Endpoint approach make it easier for decision makers for evaluation of treatment in a WWTP, and for the environmental activists to show the environmental concerns to the public. For this case study, and in terms of annual damages, if the plant continue the existing treatment method, they cause the city of Alsamawah 7.3 (± 0.8) DALYs in human, 2.5×10^{-2} ($\pm 2.9 \times 10^{-3}$) species loss, and $\$1.1 \times 10^{+7}$ ($\pm 1.2 \times 10^{+6}$) more expenses on future generations. Treatment of one cubic meter wastewater in Alsamawah WWTP cause an environmental burdens equal to 44.9 mPt. (± 4.39).

It is recommended that the City of Alsamawah put more efforts to achieve efficient treatment in reducing the discharging pathogens and other pollutants. If such efficiency was achieved, it is recommended to use solids as a resource of energy to offset burdens related to treatment.

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