Life cycle assessment of drinking water supply system: a case study of Juba City South Sudan

Mali Shadrack Paul

M-Tech student, WRD&M, Indian Institute of Technology Roorkee, ROORKEE 247667, India.

Email; malilodinya@gmail.com

Prof. Mitthan Lal Kansal

Department of WRD&M, Indian Institute of Technology Roorkee, ROORKEE 247667, India.

Email; mlkfwt@iitr.ac.in

Abstract. **Governments are working towards improving drinking water quality globally, not only to protect human health but also to boost economic growth, education, and livelihood of its people as streamlined in the sixth agenda of the sustainable development goals (SDGs). As a result of the long civil war and the continued violence in South Sudan, many of the existing drinking water supply systems (DWSS) are either dilapidated, less incapacity, or inefficient. Attempts by the government of South Sudan and its development partners to rehabilitate and design new systems in major cities like Juba has been on the top of the list. However, to assure safety in water supply plus the reduced impact of water supply discharge to nature, tradeoff between avoided and induced impacts are mandatory to mitigate and monitor the environmental loads.**

The purpose of the study is to identify the unit(s) and quantify the ecological loads from the drinking water supply system producing 7.2Ml/d, located in Juba city by conducting an environmental life cycle assessment (LCA).

The study adhered strictly to the established guidelines by the international standards organization for LCAs. Information was gathered for the operation stages, while SimaPro was utilized as the LCA examination programming with the use of the ReCipe Midpoint method. The key discoveries from the appraisal uncovered that the production/utilization of power is answerable for the majority of the environmental burdens that originate from the unit processes and the drinking water supply system, with the boosting of water to elevated tanks, being the most impactful unit.

Further analysis indicated that the utilization of conventional energy in the Juba City drinking water supply system (DWSS) has more significant environmental impacts than other energy sources such as the imported hydroelectricity power and the conventional energy country mix. The integration of these alternative energy systems with drinking water supply processes has proven to reduce environmental loads associated with DWSS. Based on these results, it is recommended that the focus should shift towards energy minimization techniques and the use of renewable sources to advance the environmental performance of water supply processes.

Keywords: **Life Cycle Assessment, Drinking water supply system, Environmental loads, Impact categories**

1.0 INTRODUCTION

Safe and adequate drinking water is an essential requirement of life and a determinant of the standard of living and health of the people in a nation. "Improving drinking water quality is a major concern of any Governments worldwide to protect human health" (Yadav et al. 2014). In recent years, populations are getting educated and therefore selective to the quality of water as they can differentiate between good and bad quality of drinking water. Hence, regulatory bodies have stringent guidelines on water quality (Garfí et al. 2016).

After a long period of the civil war, most of the facilities in South Sudan are in a dilapidated state, have limited area coverage, and unmatched capacity due to rapidly growing city's population and expanding area. Hence, urgent needs to rehabilitate, develop, design, and construct new structures to meet the drinking water needs of the city (JICA, 2009).

2.0 In South Sudan, less than 60% of people have access to safe and adequate drinking water (Uma 2019). 13% of the estimated 526,000 Juba residents have access to good quality water through the municipal water supply system, and about 87% uses water from unreliable sources making them prone to water-related diseases; typhoid, diarrhea, cholera, hepatitis A and dysentery (Cointreau. et al., 2013).

The city's drinking water supply system was constructed nearly eight decades ago when the choice from available designs was based on techno-economic criteria as the concepts of sustainability and its assessment tools were either not available or at the infancy stage of development. This system had undergone two significant rehabilitation after its design life up to date. However, the question of whether the drinking water supply system meets the environmental performance or not remains unresolved.

This report will focus on the evaluation, analysis, and integration of the environmental performance of the Juba water supply system into life cycle thinking design and address the design gap as the techno-economic and societal concerns have been explicitly discussed during the design process through the use of LCA as an alternative environmental assessment tool.

1.1 RATIONALE AND RESEARCH GAP

This study investigates the environmental impacts of the drinking water supply system by employing the LCA as an environmental assessment tool. Worldwide LCA writing demonstrates that a couple of data are available about consumable water production and supply, specifically for the ecological burden gener¬ated within the framework. (Landu and Brent, 2006). Currently, this alternative environmental assessment tool of water and associated technologies is not in use in South Sudan due to no legal requirements, policies, and lack of strategies for LCA (Nations and Programme, 2012). Besides the environmental impacts that are directly related to the drinking water supply system, water losses, the data of the auxiliary processes to the infrastructure are also deficient in South Sudan, e.g., process-specific data of electricity generation and supply, waste management, etc. Thus, the detachment to adequate life cycle stock (LCI) databases for South Sudan LCA specialists and scientists have been noted. Notably, the LCIs of the three operational parameters that are usually measured in the South Sudan water industry for eco-friendly production must be developed further: water usage, energy usage, and waste produced per processed quantity of water. However, considering the increasing demand for the provision of safe and adequate water across cities in South Sudan, it is imperative to shape the design process for future projects from the outset to reach the best outcome locally.

1.2 OBJECTIVES OF THIS STUDY

The overall objective of the study is to carry out the environmental Life Cycle Assessment of a typical water supply system meant for drinking water purposes in Juba city. The examination accordingly incorporated compiled LCI information of the supply of consumable water, which include all constituents that interact between the technosphere and nature, i.e., extraction of resources and emissions to nature, and afterward conduct a life cycle impact assessment (LCIA) of the ordered LCI to determine the general potential ecological weights related with the production of wholesome water (Lansing, 2015). By this means, the following could be achieved:

- The design gap of Juba drinking water supply system could be bridged
- Hot spot identification and environmental improvement of the potable water supply system
- Quantify the environmental loads of the water supply system, i.e., water extraction, treatment, and boosting treated water to elevated tanks.
- To evaluate alternatives of unit processes linked to high environmental loads.
- To demonstrate the benefits of conducting LCAs as an environmental management tool in South Sudan.

1.3 THE DRINKING WATER SUPPLY SYSTEM - CASE STUDY

The drinking water supply system is located on the shores of the Bahr El Jebel river, a tributary of the River Nile.

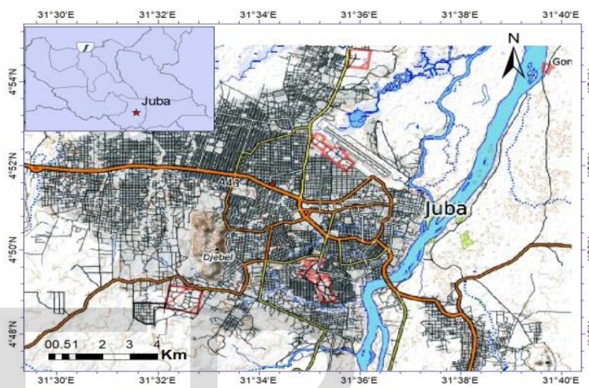

Figure 1: The location Map of Juba city

The initially screened feed water is drawn from the Juba channel (Bahr el Jebel River) with the help of a floating type intake supported by a bridge through which a flexible pipeline is mounted. Aided by two pumps, each with a design capacity of $158m^3/s$ and the third pump being on standby mode, the water is transported to the raw water tank. Under gravity, the water flows to the receiving raw water chamber where Aluminum sulfate (Soda Ash) is added and mixed by the high energy dissipated by the falling water through a weir to facilitate the coagulation/flocculation process before entering the sedimentation tank. The settled water is filtered through the rapid sand filtration technology and the flocs released to a maintenance hole where it finds its way for disposal into the river. At this treatment stage, a disinfectant (chlorine) is injected into the free gravity flowing water and finally stored in four underground tanks. The treated water is then lifted with the help of booster pumps (7 pumps) to elevated tanks located in different areas. Finally, the treated water is distributed to the user by a network of pipes or supplied by tankers to unconnected regions. A diagram of the water supply system, highlighting the key components, is presented in **Figure 2**.

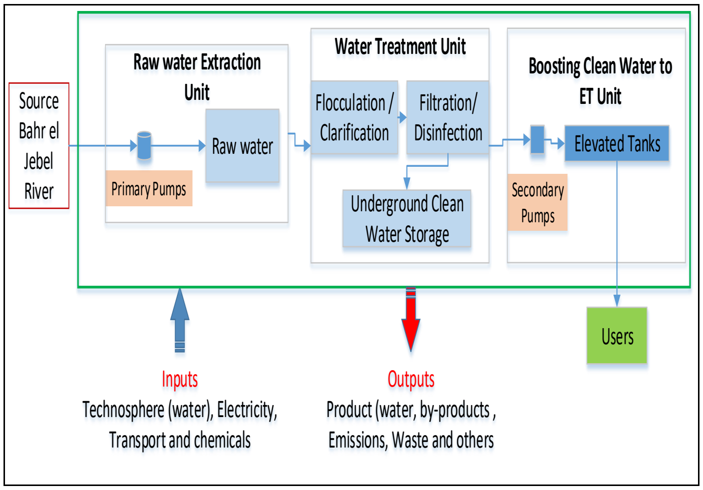

Figure 2: Simplified Process flow diagram of the Juba Drinking water supply system

2.0 METHODOLOGY

This study examines the waterworks in Juba, the capital city of South Sudan, which produces potable water based on a conventional water treatment technology. The study closely followed the four phases, as illustrated in **Figure 3**, the ISO 14040 series for conducting LCAs consists of four steps listed below and have been described in detail elsewhere (Hauschild 2017).

- Goal and scope definition. It portrays the explicit aim, indicates the target group, and application of the results of the study. A detailed description of the system boundary to be studied is included, providing a clear delimitation of scope, function and functional unit, reference flow, assumptions, and limitations made during the study.

- **LCI Analysis**. The Life Cycle Inventory (LCI) compiles the relevant inputs into the system defined by the goal and scope. The data is collected from reliable sources, processed, and output to various components of the environment is computed. Simapro software is used for the process of easing environmental accountability. It is essentially a mass and energy balance of each unit or smaller process within the more extensive network. To account for the most impactful stages, cutoff criteria of 1% environmental significance is used. ISO has provided a general framework for the inventory analysis (ISO 14041).

- **LCIA**. The Life Cycle Impact Assessment quantifies the environmental impact potential of the inventory data by selecting, classifying, and characterizing the impact indicators. For this exercise, the Recipe midpoint method was employed.

- **Interpretation**. Life cycle assessment and interpretation (LCAI) seeks for a detailed understanding of environmental implications from the previous stages of LCA and enables improvement analysis, whereby options are identified and evaluated to reduce the environmental impacts of the studied system.

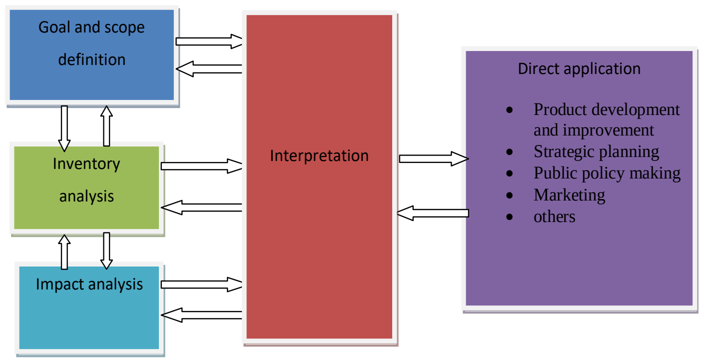

Figure 3: Standard phases of the LCA procedure

2.1 DATA REQUIREMENTS

The study subsequently compiled detailed LCI data of the supply of potable water, which include all constituents that interact between the technosphere and nature, i.e., extraction of resources and emissions to resources, and then conducted a life cycle impact assessment (LCIA) of the compiled LCI to ascertain the overall potential environmental burdens associated with the supply of potable water.

In addition to the main and sub-unit processes that are required in the direct value chain of the supplied water, auxiliary operations are needed. These are, but not limited to, the following:

- Energy inputs, in the form of electricity and fuel, which must be generated or produced separately with associated environmental impacts, and raw energy materials, e.g., coal, that are required for boilers, etc.

- The manufacturing of chemical substances that are necessary for the life cycle system, e.g., Soda ash, Alum, and chlorine gas for the chlorination phase of the purification step

- Transportation of various chemicals used in the water treatment processes, typically by road transport.

ISSN 2229-5518

Therefore, by considering all of the essential unit processes, the overall environmental burdens coupled to the life cycle system may be calculated. For this LCA study, assumptions based on literature and field observations were used to determine which unit processes should (initially) be included in the boundaries of the studied life cycle system (Goga, 2016). Following typical LCA approaches, a functional unit of 7.2 Mℓ/d of potable water supply for drinking purposes was used to which all results and discussions are based and reported.

2.2 LIMITATIONS AND ASSUMPTIONS

Data quality requirements are a general indication of the characteristics of the data for the study and thus affect the reliability of the results (Goga 2016). For the case study, data that was directly obtained from the water utility and design reports was preferable. Hence, secondary data was opted for in the study. Such data included the consumption of electricity, water extracted, chemical procurement, and use. Such efforts in gathering primary data were not possible due to;

- Time constraints
- The LCI data of the electricity generation and fuel production processes, especially, are limited to the South Sudan context. Similarly, information about chemicals that are used in water supply systems was not easily obtainable.
- The system was not designed with the consideration of collecting data for LCA. Hence data on output parameters were not available from the waterworks management.
- The SimaPro LCA software estimated emissions to air, water, and land from the reference flow input data computed by simple linear equations.

However, for specific international inputs data used during the study, a few assumptions made to bridge the data gaps include.

- The operational phase of water supply was only considered. The construction and decommissioning phase are neglected since it has minimal environmental loads compared to the overall operation of the system. The distribution and use phase have negligible ecological impacts too since most distribution to users happens through gravity.
- Data for electricity, water, and chemical consumption was obtained from the Ministry of Water Resources and Irrigation (MWRI) – South Sudan
- Waste generated during water treatment was considered negligible as water has less sludge generated compared to the overall quantity of water daily produced
- For water input, it was assumed that inflow and outflow remain undiminished. For effective environmental LCA accountability, fundamental elements such as electricity, chemical production, and transport data are obtained in the ecoinvent 3 version database from Simapro.
- It was assumed that the technology and equipment utilized would perform similarly to what is currently being used in South Sudan.

Table 1: Summary of Data Requirement for the Water Supply System

Unit process	Input Specification	Unit	Rate	Qty	Total Input	Data Source	Data SimaPro
Raw water extraction – 2 pumps	Incoming water	m^3/d	7200	1	7200	MWRI	Water, River SD
	Electricity	Kwh/ m^3	0.376	7200	2707	MWRI	Diesel @power plant US /U
Treatment Unit (Chemical)	Aluminum sulphate/ Sods ash	Kg/m^3	0.133	7200	958	MWRI	Soda power @ plant US
	Chlorine	Kg/m^3	0.04	7200	288	MWRI	Cl, chlor- alkali prod. mix
	Transportation Of Chemicals	tkm	1.245 6	1000	1246	MWRI	Truck>20t, Euro1, empty return / GLO mass
Clean water to (ET) - 7 pumps	Electricity	Kwh/ m^3	1.33	7200	9576	MWRI	Diesel @power plant US /U

2.3 THE LIFE CYCLE INVENTORY (LCI)

For this LCI, the overall inventory table consists of three main parts **(see Table 1):**

- Raw water extraction unit, including the waste treatment and disposal stage
- Water treatment unit
- Boosting of clean water to elevated tank (ET) unit

The unit processes were modeled and analyzed in the SimaPro software. The result of the comparative inventory analysis was the generation of an inventory table (**Table 2**). Through a reduced matrix, SimaPro examines the system inventory by constructing the process network and tracing the movement of materials from one stage to another. The software presents the table as a single list that is itemized alphabetically. This list is used as an input into the impact assessment phase, which seeks to understand the contribution of the various processes to the overall environmental burden.

Table 2: Partial LCI table extract from SimaPro for the water supply system as per functional unit

Substance	Compartme	Subcompartmen	Unit
Acenaphthylene	Water	ocean	kg
Acetaldehyde	Air		kg
Acetaldehyde	Water		kg
Acetic acid	Air		kg
Acetic acid	Water	groundwater	kg
Acetic acid	Water	ocean	kg
Acetone	Air		kg
Acetone	Water		kg
Acetonitrile	Air		kg
Acetophenone	Air		kg
Acidity, unspecified	Air		kg
Acidity, unspecified	Water		kg
Acidity, unspecified	Water	groundwater	kg
Acids, unspecified	Water		kg
Acrolein	Air		kg
Acrylic acid	Air		kg
Acrylonitrile	Water	groundwater	kg
Air	Raw	in air	kg
Aldehydes, unspecified	Air		kg
Aluminium	Raw	in ground	kg
Aluminium	Water		kg

2.4 ENVIRONMENTAL LCIA AND RESULTS

For the study, the ReCiPe Midpoint Method (H) was used for the life cycle impact assessment (LCIA). The ReCipe LCIA methodology is described in detail by the Center of Environmental Science, Leiden University. The primary aim of the ReCiPe method is to transform the list of inventory results, into a limited number of indicator scores. At this level, 14 impact categories were defined as depicted in **Table 3**

Table 3: Total Water Supply System Loads to the environment from unit processes

Impact Category	Unit	Raw water Extraction unit	Water Treatment Unit	Pumping Clean Water- ET	Aggregated Impacts
Global warming (Climate change)	KgCo2eq	3.09×10^3	1.26×10^3	1.09×10^4	**1.53×10^4**
Stratospheric Ozone Depletion	KgCFC11eq	0.000165	0.000681	0.000584	**0.00143**
Ozone Formation, Human Health	KgNOxeq	5.59	2.46	19.8	**27.8**
Fine particulate matter formation	KgPM2.5eq	2.09	1.31	7.38	**10.8**
Ozone formation, terrestrial ecosystem	KgNOxeq	5.79	2.48	20.5	**28.7**
Terrestrial Acidification	KgSO_2eq	7.07	4.46	25.0	**36.5**
Marine Eutrophication	KgNeq	0.0145	0.0593	0.0512	**0.0716**
Terrestrial Ecotoxicity	Kg1,4-DCB	1.82×10^3	442	6.43×10^3	**8.68×10^3**
Freshwater Ecotoxicity	Kg1,4-DCB	15.3	0.819	54.0	**70**
Marine Ecotoxicity	Kg1,4-DCB	21.5	1.29	76.1	**98.9**
Human Carcinogen toxicity	Kg1,4-DCB	5.57	1.14	19.7	**26.4**
Human Non-Carcinogen toxicity	Kg1,4-DCB	756.0	42.1	2.67×10^3	**3.47×10^3**
Fossil resource scarcity	Kg oil eq	915	243	3.24×10^3	**4.4×10^3**
Water Consumption	m^3	7.2×10^3	7.23×10^3	7.2×10^3	**2.16×10^4**

2.5 INTERPRETATION

Table 3 presents a summary of the results from undertaking an impact assessment using product system data. From the figures, it is evident that for the majority of the impact categories, the water treatment unit results in improved environmental performance. This presentation is attributed mainly to the non-consumption of electricity in the treatment unit. In contrast, the raw water extraction and boosting of clean water dominate the environmental loads in all impact categories, as presented in **Figure 4** below. An explanation of the contributing factors to each impact category will follow in greater detail.

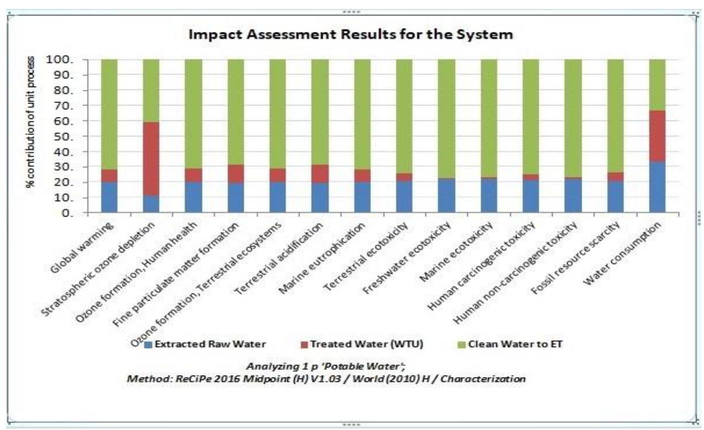

Figure 4: Overall Impact Assessment for WSS

3.0 DISCUSSIONS

3.1 Global Warming (Climate Change)

Figure 5 is a network diagram that visually represents the climate change distribution for the system process. The results in table 5.1 show that **1.53x 10^4**kg of Carbon Dioxide (CO_2) equivalent is emitted during the production of 7200$m^3$of potable water. The indication of the extent of the environmental impact for each unit operation is shown by the red shaded bars in the network diagram. It is evident that the pumping of clean water process carries the highest contribution. This can be attributed to the high electricity input required for the high-pressure feed pumps, which is highlighted in the diagram by the broad red arrow. Another pertinent point regarding energy is raised, upon examination of the diagram. Of the overall **1.53x 10^4** kg CO_2 eq greenhouse gas emissions, electricity utilized within the system is responsible for 91.8 % of the CO_2 eq contribution from the system. This impact is a direct reflection of the dominant diesel-power generated conventional electricity in South Sudan.

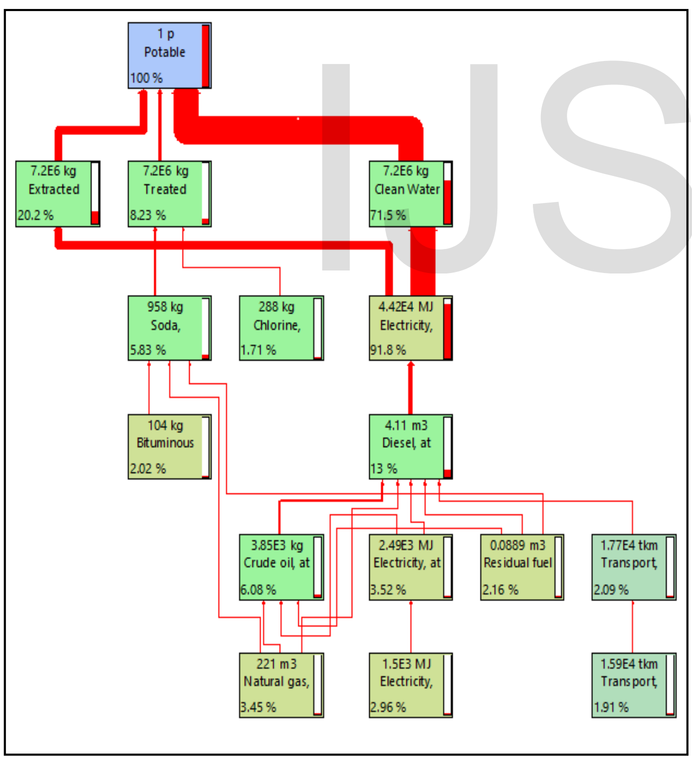

Figure 5: Network Diagram Illustrating Climate Change Contribution for Juba DWSS

3.2 Stratospheric Ozone Layer Depletion

The following chart provides insight into the contribution of each operation to stratospheric ozone layer depletion. One can ascertain that the water treatment unit, which forms the second step of the potable water production, is responsible for the majority of the emissions contributing to stratospheric ozone layer depletion. For water treatment, the release of gaseous compounds in the air is due to the chemical consumption as well as transport during the procurement process. Regarding the boosting of treated water to elevated tanks, the significant contributor to ozone depletion is electricity production and consumption for the unit. The breakdown ties in with the results in **Figure 6**, which shows the overall impact contribution due to the chemical usage/transportation in water purification as 47.6%. It is also evidenced that the combined effect of energy use in the first and third units is slightly higher than that of the water treatment unit.

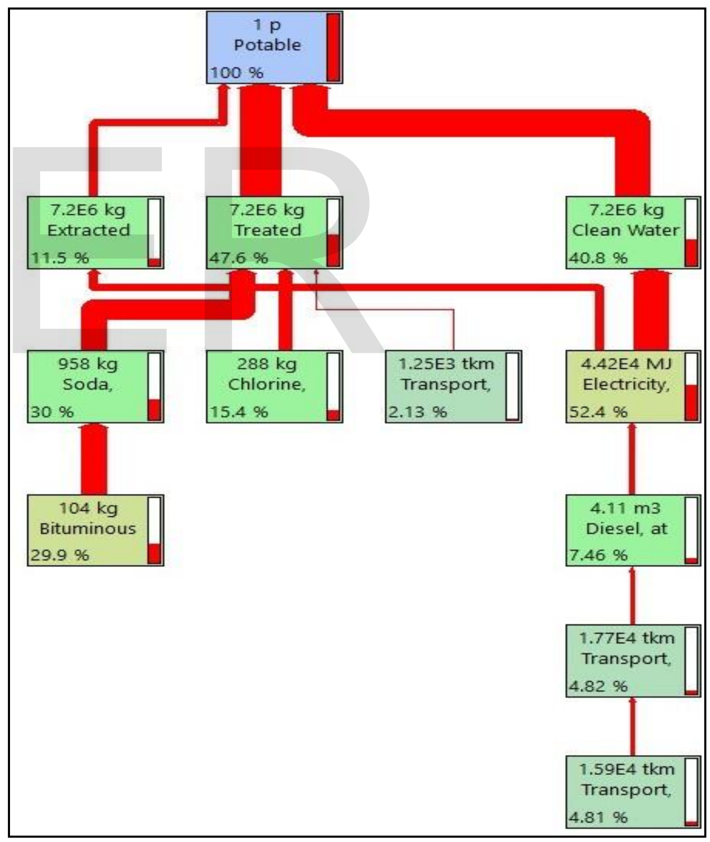

Figure 6: Network Diagram Illustrating Stratospheric Ozone Layer Depletion

3.3 Ozone Formation Human Health and Ozone Formation Terrestrial

The following figures provide insight into the contribution of each operation to ozone Formation Human Health and Ozone formation Terrestrial. **Figure 7 (a)** and **Figure 7(b)** show a similar trend – that of electricity being the most significant contributor. For the pumping unit, the release of gaseous compounds in the air is due to the energy consumption in raw water extraction and the boosting of water pressure. The breakdown ties in with the results shown in the figures mentioned above. These figures show that the percentage contribution of the combined energy usage in water extraction and pumping is 91.1% and 91.4% for Ozone Formation Human Health and Ozone formation Terrestrial, respectively

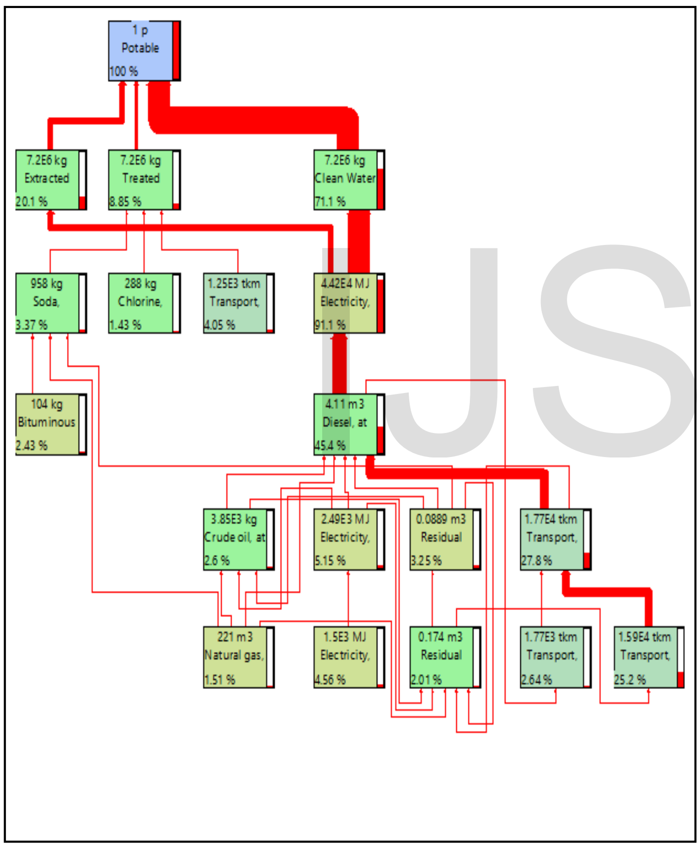

Figure 7.7 (a): Network Diagram Illustrating Ozone Depletion Human Health

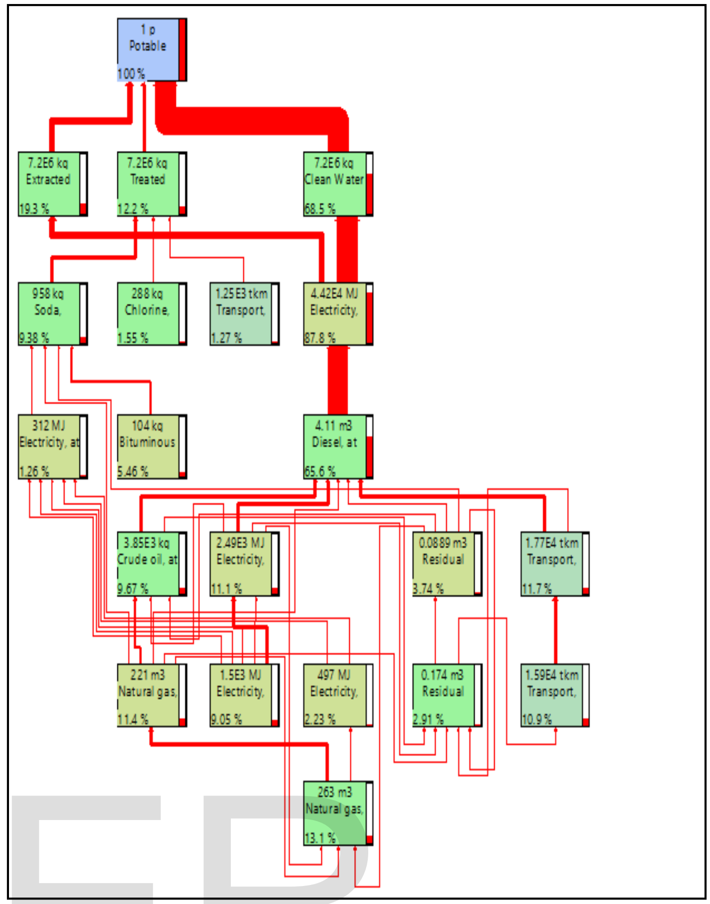

Figure 7.7 (b): Network Diagram Deficting Ozone Formation Terrestrial

3.4 Particulate Matter

Figure 8 illustrates that the primary cause of particulate matter formation for the study is electricity – its production and use within the process. Generally, airborne particles are composed of both solid and liquid substances. They can arise from various sources, such as combustion processes. The Commission for Environmental Cooperation, 2011 found that in Canada, power plants burning coal accounted for 75% and 61% of PM10 and PM2.5 emissions, respectively. This effect is directly linked to the harmful practice of burning coal for energy.

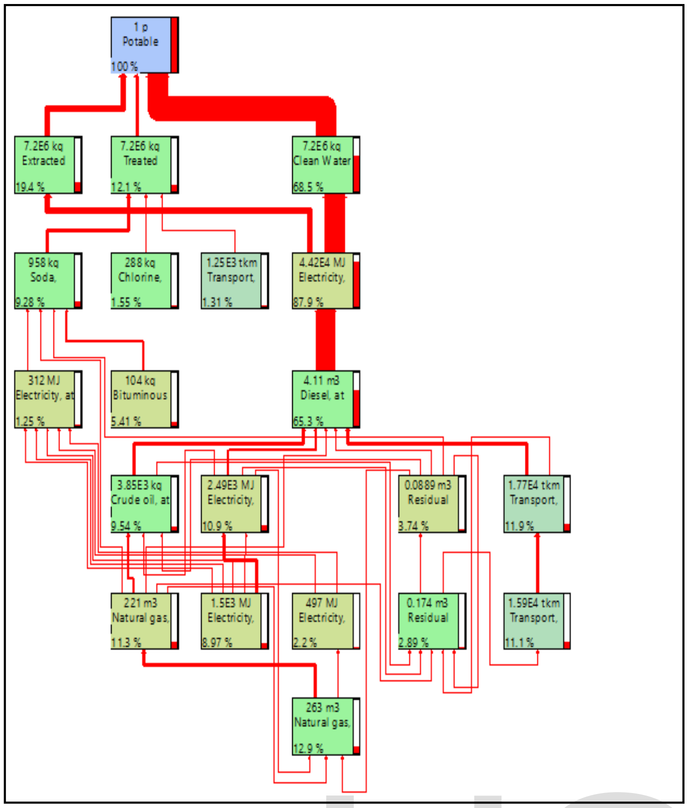

Figure 7: Network Diagram Illustrating Particulate Matter Formation

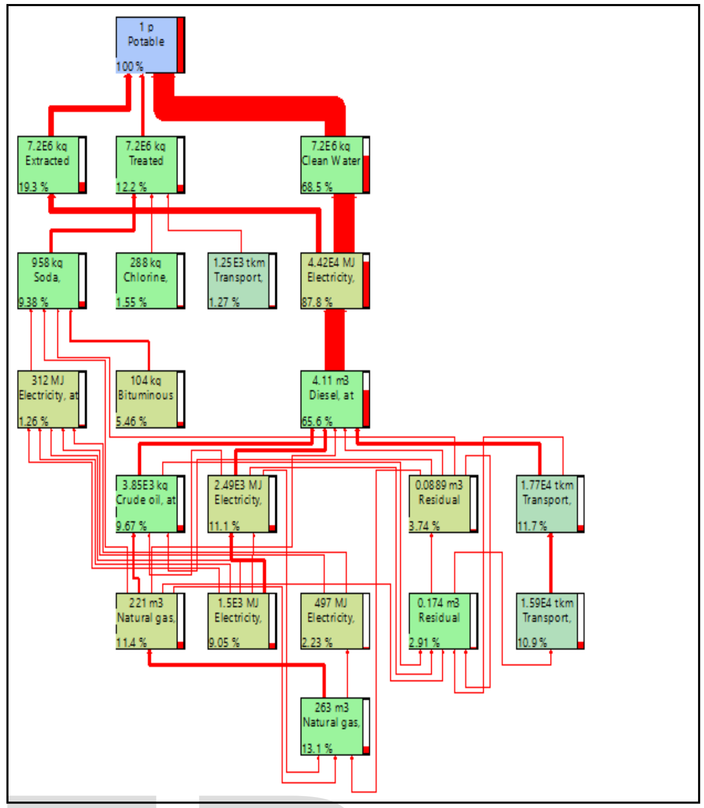

Figure 8: Network Diagram Illustrating Terrestrial Acidification

3.5 Terrestrial Acidification

For the impact category acidification, gases that create acid deposition include ammonia, nitrogen oxide, and sulfur oxide. **Figure 9** shows the contributors of individual elements to the total acidification profile. Electricity usage within the process has the highest impact as it contributes 97.8 % to the potential for terrestrial acidification by the system. This result is dependent on the electricity generation and use during the water production process that emits quantities of nitrogen oxide, and sulfur dioxide to the environment.

3.6 Marine Eutrophication

The effect of eutrophication on the environment can decrease the benefits and increase the costs related to the use of natural resources. **Figure 10** shows electricity being the highest contributor. Besides, this figure also indicates that the pumping of clean water is the stage responsible for the maximum impact. This can, in part, be related to the electricity usage for the high-pressure lift pumps.

ISSN 2229-5518

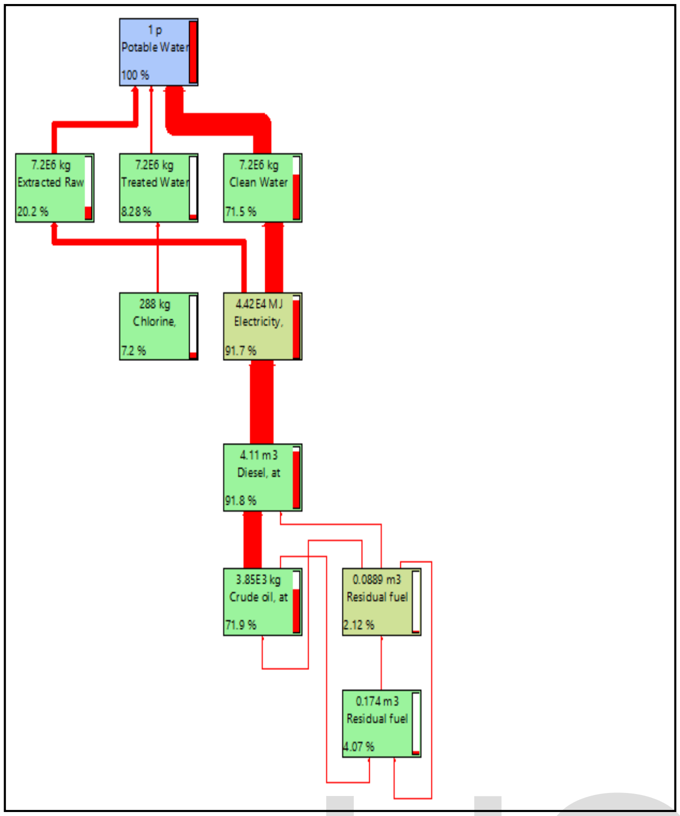

Figure 9: Network Diagram Illustrating Marine Eutrophication

3.7 Toxicity

Concerning toxicity, it was decided to group the various toxicity impact categories; terrestrial, freshwater, marine, human carcinogenic, and human non-carcinogenic. The comparative graph in **Figure 11** shows that for all toxicity impact categories indicators, energy consumption in pumps is the major contributor. However, in the case of terrestrial and human carcinogenic toxicity, the water treatment unit has a noticeable impact of almost 5% due to the production and use of chemicals in the process.

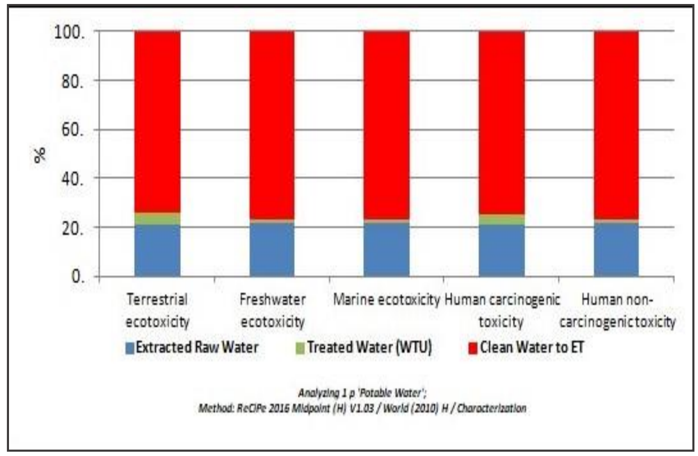

Figure 11: Impact Assessment Results Depicting Toxicity System Process

3.8 Land Use

Figure 12 below depicts land use in the form of urban land occupation and natural land transformation. The impact of the water supply system on urban land occupation and natural land transformation can be traced to the water treatment unit

Figure 10: Network Diagram Depicting Land Use for Drinking Water Supply System

3.9 Depletion of Abiotic Resources

In a general sense, this impact category refers to the reduction of non-biological resources. In the case of SimaPro, the ReCiPe method takes into account the consumption of three components: water, minerals, and fossil. **Figure 13** looks at the major contributors to such environmental impacts. From the graph, it is evident that water treatment and pumping is the dominant contributor to mineral resource scarcity and water consumption with a contribution of 100% and 33.4% respectively. Boosting clean water has a 94.5% impact on fossil resources. This effect is due to the use of diesel from crude oil and natural gases, which have a combined contribution of 94.5%. However, the treatment unit contributes less significantly to the category of fossil resource scarcity.

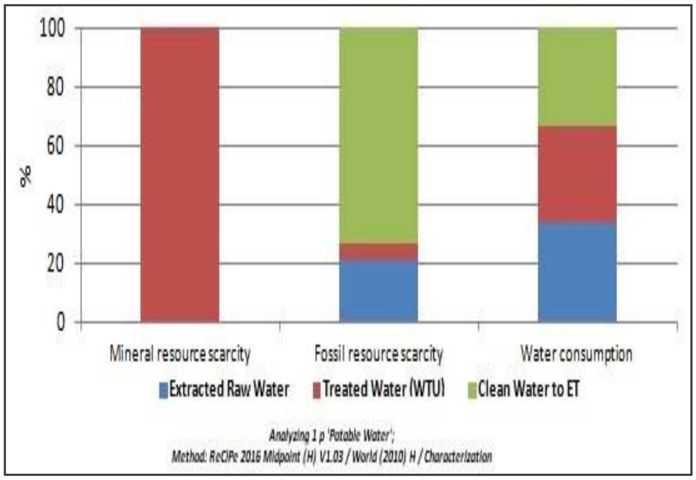

Figure 11: Impact Assessment Results Depicting Depletion of Abiotic Resources

4.0 IMPROVEMENT ANALYSIS

The results up to this point indicate that boosting clean water to elevated tanks unit in the drinking water supply system is responsible for the majority of the environmental loads due to electricity consumption. This particular unit was chosen for the evaluation of alternative energy sources upon which the selection of the source with the minimum ecological loads is based. It is noted that the improved energy resource in the selected unit will enhance the water extraction unit as both inputs to the system is electricity.

Three energy alternatives consisting of conventional diesel-generated energy (diesel Genset), imported country mix energy, and Hydro Electricity Power were modeled in the SimaPro software. A further analysis similar to that performed in section 2.4 was undertaken to compare the impact assessment results for a functional unit of 9576 kWh of electricity used for lifting 7200m^3/day of clean water to elevated tanks using conventional diesel generator electricity (electricity South Sudan), imported conventional energy mix from Sudan, and imported Hydroelectricity power from Uganda. For the diesel Genset source, the same database in **Table 1** was used. Country mix energy and Hydroelectricity power data source, the data used is obtained from the global database, carefully chosen to suit the geographic condition of the study area, and based on the metadata description.

Table 4: Impact Assessment for Various Energy Sources (Per 9576 kWh of Electricity)

Impact category	Unit	Clean Water- Electricity, Conventional Energy Mix	Clean Water- Electricity, H E P Energy	Clean Water-Electricity, Conventional Diesel Generator
Global warming	kg CO2 eq	5.46E3	234	1.09E4
Water consumption	m3	7.21E3	7.2E3	7.2E3
Terrestrial ecotoxicity	kg 1,4-DCB	1.59E3	10.5	6.43E3
Fossil resource scarcity	kg oil eq	865	2.93	3.24E3
Human non-carcinogenic toxicity	kg 1,4-DCB	60.1	1.49	2.67E3
Marine ecotoxicity	kg 1,4-DCB	1.54	0.0142	76.1
Freshwater ecotoxicity	kg 1,4-DCB	0.295	0.0732	54
Terrestrial acidification	kg SO2 eq	31.9	0.0485	25
Ozone formation, Terrestrial ecos	kg NOx eq	0.0995	0.00139	20.5
Ozone formation, Human health	kg NOx eq	0.0617	0.000862	19.8
Human carcinogenic toxicity	kg 1,4-DCB	1.42	0.0471	19.7
Fine particulate matter formation	kg PM2.5 eq	10.1	0.0151	7.38
Marine eutrophication	kg N eq	0.0147	2.61E-5	0.0512

The results presented in **Table 4** show that for most of the impact categories, the conventional diesel generator electricity in South Sudan has a higher impact when compared to renewable energy sources. This effect is evident in the case of climate change, where conventional diesel electricity is responsible for releasing **1.09×10^4 kg** CO2 equivalents per 9576kWh. Furthermore, its impact is almost two times higher than the amount of CO2 eq released from the conventional energy mix power and over 46 times greater than the equivalent amount of carbon dioxide emitted by hydropower energy.

Looking at another impact category such as human carcinogenic toxicity, the numbers suggest that conventional diesel generator releases **19.7kg 1,4 DCB** equivalents, which is significantly higher than the **1.42 kg 1,4 DCB** equivalents released via the process of electricity generation through conventional energy mix. Energy generated via hydroelectricity power has the lowest amount of 1, 4-Dichlorophenoxy with 0.0471 kg 1, 4 DCB equivalents released.

The above statistics highlight the fact that in the case of climate change and human carcinogenic toxicity, the convention diesel generator energy in South Sudan generates the highest quantity of carbon dioxide and 1, 4-Dichlorophenoxy gases when compared to HEP energy. There are, however, specific impact categories where conventional diesel generator is not the most detrimental. Considering terrestrial acidification, the conventional energy mix is responsible for the highest emission of sulfur dioxides (**31.9 kg SO_2 equivalents**) followed by conventional diesel electricity, which releases approximately **1.28** times the amount released by the previous energy source and hydroelectric power with the lowest emission of 0.0485 kg SO_2 equivalents.

5.0 CONCLUSION

The results indicate that the pumping of treated water to elevated tanks is the most predominant stage responsible for the majority of the environmental impacts attributed to the system. The raw water extraction unit ranks second. Furthermore, investigation on the water supply system reveals that the boosting of the clean water stage has a more significant environmental impact as compared to the raw water extraction and treatment unit. This consequence is mainly due to the increased energy requirement during the process, as indicated by the results. Since the impacts are highly dependent on the electricity source and use, further investigations on the replacement of fossil fuel-based energy with renewable and mixed source energy were undertaken. It was determined that the use of hydroelectricity power or conventional mixed energy could reduce the impacts of potable water production such as climate change, human carcinogenic toxicity, and terrestrial acidification significantly, among others in Juba city.

5.1 RECOMMENDATIONS

1. Since this is the first time to introduce the engineering community to the concepts and purpose of LCA in South Sudan, particularly in the water sector, the governmental departments, Nongovernmental organizations, companies, and research institutions should assist future researchers duly. This would be useful for the following purposes
   - Render the data collection process easier
   - Make stakeholders more comfortable with the sharing of sensitive data
   - The use of this management tool could become widespread.
2. An effort should be made to improve the energy and its associated environmental impacts since the results presented highlight the high burden of electricity on the studied system. This can be made possible through:
   - Energy minimization strategies use, such as increasing pumping efficiency and implementing system design improvements.
   - The use of energy from renewable energy sources such as hydroelectricity power would significantly reduce the release of hazardous pollutants from the two-unit processes that are energy-intensive.
3. The government of South Sudan should put an effort to engage all stakeholders towards the development and integration of local database representing South Sudan into the current Simapro database as information of this nature will improve the accuracy of the results obtained from the environmental LCA model. The integrated data into the ecoinvent database should not only be limited to the water sector but also for mining, agricultural, and power generation processes of the country.

REFERENCES:

1. Cointreau., et al, 2013. (2013). "The Impact of Poor Municipal Solid Waste Management Practices and Sanitation Status on Water Quality and Public Health in Cities of the Least Developed Countries : the Case of Juba , South Sudan Martin Kajokare Karija School of Environmental Studies China." *2013*, 3(4), 87–99.
2. Garfí, M., Cadena, E., Sanchez-ramos, D., and Ferrer, I. (2016). "Life cycle assessment of drinking water : Comparing conventional water treatment , reverse osmosis and mineral water in glass and plastic bottles." 137.
3. Goga, T. (2016). "A Comparative Life Cycle Assessment (LCA) of Water Treatment Plants using Alternative Sources of Water (Seawater and Mine Affected Water) by Submitted in fulfilment of the academic requirements of Master of Science in Engineering School of Engineering." (December).
4. Hauschild, M. Z. (2017). *Introduction to LCA methodology*. *Life Cycle Assessment: Theory and Practice*.
5. JICA. (2009). "Juba Urban Water Supply and Capacity Development Study." *Ministry of Water Resources and Irrigation of the Government of the Southern Sudan (Mwri / Goss)*, (September).
6. Landu, L., and Brent, A. C. (2006). "Environmental life cycle assessment of water supply in South Africa: The Rosslyn industrial area as a case study." *Water SA*, 32(2), 249–256.
7. Lansing, E. (2015). "Lecture 8 : Water treatment processes Previous lecture re-cap • Introduction of water treatment schematic concepts."
8. Nations, U., and Programme, D. (2012). "Environmental Impacts Risks and Opportunities." *Natural resources management and climate change in South Sudan*, 1–92.
9. Uma, B. J. N. (2019). "Less than 60 % of South Sudanese

ISSN 2229-5518
access clean water." (December 2015), 3–4.

10. Yadav, S. M., Singh, N. P., Shah, K. A., and Gamit, J. H. (2014). "Performance evaluation of water supply services in developing country: A case study of Ahmedabad city." *KSCE Journal of Civil Engineering*, 18(7), 1984–1990.