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Environmental Analysis of Wastewater Treatment Plant Dhalli and Malyana (Shimla, Himachal Pradesh, India): Analysis and Comparison

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KEYWORDS

LCA, wastewater treatment plant, wastewater, environmental impact, life cycle assessment, Environmental Assessment

ABSTRACT:
A wastewater treatment plant (WWTP) treats the wastewater removes the harmful elements and makes the water feasible to reuse. Life cycle assessment (LCA) is an analysis tool used for checking the product or process impact caused to the environment throughout its full life cycle. Introducing LCA in WWTP helps in understanding the impact caused by WWTP, although it is used for the benefit of the environment. This study is conducted on the low-density populated area, Dhalli and Malyana (Shimla, Himachal Pradesh, India) WWTP, here OpenLCA software is used as it is open-source software. For analysis inventory data was collected from the WWTP site visit, government website, and databases. Both midpoint and endpoint impact assessments were analyzed. It was observed that the maximum impact was on marine ecotoxicity, human health (carcinogenic and non-carcinogenic), terrestrial ecotoxicity, and global warming in the midpoint impact assessment. And in the endpoint impact assessment, the highest impact was on resource consumption. The three main reasons for these impacts were the constant use of electricity, lack of tertiary and sludge treatment, and lack of the reuse of treated water. In comparison, it was seen that Malyana WWTP has a higher impact than Dhalli WWTP**.**

1. Introduction

Water is a fundamental element required for human existence. If more water is used then it is necessary hence more wastewater is generated. Any water that has been impacted by human activity, that needs to be properly handled and treated before being released into the surroundings is included under the broad category of wastewater [6]. Organic debris, suspended sediments, nutrients (such as nitrogen and phosphorus), and potentially dangerous microbes are commonly found in domestic wastewater [25, 1]. On the other hand, industrial effluent may include heavy metals and dangerous compounds, as well as, agricultural practices contaminate wastewater by discharging pesticides, fertilizers, and animal feces [25, 32].

To remove impurities and pollutants from wastewater, wastewater treatment (WWT) facilities use several different treatment procedures [17, 33]. Physical procedures including screening, sedimentation, and flotation are used in primary treatment to remove big materials [12, 24, 36]. In secondary treatment, organic waste is further broken down and dissolved contaminants are eliminated using biological techniques [12, 24]. Advanced treatment techniques like filtration, adsorption, and disinfection, guarantee the removal of any leftover contaminants [21, 3, 18, 37].

Figure 1 represents the basic processes that are conducted in a WWTP i.e. there are 2 main parts 1st wastewater treatment and 2nd sludge treatment. In wastewater treatment, pre-primary treatment is done in which grease and large non-treated substances like plastics, paper, etc are removed. The primary treatment is done in which a primary clarifier (sedimentation tank) is present where the larger sludge particles get settled and removed. In the secondary treatment, an aeration tank is present which is used to provide large amounts of oxygen to micro-organisms to treat the wastewater at a faster rate and this treated wastewater is passed to a secondary clarifier (sedimentation tank) where the remaining sludge is settled as coagulants are used to settle the smaller particles. This wastewater is transferred to tertiary treatment where it is chemically or mechanically treated i.e. trickling filters, chlorination, and de-chlorination, and makes it suitable for disposal. In sludge treatment, the sludge collected from wastewater treatment processes is treated by anaerobic treatment which releases biogas (methane), and then it is passed for thickening of sludge by drying to remove water from it and prepare it for disposal.

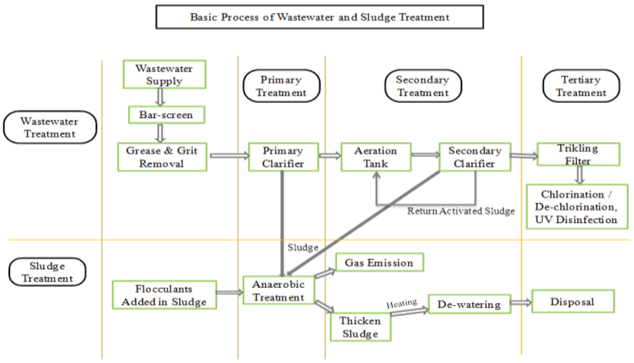

Figure 1: Basic process of wastewater and sludge treatment

A systematic methodology known as LCA (life cycle assessment) is used to analyze how a process or product will affect the environment and surroundings throughout its full life cycle [24, 12, 4, 31]. A full understanding of the impact of a service good or process is provided by LCA, which takes into account the impact caused by material gathering, processing, shipping/distribution, utilization, and disposal [25, 36, 7, 26, 33]. LCA follows 4 key steps: goal definition and scoping, inventory analysis, impact assessment, and interpretation [36, 7, 2]. Goal definition involves establishing the objectives and scope of the assessment, determining the boundaries, and identifying the relevant environmental impact (EI) categories. Inventory analysis involves quantifying both input data & output data. Life cycle impact assessment evaluates the impact caused by the identified inputs and outputs. Lastly, interpretation integrates the findings from the previous stages to draw conclusions and inform decision-making.

For LCA studies ISO 14044 and ISO 14040:2006 standards are together used for analysis and detailed studies for each step and process are mentioned in those standard codes [10]. By assuring completeness, ISO standards compliance, and reproducibility, life cycle assessment (LCA) delivers credibility and inspires confidence in its findings. The worldwide aspect of LCA promotes global materials management that is sustainable and continuously improving. By creating and freely disseminating knowledge, LCA also encourages economies of scale, which benefits all parties [13].

It is becoming more common to utilize LCA to compare avoided and induced impacts and identify trade-offs when adopting new technologies [22]. LCA in waste management investigates potential environmental effects across the waste life cycle, from generation to disposal [19]. LCA aids decision-makers in choosing the optimum management plan with the fewest environmental effects [19]. Since the first published cases, energy and resource use have been the main topics of LCA studies on wastewater treatment [22]. Numerous LCA works compare various treatment phases and methodologies, or focus on particular case studies, to treat residual water and the methods that are utilized [27].

LCA was used in the 1990s for the first time in WWTP [4]. The improvement of municipal WWTP operations, the evaluation of various sludge treatment options, and the advancement of technology for wastewater recycling can easily be linked to LCA research. LCA data can assist in the selection of more environmentally friendly designs and operational procedures and aids in pinpointing major causes of environmental pressures [5, 20, 31]. This circumstance explains why accurate techniques are required to assess and compare the environmental performances of wastewater treatment facilities. Since there are so many impacts to consider—including the toxicity and ecotoxicity of treated water and sludge, energy consumption, the greenhouse effect, eutrophication, etc. [30]. Energy/electricity consumption is the basic cause of the impacts that occurred during the WWT [9]. Greenhouse gas (GHG) emissions, fuel depletion, and ozone depletion (OD) became one of the important impacts of electricity consumption [9]. Due to several EIs of WWTP, it is preferred to make a sustainable WWTP, and the reuse of energy or generated energy like biogas or producing fertilizers for agriculture will reduce the EI which can be easily calculated using LCA methods.

The article follows a structured approach to comprehensively analyze the impact of wastewater treatment plants (WWTPs), specifically focusing on wastewater treatment plant present in Dhalli and Malyana in Shimla, Himachal Pradesh, India, the impact assessment need to be conducted so as to understand the effect of different impact categories of these WWTP in surrounding. The study employs OpenLCA software to conduct a detailed life cycle impact assessment, which includes both mid-point and end-point impact assessment categories. A comparison of life cycle assessment of Dhalli WWTP and Malyana WWTP is also conducted as the storage capacity of both treatment plants are different as Dhalli is a small WWTP having designed capacity of 0.76 MLD and Malyana is large WWTP having design capacity of 3.22 MLD.

2. Study Area and Life Cycle Inventory Collection

Study Area: Dhalli WWTP works under the process of an extended aeration tank system. 2 Wards are connected under this STP namely Ward 20 and 21. Its designed capacity is equal to 0.76 MLD The number of connections laid in the ward is equal to 869 and the length of the network is 18.55 km. In this plant, there is one aeration tank, 2 sedimentation tanks, and a sludge bed. Figure 2 represents the site images of Dhalli WWTP.

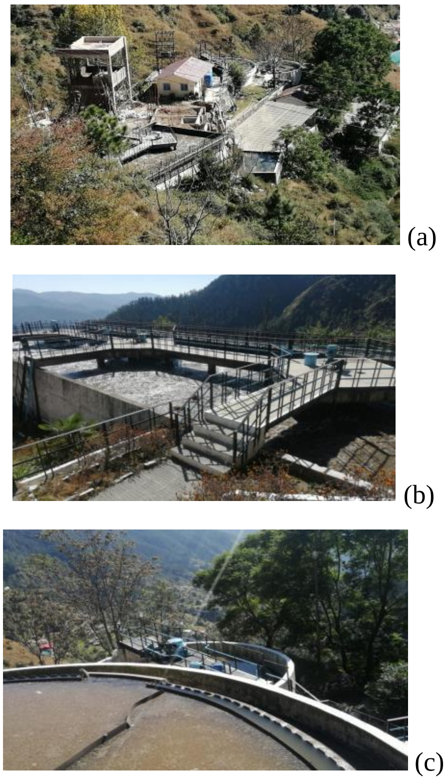
(a)
(b)
(c)

Figure 2(a, b, c): WWTP of Dhalli site visit [Environmental parameters of Dhalli, Shimla:- Average Temperature: 0°C -20°C in winters and 15°C – 30°C in summers; Precipitation: Snow and rain is common; Elevation: 2276meters; Area (2020): 1.38 km2; Population Density (2020): 553 people per km2; Total Population (2020): 764] (https://geoiq.io/places/Dhalli/J9XFnx2qbS)

Malyana WWTP also works under the process of an extended aeration tank system. Malyana WWTP covers the wastewater generated from the Malyana and Sanjauli area. There are a total of 8 wards under this STP namely 17, 18, 19, 21, 24, 25, 27, 28. It was constructed for a design capacity of about 3.22 MLD. The number of connections in the ward is equal to 3050 with a network length of about 68.5 km. Here as the capacity is high it has 2 aeration tanks, 3 sedimentation tanks, and a sludge bed. Figure 3 shows the site images of Malyana WWTP.

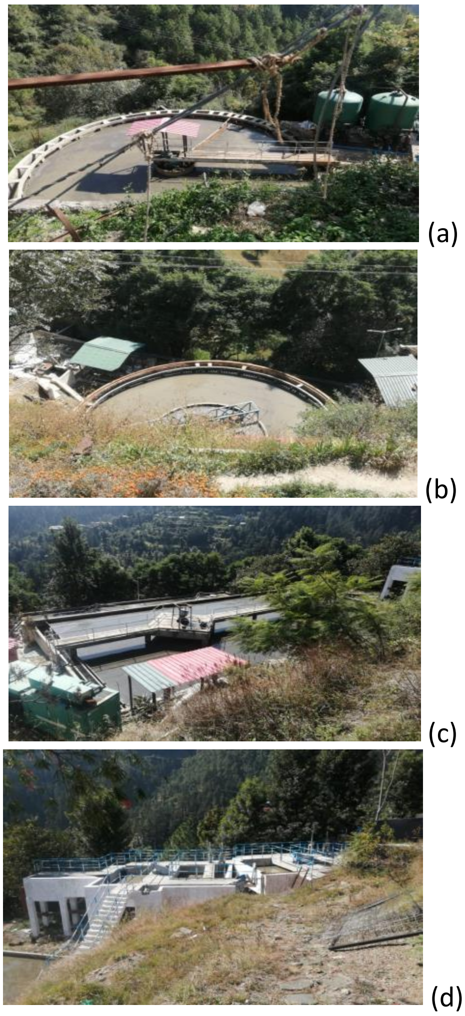
(a)
(b)
(c)
(d)

Figure 3(a, b, c, d): Malyana municipal WWTP site visit [As this plant cover Malyana and Sanjauli wastewater so environmental parameters is of both

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together:- Average Temperature: 0°C -20°C in winters and 15°C – 30°C in summers; Precipitation: Snow and rain is common; Elevation: 2276meters; Area (2020): 4.38 km2; Population Density (2020): 711.18 people per km2; Total Population (2020): 3115] (https://geoiq.io/places/Sanjauli/1VfDlNPDhI)

3. Life Cycle Inventory Collection

The process for conducting a life cycle assessment is by gathering information on the process or product whose LCA is being conducted. In this case, the LCA of the WWTP process was conducted so all the information and the data about wastewater (design capacity, number of tanks, process used in treatment of wastewater, BOD and COD), chemicals used to treat and emitted after treatment (chlorine, coagulant, flocculent, aluminum, hydrogen carbonate, etc), power/energy used (unites used per day from meter readings), gas emission (CO2, CO, NH3, N, O, etc), and area covered was collected (sewer grid area). Here the construction and demolition information are not taken as the LCA is for only the process used in the treatment of wastewater. This information about the quantity collected is called inventory data.

Here the inventory data was gathered and summarized from the site visit, government website, and different databases. A database is an organized gathering of information and data that is used to evaluate a product's, process's, or service's environmental effects throughout its full life cycle. It is used for LCA and often contains data on several environmental indicators, including energy use, emissions of greenhouse gases, consumption of water, and other pertinent factors linked to various activities and materials used during a product or process life cycle. The database namely ecoinvent v3.7.1 and agribalyse v3.0.1 is used. The French Environment and Energy Management Agency (ADEME) offers the Agribalyse 3.1 LCI database for the agricultural and food industry, the data from WFLDB and Ecoinvent are used in Agribalyse 3.1 (https://nexus.openlca.org/database/Agribalyse). More than 18000 trustworthy life cycle inventory datasets from various industries are available in the ecoinvent database, these include, among other industrial sectors, agriculture and animal husbandry, architecture and construction, plastics and chemicals, energy, forestry and wood, metallurgy, textiles, transport, tourist accommodations, waste treatment and recycling, and water supply (https://ecoinvent.org/the-ecoinvent-database/).

After the collection of data assessment is conducted is called as LC Impact assessment. LCIA is of two types i.e., midpoint and endpoint. The endpoint approach assesses the effects on the environment at the level of areas of protection (AoP), including human health, ecosystems, and resources. The midpoint approach, in contrast, evaluates the environmental impact at a point in the cause-and-effect chain between the release of a drug or the usage of a resource and the endpoint level [8]. Figure 4 represents the importance of both midpoint and endpoint assessment as the midpoint covers the environmental parameter and the endpoint gives the conclusion of those midpoint impacts.

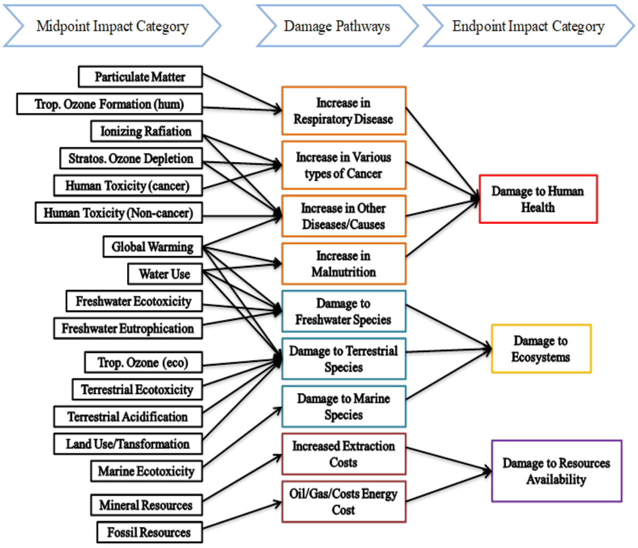
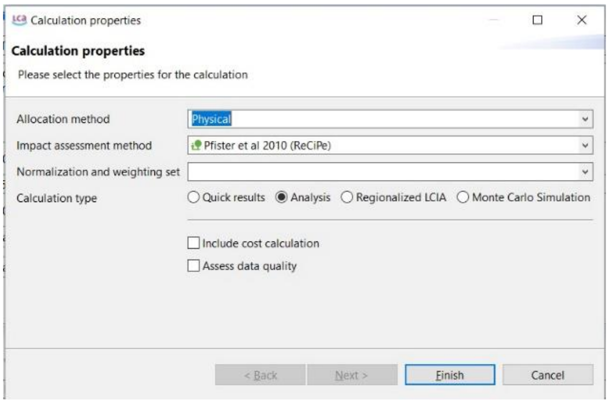


Figure 4: Relation between midpoint and endpoint impact assessment in ReCiPe (https://www.rivm.nl/en/life-cycle-assessment-lca/recipe)

For midpoint impact assessment ReCiPe Midpoint (E) method was used. ReCiPe, short for "Revised Method for Life Cycle Impact Assessment" (ReCiPe), is a popular technique for carrying out Life Cycle Impact Assessment (LCIA) in the context of Life Cycle Assessment (LCA). For evaluating the potential environmental effects of different emissions and consumption of resources across the course of a product or process life cycle, ReCiPe offers a collection of character development criteria and methodology. And for endpoint impact assessment Pfister et al 2010 (ReCiPe) was used.

LCA and LCIA are conducted in OpenLCA Software. The inventory data containing the information, values, and units is put into a new process created in the Ecoinvent database. Once complete data is entered accurately then there is an option for calculating the impact assessment. The pop-up appears as shown in Figure 5 for calculating the LCIA of the process. There we will select the parameters i.e., midpoint and endpoint, and the preferred method i.e., ReCiPe Midpoint (E) and Pfister et al 2010 (ReCiPe) one by one respectively.



Calculation properties

Please select the properties for the calculation

Allocation method: Physical

Impact assessment method: Pfister et al 2010 (ReCiPe)

Normalization and weighting set:

Calculation type: ○ Quick results ● Analysis ○ Regionalized LCIA ○ Monte Carlo Simulation

☐ Include cost calculation

☐ Assess data quality

Figure 5: Calculation properties pop-up in OpenLCA

4. Result and Discussion

Midpoint Impact Assessment of Dhalli WWTP

Midpoint impact assessment is calculated automatically by software by selecting the physical allocation method (Figure 5) and selecting the ReCiPe Midpoint (E) method. Each impact categories have its own units and the results obtained are compared to an equivalent example global warming is compared to CO_2 whereas ozone formation is compared to NO_x, etc. Each impact categories have their own importance, although sometime the lowest impact causing categories get neglected. From the result it can be observed that the highest impact is on marine ecotoxicity and the least impact is caused by stratospheric ozone depletion. After calculating table 1 shows the result of the midpoint impact assessment of Dhalli WWTP in a tabular form. As a result, value of all the impact assessments and impact categories are positive which shows that it's causing a harmful impact but the difference in each value is quite high so to represent it in figure so the log 10 of each value is taken to get a proper graphical image.

Table 1 Dhalli WWTP midpoint impact assessment

Impact category	Reference unit	Result
Marine ecotoxicity	kg 1,4-DCB (Dichlorobenzene)	36.28917423
Human non-carcinogenic toxicity	kg 1,4-DCB	30.93345678
Human carcinogenic toxicity	kg 1,4-DCB	1.226650338
Terrestrial ecotoxicity	kg 1,4-DCB	0.4662321
Global warming	kg CO2 eq	0.099910867
Fossil resource scarcity	kg oil eq	0.01879501
Ionizing radiation	kBq Co-60 eq (kilobecquerel Cobalt – 60 eq)	0.006382666
Freshwater ecotoxicity	kg 1,4-DCB	0.004375934
Land use	m^2a crop eq	0.003996675
Mineral resource scarcity	kg Cu eq	0.001621746
Water consumption	m3	0.000964859
Ozone formation, Terrestrial ecosystems	kg NOx eq	0.000340112
Ozone formation, Human health	kg NOx eq	0.000331758
Terrestrial acidification	kg SO2 eq	0.000274567
Fine particulate matter formation	kg PM2.5 eq	0.000201998
Freshwater eutrophication	kg P eq	3.1592E-05
Marine eutrophication	kg N eq	3.7896E-06
Stratospheric ozone depletion	kg CFC11 eq	1.31482E-07

The highest impact was on marine ecotoxicity, human non-carcinogenic toxicity, human carcinogenic toxicity, terrestrial ecotoxicity, and global warming. One of the conman reasons was the high amount of electricity

consumption. Another cause for marine ecotoxicity, human non-carcinogenic and human carcinogenic was the large amount of chemicals used and lack of tertiary treatment as there are small amounts of heavy metal present in wastewater.

Endpoint Impact Assessment of Dhalli WWTP

Calculation of the Endpoint by the system was done by using the Pfister et al 2010 (ReCiPe) method. Table 2 represents the result of the endpoint impact assessment of Dhalli WWTP.

Table 2 Dhalli WWTP endpoint impact assessment

Impact category	Reference unit	Result
Resources	$ surplus	0.000162666
Human Health	DALY	6.54781E-10
Ecosystem Quality	species*year	8.11389E-12

The resource consumption was highly impacted due to the high consumption of electricity, land use, and resources required for manufacturing chemicals.

Midpoint Impact Assessment of Malyana WWTP

Calculation of the midpoint is done by software using the ReCiPe Midpoint (E) method. The results observed were similar to the Dhalli WWTP. The cause and the order of impact are the same as that of Dhalli WWTP. But Malyana WWTP is a large WWTP so the construction and the pipe manufacturing and distribution also cause the high impact. The results of the midpoint impact assessment of Malyana WWTP are represented in Table 3.

Table 3 Malyana WWTP midpoint impact assessment

Impact category	Reference unit	Result
Marine ecotoxicity	kg 1,4-DCB	74608096073
Human non-carcinogenic toxicity	kg 1,4-DCB	63309056235
Human carcinogenic toxicity	kg 1,4-DCB	1627831939
Terrestrial ecotoxicity	kg 1,4-DCB	1228222587
Global warming	kg CO2 eq	130390484.7
Fossil resource scarcity	kg oil eq	27129766.66
Ionizing radiation	kBq Co-60 eq	11443623.31
Freshwater ecotoxicity	kg 1,4-DCB	8241163.825
Mineral resource scarcity	kg Cu eq	3341962.837
Water consumption	m3	1762749.775
Land use	m2a crop eq	4125360.465
Terrestrial acidification	kg SO2 eq	417806.1123
Ozone formation, Terrestrial ecosystems	kg NOx eq	366956.2177
Ozone formation, Human health	kg NOx eq	353461.2109
Fine particulate matter formation	kg PM2.5 eq	224401.4977
Freshwater eutrophication	kg P eq	55735.46372
Marine eutrophication	kg N eq	3271.695074
Stratospheric ozone depletion	kg CFC11 eq	45.42209063

Endpoint Impact Assessment of Malyana WWTP

Similar results were observed in Malyana WWTP after applying the Pfister et al 2010 (ReCiPe) method for endpoint impact assessment. As the construction of tanks and distribution and manufacturing of pipe is in large amounts it adds to the resource consumption impact. Table 4 shows the endpoint impact assessment results of Malyana WWTP.

Table 4 Malyana endpoint impact assessment

Impact category	Reference unit	Result
Resources	$ surplus	142807.9609
Human Health	DALY	0.554623449
Ecosystem Quality	species*year	0.008038645

Comparison of LCA of Dhalli and Malyana WWTPs

For comparing the two treatment plants the main criteria will be the amount of wastewater treated per day. On comparing the results of both plants, it was seen that Malyana WWTP causes a higher impact as compared to Dhalli WWTP because of having a high capacity of wastewater in MLD (million liters per day). Malyana WWTP treats about 3.22 MLD which is consuming a

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huge source of resources and chemicals. Dhalli and Malyana being less densely populated areas it was seen that small-scale is more efficient than large-scale WWTP for low population density areas. Figures 6 & 7 represent a graphical comparison of both midpoint and endpoint impact assessment of Dhalli and Malyana (Shimla, Himachal Pradesh) WWTPs. Some of the reasons are as follows:

1. Large-scale WWTP collects wastewater from larger areas so a larger amount of grid pipes lay over the area for collection of waste-water which increases the construction impact and cost.
2. As the scale of WWTP increases the amount of electricity consumption also increased
3. The treatment of wastewater coagulants, flocculants, and chlorination is done using chemicals, so as the amount of WW ↑'s the quantity of chemical usage also ↑'s leads to higher production of chemicals.

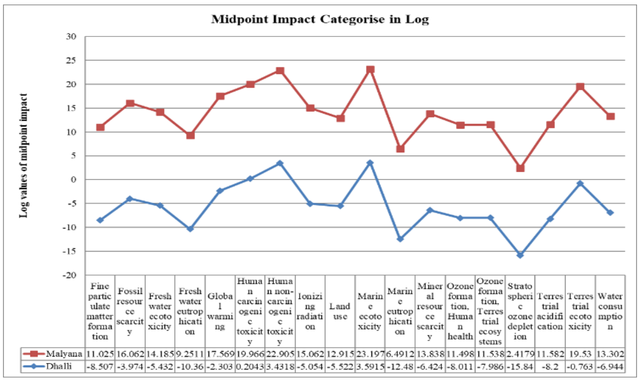

Figure 6: Comparison of midpoint impact assessment of Dhalli and Malyana WWTP

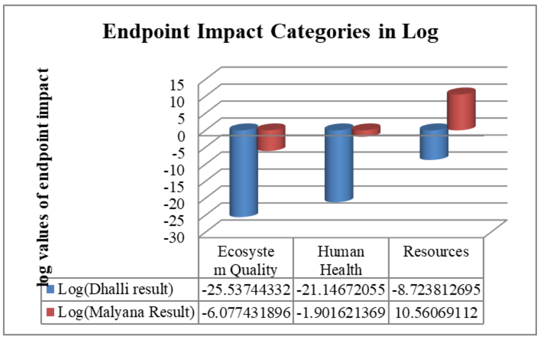

Figure 7: Comparison of endpoint impact assessment of Dhalli and Malyana WWTP

5. Conclusion

It can be seen that the maximum impact caused by the treatment process used in Dhalli and Malyana WWTP is marine ecotoxicity, human non-carcinogenic, terrestrial ecotoxicity, and global warming. As both treatment plant uses only sedimentation and aeration treatment process along with chlorination, the absence of a tertiary treatment process may lead to the direct emission of the chemicals used for treatment and the heavy metals that are present in very small quantity. The constant use of electricity is a major impact-causing source of marine ecotoxicity, human non-carcinogenic, and Global Warming. The minimum impact is caused by the eutrophication potential and ozone depletion as the treatment plant removes the nutrients. The endpoint results of both LCA showed that there is an impact in the order of resources > human health > ecosystem quality because it constantly uses electricity as well and the land area is occupied. After comparing both the Dhalli and Malyana WWTP it was observed that the Dhalli plant causes very less impact as compared to Malyana WWTP. Hence developing a small-scale treatment plant in a less densely populated area appears to be more beneficial than a large-scale WWTP.

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