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The Life Cycle Installation Assessment of Wastewater Treatment Plants in the Indian Sub-Continent

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Abstract The life cycle installation process for wastewater treatment is the advanced treatment assessment measure for the wastewater treatment and reuse of water resources. Utilizing the methods and concepts of "Life Cycle Assessment" for wastewater treatment and reuse of water is carried out using LCA software like Umberto, SimaPro, Gabi, etc based on the infirmity of calculations of "Life Cycle Inventory Data". LCA method helps in analyzing the various emissions and impacts of the "wastewater treatment plant" (or WWTP). A secondary data analysis study is designed on the basis of various data and information collected from 15 research papers with applicable and defined sources on wastewater treatment plants in India and LCA method. The data analysis configured the positive impact of the researched categories. LCA data analysis provided the idea that positive effects tend to override the negative impacts of recycling wastewater treatment process. The assessed categories for LCA data analysis are "global warming potential", "eco-toxicity potential", "fossil depletion potential" "particulate matter formation" and so on, which are highlighted in this project. The negative impacts can be associated with the effects of untreated sewage and compost produced by the "wastewater treatment process". The project analyses and evaluates the various aspects of the "life cycle assessment" application in the "wastewater treatment plants" in the Indian subcontinent. This is done particularly in the Madurai city, of the Indian subcontinent. The LCA assessment highlights the environmental impact of the water purification processes adopted in the mentioned waterplant. The ecological impact is measured on various scales like "ecological toxicity", "marine toxicity", "freshwater Eutrophication" etc. Similarly, the assessment highlights the impacts on the resources like fossil fuels, and most importantly on the human health. In addition, the project also highlights the various mitigation measures and techniques to increase the ecological efficiency of the wastewater processes.

Keywords LCA (Life Cycle Assessment), WSS (Water supply system), WWTP (Wastewater Treatment Plant), LCI (Life Cycle Inventory), ISO (International Standard Organization)

1. Introduction

Water is important for the survival of each human being and all forms of living organisms on the planet. According to USEPA, wastewater is any form of water which is degraded in the quality due to anthropogenic actions. The concept of LCA or "Life Cycle Assessment" is known primarily used as a tool for undertaking appropriate decision-making skills with respect to sustainable development of the environment. LCA helps in evaluating the potential impacts of products, activities or processes on the environment. Thereby, wastewater treatment effects

and its impacts can also be studied on the basis of LCA assessment of the "wastewater treatment plants". LCA assessment of wastewater treatment procedure and plants are performed on the basis of the data evaluation from the inventory structure. The data extracted is further evaluated on the basis of software analysis. There are various software's or LCA tools for quantitative and qualitative data analysis. One of the most common software utilized for analyzing the impacts of wastewater treatment data is "Umberto NXT Universal". The WWTPs receive chemicals from various drainage sources for further degradation, and LCA helps in analyzing chemical behavior of the chemicals like degradation, volatility, discharged without changes, or partitioned to sludge. The aim of the research assessment is to identify the various factors that can affect the "life cycle installation assessment" of wastewater treatment plants in the Indian sub-continent.

2. Scope & Methodology

The LCA method is applied in accordance with the LCI (Life Cycle Inventories) tools (as shown in Fig.1) to predict the fate and impact of distinct chemicals in a WWTP, as well as to the nature or environment.

Application of LCA methods should strictly adhere to the ISO standards and guidelines [1]. However, there can be functional variance in the depiction of system boundaries and functional units on the basis of the conditional resources and chemical consideration. The "Life Cycle Assessment or LCA" methodology with reference to ISO (International Standard Organization) is used to evaluate the effect of treating sewage water on the environment. Various ways are taken into consideration during the implementation of LCA to evaluate the environmental impacts [2]. The model to understand and quantify the energy flow and material flow is carried out using the potential LCA software like "Umberto NXT Universal".

2.1. Life Cycle Assessment Methods

The common LCA methodologies are as shown in Fig.2, which are also frequent in the analysis of water related LCA are 'Eco-indicator 99', 'CML-IA', 'TRACI 2.1' and 'ReCiPe'.

2.1.1. 'Eco-indicator 99'

'The Eco-indicator 99' process showcases the several environmental implications and marks the ultimate outcome in data [4]. Damage categorization takes into consideration while following normalization and weighting. 'Eco-indicator 99' is the damage oriented approach. 'Eco-indicator' also indicates several categories which may include several environmental impacts.

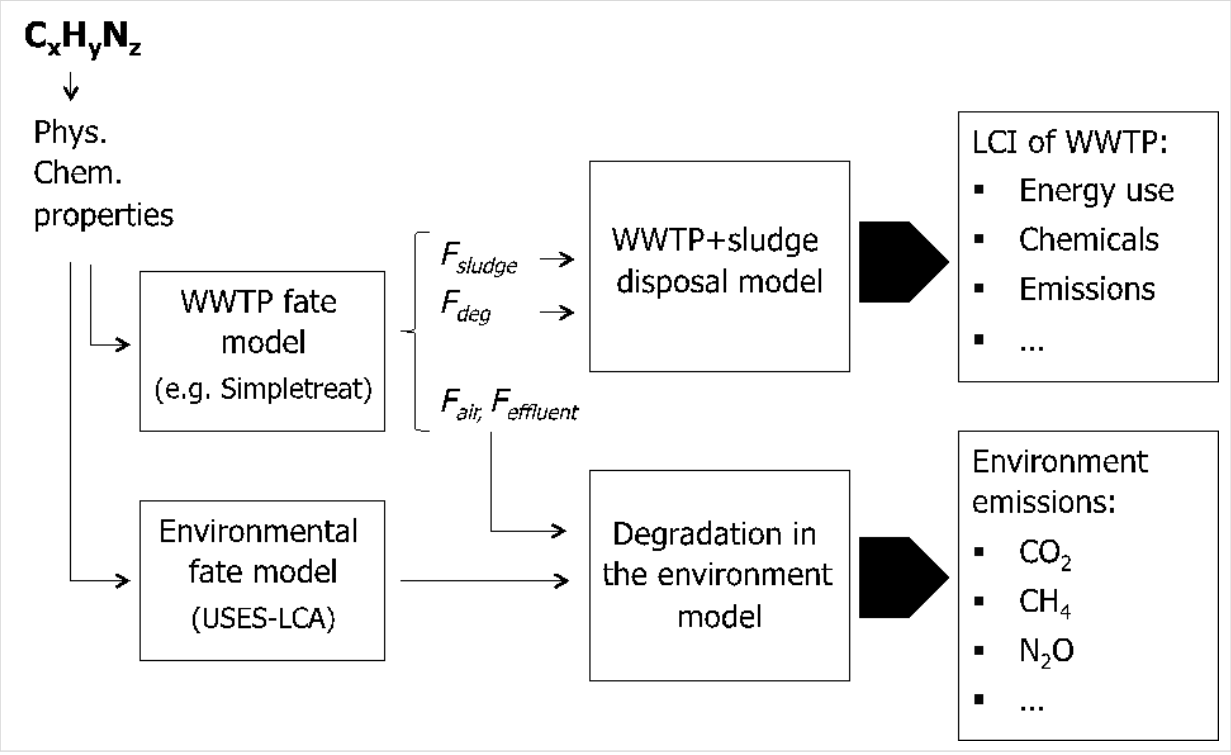

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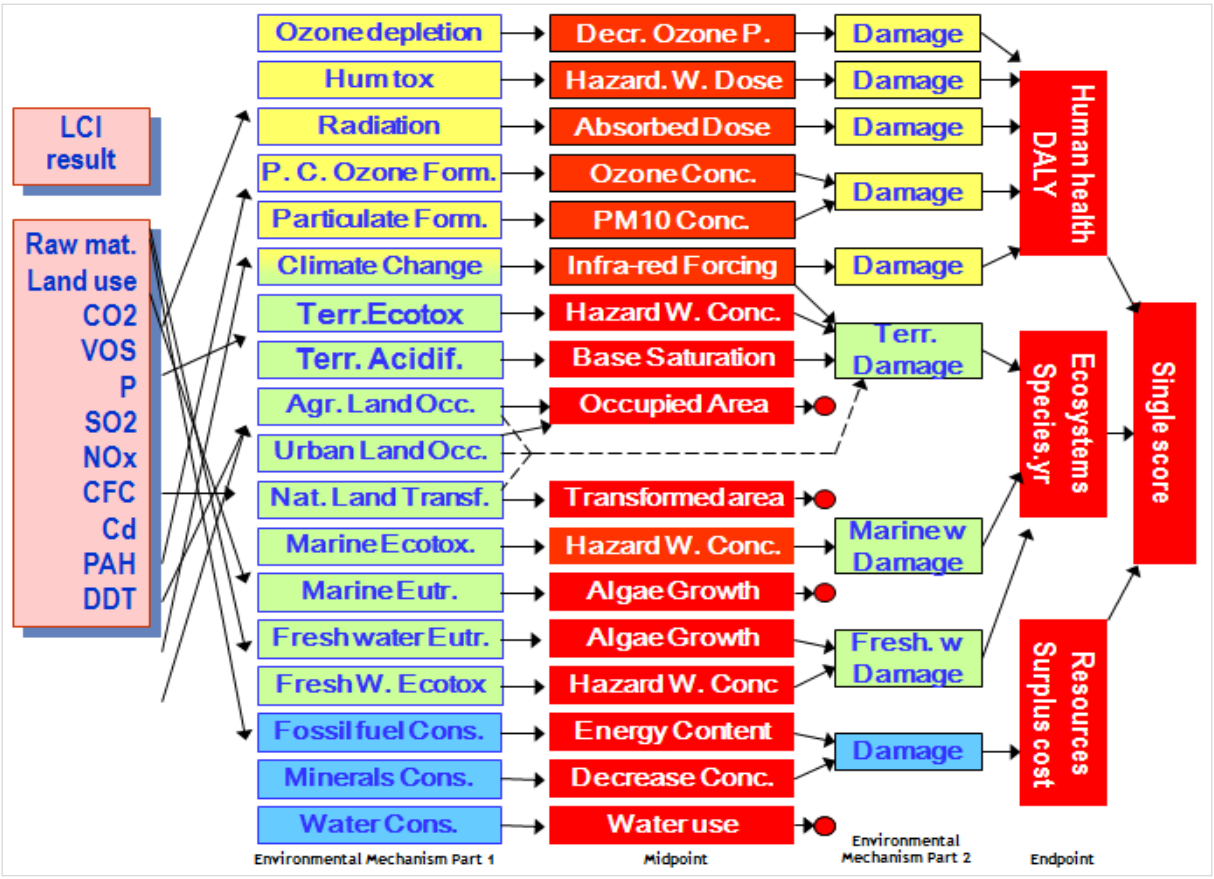
Figure 1. Schematic Diagram for LCI Tool



Source: https://www.researchgate.net/publication/343515039_Environmental_Life_Cycle_Assessment_for_a_Large-Scale_Gold_Mining

Figure 2. Relationship among midpoint indicator, endpoint indicator and single score indicator

2.1.2. 'CML-IA'

The CML method of LCA provides a variety of assessment aspects that have possible environmental impact [5]. Category indicators are used in most LCA. The CML-IA focused on resource utilization, environment change, Eco toxicity, marine eco-toxicity and acidification are included in the impact categories of LCA analysis.

2.1.3. 'TRACI 2.1'

'TRACI' highlights the impact categories which are highlighted in 'TRACI' [6]. These are global temperature arise and its adverse impact on human health criteria-related effects, disease effect, energy crisis and soil erosion.

2.1.4. 'ReCiPe'

'The ReCiPe' method mainly focuses on problem-oriented factors. Sometimes it causes the uncertainty of results [7]. Recipe consists of midpoint and endpoint impact categories.

3. Literature Review

According to [1], the implementation of "life cycle assessment" approach towards wastewater treatment plants and the cost-effectiveness of the process are one of the major reasons for the affirmation of the approach. The LCA approach was applied to measure the environmental impacts and eco-efficiency of the small-scale WWTPs or "wastewater treatment plants" as shown in fig 3. The research paper highlights the environmental effects and the eco-efficiency of two non-centralized "wastewater treatment plants" which are adjoined with constructed wetlands. There are two systems in the entire structure and they consist of a functional unit of 1meter cube of water undergoing treatment with a lifetime of more than 20 years. The LCA software implied here is aided with Ecoinvent 3.3 data. The end-point and mid-point assessment were carried out with the help of the ReCiPe method. This study resulted in the analysis of the operation stage of the procedure with utmost environmental impact. The impact of the operation stage can be defined with the characterization of 64% Accenture for Human Toxicity and almost 100 % "Freshwater Eutrophication". This study defines Aeration process is environmentally more beneficial in the treatment process of wastewater. Moreover, the Aeration Process is quantitatively more cost-effective also.

According to [18], LCA or "life cycle assessment

approach can be implied to "wastewater treatment plants" to configure and analyze the toxic emissions and the complemented environmental impact. The "wastewater treatment plants" undertake processes that remove pollutants dissolved in and convert them into greenhouse gases like CFCs (Chlorofluorocarbons), methane, Carbon dioxide, etc. The LCIA or "life cycle impact assessment" using Eco-indicators are used to assess the results. The proper application of LCA methodology which is consistent with the guidelines and principles of ISO 14040:2006 should be applied Liu [18]. These include the completion of 4 primary and key stages namely: clearly stating the scope and goals of the assessment, proper analysis of the inventory data, undertaking the mid-point and end-point assessment clearly, and lastly interpreting the acquired data using the appropriate LCA software.

According to [19], the integrated analysis and study of Hyderabad's GHG ("Green House Gases") emissions from WWTPs and the potential presumed benefits of reusing effluents from "wastewater treatment plants". Various methods are applied in each of the sub-systems including LCA approach towards WWTP. The treated wastewater is partly used for agricultural purpose and the remaining water is transferred into water bodies like rivers. The N-WWTP is the selected specific site for the comprehensive case study as shown in. Fig 4. This treatment plant is newly implemented and is located in close proximity to the agricultural area (Urban). This paper draws influence on the absence of proper LCA studies in developing countries. In this paper LCA was applied to consider the energy use of the entire system and GHG emissions for wastewater treatment and agricultural reuse [9]. Three farm plots of identical size (12 meter square) were utilized for proper determination of LCA factors.

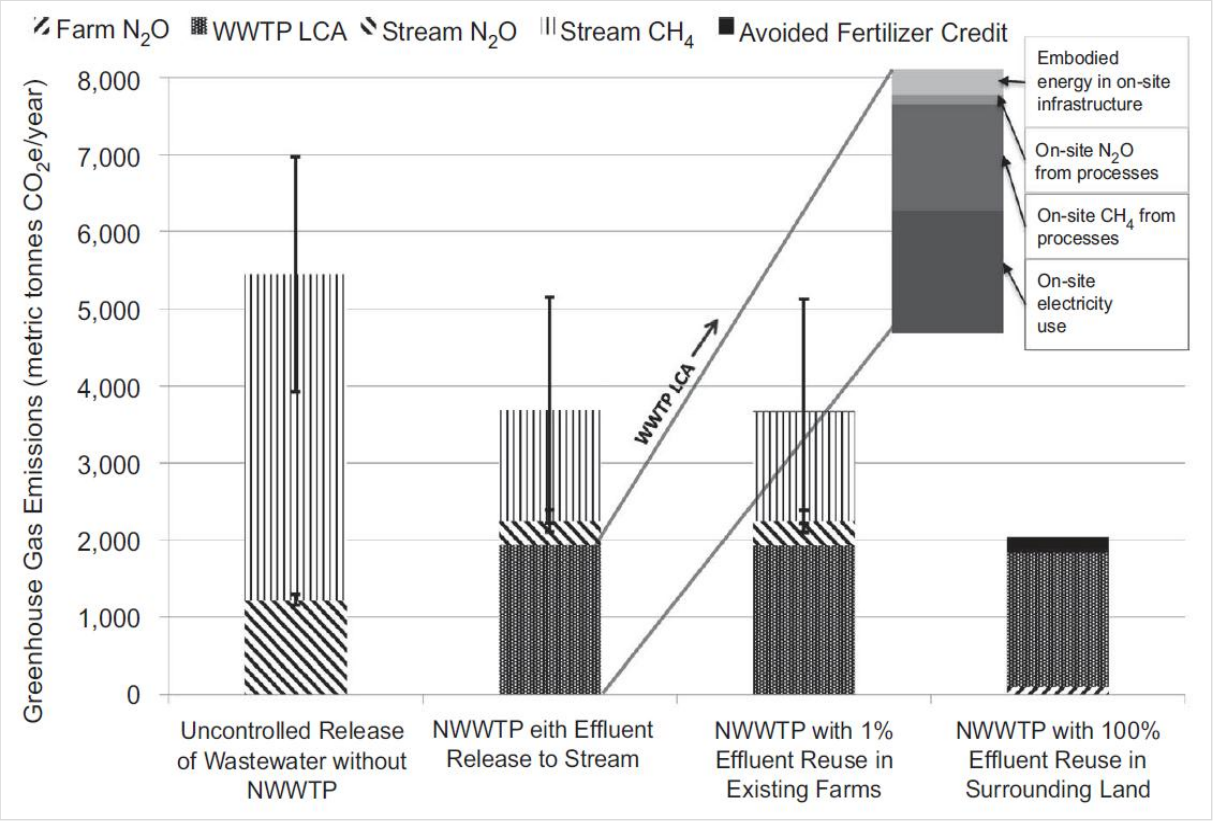


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Figure 3. LCA Results for Combination of wastewater Treatment and Reuse for Agricultural Purposes

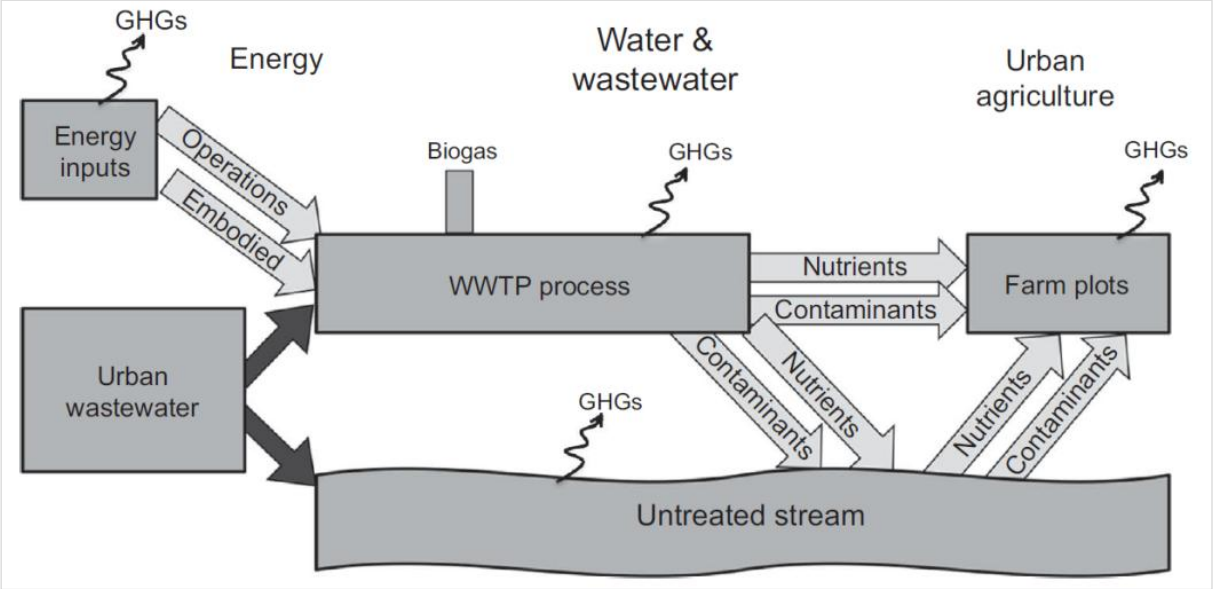

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Figure 4. Location of LCA Analysis in Hyderabad. The aerial view and the schematic view of N-WWTP

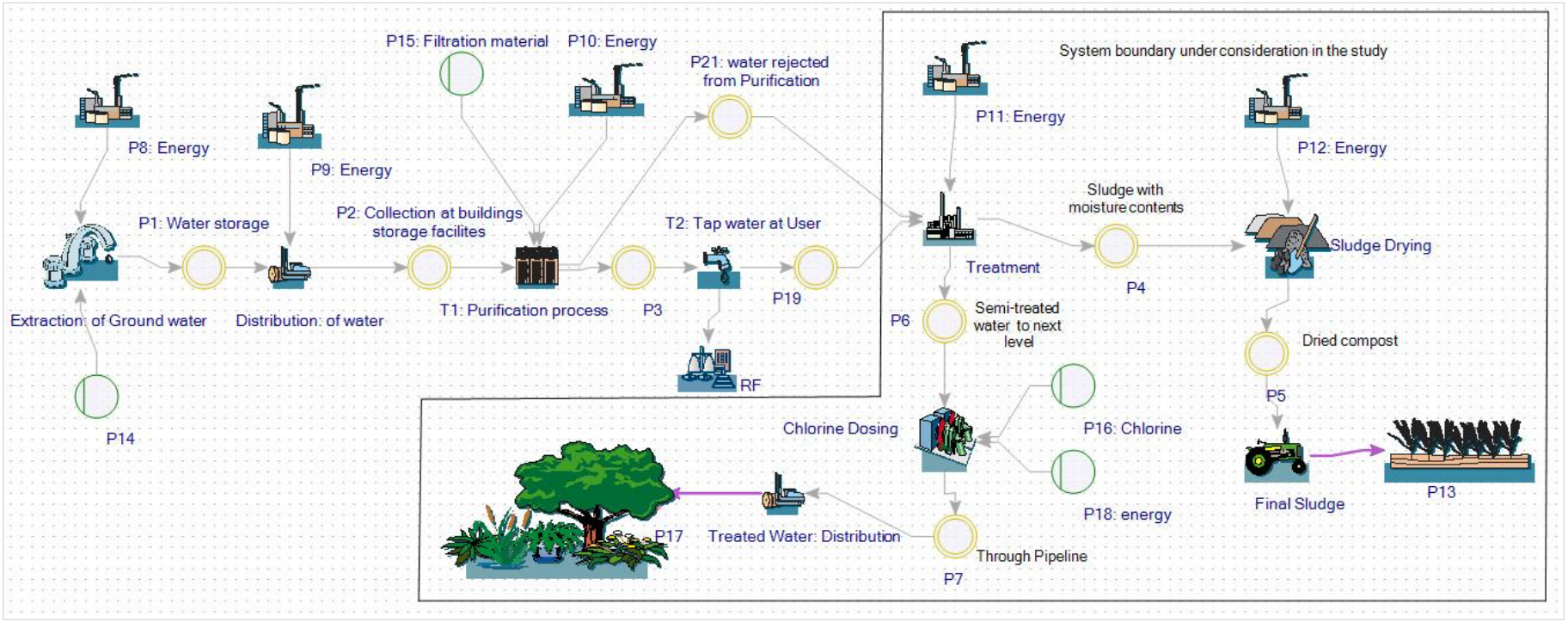

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Figure 5. Wastewater Treatment Plant in a University of Rajasthan

4. Area of Study

The various areas where the "wastewater treatment plants" are quantitatively and qualitatively analyzed with LCA methodology and results are calibrated on an identical basis or background. In accordance with [16] university of Rajasthan is the considered area of study. The designated wastewater treatment plant as shown in Fig. 5 in the University was established around 50 years ago and is used on a continuous basis and LCA approach was applied to estimate the impacts of the WWTP on the environment and search for the hotspots in the treatment process. The designated system boundary for this study consists of the process of "wastewater treatment" at the "sewage treatment plant" and reapportionment of the treated water with respect to the purpose of irrigation. The analysis is carried out utilizing the "gate to gate" approach. The sludge generation is considered till the remaining waste material is dewatered and thickened prior to incineration in the "sewage treatment plant". The various processes working in a WWTP includes collection of water sample, activation of sludge, treatment of wastewater, purification of wastewater, and re-distribution of pure water. Another important consideration is the functional unit of the LCA method. For the mentioned study, the considered wastewater is the amount of inflow of wastewater, and the amount of water is treated by the WWTP per day. The defined statistics are noted as 1500 meter cube of wastewater treated per day with a working capacity of 24 hours and the entire year (365 days). The total working life of the WWTP is 50 years. The LCI or "Life Cycle Inventory" is the quantitative data collection process, which is noted repetitively during the working hours of the plant. The secondary data modeling is generalized with the following assumptions:

1. Diesel quality used in the plant is of constant structure. And the input quality is the monthly average production.
2. The sludge transportation means are economically neglected, as camel carts etc are used for the purpose.

The primary data is collected during wastewater inflow at different times of the year. And data related to the treatment process is generated on the basis of the overview and ideas of the working staff. Next process that structured the order of events is the "life cycle impact assessment". Using the software "Umberto NXT Universal" and its analysis based on its "eco-event" dataset is configured in 5 phases mentioned earlier. The energy inputs of the study are based on the Indian electricity and diesel generators. ReCiPe method is incorporated for end point assessment.

The LCA analysis method is based on three areas of specific knowledge about scientific and logical consideration. These areas are termed as spheres [17]. The three spheres are namely:

- Technosphere
- Ecosphere
- Valuesphere

Techno sphere defines the life cycle of the process in consideration and the model of LCA analysis is based on this sphere. Ecosphere reflects the changes in the environment due to the effect or impact of the wastewater treatment process [8]. This sphere is utilized to understand and analyze the results in the inventory table and generate a link with the categories with potential damage qualities [15]. Valuesphere provides a model to analyze challenges and helps to weigh the three endpoints with respect to a single indicator.

5. Results & Discussions

The results of the studies carried out in different places are generally reflected as operational outputs. Moreover, the ReCiPe method helps in accessing results in the three primary categories for determining endpoint, namely: quality of the ecosystem, resources, and human health [10]. The various factors considered under the quality of the ecosystem are noted below:

- "Agricultural land"
- Occupation
- Climate Change
- "Marine Eco-toxicity"
- "Freshwater Eutrophication Potential" (FEP)
- "Terrestrial Eco-toxicity Potential" (TETP)
- "Freshwater Eco-Toxicity Potential" (FETP)
- "Global Warming Potential" (GWP)

Similarly, human health can also be sub-divided into various sub-categories for better understanding of the impact of "wastewater treatment plants". These sub-categories are as follows:

- "Climate Change- Health change" (CC-HH)
- Ionizing Radiation
- Human-Toxicity
- "Ozone Depletion Potential" (ODP)
- Photochemical oxidant
- "Particulate Matter Formation" (PMF)

And the resources with possible severe affect due to the implementation of "wastewater treatment plants" will include the following two distinct categories of depletion:

- "Fossil Depletion Potential" (FDP)
- "Metal Depletion Potential" (MDP)

The graphical statistics from the research papers are amalgamated to preconceive the impacts and results of LCA approach. The research conducted in Rajasthan University campus provides the following statistical data [16]. The Entire LCA process can be divided into two assessment types. End point assessment as shown in Fig. 6 provides the final result of the impacts of WWTP and wastewater treatment process on the environment, human health, and resources.

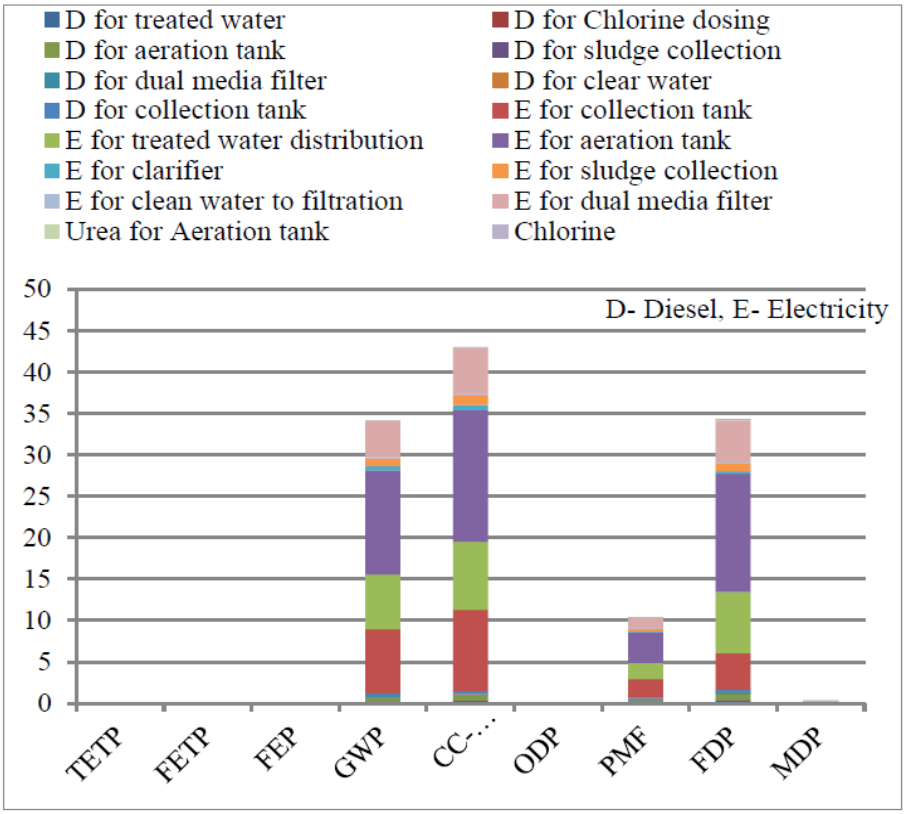

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Figure 6. The End Point Assessment Results for Studying Impact of WWTP

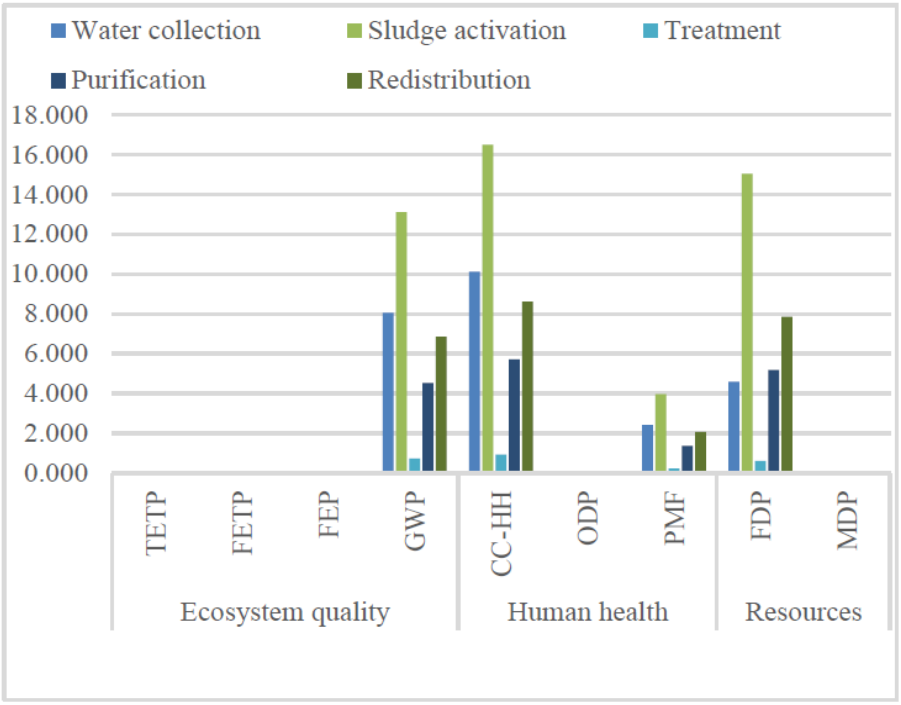

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Figure 7. End Point Assessment of Factors in Terms of Material and Energy Consumption

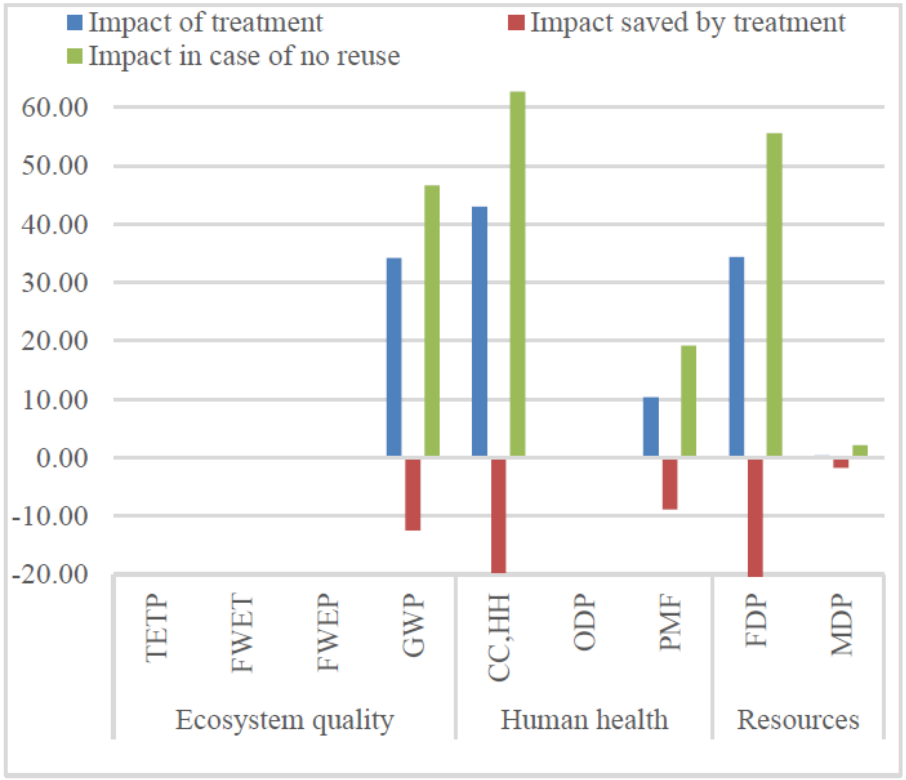

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Figure 8. Endpoint Assessment of Treated Water, Reused Water and Untreated Water

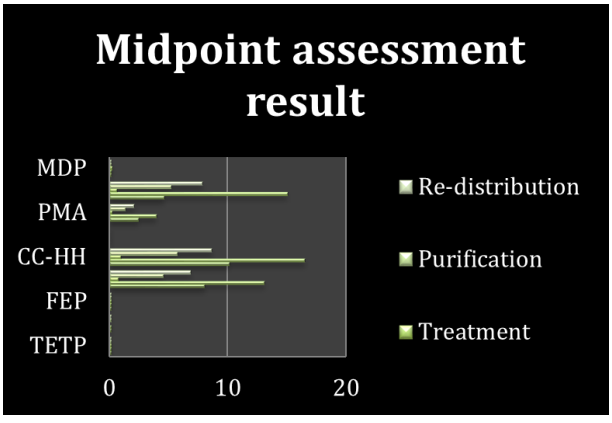

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Figure 9. Mid Point assessment Graph

Mid Point Assessment for the above-mentioned project highlights around 18 sub-areas of impact specification [16]. ReCiPe method helps in the utilization of the 18 mid-point categories namely, climate change, fossil depletion, agricultural occupation land, freshwater Eutrophication, freshwater eco-toxicity, transformation of natural land, depletion of ozone, formation of particulate matter, photochemical oxidant, eco-toxicity of terrestrial land, urban occupation of land and depletion of water resources.

The graph identifies the most critical categories facing the negative impacts of the "wastewater treatment plant" includes impacts on climate change and health change. Formation of particulate matter also increases thereby environmental degradation is inevitable. The increase in the quantity of particulate matter in air leads to the degradation of air quality index and in turn deteriorates health quality [3]. The graphs as shown below in Fig. 7 and Fig .8 indicate the similar reflection that emission of Green house gases and decrease in quality of Climate and human health can be highly attributed to consumption of fossil fuels and electricity.

Fig 9 indicates the intensity of environmental impacts with respect to material and energy consumption events [14]. The proper endpoint results retrieved are as given in the table 1 below:

Table 1. Mid Point Assessment Results

	Ecosystem quality				Human health			Resources	
	TETP	**FETP**	**FEP**	**GWP**	**CC-HH**	**ODP**	**PMA**	**FDP**	**MDP**
Water collection	0.014	0.002	0.008	8.048	10.12	0	2.435	4.608	0.073
sludge activation	0.023	0.004	0.013	13.11	16.49	0	3.962	15.04	0.123
Treatment	0.002	0	0.001	0.736	0.945	0	0.246	0.609	0.24
Purification	0.008	0.001	0.005	4.536	5.707	0	1.372	5.194	0.041
Re-distribution	0.012	0.002	0.007	6.852	8.621	0	2.081	7.862	0.062

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Table 2. Mid Point Assessment Study Results

Phase	**GWP**	**FETP**	**FEP**	**HTP**	**MDP**	**ODP**	**PMFP**	**TETP**	**WDP**
Water collection	295.7	1.8	0.1	3491.4	1.6	0	1	0.1	0.9
Sludge activation	295.7	1.8	0.1	3491.4	1.6	0	1	0.1	0.9
Treatment	28.2	0.2	0	296.2	0.5	0	0.1	0	0.1
Purification	166.6	1	0.1	1967.7	0.9	0	0.5	0	0.5
Redistribution	283.2	1.7	0.1	9957	1.5	0	0.9	0.1	0.9

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This graph indicates the percentage impact of various processes on the basis of mid-point assessment as shown in Fig. 10. It highlights as shown in table 2 that the more impacting categories are sludge activation, redistribution of treated water, and water collection [11]. Also, it highlights that the treatment phase has almost negligible impact on environmental degradation. The graph as shown in Fig.11 can highlight the impacts of reusing treated water. The impact is sub-divided into three categories i.e. environmental impact of the wastewater treatment process, followed by the consequence of the treatment process, and lastly use of treated water for irrigation purpose [13]. The reused water for agricultural purposes tends to reduce the impact on environmental factors.

Results derived from secondary data analysis provide the ground for analyzing the positive impacts of treating wastewater in WWTPs and reusing for irrigation purposes as shown in Fig. 12 and other organizations [12]. The negative impacts are also considered which includes sludge activation processes and depletion of energy sources.

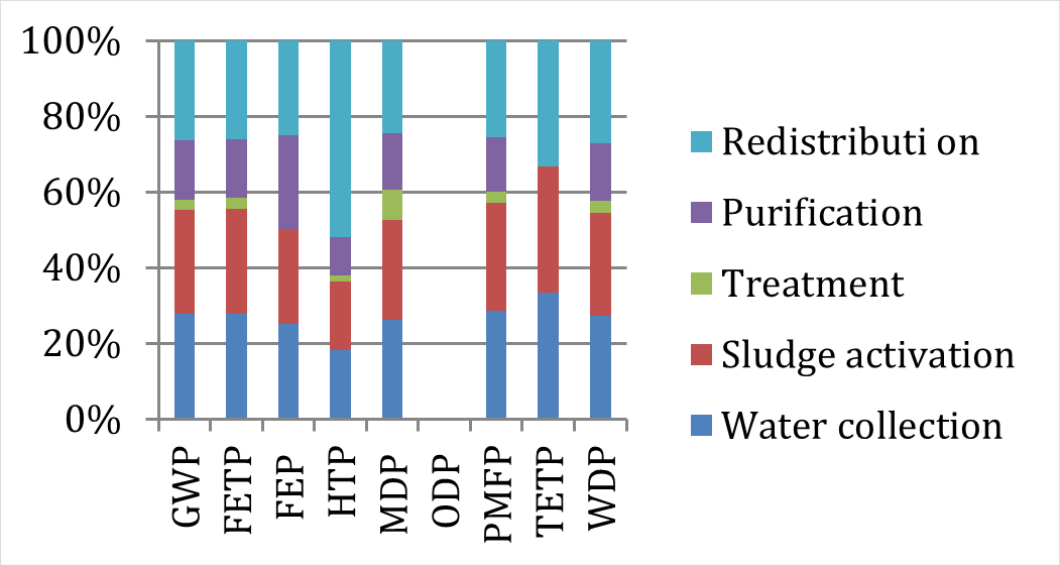

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Figure 10. Mid Point Assessment Graph

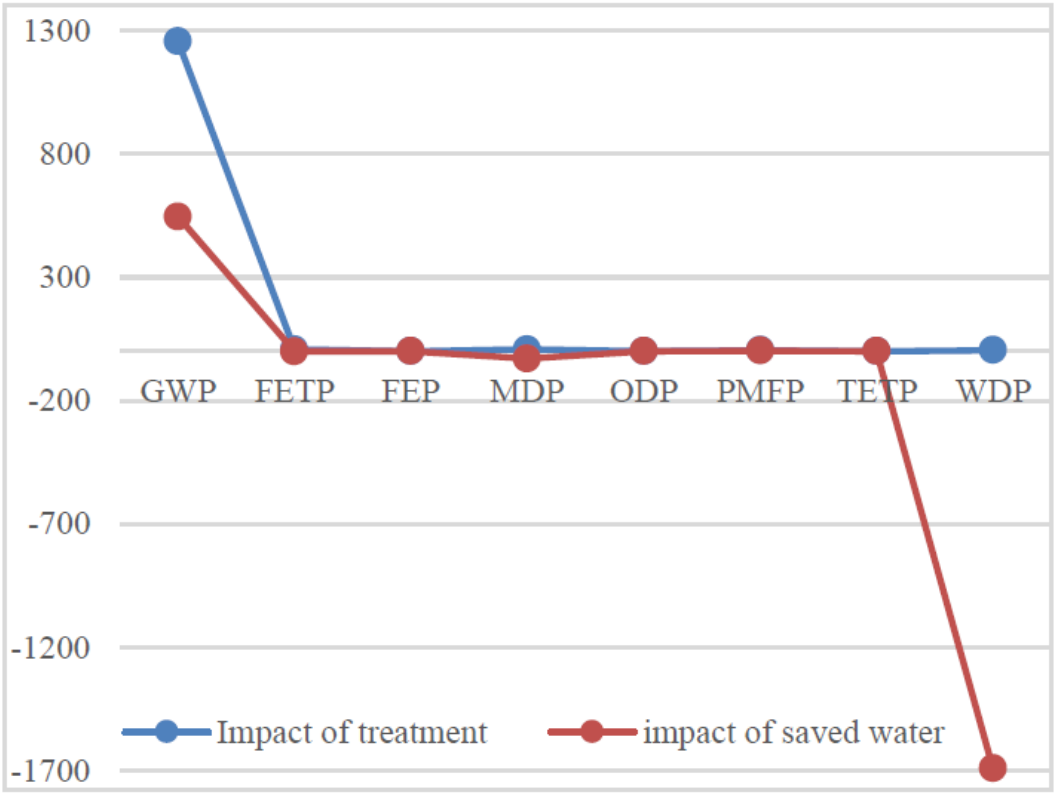

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Figure 11. Mid Point Assessment of Reused Treated Water

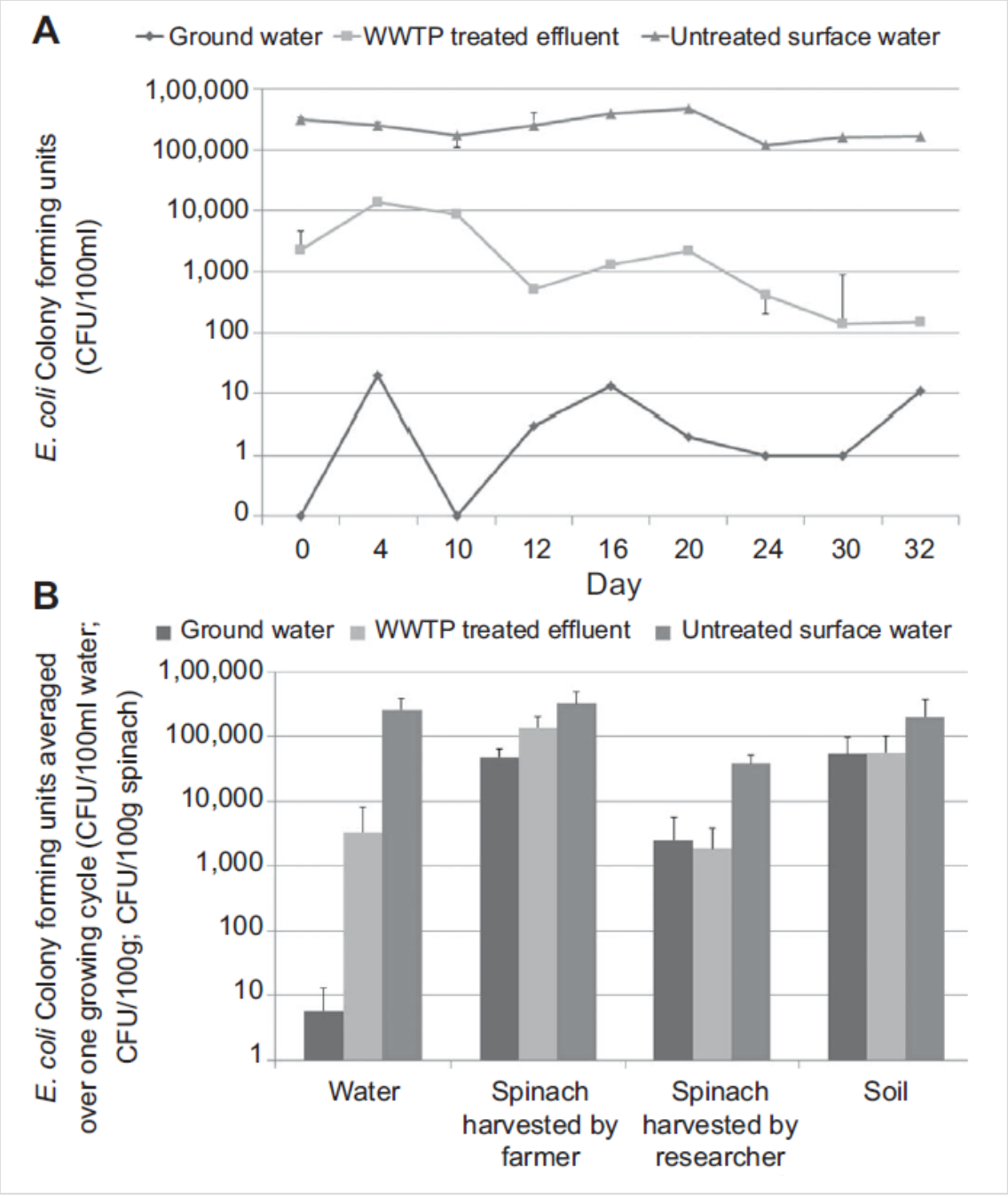

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Figure 12. Impact of "Wastewater Treatment" on Agricultural Practices

6. Conclusions

The report on life cycle analysis or LCA approach helps in understanding the positive and negative impacts of "wastewater treatment process" on the environment. The goal is to determine WWTP's environmental burden as well as to determine viable mitigation actions in terms of maintaining wastewater operations. Overall results of the LCA approach reveal that sewage treatment plant pollutants or outflows have such a huge environmental impact. Most important potential effects were climate change, grassland degradation, marine habitats nutrient enrichment, agricultural Eco toxicity, & terrestrial and aquatic Eco-Toxicity. The results and findings of LCA approach will be useful towards the treating wastewater sector although they will evaluate the whole environmental impact of such a treating wastewater system development cycle. According to the construction of the treated wastewater, it was strongly advised that the government or private industry study and assess these results. This study also suggests the need for alternative energy as a source for operation of the wastewater treatment process. Even

though any use of Life cycle assessment throughout analyzing public utility processes has grown considerably in recent decades, there were some concerns that need to be applied to enhance this topic of study, including such creating LCA techniques which include macroeconomic variables in hydraulic fluids performance of the system, tweaking evaluation metrics by formulating better metrics and measurement device for something like a truthful and accurate climate change adaptation, etc.

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