Life cycle assessment modelling for a developing city’s water system

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Abstract. The research objective to analysis the urban water system (UWS) includes water treatment and distribution, wastewater collection, treatment, and disposal for Raipur city of Chhattisgarh state in India. The city has a dry tropical climate and a warm summer. Developing city is being under pressure due to rapid population expansion, urbanization and industrialization that causes a considerable change in water resources and their services. Using SIMA-PRO LCA technology with ReCiPe and IPCC methods, the environmental impact assessment for the urban water system in Raipur was calculate by conducting a life cycle assessment (LCA). LCA tool focuses on water treatment and supply, wastewater, storm water, energy consumption, emission of pollutants and heavy elements to the water bodies and to sewage sludge and others spatial considerations such as population, economic and social assessment, water quality along with stakeholder engagement. LCA is a useful tool for identifying alternative environmental impact solutions and urban water operation scenarios for future strategic planning. In assessment, we found that water losses in distribution network and electricity consumption in water treatment have highest impact on environment while reducing this two by 15% and 2% then it reduces impact about 16%. We studied the existing conditions and different scenarios in this research to enhance the system's environmental quality and to find solutions to improve sustainability.

1. Introduction

In developing countries like India population growth and urbanization has been, pressurize the urban water infrastructure of the cities. Nowadays half of the population in the world is shifting to the urban vicinities. This proportion will increase day by day and with an increase in the demand of natural water resources and pollutants loads to the environment. Water scarcity is therefore a major problem worldwide and there is no safe drinking water for about 1.5 billion worldwide. With urbanization, industrialization and population expansion, this condition is getting worse. According to UNESCO, sustainability is the solution for the urban water system. It is necessary to provide sustainable urban water system in the cities should protect human health, resources and ecosystem. Along with the water consumption, energy, chemicals, nutrients and pollutants impact should consider to analyses the environment sustainability. It should identify these harmful effects for environmental sustainability as an indicator.
Urban water systems in the metropolitan’s cities are going through a phase of generous changes. To minimize their dependency on withdrawal from natural water resources, many cities are finding options for water resources supply. Wastewater collection and treatment system have loads of high levels of nutrients removal and disposal of solids that increases the system complexity. Integrated urban water management (IUWM) is therefore mandate to make available adequate water for existing and future generations. It needs to examine the situation at the local level and find solutions for an IUWM, in order to manage such systems, it is necessary to map water demand, leakage, water consumption, wastewater treatment.

In this research, we had done the environmental impact assessment (EIA) of the urban water system of a developing city Raipur of Chhattisgarh, India regarding to use the water resources and environmental loads due to pollutants. The work only deals with the functional aspects of an urban water system and not including the infrastructure destruction and improvement of the water system. This will required the precise investigation for environmental impact assessment by using Life Cycle Assessment (LCA) method. The method is often helpful in decision-making framework with an combination of manifold life cycle phases and impact categories. It also allows the tradeoffs without involving the results of weighing and a framework provided by ISO standards to make sure for consistency and avoid their mishandling or misinterpretation. There results have been used to goal particular design and for different functional movements to encourage the environmental policies and distinguish future needs for research. From last many years, Life cycle assessment (LCA) is a tool to quantify environmental impacts coupled with urban water system i.e. water supply, water distribution, wastewater storm-water and integration of the urban water system. This work described the influence of the Life Cycle Assessment (LCA) method for developing an enhanced perceptive of integrated urban water systems and to implicate the expected changes in how water supplied to urban population, three scenarios considered for the water treatment, distribution and wastewater services to urban population in Raipur.

2. Materials and methods
2.1. Literature review
For small-scale sewage treatment, LCA tool used for environmental impact assessment for water utility providing a valuable approach in life cycle impact assessment. The following important areas identified through LCA i.e. Ensure the energy attainment in aeration systems at an optimum level; defined the waste products can be reuse and recycle; and planned the company policy on an environment that sound should purchase and contracting [5]. Environment sustainability indicators (ESI) also revealed that they have to an increased understanding and scrutinizing to support the necessities and challenges of the urban water system (UWS) [8]. Including a case study-based real-time functional information taking into account water supply, water abstraction, water treatment and distribution, wastewater treatment, desalination and reclaim by using a holistic approach [1].

This tool also operated to generate information about the environmental impacts causes by water treatment process. Tool can analyse and compare different process or systems through their contribution to worldwide environmental impacts. The important in this is to using LCA tool that define a functional unit for each system to allow a clear comparison of different stages or systems in LCA [2]. As an environmental tool, LCA have unique capabilities to quantitative the life cycle can deal with complexity of systems, to balance environmental impacts [3]. One of the research highlights that appropriate analysis of positive and negative environmental impacts needs a life cycle impact assessment and weighing of costs and benefits for competing environment [6]. LCA applications used in the City of Scottsdale, Arizona, where comprehensive environmental impacts compared to water supply, recycling and desalination suggest that desalination of seawater has the highest impact, while recycling has a lower environmental impact [7]. LCA is a very helpful method for considering alternative future planning scenarios. Systems include analytical decisions in life cycle analysis of significant water and wastewater, which are testing through several phases of the system [11].
2.2. Study Area
LCA’s study area is Raipur City, is one of Chhattisgarh’s largest city and became capital on November 1, 2000, before it, Chhattisgarh was the former south-eastern part of undivided Madhya Pradesh. After division Chhattisgarh, state touches the boundary in an east to Orissa, west to Madhya Pradesh and Maharashtra, north to Uttar Pradesh, Jharkhand, and south to Andhra Pradesh. City have fertile plains located between 22 ° 33’ N and 21 ° 14’N Latitude and 82 ° 6 ’ to 81 ° 38’E Longitude. It surrounded by Raigarh and part of the state of Orissa in the East and Durg in the West, Bilaspur in the North, Bastar and part of the state of Orissa in the South. The southeastern part of the upper Mahanadi river and south and west border region occupied by the city.

City located at an attitude of 298.15 m and area under Raipur as per master plan scheme is 226 km2. According to 2011 census, the population of Raipur city reaches up to 10, 10,087. The city’s climate is tropical, with temperatures ranging from 5 ° C to 48 ° C and humidity ranging from 30 to 85%. The average annual rainfall receives of 1300 mm in June to October. There are 13 tehsils and 15 revenue blocks which administrated by district. The location map of the study area shown in Figure.1

![Figure 1. Location map of the study Area (Source: Google)](image)

2.3. Methodology
Life cycle assessment defines term sustainability of a product or services by the realistic analysis of its whole life cycle. This research helps us to assess the environmental impact of products or services over their lifespan. There are three fundamental issues that have to focus in LCA are to protected the human health, conservation of natural resources and preservation of natural environment.

This includes Life Cycle Impact Assessment (LCIA) in which device inventories in many areas into potential impact measures. Because of emission of a particular substance, from a product or from services, which follows a complex series of stages and phases that may cause either unexpected damage or degradation occurs in climate change, environment and human health. The measures of these damages are defining as endpoint indicators as they focus on concern impact.

LCA is a standard tool of EIA that gives its consistency and simplicity. The International Organization for Standardization (ISO) describes guidelines for this method in ISO 14040 and 14044, defining the four main stages of a LCA:
1. Goal and scope
2. Inventory analysis
3. Impact assessment
4. Interpretation

1. Goal and Scope definitions: Goal defines the LCA will perform as a model for product life cycle, service or system. LCA model for the simplification of a complex reality and its simplification will not distort reality in some other way. So this is important for the model developer, LCA simplifications and interpretations should not distort the findings. This will address by defining the objectives and scopes of the LCA study. And it describes the reason for executing the LCA, and it’s precise the life cycle of products or services and system boundaries.

2. Inventory Analysis: In the second step analysis for LCA inventory is performing with including all environmental inputs and outputs of concern products or services such as raw material, fuels, energy, emission of pollutants, energy emission.

3. Life cycle Impact Assessment (LCIA): At this stage, the conclusion will remark for better business decisions and translate them into global warming or human health and environmental policies. It gives the important for choices to a level of integration of results.

4. Interpretation: During the phase of interpretation stage, conclusions need to check it will sustain or not according to ISO 14040 and 14044 standard.

3. Results and discussion

Life cycle assessment (LCA) used for the environmental impacts couple with existing infrastructure for urban water systems in Raipur and identify key opportunities for reducing their impacts. We consider three situations for carrying out LCA for the urban water system. From the survey of the existing state of the urban water system in Raipur, three different scenarios are performing, i.e. reduction of leakage of water in the distribution network up to 15 percent, reduction of electricity in treatment up to 2 percent, and last one combination of this two scenarios. For modelling of LCA, define a functional unit and system boundary for study area is as follows;

3.1. Functional unit

The functional unit identified for LCA Study is the supply of one-meter cube of water at the city's point of intake. The maximum drinking water demand in the Raipur Municipal Corporation (RMC) is 126MLD.

3.2. System boundary and description:

There are following system boundaries are considering in the LCA for Raipur:

1. Water treatment
2. Water distribution and sewage collection
3. Wastewater treatment and disposal
4. Receiving water bodies

3.2.1. Water treatment

There is only one treatment plant in Raipur located near Ravanbhata at the south of the city. This plant serves the population of about 8 lakhs. Design capacity of the treatment plant is 47.67MLD and its augmentation is in progress to increase the capacity by 80 MLD. In plant, conventional treatment is practice for treatment of water with following process includes coagulation, flocculation, filtration and chlorination. It stores the clean water in a sump of the treatment plant. Chlorine gas is use for chlorination of treated water after filtration. When chlorine gas cylinders are not available, bleaching powder slurry prepared in buckets is use for chlorination. Raipur Municipal Corporation is responsible for the water treatment and water supply in the city. The Superintending Engineers are
overall in charge of water supply, assistant Engineers are in charge of Head Works and the executive Engineers are responsible for distribution, remaining infrastructure and administration.

3.2.2. Water distribution:
There are 12 service reservoirs in the different area for supplying treated water in the city. The present rate of water supply is 70 lpcd for 1 hour in the morning and evening. RMC meets the total demand of water supply through the water from the treatment plant along with groundwater. The groundwater and surface water are mixed in service reservoirs before distribution. In city about there are 3319 public stand posts and 26,536 private connections. During the field survey, it has been finding that the public stand posts and the distribution system based on the bore wells do not have taps. City divides into seven zones for water supply and these zones are to be looking after by sub-engineer. No organized leak detection programme in Raipur and these leakages are repair based on public complaints and as notice by water supply department. It has been a report by personnel of RMC that about 10% of water is Unaccounted for Water (UFW) because of leakages, wastage, etc. This reported percentage is low and need be a test.

3.2.3. Wastewater and Sewage treatment plant:
There is no well-organized sewerage treatment system in Raipur city. There is an open drainage system in most parts of the city. In some, develop residents to give aesthetic look they have covered drains. There are three oxidation ponds at Dalalseoni, Birgaon and Changorabhata. Though the sewerage system constructed and commissioned in 1984, the connections from sewerage line to individual houses did not charge and domestic waste discharged in open drains, which goes to the nearby lake. After the Raipur became the capital, the Corporation applies charges for individual sewer line i.e., the drain connection from private premises up to public sewerage line compulsory and work for such connections is in progress. Heavy algal bloom along with water hyacinth observed in these lakes because of bathing, washing of cloths and other human activities. However, these lakes are not the parts of organized water supply system of RMC.

3.2.4. Disposal:
Number of nullahs that discharge industrial effluents and domestic sewage without treatment into the Kharun river. The river has been the lifeline of Raipur city for over 40 years. In the last one-decade, the quality has deteriorated from untreated sewage and industrial effluents finding its way into the river. Now, the water quality has declined so much that it is not even fit for bathing, let alone consumption.

Sima-Pro 8.5.2.0 used for Life cycle assessment of the urban water system. The result of LCA states that the energy consumed for scenario 1 and scenario 2 are maximum while energy required for the scenario 3 is the minimum. This will be achieved by eliminating water losses in the distribution network and reducing the supply of power in water treatment throughout the phases. LCA shows the detail results of the ReCiPe endpoint approach in figure 2. Present urban water system have 1499.361points, while for scenario 1, scenario 2 and scenario 3 holds 1471.185, 1288.44 and 1260.264 impact points. As compared to present condition of water system, scenario1 and 2 having high impacts, while in scenario 3 impacts are decreasing by 15.94% under the category of resources (16.58%), human health (15.53%) and ecosystem quality (15.11%). The results of the different scenario regarding present condition as shown in figure 3. Another assessment made by IPCC GWP 500a V1.01 kg Co2 eq. for all four conditions that also shows that scenario 3 has a minimum emission of kg Co2 eq. (figure 4).
Figure 2. Detailed ReCIPe endpoint (E) V.1.13/World ReCIPe E/E

Figure 3. Detailed ReCIPe endpoint (E) V.1.13/World ReCIPe E/E for present water system and three different scenarios
4. Conclusion
The environmental impacts of the urban water system for the Raipur municipal corporation (RMC) analyzed for year 2018-2019. Along with scenario analysis in addition are improvements need to put into practice at the same time such as more reduction in water losses, wastewater treatment plant set up near receiving water bodies. The proposed improvements based on decision-making process regarding future investments towards sustainability of the urban water system environment. This study provides the life cycle assessment of the urban water system for Raipur city in India. The environmental impacts of the existing urban water system described in the different categories. When considering the data from the observation that used for the LCA, it must be that much information estimated from field survey and literature review. From the results, we can conclude that;

1. Water leakage and electricity consumption is the major source of impacts.
2. Key finding an impact in this category is because of distribution of water.
3. Study shows that the by reducing electricity by 2% and water leakage reduce by 15% will diminish the environmental impact of the urban water system of Raipur by almost 16%.

The city has already starting to set up a waste treatment plant near the Kharun River. The study based on the existing water supply conditions of the Raipur city.

References
[1] Amores, M.J., Meneses, M., Pasqualino, J., Antón, A. and Castells, F 2013 Journal of Cleaner Production 43 84-92
[2] Bonton, A., Bouchard, C., Barbeau, B., & Jedrzejak, S 2012 Comparative life cycle assessment of water treatment plants Desalination 284 42–54
[3] Buckley, C., Friedrich, E., & Von Blottnitz, H 2011 Life-cycle assessments in the South African water sector: A review and future challenges Water SA 37(5)
[4] CPHEEO Manual
[5] Emmerson, R. H. C., Morse, G. K., Lester, J. N., and Edge, D. R 1995 Water and Environment Journal 9 3 317–325
[6] Foley, J., de Haas, D., Hartley, K., & Lant, P 2010 Water Research 44 (5) 1654–1666
[7] Lyons, E., Zhang, P., Benn, T., Sharif, F., Li, K., Crittenden, J., Costanza, M., Chen, Y.S 2009 Water Supp 9 (4) 439-448
[8] Lundéhn C., Morrison G.M 2007 An assessment framework for urban water systems – a new approach combining environmental systems with service supply and consumer perspectives. In:
[9] Morrison G.M., Rauch S. (eds) Highway and Urban Environment. Alliance For Global Sustainability Bookseries vol 12. Springer, Dordrecht
[10] Punmia, B. C., Jain, A. K., Jain, A. K. 1995 Water supply Engineering: Environmental Engineering.
[11] Parliament of India 1993: IS 1172: Code of Basic Requirements for Water Supply, Drainage and Sanitation (Fourth Revision): BIS 1172:1993
[12] Lundie, S., Peters, G. M., & Beavis, P. C 2004 Environmental Science & Technology 38 (13) 3465–3473
[13] V. Bhakar, N. Sihag, R. Gieschen, S. Andrew, C. Herrmann, and K. S. Sangwan 2015 Procedia (CIRP) 29 468–473