



Life Cycle Assessment of Potable-Water and Treated Greywater Concrete to Quantify Environmental Benefits

Jayant Awasthy^{1*} and Sharad Naik²

^{1,2}Department of Civil Engineering, Acropolis Institute of Technology and Research, Indore, India

jayantawasthy@acropolis.in^{*}, sharadnaik@acropolis.in

Abstract

This comparative study aims to evaluate the Life Cycle Assessment (LCA) of making concrete with Treated Grey Water (TGW) over Potable Water; LCA evaluates the amount of Green House

Gaseous (GHG) emissions as well as water efficiency to set environmental advantages.

The quantity of greenhouse gases that will be saved directly because of the substitution of potable water with treated grey water might be minimal. Nevertheless, when energy efficient production of treated grey water is done, and/or when the supply of potable water is taken out of carbon-intensive sources, the amount of water conserved becomes significantly high. The emission of the greenhouse gases and the use of water were measured against a Functional Unit, one cubic meter of Ready-Mixed Concrete. Findings of the base-case analysis showed a marginal quantity of Direct Global Warming Potential (GWP) was spared ($\sim 0.05 \text{ kgCO}_2 / \text{m}^3$); the benefits of conservation of water were high. According to the sensitivity analysis, the GWP savings will be significant in case the supply of potable water is carbon intensive and/or the Treated Grey Water Treatment is energy efficient. This research is expected to satisfy an immediate requirement of building materials which are eco friendly, and the utilization of grey water (treated) rather than drinking water in construction work, and the growing worry of water shortage and heavy carbon foot print of conventional building practices. Suggestions on inclusion of treated grey water to concrete production are given.

Keywords: *Life Cycle Assessment; Concrete; Treated Greywater; Potable Water; Green House Gas Emissions; Sustainability*

1. Introduction

Concrete is the greatest manufacturer of building material in the world; more than 14 billion cubic meters of concrete are manufactured annually. The low cost coupled with high strength, coupled with its durability has made concrete an essential part of nearly all projects involving new construction and repair works in almost every part of the world. Concrete has enabled the modern world, but the same can be stated with the manufacture of concrete itself, the manufacture of Portland cement is a very costly process which is environmentally expensive. Cement sector generates approximately 7-8 percent of carbon dioxide in the world, and this makes the cement industry one of the major contributors of greenhouse gases in the world. Cement produces a lot of

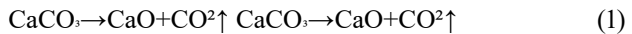
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greenhouse gases as well when it comes to making concrete.

The traditional method of production of the concrete was based on potable water that was subject to extensive treatment and costly and had significant environmental effects during extraction to distribution. The emission of greenhouse gases by the production of concrete is based on three primary sources of production, first, the production of cement (clinker), second, the use of fossil fuels to obtain the high temperature necessary to fire in the kilns of the cement production plants and thirdly, the electricity consumed to grind the clinkers and raw materials to fine powders and to process and handle the fine powders. There are two major processes of cement manufacturing namely the dry process and the wet process. The dry process involves the use of heat to dry the slurry limestone and clay and further burn it at very high temperatures until it melts and coagulates into a hard substance called the clinker. The wet technique is close to it except that the mixture is fired and dried in the same kiln. The manufacturing of cement is achieved by heating limestone (CaCO_3) to large temperatures to make clinker as follows:



Calcification refers to the act of heating limestone until it melts to form calcium oxide and carbon dioxide gas. Calcination contributes to the greenhouse gas emissions in the cement production more than any other single source with a proportion of about 60-65 percent of the total CO_2 captures that are linked to cement industry. Heat to heat the kilns to the very high temperatures required to make cement must be supplied by fuel. The kind of fuel is different to the availability of the type of fuel in the various countries but it is inclusive of fossil fuel e.g. coal, petroleum coke and natural gas. The combustion of these fossil fuels leads to an additional 30-35 percent of greenhouse gases of the cement industry. The last production sector that causes greenhouse gas emissions is the electric power that is utilized in grinding the clinkers and the raw materials into fine powders as well as the electrical power used to move and process the fine powders.

There is also a high influence of aggregate production and transportation on the greenhouse gases. Aggregates quarrying, extracting and crushing are energy-intensive activities and the transport of raw materials and ready-to-use concrete, particularly over extensive distances, leads to even more emissions of greenhouse gases to the manufacture and delivery of concrete. Although the actual greenhouse gases produced by mixing of concrete are relatively far less than those produced by the production of cement, there is also the production of some greenhouse gas emissions by the use of electrically-powered mixers. The greenhouse gas emissions also take place in precast concrete manufacturers because of the curing processes which presuppose the use of electrically heated air, steam, etc. to control and ensure the required concrete moisture content. Lastly, besides the steps that have been identified earlier during production and delivery of concrete that cause greenhouse gas emissions, numerous other steps such as packaging, transportation and storage cause greenhouse gas emission, and adversely impact the environment the world over.

Although the percentage of the total GWP of Concrete Production is less than Cement or Aggregate Processing it remains a major and non-renewable resource in the Areas facing Water shortages. Historically Potable Fresh Water has been used as Concrete Mixing and Curing due to its Perceived Purity and Consistency.

Alternative Water Sources are being considered because of the growing pressures that are being exerted on Global Fresh Water Supplies through Urbanization, Population Growth and Climate Change. The use of Treated Grey Water (TGW) is one of the possible initiatives to achieve this. Grey Water refers to Wastewater Derived out of Non-Toilet Domestic Activities such as Washing Dishes, Bathing, Laundry and Hand Washing; which may be used in mixing Concrete and in building Construction Processes. When Properly Managed and Treated, TGW can be exploited to greatly reduce reliance on potable water supply in the production of concrete without affecting the structural integrity and performance of the concrete. Use of TGW is a worthwhile alternative in the construction industry towards sustainable water conservation as pressures on world fresh water are mounting.

About 50 to 80 Percent of the total domestic wastewater produced in the house falls under grey water. Black Water is made by Toilet and usually rich in the concentrations of pathogens and organic matter; and Grey Water by Non-Toilet Domestic Sources such as Bathrooms, Laundry and Sinks, which has comparatively lower levels of contaminants. Hence, Simple Treatment Steps like Filtration, Sedimentation or Simple Biological Treatment may be of good quality to satisfy the requirements of many non-portable applications.

Despite this Potential, in most Urban Areas, there is a general practice of releasing the grey water without treatment into the sewers, or into the surface waters leading to environmental contamination and wastage of a precious water source. Recycles of grey water in construction sites or at Ready Mix Concrete Plants provides a significant attainment of the water loop, burdens on fresh water sources and wastewater systems and infrastructure.

A Life Cycle Assessment (LCA) is a Systematic Tool that is Widely Applied in the Civil Engineering to determine the entire scope of the environmental consequences related to construction materials, processes and infrastructures. An LCA gives a full picture of both direct and indirect environmental impacts on a product throughout its entire life cycle starting with the extraction and processing of raw materials, construction, operation and maintenance and finally the disposal or recycling of the product at the end of its life. Through Quantifying Resource Use, Emissions and Energy Consumption at All Stages, LCA helps engineers and decision makers to find opportunities to reduce the environmental footprints and to encourage the adoption and use of sustainable construction practices.

Civil Engineering Projects can go beyond their traditional cost and performance orientations to adopt the idea of long-term environmental stewardship by Adopting a Life Cycle Assessment (LCA) Framework. The measurement of the Environmental

Benefits of Treated Grey Water (TGW) by comparative LCA not only responds to the urgent needs of water shortage, but also aligns the construction activities with the interests of global sustainability that are directed at dismissing climate change reducing resources depletion, and safeguarding the ecosystem.

The resultant Holistic Approach here is the ability to make informed decisions that promote the development of resilient and environmentally responsible infrastructure development. The environmental benefits of using TGW are quantified in this paper by a Comparative LCA.

2. Literature Review

The concrete material is being used way more than any other material used in the building process in the entire world and Portland cement is the biggest contributor to the greenhouse gas emission in the life cycle of concrete because of the embodied carbon in the material.

Concrete is the most widely used construction material worldwide, and Portland Cement production is the largest contributor to greenhouse gas emissions in the concrete life cycle due to its high embodied carbon. Studies analyzing Environmental Product Declarations (EPDs) confirm that cement production accounts for nearly 70–80% of the total Global Warming Potential (GWP) of concrete, while aggregates and admixtures contribute significantly less [1]. Although water-related emissions are generally small compared to cement, the energy required for water extraction, treatment, and distribution can become substantial in water-scarce regions or where long-distance transport is required.

As researchers continue efforts to decarbonize cement production, attention has expanded toward other life cycle stages, including mix optimization and sustainable water sourcing. Increasing interest has emerged in alternative water sources such as recycled wastewater, harvested rainwater, and treated greywater (TGW). Life Cycle Assessment (LCA) has been widely applied to evaluate environmental impacts of wastewater and water treatment systems [2], as well as greywater treatment and reuse systems in rural and decentralized contexts [3–4]. Recent studies also assess the integral water cycle in industrial supply systems using LCA methodologies [5].

Greywater, defined as wastewater from non-toilet activities such as bathing, laundry, and dishwashing, has potential applications in irrigation, toilet flushing, and construction. [6] investigated the influence of treated greywater on the physical and mechanical properties of mortar and concrete. Their findings showed that compressive strength of concrete prepared with treated greywater was comparable to or slightly higher than that prepared with potable water. Although minor reductions in workability and slight setting delays were observed, overall durability and mechanical performance were not adversely affected. These findings support the feasibility of TGW use, particularly in arid and semi-arid regions where construction

activities compete with domestic and agricultural water demands.

However, most existing research primarily evaluates mechanical properties rather than comprehensive environmental impacts. While LCA studies extensively assess greywater treatment systems at household or community levels, limited research integrates cradle-to-gate LCA comparisons of concrete mixes prepared with different water sources (potable versus treated greywater). Furthermore, quantifiable GWP reduction and water footprint benefits at large construction scales remain insufficiently documented.

To address this research gap, the present study conducts an ISO 14040/14044-based comparative LCA of concrete prepared with potable water and treated greywater. The study quantifies reductions in GWP and freshwater consumption per cubic meter of concrete and extends the findings to project-scale applications, thereby linking material performance with environmental sustainability assessment.

3. Methodology

The ISO 14040 establishes the fundamental principles and framework of determining the environmental impacts by the use of life cycle assessment (LCA). The two international standards are used to describe the procedures to be followed in ensuring consistency and transparency throughout all the stages of an LCA. ISO 14044 elaborates the general standards of ISO 14040, and gives specific standards and guidelines of each stage of an LCA. These involve the purpose of the study; the area of study; analysis of the inventory; the effects analysis and the interpretation and reporting of results. When integrated, ISO 14040 and ISO 14044 offer an overall structure of assessing environmental impacts throughout the life cycle of the materials and products, i.e. since the stage of the acquisition of raw materials, processing and manufacturing of the materials to the end of the product disposal.

In traditional concrete production, potable water is normally used as the mixing agent due to its assured chemical purity and adherence to national building codes including those of India through the IS-456, and the U.S. through the ASTM C1602. Sadly, the consumption of fresh water in mixing further creates pressure on the available and sometimes scarce water resource in most regions across the globe. Even though cement production contributes about 70-80 percent of greenhouse gas emission (GHGs) caused in the production of concrete, using the most environmentally friendly mixture water will play a strategic purpose in saving natural resources and ensuring a more sustainable development practice.

It has been demonstrated that recycled domestic greywater (DW) processed to yield a high-quality recycled water that can be used to serve as a mixing and curing agent in concrete, called treated greywater (TG) is able to save huge volumes of fresh water and save the environment. Last studies show that even DW that is properly treated can

be reused as a mixing and curing agent without any impact on the mechanical properties of concrete or its performance and workability. DGW can also be used in large scale construction work or in regions where there is an expensive system of distributing potable water through expensive energy-intensive methods, thereby realizing cost reduction. Besides creating less pressure on the use of fresh water resources, using DGW would also assist in developing a closed system of water use in the construction industry and, in the process, the environmental effects of concrete production would be minimized. The methodology that will be adopted in this study will involve comparative analysis of environmental impact of using potable water to manufacture concrete as compared to using treated grey water (TGW).

Besides a comparison of the GWP (kg CO₂-eq) of one cubic metre of ready-mixed concrete produced using (a) potable water and (b) treated greywater (TGW), some steps have to be taken in quantifying and comparing the two.

The comparison unit of functionality will be a trial mix designed M30 grade of concrete. The boundaries of the cradle to gate system through which LCA has been implemented will include all the processes that are involved in the extraction of the raw material (cradle) to the time when the product goes out of factory (gate). These include raw materials, processing, transportation to the factory and production related operations (batching and mixing), but not transportation to construction sites, placement, use, maintenance as well as end-of-life disposal/processing/recycling. Refer fig. 1.

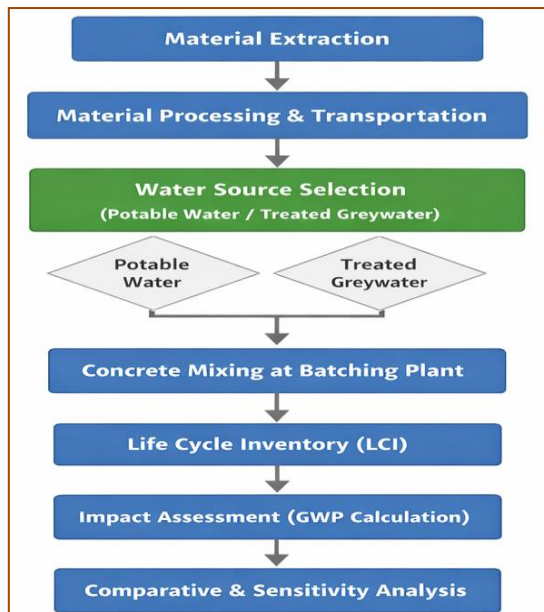


Fig 1: Flow chart of the method of assessment

The life cycle assessment can determine the environmental impacts of the production stage of concrete in more detail by taking into account the cradle to gate.

The most significant phases of the impact assessment are:

1. Stream all the data on inventory (raw materials, energy, emissions) into standardized units (kg/m^3 etc.) in order to make comparisons possible.
2. Multiply individual stream of data (inventory flow) with the individual emission factor (in $\text{kg CO}_2\text{-eq}/\text{unit}$) to give an approximation of the contribution of each stream to GWP.
3. Add up the output of each stream to get the Total GWP of the particular functional unit (i.e. one cubic metre of concrete).
4. Give the results in terms of absolute values and relative difference/ percentage changes between the scenarios of using potable water and treated greywater (TGW).
5. Perform sensitivity analysis to investigate the impact of changes in some of the most important parameters (e.g. a 20 percent change in emission factors, the distance transported, and energy used to treat TGW) on the outcomes. Besides, it is recommended to conduct an uncertainty analysis based on Monte Carlo simulation in case it can be performed to identify the extent of confidence in the results.
6. In general, these techniques allow a complete and impartial comparison of the environmental effects of the production of concrete by different methods of production that use water.

4. Results

Life Cycle Inventory (LCI) data of the greywater treatment process is used to compute the TGW factor. The elements were then tabulated in order to see:

For M30 grade of concrete, Refer fig 2

- Cement = 350 kg.
- Sand = 650 kg.
- Coarse Aggregate = 1150 kg.
- Water = 170L = 0.17 m^3 .
- Global Warming Potential (GWP) factor = 800 kgCO_2 / t .
- Potable Water Factor = 0.6 $\text{kgCO}_2 / \text{m}^3$.
- TGW factor = 0.3 $\text{kgCO}_2 / \text{m}^3$.
- Cement (800 kgCO_2/t), Potable Water (0.6 kgCO_2/m^3), TGW (0.3 kgCO_2/m^3).

Arithmetic Digit by Digit Calculations Follow;

1. Divide the factor of cement by the CO_2 emission per kilogram of cement: $800 \text{ kg CO}_2 / 1000 \text{ kg}$

= $0.8 \text{ kg CO}_2 / \text{kg cement}$.

2. GWP of cement: $350 \text{ kg} \times 0.8 \text{ kg CO}_2 / \text{kg cement} = 280.0 \text{ kg CO}_2$.

3. Calculate the volume of water consumed: $170 \text{ L} / 1000 = 0.17 \text{ m}^3$.

4. Determine GWP of potable water: $0.17 \text{ m}^3 \times 0.6 \text{ kg CO}_2 / \text{m}^3 = 0.102 \text{ kg CO}_2$.

5. Divide TGW by GWP: $0.17 \text{ m}^3 \times 0.3 \text{ kg CO}_2 / \text{m}^3 = 0.051 \text{ kg CO}_2$.

6. Divide the total GWP (Potable Case):

Cement (280.0) plus Potable Water (0.102) equals $280.102 \text{ kg CO}_2 \text{ eq} / \text{m}^3$.

7. Total GWP (TGW

Case): Cement

$(280.0) = \text{TGW Water} (0.051) = 280.051 \text{ kg CO}_2 \text{ eq} / \text{m}^3$.

8. Calculating Absolute Reduction with TGW, Other Than Potable Water: Reduction = $280.102 - \text{TGW}$

$\text{GWP} = 280.051 = 0.051 \text{ kg CO}_2 \text{ eq} / \text{m}^3$.

9. Percent Reduction of GWP When Treated Grey Water (TGW) is used, as opposed to using Potable Water: Percent reduction = $(\text{Potable Water GWP} - \text{Treated Grey Water GWP}) / \text{Potable Water GWP} \times 100$.

$= ((280.051 - 280.102) / 280.051) \times 100 = 0.0182\% \text{ Reduction in GWP per m}^3$.

10. Cube Strength = $> 20 \text{ N} / \text{mm}^2$ Refer Fig. 3.



Fig2: M30 Concrete Mix Design Execution



Fig3: M30 Concrete Mix Design Execution

4. Discussion

The comparison of the green house gas emissions (GWP) of the potable water concrete and treated gray water (TGW) concrete show that it reduces the emissions, both absolute and percentage, by a significant difference of $0.051 \text{ kg CO}_2\text{-eq/m}^3$ and 0.018 percent respectively, compared to the total emissions of $280 \text{ kg CO}_2\text{-eq}$ of the cement production. Even though the difference in GWP might seem to be insignificant on the surface, it reflects a few important lessons on resource management, environmental policies, and broad scale sustainability effects.

Even though cement contributes about 99.96 per cent of total GWP per m^3 of concrete produced (using the 350 kg of cement), water (safe or treated graywater) has about 0.04 per cent of the total GWP. Thus, minimization of cement in terms of optimized mix designs and/or, addition of supplementary material is the best method of minimizing the total GHG emissions of concrete. Despite the fact that the GWP of treated graywater (TGW) and potable water is rather minor, it affects much in terms of water conservation and sustainability⁵.

The incorporation of treated graywater (TGW) in place of the potable water will not be detrimental to the concrete strength and its performance. Concrete application using TGW is therefore advantageous since usage of available potable water is minimized and also the quantity of water dumped to the environment is reduced. Also sustainable construction is in keeping with the use of treated gray water to concrete. The savings that come with using treated graywater (TGW) rather than potable water are small when applied to large-scale infrastructure projects (e.g., a metro rail system that consumes $500,000 \text{ m}^3$ of concrete in total), but it leads to slight decreases in overall greenhouse gas emissions (around 25.5 metric tons $\text{CO}_2\text{-eq}$).

Although such savings of emissions are minute in comparison with that of cement

production, these savings are the same value as the annual footprint of several cars. Also, treated graywater (TGW) will lead to the consumption of less potable water of 85-90 million liters; especially in arid areas, when potable water becomes a precious commodity. Moreover, the application of treated graywater (TGW) can help to minimize the expense of using potable water sources and decrease possible dependence on the municipal water sources. Both of them make projects become more resilient in case of water-related limitations and rationing. These considerations, therefore, ought to be taken into account by planners of sustainable and viable construction schemes.

Besides it may offer certain cuts in cement emissions (with cement reduction), treated graywater (TGW) can also be used in the context of better water savings and decreased energy requirements. Moreover, this can be accomplished through the use of treated graywater (i.e., LEED). To have actual multi-criteria assessments, GWP, water footprint, and economics should be in consideration in making holistic sustainability planning of construction projects.

5. Conclusions

In conclusion, treated greywater (TGW) can reliably replace potable water in concrete production without compromising strength or durability, while significantly improving water conservation. Its use is particularly beneficial in arid and water-stressed regions where construction competes with domestic and agricultural demands. By integrating TGW into the production process, the construction industry can promote a circular water economy, reduce pressure on municipal supplies, and minimize wastewater discharge. Although the reduction in greenhouse gas emissions is relatively small compared to cement-related emissions, the improvements in water footprint, local hydrology, and resource security are substantial. Additionally, TGW adoption offers economic advantages through reduced water procurement costs and potential sustainability incentives. Overall, TGW represents a viable, scalable, and environmentally responsible approach to advancing sustainable concrete production.

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