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Application of wastewater for reclamation of desert: A life cycle cost analysis

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Abstract

This article explores the financial potential of using wastewater for desert reclamation to convert barren land into arable areas capable of growing food in hunger-affected regions. It emphasizes the need to assess the financial feasibility of such projects, providing a detailed Life Cycle Cost calculation to evaluate the long-term financial viability before initiating pilot experiments. The article compares the Net Present Value (NPV) of agro products and the system after 15 years against the NPV of Life Cycle Costs incurred. It reveals a 15-year deficit of USD 292,312 per hectare in desert reclamation through continuous wastewater application over three years in each plot, and this is the first kind of work that combines LCCA with wastewater application and desert reclamation. Reclaimed desert land can be used to produce grains, oilseeds, and cotton indefinitely, providing long-term agricultural benefits. Additionally, the increased greenery plays a crucial role in carbon sequestration. This transformation not only boosts food production but also enhances environmental quality by reducing carbon dioxide levels and improving local ecosystems, making desert reclamation a sustainable solution for both food security and environmental preservation.

Keywords: Desert reclamation, Environmental benefits, Life cycle cost analysis, Wastewater reuse.

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1. Introduction

Reclaiming, recycling, and reusing wastewater is crucial for sustaining freshwater resources, reducing scarcity, and promoting environmental conservation for a sustainable future [1]. In the least developed and developing countries, Project costs are often viewed solely as capital expenditures. However, Fonseca [2] emphasizes the importance of non-capital expenses, which are crucial for sustainable system construction and operation. These additional costs include operation, maintenance, and administrative expenses, essential for long-term success.

Life-cycle costs: The total cost of delivering a service over its entire life span encompasses capital investments, operational expenses, repairs, and maintenance. These costs continue until the facility or service is retired or replaced, ensuring full financial consideration of all expenditures required for long-term sustainability and functionality [3].

Capital expenditure (CapEx): The initial investment for developing a project or system includes both infrastructure costs and expenses related to other inputs during construction. This covers materials, labor, equipment, and any preparatory work needed to establish the foundation of the project, ensuring readiness for future operations and functionality.

Operation and minor maintenance expenditure (OpEx): OpEx covers regular, ongoing expenses such as labor (staff salaries), management (transport, fuel), energy, chemicals, materials, and minor infrastructure repairs. These costs are essential for the day-to-day functioning and maintenance of a system or project.

Capital maintenance expenditure (CapManEx): CapManEx covers costs for maintenance and irregular repairs, not performed regularly, such as asset renewal, replacement, and infrastructure rehabilitation. These expenses ensure the long-term functionality and durability of systems and infrastructure beyond routine upkeep [4].

Direct support (DS) costs: Expenses for backup support include costs for monitoring services, community and student training (if not included in the school budget), and technical assistance for communities and service providers. These expenses are essential to ensure the continuous operation and effectiveness of programs, fostering resilience and enhancing the overall quality of services provided to students and the community [5].

Indirect support (IS) costs: Expenditures on non-WASH supplies or services during WASH system maintenance include costs for items like office supplies, administrative services, and training materials. These purchases support the overall functionality and efficiency of the WASH system, ensuring that related operational and administrative needs are adequately met to maintain effective service delivery [5].

Cost of capital (CoC): The costs associated with CoC include interest on borrowed funds and returns to the system owner. It is essential to calculate these expenses under detailed headings and compare them with alternative projects to ensure informed decision-making and effective resource allocation.

A study of water supply projects in Ghana found that capital and maintenance expenditures (CapManEx) account for only 4% to 22% of recurring expenditures (OpEx), indicating a significant difference in investment levels compared to ongoing operational costs [6]. Capital expenditures (CapEx) as the funds a company uses to acquire, upgrade, and maintain physical assets like property, plants, buildings, technology, or equipment. These expenditures are often made to initiate new projects or investments. Examples of CapEx include repairing a roof to extend its useful life, purchasing new equipment, or constructing a new factory [7]. Various assets can provide long-term value to a company, and several types of purchases fall under CapEx:

a. Buildings: Used for office space, manufacturing, inventory storage, or other purposes.

b. Land: Can be developed further, with accounting treatment varying for land held as a speculative long-term investment.

c. Equipment and machinery: Utilized to manufacture goods and convert raw materials into final products for sale.

d. Computers or servers: Support a company's operations, including logistics, reporting, and communication. Software may also be considered CapEx in certain situations.

e. Furniture: Furnishes office buildings, making the space usable for staff, clients, and customers.

f. Vehicles: Used for transporting goods, picking up clients, or business purposes by staff.

Capital maintenance expenditure refers to the costs associated with renewing, replacing, rehabilitating, refurbishing, or restoring assets to maintain the original level of service performance. Examples include replacing a motor on a power pump, the pump rods/rising main/handle in a hand pump, cleaning or re-excavating the base of a hand-dug well, relaying the drainage field for a septic tank, flushing a borehole that no longer delivers the desired flow, and cleaning a water tank [8]. These renewals, often carried out after several years of operation, ensure that users continue to receive the same level of service as when the asset was first installed.

LCCA is particularly valuable for assessing the costs and benefits of multiple design options, helping to determine which one offers the lowest life cycle cost (LCC) and provides the greatest economic efficiency over time [9].

To put it simply, the purpose of an LCCA is to enable the project design team to select the alternative with the "least long-run cost" and obtain the same end goal. This is done by comparing the different alternatives on a common basis: total levelized cost, which adds initial and future project costs, adjusted to take into consideration the time value of money [10].

Life-cycle cost Analysis (LCCA) plays a crucial role in guiding informed decision-making for building projects, ensuring long-term financial efficiency and sustainability. By factoring in key elements such as initial and operational costs and utilizing methods like Net Present Value (NPV), stakeholders gain a clear and comprehensive financial perspective. Real-world examples, such as the energy-efficient renovation of a Chicago office building, demonstrate the substantial benefits and cost savings achievable through LCCA [11].

LCCA, in infrastructure projects, is typically utilized to evaluate available alternatives and select the most cost-effective option with the lowest overall expenditure [12].

A well-implemented LCCA is said to offer 'win-win' strategies by identifying technologies, products, and services that balance environmental, economic, and social sustainability. It encourages policy transitions toward a systems-based approach, integrating life-cycle thinking into broader policy frameworks [13].

Research is limited on the impact of government policies, subsidies, and regulations on the economic viability of wastewater-based desert reclamation. Although short-term outcomes appear promising, there is a lack of extensive data on the long-term effects of continuous wastewater application, particularly in terms of soil health, water retention efficiency, and overall ecosystem stability.

2. Theory and Formula

A demonstration plot measuring 1 hectare (200 m long and 50 m wide) has to be fenced with barbed wire and equipped with a network of pipes. This plot is assumed to be approximately 1 km from a hypothetical sewer town in Western India, specifically in Gujarat or Rajasthan, where the wastewater treatment system is either non-existent or has become defunct. The project aims to showcase effective wastewater management practices in arid regions, highlighting the potential for land reclamation and sustainable agriculture.

Life Cycle Cost Analysis (LCCA) balances present and future costs by converting all expenses into present-day dollars. The total cost for each alternative, expressed as the Net Present Value (NPV), allows for easy comparison of different options. By calculating NPV, decision-makers can assess alternatives with consistent units. The NPV formula provides a clear method for determining the total cost over the life cycle of a project, helping guide cost-effective decisions [14].

LCC = C + PV Recurring – PV Residual.

Where 'LCC' represents the life cycle cost, 'C' denotes the initial construction cost at year zero or the CapEx, 'PV recurring' is the present value of all recurring costs, 'PV residual' is the present value of the residual value at the end of the project. PV Recurring = PV of (OpEx + CapManEx + DSEx + IDSEx). Among the four recurring expenditures, the last one IDSEx does not seem to be very significant in this case and thus, has been omitted. So, PV Recurring = PV of (OpEx + CapManEx + DSEx).

Experimental setup: A configuration of the pipeline and other fixtures is shown below in Figure 1:

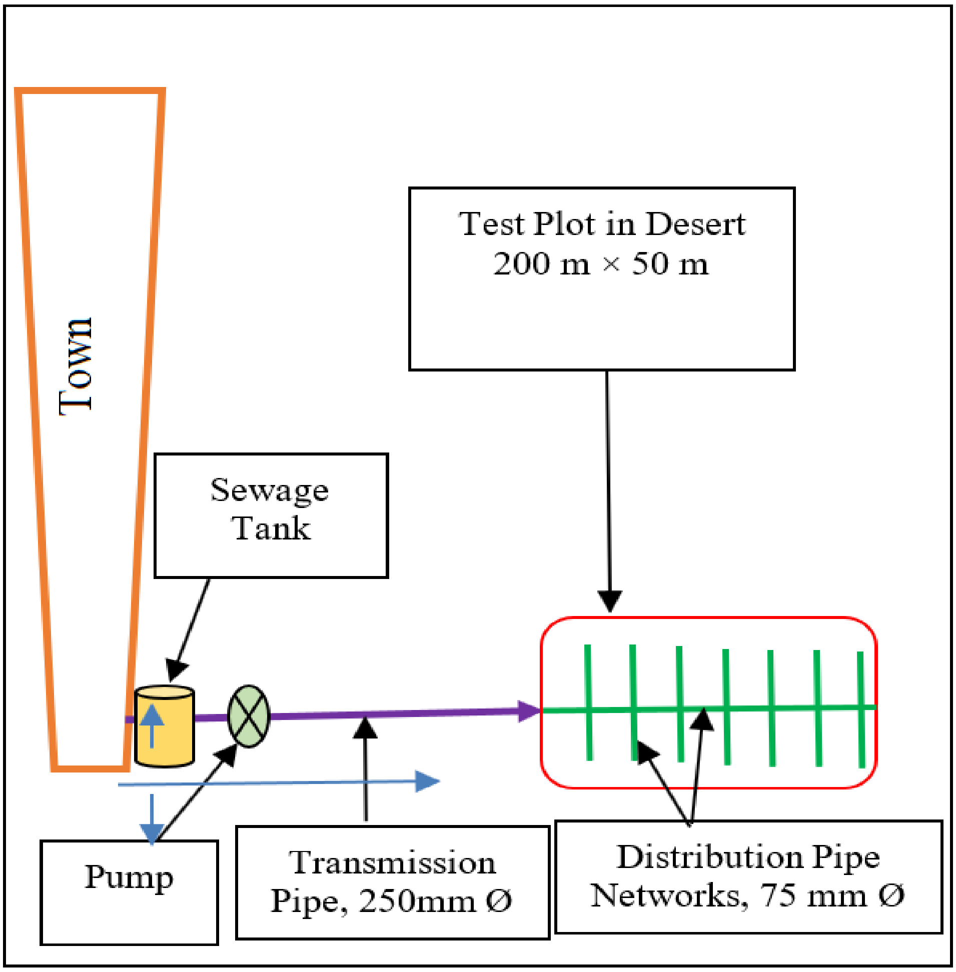

Figure 1.
Configuration of Experimental Pipe Networks and Test Plot Boundary.

The LCCA for the project's recurring expenses has been carried out using standard formulas. For this analysis, an annual discount rate of 8.4%, reflecting the current interest rates in Indian commercial banks, has been used. The calculation of Life

Cycle Costs includes PV Residual as the analysis covers only 15 years, despite the project lifespan being estimated at 50 years for typical civil engineering projects. The annual depreciation is deducted and NPV is added at the rate of the aforementioned discount rate. The cost components are categorized into four broad headings: CapEx (Capital Expenditure), OpEx (Operational Expenditure), CapManEx (Capital Maintenance Expenditure), and DSEx (Direct Support Expenditure). CapEx includes initial construction costs, while OpEx accounts for recurring operational expenses such as maintenance, salaries, and utilities. CapManEx covers costs related to periodic major repairs or upgrades, and DSEx involves the costs associated with the project's technical support costs during its useful life. The CapEx calculation has been detailed in an Excel sheet, based on current Indian prices.

3. Results and Discussion

Table 1 presents these costs, including reinforced concrete tank construction, HDPE pipes, office equipment, and other initial setup expenses as shown in Figure 1. This thorough cost breakdown provides a clear picture of the initial investments required for the experimental project.

The total initial construction cost (CapEx) for the project is USD 126,156.25. This includes key items such as a 10-cubic meter Reinforced Cement Concrete tank, 1 km of 250 mm diameter HDPE pipe, 1 km of 75 mm diameter HDPE pipe, and the associated laying and jointing work. Additionally, it covers the cost of initial office equipment and supplies, including a vehicle and a laptop, as well as the overall construction costs. This CapEx represents the investment for the first year of the project.

Table 1.
Details of CapEx in Year One.

SN	Item	Unit	Quantity	Rate, $	Amount, $	Remarks
1	RCC (1:2:4)	Cum	5	70-100	425	10 Cum size, 2m*2m*3m
2	Pump (50m Head)	pc	1	14000	14000	150 KW, 250 lps discharge
3	HDPE Pipe 250 mm	m	1000	20	20000	6 Kgf/ Cm^2 Pressure
4	HDPE Pipes 75 mm	m	1000	1.5	1500	
5	Pipe Laying and Jointing	m	2000	5	10000	
6	Fencing work	m	500	10	5000	2 m barbed wire fencing
7	Office equipment	Set	1	50000	50000	
	Sub Total, USD				100925	
8	Overhead cost	LS	25%		25231	
Total					$126156	

Calculation of OpEx: Operational costs encompass expenses related to minor repairs and daily maintenance, salaries for two staff members (one operator and one caretaker), laboratory testing fees, electricity for the pump, fuel costs, office rental, office supplies, and communication charges. These elements collectively contribute to the overall functionality and efficiency of the water supply system.

The Wastewater application will occur over three years on an initial 1-hectare plot, after which the land will be reclaimed. Following this, the pipe network will be relocated to an adjoining plot every three years. By the end of 15 years, five 1-hectare plots of desert will have been reclaimed, effectively transforming previously unproductive land into usable, fertile space through a systematic rotation of wastewater application and reclamation efforts, enhancing overall land productivity and sustainability. The annual costs have been detailed in an Excel sheet, reflecting prices in India and reasonable assumptions for minor expenses, as shown in Table 2. This comprehensive breakdown provides clarity on the financial aspects of the project.

Table 2.
Details of OpEx for a year.

SN	Item	Unit	Quantity	Rate, $	Amount, $
1	Maintenance/ Minor Repair	Annual	1	5000	5000
2	Staff Costs	Annual	2	4000	8000
3	Lab Test	Monthly	12	10	120
5	Fuel and Electricity	Monthly	12	2400	28800
6	Office Supplies	Monthly	12	300	3600
7	Miscellaneous	Annual	1	2000	2000
Total =					$47520
	OpEx = USD	47520	per		Annum

Calculations of CapManEx: The first Life Cycle Cost of WATSAN Schemes/ Systems in Nepal calculated by the Author, R. Ghimire. and Dr. R. Ojha, while working as a consultant to a German I- NGO: WeltHungerHilfe (WHH) in 2020 mentions the yearly CapManEx as percentage of the CapEx as following in Table 3:

Table 3.
CapManEx presented as a percentage of CapEx.

S. N.	Annual Percentage of maintenance in age intervals	
	Interval	**%**
1	<5 Yrs of age	2.36
2	5-10 Yrs of age	3.84
3	10-15 Yrs of age	1.77
4	15-20 Yrs of age	3.35
5	>20 Yrs of age	5.43

The CapManEx based on the percentage of CapEx as mentioned in Table 3 is calculated in an Excel sheet and presented below in Table 4: CapManEx for 15 years and CapEx $= 126156.25.

Table 4.
Yearly **CapManEx** for 15 years.

SN	Year	CapManEx, $	Remarks
1	2025	2977.29	
2	2026	2977.29	
3	2027	2977.29	
4	2028	2977.29	
5	2029	4844.40	
6	2030	4844.40	
7	2031	4844.40	
8	2032	4844.40	
9	2033	4844.40	
10	2034	2232.97	
11	2035	2232.97	
12	2036	2232.97	
13	2037	2232.97	
14	2038	2232.97	
15	2039	2232.97	

Total CapManEx for 15 yrs. is $49528.94
Calculations of DSEx: The following Table 5 includes all the Expenditures under the heading of Direct Support:

Table 5.
Details of Direct Support Costs.

SN	Items	Unit	Quantity	Rate	Amount	Year
1	Engineering Survey, Design	Activity	1	5000	5000	First
2	Construction Supervision	Activity	1	10000	10000	First
3	3-yearly Monitoring	Activity	12	3000	36000	Third
4	Inspection visits	Activity	3	5000	15000	Third
5	Training	Activity	3	1000	3000	Third
Total					$69,000	

Note: DSEx for 15 years is $69000.

The Net Present Value (NPV) of the total Life Cycle Cost (LCC) for the "Greening the Desert" project, involving wastewater application for 3 years and maintenance for 15 years, was calculated using an annual interest rate of 8.40%. This calculation provides a comprehensive estimate of the costs over the project's duration, combining initial investments, operational costs, and maintenance. The results are detailed in Table 6, offering insight into the financial scope of the entire experiment.

The Weighted Average Cost of Capital (WACC) is a technique for determining the discount rate, taking into account the company's mix of equity and debt financing. It incorporates both the cost of equity and the cost of debt, adjusted by their respective weights within the capital structure [15].
Net Present Value (NPV) of Life Cycle Cost (LCC) with Discount Rate: 8.4%

Table 6.
Net Present Value of the Life Cycle Cost (LCC) of the Project.

Year	CapEx, $	OpEx, $	CapManEx, $	DSEx, $
1	126156.25			33000
2	136753.4	47520	2977.29	19512
3	148240.66	51511.68	2977.29	21024
4	160692.9	55838.66	2977.29	
5	174191.08	60529.11	2977.29	
6	188823.1	65613.55	4844.40	
7	204684.27	71125.09	4844.40	
8	221877.7	77099.6	4844.40	
9	240515.48	83575.97	4844.40	
10	260718.8	90596.35	4844.40	
11	282619.15	98206.44	2232.97	
12	306359.2	106455.8	2232.97	
13	332093.33	115398.1	2232.97	
14	359989.2	125091.5	2232.97	
15	390228.26	135599.2	2232.97	
NPV	390228.26	1184161	47295.98	73536
Total NPV of 15 Years			$1695221.24	

The calculated Net Present Value (NPV) of the Life Cycle Cost (LCC) for the project is USD 1,695,221.24. The NPV of the created asset, including an electrical sewage pump with an economic life of 15 years (with proper maintenance), and other long-lasting components like pipelines and R.C.C. tanks with lifespans exceeding 50 years, has been determined.

The NPV calculation, considering an annual asset depreciation rate of 2% (50 years' life span of civil infrastructures), is carried out in an Excel sheet and presented in Table 7, providing a clear overview of asset value over time.

Table 7.
NPV of the Assets created in 15 years with depreciation.

S.N.	CapEx, $	CapManEx, $	Total NPV of Asset, $
1			
2	134018.31	2917.74	
3	142311.03	3098.28	
4	151051.3	3338.37	
5	160255.79	3578.46	
6	169940.81	6472.12	
7	180122.16	6879.05	
8	190814.86	7285.98	
9	202033	7692.91	
10	213789.4	8099.84	
11	226095.32	4108.66	
12	238960.15	4296.23	
13	252390.93	4483.79	
14	266391.99	4671.36	
15	280964.35	4858.93	
Total	USD	71781.72	352746.07
Total NPV of Asset $ 352746.07.			

3.1. Benefit from the Reclaimed Desert Plot

Gujarat, India, has favorable soil and climate conditions for growing a variety of crops year-round. Three major crops cultivated in the state are:

A. Cotton: Gujarat is one of India's largest cotton producers. Cotton is sown in the summer and harvested in winter, thriving in the state's warm climate.

B. Peanut: Peanut is another important crop, primarily grown during the Kharif season. It is well-suited to Gujarat's semi-arid conditions, making it a staple in the state.

C. Wheat: Wheat is a significant winter crop, covering fields from winter until spring. It plays a key role in Gujarat's agricultural economy, ensuring year-round farming productivity.

Yield of Various Crops: A typical yield of different crops is presented in the following Table 8:

Table 8.
Income from the Reclaimed Desert.

SN	Crop	Yield, T/ ha	Price, $/T	Income per year, $
1	Cotton	0.569	860	490
2	Peanuts	1.2- 2.07	660	1080
3	Wheat	3	325	975
Total = USD 2545 per hectare per year.				

Source: Market price of Cotton, Peanuts, and wheat in Gujarat, India in 2024.

The first 1-hectare desert plot will be transformed into arable land after 3 years, allowing agricultural practices to begin. With intensive cropping, three crops can be grown and harvested annually, generating an income of USD 2,545 per hectare per year. 2 hectares of land will be reclaimed after 6 years, followed by another 3 hectares after 9 years, 4 hectares after 12 years, and 5 hectares by the end of 15 years. This gradual reclamation will significantly increase the area available for farming, maximizing productivity. The total income from agriculture over the 15 years has been calculated in the accompanying Excel sheet and is presented in Table 9, illustrating the potential earnings from the reclaimed land.

3.2. NPV of Crop Yield

Table 9.
NPV of Crop yield of 12 years in the reclaimed land.

	Discount Rate		**8.40%**
Year	**Area, Hectare**	**Annual Income, $**	**Total Income, $**
4	1	3186.34	3186.34
5	1	3453.993	6640.333
6	1	3744.128	10384.46
7	2	8117.269	18501.73
8	2	8799.12	27300.85
9	2	9538.246	36839.1
10	3	15509.19	52348.28
11	3	16811.96	69160.24
12	3	18224.16	87384.41
13	4	26339.99	113724.4
14	4	28552.55	142277
15	4	30950.97	173227.9

Note: NPV of Crop Yield, $173227.9.

4. Conclusion

The 15-year Life Cycle Cost Assessment (LCCA) for the "Greening the Desert" project reveals a net deficit of USD 1.17 million, as shown in Table 10:

Table 10.
Net Income and Expenditure of the Reclaimed Plot.

No of Years		**15**			
Year	LC Cost, $	Income, $	Asset, $	Balance, $	Remarks
15	1695221	173227	352746	1169247	Deficit

This deficit is the result of comparing the total expenditures, income from agriculture, and asset values over the project's duration. This work is the first to combine LCCA with rotational wastewater application, demonstrating a deficit of USD 292,312/ha over 15 years, a benchmark for future projects. A funding source for this amount should be identified to transform 4 hectares of desert into arable land. Therefore, a Viability Gap Funding (VGF) is required to initiate such a novel project.

This calculation is limited to 15 years but, the reclaimed land will remain fertile and productive far beyond this period. The life of civil infrastructures is over 50 years and thus, benefits will accrue beyond 15 years as well. So, despite the initial financial shortfall, the long-term benefits of the project are substantial.

The reclaimed land will create sustainable agricultural opportunities for the local desert community, offering a significant improvement in livelihoods. Poor communities will benefit from increased food security and financial opportunities, while the project will also contribute positively to environmental sustainability by utilizing wastewater for land reclamation. Furthermore, intangible benefits in terms of biodiversity conservation, control of waste-related diseases, and changes in microclimate due to evapotranspiration shall also be significant.

This is the first work of LCC calculation of this novel technology and it would contribute to further research and field work on a pilot basis. The research and this article have provided a detailed Life Cycle Cost for the Reclamation of the Desert and the need for VGF.

This initiative demonstrates a feasible approach to combating desertification and enhancing land productivity in arid regions in the broader sense. The reclamation efforts not only help regenerate degraded land but also promote eco-friendly practices, fostering a resilient environment. Over time, the positive social and environmental impacts of the project will outweigh the initial financial deficit, making it a valuable long-term investment in both community welfare and environmental conservation.

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