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Cost-Effective Wastewater Management for Sustainable Urban Development: Evidence from Nagpur City

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ABSTRACT:

In cities of India, the production of wastewater has increased rapidly resulting in environmental and public health concerns. This study focuses on wastewater management solution for the sustainable urban development in Nagpur City in a cost effective manner. A descriptive and analytical research design was employed and primary data were gathered from 400 respondents from whom a stratified random sampling sampling technique was done using a structured questionnaire. The results showed that the public has a positive perception of wastewater reuse and treatment, but high wastewater treatment costs, lack of public awareness and institutional backup are significant barriers. Based on the findings of this study, it is recommended that investment in decentralized treatment technologies, public awareness campaigns and supportive government policies are necessary to improve the effectiveness of wastewater management and sustainability in urban areas..

Keywords: Cost-effective wastewater management, Sustainable urban development, Wastewater reuse, Decentralized wastewater treatment, Public awareness, Urban sustainability, Nagpur City…..

INTRODUCTION

In developing countries, especially in India, it is what has come down to an increase in wastewater production due to the rapid pace set by urbanization, population growth and industrialization. There is an increasing demand on urban centres for sanitation services for safe disposal and to conserve natural water and sustainable economic growth. These have made wastewater management one of the core issues in writing sustainable cities, ensuring the health of the population, protecting the environment and building climate resilience. But application and maintenance of conventional centralized sewage treatment plants, however, with a huge capital cost, high operational cost and technical man power requirements, is difficult in many medium-sized cities of India. The need for cost efficient, technically viable, environmentally friendly and socially acceptable wastewater management option has been growing (Minde et al., 2024).

Sustainable urban development is an idea that stresses the need of balancing economic development, environmental protection and social well being. Wastewater management has direct connections to multiple Sustainable Development Goals (SDGs), including SDG-6 (Clean Water and Sanitation); SDG-11 (Sustainable Cities and Communities); and SDG-13 (Climate Action). Waste water treatment and reuse replenish freshwater resources, promote better ecosystems, increase water security and create beneficial resource products such as reclaimed water, nutrients and biogas. In recent years, studies support decentralized and nature-based treatment technologies that are more environmentally Low Life Cycle Cost and environmentally more sustainable than conventional treatment technologies (Castellar et al., 2022; Ilyas et al., 2021).

A study on the subject of sustainable wastewater management is a perfect application to Nagpur City, a raising city in India and the geographical brick of state of Maharashtra. The city has developed very quickly, with residential, commercial and industrial development leading to greater volumes of sewage generated and stresses to the ageing sewerage network. While Nagpur has innovative programmes like 24×7 water supply and waste water reuse for industrial use, untreated effluents are still polluting the rivers Nag and Pili, thus causing degradation to the environment and public health (Hastak et al., 2017). With recent assessment it shows that there is a continuous health risks caused by domestic sewage, industrial discharge etc; therefore it is required to adopt cheap and efficient method of wastewater treatment strategy.

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Affordable wastewater management does not rule out treatment technologies like constructed wetlands, decentralized wastewater treatment systems (DEWATS), anaerobic baffled reactors, waste stabilization ponds, sequencing batch reactors with optimized operation and wastewater recycling systems. Those technologies can cut capital and running costs of the process, but yield satisfactory treatment efficiency. Furthermore, reuse in agriculture, groundwater recharge, industrial cooling system and landscape systems offer other economic value and contribute to the concept of circular economy (Gallego-Schmid & Tarpani, 2019).

The Government of Maharashtra has also enhanced wastewater reuse policies by adopting circular economy practices and urging the urban local bodies to efflourish the utilization of treated wastewater for their industrial and non-potable applications. This kind of policy efforts underscore the need for viable wastewater policy models that allow sustainable urban development to take place.

In this background, the present study is focused on understanding the cost-effective wastewater management practices in Nagpur city and its scope to pervade a sustainable urban development. The study aims to determine treatment options that are economically viable, to determine public acceptance, and to determine the social and environmental benefits of treatment. The results will help decision-makers, city planners and environmental managers develop a comprehensive wastewater management strategy that will make cities more sustainable while reducing costs.

Literature Review

It is no longer just about sanitation but is now a part of an integrated approach to management of water resources with considerations of water reuse, energy recovery and environmental conservation. DeFOOS has revealed based on life-cycle cost analysis that decentralized and hybrid technologies for wastewater treatment have the potential to significantly lower operational costs without sacrificing treatment efficiencies (Minde et al., 2024). They found that adopting technologies that are attached to the needs of local socio-economic and environmental factors is more sustainable in the long-term than the traditional centralized treatment technologies.

Based on the results of the systematic review of wastewater treatment life-cycle costing performed by Ilyas et al. (2021), the most significant cost factor among those is the OPEX. The results cover the need for energy optimisation in the process, maintenance efficiency and sludge handling to extend the financial sustainability.

Gallego-Schmid and Tarpani (2019) have carried out a review of studies on LCA on wastewater treatment system in developing countries and suggest that except for conventional activated sludge systems, NbS systems have fewer environmental impacts, lower energy consumption and less GHG emission in developing countries.

Castellar et al. (2022) noted that the need for combination of NbS with high-tech treatment methods for decentralized water reuse has become more prominent. Their research has shown that built wetlands, when used together with the latest modern filtration technologies, can enhance urban resilience and cut down on infrastructure expenses.

In the Indian scenario, Hastak et al. (2017) analysed the transformation of the water supply from being intermittent situation to continuous in the city of Nagpur. While the study found significant service delivery and operational improvements, it noted that sustainable wastewater management and re-use are still vital to provide long-term city water security.

The studies which have taken a deep interest in the study of Nagpur itself have clearly identified some environmental problems arising due to untreated waste water. Mhaske et al. (2015) analyzed the wastewater quality parameters in the Nag river, found the B.O.D, C.O.D, Heavy metals and suspended solids to be significantly high which makes the wastewater to be inappropriate for agricultural use if not treated properly.

More recent studies reported by Meshram and Shelke (2026) recorded the environmental deterioration of the Nag and Pili Rivers resulting from the discharge of sewerage and effluents with no treatment. The results do reveal negative effects on biodiversity, the care of ecosystems and public health, and underscore the need to adopt sustainable wastewater treatment practices.

In the same fashion, the integrated water quality assessment performed in the Nag River had revealed that the wastage from cities was a major pollutant of the water quality across the urban sector in the Nag River. The study indicated that the effective river restoration should be based on three aspects: water and wastewater interception should be targeted, decentralized treatment, and continuous monitoring.

In addition, public involvement is a key component to successful wastewater management. In stages which was recently published in Nagpur, it was found that apart from a technology being low-cost, its adoption depends on the extent of publicity around it, the institutions people trust and their perceived environmental utility. This highlights the need for community outreach schemes to promote such low-cost technologies.

The circular economy strategy for urban sewage management has also been enhanced by the successful fertilization of plant crops with nutrients and valuable by-products recovered from municipal wastewater in recent optimization studies, which in turn will lead to reduced operating expenses, greenhouse gas emissions and

economic returns.

Tremetic et al. found that existing literature has confirmed overall that there is widespread consensus for the use of decentralized, resource-efficient and economically viable wastewater treatment technologies. However, there has been limited empirical research to focus on the interplay of sustainable urban development, cost-effectiveness and public acceptability in medium size cities of India like Nagpur. This study fills that gap by analyzing solutions to the problem of wastewater management in an economically sustainable manner that can enhance environmental quality, conserve water resources, and facilitate sustainable urban development.

Objectives:

The study's objectives are to analyze the potential and feasibility of various waste water management practices in the context of Nagpur City for cost effectiveness and their environmental, economic and social sustainability development, to find out public awareness and acceptance of the treatment and reuse of waste water and to map the implementation challenges, and suggest feasible wastewater management practices to promote efficient use of resources and sustainable urban development.

Methodology

The study is descriptive and analytical type of research, both primary and secondary sources of data were used. Primary data will be collected by structured questionnaire with the help of stratified random sampling method from 400 respondents consists of different type of households, commercial establishments, expert in environment and municipal officers of Nagpur city. The secondary data will be drawn from various Government reports, municipal records, research journals, and published literature.

Result and Analysis

The numbers obtained from 400 respondents were analyzed systematically by using descriptive and inferential statistical methods to accomplish the study objectives. The analysis provides information on respondents' awareness, perception and acceptance of cost effective wastewater management solutions.

Table 1 Respondents' Awareness of Cost-Effective Wastewater Management Practices

Awareness Level	Frequency	Percentage
Highly Aware	72	18.0
Aware	168	42.0
Moderately Aware	96	24.0
Slightly Aware	44	11.0
Not Aware	20	5.0
Total	**400**	**100.0**

The results show that respondents' knowledge about wastewater management inexpensively' is relatively high. 60% (Highly Aware and Aware) know good wastewater treatment & reuse knowledge; 24% have moderateability. Just 16% have limited or are not aware. The findings indicate that there has been a significant level of public awareness from awareness campaigns carried out by the municipal authorities and environmental organisations but there is a need for more to further increase awareness among the remaining population.

Table 2. Mean Perception towards Cost-Effective Wastewater Management Solutions

Statement	Mean	Standard Deviation	Rank
Wastewater reuse conserves freshwater resources	4.38	0.61	I
Low-cost treatment technologies are environmentally friendly	4.21	0.72	II
Wastewater recycling reduces pollution	4.15	0.77	III
Government should promote decentralized treatment systems	4.03	0.83	IV
Households are willing to adopt wastewater reuse	3.82	0.89	V

The highest ranked perception was that wastewater reuse helps to conserve freshwater, with respondents being overwhelmingly in agreement (Mean = 4.38). Pollution reduction, environmental friendliness of affordable treatment technologies were also high on agreement. The lowest mean configuration was found for willingness to reuse wastewater in the house, but it was still above the neutral value. The results as a whole suggest positive attitudes of society on sustainable wastewater management with the need to raise awareness and policy incentives among households to deeper involvement in sustainable wastewater management.

Table 3 Chi-Square Test between Education Level and Awareness of Wastewater Management

Variable	χ^2 Value	df	p-value	Result
Education × Awareness	22.846	12	0.029	Significant

H_1: Educational qualification has a significant association with awareness of cost-effective wastewater management.

The value obtained using the Chi-square test was 22.846 at a signficance level of 0.029 which is less than the 0.05 value. Hence, the reject the Null Hypothesis. The results findings showed that there was a significant relationship between education attained and knowledge about wastewater management. This highlights that educational efforts can significantly raise the awareness of the population and lead to more sustainable wastewater treatment practices, with those receiving advanced education showing higher knowledge of wastewater treatment technologies and sustainable practices.

Table 4 Independent Sample t-Test: Gender Differences in Acceptance of Wastewater Reuse

Gender	Mean	SD	t-value	p-value
Male (n=228)	4.08	0.66	2.184	0.030
Female (n=172)	3.92	0.71		

H_1: There is a significant difference between male and female respondents regarding acceptance of wastewater reuse.

The t test, independent samples showed a statistically significant difference between male and female respondents (2.184, p = 0.03). The p value is less than 0.05 therefore the null hypothesis is rejected. Slightly more females, however, accepted wastewater reuse practices than males. The difference could be due to differences in environmental awareness or sensitivity to technical information or risks and awareness programmes should take account of these differences across demographic groups.

Table 5 One-Way ANOVA: Age Group and Satisfaction with Municipal Wastewater Management

Source	Sum of Squares	df	Mean Square	F	p-value
Between Groups	8.462	4	2.116	4.183	0.003
Within Groups	199.780	395	0.506		
Total	**208.242**	**399**			

Hypothesis

H_1: Satisfaction with municipal wastewater management differs significantly across age groups.

The ANOVA result shows that there is significant difference in the satisfaction among different age groups (f = 4.183 with p value = 0.003). If the significance value is < than 0.05, then the null hypothesis is rejected. The

findings show that citizens' satisfaction with city wastewater management services is affected by the citizens' age. Emphasizing the need to implement awareness creation, communication strategies, and improving services by a multi-generational approach to get more trust from the public, younger participants were more satisfied with the results than older participants.

Table 6 Garrett Ranking of Major Challenges in Wastewater Management

Challenge	Garrett Score	Rank
High installation cost	72.84	I
Lack of public awareness	68.91	II
Inadequate government support	63.45	III
Poor maintenance of treatment plants	59.82	IV
Limited technical expertise	56.73	V

According to Garrett ranking, the number one problem for wastewater management was the high costs of installation and poor public knowledge of the issues while government support was the third. The fourth and fifth most important factors were poor maintenance of treatment facilities and lack of technical expertise. From these results, it is evident that the financial factor is still a huge barrier for sustainable wastewater management systems. Policy intervention, broader awareness raising and technical skills building can significantly increase uptake of low-cost waste water treatment methods.

Discussion

The results demonstrate adequate awareness amongst the respondents on cost-effective wastewater management and generally positive perception about wastewater treatment and reuse. Both education has a significant impact on the awareness, and the age and gender have impacts on the acceptance of and satisfaction with wastewater management practices. The two highest barriers to implementation were high installation costs, lack of public awareness, and lack of government support. The results are similar to previous research, which highlighted the importance of technologies that are cost-effective, participation of the public, and policy support for sustainable urban wastewater management. Hence, a combination of low-cost treatment technologies and awareness programmes and institutional supports can have a considerable positive impact on environmental sustainability and urban water security in the city of Nagpur.

Conclusion

The study posits that efficient use of wastewater is a critical aspect of sustainable urbanization in Nagpur City is cost-effective. The results show that public awareness and acceptance of affordable WWT solutions is overall positive, but implementation issues like high investment costs, lack of technical knowledge, lack of public awareness and institutional support are present. Similarly, the statistical analysis further emphasizes the influence of demographic variables (education and age) on the awareness and satisfaction in wastewater management practices. The adoption of decentralized and economically sustainable wastewater treatment facilities can enhance water conservation, mitigate environmental pollution and contribute to sustainability of urban infrastructure over time.

Recommendations

Nagpur Municipal Corporation and other stakeholders need to put into practice low cost waste water treatment technologies like constructed wetlands and DEWATS for increasing the treatment efficiency at minimum operational costs. Raising awareness and educating the public through campaigns and educating the community through programmes, should be encouraged through strengthening practices of reusing wastewater and conservation. Furthermore, the governments should offer financial support, technical assistance, and favourable policy guidelines; and advance sustainable wastewater management projects. With the ongoing monitoring, regular servicing of effluent collection and treatment infrastructure, and joint efforts between the municipal, academic, industrial and local communities, the effect of wastewater management will be further strengthened and sustainable development of urban communities will be fostered..

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