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Constructed Wetlands for Sustainable Urban Wastewater Reuse: The SWAB Method in New Delhi's Rajokri Lake Rejuvenation Project

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***Abstract*— The 17 Sustainable Development Goals (SDGs) were submitted by the United Nations to commit governments to creating sustainable development goals. Currently, in urban wastewater reuse for irrigation, the wetland method has been applied as the most suitable option for pollutant removal. It offers advantages over other methods due to its low maintenance costs, low energy requirements, and simplicity. The Rajokri Lake Rejuvenation community landscape project, initiated by the Delhi government, is recognized as a pilot project for the rejuvenation of 159 water bodies in New Delhi. This project applied the Scientific Wetland with Activated Bio-Digester (SWAB) method for sewage water treatment. Sewage water is fed into an inlet channel, which transfers it to the sedimentation tank and bio-digester, where particles are removed and solid components are broken down. It then passes through an artificial wetland to filter and remove toxic substances through organic processes before being diverted to the pond. This project is a pilot for small-scale wastewater treatment, and the Indian government plans to replicate similar projects throughout the city to improve urban environments and integrate social learning with the involvement of the local community.**

Keywords—Urban Wastewater Reuse, Constructed Wetlands, Sustainable Development, SWAB Method, SDGs

I. INTRODUCTION

Environmental management is critically important in the Republic of India due to severe environmental challenges. With the world's third-largest population [1] and a vast geographic area, managing the environment presents a significant challenge for sustainable development, particularly in a world driven by economic conditions. India has developed a national plan in line with the United Nations' guidelines, which introduced the 17 Sustainable Development Goals (SDGs) in 2015 [2].

Given the severity of environmental problems in India, there is an urgent need to raise awareness about the importance of environmental management, especially concerning water resources. Water plays a central role in Indian culture, both in rituals and religion. However, India faces significant issues with its water bodies—there are over 1,100 water bodies suffering from pollution, poor sanitation, and shallowness due to accumulated waste, lack of care, and ineffective management. These issues result in drainage problems and the contamination of water bodies with shallow water from surrounding waste.

Water pollution is a critical concern, with large quantities of untreated wastewater being discharged into surface water sources [3]. This pollution adversely affects the environment and the quality of life for millions of homeless individuals living in densely populated areas. Addressing this problem requires effective management practices that involve the community, ensuring that projects are sustainable and well-maintained.

This paper examines a wastewater treatment project utilizing artificial wetland technology, based on a case study in India. The project, initiated at Bueng Ratchakrishna, serves as a pilot for developing a wastewater treatment system using artificial wetlands, providing a model for treating over 159 community wastewater sources across the country.

II. RELATED RESEARCH

Over the past several decades, wastewater treatment using the artificial swamp method, also known as constructed wetlands, has gained popularity due to its cost-effectiveness and ease of maintenance compared to other methods. Research has consistently shown that this method effectively treats wastewater

by utilizing bacteria to break down contaminants and removing pollutants through absorption, precipitation, and sedimentation. Constructed wetlands have been successfully implemented in various countries, including Denmark, Austria, Saudi Arabia, Italy, Hungary, and Thailand.

In India, research on wastewater treatment using the artificial swamp method has highlighted its potential in addressing the country's wastewater challenges. Constructed wetlands (CWs) have emerged as an effective eco-technology for wastewater treatment in India, offering significant pollution reduction and resource enhancement [4]. Various types of CWs, including subsurface flow, vertical flow, horizontal flow, and hybrid systems, have demonstrated high removal efficiencies for pollutants such as BOD, COD, nitrogen, phosphorus, and pathogens from domestic and industrial wastewater [5-6]. CWs in India typically use macrophytes like Typha latifolia and Phragmites karka, planted in gravel or sand-filled beds [4,6]. These systems have been successfully implemented in different parts of the country, including Central India and New Delhi, to treat urban runoff and improve river water quality [4, 7]. While initial investment may be high, CWs offer low operational and maintenance costs compared to conventional treatment plants, making them an economically viable solution for wastewater management in India [6-7].

Constructed wetlands (CWs) have emerged as an effective eco-technology for wastewater treatment in India, offering cost-competitive and environmentally friendly alternatives to conventional methods [8]. Various types of CWs, including horizontal subsurface-flow, vertical flow, and hybrid systems, have demonstrated high efficiency in removing pollutants such as suspended solids, biochemical oxygen demand, and nutrients from domestic and industrial wastewater. CWs have shown promise in treating hospital effluents, effectively removing antibiotic-resistant bacteria and improving water quality for potential reuse in irrigation [9]. The implementation of CWs in India has not only addressed wastewater treatment challenges but also contributed to ecosystem restoration, urban landscaping, and wildlife habitat enhancement. Furthermore, CWs have the potential to strengthen agricultural economies and improve sanitation in rural and peri-urban areas [8].

In Thailand, the artificial swamp method is also widely utilized. Sansanayuth et al. (1996) [10] analyzed the effectiveness of treating shrimp farm wastewater, which contains high concentrations of organic matter and nutrients, using an artificial swamp system with fern trees (*Acrostichum Aureum*) and gravel. Panswad and Chavalparit (1997) studied the quality of water treated with artificial swamps, comparing the presence of protozoa and metazoa in water treated by conventional and industrial effluent methods. Kantawanichkul, Pilaila, Tanapiyawanich, Tikampornpittaya, and Kamkrua (1999) [11] conducted experiments on vertical flow artificial marshes, using local plants such as vetiver (*Vetiveria Zizanioides*) and Langka grass (*Cyperus Flabelliformis*) to treat wastewater from pig farms. Their results demonstrated that this method effectively reduced total organic carbon, nitrogen, and suspended solids, with an inflow rate of 36 mm/day and an organic load rate of 55 kg COD/ha/day. Furthermore, constructed wetlands have been successfully implemented in Thailand for various wastewater treatment applications. They have been used to treat tsunami-affected areas [12], seafood industry effluents [13], and landfill leachate [14]. CWs have demonstrated high removal efficiencies for pollutants such as BOD, suspended solids, and nitrogen compounds [13-14]. Different flow patterns, including horizontal subsurface flow and free water surface, have been studied, with horizontal subsurface flow showing better pollutant removal. CWs also contribute to water reduction through evapotranspiration, particularly in tropical climates [14]. However, the sustainability of CWs in Thailand depends on proper management, maintenance, and socio-cultural factors, with some projects facing challenges due to lack of post-construction support [15]. Overall, CWs offer a promising solution for wastewater treatment in Thailand, combining environmental benefits with low operation costs. The use of artificial swamps for wastewater treatment has been widely documented in various research studies [16-17].

This paper aims to present the results of wastewater treatment data from the Rajokri Lake Rejuvenation Project, offering insights for further study and implementation of sustainable urban water treatment practices in future projects.

III. METHODOLOGY

In response to the significant wastewater management challenges in India, the government has recognized the importance of addressing these issues through collaboration with the private sector. A model project has been developed to serve as a guide for sustainable wastewater treatment. This prototype project is located in Rajokari village [18-19], southwest of Delhi. The design objectives are as follows:

1. Restore the condition of water sources.
2. Dredge and remove sludge from the basin to increase its size.
3. Enhance the flow capacity of wastewater.
4. Increase the storage capacity of the water catchment area and improve the sewage system connections.
5. Establish environmentally friendly waste and sludge trap locations.
6. Create a community-friendly environment that is easy to maintain.
7. Implement sustainable management and design elements.

The project concept is based on water restoration principles, specifically utilizing a biological approach to wastewater treatment known as Scientific Wetland with Activated Biodigester (SWAB) Technology. This technology involves the use of constructed wetlands, where wastewater is treated by flowing through shallow ponds designed for both horizontal and vertical

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subsurface flow (hybrid ponds). The system is optimized for treating wastewater with BOD values ranging from 30-175 mg/L for horizontal flow and 500-7000 mg/L for vertical flow.

The horizontal surface flow constructed wetland system, as shown in Figure 1, consists of a foundation with a water-solid layer and a middle layer of soil or gravel. As wastewater flows through the medium in the root zone of plants, organic matter is decomposed by microorganisms, while nitrogen, phosphorus, and heavy metals are fixed to the soil, effectively removing suspended solids. The vertical surface flow constructed wetland system, depicted in Figure 2, promotes uneven flow, enhancing oxygen transfer in the water. This system is particularly effective in treating suspended solids, BOD, ammonia, and phosphorus.

Within the artificial ponds, various plants such as reed bushes and cattails are planted. These plants help absorb toxins and reduce the amount of organic substances. The treated water from these ponds can be reused, and a grass filtration system similar to a bio-pond is implemented, using plants such as vetiver, soft grass, napier grass, feather grass, and rusie grass. For this particular artificial pond, plants like elephant grass (*Pennisetum purpureum*), cattails (*Typha sp.*), reeds (*Phragmites sp.),* canna (*Canna sp*.), and yellow flag iris (*Iris pseudacorus*) are used.

The SWAB Technology system integrates various treatment elements, as shown in Figure 3. The process begins with the wastewater being screened for solid waste, followed by sedimentation in a tank. The wastewater is then passed through a medium to a biological treatment pond, where plants are grown in a system known as the phytorid system. The key processes for reducing wastewater components in this biological artificial swamp system include:

1. Suspended Solids Removal: Achieved through sedimentation, filtration, and adsorption onto substrate materials.

2. BOD Reduction: Microbial degradation, both aerobic (at surface) and anaerobic (in deeper zones), decomposes organic matter into sludge.

3. Nitrogen Reduction: Through nitrification, denitrification, plant uptake, and ammonia volatilization.

4. Phosphorus Reduction: Via precipitation, sediment adsorption, and plant absorption.

5. Pathogen Reduction: Through sedimentation, filtration, microbial activity, and UV radiation from sunlight.

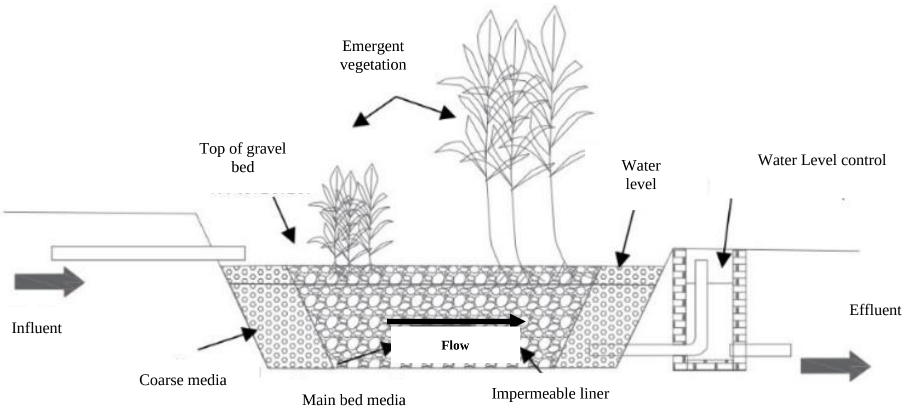

Fig.1 ***Schematic layout of horizontal subsurface flow of constructed wetlands [20]***

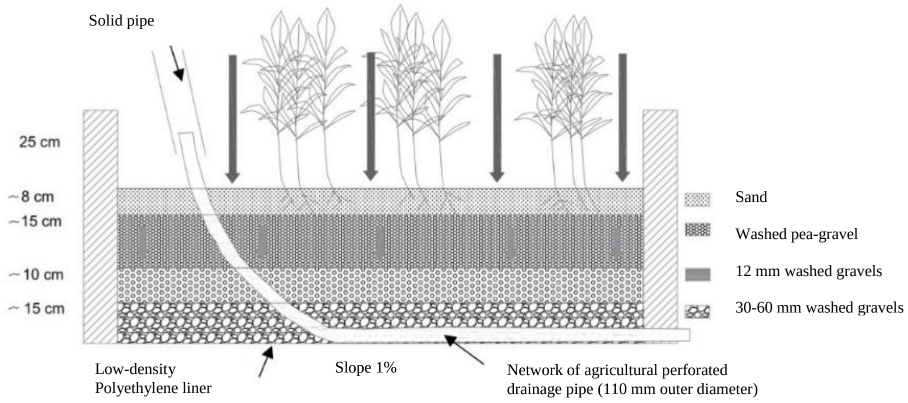

Fig. 2. ***Schematic layout of vertical subsurface flow of constructed wetlands [18]***

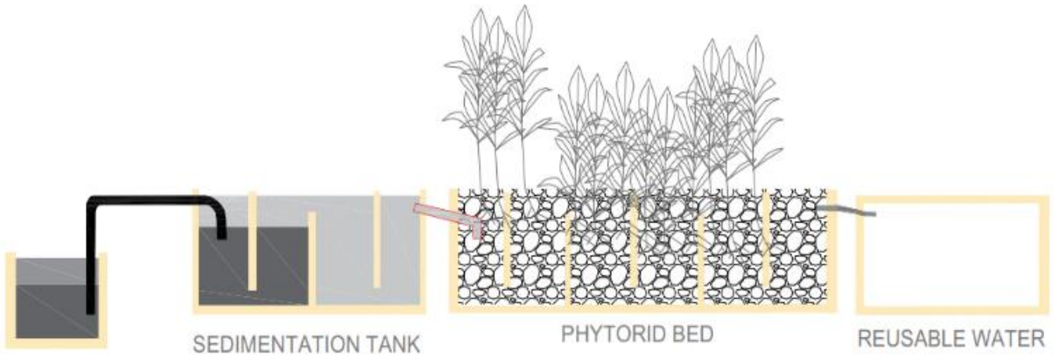

Fig. 3. ***Scientific wetland with activated biodigestion (SWAB) at Rajokri pond [18]***

Table 1 ***Pollution Indicator Parameters for the Rajokri Pond Wastewater Treatment Plant [21]****

Parameter	Main Inlet	Bioreactor	SWAB Inlet	SWAB Outlet	Lake
Total suspended solids (mg/l)	190.0	285.0	110.1	98.0	102.0
BOD 3 Days at 27^{o} (mg/l)	190.0	187.0	63.0	28.0	16.0
COD (as O_2) (mg/l)	410.0	345.0	156.0	95.0	56.0
Total Phosphate (mg/l)	5.6	8.1	3.9	2.1	1.9
Nitrogen (as N) (mg/l)	20.0	20.0	15.0	10.0	5.0

**Reference findings from previous studies [21]*

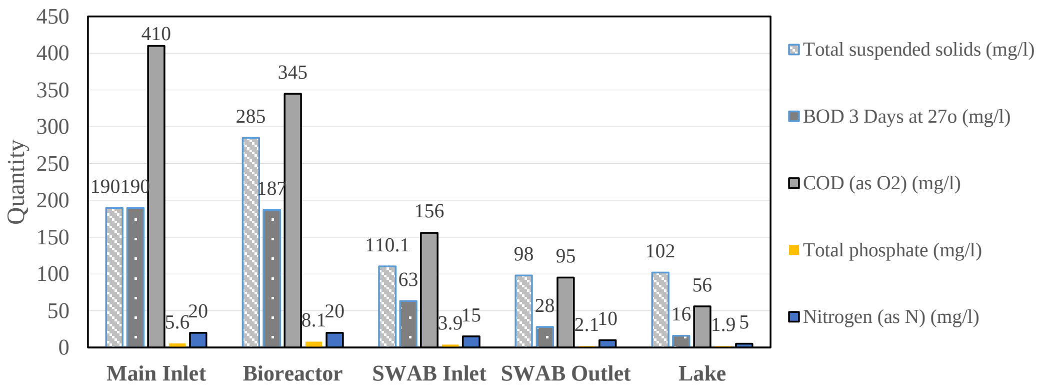

Fig.4. ***Treatment Performance for Various Pollution Indicator Parameters in the Wastewater Treatment Plants***

IV. RESULTS

The post-treatment water quality analysis of Rajokri Lake Rejuvenation Project was conducted following the methodology outlined by the Consortium for DEWATS Dissemination (CDD) Society (2019) on Feb 2019. Water samples were collected at key stages of the system: the main inlet, bioreactor, SWAB inlet, SWAB outlet, and lake (drainage point). The analysis targeted critical parameters, including total suspended solids (TSS), BOD, COD, phosphate, and nitrogen concentrations, as summarized in Table 1.

Figure 4 presents a comparison of these parameters across the sampling points, highlighting a significant reduction in TSS, BOD (3-day), COD, total phosphate, and nitrogen levels at each stage of the treatment process.

Figure 5 further illustrates the efficiency of the wastewater treatment system, showing a notable reduction in contaminants from the initial influent to the discharge into the constructed wetland. Suspended solids were reduced by 46.32%, BOD decreased from 190 mg/L to 16 mg/L (a 91.58% reduction), COD levels

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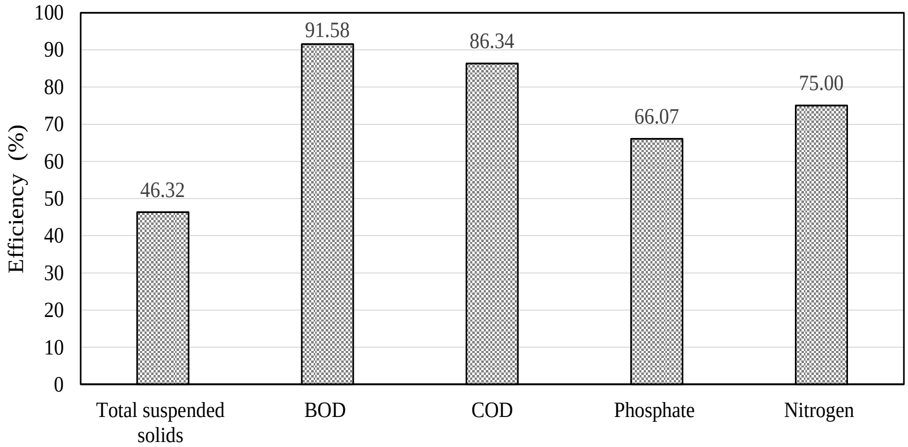

Fig. 5 ***Percent of efficient of treatment wastewater of Rajokri Lake Rejuvenation Project***

Fig.6 ***Landscape of Rajokri Lake Rejuvenation Project after construction***

were lowered by 86.34%, and phosphorus and nitrogen concentrations dropped by 66.07% and 75.00%, respectively. These findings demonstrate the treatment process's high effectiveness in significantly enhancing water quality. Figure 6 shows a photo of the Rajokri Pond area after landscape adjustments. The image highlights the integration of the park into community life, providing a space for activities that align with the project's original objectives

From a sustainability perspective, the Rajokri Pond community landscape project, initiated by the Delhi government, represents a viable solution for urban wastewater treatment. The project employs simple and sustainable methods, notably the Scientific Wetland with Activated Bio-Digester (SWAB) system, which is highly effective in pollutant removal. It offers advantages such as low maintenance costs, minimal energy requirements, and operational simplicity. As a pilot for small-scale sewage treatment, the project is set to be replicated throughout the city, aiming to improve urban environments while fostering social learning and community involvement.

V. CONCLUSIONS

1. Effectiveness of SWAB Technology: The Scientific Wetland with Activated Bio-Digester (SWAB) method has demonstrated significant efficacy in treating urban wastewater. The project at Rajokri Pond showed substantial reductions in key pollutants, including a 91.58% reduction in BOD and an 86.34% decrease in COD, confirming SWAB's potential for efficient sewage treatment in urban areas.

2. Sustainable and Cost-effective Solution: The SWAB method offers an eco-friendly, low-maintenance solution for wastewater management. Its minimal energy requirements and operational simplicity make it an ideal choice for small-scale communities, aligning with Sustainable Development Goals (SDGs) while addressing the need for sustainable urban water management.

3. Social and Environmental Impact: Beyond pollution control, the Rajokri Pond project integrates environmental restoration with community engagement. The redesigned landscape not only serves as a wastewater treatment site but also enhances the urban

environment by providing a communal green space, promoting social learning and environmental stewardship.

4. Replicability for Broader Implementation: The success of the Rajokri Pond project positions it as a pilot model for broader implementation across New Delhi. The Indian government plans to replicate this project at other locations, which will foster sustainable urban development and contribute to the rejuvenation of water bodies across the city.

5. Global Applicability of Constructed Wetlands: Constructed wetlands, as demonstrated in the Rajokri Pond project, have proven to be a cost-competitive, environmentally sustainable technology. Their successful application in India and other countries, such as Thailand and Denmark, highlights the global potential of this approach for addressing wastewater challenges in diverse settings.

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