Nehreen Majed. 2025. Chapter 4: Towards Multifaceted Mitigation of Climate Change Impacts: Ensuring Sustainable Treatment Solutions with Constructed Wetlands. In Thi Thuong Nguyen (ed.), *New Challenges in Constructed Wetlands for Sustainable Wastewater Treatment: Intensification Strategies Based on Asian Experiences*. Osaka: Asia-Japan Research Institute, Ritsumeikan University. ISBN 978-4-910550-06-0

Chapter 4
Towards Multifaceted Mitigation of Climate Change Impacts: Ensuring Sustainable Treatment Solutions with Constructed Wetlands

Nehreen MAJED

1. Background

This work begins by providing a comprehensive background overview. Afterwards, the discussion revolves around the role of CWs in climate change mitigation and their significance in sustainable treatment solutions. Following that, a further description and overview of the endeavors carried out in Bangladesh are presented. Finally, the challenges, opportunities, and future directions in this field are addressed. In the beginning, let us remind ourselves with the quote from Mahatma Gandhi: "The Earth does not belong to us; we belong to the Earth. It is our duty to protect and preserve this fragile planet for future generations." This encapsulates the essence of sustainable development.

The insufficient availability of clean water has become a pressing concern impacting human health in various countries globally, particularly in South Asia. Rapid urbanization and industrialization in South Asia have exacerbated water pollution issues, with alarming statistics revealing the extent of surface water contamination. According to the World Bank (2019), approximately 75% of surface water in Bangladesh is polluted, posing significant threats to public health and livelihoods. Costly and resource-intensive technologies have been proven ineffective in addressing the intricate water challenges arising from urbanization in these regions. Moreover, wastewater treatment plants produce substantial amounts of methane (CH_4), nitrous oxide (N_2O), and carbon dioxide (CO_2), exacerbating climate change. Hence, there is a necessity for affordable, low-maintenance, and eco-friendly wastewater treatment solutions. CWs have emerged as a natural and efficient remedy for wastewater treatment.

As highlighted in previous presentations, CWs offer numerous environmental benefits by mimicking natural ecosystems. They provide a sustainable solution for wastewater treatment that can help mitigate climate change impacts globally, with particular relevance to South Asian countries facing unique environmental and socio-economic challenges. Integrating CWs into water management strategies can contribute to both climate change mitigation and adaptation efforts in the region. According to the United Nations Environment Programme (UNEP), wetlands can sequester up to 20 times more carbon per unit area compared to other terrestrial ecosystems. The biological carbon sequestration in wetlands is depicted in Figure 1.

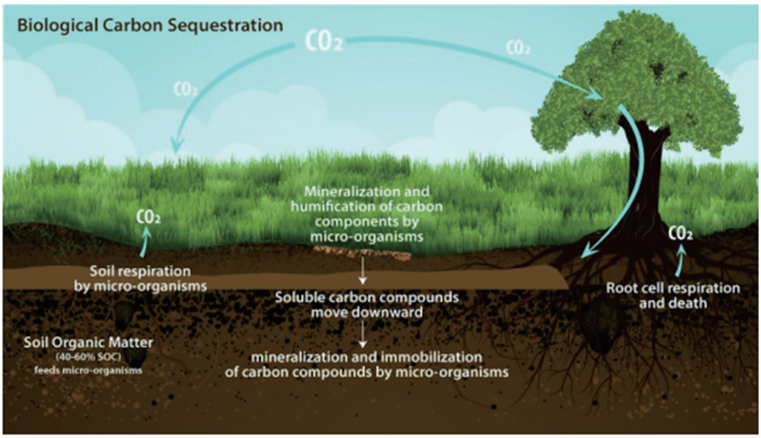

Figure 1: Carbon sequestration in wetlands. Source: calrecycle.ca.gov

Moreover, these wetlands offer invaluable solutions for managing flood control and stormwater, crucial for countries in South Asia vulnerable to climate-related disasters like floods and cyclones. The region experiences severe flooding during monsoon seasons, leading to extensive damage and disruption to millions of lives, as witnessed in Bangladesh in 2020, where over 5 million people were affected, resulting in substantial economic losses (The Guardian 2017). Figure 2 shows the potential applications of wetlands in urban areas.

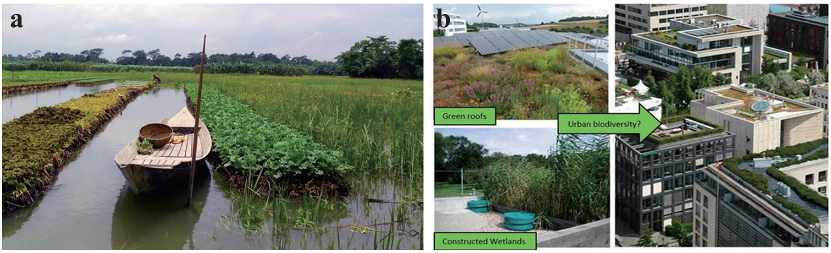

Figure 2: a) The remarkable floating gardens of Bangladesh, b) CWs as Eco-technologies in urban areas. Source: Author

In addition to their water purification functions, CWs play a pivotal role in conserving biodiversity by providing habitats for diverse plant and animal species, thus bolstering ecological resilience across South Asian countries. Research by Kadlec and Wallace (2009) underscored the importance of wetlands in supporting a wide array of species, contributing significantly to biodiversity conservation efforts.

Successful case studies from countries like India, Bangladesh, and Sri Lanka illustrate the potential of CWs in addressing water pollution, mitigating flood risks, and conserving biodiversity. For instance, in Chennai, India, the implementation of CWs for decentralized wastewater treatment has led to notable improvements in water quality and a reduction in pollution levels in surrounding water bodies, as documented by the United Nations Environment Programme (Obaideen et al. 2022). Thus, we need to focus our concerns and prioritize integration towards environmental protection. Global-level knowledge sharing and collaboration among researchers, policymakers, and communities are indispensable for amplifying the adoption of sustainable treatment solutions involving CWs, particularly in South Asian countries.

2. The Role of CWs in Climate Change Mitigation and Sustainable Treatment Solutions

(1) The Role of CWs in Climate Change Mitigation

Climate change impacts, such as increased water pollution and reduced water availability, can be effectively addressed by CWs. CWs play a crucial role in enhancing water quality by effectively removing pollutants such as nitrogen, phosphorus, heavy metals, and antibiotics from water bodies, thereby addressing the pressing challenges of water pollution. Mitsch and Gosselink (2015) have shown that CWs can achieve remarkable removal rates, with the potential to eliminate up to 90% of nitrogen and 70% of phosphorus from wastewater, thereby significantly enhancing water quality standards. Additionally, they play a significant role in water conservation efforts by promoting groundwater recharge and reducing water demand for irrigation (Vymazal 2013).

CWs offer a nature-based approach to mitigate the hazards linked to rising sea levels and escalating coastal erosion. Acting as natural barriers, wetlands serve as buffers against storm surges and tidal waves, safeguarding coastal regions (Gedan et al. 2011). Mangrove wetlands, in particular, play a crucial role in stabilizing coastlines and defending against erosion (Donato et al. 2011). CWs bolster resilience against extreme weather occurrences like floods and cyclones by enhancing water management and mitigating flood risks. Serving as natural flood buffers, they absorb surplus water during intense rainfall events. Moreover, they can be engineered as floodwater storage zones, curbing downstream flooding and shielding susceptible communities (Kadlec and Wallace 2009).

Wetlands can sequester significant amounts of carbon through the accumulation of organic matter in their soils and biomass. The anaerobic conditions found in wetland soils slow down the decomposition process, allowing organic matter to accumulate over time. According to the Ramsar Convention on Wetlands, which is an international treaty for the conservation and sustainable use of wetlands, wetlands cover only around 6% of the Earth's land surface but are estimated to store around 35% of global terrestrial carbon. Mitsch et al. (2012) also estimated that wetlands can sequester 50–100 g of carbon per square meter per year. This underscores the importance of wetlands in global carbon cycling and climate change mitigation efforts.

Furthermore, the incorporation of CWs into urban planning and landscape architecture yields numerous advantages, notably in climate change mitigation. CWs play a role in carbon sequestration, aiding in the reduction of greenhouse gas emissions. Additionally, CWs foster biodiversity conservation, providing habitats for diverse plant and animal species, thus fortifying ecosystem resilience.

(2) Sustainable Treatment Solutions with CWs

1) Water Treatment Benefits of CWs

CWs have demonstrated a remarkable ability to enhance water quality. A study conducted by Kadlec and Wallace in 2009 indicated that CWs removed up to 90% of nitrogen and 70% of phosphorus from wastewater, contributing to improved water quality. Another study conducted in South India demonstrated that a CW system effectively reduced the concentration of heavy metals, including copper and zinc, by up to 90% (Kumar et al. 2021). The natural processes within CWs, such as microbial degradation and plant uptake, play a vital role in pollutant removal (Vymazal 2013).

2) Climate Change Resilience Benefits of CWs

Wetlands act as natural buffers against rising sea levels and storm surges, protecting coastal communities and habitats from erosion and inundation. Each hectare of wetland can store an estimated 1.5 million liters of floodwater, helping to reduce the risk of downstream flooding (Ramsar Convention 2018). CWs have been shown to reduce downstream flooding by 20–30%, providing critical flood control during extreme rainfall events (Obaideen et al. 2022). The presence of wetlands in coastal areas can also dissipate wave energy, reducing the impact of coastal erosion (Gedan et al. 2011).

3) Economic Benefits of CWs

CWs have demonstrated cost-effectiveness compared to conventional treatment methods, with potential savings of up to 50% in capital and operational costs (Bui et al. 2018). For instance, a case study in China found that the revenue generated from ecotourism activities in a constructed wetland area amounted to approximately USD 35,000 per year (Li et al. 2020). In addition to cost savings, CWs can generate economic benefits through ecotourism and recreational activities, contributing to local economies (Li et al. 2020).

4) Social Benefits of CWs

CWs enhance biodiversity, providing habitats for various plant and animal species, and promoting ecological education and environmental awareness. Each square meter of wetland can support a diverse range of species, contributing to the conservation of local flora and fauna (Mitsch and Gosselink 2015). Wetlands can be integrated into urban landscapes, providing aesthetic and recreational spaces for communities to enjoy and connect with nature (Gedan et al. 2011).

5) Implementation Considerations for South Asian Countries

CWs can support fossil fuel divestment efforts by addressing environmental challenges associated with fossil fuel extraction and consumption, promoting sustainable land use practices, and raising awareness about the need for a transition to renewable energy sources and a low-carbon economy. South Asian countries, such as Bangladesh, with high population density and limited land availability, can benefit from the compact nature of vertical flow CWs for wastewater treatment (Bui et al. 2018). Additionally, CWs can complement and support the broader movement for climate justice, environmental sustainability, and youth empowerment. Engaging local communities and stakeholders in the planning and management of constructed wetlands is essential for ensuring their acceptance, success, and long-term sustainability (Obaideen et al. 2022). Furthermore, CWs can offer multifaceted benefits for commercial-scale plants, supporting their wastewater treatment needs, regulatory compliance efforts, environmental sustainability goals, and economic objectives. Customizing the design and operation of constructed wetlands to suit local conditions, including climate, water quality challenges, and available resources, is crucial for optimal performance and maximum benefits (Mitsch and Gosselink 2015).

3. Endeavors for a Sustainable Future through CWs in Bangladesh

In this section, I would like to delve into some studies conducted primarily by our research group. Our endeavors are directed toward shaping a sustainable future through the application of CWs for wastewater treatment.

(1) Biggest Floating CW System in Bangladesh

Firstly, I want to introduce a large-scale floating CW system in Bangladesh which was installed by our research team. This is a research project between University of Asia Pacific (UAP) and the Water Supply and Sewerage Authority (WASA) to improve water quality in the Dhaka-Narayanganj-Demra (DND) canal by employing floating constructed wetlands. We installed a significantly large-sized floating CW system in Bangladesh. The project aimed to minimize the treatment costs associated with the secondary treatment phase, thereby alleviating the burden before the wastewater flows into further treatment processes. In the project the estimated volume of treated water per day was nearly 50 m^3. Figure 3 shows the pilot application of the floating CW. However, it has not gone into large-scale operation yet.

Figure 3: The biggest floating CW system in Bangladesh. Source: Author

(2) Wastewater Treatment with Surface Flow CWs

Next, I will focus on the treatment solutions published by the research group at UAP already. The treatment for removing pollutants was accomplished using two CW systems (Saeed et al. 2019). The diagram of surface flow CWs is shown in Figure 4.

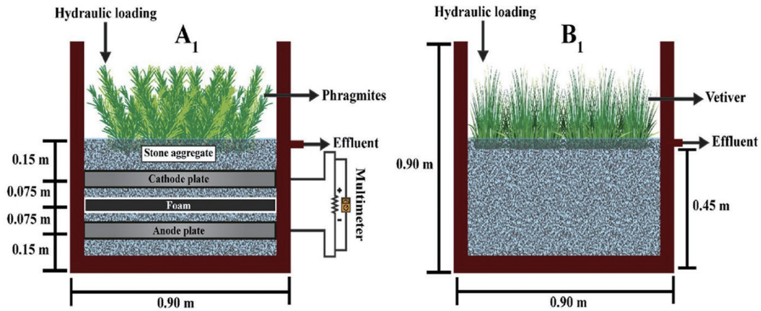

Figure 4: Schematic diagram of surface flow wetland arrangement.
Source: Saeed et al. 2019

In this experiment, two pilot-scale CWs were used employing two types of plants, namely Phragmites reeds and Vetiver grass, in both vertical and horizontal configurations. The CW systems were operated under constant and shock hydraulic load periods. The COD, nitrogen, and phosphorus input loadings varied 61–2181, 7–1040, and 2–194 $g/m^2/d$, respectively. After the treatment, the removal efficiency for COD, nitrogen, and phosphorus was, respectively, 39–97%, 20–100%, and 16–86% in the first stage. In the second stage, these values were 11–83%, 4–85%, and 1.4–100%, respectively. The plant accumulation for nitrogen was ≤7%, and for phosphorus, it was ≤14%.

(3) Wastewater Treatment with VFCWs

Another experiment conducted by the UAP research group investigated the removal of organic matter, nitrogen, and phosphorus by using VFCW configurations (Saeed et al. 2019). The diagram of the experimental setup is depicted in Figure 5.

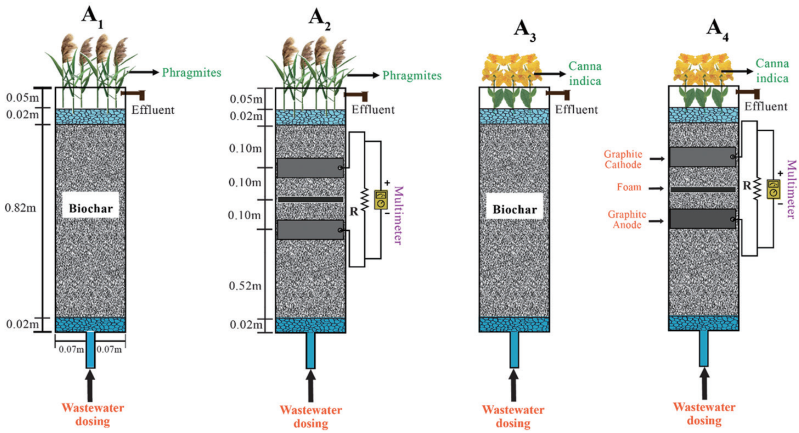

Figure 5: Schematic diagram of vertical flow wetland arrangement.
Source: Saeed et al. 2019

Phragmites and *Canna indica* were used as wetland plants in this research. The filter media used with different layers are shown in Figure 5. In the initial stage of VFCWs, the input loadings of nitrogen, phosphorus, and COD were 48–145, 1–7, and 56–191 g/m^2/d, respectively. The results showed that the decreased removal of organic matter in VF wetlands was attributed to the presence of recalcitrant compounds from the synthetic recipe. Furthermore, the adsorption of NH_4-N and carbon leaching properties of biochar stimulated nitrogen removal (ranged from 19–102 g/m^2/d) in partially saturated VFCWs. The removal percentages for biochemical oxygen demand, chemical oxygen demand, nitrogen, phosphorus, solids, and coliform from the drained wastewater were 96%, 99%, 89%, 99%, 98%, and 97%, respectively, across all systems. Partially wetland systems achieved removal rates exceeding 90% for biochemical oxygen demand, over 97% for nitrogen, and complete (100%) removal of phosphorus.

(4) Removal of Heavy Metals

Now, I am going to discuss the aspect of heavy metal removal, as demonstrated in the publication by Saeed et al. (2021). This study investigated the removal of four heavy metals — zinc (Zn), chromium (Cr), nickel (Ni), and lead (Pb) — from landfill leachate using two hybrid subsurface flow CW systems. The diagram of the experimental setup is presented in Figure 6.

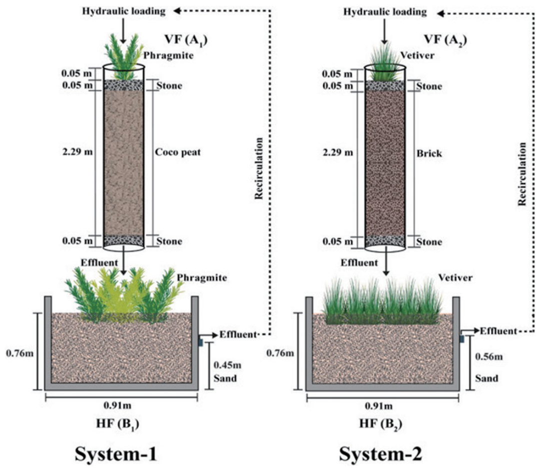

Figure 6: The diagram of pilot-scale hybrid CWs. Source: Saeed et al. 2021

Each system consisted of a vertical flow followed by a horizontal flow wetland. The wetland systems were filled with either organic materials (coco-peat) or construction materials (brick, sand), and planted with either *Phragmites australis* or *Chrysopogon zizanioides* (Vetiver). Both systems were operated with and without effluent recirculation protocols. The concentrations of Cr, Ni, and Pb accumulated on Phragmites were, respectively, 2–73, 3–12, and 0–27 mg/kg. In Vetiver, these concentrations were 8–34, 3–15, and 0–14 mg/kg, respectively. In vertical flow CWs, the presence of organic carbon and iron in coco-peat and brick substrates facilitated the removal of metals. However, this accumulation was not measured in sand-based HFCWs. The removal rates of heavy metals throughout the experiment are shown in Figure 7. In general, heavy metals can be removed effectively in the two-hybrid wetlands, representing 20–97%, 95–99%, 55–73%, and 69–83% for Zn, Cr, Ni, and Pb, respectively. During the effluent recirculation phase, the removal percentages of Zn, Cr, Ni, and Pb increased to varying degrees in vertical flow CWs, ranging from 75% to 98%, 29% to 41%, 14% to 48%, and 23% to 26%, respectively, compared to their removal without recirculation. In the recirculation phase, a decrease in heavy metal removal was observed in HFCWs.

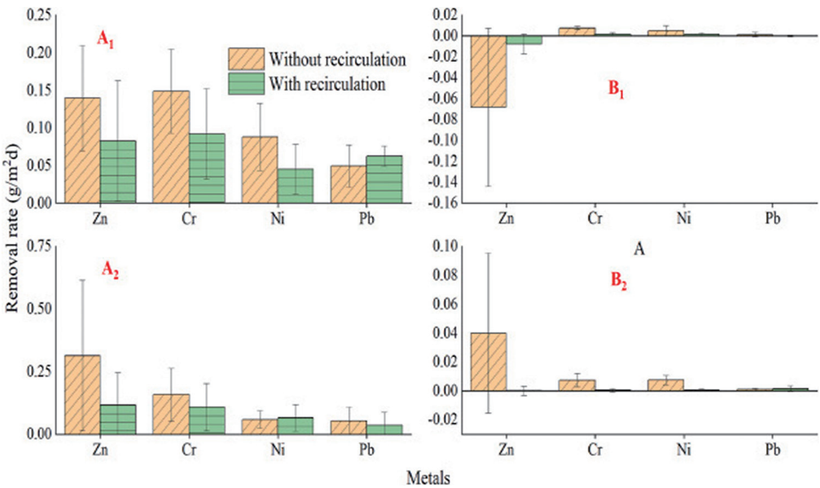

Figure 7: The average rates of metal removal in hybrid-CWs.
Source: Saeed et al. 2021

(5) Leachate Treatment

Leachate treatment represents a significant achievement accomplished by CWs. Leachate, the liquid that drains from landfills, often contains high concentrations of pollutants and contaminants, posing a considerable challenge for management. Table 1 presents the primary pollutant concentrations found in landfill leachate used in this study.

Table 1: The average composition of the leachate wastewater, with standard deviation values provided in parentheses

Parameters	**Unit**	**Concentration**
pH		6.9 (0.5)
Eh	mV	91.2 (107.0)
TKN		186.6 (132.3)
NH_4-N		103.5 (80.0)
NO_2-N		0.7 (0.7)
NO_3-N		12.6 (11.3)
TN	mg/L	201 (131.3)
TP		51.5 (36.0)
BOD		241.5 (149.0)
COD		1481 (693.0)

(Eh: Redox potential, TKN: Total Kjeldahl-Nitrogen, NH_4-N: Ammonium-nitrogen, NO_2-N: Nitrite-nitrogen, NO_3-N: Nitrate-nitrogen, TN: Total nitrogen, TP: Total phosphorus, BOD: Biochemical oxygen demand, COD: Chemical oxygen demand)

This study discovered that landfill leachate can be effectively treated by tidal flow CWs. The removal percentages for chemical oxygen demand, total nitrogen, total phosphorus, and coliform ranged from 96% to 99%, 82% to 93%, 91% to 98%, and 86% to 96%, respectively. These results remained consistent throughout the experimental period. The nitrogen and phosphorus accumulation percentages in wetland plant tissues were low, representing 0.4–2.2% and 0.04–0.8%, respectively. Additionally, the CW systems also provided power generation. During the continuous aeration period, the electrode-integrated tidal flow CWs achieved higher power density production, ranging between 859 and 1432 mW/m^3.

(6) Bioenergy Production

Constructed wetlands (CWs) can serve as multifunctional systems, simultaneously providing wastewater treatment and generating bioenergy. Implementing bioenergy production in CWs offers several advantages, including utilizing renewable resources, mitigating greenhouse gas emissions from waste treatment, and potentially offsetting energy costs associated with wetland maintenance. This accomplishment is also a highlight of our research group’s work. The findings of this study were published in a highly respected journal, *Science of the Total Environment*, Asia Pacific (UAP), by a research group led by Professor Saeed (Saeed et al. 2022). In this study, four hybrid CW systems comprising vertical flow (VF) followed by horizontal flow (HF) configurations were utilized, with or without vegetation. Among them, two systems integrated planted electrodes into microbial fuel cells (MFCs). Figures 8 and 9 illustrate the microbial fuel cell wetland and the hybrid CW systems.

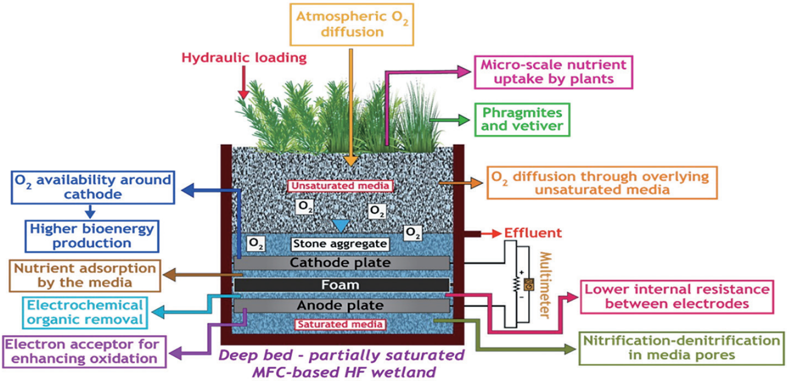

Figure 8: Microbial fuel cell wetland. Source: Author

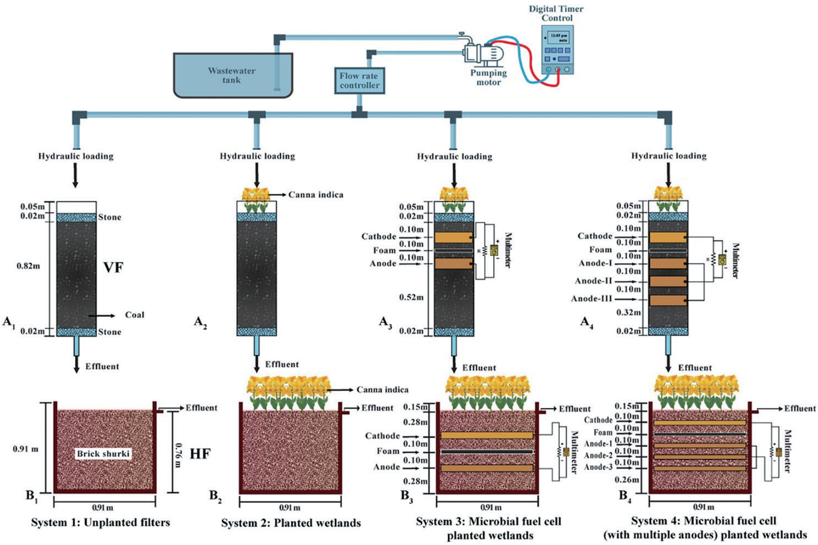

Figure 9: Operational arrangement of the CW systems.
Source: Saeed et al. 2022

The average initial pollutant concentrations of the real wastewater used in this experiment are shown in Table 1. The hybrid systems operated in a free-draining mode. After 33 weeks of operation, the hybrid CWs exhibited high removal efficiency for biochemical oxygen demand (BOD), chemical oxygen demand (COD), nitrogen, and phosphorus, achieving percentages of 90%, 92%, 88%, and 89%, respectively, across all systems. Additionally, solid and coliform removal rates were 98% and 97%, respectively. The electrodes-integrated CWs demonstrated a 27% higher organic removal and a 14% higher nitrogen removal compared to those without electrode integration. The higher pollutant removal efficiency was observed in microbial fuel cell (MFC)-based CWs with vertical flow. This may be attributed to the contribution of dissolved oxygen from the atmosphere and oxygen released from the root zone. The physicochemical properties of the filter media also facilitated both biotic and abiotic mechanisms for organic matter and nutrient removal. During the second phase, the efficiency of organic matter and nutrient removal in HF-CWs decreased due to higher input loading and substrate saturation. The increased input loading rate in phases II and III also resulted in a decrease in bioenergy production across MFC-based hybrid CWs (as shown in Figure 10).

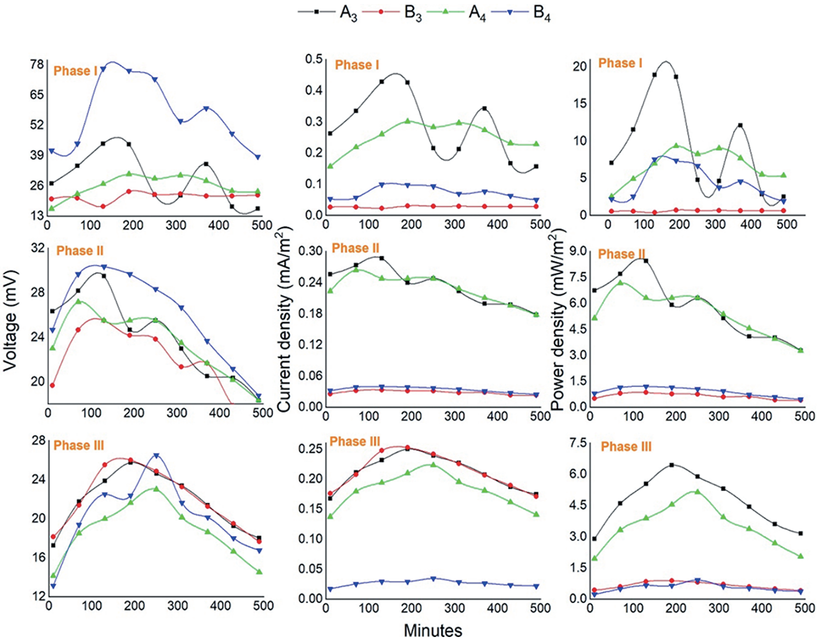

Figure 10: Profiles of bioelectricity generation during the experimental period. Source: Saeed et al. 2022

Activation, ohmic, and concentration losses affected the bioenergy generation in MFC-integrated wetlands. A maximum power density production rate of 60 mW/m^2 was recorded. The highest power density production was observed in phase I, reaching 294 mW/m^2 in the VF wetland with a single anode electrode, and 192 mV in the HF system (B4) with multiple anode electrodes.

(7) Mitigating the Challenges of Industrial Growth and Climate Change Impacts in Developing Countries

An important study that our group has accomplished specifically investigated the role of CWs in addressing the challenges posed by industrial growth and the impacts of climate change in developing countries (Islam et al. 2022). This study aimed to provide a comprehensive overview of various practices, uses, and research on CW systems for removing pollutants from wastewater in developing countries, placing them in the context of climate change, environmental resource planning, and sustainable wastewater treatment systems. Table 2 provides a summary of the operational features and treatment effectiveness of hybrid CW systems in several Asian countries, such as China, Nepal, Bangladesh, Indonesia, Turkey, and Thailand.

Table 2: Characteristics of hybrid CW systems used in several Asian countries

	Type of wastewater	**Treatment performance**						**Plant species**	**HLR**
		TSS	BOD_5	COD	NH_4-N	TN	TP		
China									$0.58m^3/m^2/d$
Eff (mg/L)	Lake water	12.3	5.9	5.4	4.3	6.3	0.1		
RE (%)		99.1	77	67.4	52.8	99	77		
Nepal									$20m^3/d$
Eff (mg/L)	Hospital wastewater	2.8	3.3	20.2	1.61	NA	4.2	*Phragmites karka*	
RE (%)		97.3	97	93.8	95.1	NA	46.6		
China									0.25m/d
Eff (mg/L)	Municipal wastewater	NA	59.9	22.5	0.4	1.5	NA	*Thpha orientalis*	
RE (%)		NA	62.8		80.7	51	NA		
Bangladesh									
Eff (mg/L)	Industrial wastewater	12.3	5.9	5.5	4.3	6.4	0.1	*Phragmites*	
RE (%)		99.1	77	67.4	52.8	99	77		
Nepal									0.13m/d
Eff (mg/L)	Municipal wastewater	37.8	173.3	319	45	NA	17.1	*Phragmites karka*	
RE (%)		97.5	89.1	89.1	68.3	NA	29.9		
Indonesia									$31m^3/d$
Eff (mg/L)	Laboratory wastewater	15	4.75	5.32	3.1	2.1	1.6	*Phragmites*	
RE (%)		68.8	77.86	87.3	74.3	75	39.3		
Turkey								*Iris australis*	$60 L/m^2/d$
Eff (mg/L)	Municipal wastewater	NA	NA	NA	3.2	0.3	4.5	*Phragmites australis*	
RE (%)		NA	NA	NA	91.2	89	91.3		

Thailand									400
Eff (mg/L)	Municipal wastewater	16	25	NA	NA	33	4.5	*Canna, Heliconia Papyrus*	
RE (%)		90	91.5	8	NA	39	46.4		

(NA: Not available, Eff: Effluent, RE: Removal efficiency).

Source: Islam et al. 2022

Among the eight hybrid CW systems examined, four were designed for treating municipal sewage, while others targeted various types of wastewater such as lake water, and hospital and laboratory wastewater. These hybrid systems demonstrated impressive contaminant removal efficiencies, achieving up to 93.82% for total suspended solids, 85.65% for chemical oxygen demand, and 80.11% for ammonia nitrogen, which were comparable to or better than other viable alternatives. Regarding BOD removal, hybrid-constructed wetlands showed the highest elimination rate (84.06%) compared to free water surface CWs (65.34%), horizontal sub-surface CWs (75.1%), and floating treatment wetlands (55.29%). The removal efficiency for phosphorus and nitrogen was moderate, representing 54.75% and 66.88%, respectively. Their removal rates depended on factors such as system design, HLR, and plant species.

Table 3: The use of MFC-based CWs for electricity production in some countries

Country	**Wastewater flow**	**Volume (L)**	**Electrode**	**Initial COD (mg/L) and (% removal)**	**Electricity**
India	Vertical flow	5.4	Anode–Graphite Plate	1500 (74.8)	15.7 mW/m^2
India	Vertical flow	1.8	Anode–Granular, and Activated Carbon	770–887 (90.9)	43.63 mW/m^3
China	Vertical flow	1.5	Cathode–Granular Graphite, and Activated Carbon	500 (80)	87.79 mW/m^2

China	Vertical flow	12.5	Cathode–Granular Activated Carbon	205 (95)	12.42 mW/m^2
Malaysia	Vertical up flow		Cathode–Activated Carbon	625 (99)	93 mW/m^3
Bangladesh	Vertical flow		Anode–Powder, and Cathode–Granular Graphite	559.5 (79)	86 mW/m^2

Source: Islam et al. 2022

Table 4: A comparison of biofuel ecosystem production

Item	Bioenergy production (GJ/ha/yr.)	CO_2 sequestration	GHG emission
CWs	1836	31	28.8
Land grassland	88.8	4	0.3
Switchgrass	199.1	16.2	0.4
Corn	158.1	NA	0.7
Soybean	45.8	NA	0.7
WTP	NA	17.1	592.2

(NA: not available).

Source: Islam et al. 2022

Tables 3 and 4 present data regarding the results of a comparative assessment of studies employing CW-MFCs for electricity generation and a comparison of biofuel ecosystem production, respectively. In general, the MFC-based CWs showed high COD removal rates (74.8–99.0%), achieving a maximum power density generation of 86 mW/m^2 in Bangladesh and 93 mW/m^3 in China using vertical flow. Additionally, CWs showed the highest bioenergy production with 1836 GJ/hectare/year. Each year, WTPs produce approximately a hundred times more GHGs than CWs. In Nepal, a CW system was installed at Dhulikhel Hospital to treat hospital wastewater over five years, with a volume of 500,000 m^3 of treated wastewater. This system did not require any electric energy due to hydro-mechanical feeding into the beds. It was approximated that utilizing the CWs rather than a wastewater treatment plant could potentially result in savings of around USD 50,000.

In the present era of urbanization, the widespread installation of wastewater treatment plants can result in a considerable expansion of land use for upstream activities, exacerbating pressure on water resources and available land. Moreover, these technologies typically demand high energy and consistent maintenance. Thus, implementing CWs can alleviate these challenges. It was estimated that for every 1 m^3 of wastewater treated, the CW occupies 0.05 m^2 less space compared to the centralized water treatment system. Figure 11 illustrates the potential for land conservation and the per capita land savings for each province in 2017, under the assumption of replacing urban WTPs with CWs in China.

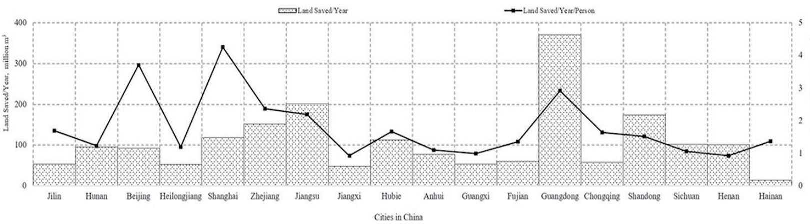

Figure 11: The amount of land saved annually, both in total and per person, by employing CWs in China. Source: Islam et al. 2022

(8) Life Cycle Analysis

Another study by our group (Alam et al. 2023) accomplished the life cycle analysis of various configurations of CWs and how the configurations influence CWs through the utilization of different media sources. We used five configurations of CW applications from previous studies (as shown in Figure 12) with different filter media including coco-peat, biochar, sand, gravel, sugarcane bagasse, cement mortar, brick chips, and scraped metals. The characteristics of five CWs and the quality of influent and effluent are presented in Table 5, while their diagrams are presented in Figure 12. This study employed life cycle assessment (LCA) through SimaPro software to measure the environmental effects of constructed wetland systems.

Table 5: Characteristics of the constructed wetland system and influent/effluent composition

	Unit	S1	S2	S3	S4	S5
System Characteristics						
Flowrate	L/d	38	4	4	4	6
Plants		*Phragmites australis*	*Phragmites australis*	*Cannaindica*	*Cannaindica*	*Phragmites australis*
Hydraulic retention time	D	12.5	32.8	27.9	27.9	28.3
No. of vertical CW cells		2	2	1	1	1
Vertical cell dimensions	m (H × D)	0.73 × 0.91	1.5 × 0.15	1.53 × 0.15	1.53 × 0.15	2.13 × 0.15
No. of horizontal CW cells		1	1	1	1	1
Horizontal cell dimensions	m (H × L × W)	0.78 × 1.32 × 1.01	0.5 × 1.22 × 0.61	0.92 × 0.90 × 0.30	0.92 × 0.90 × 0.30	0.91 × 1.22 × 0.61
Influent quality						
BOD	mg/L	4200 (43.5)	131.5 (3.4)	215 (6.1)	215 (5.5)	96.4 (4.5)
COD	mg/L	11500 (410.2)	420.3 (13.3)	1098 (32.5)	1098 (21.4)	171.5 (10.5)
TN	mg/L	100.3 (5.4)	31.3 (1.9)	17.3 (1.5)	17.3 (1.4)	59.3 (3.5)
TP	mg/L	30 (2.1)	2,3 (0.2)	4.6 (0.12)	4.6 (0.2)	14.1 (0.4)
Effluent quality						
BOD	mg/L	80 (3.5)	8.8 (1.5)	28.4 (3.5)	56.2 (4.8)	3.7 (0.5)
COD	mg/L	200 (5.1)	45.2 (3.9)	184 (4.2)	362.9 (8.2)	22.2 (1.5)
TN	mg/L	49.8 (5.2)	3.1 (0.15)	3.4 (0.2)	5.6 (0.3)	2.4 (0.2)
TP	mg/L	3 (0.25)	0	0.5 (0.05)	1.6 (0.01)	0.5 (0.01)

Standard deviations are enclosed in parentheses.
Source: Alam et al. 2023

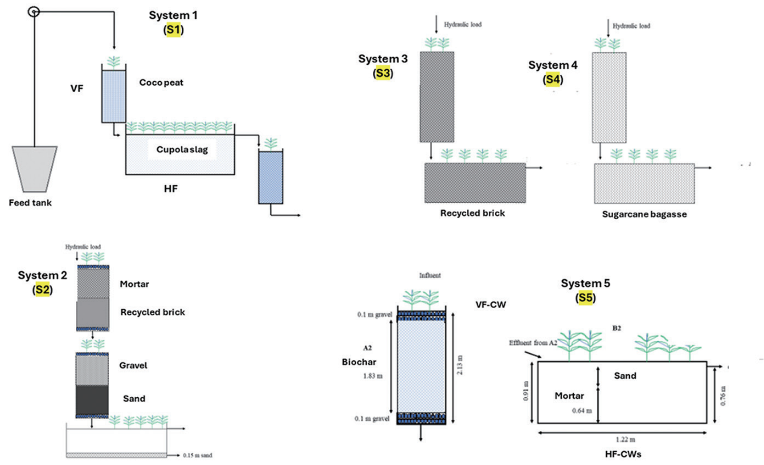

Figure 12: Diagrams of five CW systems. Source: Author

The findings indicate that all five CWs effectively remove organic matter and nutrients. The influence of the media materials used in CWs on global warming, fossil resource scarcity, terrestrial, and freshwater ecotoxicity categories is illustrated in Figure 13.

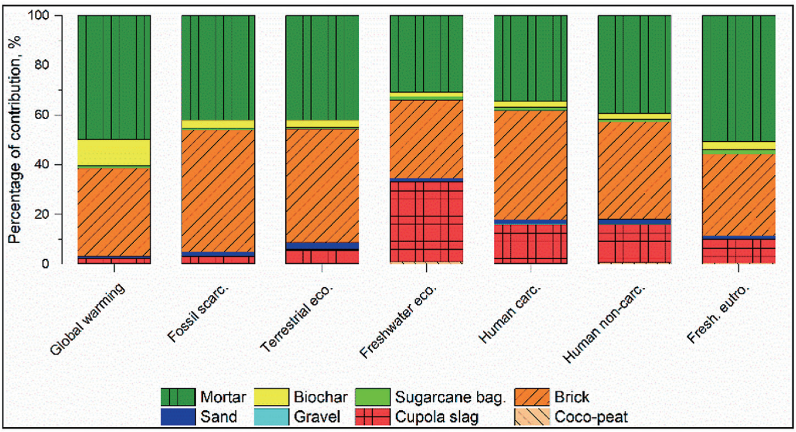

Figure 13: Comparative assessment of the impact of media materials throughout their life cycles on selected categories. Source: Alam et al. 2023

Among the CW systems studied, those utilizing cement mortar exhibited the highest environmental impact. Conversely, natural media options such as sugarcane bagasse and coco-peat have shown to be environmentally advantageous. Using recycled materials like brick and steel slag in media could significantly mitigate the previous environmental burdens associated with these materials, while also enhancing treatment efficiency. Overall, the assessments indicated that careful selection of media materials is crucial to ensure the sustainability of CWs. CWs demonstrate greater advantages and environmental friendliness compared to other treatment methods, particularly when designed at large scales.

4. Challenges and Opportunities

While CWs offer numerous advantages, their widespread implementation still encounters several challenges. One such obstacle is the limited availability of suitable land for CW construction, especially in densely populated urban areas. In regions like South Asia, such as Bangladesh, where population density is high, finding adequate space for CWs is particularly challenging (Byomkesh et al. 2009). Another challenge lies in the lack of awareness and understanding of the benefits and operations of CWs among policymakers, communities, and stakeholders. A survey conducted in India revealed that only 28% of respondents were aware of CWs as a wastewater treatment solution (Kumar and Dutta 2018). Furthermore, inadequate funding and financial resources pose significant barriers to the design, implementation, and maintenance of CW projects. A study conducted in Sri Lanka emphasized the financial constraints encountered in implementing CWs, with limited funding available for long-term maintenance and operation (Pathirana and Manatunge 2022). Moreover, climate changeinduced alterations in precipitation patterns and extreme weather events may affect the performance and efficacy of CWs. Reports from the Intergovernmental Panel on Climate Change (IPCC) suggest an increase in the frequency and intensity of extreme weather events, such as heavy rainfall and droughts, which could disrupt the hydrological balance of CWs (IPCC 2021).

However, CWs also present numerous opportunities, such as their integration into urban planning and development strategies for sustainable water management. According to Kumar et al. (2022), incorporating CWs into urban development can offer cost-effective solutions for wastewater treatment and water resource management, thereby supporting sustainable urban growth. Furthermore, collaboration and partnerships among government agencies, local communities, researchers, and non-governmental organizations (NGOs) can promote the adoption and implementation of CWs. An example of successful collaboration is seen in Bangladesh, where the Municipality of Dhaka partnered with NGOs to implement CWs for wastewater treatment, demonstrating the potential of multi-stakeholder partnerships (Bui et al. 2018). Additionally, harnessing the potential of nature-based solutions, such as CWs, can contribute to achieving multiple Sustainable Development Goals (SDGs). CWs contribute to SDGs related to clean water and sanitation (SDG 6), climate action (SDG 13), and life on land (SDG 15), offering opportunities for integrated and holistic approaches to address various challenges. Incorporating CWs into climate change adaptation and mitigation strategies at national and regional levels is also important. The South Asian region, in particular, can benefit from including CWs in climate change adaptation plans, as they can help reduce the vulnerability of coastal areas to sea-level rise and provide natural infrastructure for flood management (Ramsar Convention 2018).

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4. Dr. Nehreen MAJED

Chapter 4. Towards Multifaceted Mitigation of Climate Change Impacts: Ensuring Sustainable Treatment Solutions with Constructed Wetlands

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