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The multi-site study of Asian Wetland: Integrated Evaluation of Urban and Rural Wetland Systems to Enhance Water Quality and Mitigate Health Risk

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Abstract: *This study at multiple sites aims at establishing the use of natural and constructed wetlands in divergent urban and landscapes in Asia, including India, China, Bangladesh, and Ethiopia in improving water quality and reducing the impact on the health needs of the population. Through increasing urbanization and release of wastewater into the environment without treatment, the wetlands are seriously degraded, and they still amount to critical ecological infrastructure. It uses physicochemical measurements, machine learning prediction, and risk estimations of the humans health to make comparisons amid wetland performances. The Amanaka wetland in Raipur, India showed good performance in reduction of pollution (e.g. 87.9 percent COD removal, 87.2 percent nitrate removal) and engineered wetlands in Chhattisgarh showed the same even with passive design. Tech-driven improvements in water quality management are evidenced by the application of predictive models (XGBoost, RF) to track pollution in real-time by the coastal cities in China. Mirpur, Bangladesh, on the other hand, has great health risks posed by trace metals in school tap water, with THQ ranging >1 between the arsenic and lead. In addition, socioeconomic considerations of the Gudera Wetland in Ethiopia also showed high-community willingness to pay (WTP) on restoration of wetlands. Taken together, the findings support the deployment of context-sensitive wetlands solutions, which brings together natural system solutions, predictive technology, and population engagement. This paper reaches a conclusion that scalable and decentralized systems of wetlands implement a sustainable way of resolving the interrelated water quality and the health issue facing Asia provided they are designed contextually, well-monitored and democratically controlled.*
Keywords: *Water quality, sustainable growth, Wetland, Health Risk*

1.INTRODUCTION

Wetlands play a crucial role in ecosystems, providing climate control, habitat creation, water filtration, and flood control. However, they face increasing pressure from urban development, agricultural intensification, and untreated wastewater discharge in Asia, where megacities and rural populations live. This threatens biodiversity, public health, and water security.

In South and East Asia, urbanization has led to land use conversion, invasion of wetland buffers, and increased release of untreated household and industrial effluent into aquatic environments. In India, urban areas like Raipur produce large amounts of greywater and sewage that end up in both natural and manmade wetlands. Despite these challenges, wetlands show high pollution removal efficiency, underscoring their role as natural treatment systems.

Agricultural activity in rural areas adds to wetland stress through runoff containing fertilizers, pesticides, and sediment loads. However, communities often have a closer cultural and financial relationship to wetland ecosystems, offering opportunities for wetland rehabilitation. A contingent valuation study of the Gudera Wetland in Ethiopia revealed that rural households are willing to pay for wetland rehabilitation (Asmare et al., 2022).

Declining water quality is linked to health hazards, particularly in highly populated, underprivileged urban environments. A case study from central Bangladesh showed that tap water from school grounds contained metal contaminants, highlighting the need for wetland-based purification techniques to reduce health risks in sensitive areas.Wetlands also suffer indirect pressures such as decreased recharge due to infrastructure development, illegal encroachments, and diversion of natural water flows (Zhang et al., 2021). Predictive models, such as machine learning models, have been developed to evaluate and track water quality, but these interventions must be complemented with on-the-ground ecological assessments. Ramasamy and Cheng (2024) investigates the customers' attitude and behaviour in decision-making for water conservation in Malaysians private higher learning institutions.The primary aim of this research is to fill this important gap by conducting a multi-site, comparative study of wetland systems across Asia. Through this cross-regional, multi-disciplinary approach, the study seeks to demonstrate that wetlands whether natural or constructed, rural or urban can serve as scalable, resilient infrastructure for environmental management and public health protection in the diverse ecological landscapes of Asia.

Literature Gap

The research on wetlands in Asia is largely methodologically and geographically isolated, with studies focusing on one site and limiting generalisability across ecological zones and governance settings (Asmare et al., 2022). For example, India's Amanaka study highlights removal efficiencies but lacks comparable analysis with other wetland systems in diverse socio-environmental settings. Rural locations like Ethiopia's Gudera Wetland lack quantitative water quality assessments and pollution tracking. Bangladesh's efforts on school tap water focus on health risk and contamination, but do not connect this to the function of wetland systems in improving water quality or lowering exposure (Md. Joynal Abedin et al., 2023). ML-based predictive studies in China function in silos without ecological grounding or transregional comparison. Comparative performance studies show a methodological disparity in the limited integration of natural and constructed wetlands, with variations in seasonal monsoon patterns, greywater sources, and community usage complicating the extrapolation of localized results to more general wetland policy frameworks. Therefore, a synthesised, cross-regional assessment is needed to evaluate the co-benefits for public health and ecosystem sustainability, compare wetland systems across urban and rural environments, and evaluate their pollution removing capacity under different conditions.

Study sites

India, Amanaka Wetland, Raipur, India (Urban)

The Amanaka wetland system in Raipur, Chhattisgarh, India, is a natural wetland ecosystem that faces anthropogenic stress due to its proximity to marketplaces, small businesses, and densely packed homes. The system faces untreated greywater discharges and solid waste flows from surrounding towns, which provide ongoing inflows for the wetland. Despite these challenges, the system has shown great resilience in reducing pollutants through natural purification mechanisms. Ten sampling points, including influent drains, internal wetland nodes, adjacent ponds, and borewells, revealed a strong water quality monitoring framework.The water's physiochemical characteristics indicate significant pollution removal, with elevated levels of electric conductivity (EC) and total dissolved solids (TDS) indicating high ionic and solute content in the untreated greywater. High total hardness indicates a significant presence of calcium and magnesium salts. As water moved across the wetland and nearby ponds, these concentrations gradually dropped, confirming the system's function in mineral content attenuation. The pH stayed relatively neutral over the treatment course, confirming the urban nature of the pollution load and the buffering capacity of the wetlands.The biological and nutritional values offered by the Amanaka wetland are remarkable, with the removal efficiency of Chemical Oxygen Demand (COD) at 87.9%, Total Kjeldahl Nitrogen (TKN), and nitrate-nitrogen (NO_3^--N) at 87.2%. These records point to active microbial processes, such as ammonification and denitrification occurring in the root zones of the wetland. Total phosphorus removal efficiency was recorded at 56.5%, a noteworthy result. Sequential reduction in nutrient concentrations from influent drains through the wetland to the ponds and borewells exposes a layered treatment gradient moulded by biogeochemical interactions.The Amanaka wetland serves both as a treatment area and a habitat supporting biodiversity by water. Among the aquatic macrophytes the system hosts are Typha latifolia, Eichhornia crassipes, Ipomoea aquatica, and several filamentous algae. These plants improve hydraulic retention times, offer substrates for microbial consortia responsible for nitrogen and phosphorus cycling, and help absorb pollutants. Their root systems trap suspended solids, offer shade to control algal blooms, and promote biofilm development supporting nitrifying and denitriding bacterial activity.The Amanaka wetland stands out among many other urban treatment systems in that it can preserve nearby groundwater supplies. For most criteria including pH, hardness, nitrate, and heavy metals, borewell samples taken from three surrounding sites showed no exceedance of WHO drinking water quality limits. This implies that the wetland pond groundwater interface serves as a pollution barrier, suggesting a positive externality of wetland-based treatment groundwater protection in a high-risk urban zone.From a policy and infrastructure planning standpoint, the Amanaka case shows how even naturally occurring wetlands in cities can be distributed, low-cost wastewater treatment plants. However, the modest removal of BOD_5 implies that the system may be compromised under conditions of peak flow or organic shock load. Additionally, seasonal fluctuations in pollution loads or treatment efficiency could also impede treatment performance.In conclusion, the Amanaka wetland of Raipur presents a useful case study of urban Indian natural wastewater treatment. By reducing COD, TKN, and nitrate, the system supports safe groundwater quality downstream by reducing water pollution. The study also highlights the potential of urban wetlands as a distributed, sustainable water treatment system in rapidly expanding metropolitan areas.

China (Urban – ML-Based Water Quality Forecasting)

In the case of the coastal China, due to interaction of household wastewater export, industrial waste, agricultural waste and the incoming tides, water quality management has become a problem due to urbanization. In a bid to manage such problems, cities have resorted to the use of predictive modelling such as Random Forest (RF) and XGBoost to dampen the risk of environmental-induced health effects and manage the quality of water. The final research demonstrated the good predictive capacity of XGBoost models in various hydrological circumstances and seasons by Xu et al. in 2024.The research work was aimed at assessing key water physicochemical parameters and its impact on overall Water Quality Index (WQI). The authors trained and tested out models to predict variations of DO, pH, ammonia nitrogen (NH 3 -N), COD among other factors in the coastal city water bodies through the high-resolution data. XGBoost worked better than Random Forest in coefficient of determination (R 2) above 0.90 and lower values of root mean square error (RMSE) over multiple sites. Incorporating the forecast, generated by ML, where natural or artificial wetlands will help to provide seasonally adaptable strategies to remove pollution, dynamically control the flow, and extended retention times will be possible.Ammonia nitrogen and COD were determined as the most significant parameter in the determination of variability in WQI, and this concurs with the factors used to determine efficiency of wetland in removing pollution. This machine learning strategy provides a transferable analysis tool which can be incorporated within multi-site wetland monitoring networks.The Chinese paper gives a technologically superior alternative to passive treatment models, which can enhance the resiliency of the system and reduce health risks significantly when morphological data on wetlands is incorporated into the predictive model. By integrating real-time data analytics and nature-based design, it is an option to solve the challenges of urban water governance in Asia where wetland managers seek intelligent solutions.

Mirpur, Bangladesh (Urban Tap-Water Crisis and Health Risk Assessment)

Because of the junction of domestic wastewater discharge, industrial pollutants, agricultural runoff, and tidal influences, urbanisation in coastal China has produced difficult water quality management problems. Cities along China's eastern coast have responded by turning more and more to predictive modelling tools to control water quality and lower environmental health risks. Applying machine learning models specifically Random Forest (RF) and XGBoost to evaluate and forecast the Water Quality Index (WQI) in several urban water bodies gives a strong proof of this approach in the 2024 study by Xu et al. The study shows how early warnings created by computational intelligence in conjunction with time-series environmental monitoring can guide wetland and river basin management plans.The main goal of the work was to evaluate important physicochemical water parameters and their effects on general WQI. The authors trained and validated models to forecast changes in DO, pH, ammonia nitrogen (NH_3-N), COD, and other important variables using high-resolution data acquired from coastal city water bodies. With a coefficient of determination (R^2) > 0.90 and low root mean square error (RMSE) values over several sites, XGBoost especially beat Random Forest. Under different hydrological and seasonal conditions, this shows the strong predictive ability of the model (Xu et al., 2024).Although the study does not specifically use wetlands as a treatment medium, its ramifications for wetland-integrated systems are important. Applications of predictive models such as XGBoost to wetland inflows and outflows help to maximise hydraulic loading rates and identify pollution events in real time. For instance, wetlands close to estuaries are particularly sensitive to mixed pollution loads and saltwater intrusion, thus real-time monitoring is quite important. Combining such ML-driven forecasts with either natural or manmade wetlands could enable seasonally adaptive pollution removal strategies, dynamic flow control, and improved retention times.Furthermore in line with wastewater-dominated water bodies, the study found ammonia nitrogen and COD as the most important determinant of WQI variability. Studies from India and Bangladesh show that these markers greatly coincide with those used to assess the efficiency of wetland pollution removal. Therefore, even if the Chinese cities under study might not depend on nature-based treatment systems directly, the machine learning approach offers a transferable analytical tool that can be included into multi-site wetland monitoring networks (Md. Joynal Abedin et al., 2023).Within the general goal of this research to evaluate urban and rural wetland systems across Asia the Chinese study provides a technologically advanced counterpoint to more passive treatment systems. It provides a predictive model that, combined with ecological data from wetlands, can greatly improve system resilience and health risk reduction. Combining real-time data analytics with nature-based systems offers a viable road forward in Asia's urban water governance scene as wetland managers search for smart solutions.Study of (Md. Joynal Abedin et al., 2023), the research site was Mirpur, Bangladesh (Urban, Tap Water Crisis) Tap water from schools in central Bangladesh contains metal(loid)s, with potential health risks from lead and arsenic, likely due to pipeline scaling over time. - The concentrations of metals and metalloids in tap water from schools in central Bangladesh were mostly within safety limits, with exceptions. - Hydro-geochemical processes govern major elements, while anthropogenic processes, particularly pipeline scaling, control trace elements. Older schools have higher metalloid levels due to gradual pipeline scaling, posing carcinogenic risks from lead and arsenic. Elemental abundances of Na, Mg, K, Ca, Cr, Mn, Fe, Co, Ni, Zn, As, Cd, and Pb in tap water samples ($\mu gL-1$); Water quality assessment; Source apportionment; Non-carcinogenic and carcinogenic health risks estimation.Collection of 25 composite tap water samples from schools and colleges in central Bangladesh. - Analysis of samples using atomic absorption spectroscopic technique. - Multivariate statistical approaches to assess hydro-geochemical processes. Cluster analysis to group sampling sites by establishment years.

Comparative summary of the studies and synthesis

Parameter	Amanaka (Raipur)	Coastal China	Mirpur (Bangladesh)	Chhattisgarh HFWSF
System Type	Natural wetland	Predictive ML–Urban AI	Tap-water (no wetland)	Engineered wetland
Urbanization	High	Very High	Very High	Medium-Urban Edge
Pollutants	BOD_5, COD, TN, TP	COD, NH_4^+, DO	As, Pb, Cr	BOD_5, COD, TP, TN
Tech Intervention	None (passive)	Machine Learning	None	Design-optimized CW
Health Risk Evaluation	Minimal	Modeled (WQI)	THQ > 1 (children)	None conducted yet
Vegetation	Typha, Eichhornia	Not specified	N/A	Typha, Phragmites
Performance Highlights	COD RE: 87.9%	XGBoost $R^2 > 0.90$	Tap water unsafe	BOD_5 RE: 82%, TSS > 85%

Key Data for Each Site:

The four chosen research sites reflect different hydrological, ecological, and socioeconomic settings over Asian metropolitan areas. These comprise engineered wetlands in Chhattisgarh, India; coastal cities in China; Amanaka Wetland (India); Mirpur in Bangladesh. Every site was selected based on their representativeness in urban wetland dynamics and applicability to water quality and risk reduction of health hazards.

Coordinates and hydrological context

Situated inside a low-lying depression surrounded by residential areas and natural ponds, Amanaka, Raipur, India, is fed by urban drainage and surface runoff at about 21.25°N, 81.63°E.

China's coastal cities are estuaries along the eastern seaboard, usually within the Yangtze or Pearl River delta areas, subject to mixed freshwater and saline impact from tidal dynamics.

Mirpur in Dhaka, Bangladesh: Mirpur, which lies close to 23.80°N, 90.35°E, depends on piped tap water abstracted from municipal sources or groundwater aquifers with little wetland or buffer zones (Md. Joynal Abedin et al., 2023).

Designed for distributed greywater treatment, Chhattisgarh HFWSF Wetlands are built horizontal free-water systems close to semi-urban communities in central India.

Urbanization level

Every site falls in high to very high urban pressure zones. With few ecological buffer zones, Mirpur and the coastal Chinese cities are rather densely populated. Though the latter preserves engineered vegetation buffers, Amanaka and Chhattisgarh sites suffer modest to high urban encroachment.

Main Sources of Pollution

Greywater, sewage, and metal pollution from urban and peri-urban runoff rules India and Bangladesh's pollution scene. Often from domestic and industrial sources, ammonia nitrogen and COD rule in China.

Kind of Wetlands

Amanaka is a natural wetland; Chhattisgarh makes use of created free-water surface wetlands. China depends more on digital monitoring than on a real wetland component. Mirpur neither has natural nor manmade wetlands.

Socioeconomic Characteristics

There are notable vulnerable groups among the economically varied populations that abound at all sites. While in Mirpur resource limitations prevent safe water access, Willingness-To- Pay (WTP) evaluations in Ethiopia (reference site) have shown support for wetland rehabilitation (Asmare et al., 2022).

5. MATERIALS AND METHODS

5.1 Water Sampling & Physicochemical Analysis

Each wetland or water system had water samples taken at inflow, mid-wetland, and outflow points. Analysed values included pH, Electrical Conductivity (EC), Total Dissolved Solids (TDS), Dissolved Oxygen (DO), Biochemical Oxygen Demand (BOD_5), Chemical Oxygen Demand (COD), Total Kjeldahl Nitrogen (TKN), Nitrate (NO_3^-), Total Phosphorus (TP), and selected heavy metals (e.g., As, Pb, Cr). Standard testing used APHA 23rd Edition procedures to guarantee site comparability (Chongjian et al., 2023).

5.2 Health Risk Assessment

Target Hazard Quotient (THQ) for trace metals in drinking water (Bangladesh site)

One of the most important goals of this study was determination of human health-related risks, which are posed by the wastewater that has flowed through or avoided the wetland systems, especially, in the urban Asian settings. The health risk assessment was specifically focused on the site of Mirpur, Bangladesh where the children attending the public schools were observed to be drinking water toxic levels of the trace metals such as arsenic (As), lead (Pb) and chromium (Cr). This type of contaminant is very risky in terms of non-carcinogenic and, possibly, carcinogenic hazard by chronic ingestion (Alikhani et al., 2021). The risk assessment methodology employed the Target Hazard Quotient (THQ) model as recommended by the United States Environmental Protection Agency (USEPA). The THQ quantifies health risk by comparing the estimated daily intake (EDI) of a contaminant with its reference dose (RfD). The general formula used is:

$$THQ = (EFr \times ED \times IR \times C) / (RfD \times BW \times AT) \times 10^{(-3)}$$

Where:

EFr = Exposure frequency (days/year)

ED = Exposure duration (years)

IR = Ingestion rate (L/day)

C = Contaminant concentration (mg/L)

RfD = Reference dose (mg/kg/day)
BW = Body weight (kg)
AT = Averaging time (days)
When THQ > 1, there is a possible health hazard, particularly among the vulnerable like the children. Out of school tap water samples collected in Mirpur, a total of 650 tap samples had a THQ > 1 in arsenic and lead concentrations as well, which demonstrates the necessity of intervention (Abedin et al., 2023). These findings were checked against World Health Organization (WHO) drinking water standards. Notably, such an approach enabled a quantitative health risk attribution to the lack of ecological filtration systems such as wetlands, which points to the necessity of decentralized and nature-based water treatment alternatives in high-density urban environments (Natarajan et al., 2017).
5.3 Socioeconomic Survey (Ethiopia site)
In the quest to combine scientific way of evaluating environmental risk, this study incorporated a Contingent Valuation Method (CVM) in assessing the support of the people and the economic valuation of wetland ecosystems. It was based on this case analysis presented by the Gudera Wetland in Ethiopia that, although this was not the subject of water sampling, it offered vital comparative information in the area of community participation and service pricing of the ecosystem (Alikhani et al., 2021).
CVM is a stated-preference economic technique that is employed to determine the financial worth that people attach to non-market environmental commodities e.g. clean water or the health of the ecosystem. The technique was in form of structured surveys whereby homes were interviewed on their willingness to pay (WTP) to the restoration or preservation of wetland services. This was achieved in form of scenario subjects involving hypothetical payment payoffs, which simulated actual decision-making situations (Chongjian et al., 2023).
Key determinants influencing WTP included:
Household income
Education level
Proximity to the wetland
Perception of wetland benefits (e.g., flood control, water purification)
Strong community-based conservation potential was highlighted by results showing a noteworthy number of rural households ready to make financial contributions to wetland rehabilitation (Asmare et al., 2022). The socioeconomic data provide important new perspectives on the viability of participatory wetland management in many Asian social environments.
Grounding the research in both environmental science and human-centered economics, the THQ and CVM approaches together provide a complete framework for understanding the health consequences of degraded wetland systems and public willingness to support their preservation (Alikhani et al., 2021).
Contingent Valuation Method (CVM) to estimate WTP
CVM would refer to the Contingent Valuation Method or the stated-preference method of economics used to quantify the Willingness to Pay (WTP) of people towards non-market environmental commodities, e.g. preservation of wetlands or the purification of water. As applied in this study, CVM was employed to determine the maximum amount of money that rural households will provide in the restoration of the degraded wetlands basing on the case of the Gudera Wetland in Ethiopia. Using structured surveys with payment scenarios that are hypothetical, the participants were question on how much they would pay on improved wetland services which include clean water, the preservation of biodiversity and flood control (Cui et al., 2020). Their answers depended on such factors as income, education, awareness about the environment, and the closeness to the wetland. The results revealed that the local community is willing to economically benefit through the ecosystem services providing solid grounds on the use of community-based approaches to wetland management and incorporation of WTP into the environmental policy development (Asmare et al., 2022).

6. RESULTS
6.1 Physicochemical Parameter Trends
The result of the water quality parameters assessment in individual sites was that there were clear variations in the concentration of a pollutant up-stream and down-stream of the wetlands. In Amanaka

wetland of Raipur, India, many physico-chemical parameters had elevated levels in the presence of influent water being a sign of domestic greywater and urban runoffs. As an example, Total Dissolved Solids (TDS) in the inflow varied between 710789 mg/L, and Electrical Conductivity (EC) reached its maximum at 1247 0S/cm, which is an indication of high ionic loading. pH levels at all the points were relatively constant with the values of 6.97, 7.3, which indicates neutral or slightly alkaline conditions, which are favourable to microbial activity (Zhang et al., 2021). Having gone through the wetland and other nearby ponds, decreasing TDS, total hardness, and parameters of nutrients were monitored, which proved the ability to reduce such parameters and approve the natural system treating the water and increasing its quality (Cui et al., 2020).On the contrary, coastal cities in China employed the use of machine learning models to forecast changes in the water quality parameters including ammonia nitrogen (NH 3 -N), COD, and DO levels in real-time rather than monitoring physical decrease. Predictive model indicated that the temporal and the type of pollutant had a significant impact, whereas ammonia nitrogen and COD were the most powerful factors affecting the variability on WQI. Although such systems do not include specific wetlands management, monitoring strategy of such systems is priceless in predicting pollutant surge states and how dissolved substances can be handled in complex-urban type of water (Zhang et al., 2021).The case proved to be very different at the Mirpur site of Bangladesh in Dhaka. The measures adopted to determine water quality were restricted to sample of tap water which the school-going children consume that bypass any naturally occurring or constructed treatment facility. Such samples raised the levels of metal(loid) pollutants citing high levels of arsenic, lead, and chromium, implying substantial source or spread pollution. No decreases were detected after the distribution, and it highlights the fragility of communities devoid of ecological, or engineered filtration systems.

6.2 Pollutant Removal Efficiency

Removal efficiencies of main contaminants were high in the Amanaka wetland. The removal of COD was the highest with 87.9%, nitrate (NO 3 -) with 87.2% and Total Kjeldahl Nitrogen (TKN) with 71.4%. The BOD was BOD 5 was lowered by 50.0 and the total phosphorus (TP) lowered by 56.5. Such findings indicate healthy microbial processes and vegetative absorption, which were supported by the availability of water plants Typha latifolia and Eichhornia crassipes.Similar pollutant removal was attained in the Chhattisgarh engineered wetlands that consist of horizontal free-water surface flow systems. The removal of BOD 5 and COD were 82% and 73% respectively and TKN was removed more than 60%. The fact that the TSS removal was higher (>85%) was explained by sedimentation and the filtration of the substrate layers, providing a relatively inexpensive and scalable treatment option (Cui et al., 2020).Conversely, there was no treatment intervention in the Mirpur site and therefore no pollutant removal was made. The level of metal in school tap water was still high, which once again confirmed the weakness of the system. Measurement of removal was not done in the coastal China study and instead it applied the predictive modeling to indicate seasonal change in COD and NH3-N, implying variable pollution levels and not steady mitigation (Zhang et al., 2021).Although Gudera Wetland in Ethiopia was not assessed on the removal of chemicals, the services that the community identified are nutrient retention and water purification. The fact that the community relies on the wetland means that it is functional, even though there would be need to compare them quantitatively. However, cross-site comparison makes it clear that natural and constructed wetlands perform way above systems, which do not have the benefit of ecological buffer, namely, nutrient and organic load alleviation (Cui et al., 2020).

6.3 Public Health Risk Profiles

The most evident of the risks to the population health connected to the problem of the water quality were at the Mirpur, Bangladesh location. The concentration of arsenic in water samples collected at the public schools ranged up to 0.094 mg/L, which is in excess with WHO drinking water standards, lead of 0.04 mg/L, and chromium of 0.038 mg/L which is also above the WHO drinking water standard. Target Hazard Quotient (THQ) analysis showed that in most of the students, THQ was greater than 1 particularly on arsenic and lead (Natarajan et al., 2017). This is a clear indication of the existence of a significant non-carcinogenic danger especially to children, whose body weight is lower and the rate of ingestion is higher; this makes them more prone to the effects of the toxic intake (Kashif Imdad et al., 2023). There was not a single application of any type of pre-treatment, natural or otherwise, which emphasized the systemic threat of water delivery infrastructure unrestricted by ecological precautions. Conversely, Amanaka wetland buffer zone and engineered systems developed in Chhattisgarh indirectly or effectively eradicate these risks as nutrient and pathogen levels are greatly minimized before the water invades the local aquifers or wades to other nearby water bodies.

6.4 Ecosystem Services & WTP

Wetlands also provide important ecosystem services that include purification of water. The recreation component of these services is reflected with the concrete realization of households in the Gudera Wetland case in Ethiopia using Willingness to Pay (WTP) measures obtained using the Contingent Valuation method (CVM). Majority of the respondents observed that they were willing to offer their financial resources towards wetland restoration through perceived benefits like provision of quality water, water supply to agriculture and curbing of floods. The important predictors of greater WTP were the level of education, the household income, and the closeness to the wetland. These results substantiate that wetland services cannot be valued in non-market terms, because in the event of informed, involving community, the community is ready to contribute finance towards conservation (Vivien Chikogu Ameso et al., 2023).This is as compared to the pollution levels of water in cities such as Mirpur where residents have no association with ecological solutions to the urban water problem since they have not seen any wetlands. In places such as Amanaka, informal community stewardship formed spontaneously, as a result of the apparent effect the wetland has on water quality and biodiversity. In this way, we could add social and economical elements like WTP to the models of sustainable and community-based wetland management, particularly, in low- or middle-income areas of Asia.

7. DISCUSSION

This multi-site study offers important new perspectives on how constructed and natural wetland systems in urban and rural environments perform under different environmental and demographic loads. Comparatively between wetland-based water treatment across India, China, Bangladesh, and Ethiopia, the study emphasises the multidimensional function wetlands perform in improving water quality and lowering health hazards as well as the need of context-specific strategies in their management (Natarajan et al., 2017).Despite significant greywater load, the Amanaka Wetland in urban Raipur showed great pollution removing efficiency (e.g., 87.9% COD, 71.4% TKN). On the other hand, despite lacking quantitative water quality assessments, rural wetlands such as Gudera (Ethiopia) were highly valued by the community especially in terms of informal purification and flood control. Although their pollution loads are usually higher, urban wetlands gain from structured monitoring and intervention possibilities. Although less threatened, rural wetlands are sometimes underfunded or overlooked in national water policy.

Natural Systems vs Built Ones

According to the study, if properly built, constructed wetlands like the Chhattisgarh horizontal free-water systems can either equal or surpass natural ones. Like Amanaka's natural system, these systems attained BOD_5 removal efficiencies of 82% and COD up to 73%. Designed with flexibility in mind, hydraulic control, and plant choice, constructed wetlands fit for distributed treatment in growing peri-urban zones.

Seasonal Variations and Monsoon Effects

Wetland dynamics are much influenced by seasonal variations, particularly monsoon floods. Reduced hydraulic retention times brought on by heavy rain could possibly lower treatment efficiency by diluting and overflowing. But, if wetlands are properly maintained, monsoons also present a natural recharging source. Most of the sites in this study indicated a need for longitudinal data collecting since most of them lacked thorough monitoring of seasonal trends (Sileshi et al., 2020).

Factors Affecting Removal Efficiency (RE)

Wetland vegetation greatly affects RE. Species that help with nutrient absorption and sediment stabilisation include Typha latifolia and Eichhornia crassipes. The dense root systems of these plants encourage microbial biofilms in charge of nitrogen and phosphorus transformations. While population density determines inflow volume and pollution concentration, particularly in uncontrolled urban catchments, greywater composition with high organic matter and detergues can affect microbial balance.

Effects on Health Risk

The Mirpur (Bangladesh) site amply demonstrated the effects on public health of insufficient treatment. Children attending schools run unacceptable health risks based on THQ > 1 for arsenic and lead. Sites with natural or built wetland buffers showed improvements in water quality, so indirectly lowering exposure risks by stopping contaminant seepage into drinking sources or groundwater (Kashif Imdad et al., 2023).

Suggestions for Policy

Several policy decisions are advised to realise the full possibilities of wetlands in Asia. First, legal designation and enforcement of wetland buffer zones around metropolitan wetlands should help to lower direct sewage flow and stop encroachment. Second, pollution load mapping over catchments can direct the siting and size of built wetlands and guide adaptive management (Sileshi et al., 2020). At last, public participation in wetland valuation as shown by Ethiopia's WTP results should be included into wetland preservation plans to support sustainable financing sources and co-management.

All things considered, wetlands urban or rural, natural or manmade are indispensable for attaining integrated water and health security over Asia. Still, their success relies on context-aware design, ongoing community service, and evidence-based policy development.

8. CONCLUSION

The multi-site study reinstates the fact that wetlands are very important, multifunctional ecosystems that can solve two out of the top three most serious environmental issues being faced in Asia today: the worsening water quality and increase in the health hazards. In the wide range of the study site, such as the natural urban wetland of Amanaka in India, the managed engineered systems in Chhattisgarh, the predictive monitoring of wetland in the coastal city of China and the crisis of untreated tap water in Bangladesh, there is a common word that wetlands are a cost-effective, decentralized system to treat wastewater so long as it is properly managed. They help not only to decrease a number of pollutants: BOD 5, COD, nitrates, and TKN but also protect the areas where local populations live indirectly by avoiding their exposure to harmful pollutants including trace metal (Sileshi et al., 2020).Performance of these systems however varies widely in regard to the geographical context, the type of wetland (natural or constructed) and the degree of urbanization. City wetlands may have even more hydraulic and pollution pressure but the benefit is that data are available and interventational activities are possible. Rural wetlands on the contrary are less pressured and community oriented but not usually monitored and guided through guidelines.Notably, site-specific results once combined and synthesized into a pooled comparative perspective disclose answers that are beyond the focus of particular case studies, such as shown in the current research. Such comparative insight permits the development of flexible, scalable and region-specific wetlands systems, which is appropriate to broadly varying environmental and socioeconomic scenarios across Asia (Vivien Chikogu Ameso et al., 2023).To summarize this discussion, the right kind of wetlands can be used as a decentralized means to treat wastes, as well as to provide enhanced protection to the health of the people. They should be allowed to work together and ensure the preservation of the extant wetlands, build new treatment systems at the places where they may be required, and inculcate the valuing of wetlands into city water governance. Such a solution will contribute not only to the improvement of environmental sustainability but will also provide sustainable resistance to the growing water-related health risk in the Asian continent.

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