Existing Solutions for Overcoming Construction Challenges in Water Treatment Plants

Mohd Anuar Mohamad[1,2], Musmuliadi Kamaruding*[1]

[1]Faculty of Civil Engineering, Universiti Teknologi MARA, 40450, Shah Alam, Selangor

[2]Gamuda Engineering Sdn Bhd, Menara Gamuda, PJ Trade Centre, No. 8 Jalan PJU 8/8A, Bandar Damansara Perdana, 47820 Petaling Jaya, Selangor, Malaysia

***Corresponding Author**

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ABSTRACT

This paper is a wide-ranging review of the obstacles and solutions involved in the construction of water treatment facilities (WTPs) based solely on an up-to-date literature review. Water treatment is key to opening clean water access, but WTP establishment is hindered by some technical, environmental, financial, and administrative challenges. Among the issues listed are very high costs of construction and operation, challenges of site selection, high energy consumption, greenhouse gas emissions, unsustainability of materials, and various regulatory constraints. A paper also enumerates strategic methods of overcoming these constraints, including the integration of renewable energy sources, conducting life cycle assessments, preferring green materials, improving project planning and management, and increasing the involvement of stakeholders. The review, through the confluence of scholarly and technical sources, is an advocacy for multidisciplinary approaches, the use of green technologies, and policy reforms that would take place to enhance sustainability. The perspective is provided to assist policymakers, engineers, and project managers in making more effective decisions during future water infrastructure undertakings.

Keywords: WTP; Construction Challenges; Strategies; Literature Review

INTRODUCTION

The global water demand for clean and reliable water continues to grow as a result of rapid urbanization, industrial development, and the increasing population density globally. This skyrocketing requirement reiterates the basic point, reflecting the necessity of establishing water treatment plants (WTPs) as foundational infrastructure for the delivery of clean water for domestic, industrial, and environmental applications (Melero et al., 2024; Nawgaje, 2022). Furthermore, while WTPs can play vital roles in public health and sustainable development, they are still associated with a long list of complex and interconnected problems that extend beyond the technical area of construction (Jayaraj, 2024).

The most significant problem lies in the inefficiencies of project execution. They include boundaries of the unclear work, inconsistency of the interagency communication, and unsuitable planning. Above all, this issue is more poignant in large-scale or publicly funded projects, interfering with the timely completion of projects, overrunning balanced budgets, and decreasing efficiency levels (Nawgaje, 2022). In fact, picking a site also brings considerable challenges, since it includes environmental assessments, availability of land, regulatory compliance, and a projected demographic change (Melero et al., 2024). On the one hand, modern technology and evolving regulatory requirements are at the core of WTPs. On the other hand, they should consider adjustable designs that can handle future innovations and upgrades (Davies et al., 2021).

Environmental factors tend to grey out the picture of WTP growth. This construction phase and the operation phase consume significant energy and raw materials, which consequently contribute to greenhouse gas

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emissions and ecological degradation. In response, green practices, including the utilization of low-impact components, renewable energy systems, and energy-efficient systems, are promoted gradually to reduce carbon footprints (Zhang et al., 2024). Beyond environmental factors, social and regional constraints such as local efforts opposing our projects, inadequate infrastructure, the role of climate in the whole picture, and lack of land can spur along, especially in the developing and vulnerable regions (Melero et al., 2024; Shao & Xu, 2023).

Therefore, due to the complexity and variety of these kinds of issues, both the challenges and the mitigation strategies play a significant role in the successful WTP planning and implementation. The discussion of identifying sophisticated challenges of WTP construction through education literature, as well as examining strategic responses to this in technical, environmental, financial, social, and governmental aspects, is the main purpose of this article. Future WTP projects can be modified in a way that they become more resilient, transparent, and accepted by the public by taking the entire system into account and using a stewardship approach.

Challenges in Water Treatment Plant Construction

Constructing a WTP entails numerous multifaceted challenges that extend beyond the purely technical aspects of engineering and design. These challenges intersect across technical, environmental, social, and regional dimensions, often compounding one another to create complex barriers to timely and efficient project delivery. Figure 1 illustrates the broad categories of challenges commonly encountered in WTP construction projects.

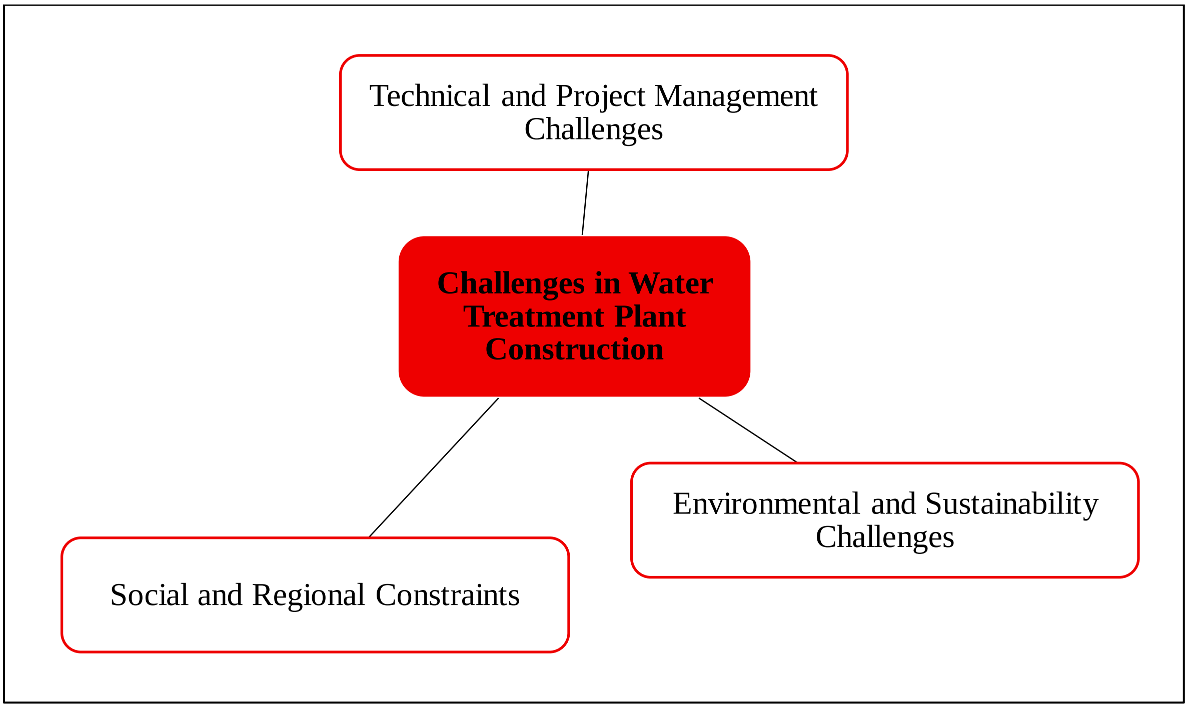

Figure 1. Challenges in WTP Construction

Technical and Project Management Challenges

Among the primary concerns in WTP construction, as it is applicable, are the technological intricacy and the managerial shortcomings of the project. WTPs and other public infrastructure schemes often face ineffectiveness in their planning and execution, which is caused by the limitation of a budget, strict company timelines, and unfocused project management (Abbasi et al., 2021). It is even more evident in the case of public-sector construction projects, where there is a requirement for many kinds of licenses and regulatory approvals, and therefore, stakeholder involvement is at a higher level. The projects are usually characterized by poor scope definitions, dysfunctional interactions among different government agencies, and slow decision-making processes, all of which are responsible for delays and increased project costs (Khuzwayo & Chirwa, 2020; Jayaraj, 2024).

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Another source of the problems stems from the shortcomings of the respective risk management systems. Failure to formulate and enforce preventive strategies on risk identification and mitigation could expose projects to unforeseen disruptive incidents like delays in procurement, construction hazards, and technical design errors. According to Nawgaje (2022), managing a complicated overlay that involves contractors, engineers, consultants, and government institutions calls for superior project management capabilities, a skill that might not easily be found in developing regions.

As for the site selection, it itself is the main factor of technical difficulties. The general idea that any land could serve WTPs does not hold, as it is important to choose locations that would take into consideration such factors as environmental sensitivity, hydrological conditions, and distance to the areas served. Labor-intensive on-site assessments of the environment, geographic barriers, and the long, cumbersome, and expensive land acquisition processes are invariably the case. Melero et al. (2024) noticed that project timelines can be extremely delayed by the administrative red tape, which includes getting permits and handling local administrative affairs.

This issue of technological integration further deepens the complexity. Modern WTPs require the inclusion of smart control systems, SCADA (Supervisory Control and Data Acquisition), and automatic process integration, which are the basis for modern STPs. The goal remains to play around with concepts that not only accommodate current operational requirements; however, they must also be flexible enough to adapt to future regulatory amendments and technological advancements. This leads to the challenge of keeping a high enough level of technical foresight and adaptation in terms of design, which often seems rather unfitting in conventional public procurement practices (Artiom, 2023; Kamal & Ali, 2023).

Environmental and Sustainability Challenges

Environmental issues have been a particular cause of concern lately in the field of WTP construction in view of increasing awareness of such projects' carbon footprint (Melero et al., 2024). The construction phase is when the vast quantity of concrete, steel, etc. is used, and that produces greenhouse gas emissions. The other problem regarding construction works is the local ecosystem damage, soil and water pollution, and biodiversity loss if the construction activities are not well managed. Zhang et al. (2024) carefully address the fact that the need for construction in the presence of great ecological sensitivity is one of the major concerns in these protected areas.

Consequently, WTPs during operation present a huge drain on these resources. The treatment of water is highly energy-intensive, which is usually generated from fossil fuels, and on the chemicals whose waste would otherwise be pollutants to the rivers, streams, and oceans that affect aquatic animals. In places with environmental regulations that are of low or poor enforcement, consequent to this effect, these harmful effects become magnified. Adapting to evolving environmental standards while protecting cost-efficient operations needs a lot of attention from the designers and the contractors (Masindi & Manjoro, 2024).

Moreover, climate change leads to the introduction of a new layer of multifaceted problem sets. Rising temperatures and erratic rainfall patterns, together with adherence to the increasing incidence of extreme events, are some of the considerations that should be factored into the design of future WTPs. This composition seeks to affirm that modern water quality monitoring will take into consideration upsurges in raw water quality (two distinct sources), unpredicted changes in demand patterns, and vulnerability to floods, droughts, and other natural disasters. Ignoring these aspects in the planning of the system may lead to the breakdown of the system or require retrofitting soon after it is commissioned (Compaoré et al., 2023).

Social and Regional Constraints

A WTP project construction is entitled to several relevant non-technical relations and regions that affect its overall effectiveness, design, and implementation. However, ongoing urban sprawl as well as a growing population in several regions have resulted in heightened demand for treated water, which is almost always quicker than the construction of the infrastructure (Beker & Kansal, 2023). In pedestrian urban fabric cities, urban land comes under great pressure, and sometimes construction of treatment plants hardly happens in landscarce areas. Urban flooring is not only pricey but also politically and logistically time-consuming and costly, particularly in regions where informal settlements are present or competing development trends or interests can be found (Liu et al., 2024).

Development of infrastructure in those very regions proved to be a complicated task due to the presence of such underdeveloped connectivities as transport, energy supply, or sanitation systems. The problems of access roads that are dilapidated, an electricity supply that is distorted, and the network that is limited network may prolong the delivery time of construction materials to the site or hinder some operations. These logistical issues are most evident in rural areas and remote zones, which require additional financial resources and consume time to move around (Shao & Xu, 2023).

Furthermore, what makes these processes complicated is the fact that there is a variety of community outlooks on development and the political environment. Positional opposition of the general community, which is centered on fears of environmental pollution, displacement of communities, or disruption of cultural values, could stop or suspend the project entirely (Alfirdaus et al., 2023). Collaboration with local communities is often inefficient or unorganized, which causes distrust and project opposition. This situation means that social license, no less than technical permits, is a prerequisite as well (Khoury & Scott, 2023).

Furthermore, regional disparities in governance and institutional capacity are considered quality determinants and impact project results. Destinations characterized by weak enforcement of regulations, diffusion of authority among overlapping jurisdictions, or absence of labor with the required skills may go through a prolonged project implementation period and issues with construction quality. Shao and Xu (2023) maintain that it is the outdated infrastructure of these WTPs that is characterized by weakness under these circumstances and is also ill-equipped to respond to new stressors such as climate-driven water resource variability, which both create urgency for the system upgrade and difficulty because of the lack of time.

Strategies to Address Challenges in WTP Construction

Addressing the multifaceted challenges in water treatment plant (WTP) construction requires an integrated and systemic strategy that goes beyond isolated technical fixes. As illustrated in Figure 2, effective solutions must incorporate innovations in engineering design, financing models, policy frameworks, and community engagement mechanisms. A reactive or fragmented approach is no longer viable in the face of climate uncertainty, urbanization pressures, and regulatory complexity. Instead, a proactive, cross-sectoral approach is essential to ensure the delivery of resilient, adaptable, and sustainable water infrastructure.

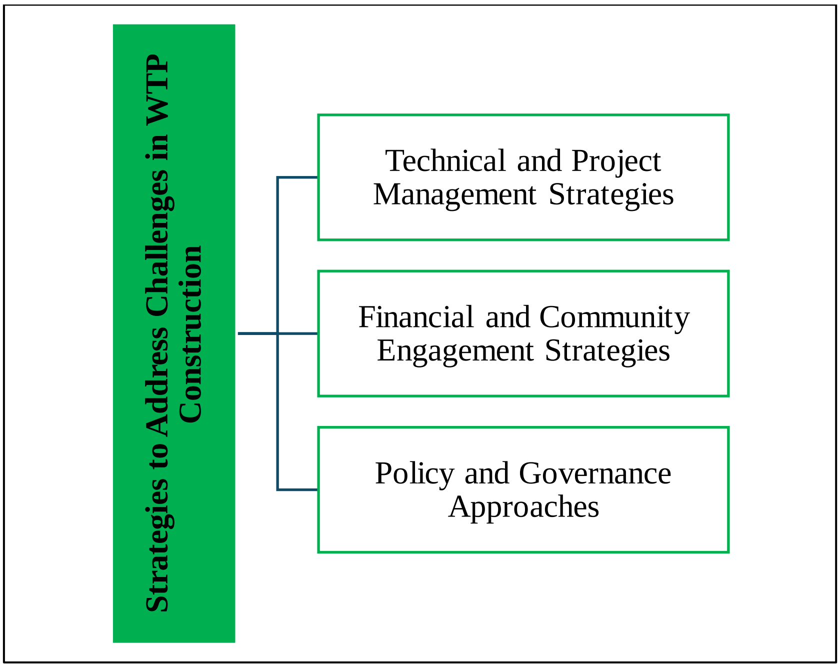

Figure 2. Strategies to Address Challenges in WTP Construction

Technical and Project Management Elements

The earlier mentioned sophisticated technical and project management encumbrances, which include improper planning, flawed risk management, and uncoordinated stakeholders, can well become a reality due to the inadequacy of conventional engineering and project management methods. A critical strategy is the application of flexible and gradual design principles, which enable the upgrade or reconfiguration of infrastructure components in line with future changes in population growth, environment, or technology development. To truthfully illustrate, seismic-resilient framework systems or scalable membrane filtration systems can drastically make the plant more adaptive under physical or regulatory stress (Batukan et al., 2021; Davies et al., 2021).

Another key technical method is transforming the old-type design-bid-build (DBB) model to modern techniques such as design-build (DB). In stark contrast to DBB, which divides the design and production stages and often sees miscommunication and redoing them, the DB method promotes stronger collaboration between the design team and the production team from the start. The service in this way provides quicker decision-making, fostering greater dynamic collaboration as well as better governance between the project team and the implementation team. Davies et al. (2021) make a noteworthy point that DB strategies are especially suitable for the types of projects wherein the time, costs, and stakeholder complexity are significant constraints.

The instrumental character of professional project management, however, cannot be underestimated as well. Well-trained managers provide valuable coordination, budgeting, and performance monitoring functions that are often non-existent in disjointed or government-inclined projects. As per the project managers' experience, they are versed in risk anticipation, dynamically modifying schedules, and ensuring quality in a multi-disciplinary environment. Lopes et al. (2024) have the point that the provision of strong project management reduces delays and cost overruns and, at the same time, tackles the problem of technical and managerial challenges.

Financial and Community Engagement Strategies

In countries or regions, businesses are facing obstacles like public opposition, lack of resources, and financial gaps that hinder their operations. Consequently, financial models and approaches for stakeholder engagement for businesses offer sustainable ways to deal with these challenges. Transparent communication about the construction site's intention, advantages, and possible harms is crucial for building public confidence and goodwill to operate. It can be communicated to the community in case the project extends over a long time and will entail more cost (Forman & Udvaros, 2023; Misnan et al., 2024).

On the financial side, equity-based contracts with Guaranteed Maximum Price (GMP) have the potential to contain the engulfing financial risks of the budget overruns of WTP. By providing a ceiling for this cost, the GMP contracts give confidence to both the funders and the contractors, making them more responsive and careful in their dealings (Chammout et al., 2024). Secondly, through public-private partnerships (PPPs), these methods have developed into financing modalities that can address public funding shortfalls. These public-private partnerships enable governmental agencies to supplement public funding with private capital, technical know-how, and risk-sharing umbrellas so that public-financing pressure is reduced and public project delivery is more efficient (Fouad et al., 2021).

Further your financial strategies through the adoption of green technology integration, such as solar-powered systems or energy-efficient pumps. They may require upfront investment, but also realize long-term operational savings. Enterprises are those with the key foundations for these sustainable practices and a huge investor and innovator share, especially with low resources (Rumbayan et al., 2025)

Policy and Governance Approaches

The deficient governance systems, red tape, and a single plan for all infrastructure do build critical obstacles in WTP construction. These problems can be put in check by early and full stakeholder involvement from the very beginning of the project. Identifying the locally-based leaders, residents, regulatory federations, and landowners at the outset ensures accessibility to context-specific inquiries and minimization of counterarguments to land acquisition or construction (Ding et al., 2019). Such inclusive governance additionally reinforces the sense of ownership in stakeholders as the projects become legitimate, and compliance is enhanced.

Localized governance structures are significantly pivotal in rectifying regional inequalities. By gradualization, a federal regulation may be too standardized or inappropriate for a given ecological or social context. Adapting governance to local situations, like customizing environmental compliance procedures using regional water quality norms or modulating construction standards based on local geological background, could enhance the efficiency of the approval processes and increase the relevance of projects. Flores (2022) claims that when governance is sensitive to the particular challenges of each site, it not only avoids delays but also expedites the sustainability performance.

Furthermore, on the policy coordination front between local, regional, and national bodies, continuous efforts are made in order to get rid of discrepancies that hamper the progress of construction (Chen et al., 2025). Prioritization of the inter-agency task forces for WTP construction ensures that the technical, environmental, and regulatory assessments are not looked after separately. The integration of a dedicated governance network results in a more streamlined permit processing system, improved land-use planning, and a more comprehensive implementation of urban water strategies (Kalogiannidis et al., 2023; Owatsakul et al., 2025).

CONCLUSION

The construction of WTPs is essential for ensuring a sustainable and reliable water supply, particularly in the face of rapid urbanization, population growth, and climate uncertainty. However, as highlighted in the reviewed literature, WTP development is fraught with multidimensional challenges that span technical shortcomings, environmental constraints, financial limitations, and socio-political resistance. Common issues such as inadequate planning, fragmented stakeholder coordination, prolonged regulatory approvals, inappropriate site selection, ecological degradation, and limited public acceptance continue to hinder timely and effective implementation.

Overcoming these obstacles demands a holistic and integrated approach. Technically, the adoption of modular and adaptable designs, coupled with the integration of advanced and energy-efficient technologies, can enhance operational flexibility and long-term resilience. Project delivery models such as Design-Build (DB) offer improved coordination and time efficiency over traditional methods. On the financial front, risk-sharing mechanisms like GMP contracts and PPPs can ease budgetary pressures and accelerate project delivery, especially in resource-constrained regions.

Equally important are social and governance strategies. Building trust through transparent community engagement and ensuring meaningful stakeholder participation contributes to smoother implementation and long-term public support. From a policy perspective, aligning regulatory frameworks with local environmental, demographic, and legal contexts enhances both compliance and relevance. Early involvement of all relevant actors promotes accountability, mitigates conflict, and fosters shared ownership.

Ultimately, the success of WTP construction projects hinges on the ability of engineers, planners, and decision-makers to anticipate and respond to complex, evolving challenges with innovative, inclusive, and context-sensitive solutions. As global water demand and environmental risks intensify, investing in robust, sustainable, and community-aligned WTP infrastructure is not only a technical necessity but a societal imperative.

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