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“The Best Solution for Centralized and Decentralized Wastewater Treatment in the Makkah Region in Saudi Arabia”

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Abstract:

The research establishes the best solution for centralized and decentralized wastewater treatment in the Makkah region in Saudi Arabia. The research used a thematic coding approach to identify literature materials on the research problem. The literature review indicated that wastewater treatment could be optimized by integrating multiple practices. The proposed solutions include creating awareness and optimizing safety standards, expanding the treatment plants and optimizing them, integrating treatment processes through centralized and decentralized wastewater treatment plants, using simple systems and technologies, expanding existing plants, optimizing performance, adopting cost-efficient strategies, and using the Right Technology, Control, and Integration Systems.

Introduction:

The wastewater management system and practices in Makkah Governorate (MG) are critical to environmental sustainability and population health and safety. A review of the region's population influx and unsustainable wastewater treatment practices indicates the need for improving, improvising, or adopting modernized strategies to optimize wastewater treatment (WT) practices. The city's geological, cultural, and religious significance to Saudi Arabia (SA) and the middle east makes its management a top priority. Osra et al. (2022) note that it has undergone rapid development, urbanization, and infrastructure burden. WT is part of the management process essential to healthy urban communities. A considerable proportion of the waste disposed of in the city is from foreign visitors, both domestic and international tourists, to the city (Osra et al.). The celebration of feasts and other cultural periods brings together multitudes to the city, necessitating an efficient system to manage waste disposal.

Essential aspects of waste management include clean water, drainage system, toilets, and solid waste. An efficient waste management system should cater to every user in public spaces, including individuals with disability ty. However, achieving the optimum or ideal waste management system is challenging for the management due to poor systems and public misconduct. Notably, waste management issues include the factors impeding or enhancing the established system's efficacy and external factors, including the public's behavior towards public space use and waste disposal. WT focuses on the system's efficiency. SA has a pressing waste challenge at the national level. According to the International Trade Administration (ITA), the country generates approximately 53 million tons of waste materials annually (International Trade Administration., 2023). The waste is responsible for water contamination and soil pollution. The country incurred approximately $1.3 billion to waste management or mismanagement in 2021. Makkah is not among the largest contributors to waste. ITA identified Dammam, Jeddah, and Riyadh as the leading waste accumulators, contributing 8%, 14%, and 21%. They cumulatively make up 43% of the nation's waste. Their share and status influence other cities and regions' attitudes and approaches to WT. they must lead in WT to reduce the burden of such disposals to the nation's ecosystem. Nevertheless, other cities and urban locations, including Makkah, have a significant role in creating a sustainable ecosystem to assure its visitors and inhabitants of clean water, hygienic toilets, public spaces, and efficient drainage and WT systems.

Makkah plays a central role in WT in SA, and this reputation requires optimization through strategic development and revelation of the region's WT mission and goal. According to Nizami et al. (2015), the city's waste management system is overloaded during festive seasons. The landfills receive approximately 2750 tons of waste, but the proportion increases disproportionately during Hajj and Ramadan as the landfills receive 3000-4706 tons daily. The festival seasons significantly impact waste management practices as a significant volume of untreated waste is released. For instance, 2.5 million tons of untreated waste was released into the environment during 2014's Hajj. Further, approximately 2.1 million Zam-Zam cups were disposed of during the 2014 Ramadan season. Despite this waste disposal, Nizami et al. note that Makkah and SA lack a waste-to-energy treatment plant. This would become a transformative project should the government of Makkah and SA's national government establish a WT plant to help manage the organic and inorganic waste released during the festivals and other occasions. Organic waste treatment would generate approximately 2171.47 TJ, and a plastic WT would produce 8852.66 TJ. Therefore, SA would generate alternative energy sources, contributing to its goal of reducing its greenhouse gas footprint. There is a vision to create waste management systems focusing on the solid waste that could overlook the impact of wastewater treatment.

Wastewater treatment is a major issue linked to solid waste management and a practical challenge in Makkah socially during festivities. It forms a critical interface in the public space waste release collected through the sewage systems. Alahdal et al. (2021) state that SA has a centralized and decentralized wastewater treatment mechanism. However, they are chaotic and likely to fail in a high-demand situation. for instance, they observe that in Damman, Riyadh, and Jeddah, only 78, 60, and 50% of the wastewater from sewages and other public spaces are treated. The untreated 12-50% possess significant environmental and health hazards. Moreover, the article indicates that efficient wastewater treatment occurs only in half of the urban centers, and the other half is managed through septic tanks and other unregulated mechanisms. The national water company (NWC) operates in Makkah, Jeddah, Riyadh, Medina, and AL Tafi, forming a centralized wastewater management system. The generated cleaned water is applied to other uses, including irrigation. Understanding wastewater

treatment within the broader tourism framework, public use of public spaces, and management systems is imperative. Therefore, what is the future of Makkah's WT and environment management? Advancing requires integrating systems, personnel, policies, and equipment to optimize the WT process and make Makkah a healthy and attractive destination for local and international tourists during various festivals. Moreover, it is essential to the health and continuity of Makkah's inhabitants, who must adjust to the tons of waste, including plastics, glasses, and organic food left behind. A rigorous wastewater treatment and management system in Makkah must address the challenges of excess waste before, during, and after festivities through a system that enhances collaboration among stakeholders, tracks the water treatment process, adopts alternative treatment processes, builds awareness, uses best practices, monitors compliance and embraces a long-term strategy.

Methodology

Method

The study adopted a grounded theory research approach. The design analyzes established information acquired through systematic data collection approaches. Grounded theory (GT) focuses on developing a theory by analyzing data on a phenomenon (Noble & Mitchell, 2016). The research focused on identifying an optimum solution for centralized and decentralized wastewater treatment in the Makkah region of Saudi Arabia. The proposal requires proceeding from established knowledge or information to a theory of practice that can inform the water treatment system. The study method qualities include simultaneous data collection and analysis, categorizing data using themes and codes derived from the data, and integrating their categories into a theory. The research used a systematic review integrated with the GT method. Bowers and Creamer (2021) note that research techniques are evolving, and integration of the GT into systematic review (SR) has been used by other scholars, despite variations in how the techniques are blended and what sections of GT are emphasized when coding and revising the data and theory.

The fundamental concepts of GT guided the study. The core principles include theoretical sampling, theoretical sensitivity, and data analysis (Noble & Mitchell, 2016). Theoretical sampling involves data collection, coding, and analysis. Further, the researcher develops a concise position on the data relevance, application, and impact of the outcomes on future studies. This approach was instrumental in the study data collection, coding, analysis, and conclusion. The researcher grounded this outcome in the study background, highlighting issues in the wastewater management system, contextual factors, and possible outcomes in an unbiased study. This required integrating the theoretical sensitivity concept into the research. Theoretical sensitivity relates to the researchers' ability to think critically, creatively, and objectively in data analysis (Noble & Mitchell, 2016). The concept was developed through comprehensive literature from the study background and evaluation of other materials.

The SR approach has a concise and objective data collection and analysis strategy. The research method focuses on conducting a rigorous literature review of higher quality than a simple literature review section in general articles. According to Bowers and Creamer, the study must follow specific steps, including developing a research question, searching literature materials, screening them to establish relevance and quality, extracting, analyzing, synthesizing data, and sharing data. A researcher using this technique can use interpretive synthesis to code and develop themes from the research. Therefore, the study adopted the interpretive synthesis in the systematic literature survey within the framework of grounded theory design.

Materials: Data Collection

Sampling

The research used a seven-step approach to identify and sample literature materials. The steps included using the research question, establishing keywords, querying databases (ProQuest, Science Direct, EBSCOhost, Google Books, and Google scholar), establishing a list of suitable sources, selecting the sources providing answers to the research question, categorizing the sources based on themes, and summarizing the themes using a three-step data analysis process (1) open-ended coding, (2) axial coding, and (3) selective coding.

Research Question

How can Makkah optimize its centralized and decentralized wastewater treatment to enhance the public and tourists' safety?

Keywords

Makkah, wastewater, treatment, centralized, decentralized, safety, public, tourists

Literature search strategy

The research sought literature materials using the keywords. The search included developing phrases for targeted and general searches on the internet to query literature materials. The following phrases/questions (Table 1) were used to identify relevant materials.

Table 1 phrases/questions were used to identify relevant materials

Question	Objective

What are the best strategies to optimize Wastewater treatment?	Identify articles on strategies to optimize wastewater treatment
What are the challenges of centralized and decentralized wastewater treatment?	Identify articles on the centralization and decentralization of wastewater treatment globally.
How has Makkah managed its wastewater treatment?	Limited search to Makkah on its wastewater management practices.
What are the opportunities for wastewater treatment in Makkah?	Limited search to Makkah- identifying opportunities for wastewater treatment.
What are the best wastewater treatment technologies globally?	Global search on what other countries and cities have done to improve wastewater management.
What are the causes of failed wastewater treatment practices?	Search materials on Makkah and other countries' wastewater management practices to identify the best or most feasible approach.
What are the best practices to optimize water treatment?	Local, national, and international best practices have created safe drinking water. The goal is to identify the best wastewater management practices.
Are tourists visiting Makkah happy with the waste management system?	To establish studies on tourists' perception of Makkah's wastewater management practices and their attitude towards public spaces' safety and quality standards.
How can Makkah optimize its centralized and decentralized wastewater treatment to enhance the public and tourists' safety?	To identify studies conducted on wastewater management practices and systems in Makkah. To identify Makkah's ongoing wastewater management practices. Identify articles on how the wastewater management system can be optimized.

Data Analysis

The research used three data analysis stages in the research analysis. Noble and Mitchel propose open, axial, and selective coding as the three data analysis steps applicable to GT. Open coding is a systematic approach to data analysis requiring rigorous analysis of each line. In the first stage, the researcher develops a summary and overall analysis of the data to form categories. The categories are further synthesized to form the next category. Notably, the researcher proceeds from general to specific theory. Moghaddam (2006) defines open coding as a strategic tool for breaking down large data into categories whereby the clustered concepts are based on a theme. The steps include analyzing, comparing, labeling, and categorizing (Moghaddam, 2006). The next stage, axial coding, involves establishing a relationship between the categories. The researcher analyzes the codes formed in the open coding phase and synthesizes them into simpler codes based on their relationship. Therefore, the technique progresses in a pyramid-like manner whereby more information at the base gets simplified as the analysis progresses (Moghaddam). The core categories have unique qualities, including being relatable to other codes, having higher appearance frequency, possessing abstract qualities that allow research into other areas, and can explain variation and concepts conveyed by the data. The final stage, selective coding, targets establishing the theory from the data summary and categorization in the open coding ad axial coding phases. At this phase, the researcher relates other categories to the core category (Moghaddam; Nobel & Mitchel). The research progresses to establish conditional relations between the categories and the core category.

Validity and Reliability

Research data reliability, credibility, and validity are critical to establishing the quality of the research paper. The research considered multiple factors to establish the literature's material credibility. First, the study established reliable and credible journal platforms. These included ProQuest, Science Direct, Ebscohost, Google Books, and Google scholar. Next, the researcher determined the sources' credibility by evaluating the researcher's professional credentials, publication date, and research rigor. The researcher's credibility involved determining whether they were professionals in their writing area. The studies must have been published within the past ten years. Notably, the researcher considered materials from various nations, not limiting the study to papers published in Saudi Arabia. This approach was necessary to gain knowledge and history of what other cities or countries have done to optimize wastewater management systems. Information from the diverse pool formed the basis for recommending strategies to apply within Makkah and SA.

An empirical approach is a critical tool in establishing GT research validity. Lomborg and Kirkevold (2003) note that the realist ontological approach to truth and knowledge is fundamental to establishing research validity and reliability. Realist ontology postulates that reality and truth exist regardless of the researchers' knowledge, belief, or practices. Its position indicates that humans can access truth, knowledge, or information aligned with the real world. Therefore, the information is only true if it is validated by the practical, real, or external world. Moreover, the realist ontological view posits that the ultimate truth is often beyond reach, but the researcher should relentlessly seek the truth. Epistemology provides the basis for assumptions, limitations, and the need for further research since no truth is final, but all truths are important. Therefore, the research adopted a realist ontological perspective in collecting literature on subjectivity and summarizing thematically to establish the best practice standards for optimizing wastewater treatment in Makkah. Therefore, a qualitative study's validity depends on the researchers'' objectivity and structured approach to data collection and analysis. Moreover, it depends on the rigor of the literature materials forming the basis of the study. **Results**

The research sampled eight articles answering the research questions. The results are summarized in table 2 below. The literature search focused on ensuring the literature articles were specific to the research problem and extensive in answering the research question. Moreover, the table summary includes pertinent information that guided the discussion section, including the study question, article, authors, publication date, journal platform, study methodology, themes, and summary. Importantly, the questions were condensed to six essential questions whose articles answered the key question and the need for safety assurance.

Table 2 Results Summary

Question	Authors and Date	Focus	Journal	Themes	Summary
1. What are the best strategies to optimize Wastewater treatment?	Bai, Tu, Sun, Zhang, Yang, and Ren published the article in 2021.	Optimization of wastewater treatment strategies using life cycle assessment from a watershed perspective.	The article was published on a credible journal platform: Cleaner Production. It used a Case study methodology.	Sustainability	The article recommends adopting a sustainable wastewater management practice that lowers the overall burden on the environment and considers the capacity of the receiving waterbody, including river, sea, or ocean. The authors note that extreme and complex management systems can become costly and detrimental as more chemicals and other unsustainable materials are released into the water bodies. The study recommends using decision-supported tools to establish the best approach based on the situation.
	Rajaei and Nazif published the article in 2022.	Improving wastewater treatment plant performance based on effluent quality, operational costs, and reliability using control	Process Safety and Environmental Protection It used a Case study methodology.	Sustainability	The article recommends using a control strategy to regulate the rate at which the sludge flows and the oxygen concentration and aeration. They observed that the effluent quality increased when the sludge line and oxygen concentration were optimized; the effluent quality improved by at least

		strategies for water and sludge lines.			9%, and the operational cost increased by 1%.
2. What are the challenges of centralized and decentralized wastewater treatment?	Capodaglio published the article in 2017.	Integrated, decentralized wastewater management for resource recovery in rural and peri-urban areas.	Resources	Sustainability	The research recommends decentralized wastewater treatment alternatives as sustainable approaches to managing wastewater locally. The author presents decentralized WT as beneficial to solving local water needs by providing mechanisms to recycle the water or alternative sources of water for agriculture. The author recommends a technology selection strategy suitable for local or wastewater treatment plant needs. The author argues that sustainable technology is affordable, environmentally protective, institutionally and technically consistent, and socially agreeable. However, the decentralized approach is flexible and could be less regulated.
	Gómez-Román, Lima, Vila-Tojo, Correa-Chica, Lema, and Sabucedo published the article in 2020.	"Who Cares?": the acceptance of decentralized wastewater systems in regions without water problems.	The article was published on a credible journal platform: the International Journal of Environmental Research and Public Health. The researchers used a systematic literature review.	Technology Awareness	The article observes that population awareness of the benefits or limitations of decentralized or centralized wastewater treatment influences the acceptance of either strategy. They note that decentralized wastewater treatment can help resolve local communities' water problems.
3. How has Makkah managed its wastewater treatment?	Alkhudhiri, Darwish, and Hilal published the article in 2019.	Analytical and forecasting study for wastewater treatment and water resources in Saudi Arabia.	The article was published on a credible journal: Journal of Water Process Engineering. The research used a Quantitative research methodology.	Technology	The study notes various technologies adopted across Saudi Arabia. Makkah uses a Tricking filter/Activated sludge, a tertiary treatment type. The first phase would direct the water to agriculture, and the second phase to industrial development: The lack of incentives to improve the water treatment practices

					and poor wastewater treatment are obstacles to developments in the industry.
4. What are the opportunities for wastewater treatment in Makkah?	Alkhudhiri, Darwish, and Hilal, published the article in 2019.	Analytical and forecasting study for wastewater treatment and water resources in Saudi Arabia	The article was published on a credible journal: Journal of Water Process Engineering. It used Quantitative research – forecast design.	Technology	The study proposes several areas the wastewater treatment sector can target using technologies like media filtration and oxidation ditch that are not practiced in Makkah but with a larger capacity to treat up to 133,000 to 210,000 m^3/day. Makkah's current approach uses Tricking filter/Activated sludge with a treatment capacity of 24,000-50,000.
5. What are the best wastewater treatment technologies globally?	Khan, Ponce, Yu, Golpîra, and Mathew published the article in 2022.	Environmental technology and wastewater treatment: Strategies to achieve environmental sustainability.	The article was published on a credible journal platform: Chemosphere. The research used a Quantitative method- forecast design.	Sustainability through technology integration	The study presents water as an essential resource. They note that water treatment5 should achieve an optimum decontamination process whereby the treated wastewater can be recycled, used for domestic consumption, or released to the environment. The paper asserts that the right technology is essential to achieving environmental sustainability. They evaluate several technologies, including nanotechnology, ionic liquids, and 3D technology that removes heavy metals, nitrogen, and copper. Moreover, the article recommends the integration of renewable energy to lower energy consumption and boost wastewater treatment.
6. What are the best practices to optimize wastewater treatment?	Li, Su, and Wang published the article in 2021.	An effective integrated control with intelligent optimization for the wastewater treatment process.	The article was published on a credible journal platform: Journal of Industrial Information Integration. The researchers used a Case study design.	Sustainability: safety and energy consumption	The article proposes the adoption of an integrated control framework using intelligent optimization. Other tools include data models, dynamic optimization, control, and intelligent decision-making.

The results indicate a general emphasis on wastewater treatment technology's cost, sustainability, and energy consumption. The studies used various methodologies, including quantitative forecasts, case studies, and literature surveys. They were all retrieved from journal publications published between 2017 and 2022. The articles underscored the need for safe, efficient, and cost-friendly technology to purify water faster and lower operational costs.

Discussion (1330)

The literature emphasizes the need to adopt technologies for sustainable wastewater treatment. Li et al. (2021) introduce the intriguing dynamics of intelligent technologies, capturing the role of data, decision models, and control frameworks. This observation is essential to accomplishing the proposed control systems recommended by Rajaei and Nazif (2022). The concept of sustainability is widely promoted, especially in declining global climate health. Countries in the Middle East and Northern Sahara are likely to be affected more as they are already located in Arid and desert environments. SA is experimenting with sustainable development initiatives, including large-scale agriculture, to meet the needs of a population that is migrating from rural farming regions to cities (Al-Shayaa et al., 2021). Therefore, it is imperative to consider the gains the country, and specific regions, including Makkah, would gain through the direction of treated wastewater used in large-scale farming and other urban development needs, such as its application in Southern Jeddah, Saudi Arabia. Southern Jeddah has redirected treated sewage water into farming; an examination of the soil revealed rich nutritional value that can promote plant growth and rich harvest (Aljeddani, 2022). Water is an essential resource, and the treatment process should attain an optimum decontamination process whereby the treated wastewater can be recycled, used for domestic consumption, or released into the environment (Khan et al., 2022). The people of Makkah, including tourists and local dwellers, are accountable for using natural resources, especially water, and the impact on the water cycle. Population awareness is a critical ingredient for successful wastewater treatment. Gómez-Román et al. (2020) observe that population awareness of the benefits or limitations of decentralized or centralized wastewater treatment influences acceptance of either strategy. Resistance to emerging technologies by the leadership, policymakers, and the public prevents communities from improving WT management practices and resolving local communities' water problems. Makkah could gain more from optimized and efficient wastewater treatment as they focus on public and environmental safety.

Sustainable Management: Integrated and Expanded Wastewater Treatment Plants

Makkah's traditional wastewater treatment practice requires improving its safety standards for public use and efficiency in delivering to the large population. Alkhudhiri et al. (2019) study noted various technologies adopted across Saudi Arabia. They noted that Makkah uses Tricking filter/Activated sludge, a tertiary treatment type in its wastewater treatment sites, which is infective in size and expected outcomes. Shukla and Ahammad (2023) note that modifying such systems can efficiently eliminate components like antibiotic-resistant bacteria, antibiotic-resistant genes, and personal care products and pharmaceuticals from sewages. Makkah can achieve higher Alkhudhiri et al. indicated that the first phase of Makkah's Tricking filter/Activated sludge would be directed to agriculture and the second phase to industrial development. The benefits can increase through an optimized system, integrating modern practices and buffering conventional systems. However, this is challenging in Makkah, where the leadership, systems, and the public lack or have low incentives to improve the system or encourage poor wastewater treatment levels. Makkah's current wastewater treatment plants have a treatment capacity of 24,000-50,000, significantly lower than other systems adopting media filtration and oxidation ditch with a larger capacity to treat up to 133,000 to 210,000 m^3/day (Alkhudhiri et al.). Makkah must appreciate the benefits it would achieve through optimized WT practices to achieve sustainability in agriculture and safety. Urgent action on expanding the treatment plants and optimizing them through integrated treatment processes can improve centralized and decentralized wastewater treatment plants.

Simplified but efficient WT plants

Next, Makkah should implement simplified and efficient WT plants to achieve cost sustainability while gaining the benefits of integrated systems. Other scholars also repeat the urgency of a sustainable WT plant through simple mechanisms. Bai et al. (2021) recommend adopting a sustainable wastewater management practice that lowers the overall burden on the environment and considers the capacity of the receiving waterbody, including river, sea, or ocean. This implies that a WT plant should not use energy sources and chemicals that harm the environment as they purify wastewater. Kim and Farnazo (2017) note the presence of nanoparticles in WT effluents causes environmental toxicity and pollution. Therefore, mechanisms designed to treat sewage and other water systems can become poisonous and dangerous to the ecosystem. Extreme and complex management systems can become costly and detrimental as more chemicals and other unsustainable materials are released into the water bodies. Makkah's centralized and decentralized WT plants can perform efficiently and sustainably if they integrate a cost-effective approach, accounting for the safety issues in released water.

The Right Technology, Control, and Integration Systems

Technology is essential to optimizing Makkah's centralized and decentralized WT. First, decentralizing the country's wastewater management system can help SA and Makkah achieve goals specific to their targeted population. Capodaglio (2017) recommends decentralized wastewater treatment alternatives as sustainable approaches to managing

wastewater at the local level. Decentralized plants are beneficial to solving local water needs by providing mechanisms to recycle water or alternative water sources for agriculture, domestic use, and other activities. According to Capodaglio, a suitable sustainable technology is affordable, environmentally protective, institutionally and technically consistent, and socially agreeable. However, the decentralized approach is flexible and could be less regulated. Ksibi (2023) also reports that advanced technologies are eco-friendly and cost-effective. The technology systems can be integrated to achieve optimum performance. A control system must involve multiple systems and gain maximum output from each segment. The essential components of an integrated system include control operation, wastewater sources, data gathering and analysis, and optimization (figure 1). The components create a complex platform. However, it is an organized and efficient system capable of providing long-term benefits to Makkah.

The control system is essential to the optimized system's performance. Rajaei and Nazif (2022) recommend using a control strategy to regulate the rate at which the sludge flows and the oxygen concentration and aeration. Effluent quality increased when the sludge line and oxygen concentration were optimized. Moreover, the effluent quality improved by at least 9%, while the operational cost increased by 1%. Therefore, the cost of establishing such a system is slightly insignificant. Bai et al. recommend using decision-supported tools to establish the best approach based on the situation. Figure 1 provides an overview of integrated WT systems Makkah should adopt, including artificial intelligence as a core data collection and analysis component. Artificial intelligence technologies are increasingly becoming part of human life, and early recognition and integration can speed up the process of gaining from their input to complex tasks.

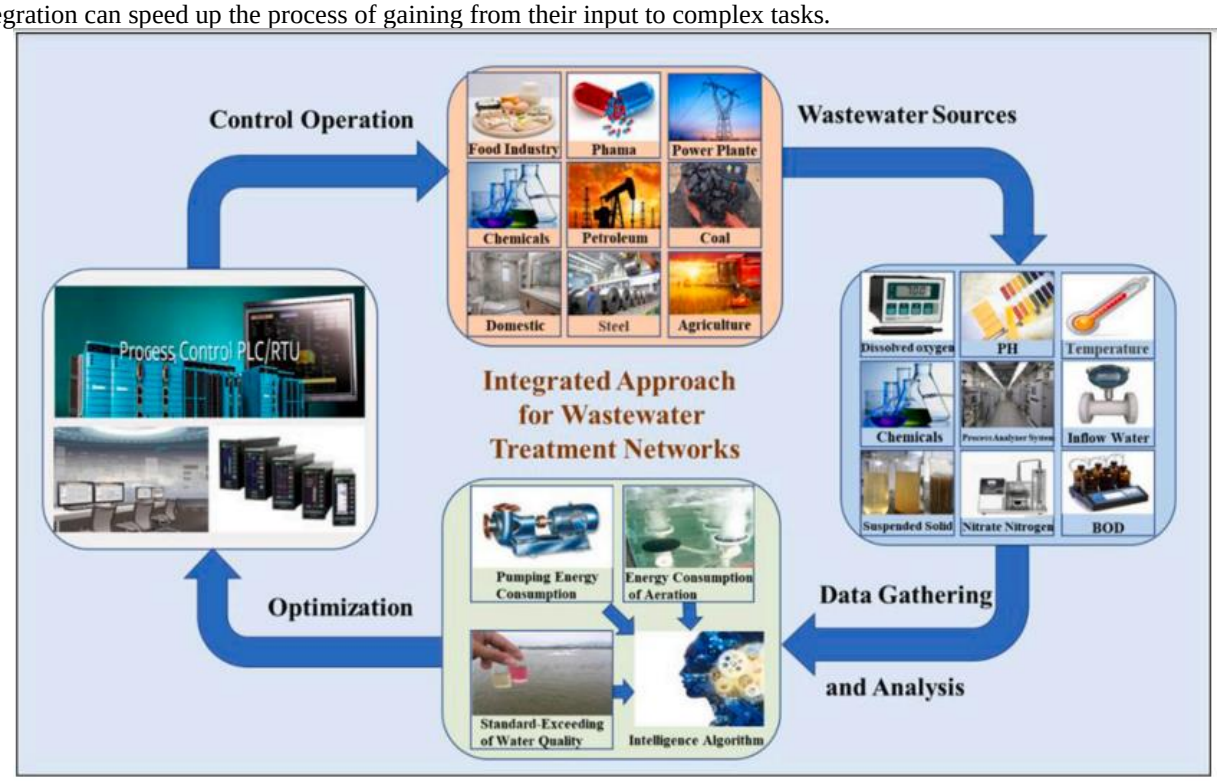

Figure 1 an integrated and optimized Wastewater treatment system.

Note: The figure by Li et. (2021) illustrates integrating four systems (data collection and analysis, wastewater sources, control operation, and optimization). Makkah can optimize its WT by integrating a similar technology and practice integration.

Various technologies are transforming WT and generating safer water at a faster rate and an efficient process. Khan et al. (2022) note the integration of nanotechnology, ionic liquids, and 3D technology that removes heavy metals, and nitrogen, copper. Nanotechnology uses activated carbon magnetite to eliminate copper particles. Ionic liquids can eliminate 80-85% of dissolved copper. 3D technology eliminates approximately 63% of the nitrogen in wastewater. Khan et al. further recommend the integration of renewable energy to lower energy consumption and boost wastewater treatment. Renewable energy sources are likely to enhance WT. SA is making significant milestones in harnessing its wind and solar energy, which it can direct to WT.

Conclusion

Makkah can improve its wastewater treatment through an integrated data collection and analysis system, wastewater sources, control operation, and optimization systems. First, the country should create awareness among its citizens, tourists, and public officials on the importance of supporting the goal. Next, Makkah should evaluate and adopt a cost-effective and efficient technology. The cost-benefits of adopting an efficient technology will outweigh the cost implications. Makkah could become more profitable as it directs the treated water to economic activities, including agricultural production. Overall, there is no perfect solution for Makkah's WT. the optimum approach entails creating awareness and optimizing safety standards, expanding the treatment plants and optimizing them, integrating treatment processes through centralized and decentralized wastewater treatment plants, using simple systems and technologies, expanding existing plants, optimizing performance, adopting cost-efficient strategies, and using the Right Technology, Control, and Integration Systems.

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"الحل الأفضل لمعالجة مياه الصرف الصحي المركزية واللامركزية في منطقة مكة المكرمة في لمملكة العربية السعودي"

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الملخص:

يحدد البحث الحل الأمثل لمعالجة مياه الصرف الصحي المركزية واللامركزية في منطقة مكة المكرمة بالمملكة العربية السعودية. استخدم البحث منهج الترميز الموضوعي لتحديد المواد الأدبية المتعلقة بمشكلة البحث. أشارت مراجعة الأدبيات إلى أنه يمكن تحسين معالجة مياه الصرف الصحي من خلال دمج ممارسات متعددة. وتشمل الحلول المقترحة خلق الوعي وتحسين معايير السلامة، وتوسيع محطات المعالجة وتحسينها، ودمج عمليات المعالجة من خلال محطات معالجة مياه الصرف الصحي المركزية واللامركزية، باستخدام أنظمة وتقنيات بسيطة، وتوسيع المحطات الحالية، وتحسين الأداء، واعتماد استراتيجيات فعالة من حيث التكلفة، و باستخدام التكنولوجيا المناسبة وأنظمة التحكم والتكامل.