Sustainability Assessment of Sewerage Infrastructure Projects: A Conceptual Framework

Ali Alnoaimi and Anisur Rahman

***Abstract*—Sustainable sewerage infrastructure projects are essential in achieving sustainable development, as infrastructure directly affects all measures of such development. However, sewerage infrastructures face a variety of challenges and threats to their sustained performance throughout their life cycle, including effects of aging, aggressive environmental factors, inadequate design, underfunding, improper operation, and maintenance activities. These challenges lead to the enhancement of the risks of failure, for example, sewer leakage, overflow, and odor. These issues can have serious impacts on the environment, public health and safety, the economy, and the service lives of assets. Only a few research has focused on assessing sustainability at the project level, and to the best of researchers' knowledge, no study has assessed sewerage throughout its project life cycle. In response to this issue, this study proposes a sustainability assessment framework that focuses on all aspects of sustainability throughout the project life cycle. Furthermore, this framework supports the decision-making process throughout the life cycle of assets, ensuring the long-term sustainability of the projects and providing greater transparency for the stakeholders.**

***Index Terms*—Project life cycle, project management, sanitation system, sewerage system, sustainability assessment, wastewater collection systems.**

I. Introduction

Infrastructure is a main priority in both developing and developed countries. Having a sustainable infrastructure is essential because it directly affects all measures of sustainable development. As it is essential for every society and its economy, the sewage infrastructure system is critical in both developing and developed countries. Furthermore, having a sustainable infrastructure can accelerate the balance of the economic, social, and environmental aspects of sustainable development in developing countries [1]. It also influences the success of infrastructure construction projects [2].

Currently, the principles of sustainability are widely referenced in laws, policies, and strategies in both developed and developing countries [3], [4]. To maximize the possibility of achieving sustainable development goals, sustainability assessment and reporting tools must be developed to inform stakeholders about the progress being made toward sustainable development goals. Moreover, assessing the sewerage infrastructure system supports decision making and policy creation in broad environmental, economic, and social contexts, thus transcending purely technical or scientific evaluations [5]. However, the current practices continue to favor formal rationality, which entails using traditional economic appraisals to support decision making [6], [7]. In recent years, the number of sustainability reporting tools has rapidly grown, including those using various methodologies and criteria. This growth has created massive complications for stakeholders [8]. A comprehensive sustainability assessment of any civil infrastructure requires the evaluation of its three major components: economic, environmental, and social impact [9]. However, most of the existing sustainability assessment frameworks focus more on the environmental aspect than on the social and economic aspects. Furthermore, the long-term sustainability of sewerage infrastructure projects throughout their life cycle has not been properly addressed.

The sewerage infrastructure system faces a variety of challenges and threats to its sustained performance throughout its life cycle, including aging, deterioration, underfunding, disruptive events, population growth, improper operation and maintenance activities, disruptive events, regulatory sanctions, and third-party intervention [10]-[14]. These challenges and issues increase the risk of failures, such as sewage flooding, odor, infiltration, and exfiltration, which can seriously affect public safety and health, the environment, and the economy [10]. Moreover, poor management throughout the life cycle of assets negatively affects the economy, society, and the environment in the long term [15]. Therefore, to guarantee the long-term sustainability of a system, ensuring that the system is functional and that it can survive its vulnerabilities in crisis situations is important [16].

This study, which is part of a larger research project, contributes to the literature by proposing a sewerage sustainability assessment framework that focuses on all aspects of sustainability, namely, environmental, economic, and social aspects, throughout the project life cycle. This framework is set apart from most existing frameworks, which focus more on the environmental aspect than on the social and economic aspects.

The rest of this paper is structured as follows: Section 2 presents the literature review. Section 3 discusses the methodology. Section 4 proposes the sustainability assessment framework. Section 5 gives the conclusion and future research.

II. Literature

Sewerage networks are part of the main underground infrastructure and thus have substantial influence on all modern societies across the three sustainability aspects:

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environmental, economic, and social [17]-[19]. Furthermore, having a sustainable sewerage system means having sewerage that is designed to ensure that it will perform its function to the fullest throughout its life span, thus protecting users' quality of life at the lowest possible cost. However, designers of such systems face a variety of challenges and potential threats to sustained performance, including aging, deterioration, underfunding, disruptive events, and population growth [10], [12], [14].

In the existing literature, researchers assessed the sustainability of wastewater treatment in many studies, often focusing on the sewage that sewers carry and assessing the sustainability of wastewater treatment systems, and the goal was to develop more sustainable wastewater treatment systems and technologies [6], [20]-[28]. Furthermore, researchers in various studies assessed treated wastewater schemes to ensure that they use the most sustainable practices, thus expanding the current schemes and exploring new uses of recycled water [29]-[33]. However, evidently, little attention has been given to the impact sewerage systems have on the environment. For example, [34] stated that the Norwegian authorities neglected sewerage and drainage system issues, such as flooding, infiltration, water leaks, and pollution, thus leading to a massive effort to address the pollution of wastewater treatment plants in the past decades. These studies also showed that sewerage systems could affect the efficiency of wastewater treatment plants [35]. Moreover, wastewater treatment is easier when wastewater is fresher [36]. The sewer system greatly affects all categories of the life cycle environmental assessment of the wastewater treatment system except eutrophication [28]. Moreover, [37] found that the environmental impact of a sewer system is higher than that of a wastewater treatment plant in 10 of the 18 studied impact categories, including natural land transformation, particulate matter formation, marine ecotoxicity, freshwater ecotoxicity, climate change, terrestrial ecotoxicity, and water depletion. The construction phase of the sewers was the main contributor. To the best of the researcher's knowledge, few studies have investigated sustainability assessments for sewerage systems [10], [17], [37]–[46]. Indeed, none of these studies focused on assessing sewerage projects throughout their life cycles. Notably, some studies focused on assessing the materials of the sewer system to find the most sustainable materials [10], [39], [46]. Two such studies [39], [46] found that the most sustainable material was concrete. However, [10] found that polyvinyl chloride was the most sustainable material for sewer systems. In addition, [37], [45] environmentally assessed wastewater systems, including sewerage systems. [37] clearly indicated the importance of the operation and maintenance of sewer systems, and the results showed that sewer construction had a larger effect on the environment than the construction and operation of wastewater treatment plants. [45] found that some sewerage systems have a higher potential to benefit the environment than others depending on the configurations of the systems. Other researchers focused on assessing sewerage projects based on their social impact [40]. [40] argued that the implementation of the mitigation process largely affects the relationship between appraisal and implementation. This issue requires both implementation and appraisal to be effectively interconnected entities rather than separate phases. Furthermore, [41] compared multiple methods for calculating the sustainability indices for sewerage systems and found that proving that one system is more sustainable than another is possible, but doing so is difficult as it requires expert scrutiny because of the various selected indicators and the weighting and normalization methods. In another study, [38] assessed the technical sustainability of a sewerage system through an Ethiopian case study. The causes of the sewerage failures were identified, and operation and maintenance were found to be the main causes of these failures, followed by construction and design. Other studies were conducted to identify the critical variables in sewer systems throughout their life cycles, and some used the eco-efficiency assessment approach. The results of these studies demonstrated that the maintenance and operation of the sewer were the critical stages in terms of impact on the environment. However, these effects were associated with the location of the nearest wastewater plant, as greater distance led to a greater need for energy. Additionally, the construction stage had the most significant effect on economics. The economic flow was the most important factor for investments in the installation of the sewers [44]. A recent study conducted in Norway [17] assessed the sustainability of strategic management for a wastewater transport system. This study aimed to present a methodology to compare variable pathways toward the sustainable management of wastewater systems. The research focused on the economic, physical, environmental and energy aspects of water infrastructure, mainly in strategic planning. [17] found that evaluating the variable aspects of sustainability and administering them in a comprehensive system are essential to accomplish strategic planning in the sustainable management of a sewer asset. Moreover, the sustainable management of water infrastructure can be considered in the strategic long-term planning for urban water systems to obtain economic and environmental benefits for society [17]. The results of a sustainability assessment depend on a country's situation and can be based on the configuration of sewerage projects, as every configuration and situation has alternatives that can produce more sustainable sewerage infrastructure. When sustainable practices are in place, it is not necessary that the best practice be in place. For example, [42] reviewed the use of sustainable sanitation in Africa and found that some countries could not afford to implement them, even as they tried to find sustainable solutions that fit their needs, because of the expense of sewage infrastructures. Indeed, having a poor sanitation system negatively affects the quality of natural water resources and causes health risks to the populations involved. Owing to the lack of funding and to the expensive maintenance and operation of a sewerage system, the implementation of such a system would probably end up failing in terms of functionality. Onsite sewerage systems are more affordable and widely accepted, but they usually fail because of the lack of institutional arrangements that are vital to guaranteeing suitable designs and the sustainable management of fecal sludge. Furthermore, they can affect water resources and in turn increase the risk of waterborne diseases (among other issues). Therefore, to ensure sustainable sanitation in African countries, simple technologies are needed to treat and separate wastewater in a location as near as possible to the point of generation.

A sustainable infrastructure system can be achieved by focusing on the three pillars of sustainability: the environment, society, and economy. The environmental pillar encourages establishments that benefit the planet through sustainable practices, such as the use of appropriate materials that minimize the impact on the environment during the life cycle of an infrastructure. The social pillar intends to improve the lives of those involved with the projects from various areas (including public safety, health, security, and social equity). The economic pillar is focused on achieving the right balance of long-term service, low maintenance, and low life cycle costs [47], [48]. Furthermore, a sustainable sewerage system can be attained by addressing sustainability and supporting decision making in the earliest stages of the sewerage projects and throughout their life cycles by focusing on the long-term sustainability of these projects. Doing so could mean choosing sustainable materials, providing a suitable sewerage capacity, choosing the best scenarios, and comparing alternatives. Therefore, integrating sustainability assessments into the early planning of a project may help to meet the needs of the infrastructure project and throughout its life cycle [49]. However, previous studies focused more on project sustainability in terms of deliverables (e.g., feasibility studies, design, and planning) and less on the sustainability of project implementation [50]. Therefore, assessing sewerage infrastructure projects throughout the life cycle of the projects is important.

III. Methodology

A comprehensive review of the literature and reports collected from Bahrain (e.g., the National Master Plan for Sanitary Engineering Services (NMPSES), operations and maintenance reports, quality assurance reports, and procedure manuals) related to sewerage assets gave the following steps: 1) reviewing the project management life cycle and the sustainability assessment research on sewerage infrastructure projects, 2) identifying the sustainability element of the sewerage failure, 3) determining the sustainability issues in the sewerage infrastructure projects, and 4) defining the links to the sustainability development of the wastewater collection system. Based on these four steps, the preliminary sustainability assessment framework for sewerage infrastructure projects was developed.

IV. Sustainability Assessment Framework for Sewerage Infrastructure Projects

The proposed framework aims to assess sewerage infrastructure projects throughout their life cycle. The reduction of the risk of sewerage failure and the contribution to the sustainable development of wastewater collection systems are considered in this framework.

The preliminary sustainability assessment framework for sewerage infrastructure projects throughout their life cycle is presented in Figure 1. The framework contains six stages: the current sewerage system; contextualizing the project; planning, designing, and implementation; operation and maintenance; periodic assessment; and rehabilitation/upgrading with major considerations and expected outputs in every stage.

Stage 1: Sewerage System

Identifying and understanding the existing sewerage network are crucial to apply the framework. The two main aspects that should be considered are the hydraulic and the physical conditions of the network. The hydraulic condition should be assessed using the hydraulic model software to measure the system capacity. The hydraulic model needs to be calibrated frequently to reflect the actual condition of the pipelines and pumping stations. The physical condition should also be assessed by inspecting the pumping stations and the closed-circuit television of the pipelines. The network should have an inventory of the physical and hydraulic conditions of the network, so that future studies can be performed on the network. At this stage, sustainability issues need to be clearly identified to ensure all risks are considered in the engineering solutions.

Stage 2: Contextualizing the Project

At this stage, the scope of work of the proposed sewerage project is developed by entering the proposed scenarios into the hydraulic model and analyzing the outputs. This stage involves defining the budget that needs to be allocated as part of the Ministry of Works' program for design, supervision, and construction. The proposed project can require the allocation of land for the proposed pumping stations. The process of allocating lands for public services needs to be initiated. Furthermore, the state's sustainable development policy should be considered, and the project should be rejected if it does not comply with that policy [51]. Moreover, the sewerage infrastructure project should be categorized into one of the four types of projects: newly developed area projects, extension projects, rehabilitation projects, and upgrade projects. Based on this choice, indicators are selected while accounting for the sustainable development plans and policies. Moreover, the criteria and indicators for the sustainability assessment should be stratified under two objectives: reducing the risk of sewerage failure and contributing to the sustainable development of wastewater disposal systems.

Stage 3: Planning, Designing, and Implementing the Project

After selecting the type of project with the proper indicators, the second stage covers the planning, designing, and construction. Based on the type of project, various alternatives and scenarios can be compared, as there are four possible sewerage projects:

1) Newly developed area projects

This project features more flexibility in the possible scenarios, and it can include a newly developed area that is not connected to the current network. This project usually involves a treatment plant. The process used is similar to that in another study [51]. However, the indicators are different because each one is compared to provide a better decision-making process based on the sustainability criteria.

2) Extension projects linked to the network

The alternatives are limited in this kind of project, and the best solutions are based on existing sewerage. The alternative design is based on other studies [52], [53], but the indicators are different.

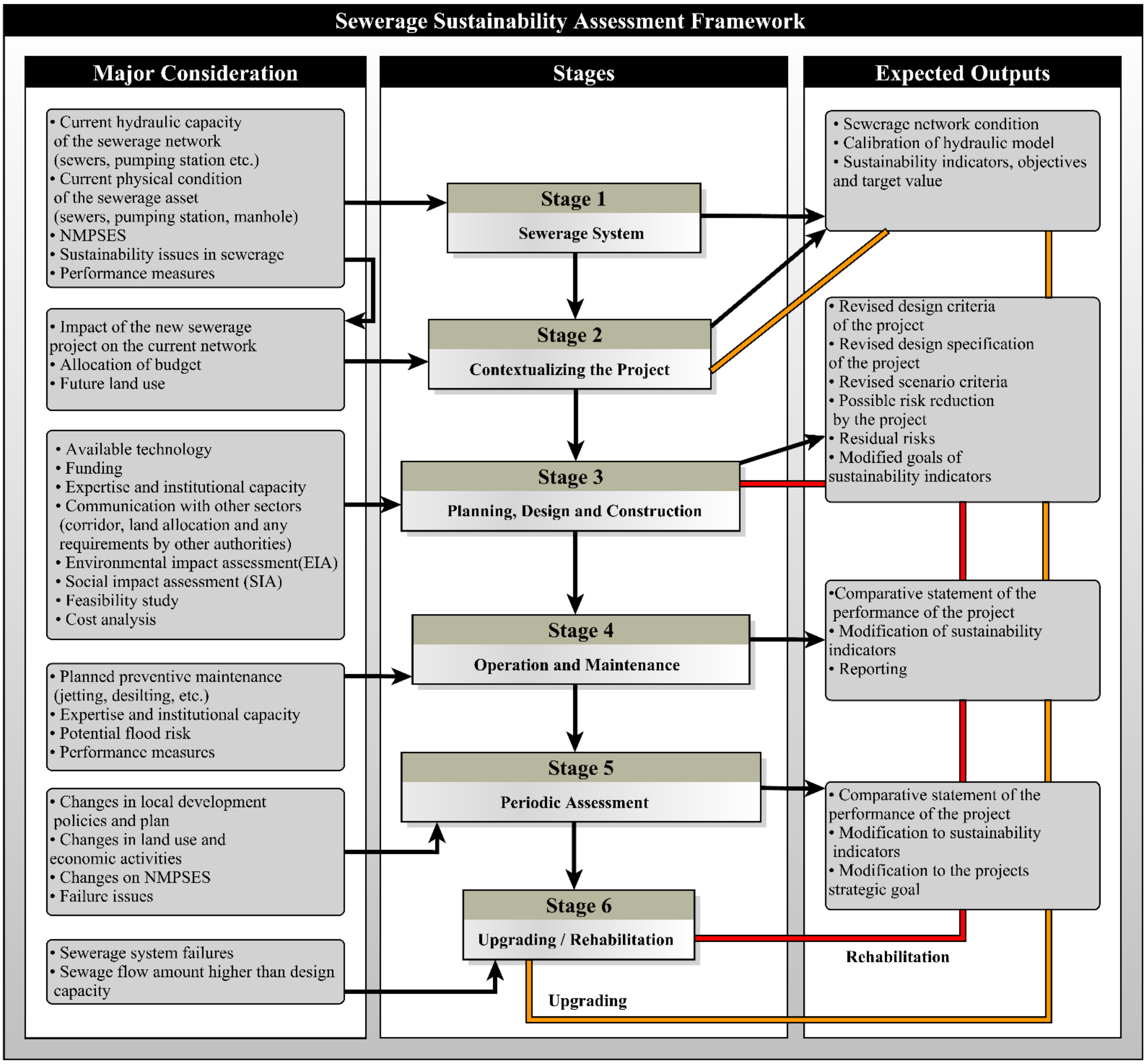

Fig. 1. Preliminary sustainability assessment framework for sewerage infrastructure projects.

3) Rehabilitation projects

Rehabilitation technologies are assessed to suit the type of damage in the pipes. Some rehabilitation technologies, such as curing the pipes in place, can slightly reduce the pipe size and thus decrease the pipe capacity. Therefore, a hydraulic assessment needs to be completed to ensure that the project does not cause any interruptions in the service.

4) Network upgrades

In this project, various scenarios are compared to find the most sustainable one. The process is the same as that in another study [51], although the indicators are different. After defining the type of project, the next phases are conducted using the specified project type.

Planning and Designing Phase

Generally, in the planning and designing stage of the project, the availably of construction technologies in Bahrain must be considered. For example, deep gravity sewer projects require specialized contractors to perform micro-tunneling. This technology may not be available in Bahrain when construction works are scheduled, as contractors from nearby countries provide it and no local contractors are available. Further, ensuring the availably of contractors requires attracting contractors from nearby countries. This step requires prior advertisement and invitations to participate in the tender of the project. As some projects require specialized staff to engage in the design and construction processes, ensuring that the required expertise is available within the Ministry of Works is important. A comprehensive feasibility study needs to be performed on the proposed options and scenarios. The project funding becomes clear as the design progresses. Cost analysis of the project's financial requirements, starting from the design up to the operation and maintenance, must be performed to control the expenditures as the project progresses.

Coordination with other concerned organizations is usually conducted in this phase to grant the necessary permits.

In Bahrain, the process of allocating corridors on roads to lay pipelines is commonly performed under the Planning Permission application, which is filled in with the project information and supported by detailed design drawings. Then, the application is distributed to all service providers to collect their comments and ultimately gain their approval. If required, land parcels are allocated in this phase as well, and the allocation involves granting approvals from the Survey and Land Registration Bureau and Authority of Urban Planning.

Environmental impact assessment and social impact assessment are performed at this stage. Approvals from the concerned authorities, such as the Supreme Council of Environment, are granted. This process must be assessed at this stage. Furthermore, the time and cost required for all activities mentioned at this stage need to be clearly identified.

The sustainability indicators must be validated throughout the assessment process, and any required modifications need to be performed to suit the project's scope of work. The system must be designed and constructed to provide an efficient service while considering failure risk and meeting the design horizon.

Implementing Phase

The processes of monitoring and controlling the construction activities of the project need to be assessed. The environmental and social plans set in the previous stages should also be assessed to ensure that the sustainability targets are achieved through the indicators. As a result of this stage, the design targets and proposed modifications during the construction period are assessed to validate the sustainability indicators and to suggest modifications to enhance the effectiveness of the framework.

Stage 4: Operation and Maintenance

The assessment of this stage is critical because this stage represents the longest period of the project life cycle. This stage reflects the efficiency of the design and construction of the project. The assessment needs to ensure the availability of comprehensive operation and maintenance plans, such as planned preventive maintenance, to keep the assets efficient and functional as desired for the anticipated life span. The assessment should also consider the institutional capacity, as operation and maintenance works require specialized staff in the field. The performance measures and risk assessment associated with sewerage failure must be conducted in the entire operation and maintenance period to compare the statements of the project's performance.

Stage 5: Periodic Assessment

Periodic assessment should be performed to ensure that the system is functioning with low risks for sewerage failure. Assuming that the assets are operated and maintained properly, other factors, such as land zoning classification and policies, need to be assessed. Land zoning can be changed by the master plan of land use in Bahrain, which defines the allowable economic activities in the region. This change can directly affect the quantities of sewage generated, as sewage can be increased or decreased. Either way, the network needs to be assessed to ensure that the sewage velocity is within the self-cleansing velocity range and that the pipelines and pumping stations are capable of conveying the sewage if it increases. As this assessment is critical to analyze data and predict the risk of failure, new measures are required. Management of the network must be proactive to enable sufficient periods and to plan, design, and implement these measures. Changes in policies must be considered in the periodic assessment to refine the sustainability indicators.

V. Conclusion and Future Research

Sewerage infrastructure projects face a variety of challenges and threats to their sustained performance throughout their life cycle. These challenges lead to the enhanced risks of failure, for example, sewer leakage, overflow, and odor. Such issues can have serious impacts on the environment, public health and safety, the economy, and the service lives of assets. Limited research, if any, has been conducted on the sustainability assessment throughout the entire life cycle of a sewerage asset with consideration of all aspects of sustainability (i.e., economic, social, and environmental).

Thus, this research proposed a framework to assess the sustainability of the Kingdom of Bahrain's sewerage infrastructure projects to ensure the long-term sustainability of these projects. This sustainability assessment framework intends to support the decision-making process throughout the life cycle of assets. It provides greater transparency for stakeholders and contributes to the sustainable development of wastewater management.

This work-in-progress, with results forthcoming from the second segment of the research as a mixed methods approach, will be utilized to further enhance the framework. A qualitative study followed by a quantitative study is conducted. In the qualitative phase, semi-structured interviews will be conducted with experts to verify the framework. Then, a quantitative study will be performed using a questionnaire design to statistically test the framework. Once the final research framework is developed, it will be applied to selected cases in Bahrain by utilizing the case study methodology.

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