# Development of Sustainability Assessment Framework for Sewerage Infrastructure Projects in the Kingdom of Bahrain

**Ali Dheyab Alnoaimi**

*MSc (Eng. Pm.), BSc (CE.)*

**Griffith School of Engineering and Built Environment**

**Griffith University**

Submitted in fulfilment of the requirements of the degree of Doctor of Philosophy

Sep 2020

## Statement of Originality

*This work has not previously been submitted for a degree or diploma in any university. To the best of my knowledge and belief, the thesis contains no material previously published or written by another person except where due reference is made in the thesis itself.*

(Signed) __[redacted]___

## List of publications

Alnoaimi, A. and Rahman, A., 2019. Sustainability Assessment of Sewerage Infrastructure Projects: A Conceptual Framework. *International Journal of Environmental Science and Development*, 10(1), pp.23-29.

Alnoaimi, A. and Rahman, A., 2020, Indicators for the Sustainability Assessment of a Sewerage Infrastructure Project Throughout Its Life Cycle (Intended to be submitted)

Alnoaimi, A. and Rahman, A., 2020, Application of a Sustainability Assessment Framework for Sewerage Infrastructure Projects Using a Multi-Criteria Decision Analysis: A Case Study of Bahrain. (Intended to be submitted)

Alnoaimi, A. and Rahman, A., 2020, Challenges Facing the Sustainability of Drainage Systems in Developing Countries: Shedding Light on GCC Countries. (Intended to be submitted)

# Abstract

Sustainable sewerage infrastructure projects are the keys in achieving sustainable development, as such infrastructure directly impacts on all sustainable development initiatives. Throughout its life cycle, a sewerage system faces a number of challenges and threats to its sustained efficiency, including the impact of ageing, aggressive environmental factors, underfunding, inadequate design, and insufficient operation and maintenance activities. These problems may lead to a rise in the risk of failure, including sewage leakage, overflow, discharge and odour issues. These issues can have significant impacts on the environment, public health and safety, the economy and the service lives of the assets, all of which will affect the sustainability of the sewerage system. Despite its importance and serious consequences, very little research has focused on assessing sustainability at the project level, and no research has assessed a sewerage system throughout its life cycle. In Bahrain, the sewerage system presents a notable variety of challenges related to environmental, economic, social and managerial issues that need to be considered in order to attain a sustainable sewerage system. The original contribution of this research is therefore, to develop a framework for assessing the sustainability of the Kingdom of Bahrain's sewerage infrastructure projects, thereby ensuring their long-term sustainability. The sustainability-assessment framework will focus on all aspects of sustainability throughout a project's life cycle, setting it apart from most existing frameworks that focus more on the environmental aspect than on the economic and social aspects. The framework will also support the decision-making process throughout the life cycles of the assets. It will also provide greater transparency for stakeholders. The results of this research are important in addressing shortcomings of the sewerage system in the developing counties by providing a framework for the assessment of the sustainability of sewerage projects for the Kingdom of Bahrain and throughout the Arabian Gulf region.

Throughout the research for this thesis, several methodologies were adopted to achieve research objectives, including an extensive review of the relevant literature and of the secondary data that were utilized to clarify the research problem. Then, a conceptual sustainability assessment framework was developed; this framework includes sustainability indicators to determine the sustainability of sewerage infrastructure projects. Furthermore, a mixed-methods approach was used to enhance and verify the framework. First in this approach, experts were consulted to improve the developed framework. This stage of the research resulted in the preliminary sustainability indicators that were used in the next stages of framework development. In the second part of the approach, a pilot study was conducted to improve and

enrich the survey. The third part included both quantitative and qualitative data collection through an open-ended survey conducted among experts working in the development of sewerage projects in Bahrain. In the fourth part, the collected data were analysed, resulting in the identification of 43 scored sustainability indicators that led to accomplishing the development of the framework.

The developed framework has been applied to three case studies in Bahrain, thus demonstrating how it may be applied successfully. These applications outline the process of selecting indicators, identifying weights and scoring the indicators to determine the sustainability index for the different stages of sewerage projects. The decision-support system is built in line with the project life cycle and its associated six stages: 1) current sewerage system, involves identifying and understanding an existing sewerage network; 2) contextualizing a new project according to the sustainability of the wastewater collection system; 3) planning, designing and constructing, which includes addressing sustainability issues in the project; 4) operation and maintenance, which ensures sustainability performance within the project; 5) periodic assessment, which ensures continual, effective sustainability assessment; 6) rehabilitation/ upgrading, which implements the results of the sustainability assessment in the case of rehabilitation or upgrading. A multi-criteria analysis (MCA) methodology has been adopted in the framework, using sustainability criteria and indicators in assessing sewerage projects and providing a sustainability index.

# Table of Contents

**Statement of Originality** .......... **I**

**List of publications** .......... **II**

**Abstract** .......... **III**

**List of Figures** .......... **XI**

**List of Tables** .......... **XII**

**List of Abbreviations** .......... **XIV**

**Acknowledgements** .......... **XV**

**Chapter 1: Introduction** .......... **1**

**1.1 Sustainability of the Sewerage Infrastructure Projects** .......... **1**

**1.2 Context and Justification of Research** .......... **2**

**1.3 Research Aim and Objectives** .......... **3**

**1.4 Statement of the Problem and Research Questions** .......... **3**

**1.5 Research Method Overview** .......... **4**

**1.6 Anticipated Contribution** .......... **5**

**1.7 Thesis Structure** .......... **6**

**Chapter 2: Literature review** .......... **8**

**2.1 Sustainability Development of Infrastructure** .......... **8**

**2.2 Sustainable Sewerage Systems** .......... **10**

**2.3 Overview of the Sewerage System** .......... **14**

2.3.1 Sewage system operation: collection and disposal of sewage .......... 14

2.3.2 Sewerage system in Bahrain .......... 14

**2.4 Sewerage Project Management** .......... **18**

2.4.1 Portfolios, programs and projects .......... 18

2.4.2 Project life cycle .......... 19

2.4.3 Sanitary engineering sewerage programs and projects life cycles in Bahrain .......... 22

**2.5 Sustainability Issues in Bahrain's Sewerage System ........................................28**
2.5.1 Population growth and land use ........................................29
2.5.2 Storm water and consumer behaviour ........................................30
2.5.3 Availability of corridors and lands ........................................30
2.5.4 People's dissatisfaction ........................................31
2.5.5 Pumping-station breakdowns ........................................32
2.5.6 Budget allocation ........................................33
2.5.7 Energy consumed ........................................33
2.5.8 Groundwater infiltration and sewage ex-filtration: ........................................33
2.5.9 Management issues ........................................34
**2.6 Sustainability Issues in Sewerage Infrastructure Projects ........................................35**
**2.7 Challenges and Opportunities for Ensuring Sewerage Projects' Sustainability 38**
**2.8 Sustainability Assessment ........................................38**
2.8.1 Definition ........................................38
2.8.2 Sustainability-assessment approaches and tools ........................................39
2.8.3 Assessing sustainable development at the project level ........................................41
**2.9 Summary ........................................45**
**Chapter 3: Methodology ........................................46**
**3.1 Overview of the Methodology ........................................46**
**3.2 Extensive Literature Review ........................................47**
**3.3 Research Design ........................................48**
**3.4 Understanding the System ........................................48**
**3.5 Environmental, Social and Economic Elements of Sewerage System Failure...49**
**3.6 Sustainability Issues of Sewerage Infrastructure Projects ........................................49**
**3.7 Links to the Sustainability Development of Wastewater Collection Systems....49**

**3.8 Review of the Project-Management Life Cycle and Sustainability-Assessment Research on Sewerage Infrastructure Projects ............ 50**

**3.9 Development of Sustainability-Assessment Framework for Sewerage Infrastructure Projects ............ 50**

**3.10 Mixed-Methods Design ............ 50**

3.10.1 Introduction ............ 50

3.10.2 Phase one (development of framework) ............ 50

3.10.3 Phase two (Pilot study) ............ 50

3.10.4 Phase three (Survey) ............ 51

3.10.5 Phase four (Case study) ............ 51

3.10.6 Sampling ............ 51

**3.11 Application of the Framework ............ 52**

**3.12 Results Analysis, Discussion and Conclusion ............ 52**

**3.13 Chapter Summary ............ 52**

**Chapter 4: Development of sustainability-assessment framework for sewerage infrastructure projects ............ 53**

**4.1 Overview of the Sustainability Assessment Framework ............ 53**

**4.2 Scope of the Sustainability-Assessment Framework ............ 53**

**4.3 Sustainability-Assessment Framework for Sewerage Infrastructure Projects . 54**

4.3.1 Stage 1: Sewerage System ............ 55

4.3.2 Stage 2: Contextualizing the Project ............ 56

4.3.3 Stage 3: Planning, Designing and Implementing the Project ............ 57

4.3.4 Stage 4: Operation and Maintenance ............ 61

4.3.5 Stage 5: Periodic Assessment ............ 62

4.3.6 Stage 6: Rehabilitation/Upgrading ............ 62

**4.4 Discussion and Conclusions ............ 66**

**4.5 Summery ........ 69**

**Chapter 5: Data Analysis ........ 70**

**5.1 Pilot Study ........ 70**

5.1.1 Execution of pilot study ........ 70

5.1.2 First group ........ 71

5.1.3 Second group ........ 72

**5.2 Data Collection ........ 73**

**5.3 Data Analysis ........ 74**

5.3.1 Background information ........ 75

5.3.2 Objectives and criteria ........ 76

5.3.3 Indicators ........ 77

5.3.4 Sewerage Project's Sustainability Overview ........ 84

**5.4 Chapter Summery ........ 88**

**Chapter 6: Case Study of Sewerage Infrastructure Projects ........ 89**

**6.1 Preliminary Analysis of the Baseline Situation of the Three Case-Study Projects 89**

**6.2 Overview of Hamad Town to Tubli Trunk Sewer Project ........ 90**

6.2.1 Objectives, finance and benefits ........ 92

6.2.2 Outcomes ........ 92

6.2.3 Risks of the sewerage system ........ 92

6.2.4 Activities of the project ........ 93

**6.3 Overview of Muharraq Deep-Gravity Sewer project ........ 100**

6.3.1 Objectives, finance and benefits ........ 101

6.3.2 Outcomes ........ 102

6.3.3 Risks of the sewerage system ........ 103

6.3.4 Activities of the project ........ 103

**6.4 Overview of Madinat Khalifa Sewerage Project ........ 109**

6.4.1 Objectives, finance and benefits ........ 110

6.4.2 Outcomes ........ 110

6.4.3 Risks of the sewerage system ........ 110

6.4.4 Activities of the project ........ 111

**6.5 Policy and Guidelines Followed for the Three Cases ........ 113**

**6.6 Chapter Summary ........ 115**

**Chapter 7: Application of sewerage projects' sustainability assessment framework ... 116**

**7.1 Sustainability Assessment Framework for Sewerage Infrastructure Projects 116**

7.1.1 First objective: Reduce the risk of sewerage failure ........ 117

7.1.2 Second objective: Contribute to the sustainable development of wastewater collection system ........ 118

**7.2 Assessing the Sustainability of Sewerage Infrastructure Projects ........ 120**

7.2.1 Assessing the sustainability of Hamad Town deep-gravity sewer ........ 120

7.2.2 Assessing the sustainability of Muharraq deep-gravity sewer ........ 126

7.2.3 Assessing the sustainability of Madinat Khalifa ........ 130

7.2.4 Assessing the sustainability of sewerage infrastructure projects in different contexts 133

**7.3 Discussion and Conclusion of the Implementation of the Developed Framework 134**

**7.4 Recommendation ........ 136**

**7.5 Chapter Summary ........ 137**

**Chapter 8: Conclusion ........ 138**

**8.1 The Implication of the Thesis ........ 139**

**8.2 Limitations ........ 140**

**8.3 Recommendation and Future Work** .......... **141**

**8.4 References** .......... **142**

**Appendix A: Sewer Network subdivisions in Bahrain** .......... 153

**Appendix B: Economic vision 2030 for Bahrain** .......... 155

**Appendix C: Rehabilitation methods in Bahrain** .......... 156

**Appendix D: Initiatives and performance indicators** .......... 157

**Appendix E: KAI for infrastructure project** .......... 160

**Appendix F: Letter to the Ministry of works** .......... 161

**Appendix G: Survey of experts' opinions** .......... 162

**Appendix H: Maximum and minimum target value for the sustainability indicators of Hamad Town deep-gravity sewer** .......... 175

**Appendix I: Comparable indicators between alternative 1 and alternative 2** .......... 182

**Appendix J: The score of Sustainability Index for Hamad town deep-gravity sewer of alternative 1 and 2** .......... 186

**Appendix K: Maximum and minimum target value for the sustainability indicators of Muharraq deep-gravity sewer** .......... 193

**Appendix L: The score of Sustainability Index for Muharraq deep-gravity sewer in operation and maintenance stage** .......... 202

# List of Figures

Figure 1: Performance of an infrastructure-system schematic representation (adapted from Lounis and McAllister, 2016) .......... 9

Figure 2: Project life cycle (adapted from Westland, 2006) .......... 19

Figure 3: Sanitary Engineering Affairs organizational structure .......... 24

Figure 4: Programme and project life cycles in engineering affairs (with responsibilities) .... 25

Figure 5: Expected population growth (2009-2030) according to the NMPSES (Ministry of works, 2009) .......... 29

Figure 6: Storm water flooding (Alwatan News, 2017) .......... 30

Figure 7: Number of complaints in 2015, 2016 and the first 6 months of 2017 .......... 31

Figure 8: Sewage overflow (Alwasat News, 2016) .......... 32

Figure 9: Sewage overflow (Alayam News, 2017) .......... 32

Figure 10: Number of breakdowns in pumping stations .......... 32

Figure 11: Groundwater infiltration rates in Bahrain’s sewerage system .......... 34

Figure 12: Framework for sustainability assessment (SA) (Ness et al.,2007) .......... 41

Figure 13: Research methodology overview .......... 47

Figure 14: Sustainability assessment framework for sewerage infrastructure projects .......... 55

Figure 15: The representation of the results of the sustainability assessment for the different alternatives .......... 60

Figure 16: The participants' response to the first question .......... 84

Figure 17: The participants' response to the second question .......... 85

Figure 18: The participants' response to the third question .......... 86

Figure 19: The participants' response to the fourth question .......... 87

Figure 20: The participants' response to the fifth question .......... 88

Figure 21: Locations of the three projects .......... 89

Figure 22: Hamad town trunk sewer project location....................90

Figure 23: Hamad town to Tubli trunk sewer scenarios....................91

Figure 24: Muharraq deep-gravity sewer project location....................100

Figure 25: Predicted sewage flows from Muharraq (2015-2030)....................102

Figure 26: Madinat Khalifa sewerage project location....................109

Figure 27: The locations of alternative route 1 and alternative route 2....................123

Figure 28: The sustainability index score for planning, designing and implementation, as well as the criteria status....................125

Figure 29: The sustainability index score for the operation and maintenance stage and the criteria status....................130

## List of Tables

Table 1: Elements of a sewerage system....................15

Table 2: Sewerage assets in Bahrain....................16

Table 3: Tubli WPCC Phases....................18

Table 4: Number of Stations....................33

Table 5: Sustainable assessment decision matrix....................42

Table 6: Multiple options evaluated in terms of KAI....................43

Table 7: Sustainable assessment decision matrix for alternative design....................60

Table 8: the sustainability assessment indicators for the sewerage infrastructure projects....................63

Table 9: Examples of improvement by the first group....................71

Table 10: Examples of improvement by the second group....................72

Table 11: Background information....................75

Table 12: Field of expertise....................76

Table 13: The sustainability assessment objectives and criteria....................76

Table 14: Suggested criteria........................................................................................77

Table 15: The weightage of all indicators under the first objective .......................................78

Table 16: The weightage of the suggested indicators.............................................................80

Table 17: The weightage of all indicators under the second objective...................................80

Table 18: Methods and tools used in the management of the sewerage system......................87

Table 19: Predicted sewage flows form Hamad town to Tubli ..............................................90

Table 20: Activities analysis of Hamad town trunk sewer project. .........................................94

Table 21: Muharraq deep-gravity sewer pipelines...............................................................100

Table 22: Activities analysis of Muharraq deep-gravity sewer project ................................104

Table 23: Predicted sewage flows form Madinat Khalifa ....................................................109

Table 24: Activities analysis of Madinat Khalifa sewerage project ......................................112

Table 25: The significance of policies, decrees and guidelines to the sewerage case studies ..........................................................................................................................................113

Table 26 Example of comparable sustainability indicators scores for alternatives 1 and 2 ..124

# List of Abbreviations

CCTV Closed-circuit television

EIA Environmental impact assessments

KAI Key assessment indicators

KPI Key performance indicator

LCCA Life-cycle cost analysis

MCA Multi-criteria analysis

NMPSES National Master Plan for Sanitary Engineering Services

PPP Public-Private Partnership

SA Sustainability assessment

SI Sustainability index

SIA Social impact assessment

SD Sustainable Development

STP Sewage treatment plant

TSE Treated sewage effluent

WPCC Water Pollution Control Centre

# Acknowledgements

First of all, thanks and gratitude go to Allah, my God, who has given me the strength and determination to carry out this research.

I would like to express my sincere gratitude to my parents, brothers and sister as this journey would not have been possible without their encouragement in all of my pursuits and their constant motivation, which has helped me to make my dream come true. I also want to thank all of my family members including my aunts, uncles and more for their continuous communication, prayers and support throughout my PhD study.

I can't be more thankful to my wonderful wife for supporting my decision to continue my studies overseas, especially during the most significant event in our life, the raising of our three small children. I will never forget your efforts to take care of our children and our families, especially in the last year of the thesis when I wasn't around and couldn't return to Bahrain due to COVID-19 restrictions. I am grateful for the blessing of my children, who are the joy of my life. May God bless all of you and grant you Jannah.

I would like to express my sincere gratitude to my supervisor, Dr Anisur Rahman, for his continued support throughout my PhD study, for his patience, motivation and immense knowledge. His guidance has helped me at each phase of research and in the writing of this thesis. I could not have imagined having a better advisor and mentor for my PhD study. I also want to thank my associate supervisor, Dr Sanaul Chowdhury, and my external supervisor, Dr Lei Hou, for their consistently valuable instructions and support.

My sincere thanks also go to my country Bahrain, which provided me the opportunity to continue with my PhD study in Australia.

"*(This is the) country of nobles (and) cradle of peace*
*Long live the Kingdom of Bahrain*"
(Part of the national anthem of Bahrain)

Last but not the least, I would like to thank all my friends for their significant support and encouragement throughout my PhD journey. I was truly lucky to have them in my life.

# Chapter 1: Introduction

This chapter addresses the background of the sustainability of the sewerage infrastructure system, presents the context and justification of research, the aim and objectives, statement of the problem and research questions, research methods overview, anticipated contribution and ends with the structure of the research.

### 1.1 Sustainability of the Sewerage Infrastructure Projects

Infrastructure is the priority concern of every country throughout the world, and it plays a key effective role within their economic growth. Having a sustainable infrastructure is essential as it directly impacts on all measures of sustainable development. The sewerage infrastructure system is critical in both developing and developed countries, as it is essential for every society and its economy. Furthermore, having a sustainable infrastructure can accelerate the balance of the economic, social and environmental aspects of sustainable development in developing countries (Diaz-Sarachaga, Jato-Espino and Castro-Fresno, 2017). In addition, it influences the success of infrastructure construction projects (Krajangsri and Pongpeng, 2017). Therefore, having better infrastructure is the indication of more opportunities for creating a healthier economic environment and a better quality of life.

Currently, the principles of sustainability are widely referenced in laws, policies and strategies in both developed and developing countries (Ainger and Fenner, 2014; Finkbeiner et al., 2010). To maximize the possibility of achieving sustainable development goals, sustainability-assessment and -reporting tools must be developed; these will serve to inform stakeholders about the progress being made towards sustainable development goals. Assessing the sewerage infrastructure system will support decision-making process and policy creation in broad environmental, economic and social contexts, thus transcending purely technical or scientific evaluations (Sala, Ciuffo and Nijkamp, 2015). However, current practices continue to favour formal rationality, which entails using traditional economic appraisals to support decision-making (Hoffmann et al., 2000; Reidy, Kumar and Kajewski, 2016). In Recent years, there has been a rapid growth in the number of sustainability-reporting tools, including those using various methodologies and criteria; this growth has created massive complications for stakeholders (Siew, 2015). A comprehensive sustainability assessment of any civil infrastructure requires an evaluation of its three major components: economic, environmental and social impact (Hossain and Gencturk, 2016). However, the majority 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 the life cycle has not been properly addressed.

The sewerage infrastructure system faces a variety of challenges and threats to its sustained performance throughout the life cycle, including aging, deterioration, underfunding, disruptive events, population growth, improper operation and maintenance activities, suffer regulatory sanctions, and third-party intervention (Akhtar et al., 2014; Andersson, Dickin and Rosemarin, 2016; Grigg, 2012; Upadhyaya, Biswas and Tam, 2014). These challenges and issues increase the risk of failures such as sewage flooding, infiltration and exfiltration, which can have serious impacts on public safety and health, the environment and economics (Akhtar et al., 2014). On the other hand, bad management practice throughout the assets' life cycles negatively affects the economy, society and the environment in the long term (Navarro, Yepes and Martí, 2019; Zhou and Liu, 2015). Therefore, to ensure a system's long-term sustainability, it is important to ensure that the system is functional and that it can survive its vulnerabilities in crisis situations (Upadhyaya, 2012). Having sustainable assessment framework for the sewerage infrastructure projects while taking into account all aspects of sustainability (economic, social and environmental) would contribute in ensuring having a sustainable sewerage system that is capable in facing the possible variety of challenges and threats, thus contribute having sustainable development. For this research, the Kingdom of Bahrain was chosen because it presents a notable variety of challenges related to environmental, economic, social and managerial issues. Therefore, developing a sustainability assessment tool in such a context will serve to provide various data covering the different aspects of sustainability. This research will thus help to obtain a more comprehensive sustainability assessment tool that, in turn, will help to overcome similar challenges in future projects. Moreover, this research will provide a good example for similar contexts, including the member countries of the Gulf Cooperation Council.

## 1.2 Context and Justification of Research

Certainly, the sewerage infrastructure system in the kingdom Bahrain is facing a variety of challenges associated with environmental, economic, social and managerial issues, (as described in details in Section 2.5) such as rapid population growth and improper land use, unpredictable behaviour of storm water and consumer, lack of availability of corridors and lands, people's dissatisfaction, pumping-station breakdowns, budget allocation, energy consumption, groundwater infiltration and sewage ex-filtration, and management issues. However, to ensure the continuous economic growth and development in the Kingdom of Bahrain, it is highly crucial to maintain a sustainable infrastructure that will attract investors and create a healthy economic environment. Therefore, it is highly important to optimize the use of all available resources and to find the best solutions for all obstacles. To achieve this, strict and clear sustainability assessments frameworks need to be developed and implemented. Therefore, the main aim of this research is to develop a framework for assessing the sustainability of the Kingdom of Bahrain's sewerage infrastructure by focusing on the project life cycle, therefore ensuring such infrastructure projects' long-term sustainability. A sustainable infrastructure, by itself, justifies the need for a sustainability-assessment framework, as this is an important step towards sustainable development in Bahrain.

### 1.3 Research Aim and Objectives

The main aim of the research is to develop a framework by which to assess the sustainability of the sewerage infrastructure projects in the Kingdom of Bahrain, focusing on two objectives: reducing the risk of sewerage failure and ensuring the sustainable development of wastewater-collection systems in Bahrain. To achieve the aim this study has set the following objectives.

- To study and analyse the current sewerage-system management procedures, determine whether they are achieving the Kingdom of Bahrain's sustainable infrastructure goals, and identify the issues with various sewerage projects
- To investigate the risk factors and failures of Bahrain's sewerage infrastructure projects
- To examine whether the existing approaches to sustainability and performance measures can be used to assess the sustainability of sewerage infrastructure projects
- To identify the sewerage projects' sustainability indicators and develop a sustainability-assessment framework that can solve current and future issues in the Kingdom of Bahrain and that can provide greater transparency over time
- To assess the decision-making processes for those infrastructure projects throughout the life cycles of the projects
- To provide recommendations that will help achieve a sustainable sewerage infrastructure for the Kingdom of Bahrain

### 1.4 Statement of the Problem and Research Questions

The existence of a reliable sewerage infrastructure system is an important element to enrich the quality of life in every civilization. The sewerage system in Bahrain experience a variety of challenges and threats to their sustained performance throughout the 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 and ultimately collapse of the system. that deviate and restrict it from attaining the anticipated level of sustainability. To ensure the possibility of having sustainable sewerage system, it is important to develop a sustainability assessment framework for the sewerage infrastructure projects as it will pursuit solving current and future issues, providing greater transparency for stakeholders, supports decision-making processes and finally will indicate the extent of sustainability while driving it to be more sustainable. The development of sustainability assessment framework for the sewerage infrastructure projects in Bahrain would contribute to maintaining a reliable sewerage network capable of resolving a variety of possible challenges and risks, thus contributing to sustainable development. Meanwhile, it will be presented as a good example for other countries with a similar context such as the Arabian Gulf region.

In order to achieve the research's aim and objectives described in Section 1.3, the following fundamental questions were addressed:

- What are the current practices in sewerage infrastructure-system management in Bahrain?
- What are the issues in the sewerage infrastructure projects in Bahrain?
- What are the risks and failure factors for the sewerage infrastructure projects in Bahrain?
- What are the decision-making processes for Bahrain's sewerage infrastructure projects?
- What are the sustainability indicators of Bahrain's sewerage system?
- What is best way to assess the sustainability of sewerage infrastructure projects in the Kingdom of Bahrain?

## 1.5 Research Method Overview

To develop a sustainability-assessment framework for the sewerage infrastructure projects in the Kingdom of Bahrain and to fulfil the objectives of the research, a combination of quantitative and qualitative methods were adopted. The study focused on the Kingdom of Bahrain's sewerage system, which is administered by the Ministry of Works. This study followed these steps:

1. The literature relating to the sustainable infrastructure, particularly sewerage system sustainability and their sustainability assessments were reviewed (Chapter 2).

2. The current procedures for sewerage-system management and approaches to sustainable infrastructure were studied, including those related to planning, design, construction, and maintenance processes as well as the decision-making procedures. (section 2.3, 2.4 of Chapter 2).
3. The sustainability indicators for the two objectives of sustainability assessment framework namely 1) reducing the risk of sewerage failure (sewerage flow characteristics aspects and Strategic technical aspects) and 2) Contribute to the sustainable development of wastewater collection system (social, economic, environmental and policy, decrees and institutions aspects) have been identified from previous literatures, preliminary data (Governmental reports) and case studies which have been be further verified by consulting experts in Bahrain (Chapter 4). A survey of experts has been used to weigh the identified indicators in order to create the final framework (Chapter 5).
4. A sustainability-assessment framework was developed that solves current and future issues; it covers all aspects of sustainability and provides the best decision-making that would orient toward sustainability. The framework then was applied to three case studies to demonstrate how it works (Chapter 7).

## 1.6 Anticipated Contribution

It is becoming increasingly difficult to ignore that the infrastructure should strive to comply with sustainability. Therefore, this research focuses on assessing the sustainability of the sewerage infrastructure projects, as only a few research has focused on such assessment at the project level, and to the best of researchers' knowledge, no study has been carried out in assessing sustainability in sewerage system throughout its project life cycle. The results of this research will contribute in filling gaps by providing a sustainability-assessment framework for sewerage infrastructure projects in the Kingdom of Bahrain and the Arabian Gulf region as a whole. Furthermore, the sustainability-assessment framework focuses on all aspects of sustainability, setting it apart from the majority of the existing frameworks, which focus more on environmental aspects than social and economic aspects. Moreover, the sustainability-assessment framework supports decision-making processes throughout the assets' life cycles. It also provides greater transparency for stakeholders. Finally, it leads to the solutions for various environmental, social, economic and managerial issues with Bahrain's sewerage infrastructure system. In this research, the focus is on establishing a sewerage sustainability-assessment framework to take the first steps towards sustainable development for the sewerage infrastructure system in Bahrain, all while focusing on environmental, economic and social aspects.

### 1.7 Thesis Structure

There are eight chapters in this thesis, and they are structured as follows:

- **Chapter 1 – Introduction:** Which is this chapter that includes the background of the research, context and justification of research, research aim and objectives, statement of the problem and research questions, research method overview, anticipated contribution and finally the thesis structure.
- **Chapter 2 – Literature Review:** Following the gap description in Chapter 1, the literature review chapter describes sustainable infrastructure development, particularly for sewerage systems. It also provides the base for the following chapters, including the methodologies applied in similar studies and the underpinning theoretical base for the research framework.
- **Chapter 3 – Methodology:** This chapter presents the design of the research and methodology applied in this research. It details how the research questions will be answered, and what are the tools required to govern the overall research process.
- **Chapter 4 - Development of Sustainability Assessment Framework for Sewerage Infrastructure Projects:** This chapter explains in depth how the initial framework is designed, the inclusion and exclusion criteria, and the related theories and data in which the indicators included in the framework were derived from.
- **Chapter 5 – Data Analysis:** This chapter presents the verification stage throughout the pilot study, and it's also discussed the data collection stage and the analysis of the collected data through the online survey that ended by providing the final framework.
- **Chapter 6 – Case Studies of Sewerage Infrastructure Projects:** This chapter discusses the three case studies that have been chosen for this research, for each case study it presents an overview, objectives, cost, benefits, outcomes, risks and their activities in details; these cases will then be used in the implementation of the developed sustainability assessment framework in the next chapter.
- **Chapter 7 – Application on Case Studies:** This chapter demonstrate how the developed sustainability assessment framework could be implemented, as it in detailed describes the sustainability assessment objectives, criteria and indicators as well as it shows the application of the assessment on the three case studies which includes

determining possible alternatives, applying convenient indicators, scoring, analysing, discussion and recommendations.

- **Chapter 8 – Conclusion:** Provides a summary for the all the chapters with the research implication, research limitation, recommendation and future work.

# Chapter 2: Literature Review

This chapter is a review of the literature regarding sustainability development for infrastructure, sewerage-system management in Bahrain, project life cycles, sewerage projects' life cycles in Bahrain, sewerage-system issues in Bahrain, sustainability issues in sewerage projects, approaches and tools for sustainability assessments of sewerage systems, project-level sustainability assessments and, finally, the gaps in the literature.

## 2.1 Sustainability Development of Infrastructure

The most commonly used definition of sustainable development is "development which meets the needs of the present without compromising the ability of future generations to meet their own needs" (Bruntland, 1987). The sustainable development has been discussed frequently since Bruntland's report, which introduced the concept of sustainability development. In recent years, the United Nations has presented sustainable development goals that are built around ending poverty, protecting the planet and ensuring prosperity for all. Many developing and developed countries have adopted these goals, as sustainable infrastructure is becoming a main strategic priority in nations' development strategies, laws and policies (Finkbeiner et al., 2010). Moreover, having a sustainable infrastructure is essential, as it directly impacts all measures of sustainable development (Ainger and Fenner, 2014). Furthermore, having a sustainable infrastructure can accelerate the balance among economic, social and environmental aspects of sustainable development in developing countries (Diaz-Sarachaga, Jato-Espino and Castro-Fresno, 2017). Moreover, for both developing and developed countries, infrastructure is an engine of economic development (Shannon and Smets, 2010).

Infrastructure refers to very expensive assets that are usually designed to serve for long periods; it includes utilities (e.g., gas, electricity, water and communications), transportation (e.g., airports, railways, roads and seaports) and social facilities (e.g., hospitals, educational institutions and community facilities). The development of structural elements in a sustainable infrastructure consists of many stages (e.g., planning, designing, constructing, operating and maintaining), and it has to proceed without diminishing the social, economic and environmental processes that are required to preserve human equity, diversity and natural systems' functionality.

To understand the sustainability of an asset, an example shows the relationship between an asset's performance and its service life throughout its life cycle. At the end of any asset's life cycle, a new project occurs to upgrade, rehabilitate, modify or replace the asset. There is direct proportional relationship between performance and an infrastructure asset's service life. Performance, here, is a generic term that can refer to serviceability or to the fulfilment of relevant asset-design criteria (until ultimate limit states are reached). Figure 1 shows two designs for an infrastructure system. In the first, which represents the asset's initial design, it is evident that the design will have a short service life and lead to multiple degradations. Consequently, structural repairs, rehabilitations or replacements are inevitable, leading to the start of the second structure's design. This design should improve the sustainability of the first structure design and provide a longer service life. This, in turn, means an improved ability to fulfil the sustainable criteria throughout the intended life cycle (Lounis and McAllister 2016). Furthermore, assessing the performance of the asset could increase its service life and reduce the severity of problems before they can cause a huge failure (which can cost a significant amount to repair); assessment also makes an asset more sustainable. Moreover, such infrastructures present the growth of an asset value and have benefits for the future generations who will inherit the consequences of today's investment decisions (Marlow et al., 2013).

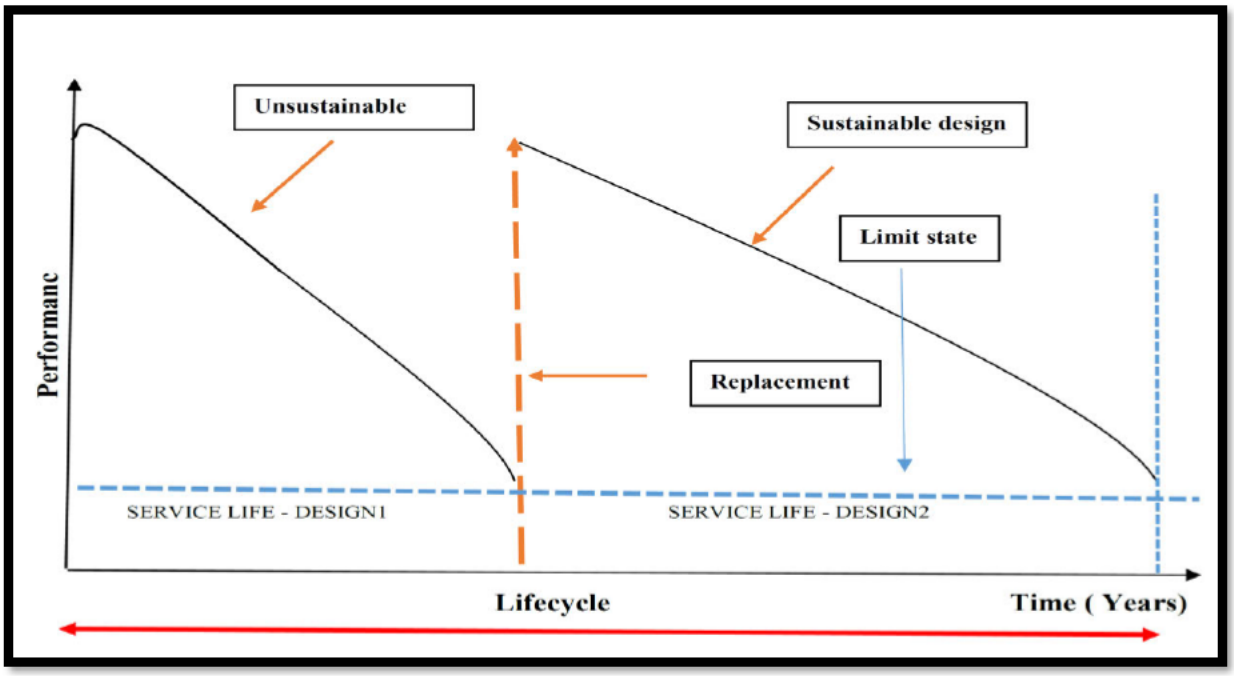



Figure 1: Performance of an infrastructure-system schematic representation (adapted from Lounis and McAllister, 2016)

Sustainability is an important performance measure that should be considered for the entire life of an asset, including planning, designing, constructing, operation, maintenance, evaluating and demolishing (Lounis and McAllister, 2016). To maximize the possibility of achieving sustainable development goals, sustainability-assessment and -reporting tools must be developed; these will serve to inform stakeholders about the progress being made towards those goals (Siew, Balatbat and Carmichael, 2016). Observations of the economy, the environment and well-being are at the core of the concept of sustainability development; these three pillars cannot be separated from the larger concept (Koops et al., 2015). A comprehensive sustainability assessment of any civil infrastructure requires an evaluation of its three major components: cost, environmental impact and social impact (Hossain and Gencturk, 2016). Furthermore, as sustainability development evolves, sustainability assessments of projects that are expected to be sustainable will move towards more practical approaches, perhaps involving decision makers even in the very early stages (Poveda and Lipsett, 2011). Nevertheless, infrastructure projects have a major influence on how the principles of sustainable development are implemented (Shen, Wu and Zhang, 2011).

### 2.2 Sustainable Sewerage Systems

The sewerage networks are part of the main underground infrastructure and thus have substantial influence on all modern societies across the three sustainability aspects: environmental, economic and social (Beheshti and Sægrov, 2017; Halfawy, Dridi and Baker, 2008; Sinha and Knight, 2004). 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 the 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 (Akhtar et al., 2014; Grigg, 2012; Upadhyaya, Biswas and Tam, 2014).

Within the existing literature, researchers have assessed the sustainability of wastewater treatment in many studies, often focusing on the sewage that sewers carry and assessing the sustainability of the wastewater-treatment systems; the goal is to have more sustainable wastewater-treatment systems and technologies (Balkema et al., 2002; Diaz-Elsayed et al., 2017; Hoffmann et al., 2000; Li, Yu and He, 2013; Molinos-Senante et al. 2014; Molinos-Senante et al. 2015; Muga and Mihelcic 2008; Murray, Ray and Nelson, 2009; Plakas, Georgiadis and Karabelas, 2015; Roux et al., 2010; Zhang and Ma, 2020; Zhou et al., 2020). Furthermore, researchers in various studies have 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 (Chen, Ngo and Guo, 2012; Fatta-Kassinos et al., 2011; Rahman, Hagare and Maheshwari, 2015; Rodriguez et al., 2009; West et al., 2016). However, it is evident from the literature that little attention has been paid to the impact sewerage systems have on the environment. For instance, Torgersen, Bjerkholt and Lindholm (2014) stated that the Norwegian authorities neglected sewerage- and drainage-system issues such as flooding, infiltration, water leaks and pollution, leading to a massive effort that focused on the pollution of wastewater-treatment plants during past decades. In addition, those studies showed that sewerage systems can affect the efficiency of wastewater-treatment plants (Neshaei et al., 2017) such as the wastewater treatment is easier when that wastewater is fresher (Agriculture and Resource Management Council of Australia and New Zealand & Australian and New Zealand Environment and Conservation Council, 1997). Furthermore, the sewer system has a high impact on all categories of the life cycle and on the environmental assessment of the wastewater-treatment system, even aside from eutrophication (Roux et al, 2010). Risch et al. (2015) found that the environmental impact of the sewer system is higher than that of the 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 (Abebe Wudineh and Chala Kuke 2015; Akhtar et al. 2014; Beheshti and Sægrov 2017; De la Fuente et al. 2016; Husbands and Dey, 2002; Lindholm, Greatorex and Paruch, 2007; Nansubuga et al. 2016; Petit-Boix et al. 2015; Petit-Boix et al. 2017; Remy and Jekel 2008; Risch et al. 2015; Vahidi et al. 2016). Indeed, none of these studies have 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 (Akhtar et al., 2014; de la Fuente et al., 2016; Vahidi et al., 2016). Two such studies (De la Fuente et al., 2016; Vahidi et al., 2016) found that the most sustainable material was concrete. However, Akhtar et al. (2014) found that polyvinyl chloride (PVC) was the most sustainable material for sewer systems. And these differences were based on the different materials they were comparing, different size of sewer, and different criteria that they have used which fits their context, such as the material cost on the market. In addition, Remy and Jekel (2008) and Risch et al. (2015) environmentally assessed wastewater systems, including sewerage systems.

However, Risch et al. (2015) clearly indicated the importance of the operation and maintenance of the sewer system. The results of this research showed that the construction of a sewer system has a larger environmental effect than either the construction or operation of wastewater-treatment plants. Remy and Jekel (2008) stated that some sewerage systems have a higher potential to benefit the environment than others do, depending on the systems' configurations. Other researchers have focused on assessing sewerage projects based on their social impact (Husbands and Dey, 2002). Husbands and Dey (2002) argued that the implementation of the mitigation process largely affects the relationship between appraisal and implementation. This issue requires that both implementation and appraisal be, effectively, interconnected entities rather than separate phases. Lindholm, Greatorex and Paruch (2007) compared multiple methods for calculating the sustainability indices for sewerage systems and found that it is possible to prove that one system is more sustainable than another; however, it is difficult to do so, as it requires expert scrutiny due to the various selected indicators and the weighting and normalization methods. In another study, Abebe Wudineh and Chala Kuke (2015) assessed a sewerage system's technical sustainability through an Ethiopian case study. The causes of the sewerage failures were identified, and operations and maintenance were the main causes of these failures, followed by construction and design. Other studies have been conducted to find the critical variables in sewer systems throughout their life cycles; some have used the eco-efficiency assessment approach. The results of this study demonstrate that the maintenance and operation of the sewer are the critical stages in terms of impact on the environment. However, these effects are associated with the location of the nearest wastewater plant, as greater distance leads 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 (Petit-Boix et al., 2017). A recent study conducted in Norway (Beheshti and Sægrov, 2017) assessed the sustainability of strategic management for a wastewater transport system. The aim of this study was to present a methodology to compare variable pathways towards the sustainable management of wastewater systems. The research focused on economic, physical, environmental and energy aspects of water infrastructure, mainly in strategic planning. Beheshti and Sægrov (2017) found that, to accomplish strategic planning in the sustainable management of a sewer asset, it is essential to evaluate the variable aspects of sustainability and to administer them in a comprehensive system. Moreover, water-infrastructure sustainable management can be considered in strategic long-term planning for urban water systems; this results in economic and environmental benefits for society (Beheshti and Sægrov, 2017).

The results of a sustainability assessment depend on the country's situation and can be based on the sewerage projects' configuration, as every configuration and situation has alternatives that can produce more sustainable sewerage infrastructure. When sustainable practises are in place, it is not necessary that the best practice be in place. For example, Nansubuga et al. (2016) reviewed the use of sustainable sanitation in Africa and found that, due to the expense of sewage infrastructures, some countries cannot afford to implement them, even as they try to find sustainable solutions that fit their needs. Indeed, having a poor sanitation system negatively impacts the quality of natural water resources and causes health risks to the populations involved. Due to this lack of money and to the expensive maintenance and operation of a sewerage system, even if such a system were somehow implemented, it probably would end up failing in terms of functionality. Onsite sewerage systems are more affordable and widely accepted, but they fail often due to the lack of institutional arrangements, which are vital to guaranteeing suitable designs and the sustainable management of faecal sludge. Furthermore, this can affect water resources and in turn increase the risk of waterborne diseases (among other issues). Thus, to ensure sustainable sanitation in African countries, simple technologies are needed to treat and separate wastewater at 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 the 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 infrastructure's life cycle. The social pillar is intended to improve the lives of those who interact 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 (Diaz-Sarachaga et al., 2016; Lounis and McAllister, 2016). Furthermore, a sustainable sewerage system could be reachable by addressing sustainability and supporting decision-making in the earliest stages of the sewerage projects and throughout their life cycles by focusing on those projects' long-term sustainability. This 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 tends to help meet the needs of the infrastructure project and throughout its life cycle (Della Spina et al., 2017). However, previous studies have focused on project sustainability regarding deliverables (e.g., feasibility studies, design and planning), and less attention has been given to sustainability of project implementation (Kivilä, Martinsuo and Vuorinen, 2017). Therefore, it is important to assess sewerage infrastructure projects throughout the projects' life cycles.

## 2.3 Overview of the Sewerage System

This section covers the collection and disposal of sewage in Bahrain, including the conceptual layout for developing a comprehensive understanding of Bahrain's sewerage network and existing sewerage assets. It also includes a description of the network.

### 2.3.1 Sewage system operation: collection and disposal of sewage

The disposal of sewage is important to daily quality of life, although it is not noticeable for some of the population because of the underground infrastructure networks. There are various disposal methods; the two main ones are on-site disposal systems (septic tanks, etc.) and sewerage systems (sewer networks). Sewerage refers to the infrastructure that is responsible for conveniently transporting both surface runoff (rainwater, storm water and meltwater) and sewage. There are two types of sewerage systems: combined (also known as conventional sewers) and separated (sanitation systems and storm water systems).

This research focuses on sanitation systems, which are the main component of all sewerage systems (Ariaratnam and MacLeod, 2002) and which are defined as sewer pipeline networks that are used to convey liquids and water-carried waste (from residential units, commercial buildings, industrial plants and institutions), as well as varying quantities of storm water, surface water and groundwater that enters the sewer system unintentionally—all of which is then carried to sewage treatment plants (STPs) (Nayyar, 2000). A sewerage system is also a structural element that connects existing urban areas and facilities such as buildings, houses and shops. A STP treats the sewage and produces treated sewage effluent, which is used for the irrigation of landscape areas, agricultural farms and industrial sectors; firefighting; sand washing' and other tasks. In some countries, treated sewage effluent (TSE) is discharged into the sea or injected into aquifers.

### 2.3.2 Sewerage system in Bahrain

The kingdom of Bahrain is a small Arab country located in the south west of Asia. Its area is 783 $km^2$ with 1.484 million inhabitants, giving a population density of 1895 per $km^2$. The country is an archipelago; the island of Bahrain is its largest island, and the capital city is

Manama. Bahrain is currently divided into 4 governorates, namely Capital, Muharraq, Northern and Southern.

*2.3.2.1 Background*

The first sewer networks in Bahrain were built in the late 1970s. Ever since, Bahrain has experienced great population growth. New developments have been implemented in many areas of Bahrain, thus requiring expanded sewer networks. However, the infrastructure has spread more slowly than overall development has (Ministry of Works, 2009). Gravity-based sewer systems have been adopted, along with lifting stations to lift the flow for discharge through other gravity pipes. Due to unavailable construction methods and technologies and the flat nature of Bahrain, the maximum depth of sewer trenches is limited to 7 meters (Ministry of Works, 2009). As a result, despite the country's small size, it has a large amount of pumping stations (more than 468), which makes the system hard to operate and maintain, as the pumping stations face a high rate of breakdowns (Section 2.5). The major trunk sewers and pumping stations were built in the 1980s and are now starting to deteriorate; they require close attention to avoid issues.

*2.3.2.2 Conceptual layout in Bahrain*

To develop a comprehensive understanding of Bahrain's sewerage network, it is crucial to understand the conceptual layout of the system. Pipes and pumping-station classifications are mainly based on function and on materials, as noted in the sewer-network description (Appendix A).

Starting upstream, sewage is generated from houses, commercial shops, factories, schools and other facilities before being collected through lateral pipes. All lateral pipes are connected to a secondary network, ending with either a minor pressure-pump station or a minor lifting-pump station. These pumping stations facilitate the discharge of sewage collected through the secondary network into the main trunk sewers, overcoming long distances and height differentials. The main role of trunk sewers is to convey sewage from various areas to STPs. Major pressure-pump stations and lifting stations are also used when required. The sewerage system consists of various elements, each of which has a distinct function as can be seen in Table 1 (Ministry of Works, 2009).

Table 1: Elements of a sewerage system

| No. | Element | Description |
|---|---|---|

| | | |
|---|---|---|
| **1** | Rodding eyes | These are located close to houses' boundary walls and are meant to allow a rodding tool to be inserted to clear blockages when required. |
| **2** | Gravity pipes | These pipes utilize the potential energy, resulting from a difference in elevation, to convey wastewater between two points. |
| **3** | Manholes | These are used for maintenance activities such as rodding and jetting. They are usually located where the direction of the flow or the slope of the pipes changes. It should be noted that a maximum distance of 120 m should be maintained between manholes due to the maintenance tools' limitations. |
| **4** | Lift-pumping stations | These occur where excavation is limited to a certain depth. The purpose is to lift the flow closer to the surface so as to maintain a slope for the wastewater to move through gravity. This type is commonly used in Bahrain due to the nation's flat topography. |
| **5** | Pressure-pumping stations | These are used to convey wastewater over long distances or to overcome the topography of the land. |

#### *2.3.2.3 Sewerage asset management*

Over years, the authorities in Bahrain have attracted investors and contractors from around the world to perform major strategic projects. One of the most advanced projects is the Muharraq Deep-Gravity Sewer and Sewage Treatment Plant (Section 6.3). A deep-gravity sewer is a technology used to implement sewer pipes at greater depths of 25 to 30 m. This allows the sewer system to run without the need of minor or even major pumping stations (Ministry of Works, 2009). Table 2 summarizes the number of assets of each type in Bahrain (Ministry of Works, 2009).

Table 2: Sewerage assets in Bahrain

| Description | Quantity | Unit |
|---|---|---|
| Pumping stations | 165 | No. |
| Major pumping stations (see definition below) | 20 | No. |
| Lift stations | 283 | No. |
| Grease traps | 46 | No. |

| | | |
|---|---|---|
| Manholes | 29,956 | No. |
| Inspection chambers | 128,561 | No. |
| Trunk sewers | 119 | km |
| Rising mains | 93 | km |
| Main sewers | 935 | km |
| Lateral sewers | 1,427 | km |
| Odour-control systems | 21 | No. |

Sewer networks receive trade wastewater and raw sewage from houses, hospitals, schools, factories and other establishments; this is then conveyed to STPs. There are 13 STPs in Bahrain; 2 major and 11 minors. The major plants Tubli Water Pollution Control Centre (WPCC) and Muharraq STP, while the minor plants are Hidd Industrial area, Ma'ameer, South Alba, Askar, Jaw, Al Dur, University of Bahrain (UOB), Hamala, Jasra, Sitra and Riffa View STPs. Most of these plants are owned and operated by Sanitary Engineering Affairs, but Muharraq STP was funded through a private–public partnership framework, due to recommendations from the Economic Vision 2030 (Economic Development Board, 2008, Appendix B). The main function of STPs is to treat wastewater until a certain quality level is reached so that the water can be reused or disposed of. There are two major STPs in Bahrain: Tubli Water Pollution Control Centre (WPCC) and Muharraq STP, which have capacities of 250,000 $m^3$/day and 75,000 $m^3$/day, respectively. The remaining STPs, such as Askar, South Alba, Hamala and Hidd, are minor. Most of these STPs receive domestic wastewater, and only two receive industrial wastewater: Ma'ameer and North Sitra, with capacities of 2,500 $m^3$/day and 16,500 $m^3$/day, respectively (Ministry of Works, 2009).

The STPs in Bahrain receive significant attention from Ministry of Works. For instance, Tubli WPCC is capable of producing around 160,000 $m^3$/day of treated sewage effluent; the remaining secondary-treated wastewater is discharged to the sea through an outfall to Tubli Bay. Moreover, Sanitary Engineering Affairs is in the process of expanding Tubli WPCC, which will increase the plant's capacity to approximately 400,000 $m^3$/day. The master plan states that more than 49% of the capacity is for infiltration water to the sewerage system (Ministry of Works, 2009), which shows the importance of having a problem-free sewerage system. Furthermore, Tubli WPCC has developed over time. Table 3 shows the phases of Tubli WPCC.

Table 3: Tubli WPCC Phases

| Phase | Year | Capacity |
|---|---|---|
| 1 WPCC Tubli | 1982 | 54,000 $m^3$/day |
| 2 WPCC Tubli | 1989 | 124,000 $m^3$/day |
| 1 TSE | 1989 | 60,000 $m^3$/day |
| 3 WPCC Tubli | 2002 | 200,000 $m^3$/day |
| 2 TSE | 2002 | 200,000 $m^3$/day |
| 2a | 2004 | Sludge-drying plant |

It is worth mentioning that North Sitra Sewage Treatment Plant's capacity is 16,500 $m^3$/day, and its catchment area includes industrial and residential units. Its treated sewage effluent (TSE) had been discharged to the sea, as it used to lack a TSE transmission line. However, in Dec 2019, a line from Sitra STP to Manama Loop was completed and has been operational since then. Moreover, Al Dur, Askar, Hamala, Hidd, Jasrah and Jau STPs are minor projects located in various areas of Bahrain. These STPs are planned to be decommissioned after the implementation of several strategic projects such as the Tubli WPCC expansion, the Western Primary Trunk Sewer and the North Muharraq Trunk Sewer.

## 2.4 Sewerage Project Management

This section describes the management of sewerage projects throughout its life cycle in Bahrain, including project life cycles in general and the sanitary engineering sewerage programs.

### 2.4.1 Portfolios, programs and projects

A project is defined as a "temporary endeavor undertaken to create a unique product, service, or result. The temporary nature of projects indicates that a project has definite beginning and end" (A guide to the project management body of knowledge, 2004). Projects are initiated to be part of programs and portfolios that are established to achieve certain strategic objectives in the organizations. For example, portfolios in the public sector aim to provide excellent services such as medical care, education, infrastructure services and others, while the private sector mostly aims to generate profit and acquire market shares. Organizational planning aims to set priorities of projects and programs by carefully studying and analysing risks, funding, resources and other considerations depending on the organization type and nature of business. To effectively manage portfolios, programs and projects, the concept of organizational project management must be clarified, as it combines project, programme and portfolio management through scope, change, planning, management, success and monitoring. For example, project management will assess the degree of customer satisfaction in terms of the product and project quality, timeliness, and budget; success is measured by the degree to which the programme satisfies the needs and benefits planned (A guide to the project management body of knowledge, 2004).

### 2.4.2 Project life cycle

Managing projects can be challenging, especially for heavy expensive civil engineering infrastructure projects. Effective project management requires a complete understanding of the project life cycle in order to ensure project delivery in time with the desired quality and within the allocated budget. There are four phases within the project life cycle, which are project initiation, project planning, project execution and project closure; these are described in the following section (Westland, 2006). Figure 2 illustrates the project life cycle.

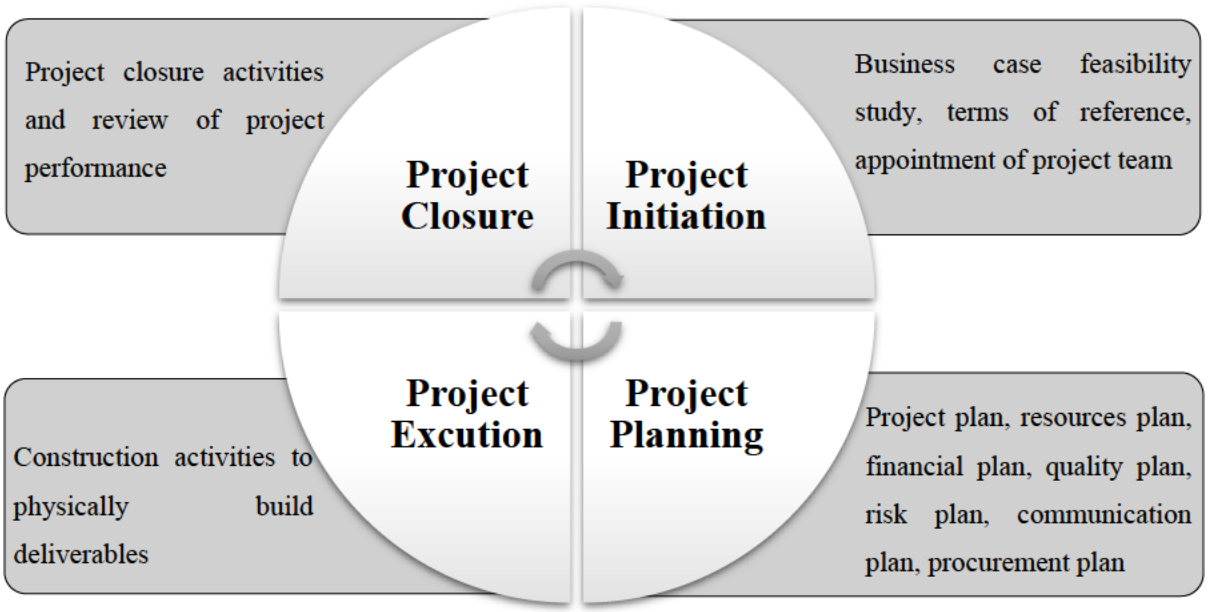



Figure 2: Project life cycle (adapted from Westland, 2006)

#### *2.4.2.1 Project initiation*

The project initiation phase is considered to be the most critical phase in the project life cycle, as the risk of project failure is directly affected by the effectiveness of initiation. In this phase, projects are created by identifying the problem, appropriate solutions to be adopted and the scope of work of the project. As part of this phase, the following activities are performed (Westland, 2006):

a) Business case: This document justifies the initiation of the project by describing the problem, providing several possible solution, listing the costs and benefits, and recommending a solution for top management approval.
b) Feasibility study: This represents a detailed assessment of current problems and identifies available solutions that could be implemented. This study provides further details not found in the business case, as the feasibility of each option is discussed, as are the risks associated with each option.
c) Terms of reference: This is prepared after the completion of the business case and the feasibility study. It is also referred to as a project charter. This document clearly defines the scope of the project's work.
d) Appointment of the project team: This identifies the roles required to appoint people to work on the project. Usually, the first person appointed is the project manager, who will be involved in the appointment of the other project team members.

*2.4.2.2 Project planning*

This phase includes preparing a set of planning documents to which to refer during the remaining phases of the project. These plans need to be developed carefully, as they need to be related and loaded with required resources. Failing to do so might cause time and cost implications to the project.

First of all, a project plan should be developed, which includes setting a work breakdown structure and milestones in a hierarchical set of phases. Then, a resources plan needs to be created to define resources required for every activities listed in the work breakdown structure. In addition, a financial plan should be created to secure the required budget for all expenses such as labour, equipment and materials. To ensure the quality of the final deliverable and to meet customer expectations, it is critical to prepare a quality plan to define quality targets and list all quality control and quality assurance procedures. It is essential to define foreseeable risks through a risk plan and set procedures to mitigate or reduce the effect. None of the mentioned plans would be effective without setting a proper project-communication plan to identify communication means and information to be exchanged between stakeholders. A project procurement plan lists elements to be procured from external suppliers, and it should include all necessary details for both goods and services. This plan is important for the procurement and tendering processes.

In terms of operation and maintenance, it is crucial to identify technologies, methods, equipment and resources during the planning stage, as it will define the roadmap after the execution phase. The main goal of operation and maintenance planning is to highlight requirements to ensure that the system is working continuously as planned (Bloetscher, 2011; Westland, 2006).

*2.4.2.3 Project execution*

In this phase, deliverables are physically constructed and delivered to the customer for approval. It is considered to be one of the most important phases and require continues monitor and control activities by the project manager to ensure that resources and expenditures are being consumed as planned. The project manager also needs to monitor time, risk, quality and procurement. There are also other duties, such as managing issues and acceptance procedures (Westland, 2006).

*2.4.2.4 Project closure*

After the acceptance of the project deliverables, the project's objective has been achieved, which requires formal closure. Activities involved in performing project closure are all aimed towards closing contracts with consultants, contractors and suppliers. The assigned project manager should finalize outstanding project activities, risks and issues. All stakeholders must be informed of the project closure.

After completing all formalities related to project closure, an assessment process needs to be started to evaluate the success of the project in terms of benefits defined in the business case, deliverables defined in the terms of the references and criteria highlighted in the quality plan. In addition, it is important to assess the project budgets and forecasts and how the project was in line with the project plan. All of this information must be documented and available for the organizations members to have access to lessons learned (Westland, 2006).

*2.4.2.5 Project operation and maintenance*

The operation and maintenance phase starts, as defined in the planning stage. Since major investments were made, the system is expected to be maintained for long-term service, as per the plan. Utilities users such as citizens and developers expect the system to function all the time with no failures, which raises the need to implement emergency plans to deal with failure scenarios. Ultimately, operation and maintenance must ensure proper management to improve system reliability, decrease operation and maintenance expenditures and improve safety (Optimizing Operation, Maintenance, and Rehabilitation of Sanitary Sewer Collection

Systems, 2003). There are three classifications for maintenance (adapted from Mobley, (2002)):

a) Corrective maintenance: This includes emergency maintenance, and it is needed when the equipment or system fails. This classification is considered as reactive, and reliance on such maintenance results in poor system performance.
b) Preventive maintenance: This includes programmed, systematic approach to maintenance activities. This classification is considered proactive, and it results in improved system performance. Examples of major elements contributing to good preventive and predictive maintenance include planning and scheduling, system mapping, records management, assets inventory and management, spare-parts management, cost and budget control, and training programs.
c) Predictive maintenance: This includes performing baseline performance data, monitoring performance criteria over a period of time and observing changes in performance. By doing so, it is possible to predict failures so that maintenance can be performed. This classification is considered to be proactive.

Organizations performing operation and maintenance activities should "reduce the corrective and emergency maintenance efforts by performing preventive maintenance that will minimize or even eliminate system failures that result in stoppages and overflows" (Optimizing Operation, Maintenance, and Rehabilitation of Sanitary Sewer Collection Systems, 2003, p. 6).

### 2.4.3 Sanitary engineering sewerage programs and projects life cycles in Bahrain

#### *2.4.3.1 Overview of sanitary engineering programs and projects*

Sanitary engineering systems in Bahrain are owned and managed by the government and specifically by Sanitary Engineering Affairs as a division of the Ministry of Works, Municipalities Affairs and Urban Planning. The sanitary engineering framework is mainly related to (and inspired by) the dynamic government policy and plans defined in the Economic Vision for Bahrain 2030 (Appendix B). In 2009, the Ministry of Works issued the new NMPSES, which is considered to be a revision of the National Strategy Plan for Sewerage and Sewage Treatment, which was issued in 1998. The new master plan is the result of a comprehensive study of all sanitary engineering systems including storm water, sewerage, STPs and TSE. Based on the study and the analysis performed, an action plan was developed to propose measures in certain intervals as described in the following:

a) Immediate Measures—2009 to 2010,

b) Short-Term Measures—2010 to 2013,
c) Mid-Term Measures—2013 to 2020, and
d) Long-Term Measures—2020 to 2030.

Examples of the measures are refurbishment and rehabilitation of certain pump stations and construction of new deep-gravity sewers in certain areas. Based on these measures, Sanitary Engineering Affairs initiated programs that comprise a number of projects to follow the action plan and allocate required budget in coordination with the Ministry of Finance and the Prime Minister's Office. Programs and project life cycles start with planning and progress to design, construction and eventually operation and maintenance. As some of the sewerage networks in Bahrain have exceeded 35 years, action plan set in the NMPSES calls for initiating rehabilitation projects in these areas (Ministry of Works, 2009).

*2.4.3.2 Sanitary engineering affairs directorates and sections organizational structure*

The Sanitary Engineering Affairs structure is arranged as a functional organization in which each directorate and section takes a certain role and part of programme and project life cycles, unlike the project management organization style in which resources and staff are allocated to project management teams. Figure 3 illustrates the organizational structure of the Sanitary Engineering Affairs (Ministry of Works, 2009).

The Sanitary Engineering Planning and Projects Directorate is responsible for planning, designing and constructing Sewer Networks, Sewage Treatment Plants and Treated Sewage Effluent Networks. It is divided into four sections, and each stage of the project life cycle is assigned to a section. These sections' roles and responsibilities are discussed in the following sections. The Sanitary Engineering Operation and Maintenance Directorate is responsible for operating and maintaining sewerage system assets, including sewer pipelines, pumping stations and STPs. It is divided into three sections: the Sanitary Network Section, the Wastewater Treatment Plants Section and the Treated Sewage Effluent Section; each section is responsible for active assets in the system.

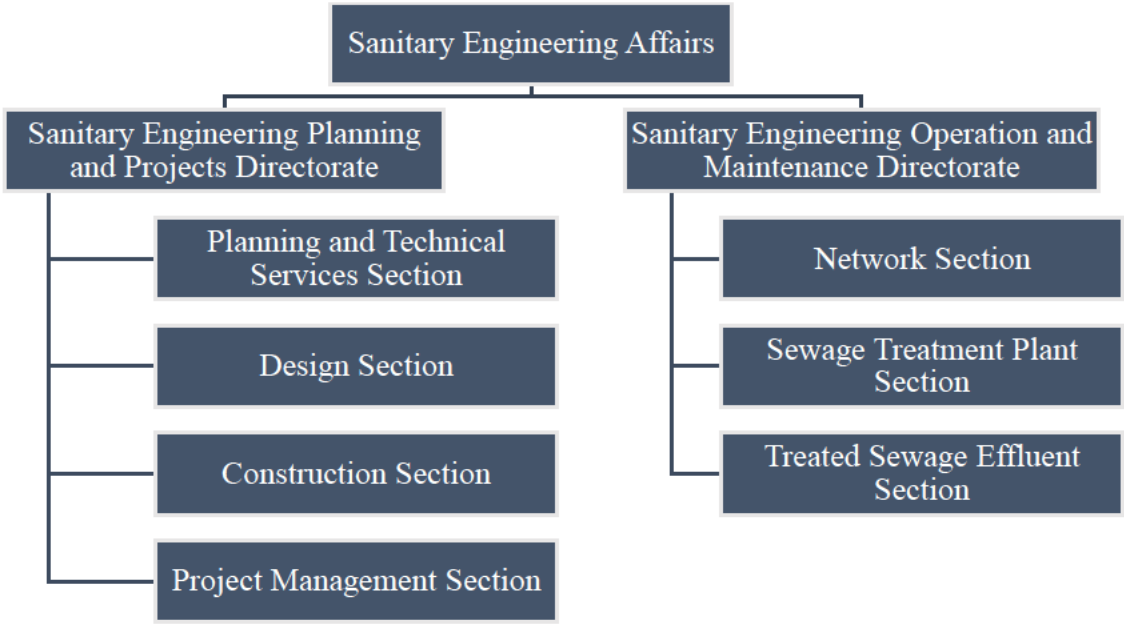



Figure 3: Sanitary Engineering Affairs organizational structure

*2.4.3.3 Sanitary engineering programs and project life cycle*

Regarding the Sanitary Engineering Affairs programs and the project life cycle, each directorate's and each section's activities and responsibilities are discussed in the following sections. Figure 4 illustrates an overview of the life cycle.

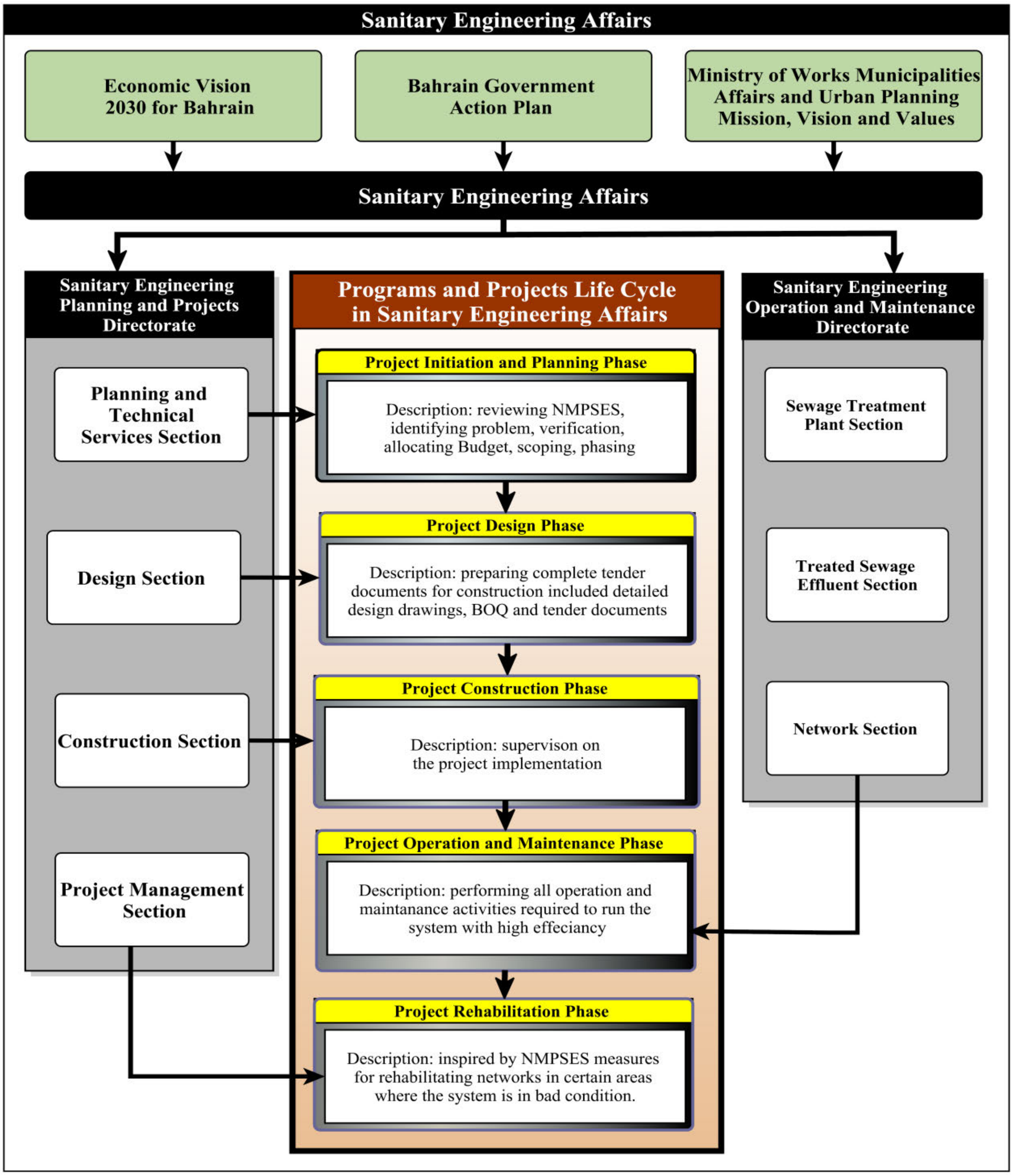



Figure 4: Programme and project life cycles in engineering affairs (with responsibilities)

#### *2.4.3.3.1 Project initiation and planning*

The initiating and planning phase usually starts with the NMPSES. Moreover, it also considers also considers complaints and requests raised by the public through means such as the media or municipal representatives. In addition, stakeholders (e.g., the Ministry of Housing, the Ministry of Industry, Commerce and Tourism and investors) are considered. Based on that, the Planning and Technical Services Section initiates new projects for top management to decide upon, based on budgetary availability and the NMPSES.

The Planning and Technical Services Section is also responsible for preparing the Directorate Programme, and it shows all of the projects' budget codes and contract numbers. The main goal of the programme is to forecast the cash flow of the directorate in order to financially manage funds allocated for current and future projects.

There are three points that are considered to decide the priorities of projects. First is the development rate, which must be between 60% and 70% of the entire proposed area. Second is the severity of the area, which can be measured by the amount of complaints. The third point is to check the capacity of the discharge point using hydraulic modelling (Ministry of Works, 2011b).

###### *2.4.3.3.2 Project design phase*

Design phase activities are performed either by a hired consultant and managed by the Consultant Design Group or by the government staff and managed by Direct Design Group, depending on the project's complexity and size. The aforementioned groups are parts of the Design Section.

The Direct Design Group is responsible for performing all tasks necessary to design sewerage schemes. These tasks include surveying areas, preparing concept designs, preliminary designs and detailed designs. The final output consists of detailed design drawings, which are then supported with bills of quantity and tender documents that allow for construction to proceed. It is worth mentioning that the role of this group is limited to sewerage schemes and storm water schemes; it does not include trunk sewers, major pumping stations, STPs or treated sewage-effluent networks.

The responsibilities of the Consultant Design Group are to manage sanitary engineering projects designed by consultants. These projects include improvements to existing networks, shallow trunk sewers, deep-gravity sewers, treated sewage-effluent networks and STPs and performing studies on future developments to address their needs. The group is also responsible for ensuring that projects developed by private sectors are in accordance with the Ministry of Works' standards and specifications.

As part of the engineer's roles and responsibilities, Consultant Design Group engineers review all technical reports and drawings submitted by the consultant such as inception reports, concept design reports, geotechnical investigation reports, hydraulic modelling reports, environmental impact assessment reports, design criteria and detailed design drawings (Ministry of Works, 2010).

*2.4.3.3.3 Project construction phase*

The construction phase is supervised by the Construction Section; it is performed by government staff under the Direct Contract Group or by a consultant under the Consultant Supervision Group.

The Direct Contract Group is mainly responsible for managing the construction works of the sewerage network projects awarded to contractors and designed by Direct Design Group or Consultant Design Group. Managing projects requires many tasks: ensuring that all permits required to start construction are granted, verifying that all health and safety procedures are followed, ensuring that all materials meet the Bill of Quantity and the specifications, managing the project programme and the progress of the work, managing the cash flow, and performing interim valuations.

Consultant Supervision Group is responsible for supervising consultants awarded to supervise projects done by contractors. Their main role is to manage these projects and ensure that they are delivered according to the project programme and to ensure that all construction activities are performed according to best practice and method statements. Their tasks also include involvement in interim valuation and payment approvals, in addition to many others (Ministry of Works, 2011a).

*2.4.3.3.4 Project operation and maintenance phase*

Planned preventive maintenance is one of the most important responsibilities of the Sanitary Network Section. The aim of this programme is to keep the network in a fully operational condition by performing several activities on all the assets in the network. The planned preventive maintenance programme has a great effect in preserving the original capacity of the collection system, which allows connection of additional areas to the existing system and therefore ensure sustainability of the system. The programme also prevents flooding events to occur in the system and reduces odour emission in the pump stations.

Gravity pipes are designed to carry liquid waste. However, because the wastewater disposed of in the collection system contains solid particles, grease, and other objects, it causes the accumulation of solid particles, which leads to blockages. Another factor that contributes to blockages is the cracks in the pipes which allow roots and soil to enter the system. There are two main methods used to clear blockages in the system: jetting and rodding.

When blockage occurs in the collection system, the first method used to clear the blockage is rodding, in which a sharp metal rod is inserted inside the pipes and pushed to break the blockage. This method is used for minor blockages. However, when the blockage cannot be cleared by rodding, the jetting method is used; it is done by inserting a metal nozzle connected to a pump in order to use the pressure power to clear the pipes. This method ensures the total removal of accumulated solids in the pipes.

Pump stations are very critical elements in the sewerage collection system, and it is very important to keep the stations in a fully operational condition by checking the pumps on a regular basis while keeping the sump clean from silt. De-silting is performed to remove silt from the sump in order to avoid blockages and keep the pump in a good condition to allow it to work efficiently. Another advantage of performing de-silting activities for the pump stations is to reduce odour emissions (Ministry of Works, 2012).

##### *2.4.3.3.5 Project rehabilitation phase*

The aim of rehabilitation projects is to improve the existing network in order to reduce infiltration rates. The rehabilitation phase is not always necessary, as a complete study and analysis must be conducted on the network's age and condition to determine the necessity of performing rehabilitation projects. Rehabilitation is the responsibility of the Project Management Section. Five methods are used in Bahrain: open trench, robotic, pipe bursting, curing in place and tightening in place (Appendix C).

Closed-circuit television (CCTV) investigation is very important in evaluating damage to pipes. The information that can be obtained from optical inspection includes deformation, cracks, infiltration and obstacles. These data were entered in software called BAYSYS, which classified the damage in each line. CCTV videos were observed by the engineer to make sure that the condition of the pipe matched the results found from the software. After getting the classification results from BAYSYS and CCTV videos, the engineer was able to choose a suitable method to rehabilitate the line (Ministry of Works, 2009).

## 2.5 Sustainability Issues in Bahrain's Sewerage System

This section shows the current problems facing the sewerage system in Bahrain. These major issues in the sewerage system have been found, according to the Ministry of Works: quality assurance, maintenance and operation reports, complaints, and newspapers.

### 2.5.1 Population growth and land use

Population growth and land use are both related, as they determine the quantities of sewage generated and the spatial distribution of the population. During the planning and design stage, it is crucial to collect current population figures as well as to project populations for the future. The spatial distribution determines the layout of the sewerage network. In the NMPSES, the methodology adopted to calculate population is the log-linear projection model. This method uses historic population to forecast future population based on a logarithmic curve. As an output of the methodology, the following curve was developed (Figure 5).

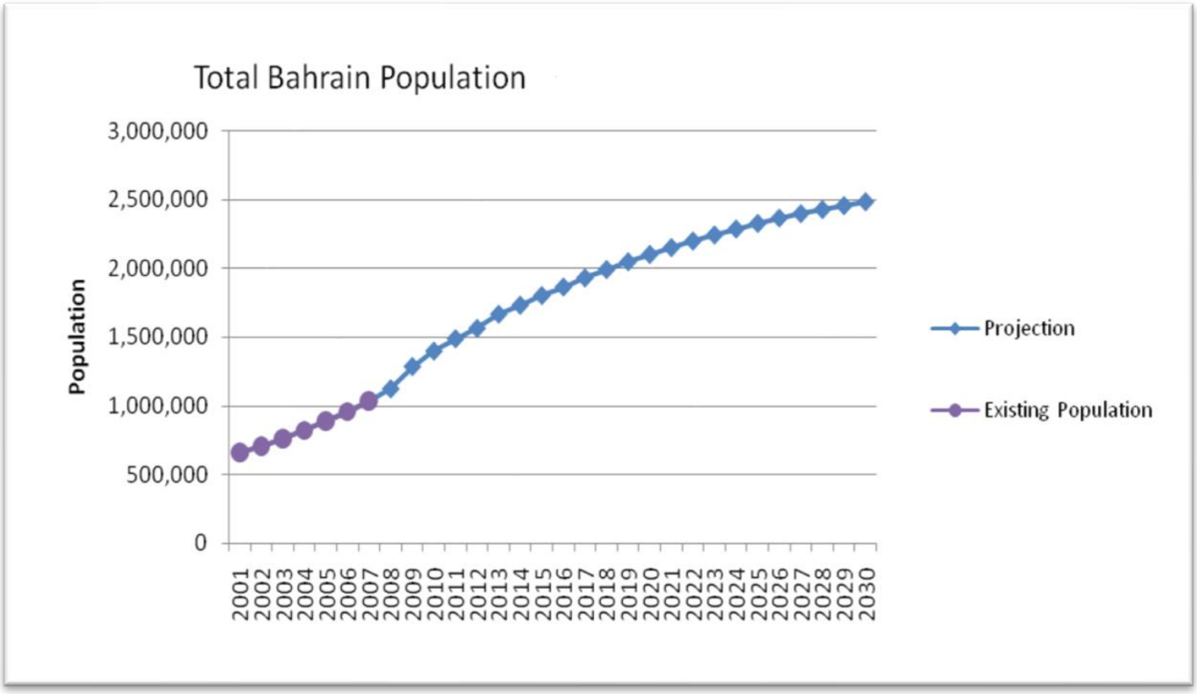



Figure 5: Expected population growth (2009-2030) according to the NMPSES (Ministry of works, 2009)

To ensure the accuracy of the projection, it is important to collect all available data from concerned authorities and previous studies. These projections are directly related to the land use, as it highlights land classifications such as housing projects, schools or industrials areas which contribute to increased accuracy.

Issues that occur in this matter are the changes in the land use plan. Changing land classifications can dramatically increase or decrease the assumed population, which leads to improper sewerage design. Another issue is the extent to which the land use plan is prepared and if it meets the design horizon of the sewerage project. In Bahrain, the latest land use map was developed up to the year 2030. Design horizons that go further than 2030 can cause errors in population assumptions and therefore reduce the accuracy of the design. Another Issue that can occur is the availability of data from previous studies and from concerned authorities (Materials Engineering Directorate, 2016; Ministry of works, 2009).

### 2.5.2 Storm water and consumer behaviour

Due to the absence of a comprehensive storm water network in Bahrain, storm seasons can be very challenging to the citizens, as storm water can accumulate in low areas and cause disturbance to transportation and in some cases damage to private property. According to the NMPSES, no CCTV surveys were conducted to investigate the physical condition of the pipes. However, it is evident that storm water networks were designed to dispose of the water to sea through outfalls that are limited to some areas. The Ministry of Works tends to build local storm water networks consisting of holding tanks and small storm water collection pipe networks. As a result, some citizens tend to open sewerage manhole covers to drain storm water, which causes flooding on the streets and an odour issue, as can be seen in Figure 6. In addition, storm water can leak through manhole covers through the system, which adds an extra burden to the network's capacity. These issues need to be addressed to ensure the efficiency and functionality of the network.

Figure 6: Storm water flooding (Alwatan News, 2017)

### 2.5.3 Availability of corridors and lands

There are issues in the availability of corridoes and land for Sanitary Engineering Affairs. To ensure the constructability of the sewerage project, it is important to allocate corridors along the roads for pipes, manholes and shafts. Also, it is important to allocate land for the proposed pumping stations. Without the availability of corridors and land, the project is physically not possible to be built. The process of allocating corridors and land can be challenging for developed areas, unlike developing master plans for newly developed areas. The NMPSES recommends constructing new main sewerage lines using a deep-gravity sewer when pipes are constructed using micro-tunnelling techniques. These measures take place in the developed areas of Bahrain. It must be noted that the process of allocating corridors and lands was not part of the NMPSES. Therefore, it requires extensive coordination with the other utility providers. As half of the area of Bahrain is currently undeveloped, there is a high risk that this issue will keep occurring in the future.

### 2.5.4 People's dissatisfaction

The issues of the sewerage system directly affect the quality of daily life. In terms of complaints filed through the Sanitary Engineering Complaints Centre, the available data are for 2015, 2016 and the first 6 months of 2017. Figure 7 shows the number of complaints recorded in every Governorate in Bahrain along with the total number; it is notable that the total number of the half of 2017's complaints is more than the half of any other year.

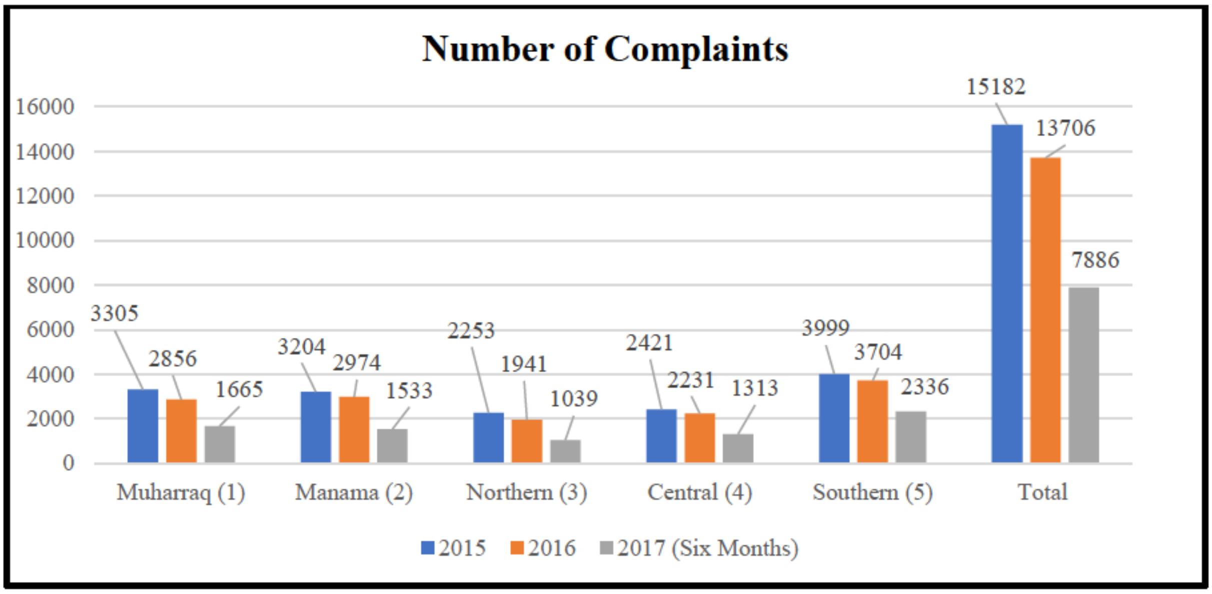



Figure 7: Number of complaints in 2015, 2016 and the first 6 months of 2017

These complaints include odour, pests, storm water accumulation, noises caused by construction activities and sewage overflow. Refer to Figure 8 and Figure 9.

Figure 9: Sewage overflow (Alayam News, 2017)

Figure 8: Sewage overflow (Alwasat News, 2016)

### 2.5.5 Pumping-station breakdowns

The total number of pump station breakdowns recorded for the years 2015 and 2016 are very high and require close attention from the concerned authorities. These numbers indicate that there are continual operational issues related to pumping stations. It also indicates that there is high risk of sewage overflow. Figure 10 shows the numbers of breakdowns in pumping stations in 2015, 2016 and the first 6 months in 2017.

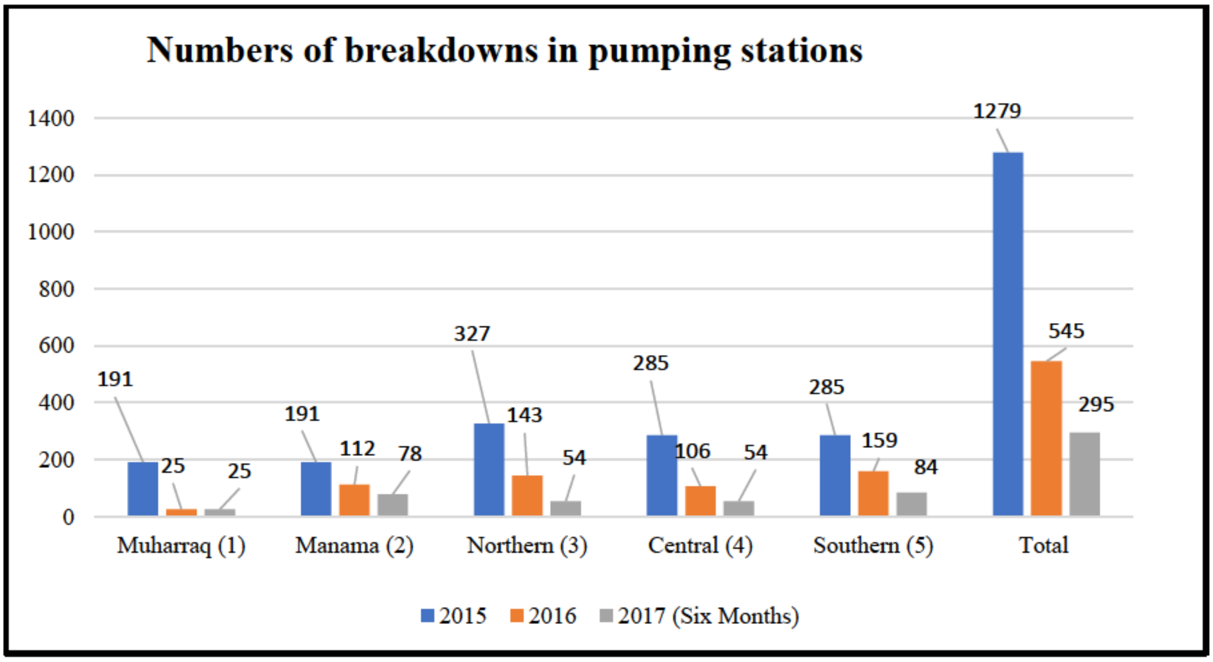



Figure 10: Number of breakdowns in pumping stations

### 2.5.6 Budget allocation

The NMPSES concluded with a set of measures categorized as Immediate-, short-, medium- and long term measures. These measures were prepared based on the assessment performed through the hydraulic model and based on the CCTV surveys to check the physical condition of the network. However, the NMPSES did not develop these measures based on the availability of budget, which is the main obstacle in transforming these measures into projects and programs. According to the Quality Reports prepared by the Materials Engineering Directorate (2016), the Ministry of Works is behind the programme set by the NMPSES in terms of implementing the projects. There is a risk of delaying the implementation even further if this issue is not addressed. Options that need to be considered through budget allocation are to adopt a private–public partnership form of contracts to transfer the burden of capital cost from the government to the private sector in addition to other options, such as contribution from developers and investors or implementing taxes.

### 2.5.7 Energy consumed

The sewerage system in Bahrain consumes energy, as it consists of a considerable amount of mechanical assets. According to the NMPSES, all sewerage stations recorded are as follows:

Table 4: Number of Stations

| Description | Quantity |
|---|---|
| Major Pumping Stations | 20 |
| Minor Pumping Stations | 165 |
| Minor Lifting Stations | 283 |

The current issue is the amount of energy consumed and the associated cost for the high number of pumping stations in Bahrain. There is a high risk that the sewerage network will not function as desired and might cause surface overflow in case electricity is shut down for any reason. In terms of cost related to human resources, such a high number of pumping stations requires a dedicated staff to manage it, which is not reasonable given the small area of Bahrain. This issue is addressed in the NMPSES, and the solution is to implement deep-gravity sewers to reduce the number of these stations.

### 2.5.8 Groundwater infiltration and sewage ex-filtration:

Groundwater can affect the sewerage system by infiltrating through the pipe joins and cracks or allowing sewage to exfiltrate from the sewerage system depending on the hydraulic gradient.

As most of the sewerage system pipes are sloped, the hydraulic gradient increases with depth. According to the NMPSES flow survey, the measured infiltration rate was found to be about 142,000 $m^3$/day, which amounts to approx. 49% of the total average daily flow measured as 289,500 m3/day. However, AB-Network has reached 53% of infiltration. The survey was performed on each network in Bahrain. The groundwater infiltration rates are shown in Figure 11.

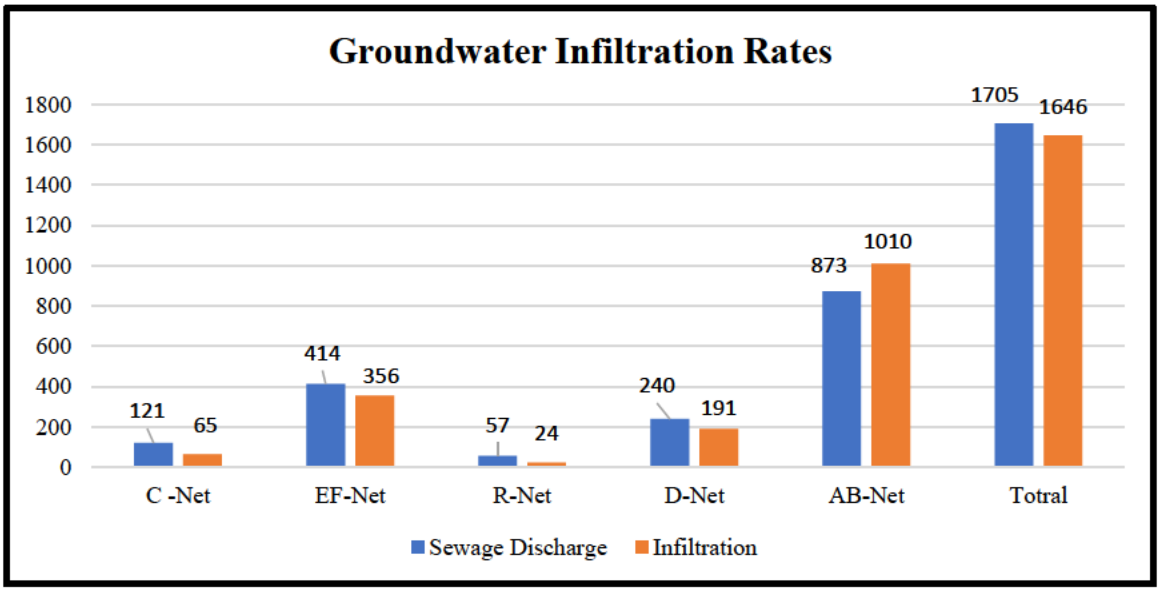



Figure 11: Groundwater infiltration rates in Bahrain's sewerage system

Infiltration rates are very high and cause negative impact on the capacity of pipes through the network. The NMPSES proposed a programme of rehabilitation projects to reduce the infiltration rates. The Ministry of Works started implementing rehabilitation projects in various areas of Bahrain. However, the 2016 quality assurance evaluation showed that many of these projects had been delayed (Materials Engineering Directorate, 2016).

### 2.5.9 Management issues

The Project Management section has reported some issues regarding the sewerage infrastructure projects management in Bahrain: clear roles and responsibilities of the Project Management section have not been defined, there is a lack of qualified staff due to the generation gap and there is difficulty in hiring due to budget constraints and the absence of specialized training (Sanitary Engineering Operation & Maintenance Directorate Director's Office, 2017).

## 2.6 Sustainability Issues in Sewerage Infrastructure Projects

Currently, the principles of sustainability are widely referenced in the laws, policies, regulations and strategies of developed and developing countries (Ainger and Fenner, 2014). Furthermore, water and wastewater infrastructure Sustainability plans were responsible for leading the charge to have sustainable infrastructure and thus the continuance of reaching sustainable development. These plans' objectives, which drive the pillars of sustainability development, have been adopted in several countries such as the UK, Australia and Bahrain (Ecologically Sustainable Development Steering Committee, 1992; Economic Development Board, 2008; Office of the Deputy Prime Minister, 2005). The sewerage infrastructure projects were conducted in order to last for a long period of time, as it is an expensive infrastructure that requires careful attention. Furthermore, the sewerage projects were expected to increase due to population growth in urban areas. Approximately 54% of the world's population are in urban areas (The World Bank, 2016), and this is expected to increase to up to 70% by 2050. However, sewerage infrastructure faces a variety of challenges and potential threats to sustained performance throughout their life cycles due to aging, aggressive environmental factors, limited political will, lack of qualified staff, inadequate design, poor service, inadequate technical support, underfunding, improper operation and maintenance activities, deterioration, disruptive events, regulatory sanctions, third-party intervention, and population growth (Akhtar et al., 2014; Andersson, Dickin and Rosemarin, 2016; Grigg, 2012; Sanitary Engineering Operation & Maintenance Directorate Director's Office, 2017; Upadhyaya, Biswas and Tam, 2014). As a result, the sewerage infrastructure condition and long-term performance might deteriorate, which can result in additional expenses associated with maintenance, repair and rehabilitation measures. These challenges can also increase the risk of failures in the system, such as sewage leakage, surface flooding and odour. Therefore, they can have a negative impact on the environment, public health and safety, economics and the expected service life of sewer assets. Furthermore, having a sustainable sewerage infrastructure directly affects the improvement of daily quality of life, and it is essential for achieving sustainable development, because infrastructure directly impacts all measures of sustainable development (Ainger and Fenner, 2014).

Sustainability in wastewater management usually refers to the sewage treatment; however, current studies have shown that sewers affect the environment more than do wastewater-treatment plants in the construction phase or even in the maintenance and operation phase (Remy and Jekel, 2008). Moreover, there are very few studies that have focused on the sustainability of the sewerage system, and this reflects the fact that many country's authorities have neglected the effect of their sewerage system on the environment while concentrating on treatment plants such as in Norway (Torgersen, Bjerkholt and Lindholm, 2014). Furthermore, even in Bahrain, the lack of performance indicators for the sewerage system shows neglect by Sanitary Engineering Affairs in the importance of the sewerage system. The Sewerage infrastructure project's main objective is to collect and convey sewage generated from households and other facilities to treatment plants efficiently and according to the desired planning and design horizon, which will contribute to preserving the environment, maintaining public health, providing infrastructure to attract investors and therefore enhancing the environment and ultimately quality of life.

The sustainability of infrastructure could be viewed through five associated sustainability dimensions: environmental, social, economic, technical, institutional and policies (Chhipi-Shrestha, Hewage and Sadiq, 2017; Harmancioglu et al., 2012; Jones and Silva, 2009; Pires et al., 2017; Upadhyaya, Biswas and Tam, 2014).

a) Sewerage failure

The sewerage projects were designed to serve for a certain period of time; keeping them efficient and functional throughout their life cycles will ensure the reduction of sewerage issues such as flooding, exfiltration, infiltration, odour, energy consumption and resource loss (Akhtar et al., 2014; Ellis and Bertrand-Krajewski, 2010; Neshaei et al., 2017; Upadhyaya, Biswas and Tam, 2014). The appearance of these issues will affect the quality of daily life, affect the environment, cost a high amount of money to fix and affect the public health, as well as affecting the efficiency of the wastewater plant. All of these issues were a result of many factors such as design mistakes, improper planning, construction mistakes, bad operation, lack of maintenance and bad consumer behaviour (Section 2.5). Properly considering all of these factors will transfer the sewage to the treatment plants efficiently and will reduce the technical issues of the sewerage.

b) Environmental issues

The malfunction of the sewerage system seriously affects the environment through sewage flooding, odour and exfiltration of sewage, which causes it to seep into the groundwater and can thus lead to groundwater contamination (Ellis and Bertrand-Krajewski, 2010). When the sewerage is near the sea, as it is in many places in Bahrain, sewage can also seep into the sea and damage fragile coral reefs, thus affecting the fishing and tourism industries (Husbands and Dey, 2002); this risk is high in Bahrain because it is an island with a high water table and because many developed areas in Bahrain are actually reclamation areas. Moreover, sewage exfiltration is considered to be a loss of resources, as it causes the loss of potentially reusable water (Roehrdanz et al., 2017). Nevertheless, exfiltration could affect public health, as happened in Campinas, Brazil, where a large amount of raw sewage was found in the city's drinking water (Sodré, Locatelli and Jardim, 2009). Furthermore, when flooding occurs, it could cause property damage and threaten public health. Moreover, the odour affects the quality of air, and it could reduce land value for some areas that face continuous odour.

c) Policy and institutional aspects

Policies are the main driver for sustainability development, followed by the Institutional practices that should reflect these policies. Usually, massive efforts were addressed to have sustainable wastewater management; however, the focus was on the treatment plants and the efficiency of the treatment process. Meanwhile, sewerages obtain less attention due to unseen problems that do not show until after they are aggravated. Furthermore, the absence of proper performance measures demonstrate that the institutions do not apply the policies properly. Sewerage infrastructure projects, through project life cycles, intersect with other sectors, such as urban planning, transportation and water supply. This leads to an impact on sewerage project performance, such as changes in land use, availability of corridors and funding. Managing sewerage project life cycle should be established as a convention in the organization, with supporting policies to introduce the concept of sustained functional and efficient sewerage to society.

d) Economic issues

All of the financial costs throughout the life cycle of the sewerage asset and the economic impacts from the sewerage system's failure is compensated in the form of the sewerage management fees on the public and more directly on the governmental institution that manages the disposal of the sewage. That will force the governmental institution to spend unscheduled, expensive costs to solve the issue of failure, which might cause a budget deficit. Furthermore, it could hinder having new critical sewerage projects and therefore cause a considerable delay of the ministry's entire program.

e) Social issues

One of the main objectives of the sewerage projects were to maintain public health and safety as well as stakeholder satisfaction. Moreover, failure of these project could affect public satisfaction, agriculture, cultural heritage, property value and public health. Moreover, consumers often do not use the sewerage services properly; for instance, in Bahrain, many blockages have been recorded due to misuse of sewerage by throwing fat from restaurants and houses (Sanitary Engineering Operation & Maintenance Directorate Director's Office, 2017). Moreover, public awareness in helping Sanitary Engineering Affairs such as by calling the control centre hotline when a minor pumping station's light alarm goes off.

## 2.7 Challenges and Opportunities for Ensuring Sewerage Projects' Sustainability

The various sustainability issues discussed in the last section were the main challenges of having sustainable sewerage infrastructure projects. Sewerage failures continuously occur, as the sewerage projects were implemented to last for a long period of time that will face a potential unknown risks. Furthermore, a conservative nature is predominant in the wastewater sector, and moreover, the engineering culture could be an important barrier against applying sustainability approaches (Torgersen, Bjerkholt and Lindholm, 2014). Understanding the current and future possible issues and linking them to the current sewerage projects will insure the sustainability of the sewerage system and reduce the risk of occurrence of these issues.

The sewerage systems in Bahrain were built more than forty years ago, and currently, some networks suffer from overloading, infiltration and exfiltration issues (Section 2.5). Therefore, a number of rehabilitation/upgrading projects are expected to be proposed during these years, which gives the opportunity to not repeat the same mistakes and use the current issues to have better decision-making from the beginning and throughout the projects' life cycles.

Sewerage users such as citizens and developers expect the system to function all the time with no failures, which raises the need to implement emergency plans to deal with failure scenarios. Ultimately, operation and maintenance must ensure proper management to improve system reliability, decrease operation and maintenance expenditures and improve safety (Bloetscher, 2011). In Bahrain, the performance measures used for the sewerage infrastructure projects (Appendix D) consist of a number of indicators that are limited to some malfunctions such as pumping failures, infiltration and complaints recorded rather than covering all factors of sustainable development for present and future scenarios.

## 2.8 Sustainability Assessment

### 2.8.1 Definition

There are several proposed definitions of sustainability assessment (SA). Devuyst (2000, p. 68) defined the sustainability assessment as *"a formal process of identifying, pre-dicting and evaluating the potential impacts of a wide range of relevant initiatives (such as legislation, regulations, policies, plans, pro-grammes and specific projects) and their alter-natives on the* *sustainable development of society".* Sala, Cffo and Nijkamp (2015, p. 314) provided a simple, comprehensive definition in which *"Sustainability assessment is a complex appraisal method. It is conducted for supporting decision-making and policy in a broad environmental, economic and social context, and transcends a purely technical/scientific evaluation."*

### 2.8.2 Sustainability-assessment approaches and tools

These days, there is no doubt that sustainability is considered to be one of the main principles in establishing public policies and corporate strategies (Finkbeiner et al., 2010). Hence, there are many sustainable development (SD) goals that are being set on both government and corporate levels. However, to ensure the possibility of achieving sustainable development goals, sustainability assessment and reporting tools must be developed; these will serve to inform stakeholders about the progress being made towards achieving sustainable development goals (Siew, Balatbat and Carmichael, 2016).

Since the last decade of the past century, many efforts have been carried out to formulate SAs and sustainability indicators (Juwana, Muttil and Perera, 2012; Waas et al., 2014). Nevertheless, as many of those assessments, tools, criteria and indicators are still far from perfect (Kaur and Garg, 2019), they do need further improvements and advancements. According to Poveda (2017), in order for sustainable development to grow, the assessment criteria need to be unified; shared definitions in guidelines, processes, and methodologies need to be used and the concepts to develop best practices need to be adequately implemented. Poveda (2017) mentioned that as a consequence of further improvements in SA, it is more probable that, in the near future, stakeholders will use more proactive methods (e.g., decision makers will be involved in the preliminary stages of any project that has sustainable development targets). Furthermore, Dalal-Clayton and Sadler (2014) argued that SA should be formulated considering the following features:

- Decision makers shall consider SA as a crucial component in their processes.
- The effects and consequences of new proposals shall be evaluated across all three pillars of sustainability.
- Progress to achieve SD shall be the objective of SA, which shall be evaluated against a well-established framework of objectives, principles and criteria.
- SA shall be implemented strongly by integrating it to policies and procedures.

Sadler (2004) indicated that integrated and systematic policymaking procedure can be introduced at all levels:

- Micro-level integration, which can be accomplished by organizing the planning of new studies such as feasibility and impact assessments, consideration of effects of new developments and actions from governmental or private sectors
- Meso-level integration can be applied by strategic planning, such as the land use plan/policy initiatives that guide and measure the achievement of sustainable development in every level of the decision-making process.
- Macro-level integration can be outlined in wider policy making perceptions at a societal, divisional and national level.

Heijungs, Huppes and Guinée, (2010) argued that the concept of sustainability had shifted the focus of assessments carried out by various stakeholders towards the inclusion of social and environmental aspects when carrying out economic assessments and cost-benefit analysis, and the usage of notions of *"supply chains, the life cycle, and extended producer responsibility"* as a result of recognizing the role every stakeholder has and the consequence of his or her actions on sustainability.

According to Heijungs, Huppes and Guinée, (2010), there are many methods for assessing sustainability; some are at the concept level, but others utilize quantitative models. These approaches involve all of the micro, meso and macro levels of analysis.

Since the concept of SA emerged, entities have suggested using various tools to assess SD. Ness et al. (2007) presented a framework (Figure 12) to classify some of the most common tools into three major categories: *"indicators/indices, product-related assessment, and integrated assessment tools."* Within the subcategory tools, any other tool can comprise financial tools. Temporal dimensions and spatial focus are also considered when categorizing the tools.

Ness et al. (2007) have concluded that most tools focused on the environmental aspect, while a marginal number of tools were capable of integrating the socio-economic aspects. Besides, Finkbeiner et al., (2010) called for a move from an approach that aims at protecting the environment to an approach that truly has sustainability as its target. Furthermore, they recommended using the Life Cycle Sustainability Assessment for products and processes.

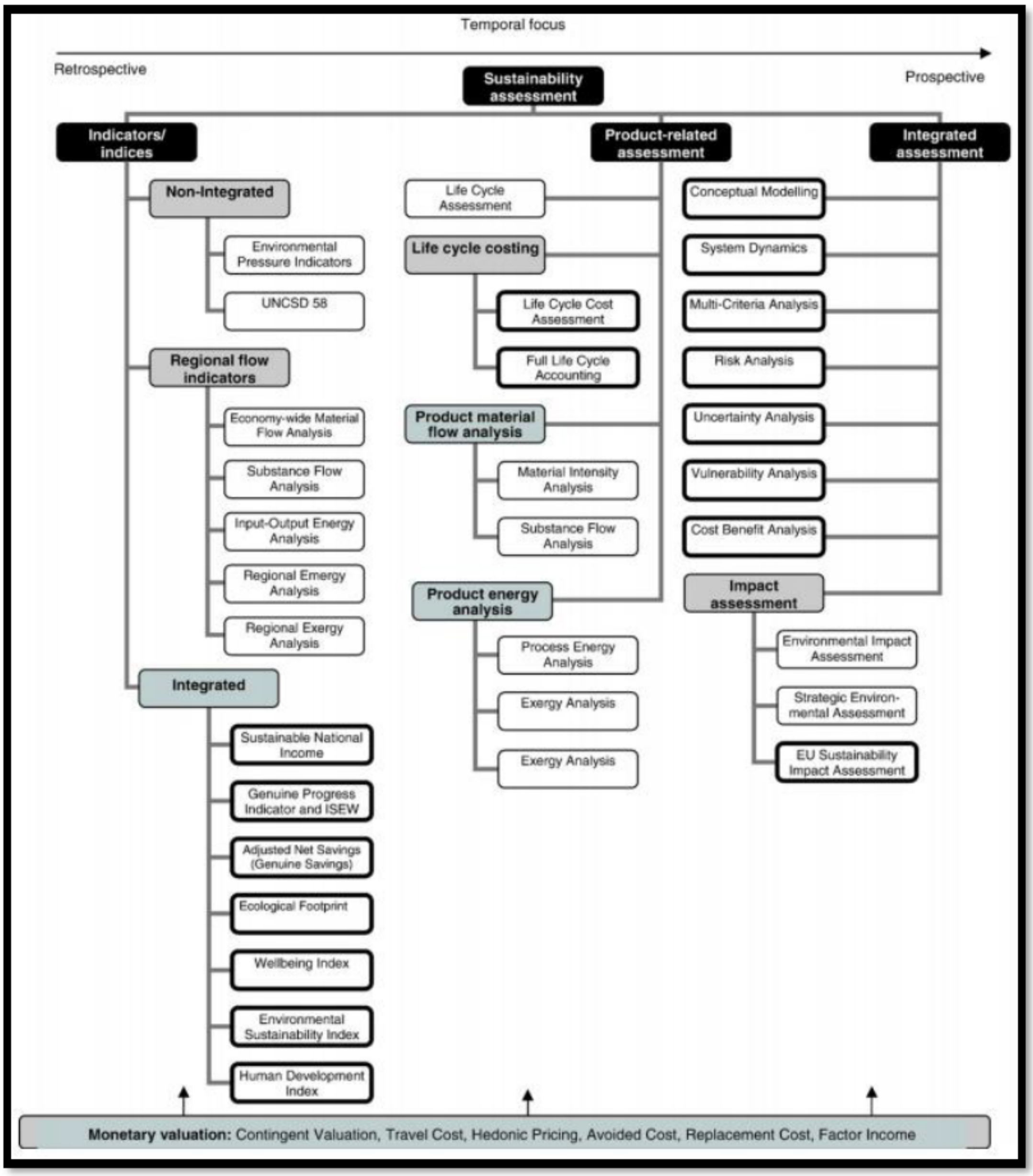



Figure 12: Framework for sustainability assessment (SA) (Ness et al.,2007)

### 2.8.3 Assessing sustainable development at the project level

The impact of an infrastructure project on the economic development of a country and the social needs of its people are highly influenced by the policies of its government. Therefore, many developed and developing countries are widely referencing the principles of sustainability in their laws, policies, regulations and strategies, as attaining a sustainable infrastructure is essential to achieve sustainable development (Ainger and Fenner, 2014). Hence, the SA of a country's infrastructure projects has been regarded as one of the most crucial tools to progress towards achieving a sustainable infrastructure (Krajangsri and Pongpeng 2017; Pope, Annandale and Morrison-Saunders, 2004).

Governments, companies and academia are continuously trying to develop suitable tools to assess the sustainability of infrastructure projects. A few studies have developed some promising tools/indicators that are used in the SA of infrastructure projects, which account for the three pillars of sustainability, namely social, economic and environmental contexts. Ugwu and Haupt, (2007) proposed key performance indicators (KPIs) for infrastructure projects, with a structured methodology and an analytical decision model for sustainability assessment of infrastructure projects. The aim of the study was to provide a sustainability assessment to be used at the project level by infrastructure designers to help them assess their designs and find the best option that conforms to sustainability objectives and strategies set by their governments. The sustainability index of design proposals can be computed through a mixture of the mathematical and computational algorithmic method, with relation to the decision-support framework. The existence of such a difficult index would create an assessment of a variety of outcomes in various aspects of the sustainability envelope: environment, resource utilization, health and safety, economy, and project administration. Table 5 explains that the sustainability assessment for the best design options could be compared to find the most sustainable design.

Table 5: Sustainable assessment decision matrix

| **Design option (D)** | **Sustainability Criteria (SC)** | | | | |
|---|---|---|---|---|---|
| | $SC_{(1)}$ | $SC_{(2)}$ | $SC_{(3)}$ | $SC_{(4)}$ | $SC_{(N)}$ |
| | $W_{01}$ | $W_{02}$ | $W_{03}$ | $W_{04}$ | $W_N$ |
| $\mathbf{D_1}$ | $d_{1,\,01}$ | $d_{1,\,02}$ | $d_{1,\,03}$ | $d_{1,\,04}$ | $d_{1,N}$ |
| $\mathbf{D_2}$ | $d_{2,\,01}$ | $d_{2,\,02}$ | $d_{2,\,03}$ | $d_{2,\,04}$ | $d_{2,N}$ |
| $\mathbf{D_3}$ | $d_{3,\,01}$ | $d_{3,\,02}$ | $d_{3,\,03}$ | $d_{3,\,04}$ | $d_{3,N}$ |
| $\mathbf{D_M}$ | $d_{M,\,01}$ | $d_{M,\,02}$ | $d_{M,\,03}$ | $d_{M,\,04}$ | $d_{M,N}$ |

Key: $SC_{(i)}$, sustainability criterion *i*; $W_i$, weight assigned to $SC_{(i)}$; $D_i$, design option *i*; $d_{i,j}$, user-assigned utility (a scalar value that measures the performance of $D_i$ for a given $SC_{(i)}$ (Ugwu and Haupt 2007).

To formulate the mathematical model, the study used a weighted sum model technique in multi-criteria decision analysis and the additive utility model in analytical hierarchical process for malty criteria decision making. Combining the two methods, the following equation (1) was used to compute a sustainability index for *i* = 1, 2, 3 . . . *M*:

$$SI_i = \sum_{j-}^{N} d_{i,j} W_j \,, \quad (1)$$

where $SI_i$ (for $i = 1, 2, 3, \ldots M$) signifies the concluding sustainability index (a crisp value); $D_i$ is the design substitute (in case there are $M$ design alternatives); $d_{i,j}$ is the usefulness of the design selection for decision criterion $d_{i,j}$ (which are the key performance indicators), out of $N$ norms (for $i = 1, 2, 3, \ldots M$; $j = 1, 2, 3, \ldots N$); and $W_j$ is the weight allocated by the decision-maker, which lies over a defined range $W_j \leq K$, where $K$ is a user-defined integer quantity.

Ugwu et al. (2006) conducted a case study in the design of a bridge in Hong Kong and used the sustainability assessment of infrastructure projects framework to choose the optimum design option according to certain sustainability criteria. However, Ugwu et al. (2006) mentioned that such a framework is best suited to choose between design options with indicators that get decent scores, but it does not guarantee that the chosen option will be sustainable throughout the project's life cycle.

Shen, Wu and Zhang (2011) introduced key assessment indicators (KAIs) to perform an SA of infrastructure projects in the planning stage. The study analysed 23 feasibility studies for various sorts of infrastructure projects in China. The researchers established a list of 30 indicators that occurred more than five times and that were grouped into the three aspects of sustainability: economic, social and environmental. After that, the fuzzy set theory, which was introduced by Zadeh (1965), was applied to find the KAIs, which increases the adequacy of the indicators' application. Then the final 20 indicators were identified (Appendix E). The purpose of the KAIs is to help the stakeholders choose the best option that has the highest sustainability performance score.

A new metro project was chosen as a case study of an infrastructure project to demonstrate the implementation of the KAIs. Four development scenarios were evaluated by five guest professionals using the developed KAIs in accordance with Table 6. Although the study provided another method to perform an SA for infrastructure projects, that method had a few limitations: KAIs were only applied to one case study, and some additional significant factors (e.g., emissions) were excluded.

Table 6: Multiple options evaluated in terms of KAI

| Group[1] | Indicator[2] | Code[3] | Scenario 1 Score | Scenario 2 Score | Scenario 3 Score |
|---|---|---|---|---|---|
| Economic aspect | Indicators<br>…. | X1<br>X2<br>X3 | (from 1-5)<br>…<br>... | (from 1-5)<br>…<br>… | (from 1-5)<br>…<br>… |

| | | | | | |
|---|---|---|---|---|---|
| | …. | | Total score = ∑ indicator score | Total score = ∑ indicator score | Total score = ∑ indicator score |
| Total score after standardization | | | = Total score × □(sum of economic indicators / number of indicators) | = Total score × □(sum of economic indicators / number of indicators) | = Total score × □(sum of economic indicators / number of indicators) |
| The weighted score for Scenario | | | =The weighted score for Scenario1 | =The weighted score for Scenario2 | =The weighted score for Scenario3 |
| [1]Same process will be repeated with other groups (Environmental aspect and Social aspect)<br>[2,3] Number of indicators will differ according to the group | | | | | |

An innovative decision support framework to assess the sustainability of flood mitigation projects was developed by Shah, Rahman and Chowdhury, (2017). The framework had been developed according to the life cycle of the projects and existing practices. It has two main focuses: sustaining flood mitigation by the project and enabling sustainable development of the floodplain. To calculate the sustainability index of a given project, a multiple-criteria analysis approach was used. The indicators were established based on previous academic and case studies. Later, the indicators were confirmed by a questioner filled by 15 professionals dealing with issues regarding flood management in Australia. The framework incorporates the five stages of SA: contextualizing the project, planning and implementing the project, experiencing a flood event, conducting periodic assessments, and making modifications or changing to a new project.

Although the approach of the proposed framework is simple for most planners, major stakeholders must choose the most suitable indicators and criteria (weights and scores) to properly connect the project to SD. The researchers suggested that the framework could be used for non-structural and structural flood mitigation projects as well as other types of infrastructure projects (e.g., roads and power).

Assessing a sewerage project requires a comprehensive understanding of the current sewerage network to identify issues and to assess the hydraulic and physical condition. The scenarios of the newly proposed sewerage project must be studied carefully and assessed using the hydraulic model software to predict how the whole network will function. The nature of sewerage projects requires studying various scenarios to find engineering solutions. The variance in these scenarios can vary is due to elements such as the viability of road corridors for use when constructing the sewer network (which can lead to changes in the routes of the proposed lines), the availability of land for constructing pumping stations, the availability of construction technologies, the design horizon and the targeted areas to be served.

## 2.9 Summary

Based on extensive literature review, studies on the sustainability assessment throughout the entire life cycle of the sewerage asset, considering all aspects of sustainability (economic, social and environmental), were not carried out, starting from the master plan and progressing to the contextualizing, planning, implementation, operation, maintenance and rehabilitation or upgrading processes. To fill this gap, a sustainability assessment framework need to be developed that aimed to assess the sewerage infrastructure throughout the projects' life cycles to provide the needed support for the decision-making of sustainable management practices for those projects. Moreover, due the numerous issues in the sewerage system in Bahrain (Section 2.5), and without taking long-term sustainability into account, while the policy aspires to do so, it is important to justify the need for assessing the sewerage projects in Bahrain in order to help the organization address the gap, and apply better decision-making throughout the projects' life cycles and from the point of view of sustainability. In fact, ensuring the implementation of the sustainability approaches through the sewerage infrastructure projects will reduce the risk of failure in the long term; thus, the sewerage system will tend to be more sustainable.

# Chapter 3: Methodology

In this chapter, the research methodology is explained in detail in order to close the research gaps identified in the literature review in section 2.9. To close the research gap, this study sets the main goal to develop a sustainability-assessment framework sewerage infrastructure projects to support decision-making throughout the life cycle of sewerage assets and ensuring having more sustainable sewerage infrastructure. To do that, a mixed-methods approach (utilizing both qualitative and quantitative methods) was adopted.

## 3.1 Overview of the Methodology

To achieve the research objectives, the following steps were followed.

1- Understand the management of the sewerage infrastructure system through its life cycle and define the sewerage infrastructure projects' management through an extensive review of published literatures and previous studies, and by concentrating on the context of the sewerage infrastructure projects in Bahrain; the data from several case studies are planned to be collected and analysed.

2- Develop a sustainability assessment framework with identifying the sustainability indicators for the sewerage infrastructure projects by reviewing extensive literature review, reports and consulting experts.

3- A pre-survey pilot study, followed by conducting an open-ended survey of experts to verify the sustainability assessment framework through emphasising the objectives and the criteria of the framework, weighing the identified indicators and the proposition of adding or removing some of the indicators and finally finalizing these data will create the final framework.

4- Apply the sustainability assessment framework of the sewerage projects on the three chosen case studies to demonstrate how the framework can be used.

The research methodology overview is shown in the Figure 13 below.

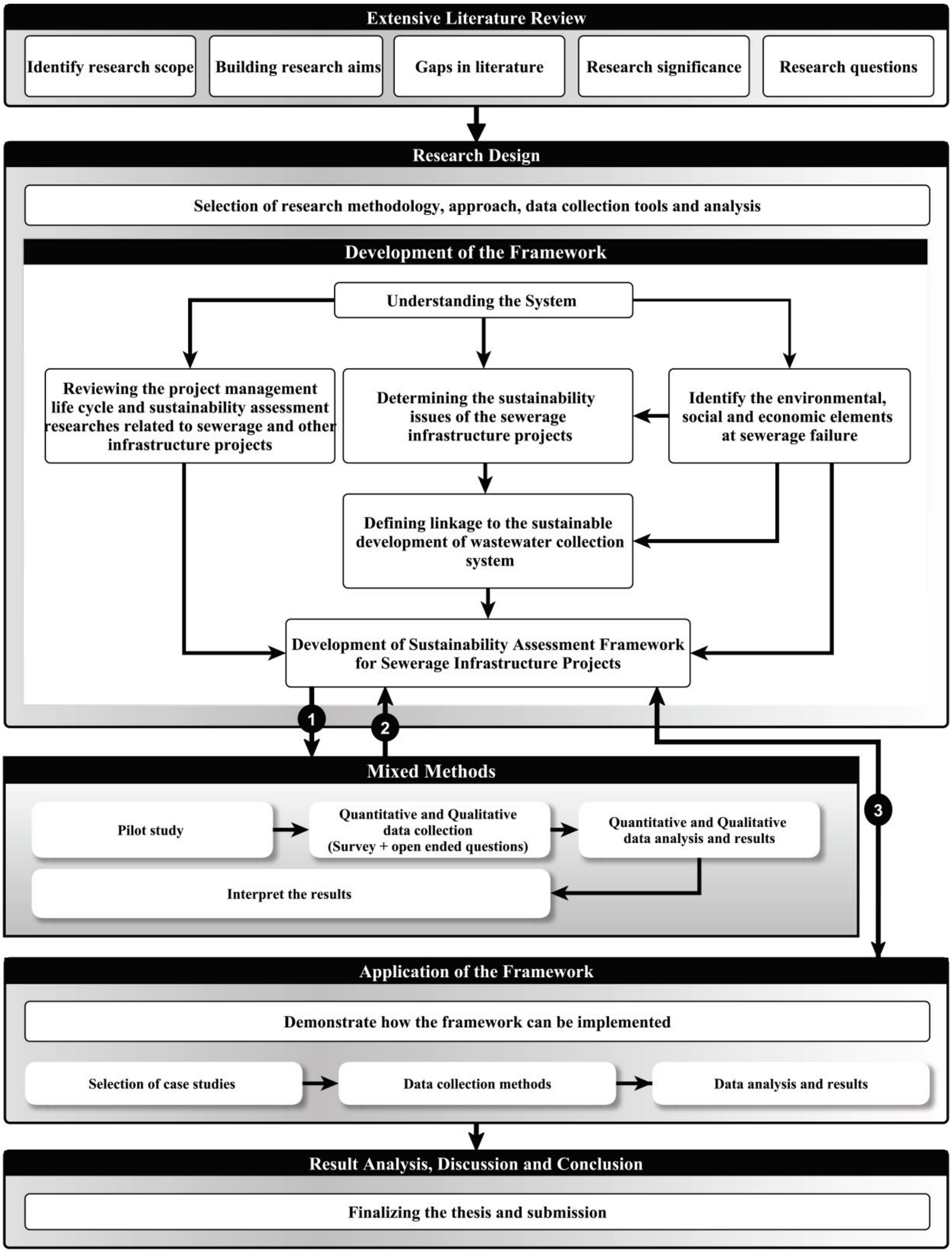



Figure 13: Research methodology overview

### 3.2 Extensive Literature Review

The required knowledge about the sustainability of the sewerage system has been developed through an extensive literature review, and the scope of the research has been identified, including the research aims, literature gaps, research questions and significance. Furthermore, a secondary data was collected from the Ministry of Works, Municipalities Affairs and Urban Planning in the Kingdom of Bahrain (Appendix F). In order to understand the sewerage infrastructure projects' management practices in Bahrain, the needed data for the three case studies (Kalifa Town, Hamad Town and Muharraq) were also collected.

## 3.3 Research Design

Similar studies were reviewed to identify the research methodology design. As depicted in Figure 13, the research starts with extensive review of the relevant literature and secondary data related to the research problem, as discussed in the previous Section 3.2. This is to enable the selection of the appropriate design for the research concerning sustainability of sewerage infrastructure projects in Bahrain. The design starts with understanding the current system in the Kingdom of Bahrain, which is considered a crucial step to ensure that the researcher is aware of the sustainability issues in the context of sewerage infrastructure projects. In detail, the comprehensive review of studies and reports related to the sewerage assets has led to the following steps: 1) reviewing the project-management life cycle and the sustainability assessment research regarding 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 sustainability assessment framework for sewerage infrastructure projects was developed, as discussed in detail in Chapter 4. Then, the developed framework was presented to experts of the sewerage system in Bahrain to assess the proposed indicators. After that, a questionnaire survey was developed and pilot tested to ensure the usability of the framework. This stage was followed by the distribution of the final survey in order to weigh these indicators based on their importance in assessing the sustainability of the sewerage infrastructure projects. The outcome of the previous stage was then used to assess three case studies in Bahrain to demonstrate how the framework can be used.

## 3.4 Understanding the System

While working on sewerage projects, it is important to understand the current network, as all sewerage networks are interrelated. Understanding the conceptual layout of the sewer pipelines and the types of pumping stations must be understood. The proposed sewerage projects are likely connected to an existing network. The connection points must be analysed carefully using hydraulic models to check the availability of hydraulic capacity. Understanding the sewerage system requires intensive review of the NMPSES, hydraulic model reports, physical condition of sewerage assets, project management practices, quality assurance reports and operation and maintenance reports. Performance indicators should also be reviewed to ensure their suitability to the proposed project to be assessed.

### 3.5 Environmental, Social and Economic Elements of Sewerage System Failure

Sewerage system failures cause sewerage surface flooding, infiltration and exfiltration that can have various negative environmental, social and economic effects. In terms of environmental aspects, sewerage can directly affect public health by exposing people to raw sewage and odours. It can spread diseases in communities and can contaminate public sources of water such as groundwater wells and farms. In addition, people will start to lose trust in the service providers, which can increase the number of complaints registered through means such as complaint centres, newspapers and social media.

Sewerage system failures can introduce a financial burden to the government’s budget due to the need to implement immediate measures to rectify flooding issues. The cost related to maintenance measures can be reduced or even can be eliminated when these issues are solved through engineering solutions. Continuous flooding events can affect commercial activities that can in turn cause financial losses and even decreases in land value.

### 3.6 Sustainability Issues of Sewerage Infrastructure Projects

The sewerage infrastructure projects’ sustainability issues have been identified from the extensive literature and from the secondary data collected from the Ministry of Works, Municipalities Affairs and Urban Planning in the Kingdom of Bahrain. The related literature and studies of sewerage projects management were reviewed to identify the environmental, social and economic elements that linked the sustainability of the sewerage system with the risk of failure. Furthermore, the current issues of the sewerage system in Bahrain have been identified in Section 2.5, as these issues were collected from secondary data: NMPSES, project management guidelines, newspapers and operation and maintenance monthly reports. Furthermore, the sewerage project issues were identified, including the issues in Bahrain and from previous studies, as can be seen in Section 2.6. The findings from these activities have been used in developing the sustainability assessment framework.

### 3.7 Links to the Sustainability Development of Wastewater Collection Systems

The wastewater management policies, strategies and plans in Bahrain and other countries such as Australia, the UK, the US and Canada were viewed to find the link to the objective of the wastewater management sustainability development with sewerage infrastructure projects.

## 3.8 Review of the Project-Management Life Cycle and Sustainability-Assessment Research on Sewerage Infrastructure Projects

Phases and stages of project management life cycle, including initiation, planning, designing constructing, operation and maintenance and rehabilitation, have been reviewed (Section 2.4.2). The sewerage project and programme life cycle in the concerned organization were better understood by going through the NMPSES and procedure manuals (Section 2.4.3).

## 3.9 Development of Sustainability-Assessment Framework for Sewerage Infrastructure Projects

A sustainability assessment framework for the sewerage infrastructure projects has been developed (Chapter 4) that aims to assess the sewerage projects throughout their life cycles. Moreover, sustainability indicators were also presented that have come from the extensive literature, previous studies and the collected secondary data from Bahrain, NMPSPS, operations and maintenance reports, quality assurance and procedures manuals.

## 3.10 Mixed-Methods Design

### 3.10.1 Introduction

The design of the research methodology for this research starts with clearly defining the objectives of the study. This is basically enabled the appropriate selection of the research methodology to be adopted in this study, including the approaches for data collection, collection methods and tools, targeted audiences, analysis plan and the writing and reporting of results. A mixed-methods approach was utilized in this research after developing the sustainability assessment framework and identifying the indicators.

### 3.10.2 Phase one (development of framework)

First, the preliminary sustainability assessment framework was developed by following the research design (section 3.3). Then, consulting experts was considered to verify the proposed framework. The outcomes of this analysis were the preliminary indicators used in the next stage of the research.

### 3.10.3 Phase two (Pilot study)

The second part of the study was the verification stage through conducting a pilot study. A two groups of engineers were chosen, first group were experts of sewerage infrastructure projects and others were general diverse group (discussed in more details in section 5.1).

### 3.10.4 Phase three (Survey)

The third part of the study involved both the quantitative and qualitative methodologies which was carried out through an open-ended survey (Chapter 5) conduct. A well designed survey questionnaire was distributed among a sample of experts represented as government workers, consultants and contractors that consists of four sections. The first section included demographic characteristics so as to describe the sample later in the analysis. The second section presented the objectives and their criterions, and the participants were asked to score the objectives and their criterions based on their importance. The third section listed the indicators for the participants to balance. The individuals were then asked to assign a score for each indicator based on its importance, according to the participants' point of view. In addition, the third section included open-ended questions for which the participants could add more indicators if they saw gaps in the second section. If any indicators were added to the second section, the process of weighing was repeated.

### 3.10.5 Phase four (Case study)

The outcome of the previous phase was the final framework that was then used in three case studies to demonstrate the framework's application. Further explanation of the three case studies can be found in section 3.11.

### 3.10.6 Sampling

Prior to the commencement of the data collection, ethical approval was obtained from the Griffith University ethics committee to ensure that all research was guided by the ethical code of conduct (GU Ref No: 2018/848). For data collection, this research used purposive sampling, specifically the nonprobability sampling technique, which is appropriate when the researcher is seeking data from a specific group of people (Taherdoost, 2016). In this research, the application of purposive sampling is threefold. First, a panel of experts in sewerage system was selected for a consultation to finalizing the research framework, and those experts contributed in deciding on some of the indicators to be included or excluded from the framework, also to give further description of some indicators. Second, subjects were selected to participate in the pilot study as detailed in section 5.1. Third, another sample from employees at sewerage government sector, consultants and contractors was selected to assist in weighing the indicators through completing the research survey. Finally, further consultation was sought during the application of the framework on the selected case studies from sewerage project experts.

## 3.11 Application of the Framework

Three projects were selected based on the availability of information, type, stage, location and variety in the sewerage network to be connected to. The selected sewerage projects to which the framework is applied are listed below.

a) Hamad Town to Tubli Trunk Sewer (section 7.2.1): This project has completed the planning and design phase and its currently on hold and will proceed to the next stages in order to be carried out after the budget allocation. It consists of constructing deep-gravity sewer using micro-tunnelling technology. This project aims to improve existing sewerage networks in Hamad Town and nearby cities by eliminating sewerage pumping stations and increasing the capacity of the network.

b) Muharraq Deep-Gravity Sewer (section 7.2.2): This project has already been constructed on Muharraq Island. The project's aim is to improve the existing sewerage network in Muharraq by adding more hydraulic capacity to allow new housing projects and other developments to be connected.

c) Madinat Khalifa (section 7.2.3): This housing project is still in the planning stage. The project location is in the east side of Bahrain Island. The existing sewerage network in that area has reached its capacity limit. Therefore, the master plan of the project includes building a new STP in addition to the sewerage network. As the project is still in the planning stage, various scenarios and options can be assessed.

The application of the framework on the above projects will demonstrate the importance of each stage and the sustainability indicators.

## 3.12 Results Analysis, Discussion and Conclusion

The results from consulting experts, identifying sustainability sewerage indicators, weighing the indicators though questionnaires and applying the assessment framework to the three case studies were analysed and discussed in further chapters, resulting in conclusions and recommendations.

## 3.13 Chapter Summary

This chapter presented (in detail) the methodology used to develop the sustainability assessment framework, mixed-methods design, sampling, application of the framework and further steps to conduct and finalise this research. Moreover, it clearly explained every component of the methodology.

# Chapter 4: Development of Sustainability-Assessment Framework for Sewerage Infrastructure Projects

This chapter presents an overview of the sustainability assessment framework, which includes the scope of the framework, the developed sustainability assessment throughout the life cycles of the sewerage infrastructure project, with illustration of all stages of the framework, and the constructed sustainability indicators.

## 4.1 Overview of the Sustainability Assessment Framework

The sewerage infrastructure projects’ main objective is to collect and convey sewage generated from households and other facilities to treatment plants efficiently, according to the desired planning and design horizon, which will contribute to preserving the environment, maintaining public health, providing infrastructure to attract investors and therefore enhancing the environment and ultimately the better quality of life. The sewerage infrastructure projects can be challenging due to the complexity of dealing with existing sewerage systems which in turn effects on maintaining an effective sewerage performance. Moreover, understanding the sewerage network and highlighting its issues are very critical to establish the foundation of the framework. Identification of sustainability indicators has been performed to ensure that an inclusive sustainability assessment is provided. Ultimately, the framework was developed to maintain an efficient and functional sewerage system and to contribute to the sustainable development of sewerage infrastructure projects.

## 4.2 Scope of the Sustainability-Assessment Framework

The sustainability assessment framework aims to assess sewerage infrastructure projects throughout their life cycles. The following considerations are made in the preparation of the sustainability-assessment framework.

a) Reduction of the risk of sewerage failure and contributing to the sustainable development of wastewater-collection systems in Bahrain

b) Applying to newly-developed-area projects, extension projects, rehabilitation projects and upgrading projects (only sewer networks, not combined networks), with wastewater-treatment plants excluded

c) Consideration of the social, environmental, economic and institutional issues and elements of the assessed project by weighing the importance of each aspect based on experts’ judgments and on the situation in Bahrain

d) Consideration of the policies, regulations and institutional practises related to sewerage infrastructure projects in Bahrain

e) Performing sustainability assessments on all the project stages, including planning, designing, constructing, operating and maintenance, periodic assessment, and rehabilitation/upgrading

f) Supporting the modification of objectives and the evolution of indicators (e.g., sustainability issues, special cases, and adding/removing indicators) at all stages of the project and from both short- and long-term perspectives

## 4.3 Sustainability-Assessment Framework for Sewerage Infrastructure Projects

The developed sustainability assessment framework model for the sewerage infrastructure projects throughout their life cycles can be seen in Figure 14. The framework contains six stages: current sewerage system, contextualizing the project, planning, designing and implementing, operation and maintenance, periodic assessment and rehabilitation/upgrading.

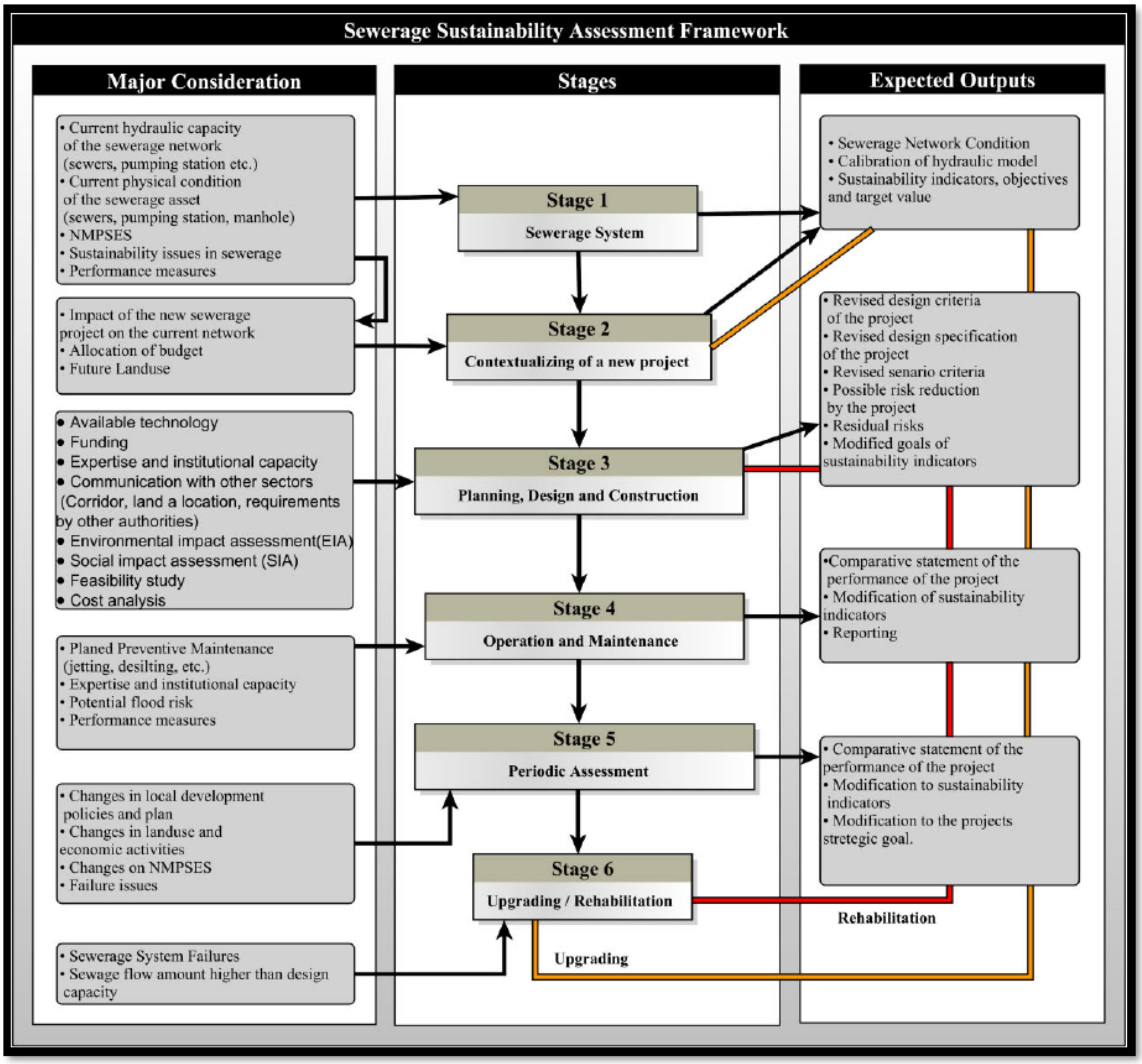



Figure 14: Sustainability assessment framework for sewerage infrastructure projects

### 4.3.1 Stage 1: Sewerage System

Identifying and understanding the existing sewerage network are very crucial for the application of the framework. The two main aspects that should be considered are the hydraulic and 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. Physical condition should also be assessed through inspection of the pumping stations and CCTV of the pipelines. There should be an inventory of the physical and hydraulic conditions of the network for future studies to be performed on the network. In addition, it is important to refer to the NMPSES to verify the effectiveness of the proposed measures given the current physical and hydraulic condition and to identify the current performance measures. For the context of Bahrain, this process is important because the NMPSES was developed in 2009, and there is a high possibility that the network has experienced changes over since that time. At this stage, sustainability issues need to be clearly identified to ensure all risks are considered in the engineering solutions. Furthermore, any updating in policies should be followed which in turn will drive the sewerage projects into their objectives. This stage is to clear things up and knowing the current management procedures and the extent of availability of the needed data for the assessment. As this stage will precede the contextualizing which is the beginning of the actual assessment of this framework, therefore any shortage in this stage would then reduce the realistic and usefulness of the assessment during the application.

### 4.3.2 Stage 2: Contextualizing the Project

In this stage, the scope of work of the proposed sewerage project is developed by entering the proposed scenarios into the hydraulic model and analysing the outputs. This stage involves defining the budget that needs to be allocated as part of the Ministry of Works' programme for design, supervision and construction. In addition, the proposed project can require allocation of land for the proposed pump stations. The process of allocating lands for public services needs to be initiated. Furthermore, the state's sustainable-development policy should be properly considered, and if the project does not comply with that policy, it should be rejected (Shen, Wu and Zhang, 2011). Then the sewerage infrastructure project should be categorized into one of four types of projects: newly-developed-area projects, extension projects, rehabilitation projects and upgrade projects. Based on that choice, proper sustainability indicators are selected, all 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- collection systems in Bahrain. The sustainability assessment indicators are presented in Table 8. These indicators were constructed through an extensive literature review of previous studies, consulting the experts and the secondary data were collected from the Ministry of Works in Bahrain including NMPSES, operation and maintenance reports, quality assurance reports among others (Appendix F). Moreover, the selection of these indicators was founded based on their criticality, relevance, significance and their possibility of capturing of a long standing issues. The condition of the sewerage should be clarified based on the available existed data, the possibility of calibration the data in hydraulic model in the existed sewerage system. In the outcome of this stage the experts would carefully select the suitable sustainability indicators and define the maximum and minimum target value of every chosen sustainability indicator to identify the sustainability index border which will then be used to assess this stage and during all the other stages of the assessment.

### 4.3.3 Stage 3: Planning, Designing and Implementing the Project

After specifying the condition of the current sewerage system, identify the type of the project, selecting the proper sustainability indicators with defining the target value of each indicator, the third stage covers the planning, designing and construction. Based on the type of the project, various design alternatives and scenarios can be compared, as there are four possible types of sewerage projects:

a) Newly-developed-area projects and Network upgrades projects

In these two kinds of project, there is more flexibility in the possible scenarios, which can include a newly developed area that is not connected to the current network or an upgrade with a new sewerage line. In Bahrain, this kind of project occasionally contains a treatment plant, and that would be based on the location of the project. The sustainability indicators would be used to assess the projects and compare between the different alternative designs or scenarios, as each is compared to provide a better decision-making process based on the sustainability assessment criteria's and objectives. Before assessing this kind of projects, its entails the return to the master plan and the technical documents checking if this project were duly considered in the plan. Precisely, seeking the required information within the existence of possible alternatives that suggested the given project, and that's so to collect the data to be used in finding the best scenario regarding the perspective of sustainability.

b) Extension projects linked to the network

In this kind of project and depending on the project location, the alternatives could be limited, and the best solutions are usually based on existing sewerage; the alternative design or scenarios for the possible lines of the sewerage could be compared based on the chosen sustainability assessment indicators. Also due to the many wastewater treatments plants in Bahrain, it enhances the possibility of existence of different paths.

c) Rehabilitation projects

Rehabilitation of sewerage projects could be done by using different technologies, and these 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, which in turn can decrease the pipe capacity. Therefore, a hydraulic assessment needs to be completed to ensure that the project does not cause any interruptions in service. The need of rehabilitation has to be in line with the concept of sustainable development, as sometimes the better solution could be implementing an upgrade, renewing the sewer or doing nothing. The decision makers should not make their decision based on a pure economic perspective. Furthermore, the different rehabilitation solutions could be compared based on their pursuit of serving the sustainability assessment indicator, which will then tend to have a better decision-making that's sustainability based.

**Planning and Designing Phase of the sewerage projects**

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-tunnelling. This technology might not be available in Bahrain when construction works are scheduled, as contractors from nearby countries provided it and as no local contractors are available. Further, ensuring the availably of contractors requires attracting contractors from nearby countries, which also requires prior advertisement and invitations to participate in the tender of the project. Since some projects require specialized staff to engage in the design and construction processes, it is important to ensure that the required expertise is available within the Ministry of Works. A comprehensive feasibility study needs to be performed on the proposed options and scenarios. The project's funding becomes clearer as the design progresses. Cost analysis of the project's financial needs, starting from the design up to the operation and maintenance, must be performed to control the project's expenditures as it progresses. Moreover, coordination with other concerned organizations is usually done in this phase to grant necessary approvals. In Bahrain, the process of allocating corridors within roads to lay pipelines is usually performed under the Planning Permission application, which is filled with the project information and supported by the detailed design drawings. After that, the application is distributed to all service providers to collect their comments and ultimately grant their approval. If required, land parcels are allocated in this phase as well, which involves granting approvals from the Survey and Land Registration Bureau and Authority of Urban Planning. Also, environmental impact assessment (EIA) and social impact assessment (SIA) are performed in this stage. Approvals from concerned authorities such as the Supreme Council of Environment would be granted, otherwise the project will be rejected as it will be against the policies and regulations.

While considering all the previously mentioned activities, one of the main benefits of the assessment will begin by comparing of different alternatives and scenario with taking into consideration all the sustainability aspects that this framework is containing. Using the sustainability indicators into comparing by different alternatives to give a decision that is sustainability based was inspired from (Shah, Rahman and Chowdhury 2017; Shen, Wu and Zhang 2011; Ugwu and Haupt 2007). And this will be done by identifying the sustainability index for the compared matter whither different scenarios or different designs. The design or scenario that will have a higher value will be the most sustainable option that serve the objectives of the framework which is reducing the risk of sewerage failure and contributing to the sustainability development of the wastewater collection system. Further explanation in the following:

To compare between alternative design or scenario:

There are steps that should be followed: 1) identify the suitable sustainability indicators that have the ability to assess the sewerage projects properly and these indicators will have a power based on their importance in achieving the assessment objectives, a scale out of 5 (1 = Not important; 2 = Less important; 3 = Neutral; 4 = Important; 5 = Very important). A survey was done in Bahrain; the final results with the weightage of the sustainability indicators can be seen in the data analysis Chapter 5. 2) based on experts judgment, a maximum and minimum target value of every chosen sustainability indicator will be identified to have the range border, then 1-5 range will be given based on the experts judgment, and that so every indicator could be then fit into one of the 5 ranges (highly negative impact, negative impact, neutral, positive impact and highly positive impact). 3) then a formulation of mathematical equation will be used whiten the multi-criteria analysis (MCA) that will result into finding the sustainability index (SI) for every alternative (A) design or scenario.

In this assessment, the following formula (1) will be used, which has been extracted from Fishburn (1967).

$$SI_{Aa} = \sum_{n-}^{N} d_{a,n} W_n \, , \qquad (1)$$

where $SI_a$ (for $a$ = 1, 2, 3, . . . M; n =1, 2, 3, . . . N) would be a significance crisp value for every alternative or scenario ; Aa is for the alternative designs or scenario (for instance a number of $M$ alternatives were identified); $d_{a,n}$ the value (based on a scalar value given by experts for every indicator) that the alternative option gained based on its performing in sustainability indicator, this would be a number 1-5 (while 1 = Highly negative impact ; 2 = Negative impact; 3 = Neutral; 4 = Positive impact; 5 = Highly positive impact); $W_n$ a weight for the importance of the specified sustainability indicator, this would be a scale of 1–5 (1 = Not relevant; 2 = Less important; 3 = Neutral; 4 = Important; 5 = Very important) (a survey was done to collect the weight of importance for every indicator the results can be seen in Chapter 5); and $SI_a$ will lies between two range $SI_{min} < SI_a < SI_{max}$, where $SI_{max}$ would be identified by using the maximum target value for every indicator that will be identified by experts and $SI_{min}$ would be identified by using the minimum target value for every indicator that will also be identified by experts.

Table 7 represents of the numerical process of the developed sustainability assessment framework for comparing between the different alternatives of designs or scenarios of the sewerage projects. And Figure 15 presents the output form of the sustainability assessment, as it presents the SI value for every alternative and the amount of tending into different criteria. The highest SI would be the best alternative that should be chosen for the project.

Table 7: Sustainable assessment decision matrix for alternative design

| **Alternative Design options ($A_a$)** | **Sustainability Criteria (SC)** | | | | | |
|---|---|---|---|---|---|---|
| | $SC_{(1)}$ | | $SC_{(2)}$ | | $SC_{(n)}$ | |
| | $SI_{(1)}$ $W_1$ | $SI_{(2)}$ $W_2$ | $SI_{(3)}$ $W_3$ | $SI_{(4)}$ $W_4$ | $SI_{(5)}$ $W_5$ | $SI_{(n)}$ $W_{0n}$ |
| $A_1$ | $d_{1,1}$ | $d_{1,2}$ | $d_{1,3}$ | $d_{1,4}$ | $d_{1,5}$ | $d_{1,n}$ |
| $A_2$ | $d_{2,1}$ | $d_{2,2}$ | $d_{2,3}$ | $d_{2,4}$ | $d_{2,5}$ | $d_{2,n}$ |
| $A_3$ | $d_{3,1}$ | $d_{3,2}$ | $d_{3,3}$ | $d_{3,4}$ | $d_{3,5}$ | $d_{3,n}$ |
| $A_a$ | $d_{a,1}$ | $d_{a,2}$ | $d_{a,3}$ | $d_{a,4}$ | $d_{a,5}$ | $d_{a,n}$ |

Key: $SC_{(n)}$, sustainability criterion $n$; $SI_{(n)}$, sustainability Indicator $n$; $W_n$, a weight for every $SI_{(n)}$, under $SC_{(n)}$; $A_a$, alternative design option $a$; $d_{a,n}$, a value (based on a scalar value given by experts) that measures the performance of $A_a$ for every $SI_{(n)}$.

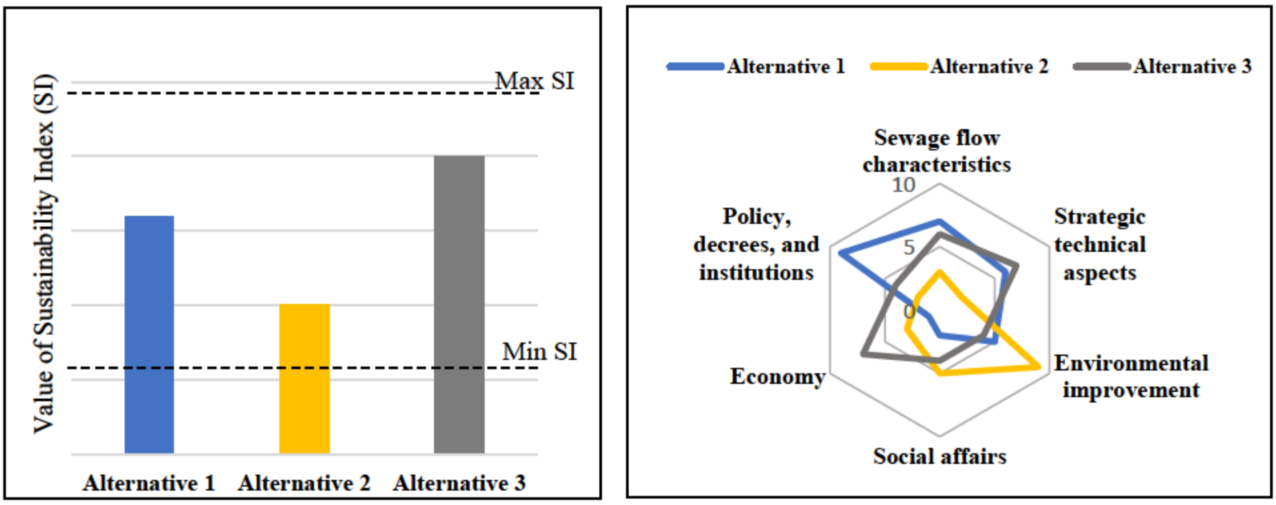



Figure 15: The representation of the results of the sustainability assessment for the different alternatives

Whether the comparison was made between different alternatives of designs or scenarios, the chosen sustainability indicators have the ability to clarify the potential of that alternative in serving the sustainable development of the sewerage system and reducing the risk of sewerage failure. Nevertheless, the sustainability indicators bring mindfulness for the possible shortening while managing the sewerage projects, however by themselves do not sufficiently promote the decision making. As analyzing the experts judgments and examine the diversity of their responses would ensure to some extent a reliable and non-biased conclusion. Furthermore, identifying sustainability indicators in a broad context taking into account all aspects of sustainability is an indispensable way that support the decision making into reaching sustainable development (Waas et al., 2014).

**Implementing Phase**

During the implementation phase, the assessment would limit through monitoring the construction activities with giving attention to the sustainability indicators and their compliance with the previous stages. Precisely, the environmental and social plans set in previous stages should also be assessed to ensure sustainability targets are achieved through the indicators. In this phase the assessment should be done aiming to capture all the changes within the project planning and whither previous phases were done properly. So, as a result of this stage, any proposed modifications have been done during the construction period would need to be assessed to validate sustainability indicators and to suggest modifications needed to raise the framework's effectiveness. After that the SI with the $SI_{max}$ and $SI_{min}$ will be calculated again with the adjusted indicators and compare it with the planning stage for further modification with the sustainability indicators. Finally, the adjusted calculated sustainability indicators will be used for the next stage which is the operation and maintenance stage for continuing the sustainability assessment.

### 4.3.4 Stage 4: Operation and Maintenance

The assessment of this stage is critical, as it represents the longest period of the project life cycle. This stage will also reflect how efficient was the planning, designing and constructing of the project. The assessment needs to ensure there are comprehensive operation and maintenance plans, such as plan 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. Furthermore, the existed performance measures and risk assessment associated with sewerage failure must be conducted for the entire operation and maintenance period. This should be performed in order to compare statements of the project's performance with the previously expected performance. Moreover, all the arise issues in this stage should be looked at them closely and deem them into further validation of sustainability indicators while suggesting modifications. This will promote the effectiveness of the framework with time.

### 4.3.5 Stage 5: Periodic Assessment

Periodic assessment should be performed to ensure the system is functioning avoiding the risks for sewerage failure while contributing to the sustainability of the wastewater collecting system. Assuming the assets are being operated and maintained properly, there are other factors that need to be assessed such as land zoning classification and policies among others. for an example, land zoning can be changed by the master plan of land use in Bahrain, which will define the allowable economic activities in the region. This change can directly affect the quantities of sewage generated, as it can be increased or decreased. Either way, the network needs to be assessed to ensure sewage velocity is within the self-cleansing velocity range and to ensure that the pipelines and pumping stations are capable of conveying the sewage as required. Assessing this stage using the sustainability indicators is very critical to analyse data and predict when there is risk of failure, thus requiring new measures. And that will help the management of the network to be proactive which will allow sufficient periods and to plan, design and implement these measures through further suggesting modification of the sustainability assessment tool. Moreover, the assessment must consider any updating including the NMPSES with any changes in the condition of the sewerage network to ensure that all sustainability issues and risks are identified and to perform effective sustained assessment, which will ultimately be reflected on having sustainable sewerage system.

### 4.3.6 Stage 6: Rehabilitation/Upgrading

Sewerage network rehabilitation and upgrading are performed when the assets reach the end of their physical life spans or their hydraulic capacity limits. It is important to review the NMPSES and policies to ensure that proposed rehabilitation or upgrading measures are in line with the overall master plan. Sustainability indicators should be validated to propose any required modifications.

Based on the information collected in Stage 5, the network needs to be assessed to identify when it will reach the design capacity. The time required for the network to reach this stage is long but needs to be considered. In case there are any sewerage system failures, the assessment must identify the causes. In the case of rehabilitation, the assessment can start from Stage 3, while, in the case of upgrading, the assessment will start from Stage 2. With considering all the modification of the sustainability indicators which will give a better robustness for the framework with time.

Table 8: the sustainability assessment indicators for the sewerage infrastructure projects

| **Sl.** | **Sustainability criteria and indicators** | | |
|---|---|---|---|
| **Objective 1: Reduce the risk of sewerage failure** | | | |
| **Criterion A. Strategic technical aspects** | | **Description** | **Measuring parameter** |
| **A1** | Planned preventive maintenance (PPM) | Perform maintenance for pipes and pumping stations as per the PPM | % of commitment to PPM |
| **A2** | Technologies | Keep up with the use of new technologies that contribute to reducing the risk of failure (e.g., software, new construction and maintenance tools) | Yes/No (likelihood) |
| **A3** | National Master Plan for Sanitary Engineering Services (NMPSES) | Comply with NMPSES | % of keeping up with NMPSES |
| **A4** | Availability of qualified staff | The presence of qualified, well-trained and specialized staff | Yes/No (level of availability of qualified staff) |
| **A5** | Communication with other internal (within the Ministry) sectors | Efficient communication with other internal sectors on the interest of the projects | The estimated late period due to the lack of efficient communication |
| **A6** | Communication with other external sectors | Efficient communication with other external sectors on the interest of the projects | The estimated late period due to the lack of efficient communication |
| **A7** | Pumping station reductions | Minor pumping stations and major pumping stations to be eliminated, if any | No |
| **A8** | Intermediate pumping stations planned to be implemented | New intermediate pumping stations that are planned to be implemented | No |
| **A9** | Pipeline rehabilitation/upgrading | The need for rehabilitation or upgrading compared with the essential plans—for example, replacing a damaged pipeline that didn't finish its planned horizon | % of the differences of the essential plans as per sewer length (m) |
| **Criterion B. Sewage flow characteristics** | | **Description** | **Measuring parameter** |
| **B1** | Projected population | The extent of accurate data from concerned authorities over time—for example, the contradiction of the predicted population with the existing population due to changes performed on land zoning in the project area | % of accuracy of the predicted flow |
| **B2** | Planning horizon | The estimated period in which the network is designed to function | Yes/No (likelihood) |

| | | | |
|---|---|---|---|
| | | efficiently compared with the actual period | |
| **B3** | High infiltration/inflow | The high levels of infiltration from groundwater and inflow from rainwater, manhole covers, yard drains, catch basins and other sources | % of infiltration/inflow to the sewerage system |
| **B4** | Missuses of sewerage by the users | The use of the sewerage system to discharge storm water, open manholes or dispose of fats, oils and grease | % users missuses recorded in the project area (such as oil and grease Mg/L) |
| **B5** | The intentional vandalism of the sewerage system | The contribution to disabling the sewerage system, whether directly or around the project area, such as difficulty accessing some areas for scheduled work | % of sabotage event around the project area |
| **Objective 2: Contribute to the sustainable development of wastewater collection system** | | | |
| **Criterion C. Economic aspects** | | **Description** | **Measuring parameter** |
| **C1** | Project capital cost | The total cost of implementing the project | Total capital cost ($) |
| **C2** | Operation and maintenance cost | The total cost through the operation and maintenance based on the estimated planning horizon | $ per year |
| **C3** | Sewage treatment plant | The reduction of the wastewater treatment plant process by reducing the income flow (e.g., infiltration) | Deviation from the normal/anticipated treatment cost |
| **C4** | Health care | The saved expenses from health care services by preventing sewage diseases | $ per year |
| **C5** | Reduction of pumping station | Operation and maintenance cost of pumping stations that could be eliminated | $ per year |
| **C6** | Replacement of pipelines | The pipelines that need to be replaced before their planning horizon ends | $ per year |
| **C7** | Replacement of pumping station | The pumping stations that need to be replaced before their planning horizon ends | $ per year |
| **C8** | Consequence caused by the absence of service corridor | Modifications to the scope of work due to the absence of a corridor in the project area | % of capital cost increment caused by the modification |
| **C9** | Served industrial areas | Industrial areas that will benefit from the project | % of served industrial areas |
| **C10** | Land value | Value of properties affected by the sewerage issues such as flooding and gasses | % of value loss of properties due to the sewerage project |
| **Criterion D. Social aspects** | | **Description** | **Measuring parameter** |

| | | | |
|---|---|---|---|
| **D1** | Public health and safety | The protection of the public from possible sewage-borne diseases, the likelihood of road collapses, etc. in the project area | No |
| **D2** | Satisfaction of the stakeholders | The reported complaints within the sewerage project area compared with contributions to reduce the complaints | % of contribution to reduce the complaints |
| **D3** | Served occupants | The served occupants by the project compared with the total occupants that required sewer service | % of served occupants out of the total no. of occupants that required sewer service |
| **D4** | Local economic development activities | Provision of sewer services to local business activities such as malls and commercial real estate | Yes/No (likelihood) |
| **D5** | Served critical infrastructures and facilities | Facilities and infrastructures (e.g., hospitals, educational institutions, airports, police and military installations and community facilities) that will maintain service from the project | % of served facilities and infrastructure out of the total facilities and infrastructure |
| **D6** | Public awareness | The extent of public awareness concerning the consequences of misusing the sewerage system (e.g., opening manholes or disposing of fats, oils and grease) | Number of houses and facilities affected by the project during construction stage in terms of pipe length (m) |
| **Criterion E. Environmental aspects** | | **Description** | **Measuring parameter** |
| **E1** | Aquifer pollution | Wastewater generated from unsewered facilities (septic tank) and leaked from damaged pipelines, resulting in sewage seepage into an underground aquifer | m3/day |
| **E2** | Odour air pollution | The generation of odour from the sewer network (e.g., septic tank, pumping stations and manholes) | OU/m3 |
| **E3** | Losses of resources (groundwater) | The amount of groundwater that reaches the sewage treatment plants | % of the high infiltration reaches the treatment plant |
| **E4** | Pumping station energy | Increment/decrement of energy consumption from the pumping station | Kilowatt /hour |
| **E5** | Land used for the sewerage projects | Construction activities causing noise, dust, gasses, dewatering or any construction waste that would disturb the environment in the surrounding areas | Total volume of trenches excavated during the construction stage (m3) |

| | | | |
|---|---|---|---|
| **E6** | Green technologies | Any green innovation that overlaps with sewerage projects that will end up saving energy, preventing pollution and recycling waste, such as a pumping station operating by means of solar panels, onsite septic systems and software | Yes/No (adopted technologies with tangible positive impacts) |
| **E7** | Sewage flooding | Contribution in reducing the areas suffering from sewage overflow | Reduction of pumping stations in the system that are considered as bottlenecks that lead to flow accumulation in the system |
| **Criterion F. Policy, decrees, institutions, and strategic visions** | | **Description** | **Measuring parameter** |
| **F1** | Strategic vision | Existence of comprehensively updated strategic vision for sewerage networks | Yes/No |
| **F2** | NMPSES | Existence of an updated master plan in line with the country's strategic vision prepared by the authority responsible for providing sewerage services | Years passed since the last update |
| **F3** | Community participation | Involvement of the public in the decision-making process | Involvement through availability channels such as media, National Complaint System, municipalities, representatives and others |
| **F4** | Local consultants | Engagement of local consultants in the project | % of total work per year |
| **F5** | Local contractors | Engagement of local contractors in the project | % of total work per year |
| **F6** | Service fees | Adoption of service fees or taxes policies | Yes/No (adopted service fees with tangible positive impact) |

## 4.4 Discussion and Conclusions

The sewerage system faces various challenges to sustain its performance during its life cycle to have a functional, effective and reliable system, while avoiding the risks of failure (e.g. overflow, odor and sewer leakage). A sustainable sewerage system should aim to perform its function to the fullest during its life span, therefore protecting the users' quality of life with the lowest possible cost and the lowest potential impact on the environment. In order to reach the desired sustainability, an assessment tool must be developed to capture any trouble that prevent the sewerage into reaching the sustainable development while considering reducing the risk of sewerage failures (Alnoaimi and Rahman, 2019). It was advised that in order to reach the sustainability of an infrastructure, all the sustainability aspects (social, environmental and economic) should be considered (Diaz-Sarachaga, Jato-Espino and Castro-Fresno, 2017; Sala, Ciuffo and Nijkamp, 2015). Further, the sustainability should be implemented into different stages of the development of that infrastructure (Cinelli, Coles and Kirwan, 2014; Shah, Rahman and Chowdhury, 2017). Without a doubt that implementing the sustainability in the project level would pursuit into having a sustainable system and eventually contributing in reaching the sustainable development. There are few researches that assess the sustainability on the project level, most of them focus on the planning, best strategies approaches and different alternatives (Ugwu and Haupt, 2007; Shah, Rahman and Chowdhury, 2017; Shen, Wu and Zhang, 2011) while their assessments stop at that level without knowing if the sustainability has been reached and if the paths that they followed were the best in relation to the sustainability. Moreover, all of these researches were in a very different context than the sewerage projects, and to the best of researchers' knowledge, no study has focused on assessing the sewerage system on the project level and throughout its life cycle. Therefore, this research aims to assess the sewerage infrastructure projects during its life cycle, making sure if the decisions that were made during all the stages were ultimately helping reaching the sustainability as planned.

The developed sustainability assessment framework performs on all the project stages, including planning, designing, constructing, operating and maintenance, periodic assessment, rehabilitation and upgrading. Implementing the assessment through the several stages of the project would give a rubout support the decision makers, that will help them define the reflection of their previous decisions. Furthermore, if an organisation does not view sustainability as an important target, Sustainability is unlikely to be taken seriously or have an excellent sustainability performance (Chang et al., 2018). Current performance measures in Bahrain are mainly on the operation and maintenance stage and rehabilitation. There are three key performance indicators that are currently being conducted: 1) the number of complains compared with the year before, 2) number of pumping stations breakdowns and reporting their issues, 3) infiltration rate comparison before and after the rehabilitation (Ministry of Works, 2009). These performance measures were limited into social and technical impact in a superficially way, whereas the impact on all aspects environmental, social and economic should be impartially considered (Hossain and Gencturk, 2016; Upadhyaya, 2012) and doing so will contribute in ensuring having a sustainable sewerage.

The aim of the developed sustainability assessment tool was to assess the sewerage infrastructure projects focusing on reducing the risk of sewerage failure and ensuring the sustainable development of wastewater-collection systems. The application of the framework was on Bahrain, and therefore some of the identified indicators show a uniqueness that serve the country. However, with some adjustment within the framework and precisely the sustainability indicators, then it would be applicable to implement it in an area with a similar characteristic. Otherwise, with a massive adjustment and deeply understanding the way of constructing the indicators then it would be applicable to implement it in a very broad different context. Forty-three sustainability indicators have been identified within the developed sustainability assessment framework. The defined sustainability indicators were driven from regulations, policies, plans and sustainability issues in Bahrain. Furthermore, while defining the sustainability indicators it was taken into consideration that these indicators should be critical, rational, relevance and have the ability to capture long-term issues. Moreover, these indicators involve a continuous evaluation process throughout the life cycle of the projects as the knowledge provided at each appraisal point will enable both current and future generations to rectify any project shortcomings and implement appropriate sustainability indicators for the sewerage projects ensuring the sustainable development of wastewater-collection systems while reducing the risk of the sewerage failure.

The method that have been adopted for the developed framework was the multi-criteria decision analysis method that were based on defining objectives, criteria and indicators. Similar methods have been used by other researches (Shah, Rahman and Chowdhury 2017; Shen, Wu and Zhang 2011; Ugwu and Haupt 2007). Further, during the assessment a sustainability index would be determined several times throughout the different stages of the projects, this is to equate project performance statements and knowing the changes with sustainability index with time. Moreover, the determining the sustainability index would benefits choosing between different alternatives of designs and scenario based on its best ability to serve the sustainability. The sustainability indicators that have been identified in this research could differ from a certain project to other, certain period to other, and that depends on the type of the projects (whether new area sewerage project , extension project, upgrading project or rehabilitation project), the missions and visions of ministry of works, the policy, regulations, the national master plan and governmental action plan. In addition, the sustainability indicators will rely on the expert’s judgment to give a weighting of the importance of every indicator (using a scale 1–5) and giving a range with a minimum and a maximum target for every indicator.

The developed framework with the identified indicators involves simple calculations to be done by decision makers through a logical approach which is easily implemented and gives a reliable firm outcome that would help into having a more sustainable system. In contrast, the developed framework with its indicators does not automatically provide the best set of sustainability indicators, criteria and metrics, but it is the duty of the decision makers to fit it properly within the context of current and future sewerage projects. Ultimately it would give a promising outcome which will reduce the risk of the sewerage failure and contribute to the sustainability development of the wastewater collection system in Bahrain.

## 4.5 Summery

This chapter presented the development of sustainability assessment framework with all the identified sustainability indicators. Firstly, an overview of the framework was presented, then the scope of the Sustainability-Assessment Framework, followed by extensive details discussion of all the stages of the framework, and finally the framework ability, limits and its context were discussed.

# Chapter 5: Data Analysis

This chapter presents verification and validation of the developed sustainability assessment framework, as determined through a pre-survey pilot study, followed by a detail description of data collection process together with the clarification of the rationale behind the survey questions. Finally, a detailed analysis of the collected data (contained in the responses) is carried out using statistical tools and technique.

## 5.1 Pilot Study

The current research project is being undertaken to provide a sustainability assessment framework for sewerage infrastructure projects in the Kingdom of Bahrain to ensure the long-term sustainability of such projects. In Chapter two, the relevant literature and studies of sewerage project management along with the secondary data analysis related to the research problem were explored and discussed. This led to the formulation of a preliminary framework that addresses concerns around the sustainability of sewerage infrastructure in Bahrain. To date only a few research has been carried out that covers the current research context. Therefore, the implementation of a framework designed for different circumstances was expected to present creditability concerns. As such, it was important to incorporate a pilot study phase into this research to enhance the credibility of conducting it and enrich the survey while the preservation of participant rights of that enrichment. To these ends, the framework was subjected to pilot testing before the full-scale study was conducted. The outcome of the pilot study furnished the researcher with an understanding of the background information necessary to perform a sustainability assessment of sewerage projects in Bahrain. Testing the proposed framework, which yielded suggestions for the addition, removal or amendment of some parts of the framework in the infancy of the study, allowed the participants to improve the content validity of the research measurement. Moreover, having a pilot study increased the likelihood of research success (Teijlingen and Hundley, 2001).

### 5.1.1 Execution of pilot study

After developing the sustainability assessment framework and identifying the sustainability indicators (Chapter 4), a survey, consisting of four sections, was prepared (Appendix G). Before conducting the survey and sending it to the participants, there was a pilot study conducted, using two groups of engineers, one group comprised of sewerage project experts and another, more generally diverse, group.

### 5.1.2 First group

The first group consisted of five experts on sewerage project works in the Ministry of Works in the kingdom of Bahrain, and those who validate the survey through further clarification of some indicators, improvement of expression, suggestions for new indicators, and the addition of questions. For instance, in one case, it was suggested that a conflict existed between two indicators, namely: land zoning and projected population. Hence, "land zoning" was removed from the framework and "projected population" has been kept, which captures the accuracy of predicted users of the system. The Table 9 shows some examples of improvements to the indicators.

Table 9: Examples of improvement by the first group

| **Original proposal** | | **Suggested improvement** | |
|---|---|---|---|
| **Indicator** | **Description** | **Comment** | **The change made** |
| Land zoning | The compatibility of land zoning plan vs. design horizon. | It was counted as duplicated with projected population (indicator-B1) which take land zoning into account | The indicator was removed, because it could be a part of another indicator, the projected population (indicator-B1). |
| Infiltration / Inflow | The levels of infiltration from groundwater and inflow from rainwater, manhole covers, yard drains, catch basins, and other sources | Adding the word "high" was suggested, because just an infiltration wouldn't clarify the indicator | The word high was added in the indicator and in the description (indicator- B3) |
| Communication with other sectors | Efficient communication with other sectors on the interest of the projects | Its suggested clarification of the sectors if it's within the ministry of works (internal) or an external sector | This indicator has been divided into two indicators, communication with internal sector (indicator-A5) and communication with external sector (indicator-A6) |

| Original proposal | | Suggested improvement | |
|---|---|---|---|
| Technologies | Keep up with the use of new technologies that contribute to reducing the risk of failure | A clarification was required on the type of technologies: whether it is any new technology or just a green technology. | Some examples were added to this indicator (indicator-A2) to clarify it and another indicator expressed that green technology was added (indicator-E6) |

### 5.1.3 Second group

After using valid indicators to prepare the survey, it was then administered to the second group, which included two civil engineering experts and three PhD candidates, who were focused more on wording in general and the structure of the survey, because they lacked expertise in sewerage projects and could not provide data to inform the indicators. For instance, a PhD candidate offered enrichment to the second question in the background information section with the suggestion to mention all fields of expertise that may enable clearer and easier capacity for participants to distinguish between the disciplines as it will also help during analysing the data. The flowing Table 10 shows some of their improvement.

Table 10: Examples of improvement by the second group

| Case | Note | The change made |
|---|---|---|
| Section two of the survey was displayed in a complex way, with all the questions linked together; the weighting of the first indicator and the second should be 100, and the given amount of every objective should be distributed to the criteria in every objective. So, all questions of the section were linked together. | It was somehow hard to follow and takes time to understand, which might cause the participants to stray away from the survey. There was a suggestion to change the questions into distributing points for each question separately. Then, during the analysis, the distributed points would be | All questions of Section two were represented in a simpler way, so that each question could be answered individually, without prejudicing the objectives of this section. |

| Case | Note | The change made |
|---|---|---|
| | translated into a weightage out of 100. | |
| Section three became a mess when using the mobile phone while conducting the survey. | There was a suggestion to use a JavaScript to solve this issue or to add a note in the beginning of the survey. | A note, in bold red font, was added at the beginning of the survey, saying: If you are using your mobile phone, please do not complete the survey, as some of the questions will not show properly. |
| The second question in the first section: what is your field of expertise? And an empty mandatory box was given. | It was suggested to add all the disciplines and all the field of expertise for clarity and easily distinguish between them as it will also help during analysing the data to know if the experts' fields would affect the answers. | The question was improved by adding the disciplines (planning, designing, constructing and operating) and the field of expertise (sewerage networks, sewage treatment plants, treatment sewage effluent network). |

## 5.2 Data Collection

The survey was divided into four sections, as can be seen in Appendix G. The first section consists of the background information; this section records the qualification of the participants, field of expertise, years of professional experience, their roles on the projects, as well as their age and gender. Analysing the background information of the participants will facilitate an examination of the diversity of the responses, thereby ensuring a reliable and non-biased conclusion. Further, it will enable further examination of cases that may present unexpected or irrelevant outcomes.

The second section is comprised of the objectives and criteria, which present the two objectives of the sustainability assessment framework with their criteria; participants were asked to evaluate the objectives and their criteria, based on importance. Analysing this section facilitated construction of the sustainability assessment framework of the sewerage projects, by extracting the score of the objectives and criteria to be considered as a part of the metrics of the sustainability assessment tool in the context of Bahrain.

The third section includes the evaluation of potential sustainability indicators, and this section is regarded as an essential part of this survey and the actual basis of this research. It presents all the identified indicators and the participants were asked to rate these indicators, on the basis of importance, in measuring the performance of the project throughout its different stages. And analysing the collected scores of the indicators will lead to the development of the sustainability assessment framework, as it will be ready to implement in a case study to demonstrate how its work.

The fourth section is the sewerage project's sustainability overview, and it reflects on the extent to which it captures the sustainability of the sewerage projects, consideration of the sustainability, sufficiency in sustaining sustainability issues, the currently used methods or tools, the stages that implement the sustainability and, finally, an open invitation for suggestions to further improve the sustainability of sewerage projects. Analysing this section shows the participants' point of view about the sustainability of sewerage projects in Bahrain and it also clarifies whether a discrepancy exists among the answers to such specific questions. At the end of the questionnaire there were a separated optional link for collecting the emails for those who want to receive the result of this research, and this link doesn't conflict with the ethical concerns as the responses weren't linked with the emails. Moreover, the data collection completed using the Griffith University online survey platform, which guarantees the security of the collected data.

### 5.3 Data Analysis

This online survey was distributed via an e-mail containing instructions and a hyperlink. Then, periodic reminders were sent for six months. This research survey attained ethical approval and was conducted under Griffith university ethics reference number (GU Ref No: 2018/848). More precisely, it was sent to the undersecretary advisor of Ministry of Works in Bahrain, which in turn sent it to their staff working under the Sanitary Engineering Planning and Projects Directorate and Sanitary Engineering Operation and Maintenance Directorate, and those who also sent it to the appropriate consultants and contractors. Therefore, it was estimated that a link to the survey was sent to 120 participants and the responses were 52, so the response rate was 43 %, which is regarded as an acceptable rate. However, 18 of the responses were rejected (removed), due to incomplete answers, irrational answers (unreasonable period of time, unjustified repeated weightage and unjustified scatter weightage) and unreliable qualifications. And that led to a total sample of 34 responses for the analysis in the following sections.

### 5.3.1 Background information

The first section of the survey captures the characteristics of the participants through six questions. Starting with participants' qualification, field of expertise, their role on the projects, years of professional experience, age and gender. The responses to these questions can be seen in Table 11 and 12, which present the frequency and the percentages of all the answers. Notably, the responses showed that there was diversity in the sample, which in turn maintained reliable and non-biased responses, as will be reflected in the provision of a firm conclusion.

Table 11: Background information

| Background information | | | Frequency (f) | Percent % |
|---|---|---|---|---|
| **Qualification** | Diploma | | - | - |
| | Bachelor's degree | Civil Engineering | 19 | 55.88 |
| | | Electrical Engineering | 4 | 11.76 |
| | | Mechanical Engineering | 11 | 32.35 |
| | Master's degree | | 11 | 32.35 |
| | PhD | | 1 | 2.94 |
| | Other | | - | - |
| | **Total** | | 34 | 100 |
| **Years of experience** | Less than 5 years | | 1 | 2.94 |
| | 5 to 10 years | | 13 | 38.23 |
| | 11 to 15 years | | 4 | 11.76 |
| | 16 to 20 years | | 6 | 17.65 |
| | More than 20 years | | 10 | 29.41 |
| | **Total** | | 34 | 100 |
| **Roles on the projects** | Owner (Government Sector) | | 20 | 58.82 |
| | Owner (Private Sector) | | 2 | 5.88 |
| | Consultant | | 5 | 14.71 |
| | Contractor | | 7 | 20.59 |
| | **Total** | | 34 | 100 |
| **Age** | Between 22 to 31 | | 7 | 20.59 |
| | Between 32 to 41 | | 10 | 29.41 |
| | Between 42 to 51 | | 8 | 23.53 |
| | Between 52 to 61 | | 7 | 20.59 |
| | Between 62 to 71 | | 2 | 5.88 |
| | **Total** | | 34 | 100 |
| **Gender** | Male | | 28 | 82.35 |
| | Female | | 6 | 17.65 |
| | **Total** | | 34 | 100 |

Table 12: Field of expertise

| Field of expertise | | Planning | | Design | | Construction | | Operation & Maintenance | | % of participants expertise in every field |
|---|---|---|---|---|---|---|---|---|---|---|
| The total number of participants | 34 | f | % | f | % | f | % | f | % | |
| Sewerage Network/ Pumping Stations | | 17 | 50 | 16 | 47.1 | 18 | 52.94 | 7 | 20.59 | 52.94 % |
| Sewage Treatment Plants (STP) | | 12 | 35.3 | 12 | 35.3 | 12 | 35.3 | 11 | 32.35 | 35.29 % |
| Treatment Sewage Effluent Network/ Pumping Stations | | 12 | 35.3 | 13 | 38.23 | 8 | 23.53 | 6 | 17.65 | 35.29 % |
| % of participants expertise in every stage | | 50 % | | 47 % | | 52.94 % | | 32.35 % | | |

### 5.3.2 Objectives and criteria

This section presents three main questions, with open-ended sub-questions for the second and third questions. The first question articulates the two main objectives of the sustainability assessment framework and participants were asked to distribute a weight out of 10 between the two objectives. The second question presented the criteria of the first objective and asked the participant to distribute a weight out of 10 between them. The third question presented the criteria of the second objective and asked the participant to distribute a weight out of 10 between them. And the collected results were then transferred to a weightage out of 100, distributed between the two objectives and their criteria, the mean of which is the actual results, the mode, which is most repeated judgment and the weightages that were selected. And these results can be seen in Table 13.

Table 13: The sustainability assessment objectives and criteria

| No. | The Sustainability Assessment Objectives and Criteria | Mean | Mode | Chosen |
|---|---|---|---|---|
| **1. First Objective: Reduce the risk of sewerage failure** | | 50.29 | 60 | 55 |
| **1.1** | Strategic technical aspects | 22.29 | 30 | 25 |
| **1.2** | Sewage flow characteristics | 28 | 30 | 30 |
| **2. Second Objective: Contribute to the sustainable development of wastewater collection system** | | 46.76 | 40 | 45 |
| **2.1** | Economy | 13.41 | 12 | 15 |
| **2.2** | Social affairs | 9.65 | 12 | 10 |
| **2.3** | Environmental improvement | 15.65 | 18 | 15 |
| **2.4** | Policy, decrees, and institutions | 8.1 | 4 | 5 |

Moreover, an optional sub-question follows, which asks the participants if there should be extra criteria for both objectives, after which they must distribute the 10 points among them with the previously given criteria. Of the 5 participants that suggested some other criteria, four of them had more than 20 years of experience, which presents the importance of their suggestions as well as the enrichment it affords to the results. All their suggestions were previously considered and included as an indicator or as a part of an indicator. Therefore, these suggestions weren't valid to be used as criteria for the objectives. All the suggested criteria can be seen in Table 14, with further discussion for every suggestion.

Table 14: Suggested criteria

| No. | Suggested criteria | Discussion |
|---|---|---|
| **Under the First objective: Reduce the risk of sewerage failure** | | |
| 1 | Illegal discharges | It is considered as a part of indicator A4 which is the missuses of sewerage by the users. |
| 2 | Illegal connections | It is considered as a part of indicator A5 which is the vandalism of the sewerage system. |
| 3 | Inflow quantity more than the Design Flow | It is considered as a part of indicator A1 which is the projected population that is responsible to calculate the potential inflow quantity and based on it, the design is done. |
| **Under the Second objective: Contribute to the sustainable development of wastewater collection system** | | |
| 1 | Effective Implementation of the policy & decrees | The effectiveness of the implementation of policy and decrees falls under indicator F2, which is the national master plan, its comprehensive and the in line with it. |
| 2 | Performance of the Institution | The performance of an Institution is a very broad criterion, their performance in the shade of sustainability is already considered within several indicators: B4, B5, B6, C7, D1, D2, D3, D4, D5, F2 and F3. Namely, availability of qualified staff, communication with internal sectors, public health and safety, sewage flooding, satisfaction of the stakeholders, etc. |
| 3 | Reuse of the treated effluent/ sludge | This an important indicator for the sustainability of the sewage system, but it's not applicable to this research, which focuses on the sewerage system from the point of production to the point of treatment. |

### 5.3.3 Indicators

This section presents the sustainability indicators, divided under the criteria within the two objectives of the sustainability assessment framework. As the participant were asked to evaluate the importance of each indicator regarding the performance of the project throughout the different stages of the project. It was clarified that each indicator could appear in a different project stage with a different importance score and is possible to evaluate, column-wise, by focusing on each stage of the project by filling in all the scores of the indicators for this particular stage. The scale that has been used is a scale of 1–5 (1 = Not relevant; 2 = Less important; 3 = Neutral; 4 = Important; 5 = Very important). The following Table 15 represent the mean of the given weightage of all the indicators for every sustainability criterion under the first objective: Reduce the risk of sewerage failure.

Table 15: The weightage of all indicators under the first objective

| Sl. | Sustainability Criteria and Indicators | Description | Major stages of project | | | |
|---|---|---|---|---|---|---|
| | | | Planning and Design | Commissioning (Post-construction) | Operation and Maintenance | Modification / Upgrading |
| **Objective 1: Reduce the risk of sewerage failure / increase the reliability of the sewerage system** | | | | | | |
| **A** | **Strategic technical aspects** | | | | | |
| **A1** | Planned preventive maintenance (PPM) | Perform maintenance for pipes and pumping stations as per the PPM | 2.69 | 2.39 | 4.62 | 2.87 |
| **A2** | Technologies | Keep up with the use of new technologies that contribute to reducing the risk of failure (e.g., software, new construction and maintenance tools) | 4 | 3.17 | 4.04 | 3.56 |
| **A3** | National Master Plan for Sanitary Engineering Services (NMPSES) | Comply with NMPSES | 4.43 | 3.1 | 3.33 | 4.04 |
| **A4** | Availability of qualified staff | The presence of qualified, well-trained and specialized staff | 4.1 | 4 | 4.3 | 3.87 |
| **A5** | Communication with other internal (within the Ministry) sectors | Efficient communication with other internal sectors on the interest of the projects | 4.30 | 3.65 | 3.71 | 3.65 |
| **A6** | Communication with other external sectors | Efficient communication with other external sectors on the interest of the projects | 4.48 | 3.65 | 3.79 | 3.52 |
| **A7** | Pumping station reductions | Minor pumping stations and major pumping stations to be eliminated, if any | 4.43 | 2.7 | 3.5 | 4.1 |
| **A8** | Intermediate pumping stations planned to be implemented | New intermediate pumping stations that are planned to be implemented | 3.96 | 3 | 3.21 | 3.35 |
| **A9** | Pipeline rehabilitation/upgrading | The need for rehabilitation or upgrading compared with the essential plans—for example, replacing a damaged pipeline that didn't finish its planned horizon | 3.52 | 3.1 | 3.79 | 4 |
| **B** | **Sewage flow characteristics** | | | | | |

| Sl. | Sustainability Criteria and Indicators | Description | Major stages of project | | | |
|---|---|---|---|---|---|---|
| | | | Planning and Design | Commissioning (Post-construction) | Operation and Maintenance | Modification / Upgrading |
| **B1** | Projected population | The extent of accurate data from concerned authorities over time—for example, the contradiction of the predicted population with the existing population due to changes performed on land zoning in the project area | 4.26 | 2.17 | 2.83 | 3.13 |
| **B2** | Planning horizon | The estimated period in which the network is designed to function efficiently compared with the actual period | 4.52 | 2.35 | 2.87 | 2.87 |
| **B3** | High infiltration/inflow | The high levels of infiltration from groundwater and inflow from rainwater, manhole covers, yard drains, catch basins and other sources | 4.13 | 3.26 | 4 | 3.04 |
| **B4** | Missuses of sewerage by the users | The use of the sewerage system to discharge storm water, open manholes or dispose of fats, oils and grease | 2.65 | 2.61 | 4.42 | 3.17 |
| **B5** | The intentional vandalism of the sewerage system | The contribution to disabling the sewerage system, whether directly or around the project area, such as difficulty accessing some areas for scheduled work | 2.91 | 2.78 | 3.87 | 3.3 |

Further, it was followed by an optional sub-question is that asks the participants if there should be other indicators under these criterions of the first objective. One of the participants suggested two additional indicators to be included under the strategic technical aspect. Both suggestions were previously considered and included as a part of an indicator. The discussion of every suggestion with the suggested indicators can be seen in the following Table 16.

Table 16: The weightage of the suggested indicators

| Sl. | Sustainability Criteria and Indicators | Discussion | Major stages of project | | | |
|---|---|---|---|---|---|---|
| | | | Planning and Design | Commissioning (Post-construction) | Operation and Maintenance | Modification / Upgrading |
| **Objective 1: Reduce the risk of sewerage failure / increase the reliability of the sewerage system** | | | | | | |
| **A** | **Strategic technical aspects** | | | | | |
| **A10** | Assets information systems | This indicator is covered under B2, which are the technologies by mean. Keeping up with the use of new technologies that would contribute reducing the risk of failure and eventually having a more sustainable sewerage system | 5 | 3 | 5 | 5 |
| **A11** | Availability and accuracy of existing assets data | It's an important major indicator that is hard to be assessed and managed properly, however it's related to all the indicators as without an accurate reliable data the conclusion will then be ink on papers. | 5 | 5 | 5 | 5 |

The following Table 17 represent the mean of the given weightage of all the indicators for every sustainability criteria under the second objective: Contribute to the sustainable development of wastewater collection system.

Table 17: The weightage of all indicators under the second objective

| Sl. | Sustainability Criteria and Indicators | Description | Major stages of project | | | |
|---|---|---|---|---|---|---|
| | | | Planning and Design | Commissioning (Post-construction) | Maintenance and Operation | Modification / Upgrading |
| **Objective 2: Contribute to the sustainable development of wastewater collection system** | | | | | | |
| **C** | **Economic aspects** | | | | | |
| **C1** | Project capital cost | The total cost of implementing the project | 4.34 | 3.35 | 3.54 | 3.61 |
| **C2** | Operation and maintenance cost | The total cost through the operation and maintenance based on the estimated planning horizon | 4.22 | 2.83 | 4.46 | 3.26 |

| Sl. | Sustainability Criteria and Indicators | Description | Major stages of project: Planning and Design | Commissioning (Post-construction) | Maintenance and Operation | Modification / Upgrading |
|---|---|---|---|---|---|---|
| C3 | Sewage treatment plant | The reduction of the wastewater treatment plant process by reducing the income flow (e.g., infiltration) | 3.96 | 2.78 | 4.25 | 3.74 |
| C4 | Health care | The saved expenses from health care services by preventing sewage diseases | 3.83 | 3.13 | 4.12 | 3.52 |
| C5 | Reduction of pumping station | Operation and maintenance cost of pumping stations that could be eliminated | 4 | 2.69 | 3.79 | 3.56 |
| C6 | Replacement of pipelines | The pipelines that need to be replaced before their planning horizon ends | 4.04 | 3.26 | 3.62 | 3.82 |
| C7 | Replacement of pumping station | The pumping stations that need to be replaced before their planning horizon ends | 3.87 | 3 | 3.79 | 3.43 |
| C8 | Consequence caused by the absence of service corridor | Modifications to the scope of work due to the absence of a corridor in the project area | 4.65 | 3 | 2.75 | 3.34 |
| C9 | Served industrial areas | Industrial areas that will benefit from the project | 4.1 | 2.61 | 3.04 | 3.35 |
| C10 | Land value | Value of properties affected by the sewerage issues such as flooding and gasses | 4 | 2.87 | 3.46 | 3.3 |
| **D** | **Social aspects** | | | | | |
| D1 | Public health and safety | The protection of the public from possible sewage-borne diseases, the likelihood of road collapses, etc. in the project area | 3.91 | 3.69 | 4.41 | 4.04 |
| D2 | Satisfaction of the stakeholders | The reported complaints within the sewerage project area compared with contributions to reduce the complaints | 4.04 | 3.35 | 4.29 | 4 |
| D3 | Served occupants | The served occupants by the project compared with the total occupants that required sewer service | 4.35 | 3.13 | 3.5 | 3.65 |

| Sl. | Sustainability Criteria and Indicators | Description | Major stages of project | | | |
|---|---|---|---|---|---|---|
| | | | Planning and Design | Commissioning (Post-construction) | Maintenance and Operation | Modification / Upgrading |
| **D4** | Local economic development activities | Provision of sewer services to local business activities such as malls and commercial real estate | 4.30 | 2.65 | 3.29 | 3.56 |
| **D5** | Served critical infrastructures and facilities | Facilities and infrastructures (e.g., hospitals, educational institutions, airports, police and military installations and community facilities) that will maintain service from the project | 4.43 | 2.78 | 3.83 | 3.69 |
| **D6** | Public awareness | The extent of public awareness concerning the consequences of misusing the sewerage system (e.g., opening manholes or disposing of fats, oils and grease) | 3.69 | 3.43 | 4.12 | 3.74 |
| **E** | **Environmental aspects** | | | | | |
| **E1** | Aquifer pollution | Wastewater generated from unsewered facilities (septic tank) and leaked from damaged pipelines, resulting in sewage seepage into an underground aquifer | 3.91 | 3.52 | 4.29 | 3.74 |
| **E2** | Odour air pollution | The generation of odour from the sewer network (e.g., septic tank, pumping stations and manholes) | 3.87 | 2.95 | 4.17 | 3.83 |
| **E3** | Losses of resources (groundwater) | The amount of groundwater that reaches the sewage treatment plants | 3.69 | 2.61 | 3.75 | 3.43 |
| **E4** | Pumping station energy | Increment/decrement of energy consumption from the pumping station | 4 | 2.74 | 4.04 | 3.95 |
| **E5** | Land used for the sewerage projects | Construction activities causing noise, dust, gasses, dewatering or any construction waste that would disturb the environment in the surrounding areas | 4 | 3.3 | 2.79 | 3.22 |
| **E6** | Green technologies | Any green innovation that overlaps with sewerage projects that will end up saving energy, preventing pollution and recycling waste, such as a pumping station operating by means of solar panels, onsite septic systems and software | 4.48 | 3 | 3.5 | 3.96 |
| **E7** | Sewage flooding | Contribution in reducing the areas suffering from sewage overflow | 3.87 | 2.95 | 4.29 | 3.96 |

| Sl. | Sustainability Criteria and Indicators | Description | Major stages of project | | | |
|---|---|---|---|---|---|---|
| | | | Planning and Design | Commissioning (Post-construction) | Maintenance and Operation | Modification / Upgrading |
| **F** | **Policy, decrees, institutions, and strategic visions** | | | | | |
| **F1** | Strategic vision | Existence of comprehensively updated strategic vision for sewerage networks | 4.52 | 2.91 | 3.41 | 3.96 |
| **F2** | NMPSES | Existence of an updated master plan in line with the country's strategic vision prepared by the authority responsible for providing sewerage services | 4.52 | 2.96 | 3.42 | 3.91 |
| **F3** | Community participation | Involvement of the public in the decision-making process | 4.09 | 2.87 | 3.16 | 3.09 |
| **F4** | Local consultants | Engagement of local consultants in the project | 4.22 | 3.30 | 3.33 | 3.39 |
| **F5** | Local contractors | Engagement of local contractors in the project | 3.61 | 3.48 | 3.79 | 3.43 |
| **F6** | Service fees | Adoption of service fees or taxes policies | 3.52 | 3.39 | 3.75 | 3.39 |

Further, an optional sub-question was employed, which asks the participants if there should be extra indicators for the second objective, and there weren't any suggestions. During analysis of this section, there was some consideration of the likelihood of falling prey to the tendency toward giving the weightage due to the participants' backgrounds (years of experience, field of expertise, qualification and the role participants presents). Of the thirty-four participants, one participant, who was expert in operating and maintaining the sewerage has claimed that he was not aware of some of the indicators as these indicators were out of their field of expertise, and only the weightage, regarding the operation and maintenance stage, was considered. Notably, the contractors and consultants have supported the two main indicators directly focused on their engagement with projects, which is indicator F4 and indicator F5, as they gave them a high weightage which lastly tend into their interest. Except for the previous observations, undoubtedly there was a harmony reflected into the answers, notwithstanding the background differences among the sample, which in turn it shows as having a dependable and non-biased response.

### 5.3.4 Sewerage Project's Sustainability Overview

This section contains seven open-ended questions, and captures the participants' point of view on whether the sewerage system in Bahrain is sustainable, consideration of sustainability in the projects, sufficiency in terms of sustainability issues, currently used methods or tools, implementation of sustainability, and, finally, whether there are any further suggestions.

The following are the questions that were answered:

Figure 16 presents the answers to the first question in this part, as it was a straightforward question whether the sewerage system in Bahrain is sustainable in all of its aspects (i.e., economic, environmental, and social) or not. This straightforward question was intended to capture the extent of the sustainability of the sewerage system in Bahrain, from participants who were involved in all stages of the system. The results show that 40 % of the participants tend to indicate that the sewerage system in Bahrain is not sustainable, while 24 % expect that, with increasing effort, it will be able to move toward sustainability. On the other hand, 60 % stated that the sewerage system is sustainable, while 40 % acknowledged that it requires more effort to remain sustainable. Meanwhile, only 20 % firmly stated that it is sustainable. Most participants, 64%, believe that the system needs more effort. This shows that sustainability in Bahrain is a relatively new concept, which still needs more time and effort to mature.

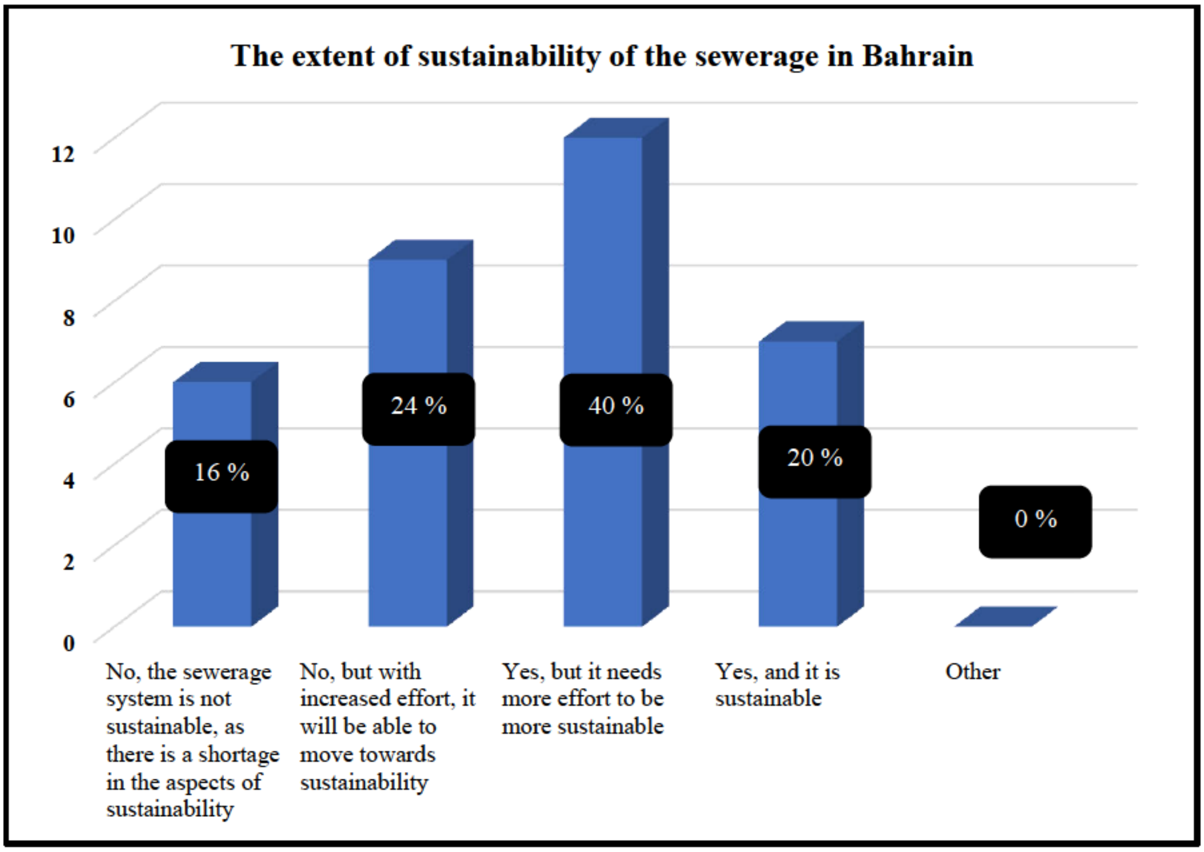



Figure 16: The participants' response to the first question

After that, Figure 17 illustrates the responds to the second question of whether the participant's organization consider having a sustainable sewerage system a top priority for decision-making or not. This question relates to awareness of whether their organizations have considered a sustainability approachin the context of the management of the sewerage system. Most of the participants, about 85 % of so, have announced that their organizations considered the sustainability while managing the sewerage system. However, 47% of them claimed that the sustainability was not properly implemented or that it was just in the early implementation stage. Knowing these facts justify the needs of assessing the sustainability of the sewerage infrastructure projects, and that to ensure the possibility of having sustainable sewerage system. Moreover, it shows that most experts are aware of the importance of sustainability.

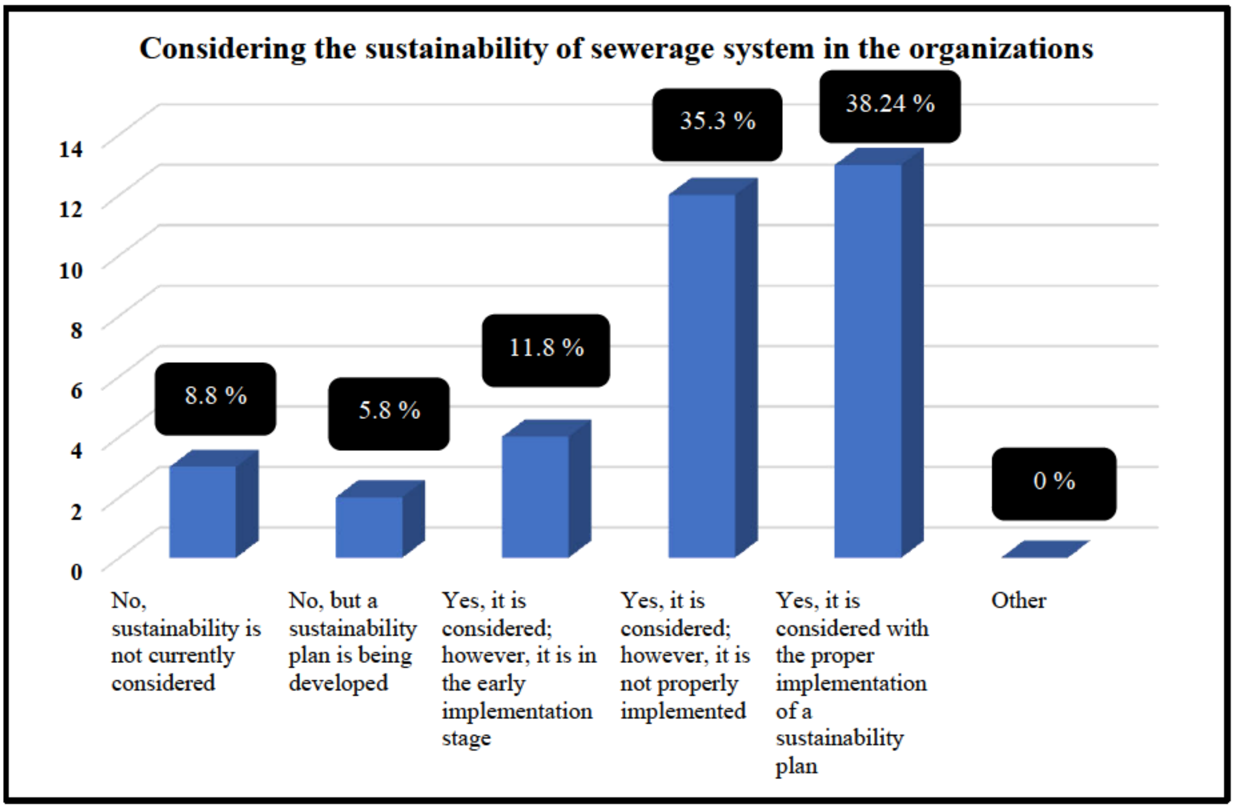



Figure 17: The participants' response to the second question

Figure 18 present the third question, which asks whether the sewerage system in Bahrain is sufficient in terms of sustainability issues (e.g., high infiltration, sewage overflows, exfiltration to underground water, financial crises, electricity issues, etc.) or not. This question was intended to determine whether there was a discrepancy between the answers. This question is similar to the first question but was constructed differently. By virtue of the results to this question, it is clear that there was little discrepancy between the answers, as 38 % of participants tended to say that the sewerage system in Bahrain will not be able to sustain these kinds of issues; while, 62 % of participants claimed that it will sustain these kinds of issues. Although 70 % stated that it will require effort to be more sustainable, 6% stated that the system will not sustain these kinds of issues. This figure is less than that of the first question by 10%. The reason for such discrepancy seems from the fact that this answer has a stronger language (No, the sewerage system is/will not be able to sustain these kinds of issues) as compared to the first question (No, the sewerage system is not sustainable, as there is a shortage in the aspects of sustainability). It implies that a higher percentage of experts believe that with more effort a sustainable system is achievable.

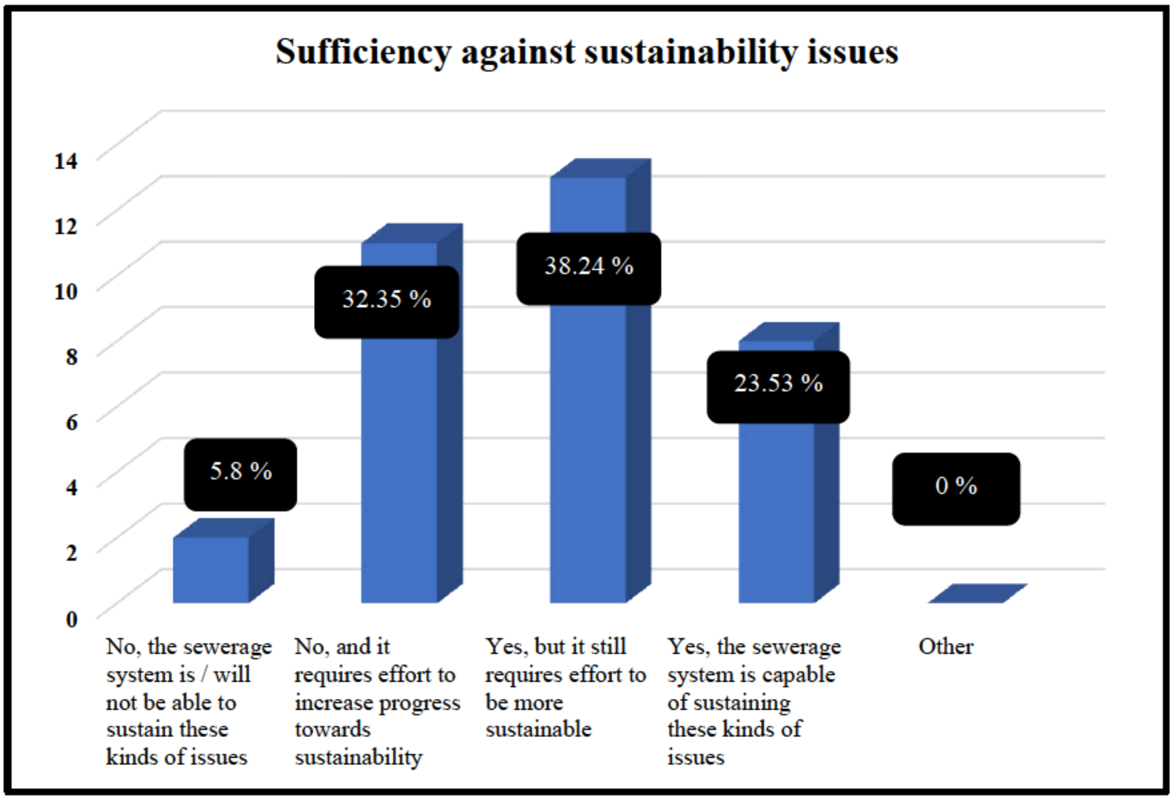



Figure 18: The participants' response to the third question

As can be seen in Figure 19, the fourth question enquire the extent to which the participant's organization follow any methods or tools (e.g., environmental impact assessments (EIA), social impact assessment (SIA), life-cycle cost analysis, and business scorecards) in managing the sustainability issues facing the current network, while 35 % of participants claimed that there were not methods or tools to manage sustainability issues that face the current network, 65 % claimed that they were using such methods and tools. The contradictions so raised were due to the different point of view in the range of dealing with these issues, moreover some of these methods were used in a certain stage of the sewerage project and they could be not aware of the existence of these methods.

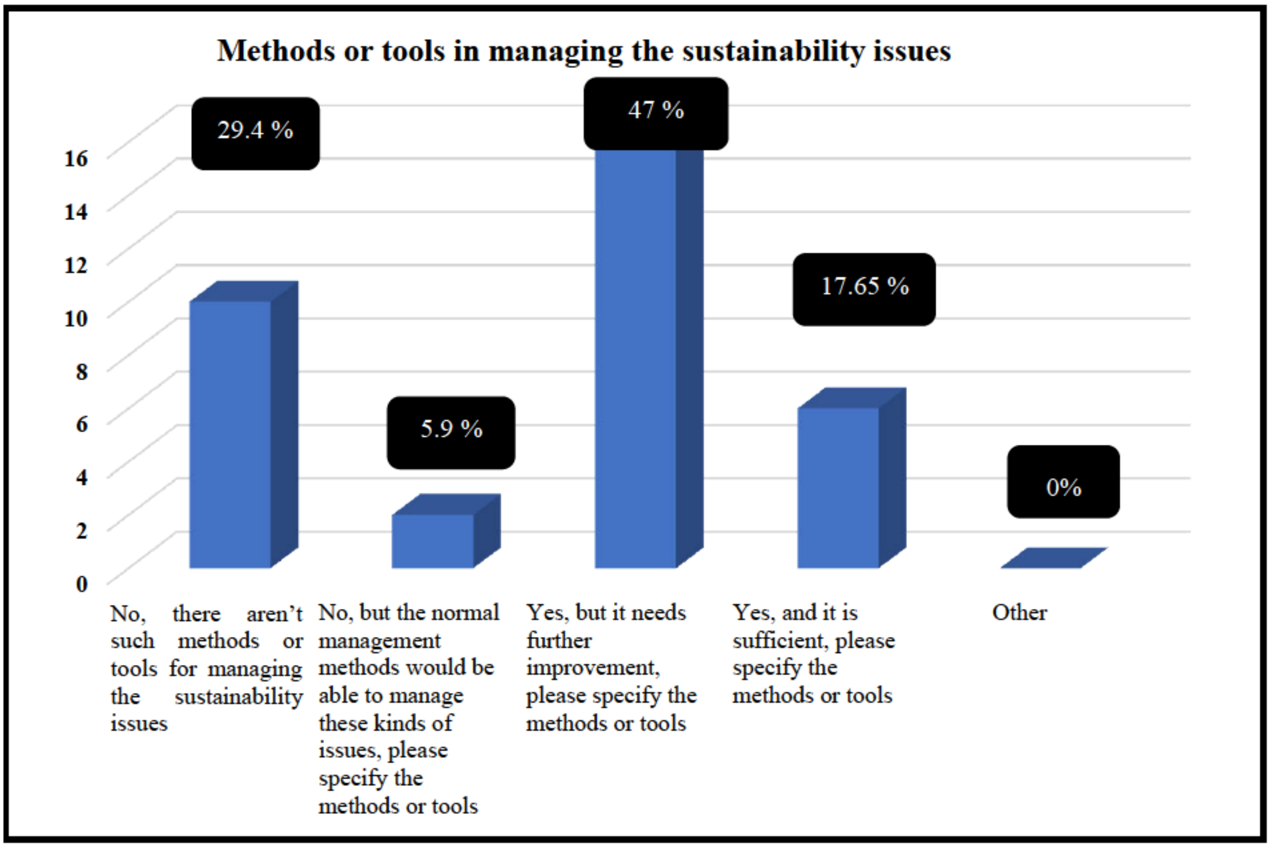



Figure 19: The participants' response to the fourth question

Furthermore, an optional sub-question asked to the participants to specify those methods and tools that they used to face the sustainability issues; the answers can be found in Table 18.

Table 18: Methods and tools used in the management of the sewerage system

| **Methods and tools used in managing the sewerage system in Bahrain** |
|---|
| Environmental impact assessments (EIA), life-cycle cost analysis (LCCA), social impact assessment, hydraulic modelling, balanced scorecard |

The following Figure 20 presents the answers to the fifth question which asks about the stage that sustainability should be implemented in the sewerage sector according to the participant's opinion. The majority of participants (73%) were aware that sustainability should be implemented in all the stages of the project, but 27 % claimed that it should only be implemented at a certain stage. This also shows the experts' awareness of the high importance of sustainability.

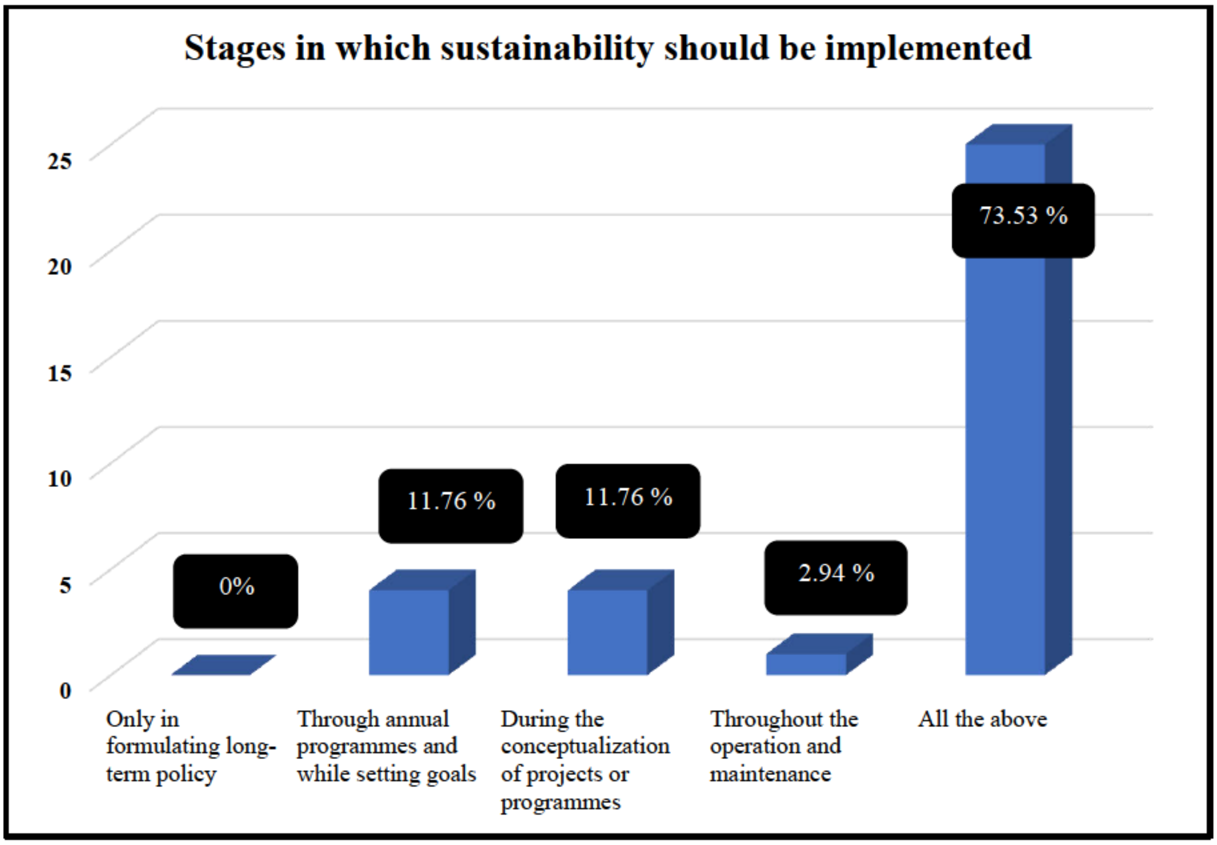



Figure 20: The participants' response to the fifth question

And finally, the last question was an optional question, and it asked the participants to provide further suggestions for improving the sustainability of sewerage projects. One of the 34 participants suggested that, "A separate unit is needed to monitor and implement the sustainability aspects of the sewerage projects in the Ministry of Works," and this suggestion reflects the importance of understanding sustainability in the context of analysing some parts of the survey where it was clear that the engineers lacked a comprehensive conception of sustainability.

## 5.4 Chapter Summery

This chapter described the verification stage of the survey, which relied on a pre-survey pilot study, followed by a data collection stage that further clarifies the motivation behind the survey questions and, finally, a detailed data analysis of the responses.

# Chapter 6: Case Study of Sewerage Infrastructure Projects

This chapter discusses the three case studies that have been chosen for this research, it presents an overview of each case, objectives, cost, benefits, risks, outcomes, the projects activities, the followed policies and guidelines; these cases will then be used in the implementation of the developed sustainability assessment framework in the following chapter to demonstrate how the framework can be applied.

## 6.1 Preliminary Analysis of the Baseline Situation of the Three Case-Study Projects

Three projects located in Bahrain were chosen to be used as a case studies for this research. These projects vary through their locations, different stages, costs and values. The first project is a proposed deep-gravity sewer starting from Hamad Town and going along Sh. Khalifa Bin Salman Highway up to Tubli Wastewater and Pollution Treatment Centre. The second project is an existing deep-gravity sewer in Muharraq Island which is located in the north-east side of Bahrain. The third project is the sewer network in Madinat Khaifa which is a new proposed housing project located on the east cost of Bahrain. Locations of these projects can be seen on Figure 21.

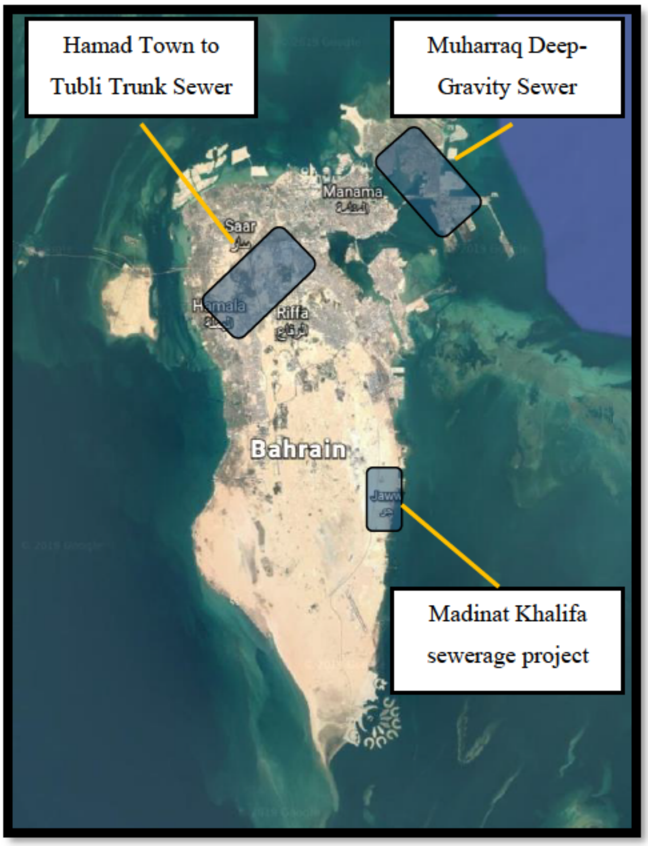



Figure 21: Locations of the three projects

The following is an overview of the three-case study including the projects objectives, finance, benefits, risks, outcomes, and the followed policies and guidelines.

## 6.2 Overview of Hamad Town to Tubli Trunk Sewer Project

The first project is an initiative proposed by the NMPSES 2009-2010, which is a deep-gravity sewer with a lift station (sewage pumping station). The sewer trunk starts from Hamad Town, in line with Zeid Bin Omera Highway until the intersection with Wali Al Ahed Highway then it will continue heading east along Sh with an approximate total length of 13.7 km. Khalifa Bin Salman Highway toward Tubli Wastewater and Pollution Treatment Centre as it can be seen in Figure 22. Moreover, there were some scenarios for the sewer route as can be seen in Figure 23.

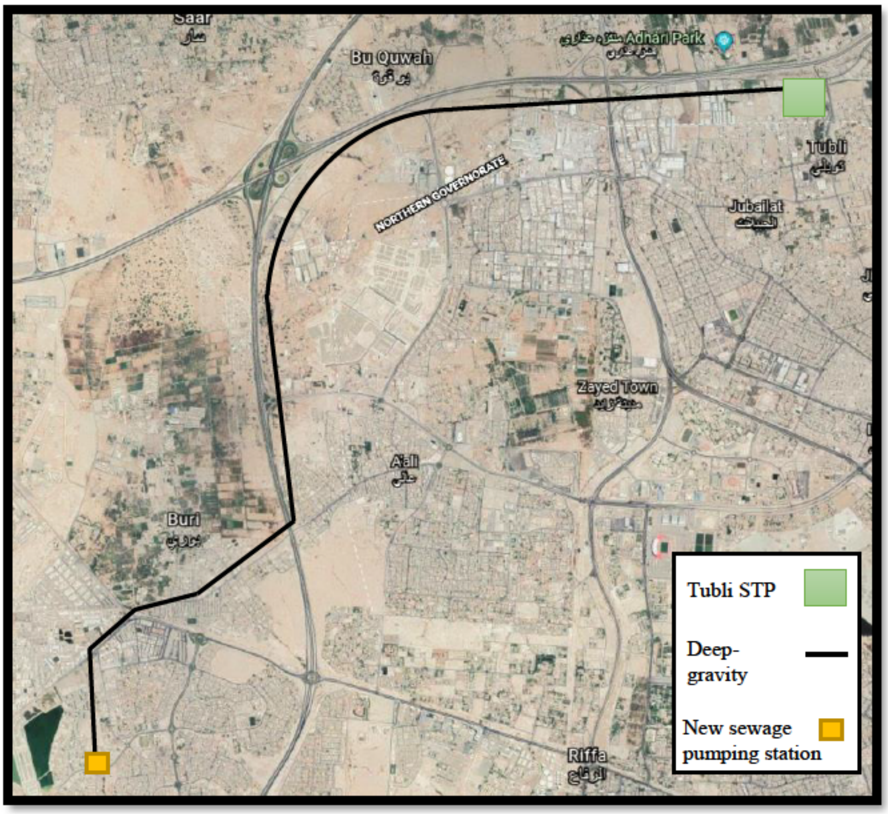



Figure 22: Hamad town trunk sewer project location

This project would serve the people in Hamad town and some surrounded areas. The project population that the proposed sewer lines would serve are presented in Table 19.

Table 19: Predicted sewage flows form Hamad town to Tubli

| Year | 2008 | 2013 | 2020 | 2030 |
|---|---|---|---|---|
| Population | 276,464 | 419,487 | 500,052 | 566,447 |
| Flow Estimation $m^3$/day | Not Available | 113,026 | 132,204 | 148,106 |

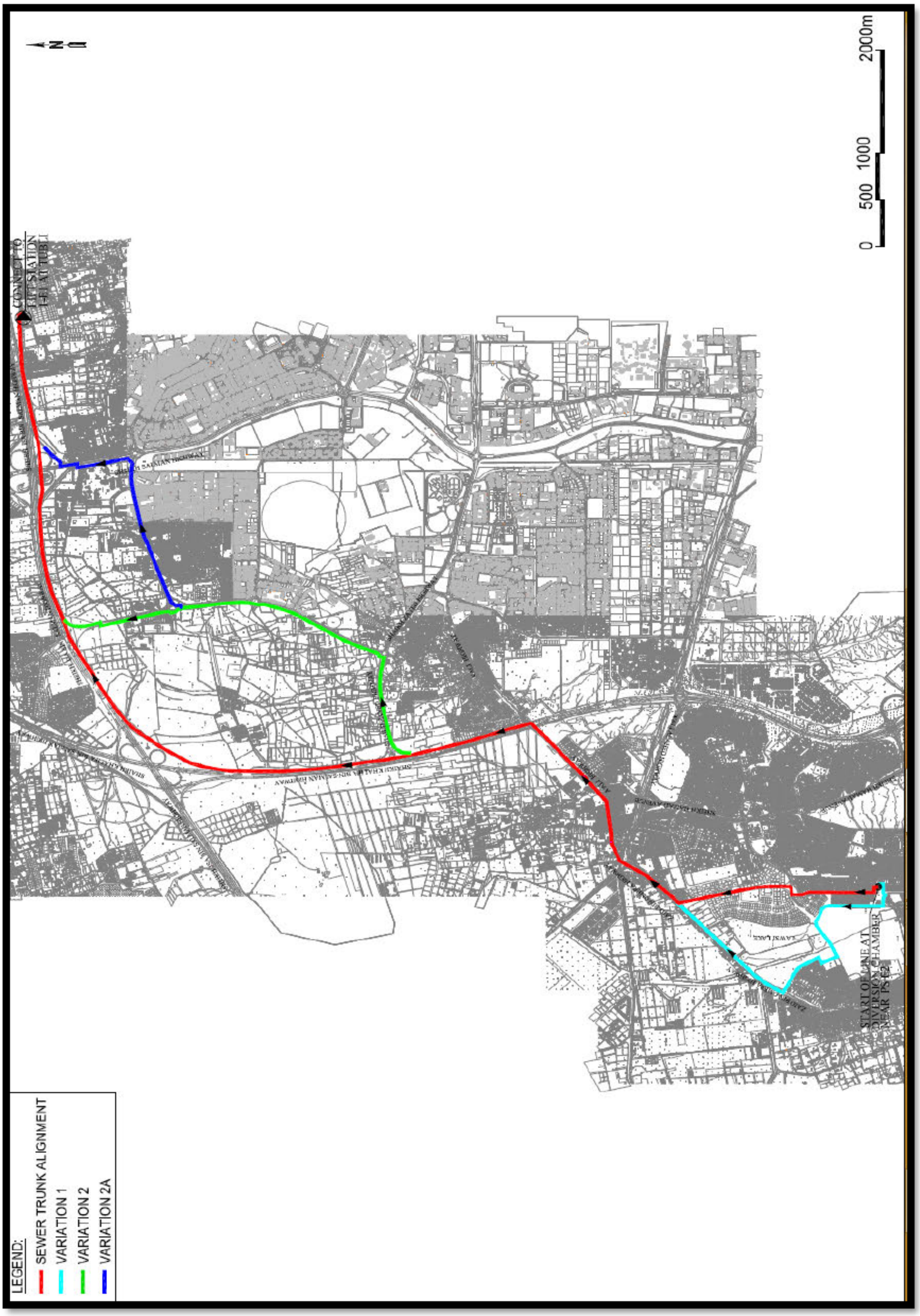



Figure 23: Hamad town to Tubli trunk sewer scenarios

### 6.2.1 Objectives, finance and benefits

The main objective of the project is to improve the sewerage network by relieving the hydraulic overloading conditions in Hamad Town and nearby cities. This will be done by constructing a new deep gravity sewer with a new sewage pumping station in which they contain the required capacity. This project will strive the abandon of a 34 years old major sewage pumping station that has a high risk of flooding. Moreover, it would include decommissioning several minor pumping stations that have a high risk of flooding. This project will also include serving new developed areas that weren't linked to the system previously.

The Preliminary cost estimation of the project was already done, but due to the statues of the project as it still didn't enter the contracting stage, the cost was considered as confidential information and it wasn't given to be discussed further in this research.

This project will surely benefit the tenants around the project area, as the operating and maintenance reports show that the current system is very loaded, dealing with a high rate of pumping breakdowns, occasionally the appearance of flooding as well as it has high infiltration rate. Therefore, it would improve the sewerage system in that area which in turn would preserve health, safety, and quality of life for the residents of that area.

### 6.2.2 Outcomes

The Hamad Town to Tubli Trunk Sewer is an upgrading project and currently in contextualising phase and is struggling with some allocating budget problems. Building this 13.7 km sewerage line with new lifting station will help increase the system's capacity and alleviate the current system's overloading conditions. Substantially, this project will accommodate more than 500,000 residents in Bahrain including the current residents that will be linked to the new sewerage system line and the future residents of the planned developments. Thus, it will help to reduce the risk of sewerage failure (odour, flooding, groundwater pollution and sewer backup), as well as it will maintain the health, safety and quality of life of the residents.

### 6.2.3 Risks of the sewerage system

The NMPSES 2009 suggested initiatives as immediate, short-term, mid-term and long-term measures, and this project were one of the urgent short-term initiatives that should be a priority project and implemented within the first four years of the plan. However, the project has not yet implemented and there is no definitive timetable for its future. In the meantime, there is a high risk of sewerage failure due to continuous occurring sewer flooding, odour, groundwater pollution in some areas in Hamad Town and nearby cities that negatively affecting the environment and the public health and safety (Materials Engineering Directorate, 2016; Ministry of works, 2009). Thus, the current sewerage system is considerably strained and willing to have solutions. The NMPSES 2009, suggested pursuing the strategy of rising the uses of deep gravity sewer while reducing the number of pumping stations. Therefore, this project was proposed in order to manage the threat of flooding, odour, high groundwater infiltration and groundwater contamination.

By implementing this project, it will increase the capacity of the system, reduce the number of pumping stations, serve new developments. Furthermore, this project will abandon one of the major pumping stations that have high risks of failure and odour issues and will also construct a new pumping station in a better location. Meanwhile, eight other pumping stations were planned to be decommissioned along the entire sewer line. Overall, the project will help mitigating the likelihood of sewerage failure (such as flooding, odour and sewer backup), it will also reduce energy consumption during service. In addition, the project will contribute to the delivery of fresher sewage to the wastewater treatment plant, which will make the treatment of wastewater easier.

### 6.2.4 Activities of the project

The project's scope of work is to construct a deep-gravity sewer from Hamad Town to Tubli Wastewater Pollution Control Centre, which includes constructing a new pumping station and decommissioning several pumping stations with high risk of flooding. In the meantime, this project has completed the planning and design phase and its currently on hold and will proceed to the next stages in order to be carried out after the budget allocation. Based on the data available, the activities that were completed and those that are to come were identified throughout the life cycle of the project starting from the current sewerage system, contextualising of the project, planning, designing, implementation, operation and maintenance and finishing up with the future prospects. These data include main activities that are needed to complete every particular stage, key focal points of that stage, parties concerned that are responsible for the activities, the outputs expected, target users for the outputs and finally the limitations of the activities in every stage as it can be seen in Table 20.

Table 20: Activities analysis of Hamad town trunk sewer project.

| No | Main Activities | Key focal points | Parties concerned | Outputs expected | Target users for outputs | Limitations of the activities |
|---|---|---|---|---|---|---|
| **Stage 1: sewerage system** | | | | | | |
| **1** | National master plan for sanitary engineering services (NMPSES-2009). | - The State of Foul Sewerage Systems (Existing sewerage network data such as Current physical condition and Current hydraulic capacity).<br>- The foul Sewerage Infrastructure future Scenarios.<br>- Scenario analysis (developing hydraulic network model, evaluate different options, implementation plans and cost analysis).<br>- Technologies review.<br>- Environmental considerations.<br>- The guidelines, specifications, standards and practices of the administration.<br>- Government laws, policies, regulations, strategies and plans. | - Ministry of Works with consultants support. | - Proposing action plane (Immediate, Short-Term, Mid-Term and Long-Term Measures).<br>- Performance measures.<br>- Determine approaches.<br>- Proposing initiatives such as the trunk sewer from Hamad Town to Tubli project as a short-term performance measure. | - Tenants of northern governorate.<br>- Sanitary engineering operation and maintenance directorate.<br>- Sanitary engineering planning and projects directorate.<br>- Researches and academics.<br>- The Ministry of Works, Municipalities Affairs and Urban Planning. | - Availability of land parcels were not considered.<br>- Preliminary route for the proposed Deep gravity sewer.<br>- No budget allocation plan.<br>- Population's projections are not accurate and Imprecision of land zoning maps. |
| **Stage 2: Contextualising of the project** | | | | | | |
| **1** | Ministry of Works' programme. | - Budget allocation of the Ministry of Works' programme for design, supervision and construction considering budget availability set by the Ministry of Finance and National Economy.<br>- Allocation of land parcels required for pump stations from Survey and Land Registration Bureau and Urban Planning and Development Authority.<br>- Compliance with the NMPSES, Government laws, policies, regulations, strategies and plans. | - Sanitary engineering affairs with consultancy services support. | - Sanitary Engineering Affairs Programme including Hamad town to Tubli trunk sewer project.<br>- Cost estimations.<br>- Project boundary. | - Tenants of northern governorate.<br>- Sanitary engineering operation and maintenance directorate.<br>- Sanitary engineering planning and projects directorate.<br>- Supreme Council for Environment.<br>- Researches and academics. | - Low accuracy of cost estimations.<br>- Budget wasn't allocated for this project.<br>- The database of other utilities is not accurate.<br>- Reliance on 2009 NMPSES Data, rather than tracking changes (such as land zoning classification, |
| **2** | Inception Report (February 2012). | - Project background data (project setting, existing situation) | | - Scoping of work. | | |

| No | Main Activities | Key focal points | Parties concerned | Outputs expected | Target users for outputs | Limitations of the activities |
|---|---|---|---|---|---|---|
| | | - Preliminary analysis (population, land use, wastewater flows, planning permits, as-built and pumping stations technical data).<br>- Site investigations (soil and geotechnical data, preliminary environmental impact assessment, etc.). | | - Concept design of the sewer trunk.<br>- Several possible alternatives for the trunk sewer. | | projected population, environmental issue). |
| **3** | Final conceptual design report (April 2012). | - Design basis (population, wastewater flows and catchment area).<br>- Design criteria and specifications.<br>- Conceptual design of gravity trunk (different alternatives of the trunk location).<br>- Planning geotechnical investigation program<br>- Hydraulic Analysis. | | | | |
| **4** | Environmental management plan (July 2012) | - Environmental policy and legislation (Compliance with supreme council for environment regulations, strategies, standards and plans).<br>- Preliminary Environmental Review (Land use and utilities, noise, air quality, roads, groundwater, archaeology and cultural heritage, aquatic ecology and socio economic etc).<br>- Preliminary review of environmental impacts (Environmental and social impact matrix, impact significance criteria, description of construction and operational impacts, and description of pumping station decommissioning impacts).<br>- Project Alternatives (Pipe material, construction methods, alternative locations of the new lift station and the alternative routes of the trunk sewers). | | - Elements of risk related to the environment.<br>- Environmental Mitigation Plan (pre-construction phase mitigation, construction phase mitigation and operational phase mitigation). | | |
| **Stage 3: Planning, Designing and Implementing the Project** | | | | | | |

| No | Main Activities | Key focal points | Parties concerned | Outputs expected | Target users for outputs | Limitations of the activities |
|---|---|---|---|---|---|---|
| 1 | • Funding application and Ministry of Finance and National Economy (future activity).<br>• Granting planning permission, wayleaves and all permits required for construction (2012).<br>• Hydraulic design report (June 2012). | - Finalizing annual funding and related formalities.<br>- Adjusting the new pipeline route and construction technologies.<br>- Availability land parcels and service corridors.<br>- Granting all required permits from other services and infrastructure entities to be affected by the project.<br>- Analysis of all design parameters such as flow, pipe size, material and slopes. | - Sanitary engineering affairs with consultancy services support.<br>- Funding by Ministry of Finance and National Economy. | - Budget allocation.<br>- Pipeline alignment and corridor allocation.<br>- land parcel allocation.<br>- Granted permits.<br>- Final Hydraulic Model Analysis of existing network to be used for the final design. | - Sanitary Engineering Affairs.<br>- Urban Planning and Development Affairs. | - Difficulties in allocating funding approvals from related government organizations.<br>- Lengthy procedures of granting approvals from related government organizations required corridors and land parcels needed for the project. |
| 2 | Preparation of final details design report (June 2012). | - Collecting information required for the design such as site levels, obstacles, and existing sewerage network conditions.<br>- Confirm where existing services are located.<br>- Collecting detailed information related to underground aquifer to avoid any damage to the environment to fulfil Agricultural Engineering and Water Resources Directorate environmental requirements.<br>- Collecting required geotechnical data.<br>- Trial holes investigation to allocate existing utilities.<br>- Performing quality assurance quality control (QA/QC) to ensure that the design meet the required standards. | - Sanitary Engineering Affairs with the help of Specialized subcontractors. | - Final Design Drawings and Report. (shows construction technologies such as open trenches or micro tunnelling).<br>- Constructability Report.<br>- General specifications (and specific specifications). | - Sanitary Engineering Affairs. | - Limited geotechnical investigation due to cost limitation.<br>- Accuracy of final details design is based on the available data and projections of future land uses and populations. |

| No | Main Activities | Key focal points | Parties concerned | Outputs expected | Target users for outputs | Limitations of the activities |
|---|---|---|---|---|---|---|
| **3** | Preparation of operation and maintenance philosophy and manuals. | - The detailed operation and maintenance manual including Planned Preventive Maintenance and emergency plans. | - Sanitary engineering affairs with consultancy services support. | - Operation and Maintenance Manual including Planned Preventive Maintenance plan. | - Sanitary Engineering Affairs. | - The Operation and Maintenance Manual can be modified depending on the outcome of the construction process (such as using different construction methods or materials). |
| **4** | Preparation of tender documents and agreements terms (2012) (future activity). | - Confirm that all tender documents (such as design drawing, bill of quantities and general specifications) and agreements are in accordance with local policies. | - Sanitary Engineering Affairs with consultancy services support.<br>- Tender Board. | - Contract awarding. | - Sanitary Engineering Affairs.<br>- Contractor. | - Lengthy procedures of granting approvals from related government organizations on the contract.<br>- Cost estimation could vary due to geotechnical limitation (unforeseen site conditions such as underground services, groundwater level and the underground geology). |
| **5** | The sewerage project implementation (future activity). | - Construction activities as per the design, specifications, construction method statement and QA/QC activates.<br>- Supervision on the awarded contractor during construction work. | - Sanitary engineering affairs with consultancy services support.<br>- Contractor. | - Constructed sewerage project.<br>- As built drawings.<br>- QA/QC report. | - Sanitary Engineering Affairs.<br>- Tenants of Hamad Town and nearby areas. | - Budget wasn't allocated for this project.<br>- Lack of technical capacity to supervise DGS construction projects. Therefore, |

| No | Main Activities | Key focal points | Parties concerned | Outputs expected | Target users for outputs | Limitations of the activities |
|---|---|---|---|---|---|---|
| | | | | | - Urban Planning and Development Authority.<br>- Supreme Council for Environment. | consultants need to be assigned for the supervision. |
| **Stage 4: Operation and maintenance (Future Activities)** | | | | | | |
| **1** | Operating the system. | - Operating the pumping stations as per the manuals. (such as adjusting the pumps pressure and reacting to electrical faults). | - Sanitary engineering affairs with possible contractor services support. | - Operation and Maintenance Reports.<br>- Recommendation to enhance the sewerage network. (such as upgrading or rehabilitation of sewerage system). | - Sanitary Engineering Affairs.<br>- Tenants of Hamad Town and nearby areas. | - Difficulties in performing comprehensive inspections (such as locating the external cracks) on all the pipeline lines and pumping stations.<br>- Limited CCTV due to its high cost. |
| **2** | Implementing planned preventive maintenance. | - Compliance with planned preventative maintenance through inspections. | | | | |
| **3** | Preparation of operation and maintenance monthly report. | - Sewerage networks Issues and Challenges Operation and Maintenance data (monitoring wastewater flow, health and safety, sewage influent quality, staff and resources, odour and noise, environmental impacts, and security).<br>- Reviewing and analysing the operation and maintenance data.<br>- CCTV inspections results. | | | | |
| **Stage 5: periodic assessment (Future Activities)** | | | | | | |
| **1** | Preparation for updating master plan. | - Incorporating changes in Government laws, policies, regulations, strategies and plans if any.<br>- Incorporating changes in landuse and economics activities, if any.<br>- Analysing possible failure issues.<br>- Updating the State of Foul Sewerage Systems (Existing sewerage network data such as Current physical condition and Current hydraulic capacity). | - Sanitary Engineering Affairs with possible consultancy services. | - Updated Master Plan.<br>- Recommendations to enhance the operation of the sewerage system. | - Sanitary Engineering Affairs.<br>- Tenants of the project area. | - Lack of expertise in the planning field. |

| No | Main Activities | Key focal points | Parties concerned | Outputs expected | Target users for outputs | Limitations of the activities |
|---|---|---|---|---|---|---|
| | | - Reviewing new technologies in the market, if any. | | | | |
| **Stage 6: Upgrading/ Modification (Future Activities)** | | | | | | |
| **1** | Upgrading or modification of the overall sewer network in the area. | - Ensure that all future flow changes are accommodated by upgrading / modifying the sewerage network and, if necessary, updating the master plan. | - Sanitary Engineering Affairs with possible consultancy services. | - Sewerage system improvement through new projects. | - Sanitary Engineering Affairs.<br>- Tenants of the project area. | - Uncertain budget availability.<br>- Uncertainty of the availability of materials (e.g. pipe liners, certain pumps). |

## 6.3 Overview of Muharraq Deep-Gravity Sewer project

The second project is located in the second largest island in the archipelago of the Kingdom of Bahrain which is in Muharraq Island. The population of this Island is around 200000 residence. The initiative for this project was a proposal by NMPSES 2009, and it will serve the entire governorate of Muharraq, one of the four governorates in Bahrain. This project consists of constructing sewerage conveyance system, which consists of a main sewerage pipeline (deep gravity sewer) (main collection tunnel) and lateral connection. The depths of the pipelines range between 5 and 15 meters, and details of the project pipelines dimensions can be seen in Table 21. This project considered as the first of its kind in Bahrain as the deep gravity sewer did not existed before this project. This project will convey the sewage from the existed sewerage networks to the treatment plant and that through building a deep gravity sewer including the lateral connection as well as an intermediate lifting station that would finally convey the sewage to the treatment plant. It is worth mentioning that this project consists of building a Sewage Treatment Plant which will not be discussed in detail as it's out of the research context. The project area is shown on Figure 24.

Table 21: Muharraq deep-gravity sewer pipelines

| No. | Material | Diameter (mm) | Length (km) |
|---|---|---|---|
| 1 | polymer-reinforced concrete | 1000 | 1.5 |
| 2 | polymer-reinforced concrete | 1400 | 5.3 |
| 3 | polymer-reinforced concrete | 1800 | 9.7 |

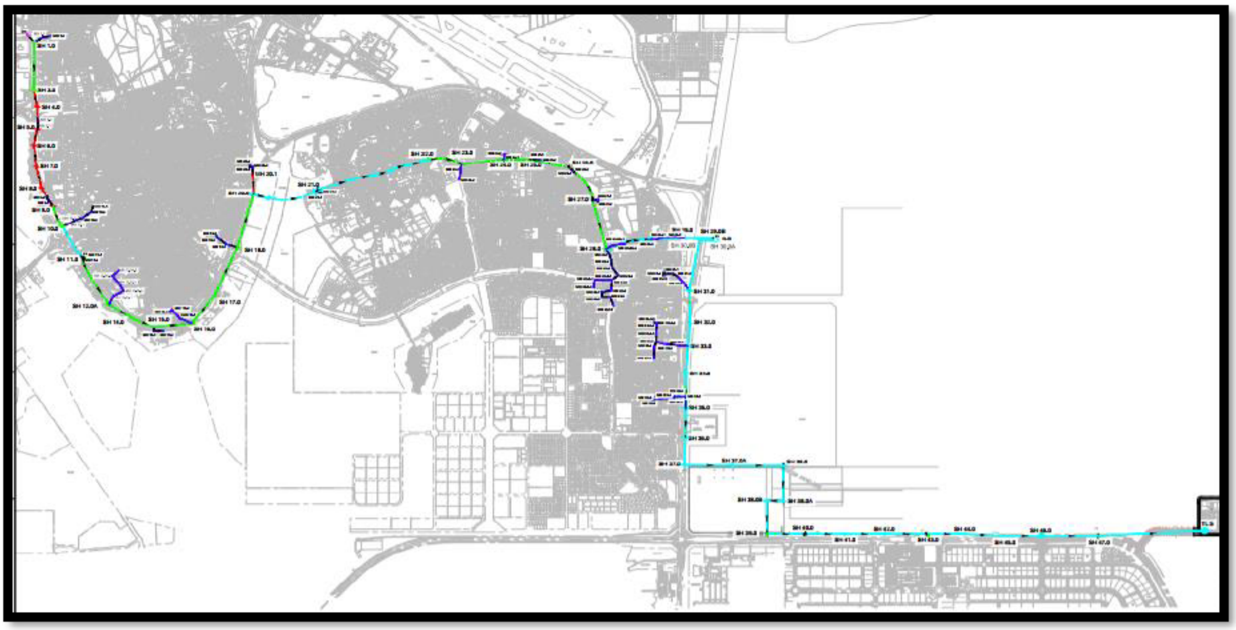


Figure 24: Muharraq deep-gravity sewer project location

### 6.3.1 Objectives, finance and benefits

This strategic project aim was to improve the sewer network while serving the growing demands by the major developments in Muharraq Island such as Diyar Al Muharraq, East Hidd Housing Project, Dilmunia, Investment Gateway Bahrain, Al Saya, historical buildings and the Airport Extension. Furthermore, the system consisted of 78 minor pumping stations and two major pumping stations, and by building this project it had eliminated two major pumping stations and 22 minor stations. Thus, it contributed in reducing the risk of sewerage failure (odour, flooding and sewers backing up), as well as reduction the uses of energy in the sewerage system operation and it also eliminated the cause of traffic disruption during the maintenance process.

According to the information collected from Sanitary Engineering Affairs, the total flow expected to be conveyed by the pipelines can reach approximately 118,000 m3/day by 2030.while the current sewage treatment plant (STP) capacity is 100,000 m3/day. Therefore, the Ministry of Works plans to expand the STP to receive the expected flow in two phases. The first phase will expand the plant to 130,000 m3/day, and the second phase will expand it to 160,000 m3/day. Figure 25 shows information of the predicted sewage flows from Muharraq.

The project financed by the government of Bahrain represented by the ministry of works municipalities affairs and urban planning; and ministry of finance and national economy. The cost of the project was 325 million American dollar and that including the STP and DGS. This project was under BOOT contract form, which is building, own, operate and then transfer to ministry of works within 27 years.

The deep gravity sewer was designed to operate for 80 years, it has promoted the infrastructure of Muharraq Island by upgrading the main sewerage line of the island. Therefore, it has served the tenants and the new developments on the island. Furthermore, it has also improved the system's capacity to reduce the risk of sewerage failures (such as odour and sewage flooding issues) while maintaining the safety, health and quality of life of the residents of the Muharraq Island.

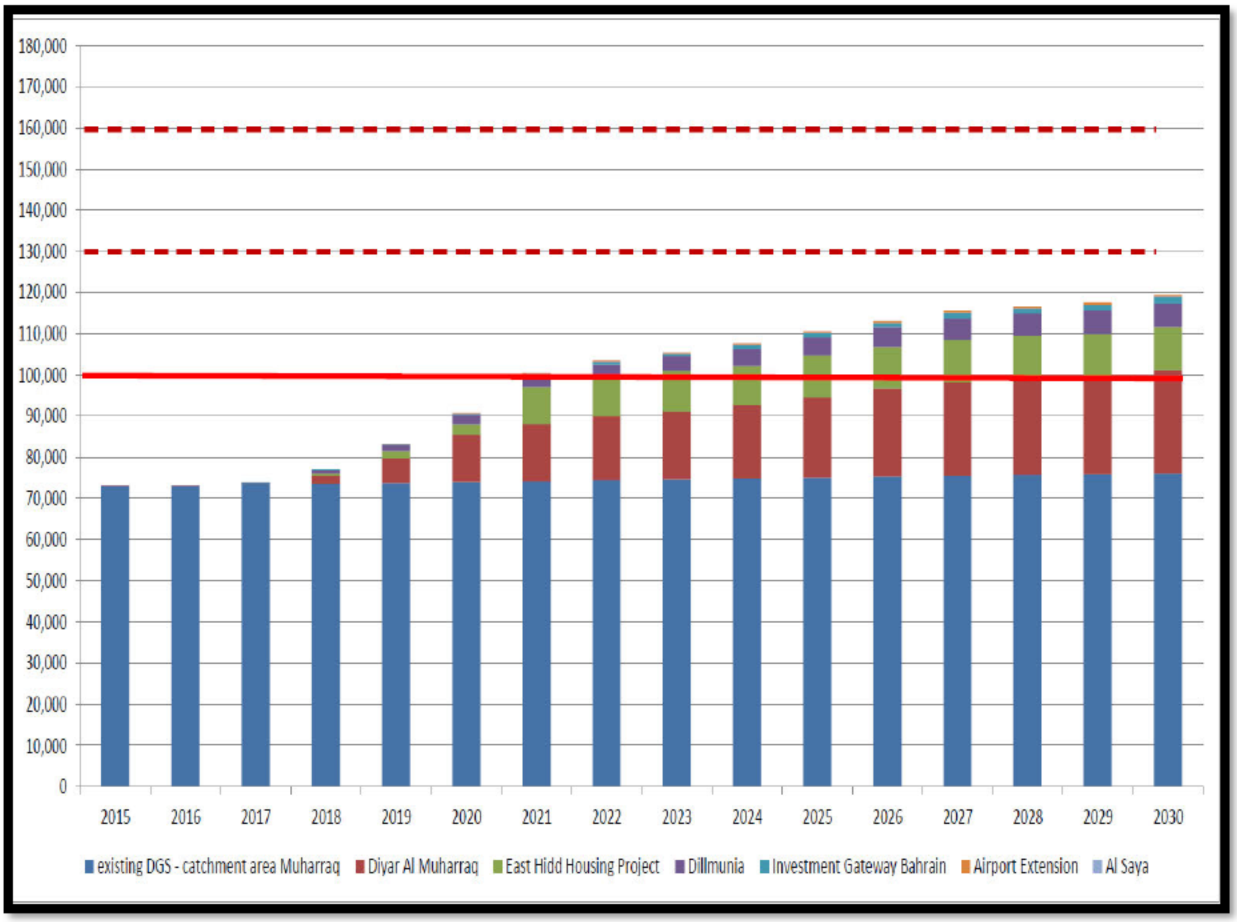



Figure 25: Predicted sewage flows from Muharraq (2015-2030)

### 6.3.2 Outcomes

The project was completed on 30 June 2014. The project improved the sewer network in Muharraq by adding more capacity to the network to allow more areas to be connected to the network. Moreover, it implemented a deep-gravity sewer using micro-tunnelling technology which was the first of its kind in Bahrain. Furthermore, by executing this DGS project, Bahrain has recorded the achievement of constructing the longest multi curvature micro tunnelling drive in the middle east at the time of implementing this project with a total length of 955 m. Also, Bahrain has recorded another achievement for the longest Sea Crossing with a total length of 892 m (Keong and Cheng, 2014). Moreover, the project life span is 80 years and currently the project is owned and operated by a private company for 27 years as agreed by the contract. After that, it would be transferred to the Ministry of Works to continue operating the system for the rest of its life span.

### 6.3.3 Risks of the sewerage system

The NMPSES 2009-2010 pointed out that the sewerage system is significantly overloaded and it will be overwhelmed in the near future which will affect the environment and public health and safety. Therefore, in order to manage the risks of surface flooding, odour and high rate of groundwater infiltration, it was recommended to follow the approach of increasing the uses of gravity sewer while limit the number of pumping stations to a minimum. Moreover, the NMPSES have proposed immediate, short-term, mid-term and long-term measures and this project was one of the short-term measures.

Through the implementation of this project, upgrades to the sewerage system increased its capacity and served many new development areas on Muharraq Island such as Dilmunia, East Hidd Housing Project, Diyar Al Muharraq, Investment Gateway Bahrain. Moreover, it has reduced the risk of flooding associated with certain pumping stations. In which 22 minor stations and two major pumping station were decommissioned along the sewer, and this is complying with the suggested approach of the NMPSES. Thus, it aided in contributing of minimizing the risk of sewerage failure (such as flooding, odour and sewers backing up), it also reduced usages of energy during the operation and the maintenance process and greatly minimized the impact of causing traffic disturbance in the project area. Further, the project contributed in delivering fresher sewage for the sewage treatment plant, which made the wastewater treatment easier.

### 6.3.4 Activities of the project

In order to execute this project, it went through many different stages represented as project activities. The existing data of the activities which reflects the execution and operation of the project were utilized to present the inventories throughout its life cycle. And that’s includes the inspiration of the project starting from the NMPSES, contextualising the project, planning, designing, implementing, passing through the operation and maintenance and ending with the future possibilities. The following Table 22 represent the main activities required to complete every particular stage, key focal points of that stage, parties concerned that are responsible for the activities, expected outputs, target users for the outputs and finally the limitations of the activities in every stage.

Table 22: Activities analysis of Muharraq deep-gravity sewer project

| No | Main Activities | Key focal points | Parties concerned | Outputs expected | Target users for outputs | Limitations of the activities |
|---|---|---|---|---|---|---|
| **Stage 1: sewerage system** | | | | | | |
| 1 | National master plan for sanitary engineering services (NMPSES-2009). | - Condition of Foul Sewerage Systems (the Existed data on sewerage networks such as Current physical state and Current hydraulic capacity).<br>- Scenario analysis (by developing hydraulic network model, assess different options, implementation plans and cost analysis).<br>- Review various technologies.<br>- The Environmental considerations.<br>- The management guidelines, specifications, standards and practices.<br>- Governmental laws, policies, regulations, strategies and plans. | - Ministry of Works with consultants support. | - Proposing an action plan (contains Immediate, Short-Term, Mid-Term and Long-Term Measures).<br>- Clarified performance measures.<br>- Determination of approaches.<br>- Proposing initiatives such this project which is Muharraq Deep-Gravity Sewer project as a short-term performance measure. | - Tenants of Muharraq governorate.<br>- Sanitary Engineering Affairs.<br>- The Ministry of Works, Municipalities Affairs and Urban Planning.<br>- Researches and academics. | - Availability of land parcels were not considered.<br>- Preliminary route of the proposed Deep Gravity Sewer.<br>- The Land Zoning maps and Population projections are not accurate. |
| **Stage 2: Contextualising the project** | | | | | | |
| 1 | Ministry of Works' programme. | - Allocated budget of the Ministry of Works' programme for design, supervision and construction with taking into account the budget availability set by the Ministry of Finance and National Economy.<br>- Land parcels allocation for the required pumping stations from Survey and Land Registration Bureau and Urban Planning and Development Authority.<br>- Compliance with NMPSES, government legislation, policies, regulations, strategies and plans. | - Sanitary engineering affairs. | - Sanitary Engineering Affairs Programme including Muharraq Deep-Gravity Sewer project.<br>- Cost estimations.<br>- The project boundary. | - Tenants of Muharraq governorate.<br>- Sanitary Engineering Affairs.<br>- The Supreme Council for Environment.<br>- Researchers and academics. | - Other utilities database isn't accurate.<br>- Project implementation is dependent on microtunneling technologies that are uncommon in Bahrain which requires expertise in the application of such projects. |

| No | Main Activities | Key focal points | Parties concerned | Outputs expected | Target users for outputs | Limitations of the activities |
|---|---|---|---|---|---|---|
| **2** | Appraisal Report (9th September 2008). | - The design basis such as population, future wastewater flows and catchment area.<br>- Design criteria, specification, geotechnical conditions and the preliminary design of the deep gravity sewer with showing the different alternative locations.<br>- The environmental impact assessment.<br>- Legal review (Public-Private Partnership, PPP alternative models).<br>- Commercial analysis.<br>- Project feasibility modelling.<br>- Project documentation and tendering strategy. | - Sanitary engineering affairs with consultancy services support. | - The scope of work.<br>- The concept design of the deep gravity sewer.<br>- Several possible alternatives for the deep gravity sewer.<br>- Several possible applicable PPP alternative models. | | |
| **3** | Environmental impact assessment report (December 2010). | - Environmental policy and legislation (Compliance with the supreme council for environment laws, regulations, strategies, standards and plans).<br>- Environmental Review (Land use and utilities, air quality, noise, roads, traffic and access, soil and groundwater quality, cultural heritage, archaeology, aquatic ecology, waste management etc).<br>- Review of environmental impacts (Environmental and social impact, significance criteria, description of the construction impact, description of the operations impacts, socio-economic impacts, human health etc). | | - Risk elements related to the environment.<br>- Mitigation plan during the construction and operation stage. | | |
| **Stage 3: Planning, Designing and Implementing the Project** | | | | | | |
| **1** | Technical specification (2nd February 2011). | - Collecting the information required for the design, such as site levels, obstacles and existing network conditions.<br>- A detailed description of the scope of work, site, civil works and the mechanical works of the project. | - Sanitary engineering affairs with consultancy services support. | - Constructability Report.<br>- General specifications (and specific specifications). | - Sanitary Engineering Affairs.<br>- The contractor. | - Limited geotechnical research due to cost constraints.<br>- The ministry of works specification dose not cover all aspects related to microtunneling since it |

| No | Main Activities | Key focal points | Parties concerned | Outputs expected | Target users for outputs | Limitations of the activities |
|---|---|---|---|---|---|---|
| | | - Clarification for the locations of the existed services.<br>- The collection of the geotechnical data needed.<br>- Performing (QA/QC) program to ensure meeting the required standards. | | | | was a new technology in Bahrain. |
| **2** | • Funding application and Ministry of Finance and National Economy.<br>• Granting wayleaves, planning permission and all permits required for the construction.<br>• Hydraulic Analysis (4th July 2011) | - Finalization of annual funding and associated formalities.<br>- Availability of land parcels and utility corridors.<br>- Granting the required permits from other utilities and infrastructure agencies to be impacted by the project.<br>- Review of all the design parameters such as pipe size, flow, material and slopes. | - Sanitary engineering affairs with consultancy services support.<br>- Ministry of Finance and National Economy. | - Allocation of the budget.<br>- determine the pipeline alignment and corridor allocation.<br>- Allocation of land parcel.<br>- Granting permits.<br>- Final Hydraulic Model Analysis of the existed network for the final design. | - Sanitary Engineering Affairs.<br>- The Urban Planning and Development Affairs. | - Difficulties in the allocation of funding approvals by related government organisations.<br>- Long procedures to grant approvals from associated government organisations related to corridors and land parcels required for the project. |
| **3** | Preparation of tender documents and agreements terms for the Private Public Partnership project. | - Confirm the tender documents (such as bill of quantities, design drawing and general specifications) and agreements are in line with local policies. | - Sanitary Engineering Affairs, tender board with the consultancy services support. | - Concession awarded by the Ministry of Works to Muharraq STP Company. | - Sanitary Engineering Affairs.<br>- Muharraq STP Company. | - Long processes to obtain approvals on the contract from relevant government organizations.<br>- Lack of institutional capacity to supervise PPP contracts as this is the first PPP project implemented in Sanitary Engineering Affairs. |
| **4** | Constructing the deep gravity sewer | - Activities of construction according to design, specifications, construction method statement and QA / QC programme. | - Sanitary engineering affairs with | - Constructed new DGS in Muharraq.<br>- As built drawings. | - Sanitary Engineering Affairs. | - Lack of technical capacity to supervise the deep gravity sewer construction |

| No | Main Activities | Key focal points | Parties concerned | Outputs expected | Target users for outputs | Limitations of the activities |
|---|---|---|---|---|---|---|
| | (Completed in 2014). | - Supervision during construction work on the awarded contractor. | consultancy services support.<br>- Muharraq STP Company. | - QA/QC report. | - Urban Planning and Development Authority.<br>- Tenants of Muharraq governorate. | projects, consequently, consultants must be assigned to supervise. |
| **Stage 4: Operation and maintenance** | | | | | | |
| **1** | Operational Environmental Management Plan (OEMP) (2014). | - Roles and responsibility of the operation and maintenance on the environmental mitigation.<br>- Guidelines of operation and maintenance in the context of the environment including mitigation measures for the potential environmental impact. | - Sanitary Engineering Affairs with consultancy services. | - Operational Environmental Management Plan that should be followed. | - Sanitary Engineering Affairs.<br>- Muharraq STP Company. | - |
| **2** | Operation & maintenance annual report 2019 (January 2020) | - Sewerage networks Issues and Challenges<br>- Operation and Maintenance data (monitoring wastewater flow, health and safety, sewage influent quality, staff and resources, odour and noise, environmental impacts and security. | - Muharraq STP Company. | - Completed reporting for the Sanitary engineering affairs | - Sanitary engineering affairs.<br>- Muharraq STP Company. | - All the collected data with reliance on the STP company. |
| **Stage 5: periodic assessment** | | | | | | |
| **1** | Preparation to update the master plan. | - Incorporate, if any, changes to government legislation, policies, regulations, strategies and plans.<br>- Incorporating, if any, changes in land use and economics activities.<br>- Analysing possible issues of failure.<br>- Update the State of Foul Sewerage Systems (Existing data on sewerage networks such as Current hydraulic capacity and Current physical condition).<br>- Review of new technologies on the market, if any. | - Sanitary Engineering Affairs with potential consultancy services. | - The updated master plan.<br>- Recommendations to improve the operation of the sewerage system. | - Tenants in the project area.<br>- Sanitary Engineering Affairs. | - The lack of expertise in the field of planning. |
| **Stage 6: Upgrading/ Modification** | | | | | | |

| No | Main Activities | Key focal points | Parties concerned | Outputs expected | Target users for outputs | Limitations of the activities |
|---|---|---|---|---|---|---|
| **1** | Upgrading or modifying the overall network of sewers in the area. | - Ensure that all future flow changes are addressed through updating / modifying the sewerage network and updating the master plan where necessary. | - Sanitary Engineering Affairs with potential consultancy services. | - Improvement of the sewerage infrastructure by new projects. | - Tenants in the project area.<br>- Sanitary Engineering Affairs. | - Uncertainty of the availability of budget and materials (e.g. pipe liners, certain pumps). |

## 6.4 Overview of Madinat Khalifa Sewerage Project

The third project is Madinat Khalifa project which is a housing project managed by the Ministry of Housing. This new city is located on the east cost of Bahrain Island. It is located between Askar and Al Dur Villages. The project would serve the new developed areas and the location of the project can be seen in Figure 26.

Both the Ministry of Works and Ministry of Housing are studying ways of connecting the existing villages to the proposed sewer network and STP. This will directly affect the design of the sewer network as it will receive sewage from a wider area. Scenarios expected to be developed for this project include connecting each village to the network which will define the sizes, routes and the phases in which the project is going to be implemented. Initial phases of the project are shown in Figure 26. The initial estimations of the sewage flow without nearby villages are presented in Table 23.

Table 23: Predicted sewage flows form Madinat Khalifa

| Phase | Phases 0 & 1 | Phase 2 | Phase 3 | Interim Land Use (Post-2030) |
|---|---|---|---|---|
| **Total sewage generated $m^3$/day** | 7,185 | 3,690 | 2,210 | 12,600 |


Figure 26: Madinat Khalifa sewerage project location

### 6.4.1 Objectives, finance and benefits

The aim of the project is to serve a new housing project with a proper sewerage system. Furthermore, it will consist of residential buildings and some facilities such as health facilities, mosques, commercial developments, offices, shopping malls, parks, and educational facilities. Furthermore, it will accommodate nearby villages such as AlDur and Askar. Therefore, it will upgrade the area and prepare it for new possible developments.

The budget required for the implementation of this project is still not allocated and not decided if it will be financed by the Ministry of works or Ministry of housing. However, the operation and maintenance will be handled later by works as it falls under their responsibilities bearing in mind that the project is currently in the early planning stages.

The tenants of Khalifa Town and surrounding areas will certainly benefit from this project. As it considered an upgrade of the sewerage infrastructure in this area, as it could link future developments. It would therefore improve the wastewater system in that area, which, in turn, would preserve the safety, health, and quality of life of the residents of Khalifa town and the surrounding areas.

### 6.4.2 Outcomes

The Khalifa town sewerage project is a new sewerage system in a new area and currently it's in contextualising stage. By implementing this sewerage system, it will serve the residents of the new town and the surrounding villages including their facilities. Furthermore, it will upgrade the infrastructure of that area for future developments. Thus, it will maintain good sewerage services that reflect the followed the policies, regulations and plans of Bahrain.

### 6.4.3 Risks of the sewerage system

This project is in a new developed area; however, the area contains some existing residential building that uses septic tanks that will removed by constructing this sewerage system. Furthermore, it will also connect nearby existing villages including their facilities such as mosques, schools, shopping malls, health facilities and parks. Therefore, there should be a sufficient sewerage system that is capable of handling the amount of flow with protecting the environment from any possible contamination whether by exfiltration, flooding, or odour. Thus, it would protect public health, safety and quality of life. Moreover, the area of the project is near to the sea, and there is a higher risk that in case of exfiltration the sewage would directly affect the beaches. However, for the infiltration the project data stated that the risk of infiltration was limited for the majority of the site because of the topography being substantially above sea level. Furthermore, by implementing this project which consists of a comprehensive sewerage network and a regional STP, the risk of failure in the sewerage network as well as the minor STPs scattered in the area will be reduced since these STPs are planned to be removed in the future.  In addition, all septic tanks of houses located in unsewered parts in the area will be removed and replaced by sewerage pipelines which will be connect to a regional STP to ensure all sewage will be treated in an ecological way to avoid any damage to the environment.

### 6.4.4 Activities of the project

This initiative is at a very early stage and it was not included in the 2009 master plan that should have covered all the projects until 2030. Therefore, there were a lack of the existing activities data. Furthermore, this project was within the responsibility of the Ministry of housing including the housing area of the city. Table 24 present only activities that were done in the first stage, it shows the key focal points, the responsible parties, expected outputs, target users for the outputs and the limitations of that activity.

Table 24: Activities analysis of Madinat Khalifa sewerage project

| No | Main Activities | Key focal points | Parties concerned | Outputs expected | Target users for outputs | Limitations of the activities |
|---|---|---|---|---|---|---|
| **Stage 1: sewerage system** | | | | | | |
| **1** | National master plan for sanitary engineering services (NMPSES-2009). | - State of Foul Sewerage Systems (Existing data on sewerage networks such as Current physical condition and Current hydraulic capacity).<br>- Scenario analysis (development of the hydraulic network model, evaluation of different options, implementation plans and cost analysis)<br>- Technologies review<br>- Environmental considerations<br>- Laws, policies, rules, tactics, and plans of the Government<br>- Guidelines, specifications, standards and administrative practices. | - Ministry of Works with consultancy services support. | - Proposing action plane (including Immediate, Short-Term, Mid-Term and Long-Term Measures).<br>- Determining performance measures.<br>- Determine approaches.<br>- Proposing initiatives. | - Residents of Bahrain.<br>- The Ministry of Works, Municipalities Affairs and Urban Planning.<br>- Researches and academics. | - The availability of land parcels was not considered<br>- Preliminary route for the proposed projects.<br>- No allocation plan for the budget<br>- The projected population and land zoning are not accurate.<br>- Not covering some unpredicted housing projects such as Khalif town. |
| **2** | Preliminary master plan for Khalifa Town project. (the year) | - Design assumptions and criteria used to prepare the master plan<br>- Analysing the risks associated with the project. | - Ministry of Works with consultancy services support. | - Preliminary sewerage network layout.<br>- preliminary master plan of the area. | - Residents of Khalifa town.<br>- Sanitary Engineering Affairs.<br>- Ministry of housing. | |

## 6.5 Policy and Guidelines Followed for the Three Cases

The sewerage infrastructure projects case studies are subjected to policies, decrees, laws, guidelines, and concerned institutions in the Kingdom of Bahrain. Therefore, these policies, decrees and directives were reviewed to determine their implication on executing sewerage projects in Bahrain, and it includes the NMPSES 2009-2010; Economic Vision 2030 for Bahrain; Bahraini Government Action Plan; Ministry of Works Municipalities Affairs and Urban Planning Mission, Vision and Values; and Policies of sustainability development in waste water management. The Table 25 shows some of these policies, decrees and guidelines and their Significance to the sewerage projects case studies.

Table 25: The significance of policies, decrees and guidelines to the sewerage case studies

| Policies, decrees and guidelines | Significance to the sewerage infrastructure projects |
|---|---|
| Decree Law No. 47 of 2012 on the establishment of the Supreme Council for the Environment. | Establishment of the Supreme Council for Environment which is specialised in environmental issues and the public health. One of the main responsibilities assigned to this entity is to assess all new infrastructure projects in order to ensure that the environmental will not be impacted. As the approval from Supreme Council for Environment is mandatory for all new infrastructure projects and all services utilities need to adhere to the requirements and restrictions mandated by the council. |
| Law No. 1 1998 - Environmental Assessment for Projects | The Environmental Impact Assessment become mandatory for all infrastructure projects, as the following points should be clarified for every project: the project description, justification, desired objectives, the possible impact on environment, actions to protect the environment as well as monitoring the emissions. And this law has highlighted one of the main important pillars of sustainability. |
| Law No. 33 of 2006 on sewage disposal and surface water drainage. | This decree clearly describes the authority given to Sanitary Engineering Affairs and the public rights in regard to the sewerage network services. The decree sets all restrictions and requirements expected to be followed by the public to avoid any possible damage to the system which could lead to interrupting the service. Also, the decree clearly mentions the procedure and formalities needed to request for a sewer connection from Sanitary Engineering Affairs. |

| | |
|---|---|
| Bahrain Economic Vision 2030 (October, 2008). | The Bahrain economic vision have provided aspirations for the government, and one of these aspirations was encouragement to "Accelerating private-sector involvement in the provision of public infrastructure services". Therefore, the Muharraq sewerage project was following PPP contract as described in Bahrain Economic Vision. |
| National master plan for sanitary engineering services (2009) | The master plan presents the results of studying the existing sewerage assets and all occupied and unoccupied areas in Bahrain in order to set a holistic plan to develop the network to ensure that the sewerage services are provided to all citizens. A list of initiatives and projects have been set and categorized as short, medium and long term for the implementation programming. All these initiatives are directed toward the sustainability of the sewerage system in Bahrain. |
| National Biodiversity Strategy and Action Plan 2016 - 2021 | Sewerage projects need to adhere to the National Biodiversity Strategy and Action Plan in order to avoid any possible damage to the marine and costal ecosystems as described in Target 3 "Improve seawater quality by 50% from wastewater and sewage discharge resulting from municipal treatment plants" bearing in mind that untreated sewage could have an adverse impact on the quality of seawater. |
| Sustainable Development Goals - Goal 6: Ensure access to water and sanitation for all | According to the latest statistics performed by the united nations, 673 million people still practice open defecation which is a clear indicator that sanitation and sewerage services are mandatory to preserve the public health. The united nations have set the following relevant targets:<br>6.2 By 2030, achieve access to adequate and equitable sanitation and hygiene for all and end open defecation, paying special attention to the needs of women and girls and those in vulnerable situations.<br>6.3 By 2030, improve water quality by reducing pollution, eliminating dumping and minimizing release of hazardous chemicals and materials, halving the proportion of untreated |

| | |
|---|---|
| | wastewater and substantially increasing recycling and safe reuse globally.<br>6.B Support and strengthen the participation of local communities in improving water and sanitation management. |

### 6.6 Chapter Summary

This chapter presents the three prechosen case studies Hamad town to Tubli trunk sewer, Muharraq Deep-Gravity sewer and Khalifa Town sewerage project. It gives an overview, objectives, finance, benefits, risks, outcome and the provided activities of each project. Furthermore, the associated policies, decrees and guidelines for the three projects were also presented. In the following chapter, these case studies will be used to demonstrate how the developed sustainability assessment framework presented in Chapter 4 can be applied throughout the life cycle of a project.

# Chapter 7: Application of Sewerage Projects' Sustainability Assessment Framework

This chapter demonstrates how the proposed sustainability assessment framework (Chapter 4) can be applied through all stages of the project by applying it to the three case studies presented in the previous chapter (Chapter 6). The first section presents detailed descriptions of the sustainability assessment objectives, criteria and indicators. The second section demonstrates the application of the assessment on the three case studies in determining possible alternatives, applying convenient indicators, identifying the sustainability index, analysing, discussing and providing recommendations.

## 7.1 Sustainability Assessment Framework for Sewerage Infrastructure Projects

Achieving a sustainable sewerage infrastructure system is a widespread challenge, and reaching sustainability will elevate such a system through the evolution of its ability to face the different challenges and threats without affecting the environment, the economy and social aspects. The challenges and threats in achieving a sustainable sewerage infrastructure system include the following: population growth and land use, storm water and consumer behaviour, availability of corridors and lands, people's dissatisfaction, pumping-station breakdowns, budget allocation, energy consumed, groundwater infiltration and sewage ex-filtration, among other managerial issues. Affectively dealing with such challenges will ensure the sewerage system provides sustainable performance throughout the life cycle. The sustainability assessment of the sewerage infrastructure project was based on achieving two objectives: reducing the risk of sewerage failure and contributing to the sustainable development of the wastewater collection system. Also, every objective was divided into criteria that simplify measuring the extent of those objectives. The first objective, reducing the risk of sewerage failure, was divided into two criteria: strategic technical aspects and sewerage flow characteristics. The second objective, contributing to the sustainable development of the wastewater collection system, was divided into four criteria: economy, social affairs, environmental improvement and, policy, and decrees and institutions. Moreover, every criterion was divided into indicators seeking to measure it and therefore achieve sustainability, and further sections will show these indicators. The following sections present the objectives, criteria and sustainability indicators with their descriptions and measuring parameter, followed by the application of the chosen case studies for further descriptions.

### 7.1.1 First objective: Reduce the risk of sewerage failure

A sewerage system faces many threats that affect its functionality throughout its life cycle, including the effects of aging, aggressive environmental factors, improper operation and maintenance activities, inadequate design and underfunding. These threats will then lead to enhanced risks of failure, such as sewer leakage, odour and overflow. Therefore, minimizing the risk of sewerage failures will lead to obtaining a better sewerage infrastructure and thus contribute to a better environment and economy, improved public health and safety and extended service lives for assets (Akhtar et al., 2014; Alnoaimi and Rahman, 2019). To reduce the risk of sewerage failure, two criteria were used, including strategic technical aspects and sewage flow characteristics.

#### *7.1.1.1 Sustainability indicators related to strategic technical aspects*

Sewerage projects are usually a part of an integrated network and are managed by a certain sector. Therefore, any shortcomings in following the strategic management of that sector would eventually threaten the sewerage system through its life cycle (including while planning, designing, constructing, operating and maintaining) and increase the risk of sewerage failure (Cardoso et al., 2005). So, it is important to ensure the efficiency of technical management because it will contribute to supporting the sewerage projects against sewerage failure. The strategic technical aspects are the link that overlaps all the management activities of the sewerage projects under the concerned sector. Nine indicators were identified under the strategic technical aspects such as NMPSES, technologies, qualified staff, planned preventive maintenance (PPM), communication with other sectors and so on. Table 8 presents all indicators with descriptions and a measuring parameter.

#### *7.1.1.2 Sustainability indicators of the sewage flow characteristics*

The basic concept of sewerage projects is to convey sewage flow from the generation point (homes, industries, commercial activities and institutions) to the disposal point. Any disturbance in the quality and quantity of the sewage could negatively affect the sewerage system, which then could increase the risk of sewerage failure (Von Sperling, 2007). Therefore, sewage flow characteristics are an important criterion to monitor and assess the reduced risks of sewerage failure. Also, five indicators were identified under this criterion, which are projected population, planning horizon, high infiltration/inflow, missuses of sewerage by the users and intentional vandalism of the sewerage system. Table 8 presents the indicators with further descriptions and a measuring parameter.

### 7.1.2 Second objective: Contribute to the sustainable development of wastewater collection system

The contribution to sustainable development became a global demand, and having a sustainable wastewater collection system will fulfil a number of sustainable development goals such as having clean water and sanitation, reducing the effect on environmental degradation and having better public health (Alnoaimi and Rahman, 2019; Ainger and Fenner, 2014). Furthermore, many countries have already adopted these goals, as having a sustainable infrastructure became a main strategic priority in developing strategies, laws and policies (Finkbeiner et al., 2010). Meanwhile, the sustainable infrastructure can accelerate the balance of the social, environmental and economic aspects of such countries (Diaz-Sarachaga, Jato-Espino and Castro-Fresno, 2017). Therefore, ensuring the proper contribution toward sustainable wastewater collection systems would ultimately contribute to sustainable development. A comprehensive sustainability assessment for infrastructure projects will require effective attention on three pillars of sustainability: environmental, economic and social aspects (Beheshti and Sægrov, 2017; Halfawy, Dridi and Baker, 2008; Hossain and Gencturk, 2016; Sinha and Knight, 2004). Moreover, the influence of laws, policies, regulations and strategies on principles of sustainability is essential to attaining a sustainable infrastructure while also informing stakeholders about the progress being made (Ainger and Fenner, 2014; Siew, Balatbat and Carmichael, 2016). To pursue contribution in the sustainable development of the wastewater collection system through sewerage infrastructure projects, four criteria were used: environmental, social, economic and policy (decrees, institutional and strategic vision) aspects.

#### *7.1.2.1 Sustainability indicators concerning economic aspects*

Infrastructure plays a key role in economic growth and is considered an engine of economic development (Shannon and Smets, 2010). Furthermore, maintaining a sustainable infrastructure will attract investors and create a healthy economic environment. The most effective sewerage system achieves the right balance of long-term service, low maintenance and low life-cycle costs (Diaz-Sarachaga et al., 2016; Lounis and McAllister, 2016). The economic aspects of the sewerage infrastructure projects are about the balance between spending and savings. Nine sustainability indicators were identified concerning the economic aspects such as project capital cost, operation and maintenance cost, consequence caused by the absence of service corridor, served industrial areas and others. Table 8 presents all indicators with descriptions and a measuring parameter.

*7.1.2.2 Sustainability indicators concerning social aspects*

A sewerage system is a large underground system, and many users don't realize the extent of its importance because it can't be seen with the naked eye. However, during critical situations, such as flooding, odour or leakage, users become more aware of their sewerage system. Furthermore, maintaining stakeholders' satisfaction requires careful attention to the impacts on users. The sewerage project is intended to improve the lives of those who interact with the projects from various areas (including public safety, health, security and social equity). Therefore, six sustainability indicators concerning the social aspects were identified: public awareness, public health and safety, satisfaction of the stakeholders, Local economic development activities, served critical infrastructures and facilities, and served occupants. Table 8 presents all of the indicators with descriptions and a measuring parameter.

*7.1.2.3 Sustainability indicators concerning environmental aspect*

The wastewater collection system is considered a critical system that transfers a large amount of raw sewage from houses, schools, hospitals, factories and other establishments to the disposal point, which is usually the wastewater treatment plant. Any disturbance in this system, such as flooding, odour or leakage, would mean a raw sewage material is directly polluting the environment and affecting the public's quality of life. However, there has been little research on the effect of a sewerage system, as many countries' authorities have neglected the effect of their sewerage system on the environment while concentrating on the effect of treatment plants (Torgersen, Bjerkholt and Lindholm, 2014). However, the sewerage system affects the environment more than the wastewater treatment plants during the construction phase and operation and while maintaining the system (Remy and Jekel, 2008). Seven indicators were identified under the environmental aspect, such as aquifer pollution, odour air pollution, sewage flooding and the contribution of using green technologies. Table 8 presents all of the indicators with descriptions and a measuring parameter.

*7.1.2.4 Sustainability indicators concerning policy (decrees, institutions and strategic visions)*

Policies are the main driver for sustainability, followed by the institutional practices that should reflect these policies. In their current state, the existing sewerage projects are the reflection of the policy that emanates from the decrees and strategic visions. Therefore, the state's sustainable development policy should be considered, and if the project does not comply with that policy, it should be rejected in the first place (Shen, Wu and Zhang, 2011). Furthermore, the institutions in turn seek to achieve these policies by developing strategies that allocate resources to complete institutions' objectives in the best way. The policies inspired six sustainability indicators such as NMPSES, strategic vision, local contractors and service fees. Table 8 presents all the indicators with their descriptions and measuring parameters.

## 7.2 Assessing the Sustainability of Sewerage Infrastructure Projects

As shown in Chapter 6, three case studies were completed for the three selected projects. The following sections will discuss the application of the developed sustainability assessment framework for the sewerage infrastructure projects (Chapter 4) on the Hamad Town deep-gravity sewer project, Muharraq deep-gravity sewer project and Madinat Khalifa sewerage network project. It is noteworthy to mention that some limitations existed during the application based on the availability of the data and the features of the project. The limitations will be clarified during the application.

### 7.2.1 Assessing the sustainability of Hamad Town deep-gravity sewer

The first project is the Hamad Town deep-gravity trunk sewer, which will also be used to further demonstrate how the established sustainability assessment would be applied for an incomplete project. This project has been given priority because it is still in the preliminary stages, and assessing this project will give appropriate attention to the objectives of the framework and therefore contribute to having a sustainable sewerage project. This strategic project is important because it will finally serve more than 500,000 people in the kingdom of Bahrain. Currently, the project is in the planning stage; thus, the assessment will focus on the first three stages of the sustainability assessment, namely the current sewerage system, contextualizing the project and the planning, designing and implementing the project stages. The following sections will present the application of the framework on the Hamad Town deep-gravity sewer project through the different stages of the project.

#### *7.2.1.1 Stage 1: Sewerage System*

The sewerage system in the area of the projects was fully surcharged; therefore, the main aim of this project was to relieve the hydraulic overloading conditions of the system in that area and to help its residents maintain their health, safety and quality of life. As this project is a part of an existing system, it is important to consider the documented reports and data of that system in the project area. The NMPSES in 2009 captured the actual condition during that period and proposed the benefits of this project. It was proposed as a short-term measure and should be done within 4 years after issuing the master plan in 2009; however, the project still has not been implemented in 2020. Furthermore, the situation of the sewerage system is still surcharged and faces a high rate of occasional pumping breakdowns and overflow due to the high amount of sewage and the high infiltration rate. Monitoring the sewerage system through the operation and maintenance team should be continuously updated with the existing situation because this project has exceeded the proposed dates by the NMPSES. Meanwhile, changes in the sewerage network could occur and must be considered to finally provide a better proposal for the project, such as proposing a new route, increasing capacity, enlarging the project area, changing the end point (e.g., ending in the new Madinat Salman sewage treatment plant instead of the Tubli treatment plant), considering newly raised issues, dividing the project into several stages or any other possibilities. Thereafter, regardless of the need for the project and its ability to reduce the risk of frequent sewerage failure in that area, it should follow the policies, regulations and plans of the kingdom of Bahrain that strive for a sustainable infrastructure.

#### *7.2.1.2 Stage 2: Contextualizing the Project*

The main purpose of this deep-gravity trunk sewer project is to alleviate the hydraulic overload conditions at the current pumping station and the existing network, which will eventually serve the public of that area. The project was contextualized in light of reducing the risk of sewerage failure and obtaining a sustainable sewerage system throughout the life cycle of the project while considering policies and regulations of the sewerage system in Bahrain. In terms of reducing the risk of sewerage failure, the deep-gravity trunk sewer will relieve the current system and minimize the number of old heavily surcharged pumping stations with the construction of a new pumping station. Regarding contextualization of the project into achieving a sustainable sewerage system, this project will encounter some concerns related to the economy, society, environment and policy that should be outlined. As for the economy, the project faces issues regarding the life-cycle cost of the project, allocating the budget and the operation and maintenance costs of the entire project. In addition, due to the delay of the project, consideration should be given to the amount of increase in the current operating costs in the area of the project and the effect of high infiltration on the increasing treatment cost. Further, providing a sustainable infrastructure enhances creation of an attractive environment that will attract investors and create a healthy economic environment. Furthermore, social concerns are related to public health and safety, public awareness, the satisfaction of stakeholders and serving the critical infrastructure that serves the community so as to ensure good quality of life. Because of the ongoing problems of sewage leakage, exfiltration and high infiltration, the existing sewerage system in the project area has a significant negative effect on the environment. These problems cause aquifer pollution, odour pollution, increased energy consumption from the pumping station and a direct confrontation between wastewater and the environment, such as the pollution of Lawzi Lake by sewage leakage. Moreover, being aware of all the mentioned concerns, this project follows the policies, decrees, regulations and institutional practices in Bahrain. Therefore, any concerns that seek to deviate the project from following the policy should be tackled. In this project, there are some concerns related to the policies because the project exceeded the duration that it should be implemented in, and there is still an absence of service fees and proper community participation.

The main consequence of this stage is determining the suitable sustainability indicators with criteria that fit the project context. Further, the criteria for determining these indicators were based on their criticality, data availability, purpose, monitoring and ability to capture long-standing issues. All of the available relevant reports regarding the project have been reviewed, such as the inception report, final conceptual design report, environmental management plan and hydraulic design report. Also, after determining the suitable indicators, these indicators were then presented to sewerage system experts in Bahrain, and they were consulted to select the indicators that are most critical for the project and that are technically feasible for institutions' monitoring during the life cycle of the project. Thereafter, twenty sustainability indicators for the Hamad Town deep-gravity trunk sewer were identified, as shown in Appendixes H and I. Moreover, the maximum and minimum target values for each indicator were set so that the effect of the sewerage scheme project on the indicators could be compared (i.e., whether they were qualitative or quantitative indicators). The range between the maximum and minimum target value was further classified into five sets, and each set has a 5-point scale (1 = Highly negative impact; 2 = Negative impact; 3 = Neutral; 4 = Positive impact; 5 = Highly positive impact), as shown in Appendixes H and I. Finally, these scores will then be used in identifying the sustainability index for all stages of the project.

*7.2.1.3 Stage 3: Planning, designing and implementing the project*

In this stage, a variety of alternatives were identified within the sewerage system, including different pipe material, different construction methods, different locations of the new lift station and two different trunk routes. This research has considered the most feasible alternatives to be used by the developed sustainability assessment framework in order to demonstrate how it is applied and to decide the most sustainable alternative. Several alternatives to the sewerage routes could be used to explain the implementation of the assessment in order to find the most sustainable alternative, except for the fact that it would be a lengthy, repetitive procedure that would complicate explanations of the assessment's application. Therefore, it was more convenient to apply it to only one of these alternatives. Figure 27 shows the two chosen alternatives (alternative 1 and alternative 2) of the routes that would be used to implement the sustainability indicators. Both of these routes start from the same point and end in the same point, which is the new pumping station, and the main route would continue to the treatment plant. Alternative 1 has a total length of 3.58 km, with a maximum depth of 14 m and a pipe diameter of 1.2–1.5 m, and the targeted areas are mainly residential and commercial. Alternative 2 has a total length of 5.18 km, with a maximum depth of 16 m and a pipe diameter of 1.2–1.5 m, and the targeted areas are residential, commercial and agricultural.

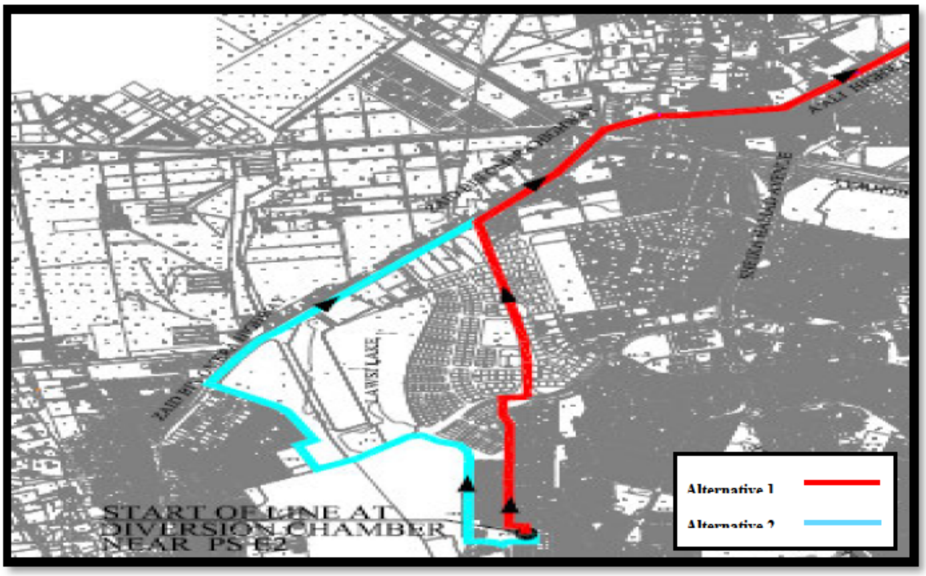



Figure 27: The locations of alternative route 1 and alternative route 2

The twenty sustainability indicators presented in Appendix H have been applied to the two alternatives using the multi-criteria analysis (MCA). However, only some of these indicators have a different score for the alternatives, as shown in Appendix I. Every sustainability indicator has a weightage of importance for every stage of the project that has been determined in Tables 15 and 17 in Chapter 5, through the survey of sewerage system experts in Bahrain.

Also, all criteria and objectives have a rate of importance that was also determined through the survey and can be seen in Table 13 in Chapter 5. Furthermore, the maximum and minimum target values for this project have been classified into five sets, as shown in Appendix H, which will be used to identify the score of the alternatives. Thus, the comparable indicators between the two alternatives will have a different score based on their impact, which can then be compared. After that, the score of every indicator was multiplied by the determined weightage of that indicator. Table 26 gives an example of some indicators that have been compared between the two alternatives.

Table 26 Example of comparable sustainability indicators scores for alternatives 1 and 2

| SI | Sustainability indicators | Description | Measuring parameter | (AL1) V | (AL2) V | (AL1) S | (AL2) S | W | SI AL1 | SI AL2 |
|---|---|---|---|---|---|---|---|---|---|---|
| **A5** | Pumping station reductions | Minor pumping stations and major pumping stations to be eliminated, if any | Number of major pumping stations to be eliminated within the catchment area | 4-8 | 8-9 | 2 | 3 | 5.3 | 10.6 | 15.9 |
| **C3** | Project capital cost | The total cost of implementing the project | Total capital cost ($) | 110-100 million dollars | 130-120 million dollars | 5 | 3 | 7.84 | 39.2 | 23.5 |
| **E3** | Land used for the sewerage projects | Construction activities causing noise, dust, gasses, dewatering or any construction waste that would disturb the environment in the surrounding areas | Total volume of trenches excavated during construction stage (m3) | 75,000 to 100,000 | 100,000 to 125,000 | 2 | 1 | 4.9 | 9.8 | 4.9 |

Key: (AL1) V, Value for alternative 1; (AL2) V, Value for alternative 2; (AL1) S, Score for alternative 1; (AL2) S, Score for alternative 2; W, weightage; SI AL1, sustainability index score for alternative 1; SI AL2, sustainability index score for alternative 2.

Thereafter, all of the indicators will be calculated, which will provide the final sustainability index for every alternative. This can be seen in Appendix J. The maximum and minimum sustainability index will also be calculated using the maximum and minimum target value that the experts consulted in this project have set. Ultimately, the sustainability index (SI) scores for both alternatives were very close, as alternative 1 was 329.2, and alternative 2 was 333.82 as can be seen in Figure 28. However, the statues of the criteria were slightly different, as alternative 1 leaned more toward the social aspects and economic aspects, whereas alternative 2 leaned more toward the environmental aspects and flow characteristics. For alternative 1, the area mainly includes residential and commercial areas. The land use classifications are relatively clear and can be used as an input to the flow calculations required to size the pipes and pump stations. Due to the high level of anticipated wastewater generation from this area, alternative 1 will positively impact the environment due to reducing the risk of future surcharges in the network. In terms of traffic disturbance during the construction stage, this option will have less of an impact on the traffic, as the total length of the line is shorter compared with alternative 2, which means it will have a lower cost compared with alternative 2. On the other hand, agricultural lands exists in the alternative 2 area, so it will be difficult to predict future changes in the land use, as these lands are prone to any changes in land classification in the future. Based on the above, the master plan of the Urban Planning and Development Authority will highly impact this alternative in the area, as well as the future vision in items of supporting the agricultural sector and the policy toward food security. As a result, flow calculations will be less accurate due to the presence of agricultural lands, which might impact the design of the pipes and pump station sizes. This alternative will have less of a positive impact compared with alternative 1 due to the clarity of future plans for the area, which might result in less or more wastewater generation in the future. A clear master plan for this area needs to be agreed upon between related government authorities. Because this alternative has a longer length of the proposed line compared with alternative 1, the impact on traffic will be much higher, which will affect the project's cost and duration. However, this route will remove more existing pumping stations compared with alternative 1, which supports the master plan approach.

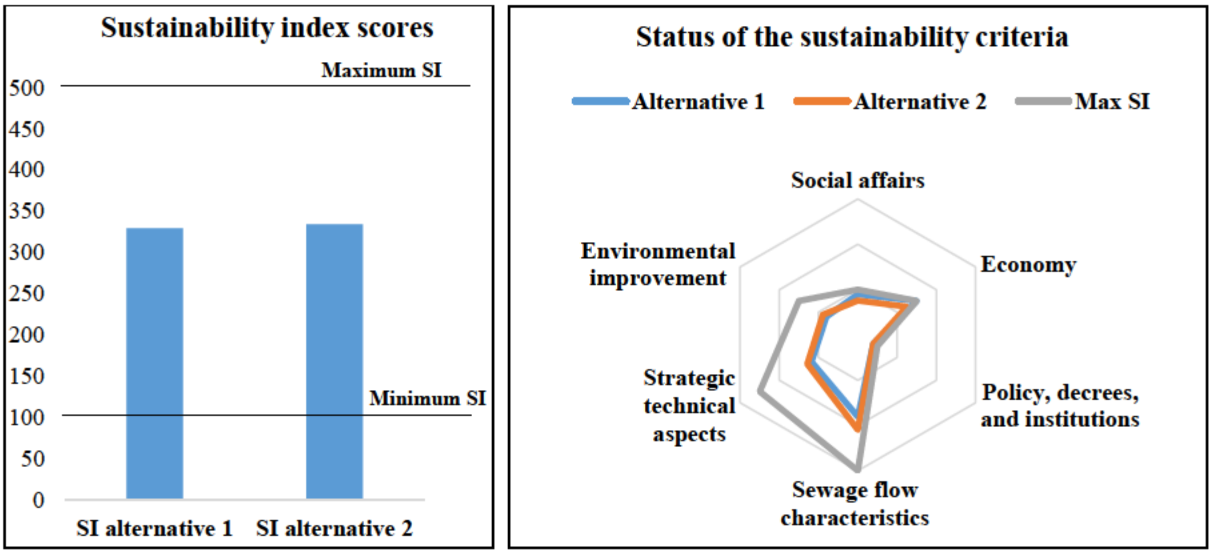



Figure 28: The sustainability index score for planning, designing and implementation, as well as the criteria status

#### *7.2.1.4 Stage 4: Operation and Maintenance*

Following the sewerage project, operation and maintenance will begin immediately. During this lengthy stage, careful attention should be given to the system's performance. In addition, further improvements to the developed sustainability assessment could be made at this stage using the collected and reported data. For instance, the sustainability indicators could be improved on the basis of the project's particular context. Any unforeseen issues that are raised could be addressed in this project, which will help to improve the assessment framework for future projects.

#### *7.2.1.5 Stage 5: Periodic Assessment*

This stage is introduced in the case of a significant event, such as updating the master plan or a system failure. This stage is mainly based on a review of policies, strategies, reports and plans, with the goal of checking for any modifications that might have occurred at that time. Meanwhile, it is important to revalidate the sustainability indicators and to test their ability to be applied over the various stages of the project. Eventually, this stage's production will be an improved sustainability assessment framework that meets Bahrain's revised laws, legislation, strategies and plans.

#### *7.2.1.6 Stage 6: Rehabilitation/Upgrading*

During an unfortunate continuous sewerage system failure, or if the sewerage system has reached its lifespan, rehabilitation or upgrading plans will be required for the sewerage system. This stage will be identical to the first and second stages, but more reasoning needs to be discussed based on the timing of this period to determine whether the sewerage life cycle was expected to end. In addition, validation should be performed for both the project's goals and the sustainability indicators to achieve the most convenient sustainable indicators.

### 7.2.2 Assessing the sustainability of Muharraq deep-gravity sewer

The Muharraq deep-gravity sewer project will be used to demonstrate the procedure of the developed sustainability assessment framework. This project was the first of its kind in Bahrain, as no deep-gravity sewer existed prior to this project. This project was completed in June 2014. Therefore, it is a good example for demonstrating the application of the sustainability assessment framework in evaluating the various completed stages of the project with the focus on the application in the current operation and maintenance. The application is limited based on the availability of the data. The first four stages are presented in detail below:

the current sewerage system; contextualizing the project; planning, designing and implementing the project; and operation and maintenance. In addition, the following sections cover the application of the sustainability assessment through the various stages of the framework.

#### *7.2.2.1 Stage 1: Sewerage System*

The first stage of the assessment starts with the existing sewerage system. The Muharraq deep-gravity sewer project is considered to be an upgrade of the existing sewerage system. NMPSES 2009 initiated this project initiative, and the project was aimed at improving the existing sewerage network while meeting the increasing demands of major Muharraq island developments, such as the East Hidd Housing Project, Diyar Al Muharraq, Investment Gateway Bahrain, Dilmunia, Al Saya, the airport extension and heritage historical buildings. Because this project is an upgraded project for an existing system, considering the existing data and the documented reports is essential. Thus, in 2009, the NMPSES identified the actual condition during that period and laid out the reasons for proposing this project. Furthermore, this was proposed as a short-term measure and would be carried out within four years of the issuance of the master plan in 2009. It was completed in 2014. Therefore, this stage no longer makes a difference in the project outcome, as the current situation of the sewerage differs from its previous situation. Meanwhile, the purpose of this stage is to take advantage of the previous experiences of this project and to demonstrate the importance of the continuous monitoring of the system. As this project is a completed project, further explanation of this stage will merge with the fourth stage, which is operation and maintenance. Furthermore, due to the accomplishment of implementing this project within the proposed period and by following the regulations, policies and plans of Bahrain, ultimately, the goal was to create a more sustainable infrastructure.

#### *7.2.2.2 Stage 2: Contextualizing the Project*

The strategic aim of this project was to upgrade and improve the sewerage network to serve the growing demands on Muharraq Island while maintaining a functional sewerage system, thus ensuring a good daily quality of life. Contextualizing the project will be based on reducing the risks of sewerage failure and contribute to achieving a sustainable sewerage system during the life cycle of the project within the sewerage network policies and regulations in Bahrain. With regard to reducing the risk of sewerage failure, the Muharraq deep-gravity sewer would increase the capacity of the sewerage system, which has been described as a significantly overloaded system that runs the risk of being overwhelmed. In terms of the contribution to achieving a sustainable sewerage system, this project has come up against some social, environmental and policy concerns that should be outlined. For the economy, the concerns will be related to the life-cycle cost of the project, including a 27-year build, own, operate and transfer (BOOT) scheme contract; years of operation and maintenance; and essentially the entire life of the project, which is designed to operate for more than 80 years. Moreover, the social concerns will be related to public awareness, public health and safety, the stakeholder's satisfaction, population growth on a limited island, serving vital community-based services, and ensuring good quality of life. As the project is located on an island and some of the project areas have been reclaimed, the water table is high, and a high risk of the infiltration of the system exists. However, in the event of sewage leakage, there is a high risk of the contamination of the sea, which can have a major negative impact on the environment. In addition, considering all of the issues posed, this project follows the laws, decrees, regulations and institutional practices of Bahrain. Any issues that threaten to keep the project from following the policies should therefore be discussed.

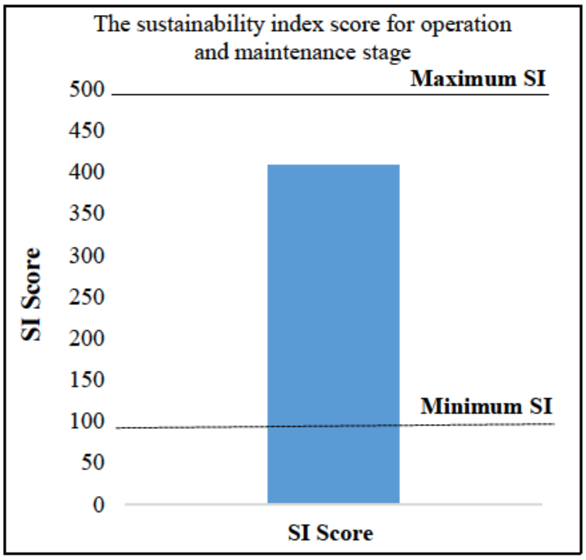
The significance of this stage is to define the appropriate sustainability criteria and their indicators, which suits the project context. The criteria for choosing these indicators are related to their criticality, the availability of data, monitoring ability, and the ability to capture long-standing issues. The reports obtained regarding the deep-gravity sewer project in Muharraq were reviewed, such as the appraisal report, environmental management plan, technical specification report, hydraulic analysis, environmental impact assessment and operation and maintenance report of 2019. They were used to determine suitable indicators that serve the project context. Thus, this information was presented to sewerage system experts in Bahrain to choose the most suitable indicators deemed crucial for the project. These are indicators that have the potential to be technically feasible for the institutions to monitor over the project's life cycle. A twenty-two sustainability indicators were selected to assess the Muharraq deep-gravity sewer project as can be seen in Appendix K. Then, the maximum and minimum target values for every indicator were identified to show the impact of the project on every indicator and to compare these indicators throughout various stages. The range between a maximum and minimum target value was further divided into five sets, and each set has a scale that goes up to 5 (1 = Highly negative impact; 2 = Negative impact; 3 = Neutral; 4 = Positive impact; 5 = Highly positive impact) (Appendix K). The previous scores will be used to identify the sustainability index for this project, which will, in turn, be used for further stages.

#### *7.2.2.3 Stage 3: Planning, designing and implementing the project*

For this project, an important limitation has to do with the unavailability of the information needed to execute this stage as well as the lack of any practical impact on the implementation of the project. As this project has already been implemented, the application would be limited to discussing what should be done. All of the reports related to planning, designing and implementing should be reviewed to find the alternatives discussed before implementing the selected sewer system. The assessment could be done without considering the proposed alternatives; however, it is recommended to use the alternatives and then to compare them to get the most benefit from the framework, as this will reveal whether the chosen alternative is the most sustainable choice. Some of the available reports show that a variety of alternatives for the system have been identified; however, a detailed description has not been obtained.

#### *7.2.2.4 Stage 4: Operation and Maintenance*

The project was completed in 2014, and is in operation. It is the longest stage during the life cycle of the sewerage system. This sewerage system was planned to operate for 80 years, and during this long period, monthly reporting has been taking place to monitor the performance of the sewerage system. Therefore, this stage relies on the monthly reports and will involve assessing the performance of the sewerage system. This framework is focused on assessing the sustainability of sewerage projects throughout their life cycles, and implementing this framework will show the extent of achieving sustainability based on the objectives, criteria and suitability indicators. This stage is considered to be critical, as it will provide a hint as to whether the previous stages were properly managed and if the desired level of sustainable sewerage has been reached. It will also assess the current stage and define the extent of reaching sustainability. From the previously selected indicators (Appendix K), the SI score for this stage was attained through implementing the MCA with the 22 sustainability indicators (Appendix L). The SI score was 407.55 as can be seen in Figure 29, which is closer to the maximum score of 500. The extent of reaching the criteria is presented in Figure 29; it shows that the score overall is in a fair distribution among all of the desired criteria scores. However, the strategic technical aspects, as well as the policy and institutional aspects, showed some decline, which will require further attention to reach the maximum score of sustainability.



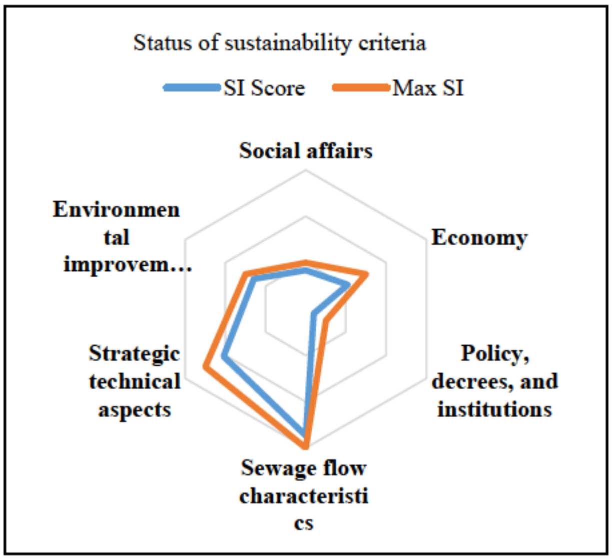




Figure 29: The sustainability index score for the operation and maintenance stage and the criteria status

#### *7.2.2.5 Stage 5: Periodic Assessment*

This stage is performed in the case of a significant event, such as updating the master plan or an unfortunate sewerage failure. In such events, the reports, plans, policies and strategies will be reviewed to pinpoint any changes that could have taken place. In the meantime, sustainability indicators must be reassessed, and their ability to be implemented through the various phases of the project must be checked. Thus, the modified sustainability assessment framework will be prepared—one that aligns with the revised strategies, regulations, laws and plans of Bahrain.

#### 7.2.2.6 *Stage 6: Rehabilitation/Upgrading*

For this project, this stage is probably very far away, as the lifespan of the deep-gravity sewer is 80 years. However, in the event of a continuous sewerage system failure, or if the sewerage system has reached its maximum capacity, the sewerage system will require rehabilitation or an upgrade. At that time, this stage would be like the first and second stages of the assessment. However, further justification will need to be discussed based on the performance of the project throughout the entire period. Eventually, to achieve the most convenient sustainable indicators, validation should be done for both the sustainability indicators and the project's goals.

### 7.2.3 Assessing the sustainability of Madinat Khalifa

The third project involves the Madinat Khalifa sewerage network projects. This project is different from the previous projects, as it is a sewerage network for a new city and not a main sewerage line. Therefore, it includes diverse sewerage projects. Furthermore, the project is still in its very early stages, and the application has been limited to the basis of the availability of the data. Therefore, it will serve as a guideline for any new sewerage network. The following section presents the implementation of the sustainability assessment across the various stages of the project.

#### *7.2.3.1 Stage 1: Sewerage System*

In the first stage, the current sewerage system should be considered in the project area. For this project, it is a new housing project in the new Khalifa City. No sewerage system previously existed in the project area. However, the area includes some of the current residential buildings that use septic tanks, which would be replaced through the implementation of this sewerage project. In addition, the NMPSES 2009 did not initiate this project, so extra attention should be paid to this area of the project. For example, a high amount of free land exists around this city, which leads to an ambiguous future for the fate of this land. Therefore, it is possible that any future developments surrounding the city would change the land zoning of Khalifa City or affect the proposed sewerage system capacity. Moreover, in addition to the housing project, the new project will connect existing villages nearby, including their amenities, such as mosques, schools, shopping malls, health facilities and parks. An appropriate sewerage network capable of managing the amount of flow should also exist to protect the atmosphere from any potential pollution, whether by exfiltration, flooding or odour. This will help to preserve public health, safety, and quality of life. Eventually, any sewerage project should follow the regulations, plans and policies of Bahrain.

#### *7.2.3.2 Stage 2: Contextualizing the Project*

The main purpose of this project is to serve a new housing project, serve some existing residential buildings and accommodate nearby villages, such as Askar and AlDur. The project was contextualized with the goal of reducing the risk of sewerage failure and achieving a sustainable sewerage network over the project's life cycle, while also considering the sewerage system policies and regulations in Bahrain. For the purpose of reducing the risk of wastewater sewerage failure, the project will provide a sewerage system for some existing residential buildings that have been using septic tanks, which directly impact the environment and pollute the groundwater. Furthermore, in the event of exfiltration, a greater chance exists that the sewage will directly impact the beaches, as it is very close to the project area. With regard to contextualizing the project to achieve a sustainable sewerage scheme, this project must address concerns relevant to the economy, social life and the environment, as well as the strategy that should be followed. For the economy, the project is still in its very early stages, so no data are available regarding matters such as budget allocation and operation and maintenance costs. However, the project will provide a better infrastructure that meets the economic development needs in the project area. For social concerns, it is necessary to serve the community and provide good quality of life by protecting public health and safety. It is also important to consider the satisfaction of stakeholders and to develop community awareness regarding the services. For the environment, in addition to getting rid of septic tanks, the sewerage project may allow for a sewerage upgrade for nearby villages, as it will increase the capacity of the sewerage system. Moreover, this project contains a regional STP that will replace minor scattered STPs, which will further improve the management of the wastewater and reduce the environmental impact. In addition, taking into consideration all of the concerns raised, this project should follow the policies, decrees, regulations and institutional practices of Bahrain. Any concerns that may keep the project from following the policies should therefore be addressed.

In this stage, appropriate sustainability indicators with criteria that fit into the context of the project should be identified. However, as the project is still barely in the contextualizing stage, the determination of the sustainability indicators with the help of the sewerage experts will not be included. However, how it will be done will be mentioned. The indicators will be chosen from Table 15 and 17 in Chapter 5, and the chosen indicators should be based on data availability, purpose, monitoring, criticality and the ability to capture long-standing possible issues. This is possible to do by reviewing the technical data of the project. Then, the experts will indicate the maximum and minimum target values for each indicator to identify the SI. This is a similar process to the previous implementations as can be seen in Appendix H and Appendix K. In addition, the following stages will be limited due to data unavailability.

#### *7.2.3.3 Stage 3: Planning, designing and implementing the project*

For this stage, the project will feature some data related to planning, designing and construction, which will be used for the implementation of the sustainability assessment. These data will include several alternatives that will be studied to define the last alternative. Comparison could be done to determine the most sustainable option. However, the assessment could also be implemented without comparing various alternatives. After this stage, the SI score will be determined, and the likelihood of meeting certain criteria will be clear. This will help with developing a better understanding of the sewerage project and its likelihood of meeting the desirable sustainability level within the range of maximum and minimum sustainability, as well as everything under the objectives and criteria of the developed sustainability assessment framework.

*7.2.3.4 Stage 4: Operation and Maintenance*

This stage will start directly after the construction of the sewerage network, with the sewerage project deemed a long-lifespan infrastructure. Thus, during operation and maintenance, the extent of reaching the desired sufficient performance levels and the existence of proper operation and maintenance will be assessed and reported. In this stage, further improvements to the developed sustainability assessment could be implemented. Any unpredicted issues should also be addressed to help with future projects.

*7.2.3.5 Stage 5: Periodic Assessment*

This stage will be implemented in the event of a major event, such as updating the master plan or a sewer failure. Mainly, this stage is based on reviewing the policies, strategies, plans and reports to look for any changes that have arisen. Meantime, the sustainability indicators must be revalidated, and their ability to be implemented throughout the various project stages must be checked. Finally, the output of this stage should be a modified sustainability assessment framework that follows the updated policies, regulations, strategies and plans of Bahrain.

*7.2.3.6 Stage 6: Rehabilitation/Upgrading*

During the case of a continuous sewerage system failure, or if the sewerage system has reached its fullest capacity, then the sewerage system will require rehabilitation or upgrading plans. This stage will be similar to the first and second stages; however, further justification needs to be addressed based on the timing of this stage to determine whether it was predicted to be at the end of the sewerage lifespan. Furthermore, validation should be performed for both the project’s goals and the sustainability indicators to achieve the most convenient sustainable indicators.

### 7.2.4 Assessing the sustainability of sewerage infrastructure projects in different contexts

In this section, the application of the framework will be discussed to clarify its capabilities in a context other than Bahrain. The sustainability framework was constructed while relying on the context of Bahrain. Therefore, the construction of the indicators should be understood to correctly adjust the indicators. The objectives and their criteria are directly related to policies, regulations and institutional plans. Moreover, the sustainability indicators are based on their criticality, the availability of data, intent, monitoring and the ability to capture long-standing problems.

The developed assessment will be applicable taking into account the different characteristics of the wastewater collection system, including policies, regulations, the type of wastewater system (such as conventional gravity system, pressurised system, combined system, separate system) and the way in which wastewater projects are managed. Thus, the experts of the sewerage system needs to make an adjustment for the objectives, criteria and sustainability indicators of the assessment in the new context. All of this should be done while keeping in mind the importance of following the policies, regulations, strategies and plans of that context. What helps a system to sustainable in one context may not help in another context. In other words, what is considered to be sustainable for one system may not necessarily be sustainable for another system, and that is because the economic, social and environmental concerns differ from one context to another. For example, if a country has a lower economic ability, the sewerage system may not even be deemed reasonable for its context, and vice versa. Another example is if the sewerage system is a combined system that contains sewage and storm water. This will add an entirely new element that needs to be considered among the many sustainability indicators. Therefore, the closer the context is to Bahrain, the easier and more logical the application will become.

## 7.3 Discussion and Conclusion of the Implementation of the Developed Framework

The developed sustainability assessment framework was applied to three case studies of sewerage projects in Bahrain. The application clearly presents the importance of the assessment and its enrichment for decision-making based on knowing the impact on all aspects of sustainability throughout the various stages of the sewerage project. However, the application was limited to the current stages of the projects, usefulness and data availability. In the first project, the project was in the planning stage; therefore, the assessment was performed until the third stage (planning, designing and implementing). The outcome of the assessment shows that the assessment has the ability to highlight and contextualize the project toward sustainability by further considering several alternatives and linking them to the ability to make the project more sustainable. Meanwhile, a sustainability assessment can be implemented without comparing various alternatives. In this situation, it would still have maximum and minimum targets of the sustainability that clarify the score of the project between them. However, it is more valuable to identify the alternatives and to apply the indicators to the various alternatives to show the more sustainable options. This would help decision-makers or managers to make a more solid decision with respect to sustainability. The second project was in the operation and maintenance stage; therefore, the assessment focused more on the fourth stage, which is the operation and maintenance stage, as it was not covered in the other projects. The findings show that some indicators cannot be applied in certain stages due to the absence of sufficient information for some indicators. Therefore, the assessment shows the application of some indicators to the current performance measures that have been reported in monthly reports on operation and maintenance. Doing this will not affect the value of the assessment in that stage, as the maximum and minimum target values will be based on the existing data. The third project was in a very early stage, so the application was somehow limited. It was presented as a guideline that shows the importance of every stage as well as assessment ability. Furthermore, the assessment gives decision-makers the opportunity to monitor the consequences of their decisions as well as enhance the robustness of their decisions toward sustainability (Cinelli, Coles and Kirwan, 2014). The developed framework has covered the sustainability issues of the sewerage projects in Bahrain, which makes it unique, as it helps with justifying or avoiding possible future issues. It will help with tracking issues that should be addressed through updating the sustainability indicators, which will provide greater transparency for stakeholders over time.

The developed sustainability assessment relies on the sustainability indicators, as 43 indicators have been identified. During the application, ideally, the sustainability assessment indicators should be selected within the earliest stages of the sewerage project. Also, the experts of that project at that time should provide weightage indicating the importance of the indicators, as well as the scores for every indicator. The minimum and maximum target values should also be determined to monitor performance through the life cycle of the project in a more accurate and beneficial way (Lindholm, Greatorex and Paruch, 2007). The identified sustainability indicators would be appropriate for the majority of the sewerage projects in Bahrain; however, they will still have to be adjusted for some cases. Thus, having specific indicators that are suitable for every scenario and context is far from possible at the moment (Juwana, Muttil and Perera, 2012; Waas et al., 2014).

With the developed framework, the decision-makers can use a simple method for conducting the sustainability assessment. However, some challenges still might hamper the ability to achieve sustainability. The appropriate sustainability indicators and criteria depend on the objectives of the assessment, and the selection of these indicators, the measuring parameters, the criteria and the assigning of weights to them weights are relative due to the decision-makers' varying points of view and areas of expertise. In addition, some measurement parameters of some indicators are considered to be complex and thus would require careful attention in certain stages. It is possible to adjust the measuring parameters as long as this change does not affect the significance of the indicator. Also, some indicators are applicable only for certain stages and cannot be applied to other stages. Meanwhile, applying the assessment in every stage would generate a database based on the sustainability indicators that would keep capturing the extent of reaching the desired sustainable system. Therefore, the ultimate benefit of the assessment should be verified both now and in the future in the best manner possible.

### 7.4 Recommendation

After developing the framework and by going through its application with a detailed discussion, findings from the framework's development and an examination of its application suggest:

- The NMPSES 2009 was created to be followed; however, in the current situation, some projects show massive delays, which obviously proves that the NMPSES wasn't followed perfectly. Thus, the lack of following the master plan is either because of the NMPSES that didn't take into account all the considerations and didn't prepare a realistic plan or that unexpected circumstances have occurred. Therefore, the master plan should be updated and further clarified and then updated recommendations should be provided. For example, the following aspects should be included:
    a) Consider the allocated budget for Sanitary Engineering Affairs Projects while preparing the plan, and the plan should not go far from what can be done with the financial limitations.
    b) Go through the procedure for the allocation of service corridors in order to properly assign sewer corridors, as improper assigning sewer corridors can cause delays and unexpected costs in the construction stage due to unforeseen issues. Also consider allocating land parcels in new developments for public sewerage services.
    c) Consider implementing green technology solutions such as solar energy facilities in major pumping stations and other sewerage facilities, if applicable.
- The Ministry of Works should encourage enhancing communication between all other infrastructure authorities to avoid any conflict which impedes public interests. It also should consider the establishment of a framework for sewerage service tariffs, as

sewerage service is currently free of charge to all citizens in Bahrain, which could lead the public to feel an absence of responsibility and importance about the sewerage system. Moreover, serious consideration should be given to using the proper software throughout the different sections, such as for operations, maintenance and asset management.

- Further attention should be paid to the current employees, as they are the core of a successful institution; thus, there is a definite need for continuous improvement for them as follows:
    a) Establish a work continuity programme to ensure that all available experience is passed on to the next generation in order to avoid gaps between the current staff and newly hired engineers.
    b) Develop a training programme for newly recruited engineers in the field, concentrating on the key skills and expertise required for each particular segment within each directorate.
    c) Further improve the employees' engineering skills to better manage the sewerage assets by strengthening employees' needed expertise through workshops, training programs and academic studies while considering the current approaches, such as the orientation towards PPP contracts.
- A closer link needs to be established with the public to better meet their needs and make them aware of the sewerage system, and that can be done through:
    a) Initiating a campaign to clearly explain to the public the impact of misusing the sewerage network, such as by oil and grease dumping.
    b) Solving the storm water drainage issue and improving public awareness about opening sewerage manhole covers, which ultimately affects the sewerage system.

## 7.5 Chapter Summary

This chapter showed the application of the developed sustainability assessment framework in three case studies: the case studies of the Hamad Town-Tubli trunk sewer, Muharraq deep-gravity sewer and Khalifa City sewerage network. It began with the clarification of the framework objectives, criteria and indicators. Then, it covered the application process through the various stages of the projects, clarifying the ability to implement the projects within various contexts other than that of Bahrain. The chapter concluded with further discussion and a conclusion concerning the sustainability assessment framework and its application.

# Chapter 8: Conclusion

During its life cycle the sewerage system faces a number of obstacles that could jeopardize its sustained efficiency, including ageing impacts, underfunding, violent environmental incidents (such as heavy rainfall), inappropriate operation and maintenance activities, and poor construction or inadequate design. These factors lead to an enhanced risk of failures such as sewerage leakage, overflow and odour issues. Such issues may have serious impacts on the environment, the economy, the public health and safety and on the service lives of the assets. Therefore, maintaining an efficient, functional and sustainable sewerage system is crucial to achieving environment conservation, maintaining public health, providing services to attract investors and eventually maintaining the daily quality of life. In other words, providing a sustainable sewerage system requires designing a system and ensure that it fulfils its purpose over its lifespan, thereby preserving the quality of life for users at the lowest possible cost. Unfortunately, only a few studies have focused on assessing sustainability at the project level and, to the best of researchers' knowledge, no studies have assessed the sewerage system during the entire life cycle of the project. The absence of such a tool to assess the sustainability of a sewerage infrastructure project throughout its life cycle makes achieving a sustainable sewerage system an unclear matter. Therefore, and in response to that matter, this thesis has established a sustainability assessment framework for sewerage infrastructure projects (Chapter 4) that focus on all aspects of sustainability throughout the project life cycle.

The developed framework assesses the sustainability of sewerage infrastructure projects throughout their life cycles on the basis of two main objectives: the contribution to sustainability and to reduce the risk of sewerage failure in the context of sewerage projects in Bahrain. The decision support system is built in line with the project life cycle and its associated six stages: 1) the sewerage system stage, which involves identifying and understanding the existing sewerage network; 2) then contextualizing a new project according to the sustainability of the wastewater collection system; 3) the planning, designing and constructing stage, which includes incorporating the sustainable issues into the project; 4) the operation and maintenance stage that ensures the sustainability performance within the project; 5) the periodic assessment stage that continues the effective sustainability assessment; and 6) the rehabilitation/upgrading stage in which the sustainability assessment occurs in the case of needed rehabilitation or upgrading. A multi-criteria analysis (MCA) methodology has been implemented by the framework which uses sustainability criteria and indicators to assess the project and provide the sustainability index. The research further outlines the process of selecting indicators, specifying the indicator weightage and scores as well as defining the sustainability index for several stages of the project. Furthermore, the framework-computing process follows methods that can be easily applied by the decision-makers.

Throughout the accomplishment of this thesis, several methodologies were adopted to achieve the research objectives, including an extensive review of the relevant literature (Chapter 2) and of the secondary data that were utilized to clarify the research problem and sustainability issues in Bahrain (Section 2.5). Then, a conceptual sustainability assessment framework including sustainability indicators were developed that determined the viability of the sewerage infrastructure projects. In addition, a mixed methods approach was used to enhance the framework that verified the effectiveness of the developed framework. The outcome of this project was categorising forty-three sustainability indicators into six criteria: strategic technical aspects, sewage flow characteristics, economy, social affairs, environmental improvement and ‘policy, decrees, and institutions’.

Once the final sustainability assessment framework was developed, it was then applied to three case studies of sewerage infrastructure projects in Bahrain, which were the Hamad Town-Tubli trunk sewer, the Muharraq deep gravity sewer and the Khalifa town sewerage network. The outcome indicates the importance of such assessments as it enriches the decision making based on knowing the impact of each aspect of sustainability throughout the sewerage project’s life cycle. The framework has the capability to contextualise the sewerage project by further considering a number of alternatives and linking them to the ability to move the project in a more sustainable direction. It is also capable of monitoring the consequences of decisions, capture sustainability issues, upgrade sustainability indicators and strengthen sustainability decisions over time.

## 8.1 The Implication of the Thesis

The developed sustainability assessment framework provides a consistent assessment pathway over the life cycle of the sewerage infrastructure projects. This framework can help decision-makers in making a more solid decision in respect of sustainability and enhancing the robustness of the decisions that would orient toward sustainability. Instead of having an independent assessment for each stage of the sewerage projects, the developed framework would improve long-term project management by tracking the sustainability indicators and incorporating possible scenarios. Implementation of the framework will improve current practice, favouring formal rationality, which entails the use of traditional economic appraisals to support decision-making, but omits the inclusion of environmental and social aspects.

Therefore, use of the framework will encourage a tendency toward sustainability, including all of its economic, social and environmental aspects. The knowledge synthesised at different stages of the assessment will lead the current and future generations towards correcting project insufficiency, improving the sewerage system that is proportional to civilization states and ultimately improve the daily quality of life. Moreover, it is a deliberate step towards having a sustainable sewerage system that can solve current and future issues in Bahrain and that will provide greater transparency, thus moving the system toward sustainability over time.

This study has identified forty-three sustainability indicators related to the sewerage infrastructure projects that help reduces the risk of sewerage failure and contributes to sustainable development. These indicators were mainly suitable for the context of Bahrain; however, the research discussed could be applied in other contexts with clarifying the needed adjustments. Meanwhile, this thesis has identified the challenges of the framework implementation including the selection of sustainability indicators and their criteria with the complexity of measuring some indicators within the absence of arranged data that would be available through the assessment application over time.

## 8.2 Limitations

The research described in this thesis carries a number of limitations as follows:

- There were difficulties in communicating with research participants; many required significant follow-up until they responded, particularly the contractors and consultants. Also, a limited number of participants were irrational, and their responses have been rejected; these responses showed a lack of awareness and an ignorance of the importance of research.
- The application of the framework was not perfectly implemented due to the lack of availability of some data from the Ministry of Works as these data were limited for confidentiality reasons, unavailability, avoidance and other circumstances. Therefore, some sustainability indicators have not been considered during the application, which affects the final score of the assessment.
- The identified sustainability assessment framework was mainly based on the context of Bahrain and the survey thus relied on the experts in Bahrain’s sewerage system. Therefore, the usability of the framework mostly serves the context of Bahrain and similar regions.

### 8.3 Recommendation and Future Work

This thesis sheds greater light on the challenges and issues that face the sewerage infrastructure projects throughout its life cycle. Moreover, this research has developed a sustainability assessment framework for sewerage projects that focuses on two objectives: reducing the risk of sewerage failure and ensuring the sustainable development of wastewater-collection systems in Bahrain. This will support the different stakeholders in making better decisions throughout the different stages of projects. Based on the framework's implementation, further research could focus on a different dataset while adjusting the sustainability indicators and expanding them, thus making them more generalized to serve various contexts. Furthermore, the assessment could be developed to include a wastewater treatment plant throughout its life cycle. Also, integrating the framework with software that would simply collect the data, monitor the system through different stages and easily apply the framework would be ideal.

Further future work should focus on other infrastructure projects and the ability to implement the developed framework on other types of infrastructures. Besides, it is possible to develop a generalized framework for infrastructure services by focusing on all aspects of sustainability and could ultimately support sustainable development. Finally, for researchers working in the context of Bahrain or similar regions, face-to-face interviews would be more convenient than the survey as the participants would take it more seriously and the researchers would end up with more reliable data.

## 8.4 References

Abebe Wudineh, F., and N. Chala Kuke. 2015. Evaluation of sewerage system sustainability technically around condominiums areas: A case study in Debre Berhan, Ethiopia. *American Journal of Environmental Protection* 4(6): 318–324.

Agriculture and Resource Management Council of Australia and New Zealand & Australian and New Zealand Environment and Conservation Council. 1997. National Water Quality Management Strategy. Australia: Australian Water and Wastewater Association.

Ainger, C., and R. Fenner. 2014. Sustainable infrastructure – Principles into practice. UK: ICE.

Akhtar, S., B. Reza, K. Hewage, A. Shahriar, A. Zargar, and R. Sadiq. 2014. Life cycle sustainability assessment (LCSA) for selection of sewer pipe materials. Clean Technologies and Environmental Policy 17(4): 973–992.

Aksorn, P., and C. Charoenngam. 2015. Sustainability factors affecting local infrastructure project. *Facilities* 33(1/2): 119–143.

Alayam News (2017). *Sewage overflow in Manama, Bahrain, taken in 22 of July 2017*. [image] Available at: http://akhbar-alkhaleej.com/news/article/1082097 [Accessed 4 Jan. 2018].

Alnoaimi, A. and Rahman, A. (2019). Sustainability Assessment of Sewerage Infrastructure Projects: A Conceptual Framework. *International Journal of Environmental Science and Development*, 10(1), pp.23-29.

Alwasat News (2016). *Sewage overflow in Buri, Bahrain, taken in 11 of November 2016*. [image] Available at: http://www.alwasatnews.com/news/1179067.html [Accessed 8 Jan. 2018].

Alwatan News (2017). *Extreme Rain in Bahrain*. [image] Available at: https://goo.gl/vTCXwJ [Accessed 10 Jan. 2018].

Andersson, K., S. Dickin, and A. Rosemarin. 2016. Towards “sustainable” sanitation: Challenges and opportunities in urban areas. *Sustainability* 8(12): 1289.

Anon, 2004. *A guide to the project management body of knowledge*. Newtown Square, Pennsylvania, USA: Project Management Institute.

Ariaratnam, S., and C. MacLeod. 2002. Financial outlay modeling for a local sewer rehabilitation strategy. *Journal of Construction Engineering and Management* 128(6): 486–495.

Balkema, A., H. Preisig, R. Otterpohl, and F. Lambert. 2002. Indicators for the sustainability assessment of wastewater treatment systems. *Urban Water* 4(2): 153–161.

Beheshti, M., and S. Sægrov. 2017. Sustainability assessment in strategic management of wastewater transport system: A case study in Trondheim, Norway. *Urban Water Journal* 15(1): 1–8.

Bloetscher, F. 2011. *Utility management for water and wastewater operators*. Denver: American Water Works Association.

Cardoso, M., Coelho, S., Praça, P., Brito, R. and Matos, J. (2005). Technical Performance Assessment of Urban Sewer Systems. *Journal of Performance of Constructed Facilities*, 19(4), pp.339-346.

Cinelli, M., Coles, S. and Kirwan, K. (2014). Analysis of the potentials of multi criteria decision analysis methods to conduct sustainability assessment. *Ecological Indicators*, 46, pp.138-148.

Chang, R., Zuo, J., Zhao, Z., Soebarto, V., Lu, Y., Zillante, G. and Gan, X., 2018. Sustainability attitude and performance of construction enterprises: A China study. *Journal of Cleaner Production*, 172, pp.1440-1451.

Chen, Z., H. Ngo, and W. Guo. 2012. A critical review on sustainability assessment of recycled water schemes. *Science of the Total Environment* 426: 13–31.

Chhipi-Shrestha, G., K. Hewage, and R. Sadiq. 2017. Selecting sustainability indicators for small to medium sized urban water systems using fuzzy-ELECTRE. *Water Environment Research* 89(3): 238–249.

Chung, S., T. Hong, S. Han, J. Son, and S. Lee. 2006. Life cycle cost analysis based optimal maintenance and rehabilitation for underground infrastructure management. *KSCE Journal of Civil Engineering* 10(4): 243–253.

Cinelli, M., Coles, S. and Kirwan, K. (2014). Analysis of the potentials of multi criteria decision analysis methods to conduct sustainability assessment. *Ecological Indicators*, 46, pp.138-148.

Dalal-Clayton, B., and B. Sadler. 2014. *Sustainability appraisal: A sourcebook and reference guide to international experience,* 1st ed. New York: Routledge.

De la Fuente, A., O. Pons, A. Josa, and A. Aguado. 2016. Multi-criteria decision making in the sustainability assessment of sewerage pipe systems. *Journal of Cleaner Production* 112: 4762–4770.

Della Spina, L., I. Lorè, R. Scrivo, and A. Viglianisi. 2017. An integrated assessment approach as a decision support system for urban planning and urban regeneration policies. *Buildings* 7(4): 85.

De Sousa, M., F. Montalto, and S. Spatari. 2012. Using life cycle assessment to evaluate green and grey combined sewer overflow control strategies. *Journal of Industrial Ecology* 16(6): 901–913.

Devuyst, D. 2000. Linking impact assessment and sustainable development at the local level: The introduction of sustainability assessment systems. *Sustainable Development* 8(2): 67–78.

Diaz-Elsayed, N., X. Xu, M. Balaguer-Barbosa, and Q. Zhang. 2017. An evaluation of the sustainability of onsite wastewater treatment systems for nutrient management. *Water Research* 121: 186–196.

Diaz-Sarachaga, J., D. Jato-Espino, B. Alsulami, and D. Castro-Fresno. 2016. Evaluation of existing sustainable infrastructure rating systems for their application in developing countries. *Ecological Indicators* 71: 491-502.

Ecologically Sustainable Development Steering Committee, 1992. *National Strategy for Ecologically Sustainable Development*. Australia: Council of Australian Governments.

Economic Development Board, 2008. *The Economic Vision 2030 of Bahrain*. Manama, Bahrain.

Ellis, J., and J. Bertrand-Krajewski. 2010. Assessing infiltration and exfiltration on the performance of urban sewer systems (APUSS). *Water Intelligence Online* 9.

Fatta-Kassinos, D., I. Kalavrouziotis, P. Koukoulakis, and M. Vasquez. 2011. The risks associated with wastewater reuse and xenobiotics in the agroecological environment. *Science of the Total Environment* 409(19): 3555–3563.

Fernández-Sánchez, G., and F. Rodríguez-López. 2010. A methodology to identify sustainability indicators in construction project management—Application to infrastructure projects in Spain. *Ecological Indicators* 10(6): 1193–1201.

Finkbeiner, M., E. Schau, A. Lehmann, and M. Traverso. 2010. Towards life cycle sustainability assessment. *Sustainability* 2(12): 3309–3322.

Graymore, M., N. Sipe, and R. Rickson. 2010. Sustaining human carrying capacity: A tool for regional sustainability assessment. *Ecological Economics* 69(3): 459–468.

Grigg, N. 2012. *Water, wastewater, and stormwater infrastructure management*. Boca Raton, FL: Taylor & Francis.

Halfawy, M., L. Dridi, and S. Baker. 2008. Integrated decision support system for optimal renewal planning of sewer networks. *Journal of Computing in Civil Engineering* 22(6): 360–372.

Harmancioglu, N., F. Barbaros, and C. Cetinkaya. 2012. Sustainability issues in water management. *Water Resources Management* 27(6): 1867–1891.

Heijungs, R., G. Huppes, and J. Guinée. 2010. Life cycle assessment and sustainability analysis of products, materials and technologies. Toward a scientific framework for sustainability life cycle analysis. *Polymer Degradation and Stability* 95(3): 422–428.

Hoffmann, B., S. Nielsen, M. Elle, S. Gabriel, A. Eilersen, M. Henze, and P. Mikkelsen. 2000. Assessing the sustainability of small wastewater systems: A context-oriented planning approach. *Environmental Impact Assessment Review* 20(3): 347–357.

Husbands, C., and P. Dey. 2002. Social impact assessment of a sewerage project in Barbados. *Impact Assessment and Project Appraisal* 20(3): 215–223.

Jones, S., and C. Silva. 2009. A practical method to evaluate the sustainability of rural water and sanitation infrastructure systems in developing countries. *Desalination* 248(1–3): 500–509.

Juwana, I., N. Muttil, and B. Perera. 2012. Indicator-based water sustainability assessment — A review. *Science of the Total Environment* 438: 357–371.

Kaur, H. and Garg, P., 2019. Urban sustainability assessment tools: A review. *Journal of Cleaner Production*, 210, pp.146-158.

Kivilä, J., M. Martinsuo, and L. Vuorinen. 2017. Sustainable project management through project control in infrastructure projects. *International Journal of Project Management* 35(6): 1167–1183.

Keong, C. and Cheng, D., 2014. Longest multi curvature sewer tunnel in the middle east. Water New Zealand Journal.

Koops, B. J., I. Oosterlaken, H. Romijn, T. Swierstra, and J. van den Hoven. 2015. *Responsible innovation 2: Concepts, approaches, and* applications. New York, : Springer.

Korving, H., F. Clemens, and J. van Noortwijk. 2006. Statistical modeling of the serviceability of sewage pumps. *Journal of Hydraulic Engineering* 132(10): 1076–1085.

Krajangsri, T., and J. Pongpeng. 2017. Effect of sustainable infrastructure assessments on construction project success using structural equation modeling. *Journal of Management in Engineering* 33(3): 04016056.

Li, W., H. Yu, and Z. He. 2013. Towards sustainable wastewater treatment by using microbial fuel cells-centered technologies. *Energy and Environmental. Science.* 7(3): 911–924.

Lienert, J., M. Duygan, and J. Zheng. 2016. Preference stability over time with multiple elicitation methods to support wastewater infrastructure decision-making. *European Journal of Operational Research* 253(3): 746–760.

Lienert, J., L. Scholten, C. Egger, and M. Maurer. 2014. Structured decision-making for sustainable water infrastructure planning and four future scenarios. *EURO Journal on Decision Processes* 3(1–2): 107–140.

Lindholm, O., J. Greatorex, and A. Paruch. 2007. Comparison of methods for calculation of sustainability indices for alternative sewerage systems—Theoretical and practical considerations. *Ecological Indicators* 7(1): 71–78.

Lounis, Z., and T. McAllister. 2016. Risk-based decision making for sustainable and resilient infrastructure systems. *Journal of Structural Engineering* 142(9): F4016005.

Marlow, D., M. Moglia, S. Cook, and D. Beale. 2013. Towards sustainable urban water management: A critical reassessment. *Water Research* 47(20): 7150–7161.

Materials Engineering Directorate, 2016. *Quality Assurance Report at Ministry of Works Projects*. QA Report No. 4/2016. Manama, Bahrain: Ministry of Works, pp.4-6.

Ministry of Works, 2009. *NATIONAL MASTER PLAN FOR SANITARY ENGINEERING SERVICES*. Manama, Bahrain: Ministry of Works.

Ministry of Works, 2010. *Design Group Manual*. Manama, Bahrain: Ministry of Works, pp.6-13.

Ministry of Works, 2011a. *Construction Group Manual*. Manama, Bahrain: Ministry of Works, pp. 8-17.

Ministry of Works, 2011b. *Planning and Development Group Manual*. Manama, Bahrain: Ministry of Works, pp.7-51.

Ministry of Works, 2012. Network *Group Manual*. Manama, Bahrain: Ministry of Works, pp. 7-20.

Mobley, R., 2002. *An introduction to predictive maintenance*. 2nd ed. Amsterdam: Butterworth-Heinemann, pp.413-416.

Molinos-Senante, M., T. Gómez, M. Garrido-Baserba, R. Caballero, and R. Sala-Garrido. 2014. Assessing the sustainability of small wastewater treatment systems: A composite indicator approach. *Science of the Total Environment* 497–498: 607–617.

Molinos-Senante, M., T. Gómez, R. Caballero, F. Hernández-Sancho, and R. Sala-Garrido. 2015. Assessment of wastewater treatment alternatives for small communities: An analytic network process approach. *Science of the Total Environment* 532: 676–687.

Murray, A., I. Ray, and K. Nelson. 2009. An innovative sustainability assessment for urban wastewater infrastructure and its application in Chengdu, China. *Journal of Environmental Management* 90(11): 3553–3560.

Muga, H., and J. Mihelcic. 2008. Sustainability of wastewater treatment technologies. *Journal of Environmental Management* 88(3): 437–447.

Nansubuga, I., N. Banadda, W. Verstraete, and K. Rabaey. 2016. A review of sustainable sanitation systems in Africa. *Reviews in Environmental Science and Bio/Technology* 15(3): 465–478.

Navarro, I., Yepes, V. and Martí, J., 2019. A Review of Multicriteria Assessment Techniques Applied to Sustainable Infrastructure Design. *Advances in Civil Engineering,* 2019, pp.1-16.

Nayyar, M. 2000. *Piping handbook*. New York: McGraw-Hill.

Neshaei, S., A. Ahmadnejad, F. Yousefi, and F. Ghanbarpour. 2017. Estimating groundwater and rainfall infiltration into sewerage. *International Journal of Sustainable Development and Planning* 12(1): 185–193.

Ness, B., E. Urbel-Piirsalu, S. Anderberg, and L. Olsson. 2007. Categorising tools for sustainability assessment. *Ecological Economics* 60(3): 498–508.

Office of the Deputy Prime Minister, 2005. *Sustainability Appraisal of Regional Spatial Strategies and Local Development Documents: Guidance for Regional Planning Bodies and Local Planning Authorities*. London, UK: ODPM.

Optimizing operation, maintenance, and rehabilitation of sanitary sewer collection systems. 2003. Lowell, MA: New England Interstate Water Pollution Control Commission.

Orlov, V., and A. Andrianov. 2014. The selection of priority pipe sections for sewer network renovation. *Applied Mechanics and Materials* 580–583: 2398–2402.

Petit-Boix, A., C. Arnal, D. Marín, A. Josa, X. Gabarrell, and J. Rieradevall. 2017. Addressing the life cycle of sewers in contrasting cities through an eco-efficiency approach. *Journal of Industrial Ecology.*

Petit-Boix, A., N. Roigé, A. de la Fuente, P. Pujadas, X. Gabarrell, J. Rieradevall, and A. Josa. 2015. Integrated structural analysis and life cycle assessment of equivalent trench-pipe systems for sewerage. *Water Resources Management* 30(3): 1117–1130.

Pires, A., J. Morato, H. Peixoto, V. Botero, L. Zuluaga, and A. Figueroa. 2017. Sustainability assessment of indicators for integrated water resources management. *Science of the Total Environment* 578: 139–147.

Plakas, K., A. Georgiadis, and A. Karabelas. 2015. Sustainability assessment of tertiary wastewater treatment technologies: A multi-criteria analysis. *Water Science and Technology* 73(7): 1532–1540.

Pope, J., D. Annandale, and A. Morrison-Saunders. 2004. Conceptualising sustainability assessment. Environmental Impact Assessment Review 24(6): 595–616.

Poveda, C., 2017. *Sustainability Assessment: A Rating System Framework for Best Practices*. 1st ed. Edmonton, Canada: Emerald Group Publishing, 2017.

Poveda, C., and M. Lipsett. 2011. A review of sustainability assessment and sustainability/environmental rating systems and credit weighting tools. *Journal of Sustainable Development* 4(6).

Rahman, M., D. Hagare, and B. Maheshwari. 2015. Framework to assess sources controlling soil salinity resulting from irrigation using recycled water: An application of Bayesian Belief Network. *Journal of Cleaner Production* 105: 406–419.

Read, G. 2004. *Sewers*. Boston: Elsevier.

Remy, C., and M. Jekel. 2008. Sustainable wastewater management: Life cycle assessment of conventional and source-separating urban sanitation systems. *Water Science & Technology* 58(8): 1555.

Ries, M. P. 2016. Sustainability at U.S. urban water utilities: A framework to assess key attributes. Ph.D. diss., University of South Florida

Risch, E., O. Gutierrez, P. Roux, C. Boutin, and L. Corominas. 2015. Life cycle assessment of urban wastewater systems: Quantifying the relative contribution of sewer systems. *Water Research* 77: 35–48.

Rodriguez, C., P. Van Buynder, R. Lugg, P. Blair, B. Devine, A. Cook, and P. Weinstein. 2009. Indirect potable reuse: A sustainable water supply alternative. *International Journal of Environmental Research and Public Health* 6(3): 1174–1203.

Roehrdanz, P., M. Feraud, D. Lee, J. Means, S. Snyder, and P. Holden. 2017. Spatial models of sewer pipe leakage predict the occurrence of wastewater indicators in shallow urban groundwater. *Environmental Science & Technology* 51(3): 1213–1223.

Roux, P., C. Boutin, E. Risch, and A. Heduit. 2010. Life cycle environmental assessment (LCA) of sanitation systems including sewerage: Case of vertical flow constructed wetlands versus activated sludge. Paper presented at the 12th IWA International Conference on Wetland Systems for Water Pollution Control, Venice, October 2010.

Sala, S., B. Ciuffo, and P. Nijkamp. 2015. A systemic framework for sustainability assessment. *Ecological Economics* 119: 314–325.

Sanitary Engineering Operation & Maintenance Directorate Director's Office. (2017). *SEOMD Monthly Report*. June. Manama, Bahrain: Ministry of Works, Municipality Affairs & Urban Planning, pp. 1–13.

Shah, M., A. Rahman, and S. Chowdhury. 2017. Sustainability assessment of flood mitigation projects: An innovative decision support framework. *International Journal of Disaster Risk Reduction* 23: 53–61.

Sharma, A., G. Tjandraatmadja, A. Grant, T. Grant, and F. Pamminger. 2010. Sustainable sewerage servicing options for peri-urban areas with failing septic systems. *Water Science & Technology* 62(3): 570.

Shannon, K., and M. Smets. 2010. *The landscape of contemporary infrastructure*, 1st ed. Rotterdam: NAI.

Shen, L., Y. Wu, and X. Zhang. 2011. Key assessment indicators for the sustainability of infrastructure projects. *Journal of Construction Engineering and Management* 137(6): 441–451.

Siew, R. 2015. A review of corporate sustainability reporting tools (SRTs). *Journal of Environmental Management* 164: 180–195.

Siew, R., M. Balatbat, and D. Carmichael. 2016. A proposed framework for assessing the sustainability of infrastructure. *International Journal of Construction Management* 16(4): 281–298.

Sinha, S., and M. Knight. 2004. Intelligent system for condition monitoring of underground pipelines. *Computer-Aided Civil and Infrastructure Engineering* 19(1): 42–53.

Sodré, F., M. Locatelli, and W. Jardim. 2009. Occurrence of emerging contaminants in Brazilian drinking waters: A sewage-to-tap issue. *Water, Air, and Soil Pollution* 206(1–4): 57–67.

Sustainability reporting statements for wastewater systems. 2012. Alexandria, VA: Water Environment Federation.

Taherdoost, H., 2016. Sampling Methods in Research Methodology; How to Choose a Sampling Technique for Research. *International Journal of Academic Research in Management (IJARM)*, 5(2), pp.22-23.

Teijlingen, E. and Hundley, V. (2002). The importance of pilot studies. *Nursing Standard*, 16(40), pp.33-36.

The World Bank, 2017. *Urban population (% of total)* | Data. [online] Data.worldbank.org. Available at: <https://data.worldbank.org/indicator/SP.URB.TOTL.IN.ZS> [Accessed 4 Oct. 2017].

Tongco, M. 2007. Purposive sampling as a tool for informant selection. *Ethnobotany Research and Applications* 5: 147.

Torgersen, G., J. Bjerkholt, and O. Lindholm. 2014. Addressing flooding and SuDS when improving drainage and sewerage systems—A comparative study of selected Scandinavian cities. *Water* 6(4): 839–857.

Ugwu, O., and T. Haupt. 2007. Key performance indicators and assessment methods for infrastructure sustainability—A South African construction industry perspective. *Building and Environment* 42(2): 665–680.

Ugwu, O., M. Kumaraswamy, A. Wong, and S. Ng. 2006. Sustainability appraisal in infrastructure projects (SUSAIP): Part 2: A case study in bridge design. *Automation in Construction* 15 (2): 229–238.Upadhyaya, J., N. Biswas, and E. Tam. 2014. A review of infrastructure challenges: Assessing stormwater system sustainability. *Canadian Journal of Civil Engineering* 41(6): 483–492.

Vahidi, E., E. Jin, M. Das, M. Singh, and F. Zhao. 2016. Environmental life cycle analysis of pipe materials for sewer systems. *Sustainable Cities and Society* 27: 167–174.

Von Sperling, M. (2007). Wastewater characteristics, treatment and disposal. *London: IWA Publishing*, pp.9-28.

Waas, T., J. Hugé, T. Block, T. Wright, F. Benitez-Capistros, and A. Verbruggen. 2014. Sustainability assessment and indicators: Tools in a decision-making strategy for sustainable development. *Sustainability* 6(12): 5512–5534.

West, C., S. Kenway, M. Hassall, and Z. Yuan. 2016. Why do residential recycled water schemes fail? A comprehensive review of risk factors and impact on objectives. *Water Research* 102: 271–281.

Westland, J. 2006. *The project management life cycle*. London: Kogan Page.

Zhang, J. and Ma, L., 2020. Environmental Sustainability Assessment of a New Sewage Treatment Plant in China Based on Infrastructure Construction and Operation Phases Emergy Analysis. *Water*, 12(2), p.484.

Zhou, J., and Y. Liu. 2015. The method and index of sustainability assessment of infrastructure projects based on system dynamics in China. *Journal of Industrial Engineering and Management* 8(3).

Zhou, G., Gu, Y., Yuan, H., Gong, Y. and Wu, Y., 2020. Selecting sustainable technologies for disposal of municipal sewage sludge using a multi-criterion decision-making method: A case study from China. *Resources, Conservation and Recycling*, 161, p.104881.

# Appendix A: Sewer Network subdivisions in Bahrain

The overall sewer network has been divided into 7 sub-networks as they are hydraulically independent. The identification of these networks was done for management purposes during the development of the hydraulic model and for the operation and maintenance activities (Ministry of Works 2009). The networks are as follows:

a) Alpha (A) Network: The A network consists of more than 67 km of sewer lines ranging from 150 mm to 1,500 mm in diameter. It is located in an area with high density such as Manama and Adliya. It is also considered one of the oldest sewer networks in Bahrain. In 2008, most of the network was surcharged and most of the pumping stations had reached their maximum capacities. It should be noted that by the time the NMPSES was developed, Muharraq Island was still connected to the A network. However, in 2014, the Muharraq STP and Deep-Gravity Sewerage were commissioned to collect wastewater generated in Muharraq Island. As a result, the A network was relieved, and more details related to this matter are discussed in other sections.

b) Bravo (B) Network: The B network consists of more than 34 km of sewer lines ranging from 150 mm to 1,000 mm in diameter. It is also considered one of the oldest networks in Bahrain with a high density. In 2008, it was found that an essential part of the network was surcharged due to undersized sewers and pumping stations. It covers areas such as Muharraq, Hidd, Arad and other villages. Recently, the B network received major improvements by introducing the deep-gravity sewer lines which relieved of parts of the networks. The remaining issues are limited to minor pumping stations, which are being resolved by upgrading and rehabilitation projects.

c) Charley (C) Network: The C network consists of more than 21 km of sewer lines starting from 150 mm up to 900 mm in diameter and over 26 pumping stations. Part of the area is still not developed and it covers medium population density. It mainly covers areas such as Jidhafs and nearby villages. In 2008, it was found that C network was partially surcharged due to high operation levels in pumping stations and exceeded capacity of pumps.

d) Delta (D), Romeo (R) and Juliet (J) Networks: These consists of more than 79 km of sewer lines ranging from 150 mm to 1,000 mm in diameter. They cover areas such as Sanad, Nuwaidrat, Isa Town and nearby villages. At the time the NMPSES was developed, the assessment performed on the area showed that small areas are surcharged due to high operating levels in pumping stations and exceeded pumping capacities. In the last years, the area experienced incremental growth in commercial development which imposed an additional load on the system.

e) Echo (E) Network: The E network consists of more than 129 km of sewer lines ranging from 150 mm to 1,500 mm in diameter. It covers areas with high populations such as Hamad Town, Malkiya and Sadad. At the time NMPSES was developed, the main trunk sewer lines were already overloaded and some of the main pressure mains were also overloaded.

f) Foxtrot (F) Network: It consists of more than 45 km of sewer lines ranging from 150 mm to 1,000 mm in diameter. The network serves areas located in the north-west side of Bahrain which consists of a group of old villages such as Barbar, Janosan and Budaiya. The area is experiencing rapid growth in both residential and commercial projects. In 2008, the assessment performed for the area showed that the network is heavily surcharged and some of the essential pumping stations were in bad condition.

Due to the high population density of the kingdom, locations of pumping stations can be found in industrial areas, road intersections or even in residential neighbourhoods. As part of the NMPSES, an assessment was done of the pumping stations to detect issues related to their locations. Operation and maintenance staff were consulted to highlight the issues in addition to field surveys to some pumping stations. The results showed that 84% of the locations did not have issues and were identified as satisfactory, whereas 10% had some difficulties and 6% were classified as severe.

# Appendix B: Economic vision 2030 for Bahrain

Economic Vision 2030 for Bahrain has been issued by His Majesty King Hamad Bin Isa Al-Khalifa. It presents the development of the economy with the involvement of the private sector, academia, development organizations and the public sector. The foundation of the Economic Vison is based on the guiding principles of sustainability, competitiveness and fairness. The Bahraini government aims to establish detailed strategic and operational plans to achieve the desired vision. Ultimately, the Bahrain government's goal is to "ensure that every Bahraini household has at least twice as much disposable income – in real terms – by 2030" (Economic Development Board, 2008, p6)

A world-class infrastructure linking Bahrain to the global economy is one of the top aspirations of Bahrainis for their government. In this term, the target is to achieve a complete link to global trade and information by 2030. The government will attract public and private funds to maintain the required infrastructure and services. Further, Bahrain aims to provide outstanding utilities such as electricity, water and gas in addition to services including logistics, public transport and telecommunications. By providing the aforementioned utilities and services, Bahrain will offer a stable base for businesses. As an example of Bahrain's initiatives to advance in infrastructure is to "*improve overall planning processes for land utilization, transportation networks, electricity supplies and other aspects of infrastructure including safety and security measures*." (Economic Development Board, 2008, p19)

# Appendix C: Rehabilitation methods in Bahrain

Methods of rehabilitation used in Bahrain:

a) Open trench: This is done by replacing the existing damaged line with new pipes by excavation. This method is used when the damage in pipes is too high for other methods to be used and when the depth is less than 2.5 m.

b) Robotic: This method is done by entering a small device (robot) in the pipe to repair a certain spot. It is used to repair minor damage in small spots.

c) Pipe bursting: This method does not require a trench because it is done by inserting a new pipe inside an existing line and it is pulled from the other side by a machine. However, it requires a small trench to install the bursting machine. Before performing this method; a study must be made by hydraulic modelling because it will enlarge the existing pipe size. This method is used when a damaged pipe is deeper than 2.5 m.

d) Curing in place: Lines with small or long cracks can be rehabilitated using this method. However, the curing-in-place method is not suitable for pipes with big cracks, as they will collapse. This method does not require a trench because it is done by inserting a liner inside the existing pipe. This liner is highly sensitive to temperature. After that, an air blower is used to blow the liner inside the pipe to form the exact internal shape of the existing pipe. Then a UV light machine is inserted inside the liner to produce heat and solidify the liner. The result of this method is a smaller pipe inside the existing one. Therefore, it is necessary to start a hydraulic model study to check whether the network will cope with the flow after rehabilitation.

e) Tightening in place: This is a trenchless method because it is done by inserting a smaller pipe from a manhole and pulling it from the next one. Hydraulic modelling must be done to check whether the network will cope with the flow after rehabilitation.

# Appendix D: Initiatives and performance indicators

The goal of this objective is to achieve "an efficient, sustainable, environmental friendly network that meets both stakeholders and customers' needs in term of ongoing future development and operation and maintenance requirements."

The risks highlighted in this objective are as follows:

1. Changing the boundary of private lands and zoning of the areas;
2. Infiltration, exfiltration due to age and material.

To achieve this objective, a set of initiatives were developed. These initiatives are as follows:

| No. | Code | Title | Description | Milestones |
|---|---|---|---|---|
| 1 | SES-P02-i01 | Operation & Maintenance of Lines and Trunks | To conduct planned operation & preventive maintenance, repair works and attended emergency works for the lines & trunks. | A. Jet Cleaning of Sewer and Storm Water System<br>B. Tanking Services for Rainfall & General Emergency Services<br>C. Emergency Over-Pumping Works<br>D. Gully Cleaning & Rodent Control Services for Areas 1, 2, 3, 4, 5, 6, and 7<br>E. Operation & Maintenance of Existing Vacuum Sewerage System in Busaiteen Block 228 |
| 2 | SES-P02-i02 | Operation & Maintenance of Pumping Stations | To conduct planned operation & preventive maintenance, repair works, breakdown and attended emergency works for the pumping stations. | F. Operation & Maintenance of Sanitary Network Pumping Stations<br>G. Rewinding of Various Types of Submersible Motor-Pump Set Stators.<br>H. Term Contract for Minor Pumping Stations |

| | | | | |
|---|---|---|---|---|
| | | | | Refurbishment & Emergency Works |
| 3 | SES-P02-i03 | Capital Maintenance & Upgrading of Networks & P station | • The foul sewerage networks rehabilitation has been programmed based on the priority of sewer damage, infiltration through pre-CCTV survey works in accordance with NMPSES and attended emergency repairers.<br>• Continuation of CCTV investigation for sewerage & drainage networks.<br><br>Upgrade, refurbishment and expansion of network & pumping station facilities in accordance with NMPSES. | A. Rehabilitation of Foul Sewerage Networks and Associated Works<br>B. Rehabilitation of Foul Sewerage Networks Phase 1<br>C. Rehabilitation of Foul Sewerage Networks Phases 2 & 3<br>D. Rehabilitation of Foul Sewerage Networks Phases 4 & 5<br>E. Rehabilitation of Foul Sewerage Networks Phase 6<br>F. Investigation & CCTV Survey Work – 2013-2015<br>G. Investigation & CCTV Survey Work – 2016-2018<br>H. Emergency Pumps Supply and Installation<br>I. Rehabilitation/Upgrading of Minor Sewerage Pumping Stations<br>J. Sewerage Works for Various Housing Schemes – Package 1 Rehabilitation and Upgrading of Selective Pumping/Lift Stations in E, F and B Networks<br>K. Sewerage Works For Various Housing Schemes Package 2: West Budaiya Trunk Sewer, |

| | | | | |
|---|---|---|---|---|
| | | | | Blocks 550, 552, 553, 555 & 557 |

The abovementioned initiatives are measured through the following KPIs:

| **No.** | **Measure/KPI** | **Calculation** |
|---|---|---|
| 1 | Number of complaints received compared with year before (flood and odour) | Total number of complains compared with the previous year in the same period |
| 2 | Breakdowns at pumping stations and reported issued | (Total No. breakdowns/No. of stations) x 100 and compared to the previous year's percentage |
| 3 | Infiltration rate | {(average minimum peak discharge before rehabilitation – average minimum peak after rehabilitation) / average minimum peak before rehabilitation} x 100 |

# Appendix E: KAI for infrastructure project

Table 3. Option List of Assessment Indicators for Infrastructure Project Sustainability (Shen et al. 2011).

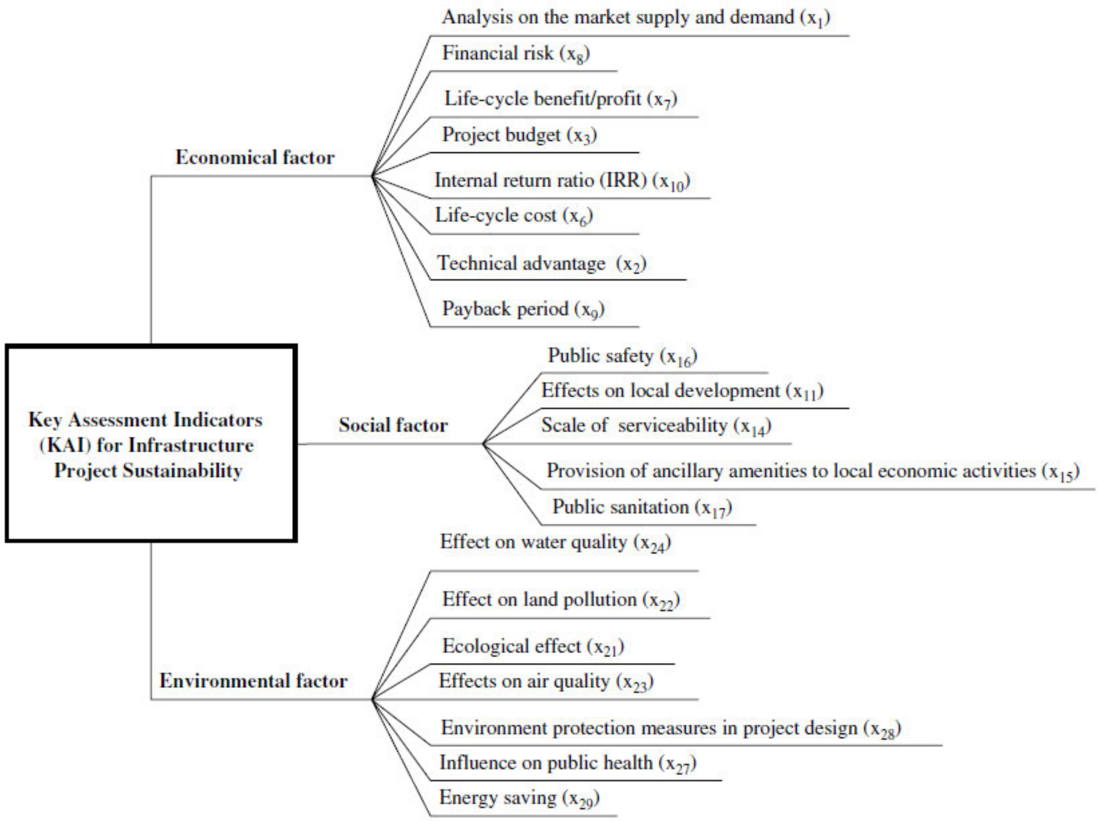



**Fig. 3.** KAIs for infrastructure project sustainability

# Appendix F: Letter to the Ministry of works

## Development of a Sustainability Assessment Framework for the Sewerage Infrastructure System

By Ali Alnoaimi, PhD Candidate, School of Engineering, Griffith University

**Description:** The main objective of this research is to develop a framework for assessing the sustainability of the Kingdom of Bahrain's sewerage infrastructure systems in order to ensure short- and long-term sustainability. Relevant data, reports and studies related to the subject need to be collected from entities such as the Ministry of Works, Municipalities and Urban Planning, and local universities.

**Data and information needed from the Ministry of Works, Municipalities and Urban Planning:**

1. NMPSES (current and old);
2. Storm Water Infrastructure Strategy by Sanitary and Roads Sectors;
3. Standard Operation Procedure for Sanitary Engineering Affairs, or any equivalent documents;
4. The Ministry's Strategic Plan including objectives, measures and initiatives;
5. Hydraulic model reports for all areas of Bahrain;
6. Decision making for funding projects and setting the budget for sanitary engineering projects;
7. How to set the priorities of engineering projects (criteria);
8. Expenditures of the assigned budgets for both Directorates in Sanitary Engineering Affairs (for the last 40 years);
9. QA/QC reports and criteria;
10. Population projection;
11. Zoning maps of Bahrain for the last 30 years;
12. Preventive Planned Maintenance plans and reports;
13. Reports showing condition of major and minor pumping stations in Bahrain;
14. Complaint reports received by Sanitary Engineering Affairs from citizens through available complaint systems;
15. Records of articles and complaints published in local newspapers for the last 10 years;
16. Environmental issues caused by sewage (reports and studies);
17. Regulation and decrees related to sanitation;
18. Any relevant studies or reports related to sustainability of Sanitary Engineering Services in Bahrain.

**Pleases assign a representative from the Undersecretary's Office for further assistance and support.**

Your continued support is highly appreciated.

# Appendix G: Survey of experts' opinions

Dear Sir / Madam,

The purpose of this survey is to gain experts' judgement to contribute to the development of a sustainability assessment framework for sewerage infrastructure projects. Experts are required to evaluate selected indicators and prioritize their significance in different stages of sewerage projects. The potential contributions of this framework will mainly support the decision-making processes and risk-assessment procedures throughout an asset's life cycle to ensure long-term project sustainability and provide greater transparency for stakeholders. This framework focuses on two main aspects: reducing the risk of sewerage failure and contributing to the sustainable development of wastewater-collection systems.

*Best Regards,*

---------------------------------------------------------------------------------------------------------

***Note: If you are using your mobile phone please do not complete the survey as some of the questions will not show properly.***

Please answer the following questions based on your professional experiences. For any additional information or any questions about the survey, please contact Mr. Ali Alnoaimi (E-mail: ali.alnoaimi@griffithuni.edu.au, Mobile: +61(04)35855438) or Dr Anisur Rahman (*a.rahman@griffith.edu.au*).

**Note:** All data generated from this survey are considered confidential and will be used only for research purposes. Completion of the survey indicates consent in participating in this research.

This research conducted under Griffith university ethics reference number **(GU Ref No: 2018/848)**. For future information you can also contact the Griffith University Human Research Ethics via **E-mail:** *Research-ethics@griffith.edu.au* or **Phone**: +617 3735 4375.

## Section 1: Background Information

**1.1 What is your qualification?**

□ Diploma
□ Bachelor degree
□ Master degree
□ PhD
□ Other________________________

**Please specify your qualification: ________________________**

**1.2 What is your field of expertise?** (Tick all that apply)

| Field of Expertise | Disciplines | | | |
|---|---|---|---|---|
| | **Planning** | **Design** | **Construction** | **Operation & Maintenance** |
| **Sewerage Network/ Pumping Stations** | | | | |
| **Sewage Treatment Plants (STP)** | | | | |
| **Treatment Sewage Effluent Network/ Pumping Stations** | | | | |

**1.3 Number of years of professional experience?**

□ Less than 5 years □ 5 to 10 years □ 11 to 15 years □ 16 to 20 years □ More than 20 years

**1.4 Who did you represent in the majority of the projects you were involved in?**

□ Owner (Government Sector) □ Owner (Private Sector) □ Consultant □ Contractor

**1.5 What is your age?**

□ Between 22 to 31 □ Between 32 to 41 □ Between 42 to 51 □ Between 52 to 61 □ Between 62 to 71

**1.6 What is your gender?**

□ Male □ Female

## Section 2: Objectives and Criteria

**Note: The following table shows the objectives and criteria that were considered for the sustainability assessment of the sewerage infrastructure projects.**

| No. | The Sustainability Assessment Objectives and Criteria |
|---|---|
| **1. First Objective: Reduce the risk of sewerage failure** | |
| **1.1** | Strategic technical aspects |
| **1.2** | Sewage flow characteristics |
| **2. Second Objective: Contribute to the sustainable development of wastewater collection system** | |
| **2.1** | Environmental improvement |
| **2.2** | Social affairs |
| **2.3** | Economy |
| **2.4** | Policy, decrees, and institutions |

**Definition of sustainable sewerage**: It is the Sewerage that is designed to ensure that it will perform its function to the fullest throughout its life span, thus protecting the users' quality of life at the lowest possible cost with the lowest potential impact to the environment.

---

**2.1 Based on the previous table, please distribute 10 points between the two objectives based on importance:**

| The Sustainability Assessment two Objectives | points |
|---|---|
| Objective 1: Reduce the risk of sewerage failure | ________ |
| Objective 2: Contribute to the sustainable development of wastewater collection system | ________ |

**2.2 Based on the previous table, please distribute 10 points between the two criteria of the first objective based on importance:**

| Objective 1: Reduce the risk of sewerage failure | points |
|---|---|
| **Sewage flow characteristics**<br>(For instance, projected population, Planning horizon, High Infiltration / Inflow, Missuses of sewerage by the users, etc) | ________ |
| **Strategic technical aspects**<br>(For instance, National Master Plan, technologies, qualified staff, planned preventive maintenance (PPM), communication with other sectors, etc.) | ________ |

**2.3 Do you think there should be extra criteria for the first objective?**
**Yes / No**

**2.3.1 If you think there should be extra criteria, please add them?**

| **Objective 1: Reduce the risk of sewerage failure** |
|---|
| ______________________________ |
| ______________________________ |
| ______________________________ |

**2.3.2 Please distribute the 10 points between them:**

| **Objective 1: Reduce the risk of sewerage failure** | **points** |
|---|---|
| **Strategic technical aspects**<br>(For instance, National Master Plan, technologies, qualified staff, planned preventive maintenance (PPM), communication with other sectors, etc.) | ________ |
| **Sewage flow characteristics**<br>(For instance, projected population, Planning horizon, High Infiltration / Inflow, Missuses of sewerage by the users, etc) | ________ |
| ______________________________ | ________ |
| ______________________________ | ________ |
| ______________________________ | ________ |

**2.4 Based on the previous table, please distribute 10 points between the four criteria of the second objective based on importance:**

| **Second Objective: Contribute to the sustainable development of wastewater collection system** | **points** |
|---|---|
| Environmental improvement | ________ |
| Social affairs | ________ |
| Economy | ________ |
| Policy, decrees, and institutions | ________ |

**2.5 Do you think there should be extra criteria for the second objective?**
**Yes / No**

**2.5.1 If you think there should be extra criteria, please add them?**

| **Second Objective: Contribute to the sustainable development of wastewater collection system** |
|---|
| ____________________ |
| ____________________ |
| ____________________ |

**2.5.2 Please distribute the 10 points between them:**

| **Second Objective: Contribute to the sustainable development of wastewater collection system** | **points** |
|---|---|
| Environmental improvement | ______ |
| Social affairs | ______ |
| Economy | ______ |
| Policy, decrees, and institutions | ______ |
| ____________________ | ______ |
| ____________________ | ______ |
| ____________________ | ______ |

## Section 3: Indicators

**General Notes:**
**Definition** of project stages:
**Current sewerage system:** the current conceptual layout of the sewerage system
**Planning and design:** consists of studying the proposed engineering solutions and simulating the sewerage network's conditions
**Construction:** monitoring the construction activities while constructing the project
**Commissioning (post-construction evaluation)**: the final form of the project and the beginning of the service
**Operation and maintenance:** monitoring the performance of the project, and keeping the assets functional and effective for the targeted service's entire planned life
**Rehabilitation / upgrading:** when assets face system failures or reach the end of their physical life spans or their hydraulic capacity limits
**Note**: All stages are not mentioned in the table, as the indicators were similar for some stages.

**Scale** of importance:
**1 = Not important; 2 = Less important; 3 = Neutral; 4 = Important; 5 = Very important**
**Please follow the below guidelines to assist you with** evaluating the importance of the indicators:

***a)*** Is this indicator required for evaluating the project performance / status in the particular stage?
***b)*** Each indicator could appear in a different project stage with a different importance score.
***c)*** It is possible to evaluate, column-wise, by focusing on each stage of the project by filling in all the scores of the indicators for this particular stage.

**3.1 The following table presents the indicators for the first sustainability criterion under the first objective: Reduce the risk of sewerage failure.** Please give a value for each indicator using a scale of 1–5 (1 = Not important; 2 = Less important; 3 = Neutral; 4 = Important; 5 = Very important) for the different stages of the sewerage infrastructure projects.

| Sl. | Sustainability Criteria and Indicators | Description | Major stages of project | | | |
|---|---|---|---|---|---|---|
| | | | Planning and Design | Commissioning (Post-construction) | Operation and Maintenance | Modification / Upgrading |
| **Objective 1: Reduce the risk of sewerage failure / increase the reliability of the sewerage system** | | | | | | |
| **A** | **Strategic technical aspects** | | | | | |
| **A1** | Planned preventive maintenance (PPM) | Perform maintenance for pipes and pumping stations as per the PPM | | | | |
| **A2** | Technologies | Keep up with the use of new technologies that contribute to reducing the risk of failure (e.g., software, new construction, and maintenance tools) | | | | |

| Sl. | Sustainability Criteria and Indicators | Description | Major stages of project | | | |
|---|---|---|---|---|---|---|
| | | | Planning and Design | Commissioning (Post-construction) | Operation and Maintenance | Modification / Upgrading |
| **A3** | National Master Plan for Sanitary Engineering Services (NMPSES) | Comply with NMPSES | | | | |
| **A4** | Availability of qualified staff | The presence of qualified, well trained, and specialized staff | | | | |
| **A5** | Communication with other internal (within the Ministry) sectors | Efficient communication with other internal sectors on the interest of the projects | | | | |
| **A6** | Communication with other external sectors | Efficient communication with other external sectors on the interest of the projects | | | | |
| **A7** | Pumping station reductions | Minor pumping stations and major pumping stations to be eliminated, if any | | | | |
| **A8** | Intermediate pumping stations planned to be implemented | New intermediate pumping stations that are planned to be implemented | | | | |
| **A9** | Pipeline rehabilitation / upgrading | The need for rehabilitation or upgrading compared with the essential plans—for example, replacing a damaged pipeline that didn't finish its planned horizon | | | | |
| ***Please write down any other important indicators that you think should be included. Rate the importance of each indicator in every stage (optional).*** | | | | | | |
| **A10** | | | | | | |
| **A11** | | | | | | |
| **A12** | | | | | | |

**3.2 The following table presents the indicators for the Second sustainability criterion under the first objective: Reduce the risk of sewerage failure.** Please give a value for each indicator using a scale of 1–5 (1 = Not important; 2 = Less important; 3 = Neutral; 4 = Important; 5 = Very important) for the different stages of the sewerage infrastructure projects.

| | | | | | | |
|---|---|---|---|---|---|---|
| **B** | **Sewage flow characteristics** | | | | | |
| **B1** | Projected population | The extent of accurate data from concerned authorities over time—for example, the contradiction of the predicted population with the existing population due to changes performed on land zoning in the project area | | | | |
| **B2** | Planning horizon | The estimated period in which the network is designed to function efficiently compared with the actual period | | | | |
| **B3** | High Infiltration / Inflow | The high levels of infiltration from groundwater and inflow from rainwater, manhole covers, yard drains, catch basins, and other sources | | | | |
| **B4** | Missuses of sewerage by the users | The use of the sewerage system to discharge storm water, opening manholes, or disposal of fats, oils, and grease | | | | |

| Sl. | Sustainability Criteria and Indicators | Description | Major stages of project | | | |
|---|---|---|---|---|---|---|
| | | | Planning and Design | Commissioning (Post-construction) | Operation and Maintenance | Modification / Upgrading |
| B5 | The intentional vandalism of the sewerage system | The contribution to disabling the sewerage system, whether directly or around the project area, such as difficulty accessing some areas for scheduled work | | | | |
| **Please write down any other important indicators that you think should be included. Rate the importance of each indicator in every stage (optional).** | | | | | | |
| B6 | | | | | | |
| B7 | | | | | | |
| B8 | | | | | | |

**3.3 The following table presents the indicators for the first sustainability criterion under the second objective: Contribute to the sustainable development of wastewater collection system.** Please give a value for each indicator using a scale of 1–5 (1 = Not important; 2 = Less important; 3 = Neutral; 4 = Important; 5 = Very important) for the different stages of the sewerage infrastructure projects.

| Sl. | Sustainability Criteria and Indicators | Description | Major stages of project | | | |
|---|---|---|---|---|---|---|
| | | | Planning and Design | Commissioning (Post-construction) | Maintenance and Operation | Modification / Upgrading |
| **Objective 2: Contribute to the sustainable development of wastewater collection system** | | | | | | |
| **C** | **Economic aspects** | | | | | |
| C1 | Project capital cost | The total cost of implementing the project | | | | |
| C2 | Operation and maintenance cost | The total cost through the operation and maintenance based on the estimated planning horizon | | | | |
| C3 | Sewage treatment plant | The reduction of the wastewater treatment plant process by reducing the income flow (e.g., infiltration) | | | | |
| C4 | Health care | The saved expenses from health care services through preventing sewage diseases | | | | |
| C5 | Reduction of pumping station | Operation and maintenance cost of pumping stations that could be eliminated | | | | |
| C6 | Replacement of pipelines | The pipelines that need to be replaced before their planning horizon ends | | | | |

| Sl. | Sustainability Criteria and Indicators | Description | Major stages of project | | | |
|---|---|---|---|---|---|---|
| | | | Planning and Design | Commissioning (Post-construction) | Maintenance and Operation | Modification / Upgrading |
| C7 | Replacement of pumping station | The pumping stations that need to be replaced before their planning horizon ends | | | | |
| C8 | Consequence caused by the absence of service corridor | Modifications to the scope of work due to the absence of a corridor in the project area | | | | |
| C9 | Served industrial areas | Industrial areas that will benefit from the project | | | | |
| C10 | Land value | Value of properties affected by the sewerage issues such as flooding and gasses | | | | |
| **Please write down any other important indicators that you think should be included. Rate the importance of each indicator in every stage (optional).** | | | | | | |
| C11 | | | | | | |
| C12 | | | | | | |
| C13 | | | | | | |

**3.4 The following table presents the indicators for the second sustainability criterion under the second objective: Contribute to the sustainable development of wastewater collection system.** Please give a value for each indicator using a scale of 1–5 (1 = Not important; 2 = Less important; 3 = Neutral; 4 = Important; 5 = Very important) for the different stages of the sewerage infrastructure projects.

| | | | | | | |
|---|---|---|---|---|---|---|
| **D** | **Social aspects** | | | | | |
| D1 | Public health and safety | The protection of the public from possible sewage-borne diseases, the likelihood of road collapses, etc. in the project area. | | | | |
| D2 | Satisfaction of the stakeholders | The reported complaints within the sewerage project area compared with contributions to reduce the complaints | | | | |
| D3 | Served occupants | The served occupants by the project compared with the total occupants that required sewer service | | | | |
| D4 | Local economic development activities | Provision of sewer services to local business activities such as malls and commercial real estate | | | | |
| D5 | Served critical infrastructures and facilities | Facilities and infrastructures (e.g., hospitals, educational institutions, airports, police and military installations, and community facilities) that will maintain service from the project | | | | |
| D6 | Public awareness | The extent of public awareness concerning the consequences of misusing the sewerage system (e.g., opening manholes or disposing of fats, oils, and grease) | | | | |
| **Please write down any other important indicators that you think should be included. Rate the importance of each indicator in every stage (optional).** | | | | | | |

| Sl. | Sustainability Criteria and Indicators | Description | Major stages of project | | | |
|---|---|---|---|---|---|---|
| | | | Planning and Design | Commissioning (Post-construction) | Maintenance and Operation | Modification / Upgrading |
| **D7** | | | | | | |
| **D8** | | | | | | |
| **D9** | | | | | | |

**3.5 The following table presents the indicators for the third sustainability criterion under the second objective: Contribute to the sustainable development of wastewater collection system.** Please give a value for each indicator using a scale of 1–5 (1 = Not important; 2 = Less important; 3 = Neutral; 4 = Important; 5 = Very important) for the different stages of the sewerage infrastructure projects.

| | | | | | | |
|---|---|---|---|---|---|---|
| **E** | **Environmental aspects** | | | | | |
| **E1** | Aquifer pollution | Wastewater generated from unsewered facilities (septic tank) and leaked from damage pipelines resulting in sewage seepage into an underground aquifer | | | | |
| **E2** | Odour air pollution | The generation of odour from the sewer network (e.g., septic tank, pumping stations, and manholes) | | | | |
| **E3** | Losses of resources (groundwater) | The amount of groundwater that reaches the sewage treatment plants | | | | |
| **E4** | Pumping station energy | Increment / decrement of energy consumption from the pumping station | | | | |
| **E5** | Land used for the sewerage projects | Construction activities causing noise, dust, gasses, dewatering, or any construction waste that would disturb the environment in the surrounding areas | | | | |
| **E6** | Green technologies | Any green innovation that overlaps with sewerage projects that will end up saving energy, preventing pollution, and recycling waste, such as a pumping station operating by means of solar panels, onsite septic systems, and software | | | | |
| **E7** | Sewage flooding | Contribution in reducing the areas suffering from sewage overflow | | | | |
| **Please write down any other important indicators that you think should be included. Rate the importance of each indicator in every stage (optional).** | | | | | | |
| **E8** | | | | | | |
| **E9** | | | | | | |
| **E10** | | | | | | |

**3.6 The following table presents the indicators for the fourth sustainability criterion under the second objective: Contribute to the sustainable development of wastewater collection system.** Please give a

| Sl. | Sustainability Criteria and Indicators | Description | Major stages of project | | | |
|---|---|---|---|---|---|---|
| | | | Planning and Design | Commissioning (Post-construction) | Maintenance and Operation | Modification / Upgrading |
| value for each indicator using a scale of 1–5 (1 = Not important; 2 = Less important; 3 = Neutral; 4 = Important; 5 = Very important) for the different stages of the sewerage infrastructure projects. | | | | | | |
| **F** | **Policy, decrees, institutions, and strategic visions** | | | | | |
| **F1** | Strategic vision | Existence of comprehensively updated strategic vision for sewerage networks | | | | |
| **F2** | NMPSES | Existence of an updated master plan in line with the country's strategic vision prepared by the authority responsible for providing sewerage services | | | | |
| **F3** | Community participation | Involvement of the public in decision-making process | | | | |
| **F4** | Local consultants | Engagement of local consultants in the project | | | | |
| **F5** | Local contractors | Engagement of local contractors in the project | | | | |
| **F6** | Service fees | Adoption of service fees or taxes policies | | | | |
| **Please write down any other important indicators that you think should be included. Rate the importance of each indicator in every stage (optional).** | | | | | | |
| **F7** | | | | | | |
| **F8** | | | | | | |
| **F9** | | | | | | |

**3.7 If you have any further suggestions, please provide them below.**

**Section 4: Sewerage Project's Sustainability Overview Questions**

**4.1 Is the sewerage system in Bahrain sustainable in all of its aspects (i.e., economic, environmental, and social)?**

□ No, the sewerage system is not sustainable, as there is a shortage in the aspects of sustainability.

□ No, but with increased effort, it will be able to move towards sustainability.

□ Yes, but it needs more effort to be more sustainable.

□ Yes, and it is sustainable.

□ Other, please specify. ____________________________

**4.2 Does your organization consider having a sustainable sewerage system a top priority for decision-making?**

□ No, sustainability is not currently considered.

□ No, but a sustainability plan is being developed.

□ Yes, it is considered; however, it is in the early implementation stage.

□ Yes, it is considered; however, it is not properly implemented.

□ Yes, it is considered with the proper implementation of a sustainability plan.

□ Other, please specify. ___________________________

**4.3 Is the sewerage system in Bahrain sufficient in terms of sustainability issues (e.g., high infiltration, sewage overflows, exfiltration to underground water, financial crises, electricity issues, etc.)?**

□ No, the sewerage system is / will not be able to sustain these kinds of issues.

□ No, and it requires effort to increase progress towards sustainability.

□ Yes, but it still requires effort to be more sustainable.

□ Yes, the sewerage system is capable of sustaining these kinds of issues.

□ Other, please specify. ____________________________

**4.4 Is your organization following any methods or tools (e.g., environmental impact assessments, social impact assessment, life-cycle cost analysis, and business scorecards) in managing the sustainability issues facing the current network?**

□ No, there aren't such methods or tools for managing the sustainability issues.

□ No, but the normal management methods would be able to manage these kinds of issues (please specify the method or tools ____________________)

□ Yes, but it needs further improvement (please specify the method or tools ____________)

□ Yes, and it is sufficient (please specify the methods or tools _____________________)

□ Other, please specify. ___________________________

**4.5 In which stage do you think sustainability should be implemented in the sewerage sector?**

□ Only in formulating long-term policy.

□ Through annual programmes and while setting goals.

□ During the conceptualization of projects or programmes.

□ Throughout the operation and maintenance.

□ All of the above.

□ Other, please specify. __________________________

**4.6 If you have any further suggestions for improving the sustainability of sewerage projects, please provide them below.**

___________________________________________________________________________

___________________________________________________________________________

___________________________________________________________________________

___________________________________________________________________________

___________________________________________________________________________

___________________________________________________________________________

**This is the end of the questionnaire.**

# Appendix H: Maximum and minimum target value for the sustainability indicators of Hamad Town deep-gravity sewer

| SI | Sustainability criteria and indicators | Description | measuring parameter | Target value | | The score of the different value | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Min | Max | 1<br>Highly negative impact | 2<br>Negative impact | 3<br>Neutral | 4<br>Positive impact | 5<br>Highly positive impact |
| **First objective: Reduce the risk of sewerage failure** | | | | | | | | | | |
| **Criterion A. Strategic technical aspects** | | | | | | | | | | |
| **A1** | Technologies | Keep up with the use of new technologies that contribute to reducing the risk of failure (e.g., software, new construction, and maintenance tools) | Yes/No (likelihood) | Very Unlikely | Very Likely | Very Unlikely | Unlikely | Neutral | Likely | Very Likely |
| **A2** | National Master Plan for Sanitary Engineering Services (NMPSES) | Comply with NMPSES | % of keeping up with NMPSES | Extremely delayed | During the proposed period | After 9 years or more | Within 7 - 8 years | Within 5-7 years | Within 4-5 years | Within the first 4 years |

| SI | Sustainability criteria and indicators | Description | measuring parameter | Target value | | The score of the different value | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Min | Max | 1<br>Highly negative impact | 2<br>Negative impact | 3<br>Neutral | 4<br>Positive impact | 5<br>Highly positive impact |
| A3 | Availability of qualified staff | The presence of qualified, well trained, and specialized staff | Yes/No (Level of availability of qualified staff) | Unavailability of most required specialties/expertise for most fields (planning, design, construction, operation and maintenance and others) | Availability of all specialties/expertise required for all fields (planning, design, construction, operation and maintenance and others) | Unavailability of most required specialties/expertise for all fields causing the inability of performing work as required | Unavailability of some required specialties/expertise for some fields causing the inability of performing work as required in some fields | Availability of some required specialties/expertise with low staff support causing the quality of work to be stable with the risk of work interruptions in case any personal leave the organization | Availability of some required specialties/expertise with low staff support causing the quality of work to be stable with less probability of having the risk of work interruptions in case any personal leave the organization | Availability of all specialties/expertise required for all fields |
| A4 | Intermediate pumping stations planned to be implemented | New intermediate pumping stations that are planned to be implemented | No. | 2 | 0 | 2 with refurbishment/upgrade of two major pumping station | 2 with refurbishment/upgrade of one major pumping station | 2 | 1 | 0 |
| **Criterion B. Sewage flow characteristics** | | | | | | | | | | |
| B1 | Projected population | The extent of accurate data from concerned authorities | % accuracy or the change | Less than 50 % | 90 % - 100 % | Less than 50 % | 50 % – 70 % | 70 % - 80 % | 80 % - 90 % | 90 % - 100 % |

| SI | Sustainability criteria and indicators | Description | measuring parameter | Target value | | The score of the different value | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Min | Max | 1 Highly negative impact | 2 Negative impact | 3 Neutral | 4 Positive impact | 5 Highly positive impact |
| | | over time—for example, the contradiction of the predicted population with the existing population due to changes performed on land zoning in the project area | | | | | | | | |
| **B2** | High Infiltration / Inflow | The high levels of infiltration from groundwater and inflow from rainwater, | % of Infiltration / Inflow to the sewerage system | 45% and more | Less than 10 % | 45% and more | 25-45% | 15-25 % | 10-15% | Less than 10 % |

| SI | Sustainability criteria and indicators | Description | measuring parameter | Target value | | The score of the different value | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Min | Max | 1<br>Highly negative impact | 2<br>Negative impact | 3<br>Neutral | 4<br>Positive impact | 5<br>Highly positive impact |
| | | manhole covers, yard drains, catch basins, and other sources | | | | | | | | |
| **Second Objective: Contribute to the sustainable development of wastewater collection system** | | | | | | | | | | |
| **Criterion C. Economic aspects** | | | | | | | | | | |
| **C1** | Sewage treatment plant | The reduction of the wastewater treatment plant process by reducing the income flow (e.g., infiltration) | Deviation from the normal/anticipated treatment cost | 5-7.5% less than the normal/anticipated treatment cost | 15-17.5% less than the normal/anticipated treatment cost | 5-7.5% less than the normal/anticipated treatment cost | 7.5-10% less than the normal/anticipated treatment cost | 10-12.5% less than the normal/anticipated treatment cost | 12.5-15% less than the normal/anticipated treatment cost | 15-17.5% less than the normal/anticipated treatment cost |
| **C2** | Consequence caused by the absence of service corridor | Modifications to the scope of work due to the absence of a corridor in the project area | % of capital cost increment caused by the modification (not applicable as the project is still not constructed) | 25-30% | 5-10% | 25-30% | 20-25% | 15-20% | 10-15% | 5-10% |

| SI | Sustainability criteria and indicators | Description | measuring parameter | Target value | | The score of the different value | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | 1 | 2 | 3 | 4 | 5 |
| | | | | Min | Max | Highly negative impact | Negative impact | Neutral | Positive impact | Highly positive impact |
| **Criterion D. Social aspects** | | | | | | | | | | |
| **D1** | Served occupants | The served occupants by the project compared with the total occupants that required sewer service | % of served occupants out of the total no. of occupants that required sewer service | 50-60% | 90-100% | 50-60% | 60-70% | 70-80% | 80-90% | 90-100% |
| **D2** | Served critical infrastructures and facilities | Facilities and infrastructures (e.g., hospitals, educational institutions, airports, police and military installations, and community facilities) that will maintain | % of served facilities and infrastructure out of the total facilities and infrastructure | 0-20% | 80-100% | 0-20% | 20-40% | 40-60% | 60-80% | 80-100% |

| SI | Sustainability criteria and indicators | Description | measuring parameter | Target value | | The score of the different value | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Min | Max | 1 Highly negative impact | 2 Negative impact | 3 Neutral | 4 Positive impact | 5 Highly positive impact |
| | | service from the project | | | | | | | | |
| **Criterion E. Environmental aspects** | | | | | | | | | | |
| **E1** | Green technologies | Any green innovation that overlaps with sewerage projects that will end up saving energy, preventing pollution, and recycling waste, such as a pumping station operating by means of solar panels, onsite septic systems, and software | Yes/No (adopted technologies with tangible positive impacts) | No green technologies implemented | Technologies with great tangible positive impact affecting 4 to 6 environmental aspects (pollution, green energy, recycling…) | No green technologies implemented | No green technologies implemented but planning to perform some in the future. | Technologies with few tangible positive impacts affecting 0 to 2 environmental aspects (pollution, green energy, recycling…) | Technologies with few tangible positive impacts affecting 2 to 4 environmental aspects (pollution, green energy, recycling…) | Technologies with great tangible positive impact affecting 4 to 6 environmental aspects (pollution, green energy, recycling…) |
| **Criterion F. Policy (decrees, institutions, and strategic visions)** | | | | | | | | | | |

| SI | Sustainability criteria and indicators | Description | measuring parameter | Target value | | The score of the different value | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Min | Max | 1<br>Highly negative impact | 2<br>Negative impact | 3<br>Neutral | 4<br>Positive impact | 5<br>Highly positive impact |
| **F1** | NMPSES | Existence of an updated master plan in line with the country's strategic vision prepared by the authority responsible for providing sewerage services | Years passed since the last update | 16-20 years | 0-2 years | 16-20 years | 12-16 years | 8-12 years | 2-8 years | 0-2 years |
| **F2** | Community participation | Involvement of the public in decision-making process | Involvement through availability channels such as: media, National Complaint System, municipalities representatives and others | No participations | Highly effective participation through available channels | No participations | Little effective participation through all channels | Slightly effective participation through all channels | Fairly effective participation through available channels | Highly effective participation through available channels |

# Appendix I: Comparable indicators between alternative 1 and alternative 2

| SI | Sustainability criteria and indicators | Description | Measuring parameter | Target value | | The score of the different value | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | 1 | 2 | 3 | 4 | 5 |
| | | | | Min | Max | Highly negative impact | Negative impact | Neutral | Positive impact | Highly positive impact |
| **First objective: Reduce the risk of sewerage failure** | | | | | | | | | | |
| | | | | | | | | | | |
| **A5** | Pumping station reductions | Minor pumping stations and major pumping stations to be eliminated, if any | Number of major pumping stations to be eliminated within the catchment area | 1 | 20 | 0-4 | 5-8 | 9-12 | 13-16 | 17-20 |
| **Criterion B. Sewage flow characteristics** | | | | | | | | | | |
| **B3** | Missuses of sewerage by the users | The use of the sewerage system to discharge storm water, opening manholes, or disposal of fats, oils, and grease | The reduction of pumping station and mechanical fittings that are prone to failure due to missuses | 0 | 9 | 0-2 | 3-5 | 6-8 | 7 | 8-9 |

| SI | Sustainability criteria and indicators | Description | Measuring parameter | Target value | | The score of the different value | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Min | Max | 1<br>Highly negative impact | 2<br>Negative impact | 3<br>Neutral | 4<br>Positive impact | 5<br>Highly positive impact |
| **Second Objective: Contribute to the sustainable development of wastewater collection system** | | | | | | | | | | |
| **Criterion C. Economic aspects** | | | | | | | | | | |
| **C3** | Project capital cost | The total cost of implementing the project | Total capital cost ($) | 150-140 million dollars | 110-100 million dollars | 150-140 million dollars | 140-130 million dollars | 130-120 million dollars | 120-110 million dollars | 110-100 million dollars |
| **Criterion D. Social aspects** | | | | | | | | | | |
| **D3** | Satisfaction of the stakeholders | The reported complaints within the sewerage project area compared with contributions to reduce the complaints | % of expected contribution to reduce the complaints | 0-10% | 70-90% | 0-10% | 10-30% | 30-50% | 50-70% | 70-90% |
| **D4** | Public awareness | The extent of public awareness concerning the consequences of misusing the sewerage system (e.g., opening manholes or | Number of houses and facilities affected by the project during construction stage in | 1000 m | 2200 m | 1000 m – 1200 m | 1200 m – 1400 m | 1400 - 1700 | 1700 - 2000 | 2000 - 2200 |

| SI | Sustainability criteria and indicators | Description | Measuring parameter | Target value | | The score of the different value | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Min | Max | 1 | 2 | 3 | 4 | 5 |
| | | | | | | Highly negative impact | Negative impact | Neutral | Positive impact | Highly positive impact |
| | | disposing of fats, oils, and grease) | terms of pipe length | | | | | | | |
| **Criterion E. Environmental aspects** | | | | | | | | | | |
| **E2** | Sewage flooding | Contribution in reducing the areas suffering from sewage overflow | Reduction of pumping stations in the system which are considered as bottlenecks that lead to flow accumulation in the system. (Unlike deep gravity sewer which can have more resilience | 0 | 9 | 0-2 | 3-5 | 6-8 | 7 | 8-9 |

| SI | Sustainability criteria and indicators | Description | Measuring parameter | Target value | | The score of the different value | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Min | Max | 1 | 2 | 3 | 4 | 5 |
| | | | | | | Highly negative impact | Negative impact | Neutral | Positive impact | Highly positive impact |
| | | | against flooding ) | | | | | | | |
| **E3** | Land used for the sewerage projects | Construction activities causing noise, dust, gasses, dewatering, or any construction waste that would disturb the environment in the surrounding areas | Total volume of trenches excavated during construction stage (m3) | 125,000 to 100,000 | 25,000 and less | 100,000 to 125,000 | 75,000 to 100,000 | 50,000 to 75,000 | 25,000 to 50,000 | 25,000 and less |

# Appendix J: The score of Sustainability Index for Hamad town deep-gravity sewer of alternative 1 and 2

| SI | Sustainability criteria and indicators | Description | Measuring parameter | Value for alternative 1 (AL1) | Value for alternative 2 (AL2) | Score for alternative 1 | Score for alternative 2 | Weightage (out of 100) | Sum AL1 | Sum AL2 |
|---|---|---|---|---|---|---|---|---|---|---|
| **First objective: Reduce the risk of sewerage failure (weight of 55 out of 100)** | | | | | | | | | | |
| **Criterion A. Strategic technical aspects (weight of 25 out of 100)** | | | | | | | | | | |
| **A1** | Technologies | Keep up with the use of new technologies that contribute to reducing the risk of failure (e.g., software, new construction, and maintenance tools) | Yes/No (likelihood) | Neutral | Neutral | 3 | 3 | 4.8 | 14.4 | 14.4 |
| **A2** | National Master Plan for Sanitary Engineering Services (NMPSES) | Comply with NMPSES | % of keeping up with NMPSES | After 9 years or more | After 9 years or more | 1 | 1 | 5.3 | 5.3 | 5.3 |
| **A3** | Availability of qualified staff | The presence of qualified, well trained, and specialized staff | Yes/No (Level of availability of qualified staff) | Availability of some required specialties/expertise with low staff support causing the quality of work to be stable with the risk of work interruptions in case | Availability of some required specialties/expertise with low staff support causing the quality of work to be stable with the risk of work interruptions in case | 3 | 3 | 4.9 | 14.7 | 14.7 |

| SI | Sustainability criteria and indicators | Description | Measuring parameter | Value for alternative 1 (AL1) | Value for alternative 2 (AL2) | Score for alternative 1 | Score for alternative 2 | Weightage (out of 100) | Sum AL1 | Sum AL2 |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | any personal leave the organization | any personal leave the organization | | | | | |
| **A4** | Intermediate pumping stations planned to be implemented | New intermediate pumping stations that are planned to be implemented | No. | 2 | 2 | 3 | 3 | 4.7 | 14.1 | 14.1 |
| **A5** | Pumping station reductions | Minor pumping stations and major pumping stations to be eliminated, if any | Number of major pumping stations to be eliminated within the catchment area | 4-8 | 8-9 | 2 | 3 | 5.3 | 10.6 | 15.9 |
| **Criterion B. Sewage flow characteristics (weight of 30 out of 100)** | | | | | | | | | | |
| **B1** | Projected population | The extent of accurate data from concerned authorities over time—for example, the contradiction of the predicted population with the existing population due to changes performed on land zoning in the project area | % accuracy or the change negatively or positively | 80 % - 90 % | 80 % - 90 % | 4 | 4 | 11.6 | 46.4 | 46.4 |

| SI | Sustainability criteria and indicators | Description | Measuring parameter | Value for alternative 1 (AL1) | Value for alternative 2 (AL2) | Score for alternative 1 | Score for alternative 2 | Weightage (out of 100) | Sum AL1 | Sum AL2 |
|---|---|---|---|---|---|---|---|---|---|---|
| **B2** | High Infiltration / Inflow | The high levels of infiltration from groundwater and inflow from rainwater, manhole covers, yard drains, catch basins, and other sources | % of Infiltration / Inflow to the sewerage system | 25-45% | 25-45% | 2 | 2 | 11.2 | 22.4 | 22.4 |
| **B3** | Missuses of sewerage by the users | The use of the sewerage system to discharge storm water, opening manholes, or disposal of fats, oils, and grease | The reduction of pumping station and mechanical fittings that are prone to failure due to missuses | 6-8 | 8-9 | 3 | 5 | 7.2 | 21.6 | 36 |
| **Second Objective: Contribute to the sustainable development of wastewater collection system (weight of 45 out of 100)** | | | | | | | | | | |
| **Criterion C. Economic aspects (weight of 15 out of 100)** | | | | | | | | | | |
| **C1** | Sewage treatment plant | The reduction of the wastewater treatment plant process by reducing the income flow (e.g., infiltration) | Deviation from the normal/anticipated treatment cost | 15-17.5% less than the normal/anticipated treatment cost | 15-17.5% less than the normal/anticipated treatment cost | 5 | 5 | 7.16 | 35.8 | 38.8 |

| SI | Sustainability criteria and indicators | Description | Measuring parameter | Value for alternative 1 (AL1) | Value for alternative 2 (AL2) | Score for alternative 1 | Score for alternative 2 | Weightage (out of 100) | Sum AL1 | Sum AL2 |
|---|---|---|---|---|---|---|---|---|---|---|
| **C3** | Project capital cost | The total cost of implementing the project | Total capital cost ($) | 110-100 million dollars | 130-120 million dollars | 5 | 3 | 7.84 | 39.2 | 23.52 |
| **Criterion D. Social aspects (weight of 10 out of 100)** | | | | | | | | | | |
| **D1** | Served occupants | The served occupants by the project compared with the total occupants that required sewer service | % of served occupants out of the total no. of occupants that required sewer service | 90-100% | 90-100% | 5 | 5 | 2.6 | 13 | 13 |
| **D2** | Served critical infrastructures and facilities | Facilities and infrastructures (e.g., hospitals, educational institutions, airports, police and military installations, and community facilities) that will maintain service from the project | % of served facilities and infrastructure out of the total facilities and infrastructure | 60-80% | 60-80% | 4 | 4 | 2.7 | 10.8 | 10.8 |
| **D3** | Satisfaction of the stakeholders | The reported complaints within the sewerage project | % of contribution to reduce the complaints | 70-90% | 50-70% | 4 | 3 | 2.5 | 10 | 7.5 |

| SI | Sustainability criteria and indicators | Description | Measuring parameter | Value for alternative 1 (AL1) | Value for alternative 2 (AL2) | Score for alternative 1 | Score for alternative 2 | Weightage (out of 100) | Sum AL1 | Sum AL2 |
|---|---|---|---|---|---|---|---|---|---|---|
| | | area compared with contributions to reduce the complaints | | | | | | | | |
| **D4** | Public awareness | The extent of public awareness concerning the consequences of misusing the sewerage system (e.g., opening manholes or disposing of fats, oils, and grease) | Number of houses and facilities affected by the project during construction stage in terms of pipe length. | 2000m – 2200m | 1400 m – 1700 m | 5 | 3 | 2.2 | 11 | 6.6 |
| **Criterion E. Environmental aspects (weight of 15 out of 100)** | | | | | | | | | | |
| **E1** | Green technologies | Any green innovation that overlaps with sewerage projects that will end up saving energy, preventing pollution, and recycling waste, such as a pumping | Yes/No (adopted technologies with tangible positive impacts) | Technologies with few tangible positive impacts affecting 0 to 2 environmental aspects (pollution, green energy, recycling…) | Technologies with few tangible positive impacts affecting 0 to 2 environmental aspects (pollution, green energy, recycling…) | 3 | 3 | 5.4 | 16.2 | 16.2 |

| SI | Sustainability criteria and indicators | Description | Measuring parameter | Value for alternative 1 (AL1) | Value for alternative 2 (AL2) | Score for alternative 1 | Score for alternative 2 | Weightage (out of 100) | Sum AL1 | Sum AL2 |
|---|---|---|---|---|---|---|---|---|---|---|
| | | station operating by means of solar panels, onsite septic systems, and software | | | | | | | | |
| **E2** | Sewage flooding | Contribution in reducing the areas suffering from sewage overflow | Reduction of pumping stations in the system which are considered as bottlenecks that lead to flow accumulation in the system. | 6-8 | 8-9 | 3 | 5 | 4.7 | 14.1 | 23.5 |
| **E3** | Land used for the sewerage projects | Construction activities causing noise, dust, gasses, dewatering, or any construction waste that would disturb the environment in the surrounding areas | Total volume of trenches excavated during construction stage (m3) | 75,000 to 100,000 | 100,000 to 125,000 | 2 | 1 | 4.9 | 9.8 | 4.9 |
| **Criterion F. Policy (decrees, institutions, and strategic visions) (weight of 5 out of 100)** | | | | | | | | | | |
| **F1** | NMPSES | Existence of an updated master plan | Years passed since the last update | 8-12 years | 8-12 years | 3 | 3 | 2.6 | 7.8 | 7.8 |

| SI | Sustainability criteria and indicators | Description | Measuring parameter | Value for alternative 1 (AL1) | Value for alternative 2 (AL2) | Score for alternative 1 | Score for alternative 2 | Weightage (out of 100) | Sum AL1 | Sum AL2 |
|---|---|---|---|---|---|---|---|---|---|---|
| | | in line with the country's strategic vision prepared by the authority responsible for providing sewerage services | | | | | | | | |
| **F2** | Community participation | Involvement of the public in decision-making process | Yes / No (involvement through availability channels such as: media, National Complaint System, municipalities representatives and others.) | Highly effective participation through available channels | Highly effective participation through available channels | 5 | 5 | 2.4 | 12 | 12 |
| | | | | | | | **Total** | **100** | **329.2** | **333.82** |

# Appendix K: Maximum and minimum target value for the sustainability indicators of Muharraq deep-gravity sewer

| SI | Sustainability criteria and indicators | Description | Measuring parameter | Target value | | The score of the different value | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Min | Max | 1 Highly negative impact | 2 Negative impact | 3 Neutral | 4 Positive impact | 5 Highly positive impact |
| **First objective: Reduce the risk of sewerage failure** | | | | | | | | | | |
| **Criterion A. Strategic technical aspects** | | | | | | | | | | |
| **A1** | Planned preventive maintenance (PPM) | Perform maintenance for pipes and pumping stations as per the PPM | % of commitment to PPM | 80-84 | 96- 100 | 80 -84 | 84- 88 | 88- 92 | 92- 96 | 96 – 100 % |
| **A2** | Technologies | Keep up with the use of new technologies that contribute to reducing the risk of failure (e.g., software, new construction, and maintenance tools) | Yes/No (likelihood) | Very Unlikely | Very Likely | Very Unlikely | Unlikely | Neutral | Likely | Very Likely |
| **A3** | National Master Plan for Sanitary | Comply with NMPSES | Yes/No (likelihood) | Very Unlikely | Very Likely | Very Unlikely | Unlikely | Neutral | Likely | Very Likely |

| SI | Sustainability criteria and indicators | Description | Measuring parameter | Target value | | The score of the different value | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Min | Max | 1<br>Highly negative impact | 2<br>Negative impact | 3<br>Neutral | 4<br>Positive impact | 5<br>Highly positive impact |
| | Engineering Services (NMPSES) | | | | | | | | | |
| **A4** | Availability of qualified staff | The presence of qualified, well trained, and specialized staff | Yes/No (Level of availability of qualified staff) | Unavailability of most required specialties/expertise for most fields | Availability of all specialties/expertise required for all fields | Unavailability of most required specialties/expertise for all fields causing the inability of performing work as required | Unavailability of some required specialties/expertise for some fields causing the inability of performing work as required in some fields | Availability of some required specialties/expertise with low staff support causing the quality of work to be stable with the risk of work interruptions in case any personal leave the organization | Availability of some required specialties/expertise with low staff support causing the quality of work to be stable with less probability of having the risk of work interruptions in case any personal leave the organization | Availability of all specialties/expertise required for all fields |
| **Criterion B. Sewage flow characteristics** | | | | | | | | | | |
| **B1** | Projected population | The extent of accurate data from concerned authorities over time—for example, the contradiction of | % of accuracy of the predicted flow | ≤ 60 % | 90 % -100 % | ≤ 60 % | 60 % - 70 % | 70 % - 80 % | 80 % - 90% | 90 % -100 % |

| SI | Sustainability criteria and indicators | Description | Measuring parameter | Target value | | The score of the different value | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Min | Max | 1 | 2 | 3 | 4 | 5 |
| | | | | | | Highly negative impact | Negative impact | Neutral | Positive impact | Highly positive impact |
| | | the predicted population with the existing population due to changes performed on land zoning in the project area | | | | | | | | |
| **B2** | Planning horizon | The estimated period in which the network is designed to function efficiently compared with the actual period | Yes/No (likelihood) | Very Unlikely | Very Likely | Very Unlikely | Unlikely | Neutral | Likely | Very Likely |
| **B3** | High Infiltration / Inflow | The high levels of infiltration from groundwater and inflow from rainwater, manhole covers, yard drains, catch | % of Infiltration / Inflow to the sewerage system | 45% ≥ | ≤10 % | 45% ≥ | 25-45% | 15-25 % | 10-15% | ≤10 % |

| SI | Sustainability criteria and indicators | Description | Measuring parameter | Target value | | The score of the different value | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | 1 | 2 | 3 | 4 | 5 |
| | | | | Min | Max | Highly negative impact | Negative impact | Neutral | Positive impact | Highly positive impact |
| | | basins, and other sources | | | | | | | | |
| **B4** | Missuses of sewerage by the users | The use of the sewerage system to discharge storm water, opening manholes, or disposal of fats, oils, and grease | % users missuses recorded in the project area (such as oil and grease Mg/L) | More than 100 | 0-25 | More than 100 | 75- 100 | 50-75 | 25- 50 | 0-25 |
| **Second Objective: Contribute to the sustainable development of wastewater collection system** | | | | | | | | | | |
| **Criterion C. Economic aspects** | | | | | | | | | | |
| **C1** | Operation and maintenance cost | The total cost through the operation and maintenance based on the estimated planning horizon | $ per year (inaccurate data) | 100-90 million dollars | 70-60 million dollars | 100-90 million dollars | 90-80 million dollars | 80-70 million dollars | 70-60 million dollars | 60-50 million dollars |
| **C2** | Sewage treatment plant | The reduction of the wastewater treatment plant process by | % of money saved per m3/day for | 0-10% | 40-50% | 0-10% | 10-30% | 20-30% | 30-40% | 40-50% |

| SI | Sustainability criteria and indicators | Description | Measuring parameter | Target value | | The score of the different value | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Min | Max | 1 | 2 | 3 | 4 | 5 |
| | | | | | | Highly negative impact | Negative impact | Neutral | Positive impact | Highly positive impact |
| | | reducing the income flow (e.g., infiltration) | possible high infiltration | | | | | | | |
| **Criterion D. Social aspects** | | | | | | | | | | |
| **D1** | Public health and safety | The protection of the public from possible sewage-borne diseases, the likelihood of road collapses, etc. in the project area. | Yes/No (likelihood) | Very Unlikely | Very Likely | Very Unlikely | Unlikely | Neutral | Likely | Very Likely |
| **D2** | Satisfaction of the stakeholders | The reported complaints within the sewerage project area compared with contributions to reduce the complaints | % of contribution to reduce the complaints compared with previous years | ≤ 30 % | 70% ≥ | ≤ 30 % | 30 % - 40 % | 40 % - 50 % | 50 % - 70% | 70% ≥ |
| **D3** | Served occupants | The served occupants by the project compared | % of served occupants out of the total no. of | 50-60% | 90-100% | 50-60% | 60-70% | 70-80% | 80-90% | 90-100% |

| SI | Sustainability criteria and indicators | Description | Measuring parameter | Target value | | The score of the different value | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Min | Max | 1<br>Highly negative impact | 2<br>Negative impact | 3<br>Neutral | 4<br>Positive impact | 5<br>Highly positive impact |
| | | with the total occupants that required sewer service | occupants that required sewer service | | | | | | | |
| **D4** | Local economic development activities | Provision of sewer services to local business activities such as malls and commercial real estate | Yes/No (likelihood) | Very Unlikely | Very Likely | Very Unlikely | Unlikely | Neutral | Likely | Very Likely |
| **D5** | Served critical infrastructures and facilities | Facilities and infrastructures (e.g., hospitals, educational institutions, airports, police and military installations, and community facilities) that will maintain service from the project | % of served facilities and infrastructure out of the total facilities and infrastructure | 50-60% | 90-100% | 50-60% | 60-70% | 70-80% | 80-90% | 90-100% |

| SI | Sustainability criteria and indicators | Description | Measuring parameter | Target value | | The score of the different value | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Min | Max | 1 | 2 | 3 | 4 | 5 |
| | | | | | | Highly negative impact | Negative impact | Neutral | Positive impact | Highly positive impact |
| **D6** | Public awareness | The extent of public awareness concerning the consequences of misusing the sewerage system (e.g., opening manholes or disposing of fats, oils, and grease) | % of reduction of recorded missuses by the users in the project area (such as oil and grease Mg/L) | 0 – 10 % | 40 % ≥ | 0 – 10 % | 10% - 20 % | 20% - 30% | 30% - 40% | 40 % ≥ |
| **Criterion E. Environmental aspects** | | | | | | | | | | |
| **E1** | Odour air pollution | The generation of odour from the sewer network (e.g., septic tank, pumping stations, and manholes) | OU/m3 | 6-5 | 2- 1 | 6-5 | 5-4 | 4-3 | 3-2 | 2- 1 |
| **E2** | Green technologies | Any green innovation that overlaps with sewerage projects that will end up saving energy, | Yes/No (adopted technologies with tangible positive impacts) | No green technologies implemented | Technologies with great tangible positive impact affecting 4 to 6 environmental | No green technologies implemented | No green technologies implemented but planning to perform some in the future. | Technologies with few tangible positive impacts affecting 0 to 2 environmental aspects | Technologies with few tangible positive impacts affecting 2 to 4 environmental aspects | Technologies with great tangible positive impact affecting 4 to 6 environmental |

| SI | Sustainability criteria and indicators | Description | Measuring parameter | Target value | | The score of the different value | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Min | Max | 1<br>Highly negative impact | 2<br>Negative impact | 3<br>Neutral | 4<br>Positive impact | 5<br>Highly positive impact |
| | | preventing pollution, and recycling waste, such as a pumping station operating by means of solar panels, onsite septic systems, and software | | | aspects (pollution, green energy, recycling…) | | | (pollution, green energy, recycling…) | (pollution, green energy, recycling…) | aspects (pollution, green energy, recycling…) |
| **E3** | Sewage flooding | Contribution in reducing the areas suffering from sewage overflow | Yes/No (likelihood) | Very Unlikely | Very Likely | Very Unlikely | Unlikely | Neutral | Likely | Very Likely |
| **Criterion F. Policy (decrees, institutions, and strategic visions)** | | | | | | | | | | |
| **F1** | Local consultants | Engagement of local consultants in the project | % of total work per year | ≤ 50 % | 80% - 100% | ≤ 50 % | 50% - 60% | 60% - 70% | 70% - 80% | 80% - 100% |
| **F2** | Local contractors | Engagement of local contractors in the project | % of total work per year | ≤ 60 % | 90% - 100% | ≤ 60 % | 60% - 70% | 70% - 80% | 80% - 90% | 90% - 100% |
| **F3** | Service fees | Adoption of service fees or taxes policies | Yes/No (adopted service fees with | No service fees implemented | Adoption of services fees with | Confirming no service fees implementation | No service fees implemented | Some intentions toward the adoption of | Some efforts toward Adoption of services fees | Adoption of services fees with |

| SI | Sustainability criteria and indicators | Description | Measuring parameter | Target value | | The score of the different value | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | 1 | 2 | 3 | 4 | 5 |
| | | | | Min | Max | Highly negative impact | Negative impact | Neutral | Positive impact | Highly positive impact |
| | | | tangible positive impact) | | a tangible positive impact | | | services fees with a tangible positive impact | with a tangible positive impact | a tangible positive impact |

# Appendix L: The score of Sustainability Index for Muharraq deep-gravity sewer in operation and maintenance stage

| SI | Sustainability criteria and indicators | Description | Measuring parameter | Value | Score | Weightage (out of 100) | Sum |
|---|---|---|---|---|---|---|---|
| **First objective: Reduce the risk of sewerage failure (weight of 55 out of 100)** | | | | | | | |
| **Criterion A. Strategic technical aspects (weight of 25 out of 100)** | | | | | | | |
| **A1** | Planned preventive maintenance (PPM) | Perform maintenance for pipes and pumping stations as per the PPM | % of commitment to PPM | 88- 92 | 3 | 4.4 | 13.2 |
| **A2** | Technologies | Keep up with the use of new technologies that contribute to reducing the risk of failure (e.g., software, new construction, and maintenance tools) | Yes/No (likelihood) | Very Likely | 5 | 6.6 | 33 |
| **A3** | National Master Plan for Sanitary Engineering Services (NMPSES) | Comply with NMPSES | Yes/No (likelihood) | Likely | 4 | 7.3 | 29.2 |
| **A4** | Availability of qualified staff | The presence of qualified, well trained, and specialized staff | Yes/No (Level of availability of qualified staff) | Availability of some required specialties/expertise with low staff support causing the quality of work to be stable with less probability of having the risk of work interruptions in case any personal leave the organization | 4 | 6.7 | 26.8 |
| **Criterion B. Sewage flow characteristics (weight of 30 out of 100)** | | | | | | | |

| SI | Sustainability criteria and indicators | Description | Measuring parameter | Value | Score | Weightage (out of 100) | Sum |
|---|---|---|---|---|---|---|---|
| **B1** | Projected population | The extent of accurate data from concerned authorities over time—for example, the contradiction of the predicted population with the existing population due to changes performed on land zoning in the project area | % accuracy or the change negatively or positively | 80 % - 90% | 4 | 8.2 | 32.8 |
| **B2** | Planning horizon | The estimated period in which the network is designed to function efficiently compared with the actual period | Yes/No (likelihood) | Very Likely | 5 | 8.7 | 43.5 |
| **B3** | High Infiltration / Inflow | The high levels of infiltration from groundwater and inflow from rainwater, manhole covers, yard drains, catch basins, and other sources | % of Infiltration / Inflow to the sewerage system | ≤10 % | 5 | 8 | 40 |
| **B4** | Missuses of sewerage by the users | The use of the sewerage system to discharge storm water, opening manholes, or disposal of fats, oils, and grease | % users missuses recorded in the project area (such as oil and grease Mg/L) | 25- 50 | 4 | 5.1 | 20.4 |
| **Second Objective: Contribute to the sustainable development of wastewater collection system (weight of 45 out of 100)** | | | | | | | |
| **Criterion C. Economic aspects (weight of 15 out of 100)** | | | | | | | |
| **C1** | Operation and maintenance cost | The total cost through the operation and maintenance based on the estimated planning horizon | $ per year | 80-70 million dollars | 3 | 7.7 | 23.1 |
| **C2** | Sewage treatment plant | The reduction of the wastewater treatment plant process by reducing the income flow (e.g., infiltration) | % of money saved per m3/day for possible high infiltration | 30-40% | 4 | 7.3 | 29.2 |
| **Criterion D. Social aspects (weight of 10 out of 100)** | | | | | | | |

| SI | Sustainability criteria and indicators | Description | Measuring parameter | Value | Score | Weightage (out of 100) | Sum |
|---|---|---|---|---|---|---|---|
| **D1** | Public health and safety | The protection of the public from possible sewage-borne diseases, the likelihood of road collapses, etc. in the project area. | Yes/No (likelihood) | Likely | 4 | 1.6 | 6.4 |
| **D2** | Satisfaction of the stakeholders | The reported complaints within the sewerage project area compared with contributions to reduce the complaints | % of contribution to reduce the complaints compared with previous years | 70% ≥ | 5 | 1.6 | 8 |
| **D3** | Served occupants | The served occupants by the project compared with the total occupants that required sewer service | % of served occupants out of the total no. of occupants that required sewer service | 70-80% | 3 | 1.8 | 5.4 |
| **D4** | Local economic development activities | Provision of sewer services to local business activities such as malls and commercial real estate | Yes/No (likelihood) | Very Likely | 5 | 1.7 | 8.5 |
| **D5** | Served critical infrastructures and facilities | Facilities and infrastructures (e.g., hospitals, educational institutions, airports, police and military installations, and community facilities) that will maintain service from the project | % of served facilities and infrastructure out of the total facilities and infrastructure | 90-100% | 5 | 1.8 | 9 |
| **D6** | Public awareness | The extent of public awareness concerning the consequences of misusing the sewerage system (e.g., opening manholes or disposing of fats, oils, and grease) | % of reduction of recorded missuses by the users in the project area (such as oil and grease Mg/L) | 20% - 30% | 3 | 1.5 | 4.5 |
| **Criterion E. Environmental aspects (weight of 15 out of 100)** | | | | | | | |
| **E1** | Odour air pollution | The generation of odour from the sewer network (e.g., septic tank, pumping stations, and manholes) | OU/m3 | 3-2 | 4 | 4.75 | 19 |

| SI | Sustainability criteria and indicators | Description | Measuring parameter | Value | Score | Weightage (out of 100) | Sum |
|---|---|---|---|---|---|---|---|
| **E2** | Green technologies | Any green innovation that overlaps with sewerage projects that will end up saving energy, preventing pollution, and recycling waste, such as a pumping station operating by means of solar panels, onsite septic systems, and software | Yes/No (adopted technologies with tangible positive impacts) | Technologies with few tangible positive impacts affecting 2 to 4 environmental aspects (pollution, green energy, recycling…) | 4 | 5.5 | 22 |
| **E3** | Sewage flooding | Contribution in reducing the areas suffering from sewage overflow | Yes/No (likelihood) | Very Likely | 5 | 4.75 | 23.75 |
| **Criterion F. Policy (decrees, institutions, and strategic visions) (weight of 5 out of 100)** | | | | | | | |
| **F1** | Local consultants | Engagement of local consultants in the project | % of total work per year | ≤ 50 % | 1 | 1.8 | 1.8 |
| **F2** | Local contractors | Engagement of local contractors in the project | % of total work per year | 60% - 70% | 2 | 1.6 | 3.2 |
| **F3** | Service fees | Adoption of service fees or taxes policies | Yes/No (adopted service fees with tangible positive impact) | Some intentions toward the adoption of services fees with a tangible positive impact | 3 | 1.6 | 4.8 |
| | | | | | **Total** | **100** | **407.55** |