EEET ECOLOGICAL ENGINEERING
& ENVIRONMENTAL TECHNOLOGY

Ecological Engineering & Environmental Technology 2024, 25(5), 333–343
https://doi.org/10.12912/27197050/186268
ISSN 2719-7050, License CC-BY 4.0

Received: 2024.03.01
Accepted: 2024.03.21
Published: 2024.04.01

Improving Reliability in Al Hoceima Seawater Desalination Plant by Failure Modes, Effects, and Criticality Analysis Model

Iman Aoueryagel[1*], Faiza Chaouket[1], Nihade Bensitel[2],
Ihssane Raissouni[1], Dounia Bouchta[1]

[1] Materials Engineering and Sustainable Energy, Faculty of Science Tétouan, Morocco
[2] Laboratory LSIA, ENSAH, Abdelmalek Essaadi University, Tetouan, Morocco
* Corresponding author's e-mail: iman.aoueryagel@etu.uae.ac.ma

ABSTRACT

The insufficiency of water resources and the need for potable water constitute a major concern for many countries, especially Morocco, which has experienced a significant increase in water demand due to population growth, economic development, and climatic conditions. To address this issue, Morocco has initiated an ambitious program to establish seawater desalination plants using reverse osmosis technology in semi-arid areas.This study addresses the pressing concern of ensuring the reliability and quality of desalinated water in the Al Hoceima seawater desalination plant, a vital initiative by Morocco to combat water scarcity in semi-arid regions. Employing the Failure Modes, Effects, and Criticality Analysis (FMECA) method, a comprehensive analysis was conducted to identify potential malfunctions compromising water quality and process reliability. Failures were ranked in descending order of criticality, and cumulative criticality was calculated to prioritize improvement actions. The Pareto diagram generated from this analysis helped identify critical failures in the studied system that require prioritized improvement actions. Notably, it was observed that 80% of the criticality corresponded to half of the failures. Consequently, an improvement plan should be developed for 12 out of the 24 predetermined failure modes, focusing on those identified as most critical. Subsequently, an improvement plan was formulated, integrating short-term corrective actions such as optimizing cleaning protocols and medium to long-term preventive measures such as upgrading equipment and implementing redundancy systems. This study contributes novel insights into enhancing process reliability in seawater desalination plants, particularly in semi-arid regions like Morocco, by providing a systematic approach to identify and prioritize potential failures, ensuring the sustainable provision of potable water.

Keywords: semi-arid regions, seawater desalination, reverse osmosis technology, process reliability, failure rate.

INTRODUCTION

Water is indispensable for life across all ecosystems (Tampo et al., 2015), playing a pivotal role in driving economic development at local, regional, national, and international levels (Talhaoui et al., 2020). In semi-arid regions like Morocco, where reliance on surface water sources has been customary since the 1960s, the construction of dams has historically sustained drinking water and industrial needs (Mehanned et al., 2014). However, burgeoning population, climate change, and recurrent droughts have rendered these conventional water sources increasingly inadequate to meet the escalating demand, culminating in an alarming global water scarcity scenario (Yousif et al., 2022).

To mitigate water stress, Morocco has embraced innovative techniques for water production, including desalination of unconventional sources such as brackish water, wastewater, and seawater. Among these methods, seawater desalination has emerged as a predominant solution. In response to this pressing need, Morocco has deployed reverse osmosis technology in various regions to bolster water supply. However, ensuring the optimal performance of these desalination plants remains imperative for their sustained operation and efficacy.

Recognizing the necessity for performance enhancement in seawater desalination plants, efforts have been directed toward implementing robust control systems and effective risk management strategies. One such systematic approach is the Failure Modes, Effects, and Criticality Analysis (FMECA), endorsed by the International Electrotechnical Commission (IEC, 1985) and employed extensively in various industries FMECA methodology aims to pinpoint qualitative and quantitative failures, assess associated risks, and facilitate the implementation of corrective and preventive measures (Zwingelstein 1995), along with estimating risks, to implement corrective and preventive actions (Noureddine et al.). This article is positioned within the context of proposing an FMECA-based analysis of the Al Hoceima seawater desalination plant. The primary objective is identifying potential vulnerabilities that could compromise water quality and plant functionality. Furthermore, the study seeks a comprehensive improvement plan to enhance overall performance and reliability. By elucidating the significance of this research endeavor, this study aims to contribute to the sustainable management of water resources.

MATERIALS AND METHODS

Location

The Al Hoceima seawater desalination plant is located 8 km southeast of the city of Al Hoceima, on a coastal site near Sfiha Beach in the municipality of Ajdir. It covers an area of 3.2 hectares (expropriated land for the account of the National Office of Electricity and Drinking Water – water branch) and has a capacity of 200 l/s for drinking water, equivalent to 17,280 m^3/day.

Methodology of the FMECA approach

The principle of this analysis is to investigate potential failure modes that could compromise the desalination process (Asma and Mestiri, 2017), tracing from potential causes to effects. The objective is to develop a corrective and preventive action plan for the processes of the Al Hoceima desalination plant. To achieve this goal, the application of the FMECA tool across the entire treatment chain was undertaken. This enables the identification of weaknesses in each treatment process, ultimately establishing an improvement plan.

To implement this process improvement approach, two crucial aspects, one quantitative and the other qualitative, are essential. These two aspects are developed by the following steps (Boubaker et al., 2021).

FMECA process flow – the steps of the approach are hierarchical in Figure 2:

1. Constriction of the work team – to succeed in this step, a multidisciplinary working team was formed.
2. Functional analysis – functional analysis is an essential preliminary step in the failure modes analysis process. For the studied system, the performed functional analysis is of the external and internal functional analysis type. It enables a comprehensive determination of the main functions of a process (Mansour, 2015).

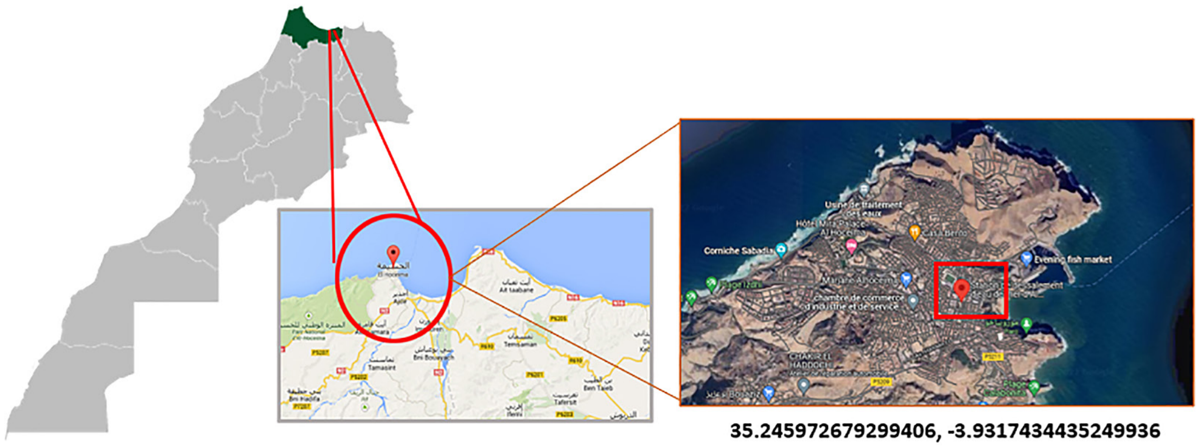

Figure 1. Geographic location of the desalination plant

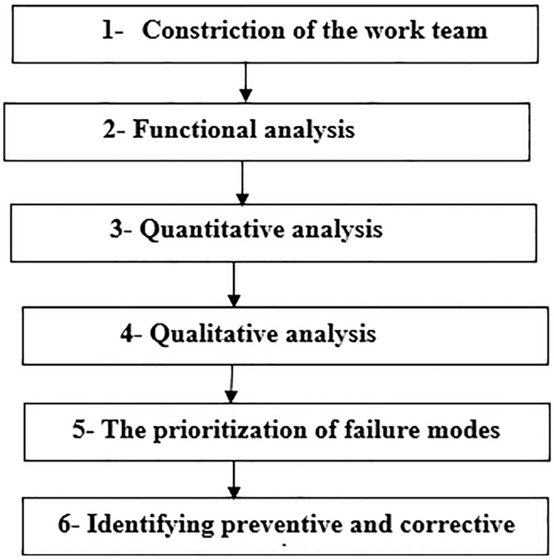

Figure 2. Steps of the FMECA approach

External functional analysis

This analysis provides a list of specific functions of the installation and their connections with external elements. For this purpose, systematic approaches based on various tools have been employed. The horned beast diagram facilitates a functional analysis by addressing three fundamental questions: (1) who does it provide the service to?, (2) what does it act on?, and (3) for what purpose? (Fig. 3). This diagram helps discern the needs of the system. Additionally, the octopus diagram elucidates the connections between the system and environment (Zehtaban and Roller 2012), showcasing both main functions (Fm) and constraint functions (Fc) (Fig. 4)

Internal functional analysis

The internal functional analysis establishes all the functions of each treatment process of the installation and their interactions. This functional analysis was carried out on all processes, from water intake to post-treatment (Fig. 5). Through this figure, the various operations for each activity in the production process and the objectives associated with these operations have been identified.

Quantitative analysis

Following the functional analysis, a systematic identification of potential failure modes has been conducted to anticipate them at each stage of the studied process. This is done to analyze and identify the possible and most probable causes of these potential failures (Moussa et al., 2006). To successfully accomplish this step, quality tools, namely brainstorming sessions and the Ishikawa diagram (Method, Environment, Material, Machine, Manpower), have been implemented as presnted in Figure 6. The aim is to highlight the failures that may affect the desalination system, thereby preventing it from fulfilling its intended mission, which is the production of potable water from saline water (Aouadi, 2018).

Qualitative analysis

In this step, it is necessary to assess the impact of failures on the studied system (Garin 1994) . Proceed to their evaluation to prioritize them for the implementation of specific actions. To successfully carry out this step, a criticality index (C) must be calculated as the multiplication of three

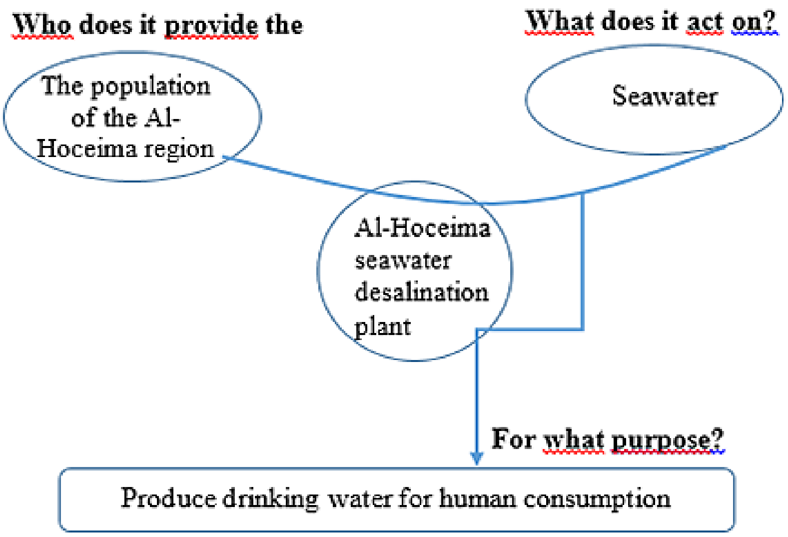

Figure 3. Desalination plant horned beast diagram

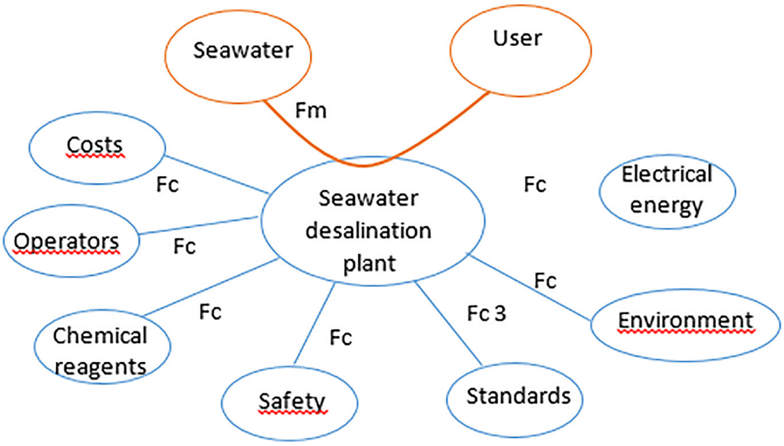

Figure 4. Octopus diagram of the desalination system studied: Fc 1 – supply electrical energy, Fc 2 – preserving the environment, Fc 3 – comply with current standards and regulations, Fc 4 – ensuring safety, Fc 5 – adding chemical reagents, Fc 6 – control the station, Fc 7 – take costs into account

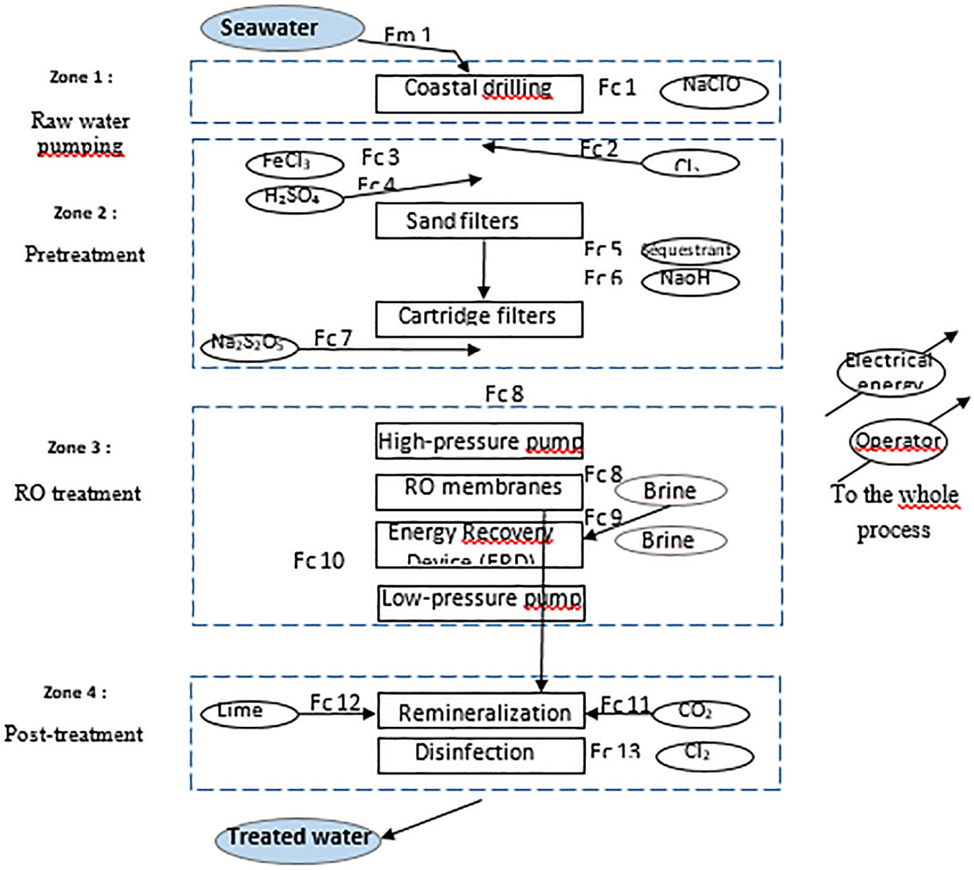

Figure 5. Internal functional analysis of the station

indices: G, F, and D. The formula is: $C = G \times F \times D$ (Thivel et al., 2008). The rating grids used in this study are presented in the Tables 1, 2 and 3:

- severity – denoted as S, it represents the impact of failure on water production (Noureddine et al., 2008). When the effects of failure modes are known, the determination at the severity level is carried out. These are presented in Table 1.
- frequency – denoted as F, it is the periodicity of the occurrence of the failure, how often does the failure occur (Lorino, 1997). To create the frequency rating grid as presented in Table 2, monitoring the water production processes and detecting repeated problems are necessary (Thivel et al., 2008).

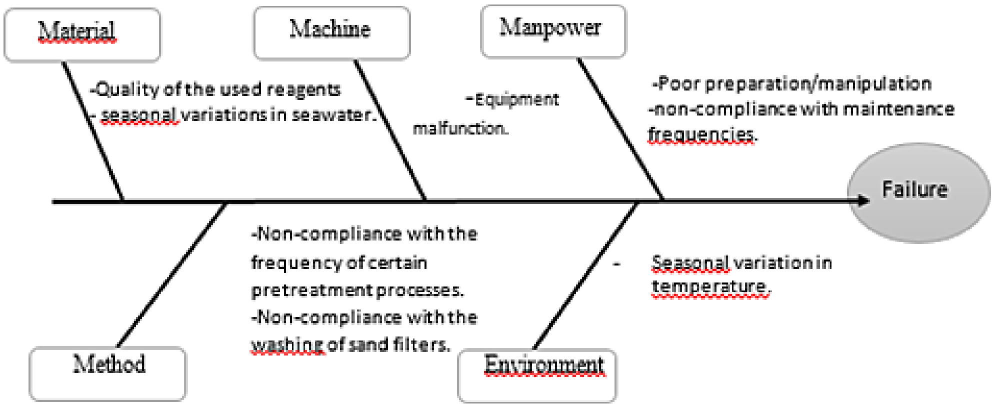

Figure 6. Ishikawa diagram applied to all stages of the treatment process

Table 1. Severity rating grid

Index	S	Severity
1	Without influence	No production line shutdown, No impact on the quality and quantity of water produced.
2	Significant	Effects that do not pose a serious risk to the quality of the produced water. Quality issues without station shutdown. Production shutdown less than 10 minutes.
3–5	Serious	Production shutdown exceeding 2 hours Quality issues (Non-compliance with standards) Decreased performance of the production chain
6–8	Very serious	Production shutdown exceeding 8 hours Quality issues (Non-compliance with standards), decrease in efficiency
9–10	Catastrophic	Production shutdown exceeding 24 hours, Quality issues (Non-compliance with standards), decrease in efficiency. Haut du formulaire

Table 2. Frequency rating grid

Index	F	Frequency
1	Very low	Very low probability of occurrence (less than once every five years)
2–3	low	Low probability of occurrence (observed approximately 1 to 2 times in five years)
4–5	Medium	Medium probability of occurrence (observed approximately once per year)
6–7	High	High probability of occurrence (observed several times per year)
8–10	Very high	Very high probability of occurrence (observed several times per month)

- detectability – denoted as D, it represents the risk of failure not being detected, characterized by the probability that the failure will not be detected before reaching the next operation, as mentioned in Table 3 (Noureddine et al., 2008).

DISCUSSION AND RESULTS

The results of the implementation of the FMEA approach are presented in Table 4. This analysis has identified 23 failure modes across the entire treatment system. Subsequently, a calculation of the criticality for each failure mode was performed by multiplying severity, frequency, and detectability. Then, a Pareto diagram was implemented to prioritize the pre-determined failure modes based on their cumulative criticalities.

Hierarchization of failure modes

To prioritize failures according to their degree of criticality for the facility, we worked with the Pareto diagram. This method allows us to highlight the most significant causes from the total number of effects, enabling targeted measures to improve the situation.(Grosfeld-Nir et al., 2007). To implement it, failures were ranked in descending order of criticality. Subsequently, cumulative criticality was calculated, and the Pareto diagram was plotted as presented in Figure 7. This diagram

Table 3. Detection rating grid

Index	Detectability
1	Highly detectable
2	Poorly detectable
3	Barely detectable
4	Difficult to detect
5	Undetectable

helps identify critical failures in the studied system that require prioritized improvement actions. According to Figure 7, it appears that 80% corresponds to half of the failures. Consequently, an improvement plan should be developed for 12 out of the 24 predetermined failure modes.

Development of the improvement plan

After the evaluation of failure modes in the seawater desalination system, an action plan comprising corrective and preventive measures was developed to continuously improve the performance of the study station.

The failure analysis of the Al-Hoceima Seawater Desalination Plant, categorized by specific failure numbers, highlights critical challenges across various process steps. Failure 20, resulting from mishandling during lime milk preparation, highlights the critical need for comprehensive training programs and consistent maintenance schedules to mitigate pipeline clogging risks. Implementing a periodic cleaning regimen for the lime dosing line, employing water infused with CO_2 and high-purity lime, requires meticulous planning and disciplined execution. Initially, a detailed schedule must be established, accounting for dosing frequency and historical performance data. Simultaneously, standardized protocols should be devised for the preparation, application, circulation, and rinsing of the cleaning solution. Moreover, sourcing high-quality lime demands thorough supplier evaluations, stringent incoming quality assessments, and optimization of storage and handling protocols. Integrating these measures with thorough personnel training and ongoing monitoring efforts can significantly minimize the likelihood of lime-dosing line obstructions, thereby bolstering overall operational reliability and efficiency within the production framework. Similarly, Failure 21, stemming from degradation in the function of the saturation unit, underscores the necessity for manual draining and maintenance programs to uphold optimal performance. Manual draining involves periodic emptying of the saturator to eliminate sediment and debris buildup, which could impede the lime preparation process. Establishing a regular draining schedule is essential to sustain saturator performance and prevent malfunctions. Furthermore, implementing a monitoring and maintenance program for the saturator is crucial. This entails continuous monitoring to detect signs of malfunction such as pressure or flow rate variations, leaks, or abnormal noises. Additionally, scheduling periodic inspections and preventive maintenance

Table 4. FMECA analysis results

Process step	Sub-processes	N°	Risks or failure modes	Cause	Effect	Detection	Criticality	
							S	*F*
Zone 1: Seawater intake and pumping								
Water intake	Seawater pumping	1	The required flow rate is not provided	- Low or very low level of intake well. - Loss of operation of the intake pumps. - Power outage.	- Low production flow rate	- Control and data acquisition system	3	6
	Shock chlorination	2	The sodium hypochlorite content injected is not sufficient	- Loss of operation of dosing pumps. - Loss of chemical properties of stored sodium chloride	- Development of living organisms and shellfish in the supply network. - Proliferation of algae. - Risk of biological fouling of reverse osmosis membranes.	- Periodic monitoring of physicochemical and microbiological parameters. - Control and data acquisition system.	3	1

Zone 2: Pre-treatment of seawater								
Pre-treatment	Pre-chlorination	3	Chlorine gas not injected or insufficient quantity injected	- Malfunction of the chlorine dosing pump. - Chlorine preparation issues. - Oxidation of seals in the hydroejector.	- Biological and organic fouling of membranes. - Development of living organisms in the pretreatment network.	- Periodic monitoring of physicochemical and microbiological parameters. - Control and data acquisition system.	4	2
	Coagulation	4	Ferric chloride not injected or insufficiently injected	- Malfunction of the coagulant dosing pump. - Issues during the injection of ferric chloride. - Clogging of injection points in the static mixer.	- Decrease in the efficiency of suspended matter removal by sand filters. - Risk of clogging in cartridge filters.	- Control and data acquisition system. - Monitoring of the turbidity of filtered water.	5	1
	Acidification	5	Sulfuric acid is not injected, or the quantity injected is not sufficient.	- Malfunction of the sulfuric acid dosing pump.	- Precipitation of calcium carbonate at the entry of the reverse osmosis system (membrane scaling). - Uncontrolled water pH.	- Control and data acquisition system. - Monitoring of the pH of acidified water.	3	1
	Sand filtration	6	Filter clogging	- Poor-quality sand. - Non-compliance with the backwashing frequency for the filter.	- Degradation of the quality of pretreated water. - Decrease in the efficiency of the station. - Decrease in production performance.	- Monitoring of pressure loss. - Monitoring of pressure.	6	1
		7	Overpressure malfunction	- Presence of water in the air ircuit.	- Washing blockage.	- Visual monitoring of the equipment	8	2
	Prevention of fouling	8	Sequestrant is not injected, or the quantity injected is not sufficient.	- Malfunction of the sequestrant dosing pump. - Leakage in the sequestrant circuit.	- Mineral fouling of membranes	- Control and data acquisition. - Normalized permeate flow rate. - Pressure loss.	10	1
	Basification	9	NaOH not injected	- Malfunction of the NaOH dosing pump. - Leakage.	- Uncontrolled water pH. - Presence of boron in the water.	- Control and data acquisition system. - Visual inspection.	5	1
	Microfiltration	10	Risk of filter clogging	-I ncrease in turbidity upstream of cartridge filters. - High load of suspended matter and contaminants.	- Decrease in microfiltered water flow rate. - Reduction in downstream pressure of the cartridge filter.	- Pressure loss at the outlet of cartridge filters.	4	1
	De-chlorination	11	Sodium metabisulfite not injected or insufficiently injected	- Malfunction of the sodium metabisulfite dosing pump.	- Oxidation/ corrosion of reverse osmosis membranes. - Abnormal discharge (brine).	- Monitoring of free residual chlorine.	10	1

Zone 3: Reverse osmosis unit								
Reverse osmosis unit	High-pressure pump	12	Malfunction of the pump	- Breakage or lack of maintenance.	- Decrease in the performance of the reverse osmosis membrane.	Visual inspection of the equipment	8	2
	Reverse osmosis membrane	13	Chemical damage (oxidation)	- Incomplete reduction of oxidants and chlorine, mainly at the entrance of the reverse osmosis unit.	- Increase in permeate flow rate. - Increase in salt passage rate. - Poor quality of permeate.	Monitoring of the operating parameters of reverse osmosis membranes: ΔP, normalized permeate flow rate, normalized salt passage rate.	9	1
		14	Physical damage to the membranes (leakage at the membrane, leakage at the O-ring joints)	- Lack of maintenance. - Pressure.	- Increase in salt passage rate. - Decrease in the quality of produced water.		9	1
		15	Mineral fouling	- Ineffective scale prevention.	- Decrease in permeate flow rate. - Increase in salt passage rate. - Increase in pressure loss.		8	1
		16	Colloidal fouling	- Ineffective pretreatment.			8	1
		17	- Bio-fouling (biological fouling). - Organic fouling.	- Insufficient pretreatment (pre-chlorination). - Contaminated raw water.	- Increase in pressure loss. - Decrease in permeate flow rate.		8	1
	Energy recovery	18	Malfunction of energy recovery device	- Presence of blocking elements (plastic, etc.) in the microfiltered water. - Lubrication path blockage.	- Increase in turbidity. - Decrease in exchange efficiency. - Degradation of the rotor-stator contact surface.	- Visual inspection of the equipment. - Control and data acquisition system.	5	6
	Booster pump	19	Loss of function	- Lack of maintenance.	- Decrease in the performance of the reverse osmosis membrane.		6	2
Zone 4 : Post-treatment								
Remineralization	Lime dosing system	20	- Incorrect dosing during the preparation of lime milk. - Clogging of lime milk delivery pipelines.	- Impurity of delivered lime. - Inadjustable quantity of added lime powder.	- Poor quality of produced water in terms of total hardness (TH) and total alkalinity (TAC). - Uncontrolled pH. - Risk of corrosion of the distribution network pipelines.	- Monitoring of the quality of lime water (TAC, TH, and turbidity).	7	9
		21	- Degradation of the function of the saturation unit	- Settling of sludge at the bottom of the saturator. - Incomplete dissolution of lime.				
	Système de dosage de CO_2	22	- Insufficient Dissolution of CO_2	- Lack of CO_2 in the storage tank. - Improper. positioning of the injection point.		- Monitoring of the quality of lime water (TAC and TH).	7	4

Final disinfection	Gaseous chlorine dosage	23	- Leakage upstream of the hydroejector. - Uncontrollable permeate flow rate.	- Malfunction of the chlorine dosing pump. Issues during the preparation of chlorine. - Oxidation of seals in the hydroejector.	- Abnormal Cl_2 levels: potential contamination of water in the distribution network. - Deterioration of the quality of distributed water.	- Visual inspection. - Physicochemical and microbiological control.	10	5

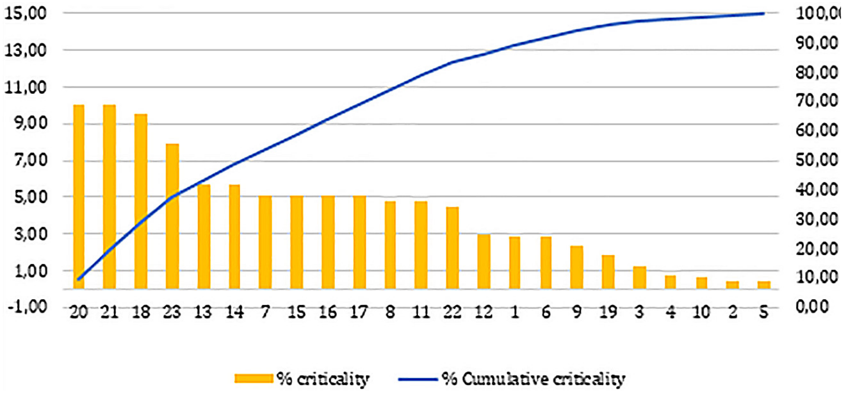

Figure 7. Pareto diagram on failures of the studied system

ensures the condition of components is checked, adjustments are made if necessary, and worn parts are replaced. Considering the use of an anionic polymer to enhance the turbidity of lime water is another avenue. This polymer functions as a flocculating agent, promoting the aggregation of suspended particles in the water and facilitating their separation. Incorporating it into the lime water treatment process can mitigate turbidity and enhance water quality, positively impacting overall station performance and compliance with water quality standards. Finally, to maintain uninterrupted station operation, measures such as implementing backup systems for critical equipment, training personnel to handle emergencies, and establishing an action plan for breakdowns or malfunctions are imperative. Ensuring continuous station availability minimizes production disruption risks and preserves optimal performance in delivering treated water.

The malfunction of energy recovery devices, as highlighted by Failure 23, underscores the critical need for regular inspections and preventive maintenance measures to uphold operational integrity. Just as with the previous failure, where leakage upstream of the hydroejector necessitated proactive steps, the malfunction of energy recovery devices demands similar attention to detail. Implementing a structured maintenance program involves conducting routine inspections to detect any signs of malfunction or degradation in the energy recovery devices. This includes monitoring for fluctuations in energy output, unusual noises, or visible wear and tear on components. Additionally, scheduling periodic preventive maintenance ensures that components are checked, calibrated, and replaced as needed to prevent unexpected failures. Considering the complexity of energy recovery systems, thorough training for maintenance personnel is vital to enable them to identify and address issues promptly. By adhering to these measures, the risks associated with energy recovery device malfunctions can be mitigated, thereby safeguarding operational efficiency and minimizing downtime in the production process.

Failure 18 underscores the need to establish preventive maintenance plans, where proactive measures were necessary to address the issue, this failure highlights the importance of a preventive approach to ensure equipment operates smoothly. Establishing preventive maintenance plans involves setting regular schedules for inspecting, cleaning, and repairing equipment to detect and rectify potential issues before they escalate into major breakdowns. This also requires training personnel to recognize early signs of failure and take necessary steps to address them. By adopting a proactive approach to maintenance, the risks of equipment failure can be reduced, ensuring operational continuity and reliability in production processes.

Failures 13 and 14, which pertain to chemical and physical damage to membranes in the reverse osmosis unit, necessitate a comprehensive approach. Firstly, in the case of chemical damage, it's crucial to identify the specific chemicals causing the damage and take appropriate measures to mitigate their impact. This may involve conducting regular water quality tests to detect any contaminants present in the feed water and adjusting pre-treatment processes accordingly. Additionally, implementing chemical dosing systems to control pH levels and remove harmful substances can help protect the membranes from degradation. For physical damage, such as membrane fouling or tearing, regular monitoring of operating conditions is essential. This includes measuring pressure differentials across the membranes, monitoring flow rates, and conducting visual inspections of the membranes for signs of wear or damage. Implementing automated monitoring systems can streamline this process and provide real-time data to identify potential issues before they escalate. Adherence to operational protocols is also critical. This involves following manufacturer recommendations for membrane cleaning procedures, including the use of appropriate cleaning agents and frequencies. Furthermore, training personnel to properly operate and maintain the reverse osmosis unit is essential to ensure that protocols are consistently followed and any deviations are promptly addressed.

Pre-treatment issues, such as suppression dysfunction (Failure 7) and insufficient sequestrant injection (Failure 8), highlight the significance of regular inspections and personnel training. Indeed, these failures underscore the need for constant vigilance in monitoring pre-treatment equipment and processes to ensure their proper functioning. Regular inspections allow for the prompt detection of any malfunction or anomaly in the suppression or sequestrant injection system, enabling swift corrective actions before issues escalate. Furthermore, personnel training is essential to ensure that operators fully understand pre-treatment procedures, including the use of suppression and sequestrant injection equipment, and can identify and report any potential problems. By combining regular inspections with adequate personnel training, pretreatment issues can be identified and addressed proactively, thereby contributing to the overall effectiveness and reliability of the water treatment process. Failures 15, 16, and 17 in the reverse osmosis unit underscore the critical importance of robust monitoring systems and targeted improvement actions to ensure the plant's efficiency and reliability in providing clean water. Failure 15, attributed to mineral fouling, emphasizes the necessity of establishing precise dosing of sequestrants through a reliable monitoring system. Similarly, Failure 16, related to colloidal fouling, highlights the need to maintain pretreatment processes' effectiveness, employing measures like initiating the coagulation process and utilizing a Silt Density Index (SDI) measuring device. Additionally, Failure 17, concerning bio-fouling/organic fouling, stresses the significance of strict pre-chlorination schedules and continuous monitoring of raw water quality to promptly address any deviations. By addressing these failures through systematic improvements and vigilant monitoring, the plant can enhance its operational efficiency and reliability, ensuring consistent delivery of clean water.

Lastly, Failure 11, linked to sodium metabisulfite injection, highlights the critical importance of conducting regular inspections and calibrations to guarantee the accurate functioning of dosing pumps. Addressing these failures through targeted interventions is essential for optimizing the plant's performance and effectively maintaining water quality standards. By implementing systematic inspections and calibrations, potential issues with dosing pumps can be promptly identified and rectified, ensuring the reliable injection of sodium metabisulfite and minimizing the risk of operational disruptions or deviations from water quality standards. Thus, proactive measures to address Failure 11 contribute to the overall efficiency and effectiveness of the plant's operations, enhancing its ability to consistently meet water quality requirements.

Indeed, this step must be complemented by the implementation and monitoring of corrective and preventive action plans. The effectiveness of the solutions implemented should be subject to a second quantitative study, a second rating, and an evaluation of frequencies, detectability, and severity, as well as the new value of the criticality index C (Thivel et al., 2008).

CONCLUSION

The results obtained demonstrate the effectiveness of this method in reducing process-related risks by identifying potential failures that could impact performance in the medium and long term. This has led to the development of an improvement plan based on corrective and preventive actions, enhancing the reliability of processes and ensuring the proper functioning of the plant. In addition to managing the operational performance of seawater desalination plants, the control of energy and environmental performance is crucial, given the substantial energy consumption required for the operation of the reverse osmosis unit.

Acknowldgments

I would like to express my deep appreciation to the dedicated team members of the Al Hoceima National Office of Electricity and Potable Water. Their unwavering support and outstanding technical assistance have been pivotal in achieving our goals. I am sincerely thankful for their dedication and proficiency, which have greatly enhanced our collaborative initiatives.

REFERENCES

1. Aouadi H. 2018. Enhancing process performance: an approach to process FMEA. Revue Interdisciplinaire, 2(2).
2. Selmen B., Dumondelle S., Dolatineghabadi P. 2021. An approach to assess risks related to information system in supply chain. IFIP International Conference on Advances in Production Management Systems. Cham: Springer International Publishing.
3. Asma G., and Mestiri Z. 2017. Improving the performance of a production process through the DMAIC Approach. International Journal of Economics & Strategic Management of Business Process. 10, 198-210
4. Garin H. 1994. AMDEC/AMDE/AEEL: The Essentials of the Method. French Standardization Association, 2-12-475013-5.
5. Grosfeld-Nir A., Ronen B., Kozlovsky N., Grosfeld-Nir A., Ronen B., Kozlovsky N. 2007. The Pareto managerial principle: when does it apply? International Journal of Production Research, 45(10), 2317–2325. DOI: 10.1080/00207540600818203.
6. Lorino P. 1997. Methods and Practices of Performance. Paris, Organisation edition, 1997, 2001, 2003.
7. Mehanned S., Chahlaoui A., Zaid A., Samih M., Chahboune M. 2014. Typology of the physicochemical quality of water in the Sidi Chahed Dam - Morocco. Journal of Materials and Environmental Science. 5(2), 1633–1642.
8. Moussa F., Kolski C., Riahi M. 2006. Analysis of dysfunctions in complex systems prior to human-computer interface design: Contributions, challenges, and case study. Revue d'Interaction Homme Machine, 7(2), 79–111.
9. National Drinking Water Board-Seawater Desalination Plant (ONEE).
10. Noureddine M., Noureddine R., Hamdadou D., Khaldi M. 2008. Automatic generation of process and product FMEA. In: Conférence Internationale – Maîtrise et Management des risques Industriels.
11. Mansour S. 2015. The role of failure modes and effects analysis (FMEA) in the industry. In: 3rd International Conference on Innovation and Engineering Management International Journal of Economics & Strategic Management of Business Process, 1-6.
12. Talhaoui A., El Hmaidi A., Jaddi H., Ousmana H., Manssouri I. 2020. Calculation of the water quality index (WQI) for the assessment of the physicochemical quality of surface waters in the Oued Moulouya (NE, Morocco). European Scientific Journal, 16(2), 64–85.
13. Tampo L., Gnazou M., Akpataku V., Bawa L., Djaneyé-Boundjou G., Nuto Y., Oueda A., Guenda W. 2015. Application of statistical methods to the hydrochemical study of waters in a tropical hydrosystem: Case of the Zio River watershed (Togo). European Scientific Journal, 11(14).
14. Thivel P.-X, Bultel Y, Delpech F. 2008. Risk analysis of a biomass combustion process using MOSAR and FMEA methods. Journal of Hazardous Materials, 151(1), 221–231.
15. Yousif Y.T., Abbas A.A., Yaseen D.A. 2022. Analysis and simulation performance of a reverse osmosis plant in the Al-Maqal Port. Journal of Ecological Engineering, 23(5), 173–186.
16. Zehtaban L., Roller D. 2012. Systematic functional analysis methods for design retrieval and documentation. International Journal of Computer and Information Engineering, 6(12), 1711–1716.
17. Zwingelstein G. 1995. Failures diagnosis. Theory and practice for industrial systems SCA: 420200; 990200; 220400; 440800; 570000; PA: AIX-27:048926; EDB-96:107518; SN: 96001612165.