International Journal of Open-Access, Interdisciplinary & New Educational Discoveries of ETCOR Educational Research Center (iJOINED ETCOR)

ETCOR Educational Research Center Inc.
SEC Reg. No. 2024020137294-00
Sta. Ana, Pampanga, Philippines
Website: https://etcor.org

iJOINED ETCOR
P - ISSN 2984-7567
E - ISSN 2945-3577

The Exigency
P - ISSN 2984-7842
E - ISSN 1908-3181

Wastewater Management Practices of Selected Semiconductor Manufacturing Companies in Laguna: Basis of Optimized Water Utilization for Sustainability

Gashmere Prisca B. Diaz*[1], Dr. Ena A. Bernal[2]
[1, 2] Colegio de San Juan de Letran Calamba, Philippines
*Corresponding Author e-mail: *gashpriscadiaz@gmail.com*

Received: 17 January 2024 **Revised**: 22 February 2024 **Accepted**: 23 February 2024

Available Online: 23 February 2024

Volume III (2024), Issue 1, P-ISSN – 2984-7567; E-ISSN - 2945-3577

Abstract

Aim: The study aimed to address water challenges exacerbated by rapid urbanization in the Philippines, particularly focusing on the semiconductor industry's wastewater generation. It sought interventions to optimize water utilization, aligning with global sustainability goals, while improving water quality, conserving resources, and ensuring regulatory compliance.
Methodology: A quantitative approach was employed, focusing on five semiconductor companies in Laguna Technopark Inc., Biñan City, representing half of the population through convenience sampling.
Results: Findings revealed that selected semiconductor manufacturing companies in Laguna favored a mixed capability approach, with applications of tailored wastewater treatment methods and operational procedures. The study discovered money, motion/time/minutes, and materials as the top management issues. Interventions such as Wastewater Management Practices Augmentation and Prioritization-Implementation Plan-Monitoring- Evaluation-Adaptive Management (PIMEA) Cycle were developed to optimize water utilization, offering valuable directives for various industries to enhance their wastewater management.
Conclusion: Findings indicate lack of attention on optimizing mechanical systems despite educational initiatives, requiring a comprehensive approach for efficiency and sustainability. Though wastewater management operational procedures are well-executed, significant challenges persist with materials, motion, and money. Derived interventions require regulatory compliance, advanced technology, and future research exploring mixed capabilities, collaborations, eco-friendly methods, for sustainability through root cause analysis and qualitative studies.

Keywords: intervention, sustainability, wastewater management, water utilization

INTRODUCTION

Wastewater management involves multifaceted initiatives such as reuse, recycle, and discharge to promote responsible water utilization, treatment, and disposal, with a focus on watershed preservation (Tahir et al., 2023). Inadequate management poses health and environmental challenges, aggravated by a global surge in wastewater generation linked to population growth and increased water demand (Razman et al., 2023). The industrial sector's demand for clean water amplifies challenges in wastewater treatment.

Intercontinental studies about wastewater management practices involved recent European advancements in production optimization and resource management (Soares, 2020). The Davis Station in Antarctica uses advanced treatment for potable water (Shady, 2023), and California has a comprehensive wastewater management system (Water Education Foundation, 2023). Fluence's technology provides efficient solutions in Antarctica (Fluence, 2023). In Asia, China, Japan, the Middle East, and Israel have established effective wastewater management practices (Haga and Feixiang, 2017; Medill Explores, 2023).

During the 18th Annual Water Environment Partnership Asia Annual Meeting (WEPA), Engr. Wilma R. Uyaco, Division Chief of Environmental Management Bureau (EMB), discussed that in the Philippines, the industrial sector

ETCOR Educational Research Center Inc.
SEC Reg. No. 2024020137294-00
Sta. Ana, Pampanga, Philippines
Website: https://etcor.org
iJOINED ETCOR
P - ISSN 2984-7567
E - ISSN 2945-3577
The Exigency
P - ISSN 2984-7842
E - ISSN 1908-3181

such as manufacturing industries is the third-largest contributor to wastewater at 27%, following domestic sources and agriculture-livestock at 33% and 29%, respectively. Disturbingly, only 10% of the wastewater undergoes treatment (Breton, 2020).

According to the Philippines Industrial Water and Wastewater Treatment Market Outlook (2022), the semiconductor and electronic industry is the primary industry that heavily depends on high-quality water, which is also the largest wastewater-producing industry in the country. Las Maria (2019) mentioned that Semiconductor Manufacturing Services (SMS) accounts for 73%, while Electronics Manufacturing Services (EMS) make up 27% of the Semiconductor and Electronics Industries in the Philippines.

Engr. Uyaco also highlighted the absence of centralized Wastewater Treatment Facilities (WWTF). The government's 2023 plan focused on monitoring compliance, implementing new water quality management strategies, and surveying industries to address wastewater issues. Technological solutions include monitoring water quality in Manila Bay, Boracay, and Laguna Lake. Laguna, encompassing the largest portion of Laguna Lake, accommodates semiconductor manufacturing companies which are also the dominant manufacturing industry in the area (PhilippineCompanies.com, 2023). The study centered on Laguna Technopark Inc. (LTI) in Biñan City, recognized as Laguna's largest industrial park. It aimed to address the growing challenges of wastewater management faced by semiconductor firms, especially those in LTI, with potential applications to related industries.

This study assessed wastewater management practices which provided optimized water utilization, including wastewater management capabilities, treatment methods, and operational procedures to address the common problems encountered in managing wastewater categorized in the 9Ms of Management from the Resource Planning Framework of Hanlon (2019), covering manpower, method, machines, materials, money, motion/time/minutes, management, measurements, and Mother Nature that leads towards sustainability. This would ensure smooth semiconductor production to support economic growth and the environment, particularly Laguna Lake that could be the basis of sustainable wastewater management practices of relevant manufacturing industries.

Specifically, this research made a notable contribution to global water conservation and sustainability, with a particular emphasis on advancing clean water objectives outlined in the United Nations Sustainable Development Goals. It offered valuable insights for effective wastewater management, supporting the Water Environment Partnership in Asia, where the Philippines is a member. It also aided the Laguna Lake Development Authority in maintaining water quality and ecosystem preservation. Additionally, it highlighted diverse benefits of enhancing wastewater management in semiconductor manufacturing companies, such as improved water quality, regulatory compliance, resource conservation, cost savings, sustainable economic growth, and positive impacts on local communities through increased awareness and engagement.

This study is also anchored in General Systems Theory aligned with Waste Management Theory. General Systems Theory, introduced by Ludwig von Bertalanffy in 1968 and cited in works such as "Philosophy of Complex Systems" by Hofkirchner and Schafrane (2011), emphasizes the harmony among system components. Consumers, competitors, government, and suppliers as part of the environment in the system theory collectively drive sustainable wastewater management. Consumers' demands and awareness influence companies, competitors foster innovation, government establishes regulations and incentives, and suppliers provide eco-friendly solutions, all contributing to effective wastewater management practices. The Waste Management Theory (WMT), which became known through Pongrácz in 2002, emphasizes the importance of managing waste to avoid adverse effects on human health and the natural environment. Furthermore, the study drew upon historical and sociological aspects of wastewater management techniques throughout human history to provide a foundation for understanding current wastewater management practices.

In relation to Waste Management Theory, it applied a conceptual framework derived from sustainable waste management phases (Yu et al., 2015), comprising pre-processing, transportation/distribution, and treatment/recycling. Inputs to this framework were existing wastewater management practices and issues in selected semiconductor manufacturing companies in Laguna, with research objectives gathered through a validated survey checklist. Data analysis identified gaps and relevance to determine effective practices for addressing wastewater management challenges. The study's output suggested interventions for optimizing water utilization to support sustainability.

ETCOR Educational Research Center Inc.
SEC Reg. No. 2024020137294-00
Sta. Ana, Pampanga, Philippines
Website: https://etcor.org
iJOINED ETCOR
P - ISSN 2984-7567
E - ISSN 2945-3577
The Exigency
P - ISSN 2984-7842
E - ISSN 1908-3181

Objectives

This study aimed to assess the wastewater management practices of selected semiconductor manufacturing companies in Laguna, focusing on identifying strategies to optimize water utilization for sustainability goals.

In particular, the following questions were addressed:

1. What are the existing wastewater management practices of the selected semiconductor manufacturing companies in Laguna in terms of capabilities, treatment methods and operational procedures?
2. What is the level of implementation of wastewater management practices in terms of treatment methods and operational procedures?
3. What is the level of severity of the problems encountered in managing wastewater of in terms of manpower, method, machines, materials, money, motion/time/minutes, management, measurement, and Mother Nature?
4. What are the interventions to optimize water utilization in support to water sustainability initiatives were developed?

METHODS

Research Design

This study applied descriptive research, utilizing quantitative method to determine the wastewater management practices applied in selected semiconductor manufacturing companies in Laguna as basis to optimized water utilization for sustainability. Primary data were gathered through the prepared and validated survey checklist designed based on the collected secondary data from the review of literature.

The said instrument addressed the research objectives of identifying the existing wastewater management practices and the problems encountered in managing the wastewater of selected manufacturing companies covering the 9Ms of Management (manpower, method, machines, materials, money, motion/time/minutes, management, measurements, and Mother Nature). This led to fulfilling the last research objective of developing interventions to optimize water utilization to support sustainability.

Population and Sampling

The research employed convenience sampling to select semiconductor manufacturing companies within Laguna Technopark, Inc. (LTI) that met study criteria, aligning with the research locale. Five out of the ten listed companies agreed to participate, representing 50% of the total semiconductor manufacturing companies in LTI. Fifteen key personnel were involved in the study, with three representatives from each selected company who held positions of authority and possessed extensive knowledge of wastewater management. This representative sample was deemed adequate for assessing pertinent wastewater management practices.

Instrument

The survey checklist was developed using insights from WaterSense and the United States Environmental Protection Agency. Sustainability Reports from 2022 to 2023 of top semiconductor companies worldwide were analyzed, emphasizing education, training, technology optimization, advancements in mechanical systems and production processes, and water reuse/wastewater recycling. The 9Ms of Resource Planning framework from "Digital Marketing: Strategic Planning and Integration" (Hanlon, 2019) guided wastewater management issue categorization. Instrument validation included content verification by language and field experts, pre-test, and Cronbach's Alpha analysis.

Data Collection

The data gathering involved two phases: Pre-Data Gathering and Data Collection. First three research objectives, focusing on wastewater management practices and common problems aligned with the 9Ms of management, used a validated survey checklist. During pre-data gathering, semiconductor companies were contacted with a letter explaining the survey purpose and method, followed by scheduling based on respondents' preferences for online or face-to-face surveys. In the data collection phase, online surveys and face-to-face visits were conducted carefully to ensure unbiased responses. The last research objective about interventions for optimizing water utilization to support sustainability, was derived from the survey checklist analysis, tallying responses to identify gaps and relevance.

ETCOR Educational Research Center Inc.
SEC Reg. No. 2024020137294-00
Sta. Ana, Pampanga, Philippines
Website: https://etcor.org
iJOINED ETCOR
P - ISSN 2984-7567
E - ISSN 2945-3577
The Exigency
P - ISSN 2984-7842
E - ISSN 1908-3181

Data Analysis

The percentage approach was employed to calculate the proportion of respondents who selected specific responses regarding existing wastewater management practices, thereby determining the percentage of respondents demonstrating wastewater management capability, treatment methods, and operational procedures.

The level of implementation across specific wastewater management treatment methods and operational procedures was analyzed to determine the completeness, complexity, and advancement of the selected manufacturing company's existing wastewater treatment methods and operational procedures.

In line with this, the severity level of commonly encountered wastewater management problems, categorized in the 9Ms of management (manpower, method, machines, materials, money, motion/time/minutes, management, measurements, and Mother Nature), helped in identifying the problems that must be prioritized to optimize water utilization to support sustainability.

A frequency-based method was employed, involving the assignment of numerical values to each response option on the level of implementation and severity. The total frequencies obtained for each level led to the analysis and comparison of the relative importance or preferences of various checklist items. After recording the frequency of the level of implementation/severity, the frequencies were summed up across all checklist items to determine the level with the highest frequency or the strongest preference attributed by the respondents. The frequency approach aided the researcher in understanding wastewater management practices comprehensively, evaluating performance, and identifying issues. These data were crucial for the development of interventions to optimize water utilization for sustainability.

Ethical Consideration

To ensure research instrument validity, secondary data were carefully gathered as a reference for the research instrument. Proper citation acknowledged contributions of related studies, avoiding appropriation of credit. Signed consent letters ensured voluntary respondent participation, with clear understanding of the study's purpose and methods. Data collection maintained accuracy and reliability, free from bias or conflicts of interest, with clear objectives and standardized instruments. Privacy and confidentiality were ensured through Non-Disclosure Agreements (NDA) and anonymization techniques, safeguarding sensitive data. Research was conducted at respondents' convenience, online or face-to-face, considering COVID-19 protocols. Ethical considerations adhered to company policies and permits, aiming for a positive impact on sustainable water utilization practices.

RESULTS and DISCUSSION

This section provides an analysis and interpretation of the data collected from study participants. The data is organized thematically, accompanied by interpretations and implications, following the sequence of the research objectives.

Existing Wastewater Management Practices of the Selected Semiconductor Manufacturing Companies in Laguna

Wastewater management capability is categorized as internal, external, and mixed capability. Mixed capabilities in wastewater management entail combining an organization's internal resources, knowledge, and expertise with external partnerships and collaborations to effectively manage wastewater. It emphasizes both internal and external resources to achieve the best wastewater management outcomes.

Aligned with wastewater management capabilities, the different wastewater treatment methods in semiconductor manufacturing companies were also examined. Each method, whether physical, chemical, biological, or sludge treatment, serves a distinct purpose. Wastewater treatment method selections are based on a thorough understanding of each company's wastewater composition and treatment goals.

Lastly, the wastewater operational procedures used were determined to identify the best operational procedures that could provide optimized water utilization for sustainability. These include education/training of wastewater treatment facilities, optimization and advancements in mechanical systems/production, optimization and advancements in water and wastewater treatment systems, and water reuse/wastewater recycling. The presence or

ETCOR Educational Research Center Inc.
SEC Reg. No. 2024020137294-00
Sta. Ana, Pampanga, Philippines
Website: https://etcor.org
iJOINED ETCOR
P - ISSN 2984-7567
E - ISSN 2945-3577
The Exigency
P - ISSN 2984-7842
E - ISSN 1908-3181

absence of each specific wastewater management treatment methods was represented as either 20% (1 out of 5 companies) or 0% (0 out of 5 companies).

In the study, the mixed capability approach was preferred by 80% of the surveyed companies, which employed customized wastewater treatment methods combining physical, chemical, biological, and sludge treatment techniques. In terms of wastewater operational procedures, all (100%) of these companies prioritized wastewater treatment education/training, 60% apply water reuse/ wastewater recycling and 40% has existing optimization and advancements in water and wastewater treatment. Only Company B (20%) applied optimization and advancements in mechanical systems and production, which signified a missed opportunity for other companies in terms of enhanced efficiency and technological advancements in mechanical systems and production.

Level of Implementation of Wastewater Management Practices of the Selected Semiconductor Manufacturing Companies in Laguna

Aside from the presence of wastewater management practices, the implementation of the existing treatment methods was examined to evaluate effectiveness, prevalence, and any emerging usage patterns of optimized water utilization for sustainability. Gaining a deeper understanding of the levels of implementation would allow adherence to sustainability objectives, resource efficiency, financial benefits, and stakeholder engagement in the selected semiconductor manufacturing companies.

This study examined level of implementation of wastewater management practices in terms of treatment methods and operational procedures which illustrated variations in implementing water treatment methods, with strong adherence to standards in physical and sludge treatment, while chemical and biological methods showed adaptability based on individual company and industry considerations. The surveyed companies exhibit full implementation in operational procedures of optimizations on mechanical system and water and wastewater treatment, including water reuse/ wastewater recycling. However, there is a need for improvement in education and training for wastewater treatment facilities, as indicated by its "Mostly Implemented" rating.

a.) Wastewater Treatment Methods

The level of implementation of the existing water treatment method varied across different methods among the selected semiconductor manufacturing companies rated as "5" (Fully Implemented), "4" (Mostly Implemented), "3" (Moderately Implemented), "2" (Partially Implemented) and "1" (Not Implemented At All). Specifically, sedimentation and filtration under physical treatment methods received "5" (Fully Implemented) as the level of implementation with highest frequency. Meanwhile, in sludge treatment method, thickening received "5" (Fully Implemented) while Sanitary Disposal/Landfill got "4" (Mostly Implemented) in the level of implementation. Chemical treatment methods had varying levels of implementation under which coagulation/flocculation had a common severity rating of "3" (Moderately Implemented) and "5" (Fully Implemented) while chemical oxidation had common severity ratings of "2" (Partially Implemented), "3" (Moderately Implemented) and "4" (Mostly Implemented).

The high levels of implementation ratings on physical and sludge treatment methods indicated a strong preference for these methods, showcasing efficiency and commitment to effective water treatment aligned with industry and environmental standards. Chemical and biological methods with differing levels of implementations from low to high showed a flexible approach influenced by individual company needs, semiconductor manufacturing processes, and regulations. This adaptability reflected the industry acknowledgment that method selection is influenced by operations, resources, environment, and finances.

b.) Operational Procedures

The existing wastewater management operational procedures received high implementation ratings among the surveyed companies. The level of implementation with highest frequency were "5" (Fully Implemented) and "4" (Mostly Implemented) which demonstrated strong commitment to efficiently carry out and adhere to established wastewater management procedures. Specifically, optimization and advancements in mechanical systems/ production, optimization and advancements in water and wastewater treatment systems and water reuse/wastewater recycling received "5" (Fully Implemented) in the level of implementation with highest frequency. This highlighted the company's strong dedication and expertise in adopting advanced technologies, aiming to enhance both operational efficiency and environmental sustainability. Education/trainings got "4" (Mostly

ETCOR Educational Research Center Inc.
SEC Reg. No. 2024020137294-00
Sta. Ana, Pampanga, Philippines
Website: https://etcor.org
iJOINED ETCOR
P - ISSN 2984-7567
E - ISSN 2945-3577
The Exigency
P - ISSN 2984-7842
E - ISSN 1908-3181

Implemented) rating for WWTF, implying the need for improvement by conducting relevant and regular trainings to better address wastewater treatment needs.

Level of Severity of the Problems Encountered in Managing Wastewater of the Selected Semiconductor Manufacturing Companies in Laguna

The level of severity with the highest frequency, known as the "common severity rating," for each of the 9Ms issues was assessed to identify the potential emerging trends. The top three problematic categories in wastewater management which need further attention and enhancements were identified as money, motion/time/minutes, and materials, showed high severity ratings indicating financial, operational, and resource concerns. Conversely, low severity ratings for manpower, method, machines, management measurements, and Mother Nature suggest effective wastewater management handling. Table 1 depicts severity levels across the 9Ms. Assessing the level of severity with highest frequency for each issue helped identify potential emerging trends.

Table 1. Overall Level of Severity with Highest Frequency of Common Problems Encountered in 9Ms of Selected Semiconductor Manufacturing Companies in Laguna (A, B, C, D and E), 2023

9Ms Category	Overall Level of Severity with Highest Frequency	
Money	1	Not Severe at All
	4	**Very Severe**
Motion/Time/Minutes	**2**	**Mildly Severe**
Materials	**2**	**Mildly Severe**
Manpower	1	Not Severe at All
Method	1	Not Severe at All
Machines	1	Not Severe at All
Management	1	Not Severe at All
Measurements	1	Not Severe at All
Mother Nature	1	Not Severe at All

As shown in Table One, Money obtained varying levels of severity of "1" (Not Severe at All) but notably garnered a high severity rating of "4" (Very Severe) in some of the finance-related issues. Both motion/time/minutes and materials received an overall severity rating of "2" (Mildly Severe), suggesting that there were mild issues that required attention in these categories. On the other hand, manpower, method, machines, management measurements, and Mother Nature obtained an overall level of severity with highest frequency of "1" (Not Severe at All) which indicates that problems in these areas were minor or insignificant.

Interventions to Optimize Water Utilization in Support of Water Sustainability Initiatives of the Selected Semiconductor Manufacturing Companies in Laguna

Wastewater Management Augmentation prioritizes stakeholder engagement, advanced treatment, and operational enhancements to meet evolving demands. PIMEA cycle—Prioritization, Implementation Planning, Monitoring, Evaluation, and Adaptive Management ensures continuous improvement by addressing critical issues, creating plans, assessing outcomes, and adjusting practices. These interventions enhance efficiency, emphasizing financial considerations for sustainable and effective management.

a.) Wastewater Management Practices Augmentation

The evaluation of the presence and effective implementation of wastewater management practices led to wastewater management practices augmentation. It refers to the comprehensive and transformational strategy for wastewater treatment management. It involves a wide range of improvements including wastewater treatment capabilities by engaging with stakeholders and fostering collaboration, adopting advanced wastewater treatment

ETCOR Educational Research Center Inc.
SEC Reg. No. 2024020137294-00
Sta. Ana, Pampanga, Philippines
Website: https://etcor.org
iJOINED ETCOR
P - ISSN 2984-7567
E - ISSN 2945-3577
The Exigency
P - ISSN 2984-7842
E - ISSN 1908-3181

methods, and improving wastewater management operational procedures. Its objective is to tackle the changing demands and challenges in wastewater management for sustainable solutions.

a.1.) Capabilities

The mixed capability approach, involving both internal and external elements in collaboration with stakeholders like suppliers and local communities can be applied to manufacturing companies. It is already applied by the surveyed manufacturing companies, particularly Company A, B, C and D, including global leaders like Dow, a U.S.-based chemical company, and 3M, known for consumer and industrial goods. They adhere to local regulations and external management systems to minimize environmental impacts, particularly in wastewater management. These companies recognize the value of strengthening internal capabilities by harnessing external resources through subcontracting and partnerships.

a.2.) Treatment Methods

Physical Treatment Method. Manufacturing companies can apply sedimentation and filtration for primary treatment which is said to be the widely used physical treatment method. Sedimentation removes suspended solids, while filtration physically eliminates various contaminants like heavy metals and organic debris from wastewater which is both adopted by Company A and B. Flotation, a method not used by the surveyed companies, involves the use of pH-adjusting chemicals. Careful management of continuous monitoring and control is necessary to minimize the environmental impact if this method is chosen for treatment. For manufacturing companies, Reverse Osmosis (RO) presents an opportunity worth considering, even though it is not currently employed by the surveyed companies. Advanced wastewater treatment systems, such as those in Israel, have successfully implemented RO. This eco-friendly approach replaces harmful chemicals, utilizing pressure and specialized membranes to safely reintegrate water into the cycle for potential reuse in production.

Chemical Treatment Method. Manufacturing companies can opt for Chemical Oxidation as a more efficient and greener alternative to coagulation/flocculation and chemical precipitation which is already implemented by Company C, D and E. Coagulation/flocculation is complex and might be inefficient due to the need for alkaline additives to adjust pH, while chemical precipitation demands a large amount of reagents and may yield low-quality results. Chemical oxidation effectively addresses a wide range of contaminants, both organic and inorganic, transforming them into less harmful substances.

Biological Treatment Method. Deciding between aerobic and anaerobic biological methods lies on the distinct characteristics of wastewater, treatment objectives, and operational considerations. A hybrid approach can be explored by manufacturing companies which combine both biological methods for a more efficient treatment and resource recovery. By integrating aerobic and anaerobic methods, wastewater treatment becomes more comprehensive, effectively addressing issues on organic matter, reducing sludge, and harnessing biogas for resource optimization.

Sludge Treatment Method. Pretreatment sludge methods, such as thickening and dewatering, vary based on the initial sludge characteristics and the objective of volume or moisture reduction. Manufacturing companies may choose thickening to reduce volume by increasing solids content for easier transport and disposal or dewatering to reduce moisture content. Combining both thickening and dewatering, as demonstrated by Company A, can enhance overall sludge treatment efficiency. All manufacturing companies must adhere to the guidelines set by the Philippines' recognized regulatory agency, Department of Environment and Natural Resources (DENR), for sanitary/landfill disposal and must reinforce it to ensure adherence to compliance.

a.3.) Wastewater Operational Procedures

Companies should embrace the Fourth Industrial Revolution (4IR) to digitize manufacturing, leveraging trends like data, connectivity, analytics, human-machine interaction, and robotics to improve productivity, reduce waste, and benefit stakeholders. This approach should also be extended to the identified best wastewater operational procedures such as educations/trainings, technology optimization and advancements in mechanical

ETCOR Educational Research Center Inc.
SEC Reg. No. 2024020137294-00
Sta. Ana, Pampanga, Philippines
Website: https://etcor.org
iJOINED ETCOR
P - ISSN 2984-7567
E - ISSN 2945-3577
The Exigency
P - ISSN 2984-7842
E - ISSN 1908-3181

systems/ production, water and wastewater treatment systems, and water reuse and wastewater recycling, fostering productivity and waste reduction.

Manufacturing companies may integrate WWTF's education and training programs to encompass essential skills, health and safety, and leadership, and thus elevate operational efficiency by emulating the approach of semiconductor manufacturing industry leaders like Analog Devices, Onsemi, Micron Technology, Samsung Electronics, and ST Micro. To maintain a skilled workforce, companies should focus on both upskilling, for current roles, and reskilling, for diverse positions.

Optimization and advancements in water and wastewater treatment systems which involve efficient water management techniques such as monitoring, metering, and advanced treatment methods could be further applied by manufacturing companies. Aside from Company A, B and C, leading semiconductor companies like Micron, Analog Devices, and Samsung already utilize these methods to enhance their environmental sustainability efforts. Micron and Analog Devices employ the Aqueduct tool and World Resource Institute Aqueduct Water Risk Atlas for water risk assessment, while Samsung integrates pollutant reduction technologies and triple-tier interlocks in their wastewater treatment facilities to ensure compliance with environmental standards.

All manufacturing companies must embrace water reuse/wastewater recycling as an essential practice for optimizing water use in sustainable water management which may lead to cost savings and resource conservation. This approach, recognized by the United States Environmental Protection Agency (US EPA), involves strategies like recovering rainwater, air handler condensate, and controlling reverse osmosis operation. Major semiconductor manufacturing companies, including Analog Devices, Onsemi, Micron Technology, Samsung Electronics, and ST Micro and surveyed companies (A, B and D), have already adopted these practices to reduce water consumption by maximizing reuse through filtration systems and redirecting reclaimed water for diverse applications.

Manufacturing companies must also prioritize optimization and advancements in mechanical systems/production to boost operational efficiency and highlight resource conservation, quality, compliance, innovation, and safety. Analog Devices and Samsung have achieved water reduction success by minimizing rinses and optimizing process controls. ST Micro improved water efficiency through nozzle optimization and flux rinse water recycling. The US EPA also acknowledged the significance of energy and water-efficient measures in buildings, such as heating, ventilation, and air conditioning (HVAC) systems, for significant cost savings through reduced resource consumption.

The application of all the listed operational procedures in line with the advancement in technology (Industry 4.0) which includes educations/trainings, technology optimization and advancements in mechanical systems/ production, water and wastewater treatment systems, and water reuse and wastewater recycling will ensure operational efficiency and regulatory compliance leading to optimized water utilization for sustainability.

b.) Prioritization-Implementation Plan -Monitoring-Evaluation-Adaptive Management (PIMEA) Cycle to Address Wastewater Management Commonly Encountered Problems
Conclusions and Recommendations

Addressing wastewater management issues and achieving optimized water utilization requires a comprehensive approach that combines manpower, technology, environmental awareness, and finances specifically categorized in terms of 9Ms of management (manpower, method, machines, materials, money, motion/time/minutes, management, measurements and Mother Nature). *Prioritization-Implementation Plan-Monitoring- Evaluation-Adaptive Management (PIMEA) Cycle* is a structured framework with five phases that addresses these problems and ensures continual refinement of wastewater management practices, ultimately leading to improved efficiency. This results in cost savings, environmental protection, public health, and sustainability, directly impacting the financial performance of the organization. Figure One illustrates PIMEA Cycle for wastewater management with five phases**.**

ETCOR Educational Research Center Inc.
SEC Reg. No. 2024020137294-00
Sta. Ana, Pampanga, Philippines
Website: https://etcor.org
iJOINED ETCOR
P - ISSN 2984-7567
E - ISSN 2945-3577
The Exigency
P - ISSN 2984-7842
E - ISSN 1908-3181

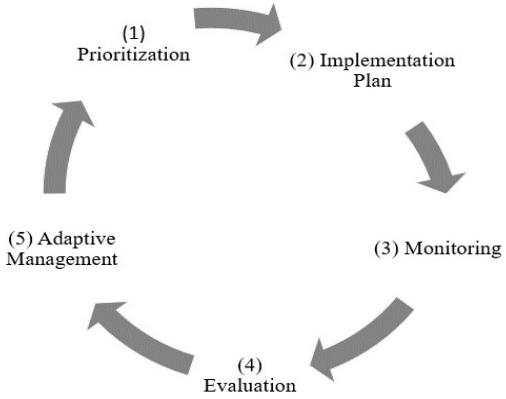

Figure 1 Prioritization-Implementation Plan -Monitoring-Evaluation-Adaptive Management (PIMEA) Cycle

In the first phase, which is prioritization, critical wastewater management issues were identified, and priorities were set based on the level of severity and its relevance to profit, cost savings, and overall financial health. Subsequently, an implementation plan was formulated to effectively address these prioritized areas, emphasizing strategies that align with financial objectives. The third and fourth phases, monitoring and evaluation, involve the collection and analysis of data to quantifiably measure the success of the implementation plan in terms of financial outcomes. The final phase, adaptive management, leverages insights from monitoring and evaluation to make necessary adjustments, ensuring flexibility to adapt to changing wastewater management conditions while safeguarding financial interests. The phases of PIMEA Cycle are discussed in detail below:

(1) Prioritization. The severity of the potential wastewater management problems (manpower, method, machines, materials, money, motion/time/minutes, management, measurements and Mother Nature) was evaluated and the problems with high severity ratings were prioritized.

The study identified the top three priority areas for improvement in the 9Ms framework, which are money, motion/time/minutes, and materials, due to their severe issues. Recommendations were presented for the remaining categories with low severity ratings, including manpower, method, machines, management measurements, and Mother Nature. It is important to note that prioritization may vary depending on the level of severity in other companies or related industries based on their actual wastewater management executions.

(2) Implementation Plan. An implementation plan for wastewater treatment improvements had been formulated to address issues with elevated severity ratings. The wastewater treatment improvements and implementation plan starting with the highly prioritized issues such as money, motion/time/minutes, and materials followed by manpower, method, machines, management measurements, and Mother Nature is discussed below:

Money: To address the funding gap between budget allocation for upgrading or expanding, operations and maintenance and laboratory tests of WWTF, it is imperative to implement public/private partnerships to ensure safe operations and funding capital projects. Additionally, prudent budgeting with a focus on future planning is crucial to prevent major maintenance issues and unmanageable debt at wastewater treatment facilities. Furthermore, attracting and retaining skilled professionals can be achieved by offering competitive incentives, thereby increasing manpower retention rate. ST Micro, a leading semiconductor company, for instance, has already initiated training programs for handling hazardous tasks and implementing process changes. It was also suggested for the companies to engage in consultants who provide professional, technical, and financial support to identify and address wastewater management challenges effectively.

Aside from budget allocation, high material costs in wastewater treatment, particularly for chemicals used in sludge and water quality maintenance, create a significant financial burden. Recent price increases in chemicals

ETCOR Educational Research Center Inc.
SEC Reg. No. 2024020137294-00
Sta. Ana, Pampanga, Philippines
Website: https://etcor.org
iJOINED ETCOR
P - ISSN 2984-7567
E - ISSN 2945-3577
The Exigency
P - ISSN 2984-7842
E - ISSN 1908-3181

and sludge disposal further aggravates the issue. To address these challenges, companies should prioritize responsible resource utilization, sustainable practices, waste reduction, and water conservation.

Identifying expensive processes in production and wastewater treatment is crucial for prioritizing optimization. One of the costliest components of wastewater treatment is managing sludge, which accounts for 40-60% of total expenses, highlighting the need for efficient sludge treatment methods. In line with this, manufacturers should also explore treatment method alternatives, such as chemical oxidation under chemical treatment method, a more efficient and eco-friendly option compared to coagulation/flocculation and chemical precipitation, especially concerning chemical usage.

In tandem with these efforts, research should concentrate on green and sustainable wastewater technologies (GSWTs) for environmentally friendly treatment. Leading semiconductor companies like Analog Devices, Onsemi, Micron, ST Micro, and Samsung are setting examples of optimizing water management through water reuse/recycling and reclamation, in both their production and wastewater treatment facilities. These comprehensive measures collectively seek to enhance both economic efficiency and environmental sustainability in the wastewater treatment processes.

Motion/Time/Minutes: Having a deep understanding of the system malfunctions through equipment or sensor behavior is highly essential to reduce delays in identifying system failures or malfunctions resulting to increase operational efficiency and productivity**.** Companies and service providers continually innovate, especially in computer applications, hardware, and software as implemented by Company A.

Taking a proactive approach to manage wastewater challenges is essential for financial resilience. For instance, Samsung optimizes operations, while Analog Devices, Onsemi, Micron, and ST Micro use tools like the WRI Aqueduct Water Risk Atlas to assess water conditions. These strategies not only demonstrate environmental responsibility but also contribute to long-term cost savings and financial stability.

Addressing lower-severity recommendations, like manpower, method, machines, management, measurements, and Mother Nature, despite their lower priority, is essential as it contributes to overall systematic improvement. These enhancements can be adopted by other or relevant companies, especially if they are identified as high-severity issues in their specific contexts. Below is the detailed implementation plan of the issues with low severity:

Manpower: Effective communication channels is crucial for preventing costly errors, safety issues, employee dissatisfaction, turnover, legal problems, reduced productivity, and lower profits in manufacturing organizations. To address these challenges, improving internal communication and employee engagement is essential. This involves setting clear objectives, benchmarking activities, addressing weaknesses, using various communication tools, and embracing technology.

Prioritizing internal communication through training programs for both managers and employees, focusing on essential skills, diversity, and inclusion, as observed in leading semiconductor manufacturing companies like Analog Devices, Onsemi, and Micron, can enhance the internal culture and ultimately improve overall organizational performance.

Method: Addressing the lack of research and development involves significant changes, such as adopting innovative wastewater treatment, decentralized solutions, resource recovery, and institutional reforms, to move away from the conventional "out of sight, out of mind" mindset. The wide adaptation of optimization and advancements in water and wastewater treatment systems and mechanical systems/production adopted by the surveyed companies and the top semiconductor manufacturing companies such as Analog Devices, Onsemi, Micro, ST Micro and Samsung firmly rooted in research and development through integrating education and technical trainings. For instance, in Biñan, Laguna, a densely populated area, a wastewater treatment plant uses nature-based technology with plants, microorganisms, biofilms, and engineered media. This approach is more energy-efficient and generates less sludge than conventional centralized treatment plants, resulting in lower expenses compared to the traditional centralized treatment plants.

Machines: Addressing electrical & instrumentation malfunctions is a strategic financial move involving the implementation of cost-effective measures. This includes incorporating mitigating devices such as harmonics

ETCOR Educational Research Center Inc.
SEC Reg. No. 2024020137294-00
Sta. Ana, Pampanga, Philippines
Website: https://etcor.org
iJOINED ETCOR
P - ISSN 2984-7567
E - ISSN 2945-3577
The Exigency
P - ISSN 2984-7842
E - ISSN 1908-3181

mitigation equipment (e.g., transformers and power conditioners) to ensure a consistent voltage, thus minimizing the risk of costly disruptions. The integration of Uninterruptible Power Supplies (UPS) and power conditioners serves as a financial safeguard for critical process systems, protecting against potential profit losses due to voltage sags. Strategically placed Surge Protection Devices (SPD) will contribute to financial risk mitigation, preventing potential financial setbacks. Effectively managing noise, particularly in signal and data circuits with higher speeds and lower voltage levels, using power filters to ensure clean AC power, promoting efficient and cost-effective operations, will thereby enhance the overall financial performance.

ST Micro saved money by using equipment more efficiently, reducing water usage by 4% through improved electrical and instrumentation technology. In addition, the low severity rating of electrical and instrumentation malfunctions in Company A and B is aligned with prudent financial practices, contributing to company's long-term cost savings.

Management: To address leadership challenges in plant supervision, consider adopting educational and leadership training, inspired by successful practices at companies like Onsemi, Micron, and Analog Devices. These companies prioritize diverse programs focusing on leadership, compliance, and skills development, which can contribute to a well-trained and efficient workforce, ultimately benefiting the company financially. Drawing from examples at Company A and B, where diversity, safety, and integrity are prioritized, can also lead to long-term cost savings. Additionally, incorporating company-wide education workshops and streamlined decision-making processes will further support organizational efficiency and financial success.

Measurements: Companies should recognize the financial benefits of leveraging intelligent wastewater treatment facility (WWTF) data analysis and predictive modeling to optimize processes. To meet regulatory standards efficiently, companies should invest in remote monitoring, advanced algorithms, Artificial Intelligence, and control systems for precise tracking of water chemical levels. This approach not only ensures compliance but also enhances operational efficiency, allowing for comprehensive analysis of process trends and performance. This contributes to high effectiveness, as demonstrated by the successful implementation at Company B.

Leading companies in the industry are already capitalizing on predictive modeling for financial gains. Analog Devices relies on the WRI Aqueduct Water Risk Atlas to evaluate water stress and availability in water-stressed regions. Micron utilizes the Aqueduct tool for a water risk assessment to understand local water conditions, while ST Micro conducts water risk assessments across all manufacturing sites to assess water footprints and associated risk factors, showcasing a financially prudent approach to water management.

Mother Nature: The Environmental Compliance Center in the Philippines enforces penalties for wastewater discharge violations, emphasizing the financial impact of strict compliance by companies.

Leakage or chemical contamination of groundwater due to industrial activities has become a growing concern over the last three decades, posing risks to human health. Wastewater treatment plants leave an environmental footprint as they require responsible disposal of extracted organic compounds. This highlights the critical need for sustainable resource utilization through responsible manufacturing, consumption, recycling, and reclamation to protect both the environment and human well-being.

(3) Monitoring. Monitoring the implementation plan involves systematic data gathering to confirm that every aspect of the plan is being executed in accordance with the defined objectives and timelines. This phase primarily focuses on the ongoing, real-time observation and data collection to ensure that the plan is on track.

(4) Evaluation. Implementation plan is evaluated through an intensive review to confirm its intended execution, track progress, identify deviations, and assess goal attainment. This phase is crucial to ensure the plan's effectiveness and typically includes a comprehensive post-implementation review of performance, often conducted at specific milestones or upon plan completion to gauge overall success and areas for enhancement.

(5) Adaptive Management. The final phase involves continual assessment and modification of the implementation plan based on ongoing financial feedback and changing conditions. This financial approach recognizes the complexity and dynamic nature of wastewater management, emphasizing the importance of flexibility and the capacity to adjust the implementation plan in response to new financial information and challenges. This

ETCOR Educational Research Center Inc.
SEC Reg. No. 2024020137294-00
Sta. Ana, Pampanga, Philippines
Website: https://etcor.org
iJOINED ETCOR
P - ISSN 2984-7567
E - ISSN 2945-3577
The Exigency
P - ISSN 2984-7842
E - ISSN 1908-3181

adaptive strategy ensures that the financial goals, including profit and cost savings, are prioritized, and maintained throughout the evolving wastewater management process.

Conclusions

Findings revealed that semiconductor manufacturing companies in Laguna highly preferred mixed wastewater management capability, emphasizing tailored treatment methods. In spite of the widespread adoption of education and training, water and wastewater treatment system optimization and water reuse/wastewater recycling, there is a lack of emphasis on optimizing mechanical systems. This calls for improved efficiency and sustainability in wastewater management through a holistic approach to mechanical systems and production processes. Furthermore, the high levels of implementation across all assessed wastewater management operational procedures reflected a strong commitment in adopting effective wastewater management practices. Motion/time/minutes, materials, and money pose severe problems, while manpower, method, machines, management measurements, and Mother Nature show less severe issues. These findings guide organizations in prioritizing and customizing improvement efforts to address challenges within the 9Ms categories. The devised interventions which include Wastewater Management Practices Augmentation and the PIMEA Cycle, offer a versatile framework to enhance wastewater management, reduce environmental impact, and help organizations achieve sustainability goals.

Recommendations

This study provided recommendations for surveyed semiconductor manufacturing companies and future wastewater management research, focusing on optimizing water utilization for sustainability. Regulatory bodies like the Department of Environment and Natural Resources (DENR) and Laguna Lake Development Authority (LLDA) are urged to enhance compliance monitoring, expedite discharge permits, and invest in advanced treatment technologies while promoting responsible management practices. Future research should explore mixed capability opportunities, assess public-private partnerships, evaluate eco-friendly treatment methods, resource allocation through cost-benefit analysis and industry benchmarking with application of Industry 4.0 (Fourth Industrial Revolution) technologies. Emphasis should be on efficiency and sustainability, with strategies considering key drivers and global frameworks for widespread adoption. Subsequent research should formulate methods considering root cause analysis and qualitative studies on wastewater management issues, to foster more sustainable approaches for a greener future.

REFERENCES

3M (2023). 3M 2023 Global Impact Report. https://multimedia.3m.com/mws/media/2292786O/3m-2023-global-impact-

Analog Devices (2023). Environmental, Social, and Governance (ESG) Report. https://www.analog.com/media/en/company-csr/2022-esg-report.pdf

Breton, J. (2023). Better Wastewater Management for Our Cities.Inquirer.net. https://opinion.inquirer.net/134887/better-wastewater-management-for-our-cities

Dow (2023). 2022 ESG Overview. The Intersection of Science & Sustainability, Culture & Accountability. https://s23.q4cdn.com/981382065/files/doc_downloads/2023/2022_dow_esg_overview.pdf

Dun & Bradstreet (2023), Manufacturing Companies In Laguna, Philippines. https://www.dnb.com/business-directory/company-information.manufacturing.ph.laguna.html

Feixiang, S. (2017). Pig Wastewater Impact to Water Environment. WEPA Group Workshop. https://wepa-db.net/wp-content/uploads/2023/02/04_S1_3_China_0221.pdf

Fluence (2023). Decentralized Wastewater Treatment. https://www.fluencecorp.com/decentralized-wastewater-treatment/

Haga, K. (2017). Pig Wastewater Management in Asia. WEPA Group Workshop. https://wepa-db.net/wp-content/uploads/2023/02/Pig-Waste-Japan.pdf

ETCOR Educational Research Center Inc.
SEC Reg. No. 2024020137294-00
Sta. Ana, Pampanga, Philippines
Website: https://etcor.org
iJOINED ETCOR
P - ISSN 2984-7567
E - ISSN 2945-3577
The Exigency
P - ISSN 2984-7842
E - ISSN 1908-3181

Hanlon. A. (2019). Digital Marketing: Strategic Planning & Integration. https://gomarketingguru.wordpress.com/2019/04/13/have-you-heard-of-the-9ms-of-resource-planning-framework/

Hofkircher, W. & Schafranek, M. (2011). General System Theory. Philosophy of Complex System. https://www.sciencedirect.com/topics/computer-science/general-system-theory

Las Marias, S. (2019). A Look at the Current Philippine Electronics Manufacturing. https://www.eetasia.com/a-look-at-the-current-philippine-electronics-manufacturing-landscape-part-1/.

Medill Explores (2023). What the world can learn from Israel's water reuse programs. Medill Reports Chicago. https://news.medill.northwestern.edu/chicago/what-the-world-can-learn-from-israels-water-reuse-programs/

Micron Technology (2023). Innovative memory and Storage solutions. https://www.micron.com/about/our-commitment/operating-thoughtfully/sustainability

ON Semiconductor. (2022). Sustainability Report. https://www.Onsemi.com/site/pdf/sustainability-report.pdf#page=23

PhilippineCompanies (2023). Businesses in Laguna Technopark. https://www.philippinecompanies.com/location/laguna-technopark/page/21

Philippines Industrial Water and Wastewater Treatment Market Outlook (2022). Philippines Industrial Water and Waste Water Treatment Market 2018-2022 - Market will Register Constant Growth at a Five Year CAGR of 10%. https://www.prnewswire.com/news-releases/philippines-industrial-water-and-waste-water-treatment-market-2018-2022---market-will-register-constant-growth-at-a-five-year-cagr-of-10-300723667.html

Pongrácz, E. (2002). Re-defining the concepts of waste and waste management. Department of Process and Environmental Engineering, University of Oulu. http://jultika.oulu.fi/files/isbn9514268210.pdf

Razman, K., Hanafiah M., Ramil, & Harun, S. (2023). Industrial wastewater treatment methods employed in Southeast Asian countries. IOP Conference Series. Earth and Environmental Science. https://doi.org/10.1088/1755-1315/1167/1/012020

Samsung Electronics (2023). Sustainability Report. https://semiconductor.samsung.com/sustainability/highlights/downloads/

Shady, A. & Araby. H (2023). Treatment Technologies and Guidelines Set for Water Reuse. In Taseli, B. (ed)., Sewage Management. https://www.intechopen.com/chapters/85878

Soares, A. (2020). Wastewater treatment in 2050: Challenges ahead and future vision in a European context. Environmental Science and Ecotechnology, (2)1. https://doi.org/10.1016/j.ese.2020.100030

ST Micro (2022). Sustainability Report. https://www.st.com/resource/en/quarterly_report/STMicroelectronics-Sustainability-Report-2022-small.pdf

Tahir, M.B., Sagir, M. & Tahir, M.B. (2023) Advances in Water and Wastewater Treatment Technology. Water Resources Development and Management. https://libgen.li/edition.php?id=143109930

ETCOR Educational Research Center Inc.
SEC Reg. No. 2024020137294-00
Sta. Ana, Pampanga, Philippines
Website: https://etcor.org
iJOINED ETCOR
P - ISSN 2984-7567
E - ISSN 2945-3577
The Exigency
P - ISSN 2984-7842
E - ISSN 1908-3181

United States Environmental Protection Agency (2023). How Communities Have Defined Zero Waste. Zero Waste International Alliance. https://www.epa.gov/transforming-waste-tool/how-communities-have-defined-zero-waste

United States Environmental Protection Agency (2023). Water Management Plans and Best Practices at EPA. https://www.epa.gov/greeningepa/water-management-plans-and-best-practices-epa

Water Education Foundation (2023). Wastewater Treatment Process in California. https://www.watereducation.org/aquapedia/wastewater-treatment-process-california

Water Environment Partner in Asia (2023). The 18th WEPA Annual Meeting. https://wepa-db.net/meeting/the-18th-wepa-annual-meeting

Yu, H. Wei Deng, S., Song, Y. & Yong, Y. (2015). A decision aided system for sustainable waste management. Intelligent Decision Technologies, (9) 1, 29-40. 10.3233/IDT-140203