Journal of Energy, Environmental & Chemical Engineering
2025, Vol. 10, No. 1, pp. 26-37
https://doi.org/10.11648/j.jeece.20251001.13

Research Article

Optimizing Various Aspects of Wastewater Treatment with AI: Case of Tanjombato (Antananarivo – Madagascar)

Rakotoarisoa Marie Eliane[1], Andriamiadanomenjanahary Harivelo Chandellina Camille[2, *], Randrianasolo Herilalaina Fabien[3], Razafindrazaka Fenolaza Tsiory[4]

[1]Génie Chimique, University of Antananarivo, Antananarivo, Madagascar
[2]Cognitive Science and Applications, University of Antananarivo, Antananarivo, Madagascar
[3]Ingénierie et Géoscience, University of Antananarivo, Antananarivo, Madagascar
[4]Ministry of Finance, Antananarivo, Madagascar

Abstract

Whether used for industrial, domestic or agricultural purposes, water is both highly coveted and polluted. Water pollution is a major environmental problem. In order to protect the environment, it is essential to treat wastewater before it is discharged into the environment. One reason for this is that the soil is not capable purifying all the pollutants present in our wastewater. In most developing countries, lack of sanitation is a major problem. Like Madagascar, we are well aware of the inadequacy of pumping stations for wastewater treatment. This study was carried out in Antananarivo, more precisely in the commune of Tanjombato, located in the south of the capital. Due to demographic growth, with a population density of 11,443 inhabitants per km², increasing industrial, agricultural needs, and climate change, the overall demand for water is rising. The industries, enterprises in this study generate large volumes of wastewater on a daily basis. In most cases, this wastewater is discharged untreated into the environment. As a result, water-related diseases are the second leading cause of death on the island. In addition to its status as waste, wastewater is now seen as a raw material that should not be neglected. Considered as resource, it is increasingly attracting the attention of public authorities and scientific researchers alike. The safety and quality of water intended for various uses is an important issue that threatens human life. The loss of millions of human and animal lives is due to the use of polluted water. With this in mind, the World Health Organization, national and international regulations have established standards and recommendations to prevent the presence of microorganisms and undesirable chemical substances in drinking water. Raw water, whether groundwater or surface water, does not always meet the required criteria in terms of chemical and microbiological quality, which means that it needs to be properly treated before consumption. This research will highlight one of our latest study in Madagascar. It's provides deep insight and case studies on the successful application from the innovative new technologies. By using AI (Machine Learning algorithms), searchers can optimize various aspects of wastewater treatment including pollutant detection, process control, resource recovery, real-time forecasting models, water quality by eliminating conventional pollutants, the preventive approach: monitoring, control and evaluation.

Keywords

Industrial Wastewater, Pollution, AI, Wastewater Treatment, Tanjombato

*Corresponding author: chandellina.camille@gmail.com (Andriamiadanomenjanahary Harivelo Chandellina Camille)

Received: 4 February 2025; **Accepted:** 21 February 2025; **Published:** 11 March 2025

1. Introduction

According to the definition, wastewater is used water. It includes substances such as human waste, food scraps, oils, soaps and chemicals. It's produced by domestic, industrial or even agricultural uses, and therefore constitutes a polluted effluent that is discharged into a sewer system. It includes domestic wastewater (black water and grey water), storm water and industrial effluent (factory wastewater) [1].

A survey was carried out in the rural commune of Tanjombato, located in the south of Antananarivo the capital, to find out about the history of the industrial zone and list the factories [2]. This survey also enabled us to obtain statistical data on the commune. The current state of the canal and rice fields was determined by field visits [3, 4].

National and international standards set indicators for the biological and physico-chemical pollution of water. Wastewater is an extremely complex medium, so a few parameters are used to characterize it. Generally expressed in mg/l: There is a wide variety of water pollution indicator parameters. These parameters can be physical, chemical or biological [5].

2. Wastewater Categories

Wastewater is characterized according to its physical, chemical and biological composition. There are several types of "waste" water

(1) Domestic wastewater.

(2) Industrial wastewater.

(3) Agricultural wastewater.

(4) Stormwater and runoff.

(5) Other. [5]

Starting from each definition, industrial wastewater is very different from domestic, agricultural and rainwater. In most cases, its types vary from one industry to another. In addition to its composition, such as organic matter, nitrogen or phosphorus, it can also contain toxic products, heavy metals, organic micropollutants, hydrocarbons, solvents, etc. Some of them must be pre-treated by industrial companies before being discharged into collection networks. They are only mixed with domestic wastewater when they no longer present a danger to collection systems and do not disrupt the operation of treatment plants. We focus on this type of wastewater, which is becoming increasingly abundant in many countries such as Madagascar [6].

3. Industrial Wastewater

Generally speaking, wastewater is defined as water that has undergone a change in composition or condition as a result of its use. In the case of industry, wastewater is dirty, impure water that is discharged after use. It is water that has acquired a mineral or organic load as a result of its use. It is a major source of pollution [5].

Because of its particular physico-chemical properties, water is used in most industrial activities. It is used, for example, as a dilution component in certain industries. It can be used as a cleaning or washing agent for products or machines. It is often used as a cooling medium, particularly in certain metallurgical plants and in thermal and nuclear power stations.

Because of its diversity, it is difficult to predict the contribution of industrial pollution. In each industrial sector, wastewater has common characteristics, but there are also differences linked to the different processes employed.

It's therefore impossible to give a typical profile of industrial wastewater. However, it is possible to describe certain characteristics of industrial wastewater:

Mineral-dominant waters from mining and mineral processing discharges are highly charged with suspended solids. They often have pH values that deviate from neutrality.

Water with a predominantly organic load from slaughterhouse discharges is highly charged with biodegradable organic matter.

Toxic water from certain chemical industries.

Hot water is discharge from conventional and nuclear power plants. This is the source of thermal pollution, which can have serious ecological consequences compared with other types of pollution.

It should be noted that almost all industrial plants have cooling circuits and discharge hot water [7].

3.1. Characteristics of Industrial Wastewater

The composition of industrial wastewater is analyzed by means of various physical, chemical, biological and bacteriological measurements [8].

3.1.1. Physico-chemical Parameters

To assess wastewater quality, the following main elements must be taken into account:

pH: This is a fundamental parameter for characterizing wastewater. The effectiveness of treatment operations requires a specific pH zone.

Temperature: Temperature plays a very important role and must be taken into account when determining the impact of discharges. Excessive changes in the temperature of receiving environments can alter the biotope and disrupt fish life. In addition, chemical reactions in water treatment processes are influenced by increases or decreases in temperature.

Suspended solids (SS): Their content varies according to the nature of the terrain crossed, the season and the rainfall.... Suspended solids (SS), expressed in milligrams per liter, include: settleable matter, which settles at rest for a period conventionally set at 2 hours, and colloidal matter, which represents the difference between SS and settleable matter [9].

Table 1. *Pollution distribution in urban water (without industrial residues) in mg.l^{-1} for a 24-hour period.*

	Mineral matter	Organic matter	Total
TSS separable by settling	130	270	400
TSS separable by settling	70	130	200
Dissolved matter	330	330	660
Total	530	730	1260

Organic matter: its presence is conducive to bad tastes, which may be exacerbated by chlorination. Humus-laden waters and those from peaty regions are harmless and have a fairly high organic matter content. On the other hand, water containing only traces of organic matter can be very dangerous due to the presence of microbial elements. This is not to say that a high organic content is always conducive to microbial contamination. The following table shows the classification of water according to organic matter content [10].

Table 2. *Water classification according to organic matter content.*

Class	Pure water	Potable water	Suspect water	Poor water
Rate	Less than 1 mg/l	1-2 mg/l	2-4 mg/l	More than 4 mg/l

Hardness: characterizes water containing calcium and magnesium salts (encrusting salts). Water with too much limestone can alter the color and taste characteristics of water containing it.

Alkalinity: Alkalinity represents the buffering capacity of wastewater and is sometimes expressed by the Total Alkalimetric Title (TAT) [10].

For natural water, it represents the sum of alkaline (Na) or alkaline-earth (Ca, Mg) hydrogen carbonate, carbonate and hydroxide anions.

The chemical reactions involved in the measurement are as follows:

$$CO_3^{2-} - + H^+ \rightarrow HCO_3^-$$

$$HCO_3^- + (Ca^{2+}, Mg^{2+}, Na^+) \rightarrow Ca(HCO_3)_2, Mg(HCO_3)_2, Na(HCO_3)$$

$$HCO_3^- + H^+ \rightarrow H_2\,CO_3$$

Its knowledge is of particular interest when physico-chemical treatments are envisaged, as it reflects the presence in solution of chemical species likely to exert a direct influence on the technical conditions of purification....

Salinity: this is the main criterion for assessing wastewater quality. It is assessed by measuring electrical conductivity.

Electrical conductivity: gives an assessment of the dissolved salt content of wastewater. It is expressed in µS/cm.

Electrical conductivity depends essentially on the total mineral content of the water: the more mineral salts a water contains, the less resistant it is to the passage of an electric current. The relationship between conductivity and mineralization is shown in the table below:

Table 3. *Relationship between conductivity and mineralization.*

Conductivity value (µS/cm)	Mineralization
< 100	Very low
100-200	Low
200-333	Accentuated medium

Conductivity value (µS/cm)	Mineralization
333-666	Medium
666-1000	High
> 1000	Excessive

Nitrogen derivatives: nitrates, nitrites and ammonium are the most frequently encountered. They are sometimes found in water, generally in low doses. They result either from incomplete oxidation of ammonia, or from bacterial reduction of nitrates [11].

Turbidity: composed of fine suspended particles or colloidal matter. It has multiple origins. Surface clays and silts carried by runoff can change the quality of the water table. Turbidity is measured by a turbidimeter, which gives a direct reading of the value displayed, in Nephelometric Units (NTU). Water with a high turbidity value cannot be consumed directly. It must be purified, either by decantation or filtration, or by a combination of these two treatments [11].

Color: it's visible to the naked eye. A distinction is generally made between the apparent color due to suspended matter and matter in solution, and the true color of the matter itself. Substances in solution are colored by humic acids, iron and manganese, which can gradually turn the color of the water green, yellow or brown. Although colored water may not be directly harmful to health, it will present drawbacks and be suspect to consumers [11].

Odor: directly felt by the olfactory organ. The test does not give a quantification but an appreciation. Odors may come from chemicals, decomposing organic matter or protozoa.

3.1.2. Biological Parameters

The concentration of organic matter is obtained from BOD_5 and COD analyses. BOD_5 represents the quantity of oxygen required by microorganisms for five days to decompose organic matter in wastewater at a temperature of 20 ℃.

Similarly, COD is the amount of oxygen required to oxidize organic matter using dichromate in an acid solution, and transform it into carbon dioxide and water. The COD value is always higher than the BOD_5 value, as many organic substances can be oxidized chemically but cannot be oxidized biologically.

Typically, BOD_5 is used to test the strength of treated and untreated municipal wastewater and biodegradable industrial water.

COD is used to test the strength of wastewater that is not biodegradable, or that contains components that inhibit the activity of microorganisms. pH analysis measures the acidity of a wastewater sample. In a typical domestic wastewater, organic matter is made up of approximately 50% carbohydrates, 40% proteins and 10% grease; the pH can range from 6.5 to 8.0.

With domestic wastewater, BOD_5 represents 0.684 of the total oxygen demand. It averages between 200 and 300 $mg.l^{-1}$.

When domestic wastewater production is between 150 and 300 l/capita/d, COD is generally between 75 and 100 g/capita/d. The following table shows the different types of water with their respective BOD: [12].

Table 4. *BOD_5 values.*

Status	BOD_5 (mg/l)
Pure and living natural water	<1
Slightly polluted river	1<c<3
Sewer	100<c<400
Effective wastewater treatment plant	20<c<40

Correlation between COD and BOD_5 : the ratio (COD/BOD_5) provides information on the biodegradability of organic matter. An increase in this ratio translates into an increase in the proportion of non-biodegradable organic matter in the wastewater [12].

3.1.3. Bacteriological Parameters

The presence of bacteriological pollutants is marked by the development of bacteria, viruses, fungi or algae. Waste and wastewater are the main suppliers of bacteriological pollutants.

Among these pollutants is Escherichia Coli, which has a high diagnostic specificity. Its presence in water indicates contamination by human or animal excreta.

But fecal streptococci are bacteria in a chain. They are the normal flora of human and animal feces, industries of recent fecal contamination, and extremely resistant to chlorinated agents.

Total and fecal coliforms are non-spore-forming rods, capable of aerobic growth at 30 ℃.

3.2. Industrial Wastewater: Case of Madagascar

In Madagascar, they are defined as water used in industrial processes. It contains potentially polluting substances such as chemicals, grease, hydrocarbons and so on. After treatment, treated industrial wastewater can be reused or discharged into a sanitary sewer or surface water in the environment.

1. Decree no 2003-943 of 09 September 2003 on spills, discharges, direct or indirect deposits in surface or groundwater.
2. ACT N°. 98-029 Carrying Code of Water (Article 32.and 33)

Most Madagascar's industries don't have wastewater treatment plants, or when they do, they don't always work properly. Many factories in this area discharge their water directly into irrigation canals, due to the lack of adequate facilities. As a result, irrigation water and industrial wastewater become one and the same.

Figure 1. *Hectares devastated by water spills.*

Figure 2. *Diversion of wastewater into rice fields.*

The latest census showed that there are 143 companies with around 50 industries spread across the Forello Industrial Zone in the Rural Commune of Tanjombato. There are a large number of factories, the best-known of which are listed in the table below:

4. Methods

According to reality and analyses carried out in the field, industrial wastewater presents a number of dangers. In many cases, it does not meet the standards for industrial wastewater discharge laid down in Madagascar's legislation. Given the quality of the wastewater on the fields studied, the use of traditional techniques gives less satisfactory results for the treatment of these industrial discharges. There are a number of methodologies available for solving this type of problem. They can be adapted to varying degrees depending on the type, size and nature of the project.

4.1. Method 01: Determination of Natural

As Wastewater should not be discharged into the environment for a number of reasons. Firstly, it can pollute surface and ground water, leading to serious health risks for humans and animals alike. Secondly, wastewater often contains excessive quantities of nutrients, such as nitrogen and phosphorus. On release into freshwater systems, these nutrients act as fertilizers, triggering algal blooms and other symptoms of nutrient pollution, and are also a risk to the environment. Wastewater is often considered more of a nuisance to be disposed of than a resource. In short, it consists of around 99% water and 1% suspended, colloidal and dissolved solids. The consequences of untreated or inadequately treated wastewater can be divided into three categories:

(1) harmful effects on human health,
(2) negative impacts on the environment,
(3) adverse effects on economic activities [13].

4.1.1. Classical Treatment Methods

Various treatment processes can be applied to urban and industrial wastewater treatment. These processes are grouped into:

(1) Physical processes (screening, settling, filtration, adsorption, etc.)
(2) Chemical processes (precipitation, coagulation-flocculation, etc.)
(3) Biological processes (nitrification, denitrification, lagooning, sprinkling, etc.)

The various treatment lines that can be envisaged are made up of a combination of these different processes, based on an economic assessment of initial set-up, running and operating costs.

This choice must be flexible enough to allow for future developments. But when it comes to urban wastewater, a general rule of thumb is to consider the following processes:

(1) Preliminary treatment (physical, chemical or biological)
(2) Primary clarification
(3) Secondary treatment
(4) Tertiary treatment

Discharge standards were established by the Ministry of the Environment, Water, Forests and Tourism in 2003 [11]. In accordance with Article 5 of Decree no. 2003/464 of 15/04/03 concerning the classification of surface waters and the regulation of liquid effluent discharges, in order to preserve water resources (quality objectives), wastewater discharges must be colorless and odorless; the parameters listed in Table 6 must not exceed the limit values indicated.

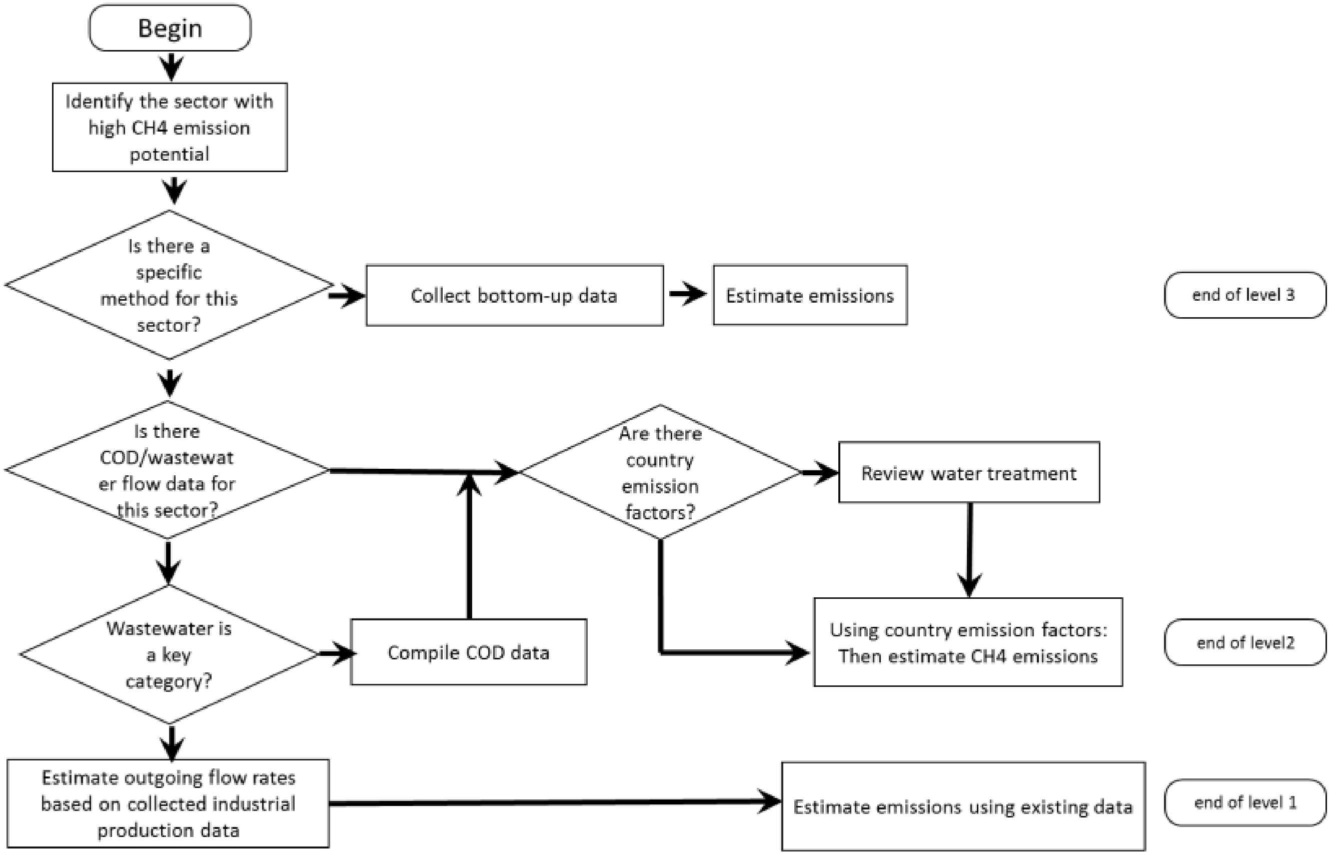

***Figure 3**. Wastewater treatment: Classical methods.*

Advanced treatment method: Solution for industrial wastewater treatment

Industrial wastewater can be treated in two categories:

(1) On-site treatment

(2) Treatment directed towards domestic sewage systems.

In the first case, CH_4 emissions found on site are estimated first. In the second case, the emissions must be included in domestic wastewater emissions. This time, we will deal with the estimation of CH_4 emissions from the treatment of case n°01. Noting that, according to a specific condition, only industrial wastewater with a high carbon load produces CH_4. Usually, organic matter in industrial wastewater is expressed in terms of COD [14].

4.1.2. Artificial Intelligence as Wastewater Treatment

In the case of the Commune of Tanjombato, one of the best solutions for extracting industrial production data and wastewater outflows is to set up a computerized system.

Artificial intelligence is currently booming in a number of sectors. In the research carried out, we took advantage of the application of its elements, such as Machine Learning, to eliminate several suspended particles. It's an effective way of using existing data to establish wastewater profiles and behaviors as part of the environmental strategy. When current trends, demands and needs are identified, smarter decisions can be applied.

The aim is to observe, improve and evaluate the effectiveness of the results at the end of the research. The system's functionality includes real-time monitoring of operations, optimization of collection routes and data management. From time to time, quantifying the COD load in wastewater may require expert judgment. While the use of IoT sensors, data management software and mobile apps for field operators is also appreciated. The specificity of this system requires training for personnel in the use of new technologies, and in the management and protection of sensitive data collected by the system.

4.2. Parameters to Be Estimated and Respected

Research in this field is entirely defined by a number of specific parameters. In cases such as this, it is extremely important to be vigilant about data collection and calculations. Finally, the parameters defined below must also be respected.

4.2.1. CH_4 Emissions

Wastewater can be a source of methane (CH_4) when treated or when dissolved CH_4 enters aerated treatment systems.

The CH_4 emissions from industrial wastewater were calculated using the IPCC Tier 1 methodology (Intergovernmental Panel on Climate Change).

In E_{CH_4} The general equation for estimating CH_4 emissions from industrial wastewater is:

$$E_{CH_4} = \sum_i [(T_{OW_i} - S_i)\, EF_i - R_i] \tag{1}$$

E_{CH_4}= emissions of $CH_4$of the inventory year, $kg\ CH_4 / year$

T_{OW_i} = total biodegradable material in wastewater from industry i in inventory year, $kg\ COD/year$

i = industrial sector

S_i = organic component disposed of as sludge in inventory year, $kg\ COD/year$

EF_i = emission factor for industry i, kg kg CH_4/kg COD for the treatment and/or disposal route or system(s) used in the inventory year.

If an industry uses more than one treatment technique, the factor should be a weighted average.

R_i = volume of CH_4 recovered in the inventory year, kg $CH_4/year$.

***Table 5**. Assumed values of MCF/EF (Micron Cartridge Filters) in the quantification of emissions.*

Type of treatment/Discharge	B_0 (kg CH_4/kg BOD)	MCF (-)	EF (kg CH_4/kg BOD)
Centralized aerobic treatment plant	0,6	0,3	0,2
Septic system	0,6	0,5	0,28
Latrine	0,6	0,1	0,06

4.2.2. Emission Factors

In order to be as effective and efficient as possible, the study required a large amount of data. These had to be collected in the field to calculate the maximum $CH_4(Bo)$production capacity of each industry. It can be seen that each potential CH_4emission is different and varies according to the different types of industrial wastewater. As mentioned above, the MCF indicates the extent to which the CH_4(Bo) production potential is achieved by each treatment method. Thus, it indicates how anaerobic the system is

$$EF_k = B_o M_{coeff_k} \tag{2}$$

EF_i = emission factor of each treatment and/or disposal route or system, $kg\ CH_4/kg\ COD$ (Cf. Table 5)

k = each treatment and/or disposal route or system

B_o = maximum CH_4 production capacity, $kgCH_4/kg\ COD$

M_{coeff_k}= methane correction coefficient (fraction)

***Table 6**. Emissions factors Based on expert judgment.*

Type of treatment or disposal route	Observations	MCF[1]	Range
Discharge into sea, river or lake	Rivers with a high load of organic matter can become anaerobic; but this situation is not addressed here.	0,1	0,0 - 0,2
Aerobic wastewater treatment plant	Must be well managed. Some CH_4 may be emitted from settling ponds and other pockets.	0,0	0,0 - 0,1
Aerobic wastewater treatment plant	Poorly managed. Saturated	0,3	0,2 - 0,4
Shallow anaerobic lagoon	Less than 2 meters deep, use expert judgment	0,2	0,0 - 0,3
Deep anaerobic lagoon	Depth: more than 2 meters	0,8	0,8 -1,0
Based on expert judgment by the lead authors of this section			

4.2.3. Choice of Activity Data

The activity data for this source category is the volume of biodegradable material in wastewater (TOW). This parameter is a function of industrial output (product) P (tons/year), wastewater production W (m^3/ton of product) and the concentration of degradable organic matter in wastewater COD (kg COD/m^3). The steps below are necessary to determine the TOW:

(1) Identify industrial sectors that produce wastewater containing substantial amounts of organic carbon by assessing the total industrial product, the biodegradable materials in the wastewater and the resulting wastewater.

(2) Identify industrial sectors that use anaerobic treatment. Include sectors that use anaerobic treatment unintentionally due to saturation of the treatment/purification system. From experience, three or four industrial sectors are key sectors.

For each selected sector, estimate the total degradable organic carbon (TOW).

$$TOW_i = P_i W_i COD_i \quad (3)$$

TOW = total biodegradable material in wastewater for industry i, kg COD/year

i = industrial sector

P_i= total industrial product of industrial sector i, t/year

W_i= wastewater produced, m^3/t produced

COD_i= chemical oxygen demand (degradable industrial organic component in wastewater), kg COD/m^3

Referring to the decision tree in the figure to estimate industrial wastewater emissions, a specific algorithm based on 3 steps could be applied.

Algorithm

Step 1: Use Equation (3) to estimate total biodegradable wastewater carbon (TOW) for industrial sector i

Step 2: Select pathway and systems (Figure 4) based on country activity data. Use Equation (2) to obtain the emission factor. Estimate, for each industrial sector, the emission factor using the maximum methane production capacity and the average methane correction coefficient specific to the industry.

Step 3: Use Equation (1) to estimate emissions, adjust for sludge removal, if applicable, and/or CH_4 recovery and then calculate the total.

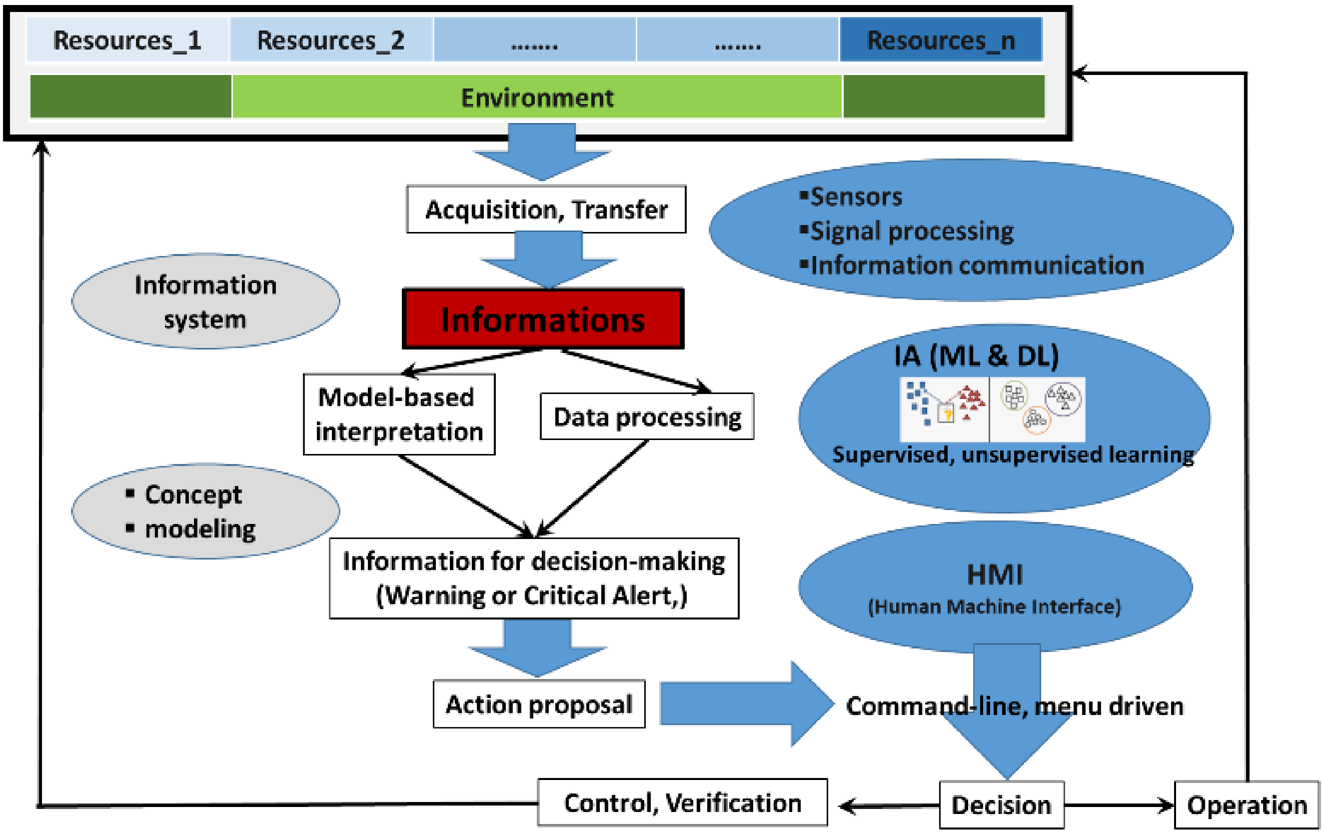

Figure 4. *Artificial intelligence as wastewater treatment.*

5. Anomaly Detection with and Thanks to AI

Identification of rare events, items, or observations which are suspicious because they differ significantly from standard behaviors or patterns [15].

5.1. The Anomaly Detection

Anomaly Detection feature uses Artificial Intelligence (Machine Learning) to learn the daily trends of a wastewater metric; to alert when its behavior deviates from its usual trend. An original and well-adapted “Cloud-Augmented” architecture relies on the Cloud to implement the resource-hungry Machine-Learning algorithms, thus preserving the supervision servers [15].

5.2. Web and Mobile Monitoring

The newly implemented application offers an efficient web and mobile application that gives users access to a wide range of information from monitoring console. It is designed to display the essentials, but can also facilitate access to detailed information, or quickly trigger actions... In fact, alert management is simplified with the possibility of receiving notifications: warning and critical [16].

Warnings: typically follow alerts and provide more detail information indicating what protective action should be taken.

Critical: alerts are dispatched when there's an issue that requires immediate attention [17].

Figure 5. Web monitoring.

This web-based system allows users to carry out remote monitoring using any web-enabled device.

6. Discussion

The supervision solution uses the AI application to increase its analysis power. We have adopted an adequate policy to offer real-time processing of all data. The sequence of tasks is materialized by:

(1) In-depth data analysis

(2) Artificial Intelligence (generated evolutionary algorithm)

(3) Machine Learning

One of the uses coveted by stakeholders is alert management. Only “justified” alerts are reported in order to reduce false positives and to focus on the two major maintenance tasks: effective curative maintenance, anticipating the arrival of alerts in order to offer preventive maintenance.

Nowadays, operators and manager's water treatment plant can look to industry best policy, practices in order to establish benchmarks that are both realistic and helpful.

7. Conclusions

Tanjombato is primarily an agricultural commune, but is also an industrial zone, particularly since the establishment of the Forello zone. Around 1997, free trade companies were promoted. Many of them set up in the Forello zone, which has since become an industrial zone. The canal, which initially served as an irrigation channel during the sowing season, is now also a receiver of industrial waste [18]. Since then, the canal has played a dual role: irrigation and receiving industrial liquid waste. Indeed, since the establishment of industrial zones, there has been no adequate infrastructure to collect factory wastewater, hence the use of the irrigation canal. The analysis showed that the physico-chemical concentrations of the industrial wastewater were relatively higher than the standards for industrial discharges laid down by Madagascar legislation [19].

This research highlights the development of AI technology in wastewater treatment. It collects, stores and processes relevant data in order to make reasonable forecasts for future trends in 365/365. An in-depth analysis, ensuring the parameters imposed by national/international authorities, has established that

(1) the optimization of real-time forecasting models,
(2) to ensure water quality by eliminating conventional pollutants,
(3) optimization of process parameters,
(4) ensuring the preventive approach: monitoring, control and evaluation

In order to make predictions and take action, sensors collect data about the physical world, while AI analyzes this data to generate information.

Sensor data can then be processed to create models that can be used to automate tasks currently performed by humans. Finally, AI then transforms decision-making into a data-driven process, where every choice is supported by concrete data. This can save money and improve efficiency. These models reduce and minimize errors. The combination of AI and sensors is a powerful way of understanding and influencing the world around us.

Abbreviations

AI	Artificial Intelligence
BOD	Biochemical Oxygen Demand
COD	Chemical Oxygen Demand
HCCP	Hazardous Chemical Control Procedures
NTU	Nephelometric Units
SS	Suspended solids
TAT	Total Alkalimetric Title

Author Contributions

Andriamiadanomenjanahary Harivelo Chandellina Camille: Conceptualization, Investigation, Supervision, Data curation, Writing – review & editing

Rakotoarisoa Marie Eliane: Conceptualization, Resources, Methodology

Randrianasolo Herilalaina Fabien: Resources, Methodology

Razafindrazaka Fenolaza Tsiory: Formal Analysis, Funding acquisition, Resources

Conflicts of Interest

The authors declare no conflicts of interest.

References

[1] UN-Water_Analytical_Brief_Wastewater_Management. https://www.unwater.org/sites/default/files/app/uploads/2017/05/UN-Water_Analytical_Brief_Wastewater_Management.pdf [Accessed: September 2024].

[2] ANDRIATSIALONINA E. – Impact socio-économiques de la pollution industrielle sur le développement local, Cas du Fokontany Ankeniheny, Commune de Tanjombato.

[3] Wastewater Basics. https://www.epa.gov/sites/default/files/2015-06/documents/ [Accessed: August 2024].

[4] Eau Potable et Eaux usées à MADAGASCAR. https://www.oieau.fr/eaudoc/system/files/documents/41/209041/ [Accessed: October 2024].

[5] Expériences de la Commune rurale de Tanjombato en matière d'assainissement. https://www.pseau.org/outils/biblio/resume.php?d=7322&l=fr

[6] USAID: Profil de L'assainissement de Madagascar. https://fr.scribd.com/document/797081178/walis-profil-de-lassainissement-madagascar-2020-fr-final [Accessed: January 2025].

[7] P. O. Ukaogo et al. Environmental pollution: causes, effects, and the remedies Microorg. Sustain. Environ. Health (Jan. 2020)

[8] Ccirsee_engees_traitement_des_eaux_usees_urbaines_2002. https://www.pseau.org/outils/ouvrages [Accessed: November 2024].

[9] How to Measure Dissolved Oxygen in Wastewater? https://www.boquinstrument.com/how-to-measure-dissolved-oxygen-in-wastewater.html [Accessed: December 2024].

[10] United Nations (2002). World Urbanization Prospects, the 2001 Revision Data Tables and Highlights. Population Division, Department of Economic and Social Affairs, United Nations Secretariat. ESA/P/WP.173. March 2002.

[11] Metcalf & Eddy, Inc. (2003) Wastewater Engineering: Treatment, Disposal, Reuse. McGraw-Hill: New York, ISBN 0-07-041878-0.

[12] Wastewater Treatment and Discharge water; Chapter 6: https://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/5_Volume5/V5_6_Ch6_Wastewater.pdf

[13] Elmolla E. S., Chaudhuri M. & Eltoukhy M. M. 2010 The use of artificial neural network (ANN) for modeling of COD removal from antibiotic aqueous solution by the Fenton process. Journal of Hazardous Materials 179 (1–3), 127–134.

[14] Dwivedi Y. K., Hughes L., Ismagilova E., Aarts G., Coombs C., Crick T., Duan Y., Dwivedi R., Edwards J., Eirug A., Galanos V., Ilavarasan P. V., Janssen M., Jones P., Kar A. K., Kizgin H., Kronemann B., Lal B., Lucini B., Medaglia R. & Williams M. D. 2021 Artificial intelligence (AI): Multidisciplinary perspectives on emerging challenges, opportunities, and agenda for research, practice and policy. International Journal of Information Management 57, 101994. [Accessed: December 2024].

[15] Artificial intelligence and machine learning for the optimization of pharmaceutical wastewater treatment systems: a review 2024, Environmental Chemistry Letters

[16] Fawzy M., Nasr M., Adel S., Nagy H. & Helmi S. 2016 Environmental approach and artificial intelligence for Ni (II) and Cd (II) biosorption from aqueous solution using Typha domingensis biomass. Ecological Engineering 95, 743–752.

[17] Fan M., Hu J., Cao R., Ruan W. & Wei X. 2018 A review on experimental design for pollutants removal in water treatment with the aid of artificial intelligence. Chemosphere 200, 330–343.

[18] MINISTERE DE L'ENVIRONNEMENT, OFFICE NATIONAL POUR L'ENVIRONNEMENT – Guide sectoriel pour la réalisation d'une étude d'impact environnemental des projets aquacoles.

[19] Projet Intégré d'Assainissement d'Antananarivo, à Madagascar. https://www.afd.fr/fr/carte-des-projets/projet-integre-dassainissement-dantananarivo-madagascar-piaa

Biography

Andriamiadanomenjanahary Harivelo Chandellina Camille is a professor in the Department of Cognitive Science in ESPA (Polytechnic High School of Antananarivo), in the Department of Telecommunication in IESAV (High School Institute of Antsirabe), and ENAM (National Administration School of Madagascar). He completed his PhD in Cognitive Sciences from STII University of Antananarivo in Dec 2017. He completed also his Master of Telecommunication from Polytechnic High School of Antananarivo in 2014 and Master of Computer Science Engineer from National Computer School of Fianarantsoa in 2004. Recognized for his exceptional contributions, his research interests span both Science Cognitive, Data and Big Data Analysis in local and cloud. In the economy research, he has worked on Micro, Mezzo and Macro Economy of Madagascar and also econometric. In addition he has made numerous contributions to IA, has focused on the big data analysis, economy, and optimization of decision making.

Rakotoarisoa Marie Eliane is a consultant and customs controller at the Ministry of Finance and Economy. She is an Engineer in Chemical Engineering from the Polytechnics of Antananarivo, specializing in the treatment of industrial waters and urban wastewater, as well as Environmental Chemistry. She obtained her Advanced Studies Diploma in Environmental Chemistry from the Faculty of Sciences at the University of Antananarivo in 2010 and her Engineering degree in Chemical Engineering from at the Higher Polytechnic School of Antananarivo (ESPA). She has expertise in standards and quality management, laboratory and chemical equipment handling, and holds a certificate in operating LECO equipment. Additionally, she is skilled in Hazardous Chemical Control Procedures (HCCP), management, economics, leadership, customs procedures and operations for import and export, as well as transit and customs operations.

Randrianasolo Herilalaina Fabien is a designer specializing in public finance control at the Ministry of Economy and Finance in Madagascar, part-time lecturer at the Higher Polytechnic School of Antananarivo (ESPA), with a focus on Geographic Information and Territorial Planning. He obtained his PhD in Territorial Planning from the University of Antananarivo in 2023 and his Advanced Studies Diploma in Agro-management from the Higher School of Agronomic Sciences in 2011. Recognized for his outstanding contributions in strategy and organizational management, Dr. Fabien has been awarded an entrepreneurial and leadership certificate from the Ministry of Youth and Sports. Additionally, he holds a diploma in diplomacy from the Center for Diplomatic and Strategic Studies (CEDS) of the Indian Ocean and has undergone training in expertise, specializing in financial administration at the National School of Administration of Madagascar (ENAM). He participated in the Agrobiodiversity Research Forum from November 29 to 30, 2017 in Fianarantsoa.

Razafindrazaka Fenolaza Tsiory is a Tax Inspector with the Ministry of Economy and Finance (MEF), specializing in Geographic Information Systems (GIS) with Madagascar National Parks (MNP) in Madagascar. He obtained his Master's degree in Electronics, Computer Systems and Artificial Intelligence (ESIIA) from the Institut Supérieur Polytechnique de Madagascar (ISPM) in 2002, and the Diplôme d'Etudes Approfondies (DEA) from the Ecole Nationale d'Administration à Madagascar (ENAM) focusing on Information and Communication Technology (ICT) in Public Administration in 2016. He also graduated from the Centre d'Etudes Diplomatiques et Stratégiques (CEDS) in Madagascar in 2017. Following a training course organized by the African Tax Administration Forum (ATAF), the International Monetary Fund (IMF) and the World Bank (WB) in 2021, he was awarded a certificate entitled Tax Administration Diagnostic Assessment Tool (TADAT) in Antananarivo.

Research Field

Andriamiadanomenjanahary Harivelo Chandellina Camille: Artificial Intelligence, Data and Big Data analysis, Economic, Mathematic, Management, Operational Research (optimization), Telecommunication.

Rakotoarisoa Marie Eliane: management, public finance, import and export, financial administration, chemistry, economics.

Randrianasolo Herilalaina Fabien: management, sociology, agronomy, financial administration, economics, tourism, engineering, territorial planning, legal science, diplomacy.

Razafindrazaka Fenolaza Tsiory: Resources, Methodology.