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HAZOP TOOL APPLIED TO THE SEWAGE TREATMENT PLANT BY ACTIVATED SLUDGE PROCESS, IN THE CITY OF ALTAMIRA/PA

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ABSTRACT

The stages of a Sewage Treatment Plant require safeguards during its processes, in order to ensure the integrity of the operational team, the surrounding community, in addition to the sustainability of natural resources. Thus, accident analysis is a primary component in any industrial activity, and in the context of sewage treatment, it has great relevance, given the 1,419 accidents recorded between the years 2012 and 2022. This study is innovative, standing out for its pioneering approach in the application of risk analysis during the secondary treatment phase for activated sludge, thus filling an existing gap in academic research on this topic. The methodology applied was the HAZOP, as it is a consolidated technique to evaluate the efficiency of these operations. 5 study nodes were adopted for the analysis of 18 parameters covering the entire sludge treatment process. Based on the results obtained, 65 scenarios were identified, of which 35 (54%) were classified as acceptable risk, 30 undesirable (46%) and none unacceptable. Regarding frequency, 92% of the events analyzed were covered, and those events with a higher probability of occurrence were classified as having a low degree of severity (acceptable or unwanted risk). Regarding severity, 94% of the events analyzed had little harmful potential. In addition to analyzing the reasons and implications of the scenarios, the adoption of preventive measures and mitigation of the consequences was suggested. In addition, a technical note was prepared containing information for the reuse of sewage sludge, in order to reduce the amount sent to the Altamira landfill.

Keywords: Accident Prevention. ETE. Risk Analysis.

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INTRODUCTION

From the industrial revolution in the mid-eighteenth century, industrial activities underwent several transformations, especially with regard to facilities, equipment and inputs used in their production processes. With the advance of industrialization, there has been an increase in cases of accidents in the industrial, technological and occupational sectors, causing negative impacts on the environment and human health.

In order to minimize the occurrence of accidents in the industrial sector, there was a movement in the political, business, as well as society sectors to find measures to prevent these events. In this sense, some of the instruments developed for the aeronautics, warfare and nuclear industries served as a reference to support analyses and risk assessments involving industrial processes, such as the petroleum, chemical and petrochemical industries (CETESB, 2011).

Sewage Treatment Plants (ETEs) have peculiar characteristics and generate by-products that, in the event of inadequate management, make their processes susceptible to the occurrence of problems such as: accidents due to the incorrect use of chemical products, risk of leaks, attraction of vectors, generation of odors and other different impacts of order and magnitude to public health and the natural environment.

The treatment stages in WWTP's require safeguards during their processes, in order to ensure the integrity of the operational team, the surrounding community, and the sustainability of natural resources. Von Sperling (2014) clarifies that, when receiving sewage discharges, a water body absorbs a diversity of disease-transmitting agents. This may not directly impact the biota of the water body, but it does influence some of the predominant uses assigned to it, such as drinking water supply, irrigation, and suitable conditions for recreational activities.

Thus, the prevention and analysis of accidents are main components of any industrial activity and when it comes to sewage treatment they tend to avoid: (i) fish mortality, (ii) eutrophication of water body, (iii) soil contamination, (iv) contamination of the water table, (v) explosion, (vi) fire, associated with this, allows the understanding of its causes and offers subsidies for the elaboration of action plan and operational procedures, for anticipating, attending to and mitigating undesirable events in a potentially polluting enterprise or activity (BARBOSA, 2014).

The research in question arose from the need to understand the stages of residual sludge management and the risks associated with it, as incorrect operations can cause

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dangerous situations with significant damage to human life, the environment and property. Rausand (2014) comments that the issue of process safety in the industry is a preponderant theme, given that the dual prevention-mitigation of accidents permeates and controls all sectors of an enterprise. To this end, the HAZOP methodology (acronym for *Hazard and Operability Study*) was the tool chosen for this research because it is a consolidated application technique, in order to evaluate the effectiveness of all phases of the operations of a specific project, from the design stage to operation and decommissioning. (BANK, 1985; ABNT, 2009).

OBJECTIVES

GENERAL

To apply the HAZOP method in the stage of treatment and disposal of sludge in a sewage treatment plant in the city of Altamira-PA.

SPECIFIC

a) To analyze the characteristics of the secondary treatment by activated sludge of the treatment plant in question, based on data obtained from municipal public administration bodies, in order to better understand this stage of the process;
b) To identify, through the HAZOP method, the possible operational and environmental weaknesses in the secondary treatment process and final disposal of the residual sludge from the WWTP in question, and
c) Propose safeguards to improve the final destination of residual sludge.

LITERATURE REVIEW

This topic presents a study of the main themes discussed in this course completion work, contemplating the bibliographic review that addresses the treatment of sanitary sewage, the problem of its contaminants and pathogens, its main variables for monitoring. In addition, a research was carried out on accidents in WWTP, defining its most important concepts, standards and techniques for identifying and evaluating risks and hazards.

SANITARY SEWER

Sanitary sewage in a municipality is formed by the collection of various generating sources such as: bars, community fairs, restaurants, residences, clandestine connections,

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treated industrial effluents and adequate to current environmental legislation. As well as the portions of rainwater and groundwater that can enter the structures of passage boxes, visit and inspection points that make up the Sanitary Sewage System (UNICAMP, 2005; BRAZIL, 2020).

In addition, the presence of organic matter (O.M.), inorganic matter and nutrients and the discharge of raw sewage in water bodies promote oxygen consumption, which can cause the uncontrolled growth of algae in reservoirs, as well as the increase of toxins by algae, causing negative impacts on human health, altering the organoleptic properties of the water supply, and may also cause changes in fishing, navigation, agriculture, livestock and recreational activities (VON SPERLING, 2014; PHILIPPI JR., ROMÉRO, BRUNA, 2014). Chart 1 presents the main quality variables applied to the evaluation of water bodies.

Table 1. Main quality variables applied to the evaluation of water bodies.

Microbiological
- Thermotolerant coliforms.
- Enterococos.

Physical
-Colour.
- Solids Series.
-Temperature.
-Turbidity.

Chemical
-Cadmium.
-Lead.
-Chloride.
- Biochemical Oxygen Demand (BOD).
- Chemical Oxygen Demand (COD).
- Total Phosphorus.
- Oils and Fats.
- Dissolved Oxygen (DO).
-Conductivity.
- Hydrogen Potential (pH).
- Organic Nitrogen, Ammonia, Nitrate and Nitrite.

Font: Adaptado de Philippi Jr., Romero, Bruna (2014).

SEWAGE TREATMENT SYSTEMS

Effluent treatment systems, as well as natural environments, are characterized as open systems, providing the coexistence of several microorganisms that establish various relationships and interactions. Treatment methods are divided into unitary operations and processes, and the integration of these processes constitutes treatment systems. Depending on the process employed, several mechanisms can act in isolation or simultaneously in the removal of pollutants (METCALF and EDDY, 1991; VON SPERLING

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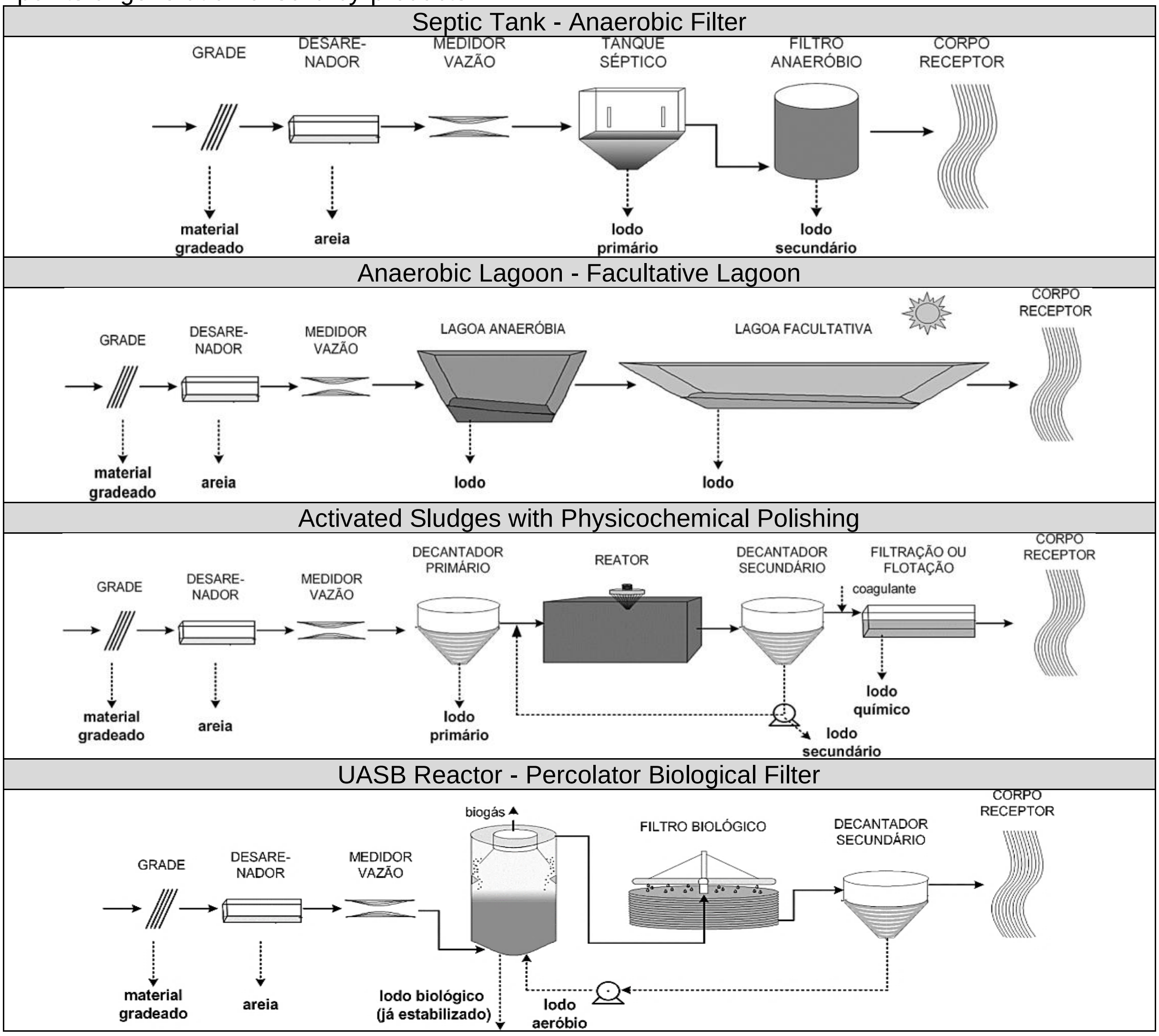
2014; JORDÃO and PESSÔA, 2017). Figure 1 highlights the main treatment systems frequently used in the treatment of domestic sewage, as shown in Figure 1.

Figure 1. Schematic configuration of some sewage treatment systems, with identification of the points of generation of solid by-products



Source: Adapted from Von Sperling (2014)

SECONDARY TREATMENT

Secondary treatment of domestic sewage is a crucial step in the wastewater purification process. It follows primary treatment and aims to remove dissolved or suspended organic pollutants, which persist in sewage after the initial stages. Its main characteristic is the use of biological processes, in which microorganisms, such as bacteria and fungi, decompose organic matter with the help of biological reactors, such as aeration tanks or sludge beds (CHERNICHARO, 2001; SANCHES, 2019).

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In the activated sludge system, microorganisms are kept in suspension and continuously aerated to promote efficient decomposition of organic matter.

Although the conventional activated sludge method demonstrates considerable efficiency, removing approximately 88% of the BOD rate (ANA, 2020), which exceeds the minimum of 60% established by article 16 of CONAMA Resolution No. 430/2011, Von Sperling (2016) presents the advantages and disadvantages of the operational variations most frequently found in this system (chart 2).

Frame 2. Most common operational advantages and disadvantages of the conventional activated sludge system

Advantages	Disadvantages
i. High efficiency in BOD removal. ii. Nitrification usually obtained. iii. Possibility of biological removal of N and P. iv. Low area requirements. v. Reliable process, as long as it is supervised. vi. Reduced chances of bad odors, insects and worms. vii. Operational flexibility.	i. Low coliform removal efficiency. ii. High implementation and operation costs. iii. High energy consumption. iv. Need for sophisticated operation. v. High mechanization rate. vi. Relatively sensitive to toxic discharges. vii. Possible problems with noise and aerosols. viii. Need for complete treatment of the sludge and its final disposal.

Source: Adapted from Von Sperling (2016)

ACCIDENTS IN SANITARY SEWAGE TREATMENT PLANTS

Over the years, industrial accidents of a technological nature have attracted the attention of government authorities, entrepreneurs, and society to create mechanisms that prevent episodes that may threaten people's safety and the quality of the natural environment (XIANG et al., 2022). According to records from the Observatory of Safety and Health at Work (SmartLab), Accident Notifications occurring in WWTP are grouped in the Economic Sector 'Management of Sewage Networks', totaling, between the years 2012 and 2022, 1,419 events – of these, 170 were in 2022. Data from the Statistical Yearbooks of Occupational Accidents, referring to the analysis between the years 2013 and 2021, show the year 2013 with the highest number of records of occupational accidents (631) and in the comparison of 2020-2021 there was an increase of 29.17%, with values of 336 and 434, respectively. In this entire series, the number of permanently disabled workers was 50 workers and 15 deaths (Fig. 2).

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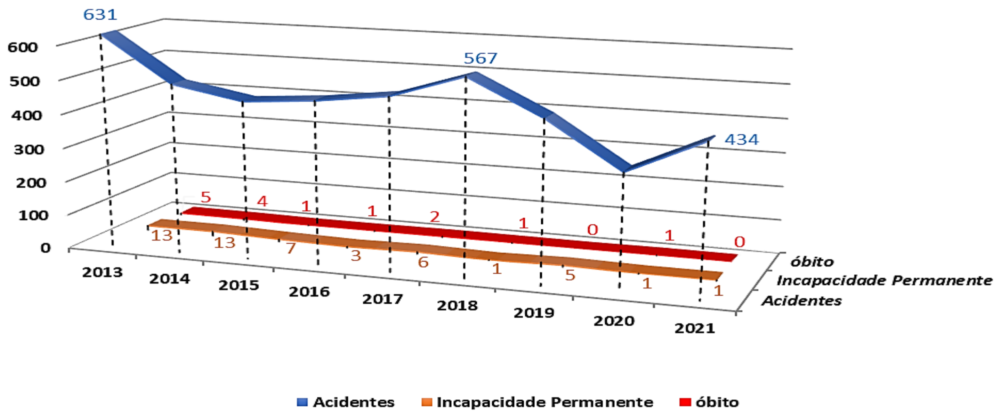
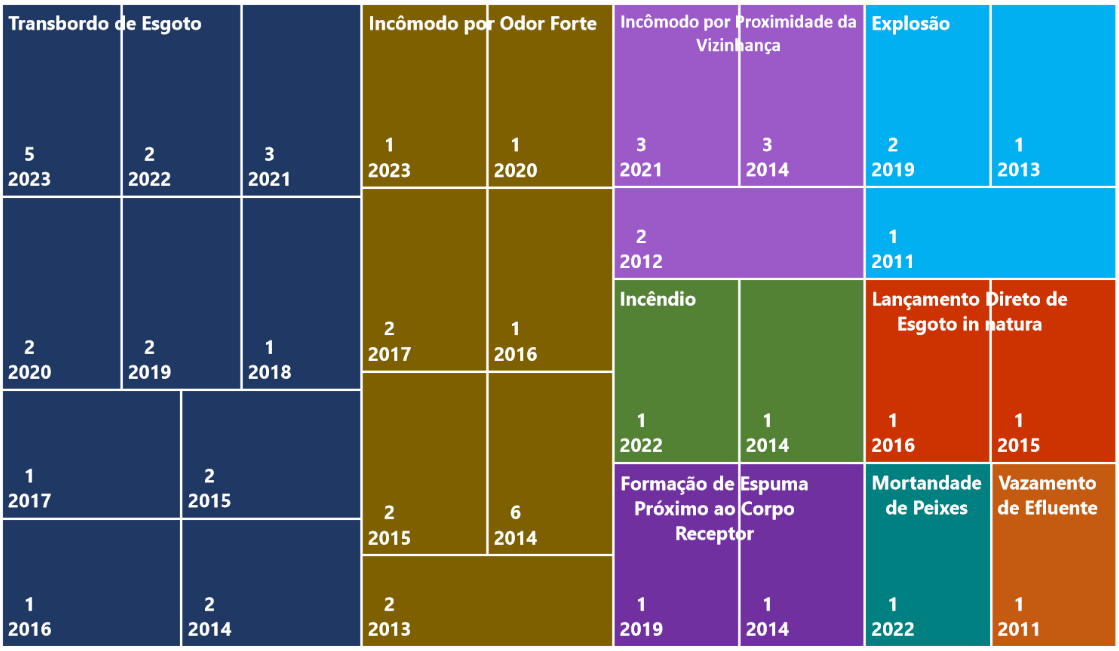
Figure 2. Occurrences Recorded in WWTPs between the years 2013 and 2021: Accidents, Permanent Disability and Deaths



Source: DATAPREV, CAT, SUB (2023). Prepared by the authors, 2025.

Due to this grouping, SmartLab does not individually demonstrate the typology of accidents recorded in WWTPs. Thus, in order to identify this aspect, a survey was carried out on the G1 news website, where 56 occurrences were reported in the period from 2011 to 2023 (Fig. 3). To a large extent, 21 events described as 'Sewage Overflow' had the highest occurrence among the reports and that may have occurred due to structural or human failures, exceeding, in some cases, the physical limits of those stations, which generated negative impacts on the inhabitants and the surrounding natural environment.

Figure 3. Tree Chart with the historical distribution of events that occurred in a sanitary sewage treatment plant



Source: G1 (2023). Prepared by the authors, 2025

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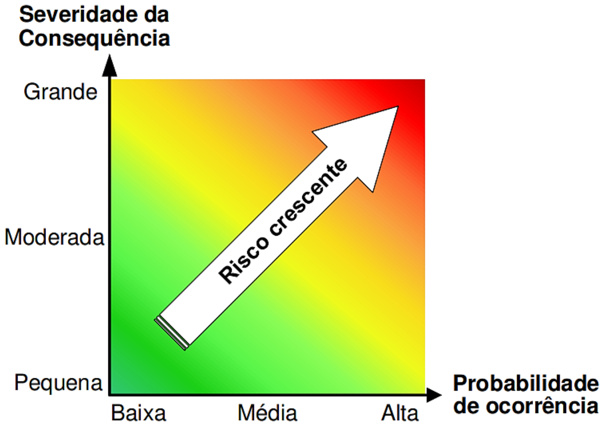
BASIC CONCEPTS AND RULES ON RISK ANALYSIS

Rausand (2011) explains the basic concept of risk as the probability of occurrence and the severity of the consequences resulting from a dangerous event (Fig. 4). This function encompasses both the frequency with which the event can happen and the associated severity when it occurs, allowing for qualitative or quantitative assessments.

Figure 3. Graphical Representation of Risk



Source: Adapted from M. Rausand (2011)

Thus, the risk produced by the activity of an enterprise has a direct correlation with the characteristics and quantities of the chemical substances handled and the level of vulnerability and susceptibility of the region where it is located or will be established (CETESB, 2011). In this context, Girão, Rabelo and Zanela (2018) conceptualize vulnerability as the condition of society in the face of the characteristics of the environment, reflecting the various variables (income, housing, education, etc.) that make it more or less susceptible, defining society as the main factor that can accelerate or delay the probability of occurrence of a specific phenomenon.

The predominant risks in the process industry arise from the emission of intrinsically hazardous materials, such as flammable or toxic ones, and/or exposure to high pressures and temperatures (KING, 2016). Thus, when designing a plant for a given activity, attention must be paid to ensuring the safety of the facilities by providing means for containment and/or mitigation of undesirable events.

Developed by the Environmental Company of the State of São Paulo - CETESB (2012), the CETESB P4261 Standard, dated December 2011, covers a methodology for classifying the risk of accidents of technological origin. The objective is to establish

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standards and improve the methodologies used in the preparation of Risk Analysis Studies and Risk Management Programs for activities considered hazardous.

Another important regulation for Risk Analysis is the Regulatory Standard - NR 9 (MTP, 2023). This standard establishes the need to evaluate all occupational risks, not limited to environmental risks. In addition, it requires the identification and classification of the risk level, in order to determine prevention measures, as well as the monitoring of the control of occupational risks.

To this end, Moller et al. (2018) indicate that the methods applied to risk analysis are divided into quantitative and/or qualitative. In this sense, qualitative analysis brings together the identification of hazards and risks with the assessment of the probability of occurrence of an episode and the impact of the risk, to indicate the level of risk in significance levels such as: "high", "medium" and "low", as defined by ABNT ISO 31010 (Brazil, 2012). Quantitative techniques are supported by numerical estimates referring to the frequencies or consequences that may arise in events from the work carried out in an industrial facility (AIChE, 1992).

In addition, CETESB (2011) states that for industrial facilities in operation, risk analysis studies have had a positive and important effect in identifying and managing residual risk and making it possible to manage it individually or in an expanded way.

Finally, Ponte Junior (2014) explains that there is no need to speak of absolute safety, since despite applying all the available technological protection apparatus, there are still risks and it is necessary to manage their control, so that engineering acts to keep risks at acceptable levels and allow the technological operability of the enterprise, forming the concept of risk and safety management.

RISK ANALYSIS

The HAZOP technique is undoubtedly the most widely recognized and employed method of risk analysis in the process industry. In addition, its adoption is recommended by standards, including Petrobras' N-2595 (GRUHN and CHEDDIE, 2006).

Kabbach et al. (2018) and CETESB (2011) explain that this is a qualitative, methodical, and thorough technique, since it applies guide words at specific points – called "study nodes" – to the main parameters of a project or a process in operation (Chart 3). At the end, deviations from the operational standards are obtained, which are analyzed to identify the relationship between the causes and their consequences, for example, when

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applying the guide word "No" associated with the process parameter "Flow" will indicate the deviation "No Flow".

Frame 3. Examples of Guides and Parameters Applied to HAZOP

Keyword	Meaning	Parameter	Detour
Less	Quantitative decrease	Flow	Low flow rate
		Level	Low level
		Temperature	Low temperature
		Pressure	Low blood pressure
		Concentration	Low concentration
More	Quantitative increase	Flow	High flow rate
		Level	High level
		Temperature	High temperature
		Pressure	High pressure
		Concentration	High concentration

Source: Adapted from Khan; - Abbasi (1998)

Vincoli (2014) evaluates that among the risk analysis techniques of a process, more than 80% can be attributed to HAZOP and hypothetical variation analysis. The rest is composed of general methods (checklist, preliminary risk analysis, etc.) and tree methods (Failure Tree Analysis, Failure Mode and Effects Analysis, among others).

METHODOLOGY

This topic deals with the materials and methodological tools used in this research, outlining the stages of execution in a clear and comprehensive way. The presentation follows a logical and chronological order, including the delimitation of the object of study and the characteristics of the conditions in which the work was conducted.

CHARACTERIZATION OF THE STUDY AREA

The municipality of Altamira covers an area of 159,696 km² (IBGE, 2015; PMA, 2010). As for the climate, it is classified by the Köppen classification as "Am" in the northern part and "Aw", with an average annual minimum temperature of 22.1 ºC, average annual maximum temperature of 32.4 ºC, and an average annual rainfall of 2,123mm (SOUZA et al., 2013; IBGE, 2008). It stands out as a commercial, political, social and cultural hub in the Trans-Amazonian and Xingu regions (UMBUZEIRO, 2012).

The study was applied in the urban perimeter of the seat of the municipality of Altamira (Fig. 5), which has a territorial extension of 111.02 km², located in the Southwest

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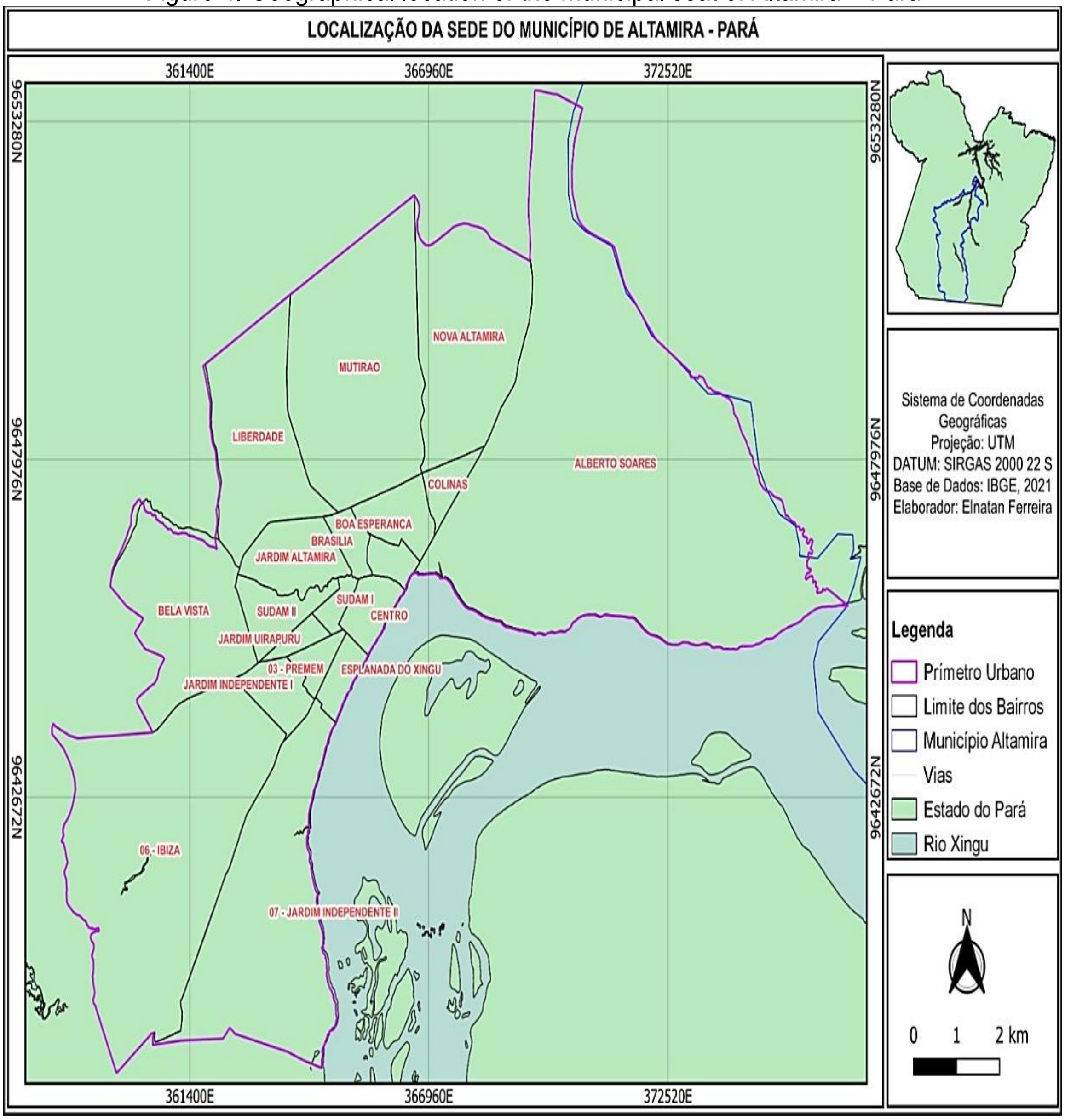
region of the State of Pará, 754 km from Belém, with a population of 126,279 inhabitants (IBGE, 2022).

Figure 4. Geographical location of the municipal seat of Altamira – Pará



Source: Ugly (2022)

SANITARY SEWAGE SYSTEM IN ALTAMIRA/PA

The Altamira Sanitary Sewage System – SES Altamira (Fig. 6), was built in compliance with condition No. 2.10 of the Installation License No. 795/2011 of the Belo Monte Hydroelectric Power Plant, and is composed of the following structures:

a. 04 sewage basins, subdivided into 21 sub-basins;

b. 17 Sewage Pumping Stations – EEEs;

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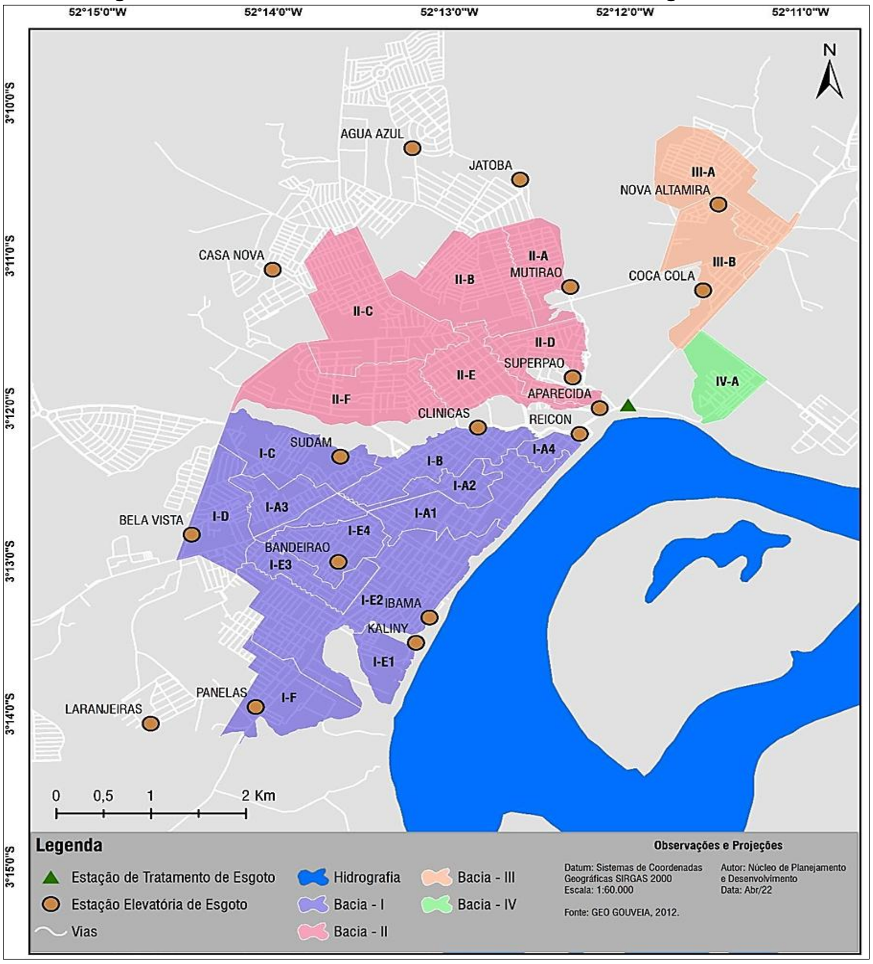
c. 01 Sewage Treatment Plant – ETE Altamira with a treated sewage lift and,

d. 01 Emissary.

Figure 5. SES Altamira with Subdivision of Sewage Basins



Source: Technical Note TFP Engenharia - SES-DGN-NTE-EEE01-HID-001, 2018

The Altamira WWTP was built by the company Norte Energia S.A. com operation from 2013 to 2023, transferring the operation to the Altamira City Hall at the end of this period. It has a treatment capacity with an average flow of 200 l/s and a maximum of 360 l/s. It was designed to remove organic matter, sedimentable solids and the nutrients Phosphorus and Nitrogen, aiming to minimize the risk of eutrophication of the waters of the backwater of the Belo Monte HPP. Its conception advocates the operation in two independent conduits – Conduit 1 and Conduit 2 – capable of treating the average projected flow with a complete effluent treatment cycle in a three-phase system – primary, secondary and tertiary – for the treatment of raw sewage, with automated and monitored input for all treatment operations.

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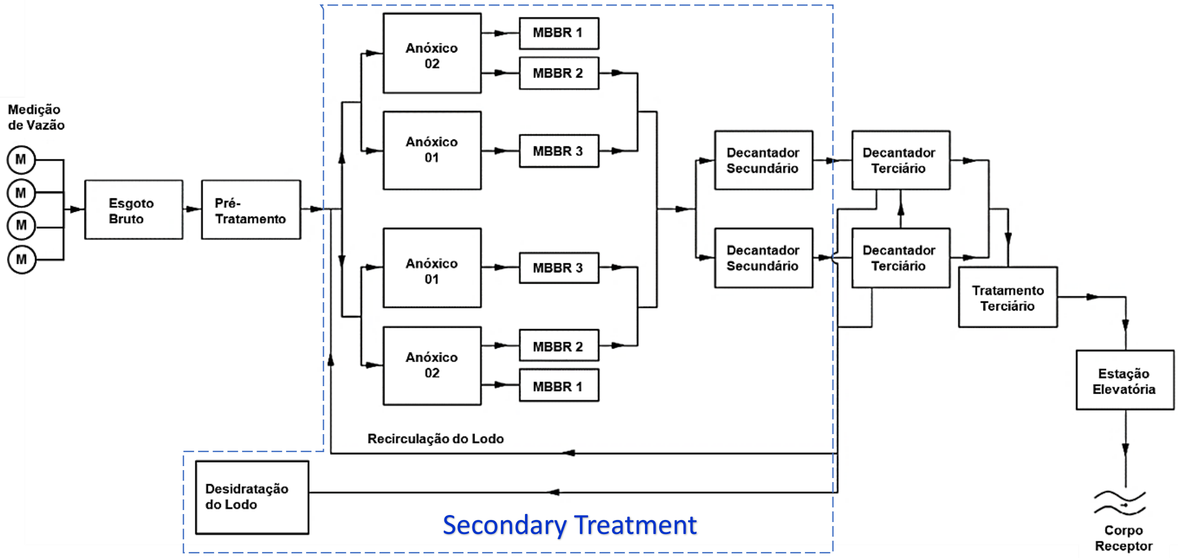
The biological treatment process adopted is by activated sludge with hydraulic regime in piston flow, using conventional aeration with coarse bubble air diffusers integrated with the support medium called Moving BedBio Reactor (MBBR) and Integrated Fixed Film Activated Sludge (IFAS) process, preceded by anoxic selector and followed by biological treatment. In this phase, sludge is formed in the secondary decanter, and a portion of this sludge returns to the biological reactors – in order to maintain control and balance of the treatment process. Another portion of the non-recirculated decanted solids also passes by gravity to the tertiary decanter tanks (ANDREOLI, VON SPERLING, FERNANDES, 2014). Figure 7 shows the flowchart of the treatment stages of the Altamira WWTP.

Figure 6. Flowchart of the Treatment Stages of the Altamira WWTP



Source: SES Executive Project, GEL/Gouvêa – Technical Report 2014

THE HAZOP METHOD

In this segment, the method for standardizing the procedure for obtaining data and preparing results is presented. Gil (2017) clarifies that the case study involves a thorough and comprehensive investigation of one or a few objects, providing a broad and detailed understanding. Thus, the application of the HAZOP method in this case study was attributed according to the sequence described in chart 4 (ABNT NBR ISO-IEC 31010-2012) with a qualitative-quantitative approach. Minayo (1997) and Triviños (2009) corroborate the understanding that quantitative research can raise questions that can be explored in greater depth through a qualitative approach, and vice versa, since the

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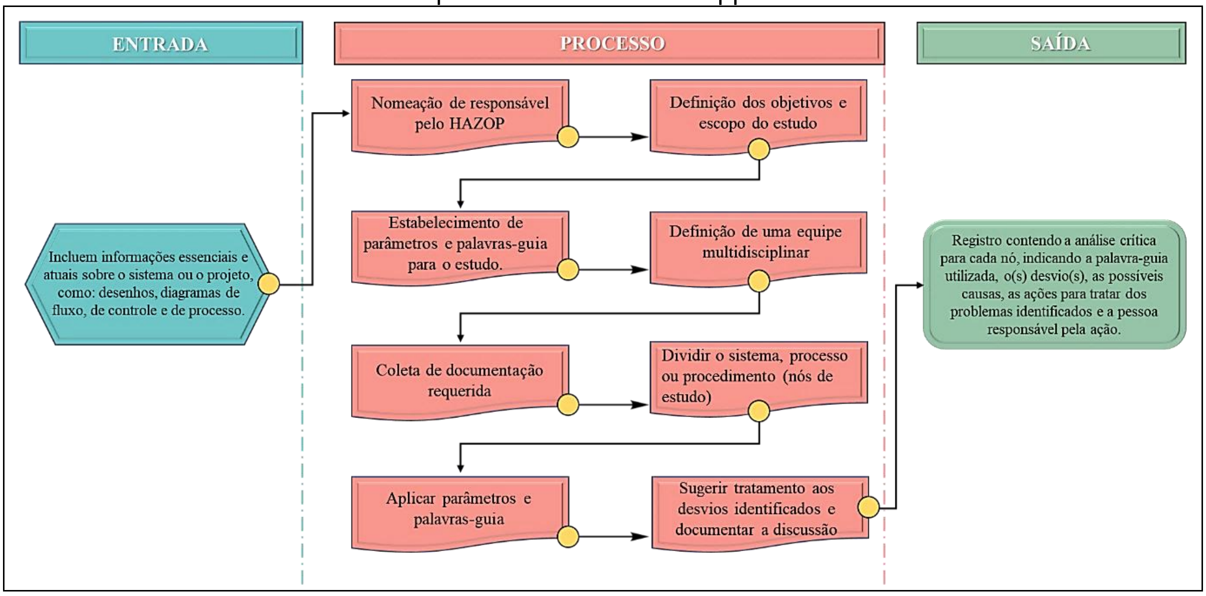
qualitative approach aims to understand and explain the data, while the quantitative approach employs experiments and statistics as guiding procedures for analytical results.

Frame 4. Description of the Phases of Application of HAZOP



Source: Adapted from ABNT (2012)

These data were analyzed by means of information interpretation techniques, among which we can mention the use of a Microsoft Excel spreadsheet to group the characteristics of the main stages of treatment of the TEE and to prepare the spreadsheets containing the HAZOP analysis (Fig. 8).

Figure 8. HAZOP Analysis Framework

Hazard Analysis and Operability (HAZOP)								
Sewage Treatment Plant								
Industry(Area)								
Knot			**Date**					
Parameter	**Detour**	**Cause**	**Effect**	**Safeguards**	**Fre**	**Sev**	**Risk**	**Recommendations**

Source: Adapted from CCPS (2011)

DEFINITION OF NODES

For a better evaluation of the process, access to information on flowchart, operational and maintenance procedures, as well as the operation of the equipment is essential for the application of the HAZOP methodology, because from this survey the plant is divided into study points (nodes), which facilitates the analysis of the processes and identification of the parameters to be evaluated.

From the analysis of the flowchart and the information obtained about the operation of the WWTP regarding the facilities, equipment and products used, the plant will be divided into nodes and the table will be filled in (Fig. 9) where the description of the process will be related, as well as the main equipment that make up the study points under analysis.

Figure 7. Chart for Description of Main Nodes and Equipment

Knot	Description	Main Equipment

Source: Prepared by the authors, 2025

To determine the probability (frequency) and severity classifications, the HAZOP allows the use of a Risk Assessment Matrix (table 1).

Table 1. Risk assessment matrix

Matriz de Avaliação de Risco			**Categorias de Frequência**				
			A Extremamente Remota	B Remota	C Pouco Provável	D Provável	E Frequente
Categoria de severidade das consequências	V	Catastrófica	5A	5B	5C	5D	5E
	IV	Crítico	4A	4B	4C	5D	5E
	III	Média	3A	3B	3C	3D	3E
	II	Marginal	2A	2B	2C	2D	2E
	I	Desprezível	1A	1B	1C	1D	1E

Índice de Risco de Perigo

Classificação de risco	**Critério de Risco**
3E, 4D, 4E, 5C, 5D, 5E	Inaceitável, Mudanças devem ser feitas
1E, 2D, 2E, 3C, 3D, 4B, 4C, 5A, 5B	Indesejável, faça alterações se possível
1A, 1B, 1C, 1D, 2A, 2B, 2C, 3A, 3B, 4A	Aceitável sem revisão

Source: Adapted from ABNT (2012)

Tables 5 and 6 present the definitions of the categories of severity or severity and probability and frequency, respectively.

Table 5. Hazard severity or severity categories

Description	Category	Personal Safety	Characteristics		
			Patrimony	Environment	Image
Catastrophic	V	Multiple intramural fatalities or extramural fatalities.	Catastrophic damage can lead to the loss of the industrial facility.	Severe damage to sensitive areas or extending to	International impact.

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				other locations.	
Critical	IV	Intramural fatality or serious extramural injuries.	Severe damage to systems (slow repair).	Severe damage with localized effect.	Impact national.
Medium	III	Severe intramural injuries or minor extramural injuries.	Moderate damage to systems.	Moderate damage.	Impact regional.
Marginal	II	Minor injuries.	Minor damage to systems or equipment.	Slight damage.	Impact local.
Despicabl e	I	No injuries, or at most a case of first aid	Minor damage to equipment without compromising operational continuity	Negligible damage	Negligible impact

Source: Adapted from ABNT (2012)

Table 6. Frequency Levels or Probability of Danger

Description	Level	Accident Identification
Extremely remote	The	Conceptually possible, but extremely unlikely in the lifetime of the station. No historical references
Remote	B	Not expected to occur during the lifetime of the facility, although there are historical references
Unlikely	C	Can occur up to once during the life of the installation
Probable	D	Expected to occur more than once during the life of the installation
Frequent	And	Expected to occur many times during the life of the installation

Source: Adapted from ABNT (2012)

RESULTS AND DISCUSSIONS

The reduction in the number of Work Accident Reports (CATs) registered by the National Institute of Social Security (INSS) between 2019 and 2020 was established due to the closure of companies during the COVID-19 pandemic, since safety measures – such as social distancing – had to be adopted, making it impossible to continue some activities.

From the analysis of the WWTP documents, 5 study nodes were defined covering the entire sludge treatment process from the storage tank, where the sludge stabilization occurs, followed by the process of dehydration, sanitization and transport to the Altamira Sanitary Landfill – ASA. Chart 7 presents the study nodes, the description and the main equipment.

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Table 7. Description of Nodes and Equipment

Knot	Description	Equipment
1	Aerobic sludge storage and stabilization	- Mud tank, Sludge tank and Clarified Mud Tank
2	Polymer Solution Preparation	Automatic polymer preparation unit
3	Increased solids concentration	Sludge Flatener, Polymer Dosing Pump
4	Reduced sludge moisture	Decanter centrifugo
5	Sanitation of dewatered sludge, transport and final disposal to ASA	Trucks

Source: Prepared by the authors, 2025

18 important parameters in the process were analyzed, whose deviation represents operational, occupational and environmental risk. The parameters analysed and the corresponding guide words are listed in Table 8.

Table 8. Parameters analysed and the corresponding keywords

Item	Parameter	Keyword
1	Level	Bigger, smaller, none.
2	Aeration	
3	Agitation	
4	Flow	
5	Temperature	Bigger, smaller.
6	Quantity	
7	Speed	
8	Viscosity	
9	Depth	
10	Flow	
11	Vibrations	
12	Lubrication	Lack of.
13	Cleaning	
14	Accident	Occurrence of.
15	Leakage	
16	Blockage	
17	Electric shock	
18	Sense	Different from.

Source: Prepared by the authors, 2025

NODE 1

Table 9 presents the results for Node 1, which comprises the sludge tank that receives the tailings from the secondary and tertiary decanters, the dense sludge tank and the clarified sludge tank that receives the liquid phase separated in the densifier and the centrifuge. In this tank, an important stage of the treatment called stabilization by aerobic digestion takes place. The diffuse aeration system ensures homogenization and creates the essential conditions for the bacteria to carry out the sludge stabilization process.

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Table 9. HAZOP analysis spreadsheet for Node 1

Análise de Perigo e Operabilidade (HAZOP)								
Estação de Tratamento de Esgoto								
Setor (Área)	Tanque de Lodo (T.L.); Tanque de Lodo Adensado (T.L.A.); Tanque de Lodo Clarificado (T.L.C.)							
Nó	1		Data	23/12/2023				
Parâmetro	Desvio	Causa	Efeito	Salvaguardas	Frequência	Severidade	Risco	Recomendações
Nível (T.L.)	Maior	Falha no sensor de nível	Transbordamento	Monitoramento do processo	D	III		
Aeração (T.L)	Menor	Falha nos sopradores	Falha na estabilização do lodo	Monitoramento do processo	D	II		Análise periódica do lodo
		Válvula fechada	Falha na estabilização do lodo	Monitoramento do processo	D	II		
Nível (T.L.A)	Maior	Falha no sensor de nível	Transbordamento	Monitoramento do tanque	D	I		
		Falha no acionamento da bomba de lodo adensado	Transbordamento	Monitoramento do tanque	D	II		
Nível (T.L.C)	Maior	Falha na Bomba	Transbordamento	Monitoramento do tanque	D	I		Bomba reserva
		Falha no sensor de nível	Falha no acionamento da bomba	NA	D	I		

Source: Prepared by the authors, 2025

NODE 2

Chart 10 presents the results for Node 2, which covers the polymer preparation stage used in the flocculation of the sludge that is performed by the automatic polymer preparation unit. Organic synthetic polymers can agglomerate in suspension with the particles, thus obtaining larger floccule dimensions, which results in faster solid/liquid separation.

Table 10. HAZOP analysis spreadsheet for Node 2

Hazard Analysis and Operability (HAZOP)			
Sewage Treatment Plant			
Industry(Area)	Automatic polymer preparation unit		
Knot	2	Date	23/12/2023

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Parameter	Detour	Cause	Effect	Safeguards	Frequency	Severity	Risk	Recommendations
Quantity (powder)	Minor	Frequency converter failure	Inadequate polymer concentration in solution	Inspect the powder feeder regularly during operation	C	I		
	Bigger							
Lubrication	Lack of	Maintenance failure	Parts wear	Perform lubrication as directed by the manufacturer	D	II		Implement an equipment maintenance plan
		Maintenance failure	Noises	Perform lubrication as directed by the manufacturer	D	II		
Viscosity	Bigger	High polymer concentration	Problems in polymer dosage and dilution	Verify information on the viscosity of the polymer used	D	II		
Flow (water)	None	Registration closed	Lack of water for polymer dilution	Process monitoring	D	II		
		Solenoid valve failure		Process monitoring	C	II		
Temperature (po)	Minor	Thermostat failure	Problems in polymer dosage and dilution	IN	C	II		
Level (storage tank)	Minor	Lack of non-feeder polymer	Lack of Polyelectrolytes for the flocculation process	Constant monitoring at the powder level and filling when needed	D	II		Operator training
		Lack of water		Process monitoring	C	II		
		Storage tank level sensor failure		Regular inspection of the tanks	C	II		
	Bigger	Storage tank level sensor failure	Polymer solution leakage	Regular inspection of the tanks	C	II		
Level (powder feeder)	Minor	Lack of Supply	Operation failure	Constant monitoring at the powder level and filling when needed	And	II		Operator training
Stirring (mixing tank)	None	Gearmotor failure	Incomplete polymer dilution	Regular inspection of the tanks	C	II		
Stirring (maturation tank)	none	Gearmotor failure	Solution decanting	Regular inspection of the tanks	C	II		

Source: Prepared by the authors, 2025

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NODE 3

The results referring to Node 3, which brings together the polymer dosing and densification process, are presented in Chart 11. Accurate polymer dosing is crucial in this process, as proper product measurement ensures efficient separation between the liquid and solid phases, which starts in the rotary sludge densifier. The rotary sludge densifier is a device used to capture and separate suspended solids in raw effluents. Solids, up to a specific size, are retained and removed by the helicoid scraping blade, located on the inside of the densifier.

Table 11. Spreadsheet with HAZOP analysis for Node 3

Hazard Analysis and Operability (HAZOP)								
Sewage Treatment Plant								
Industry(Area)	Mud Anchor; Polymer dosing pump							
Knot	3		**Date**	23/12/2023				
Parameter	**Detour**	**Cause**	**Effect**	**Safeguards**	**Frequency**	**Severity**	**Risk**	**Recommendations**
Rotation Speed	Bigger	Gearmotor failure	Failure to densify	Check Rotation in the Electrical Panel	C	I		
Cleaning	Lack of	Operator Fault	Failure to densify	Periodic lubrication	D	I		
			Blockage	Periodic lubrication	D	II		Operator training
Lubrication	Lack of	Operator Fault	Noise	Periodic lubrication	D	II		Implement an equipment maintenance plan
			Parts wear		D	II		
Vibrations	Bigger	Damaged bearings	Failure to densify	Replacement of bearings as directed by the manufacturer	D	II		
Sludge Flow	None	Registration closed	Operation failure	Operation monitoring	D	I		
		Pump failure	Operation failure	Operation monitoring	D	I		
Leakage	Occurrence of	Damaged pipes	Risk to the operator	Use of PPE	D	I		
			Possible environmental contamination	Pipeline Inspection	D	I		
Polymer Fluxo	Minor	Polymer metering pump failure	Difficulties in flocculation	Operation monitoring	D	II		
		Blockage	Difficulties in flocculation	System Cleanup	D	II		Operator training
	None	Polymer metering pump failure	Difficulties in solid/liquid separation	Operation monitoring	D	II		

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		Blockage	Difficulties in solid/liquid separation	System Cleanup	D	II		Operator training
		Lack of Polymer in UAP	Difficulties in solid/liquid separation	Polymer Storage Tank Inspection	C	II		

Source: Prepared by the authors, 2025

NODE 4

Table 12 presents the results for Node 4, which covers the centrifugation stage performed by the centrifugal decanter. The centrifugal force generated by the intense rotary movement inside the drum allows the separation of the solid, heavy liquid and light liquid phases. During this procedure, the solid material, which tends to have the highest density, is directed to the inner surface of the drum and is constantly guided by the conveyor snail towards the discharge nozzles. When passing through the cone, there is a considerable reduction in the moisture of the solid material.

Table 12. HAZOP analysis spreadsheet for Node 4

Hazard Analysis and Operability (HAZOP)								
Sewage Treatment Plant								
Industry(Area)	Centrifugal Decanter							
Knot	4		**Date**	23/12/2023				
Parameter	**Detour**	**Cause**	**Effect**	**Safeguards**	**Frequency**	**Severity**	**Risk**	**Recommendations**
Vibrations	Bigger	Improper equipment leveling	Equipment inefficiency	IN	C	II		
		Damaged parts	Noise	Periodic maintenance of equipment	D	I		
Lubrication	Lack of	Operator Fault	Noise	Perform periodic lubrication as directed by the manufacturer	D	I		
			Equipment inefficiency	Perform periodic lubrication as directed by the manufacturer	D	II		Implement an equipment maintenance plan
			Parts wear	Perform periodic lubrication as directed by the manufacturer	D	II		

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Cylinder rotation speed	Minor	Voltage drop in the power grid	Solid phase separation failure	Rotation monitoring in the electrical cabinet	D	I		
		Engine defect	Solid phase separation failure	IN	C	II		
	Bigger	Frequency inverter failure	Vibrations and noises	Electrical panel monitoring	C	II		
Viscosity	Discharge	High Solids Theory	Solid phase separation failure	IN	D	I		
Flow	None	Dense sludge pump failure	Power failure	Process monitoring	D	II		Pump reserve
		Empty dense sludge tank	Power failure	Dense sludge tank level monitoring	D	I		
Feed flow	Bigger	High Speed Pump	Degradation of the size of solids or their emulsification (incomplete clarification)	Low-speed pump use	B	I		
Blockage	Occurrence of	High concentration of solids	Operation failure	IN	D	II		
		Large particles	Operation failure	Sieving or removing larger particles	C	II		
		Overfeed volume	Operation failure	Low-speed pump use	C	II		
Electric shock	Occurrence of	Contact with the equipment	Damage to operator health	Do not touch the equipment with wet hands	B	II		Operator training
Leakage	Occurrence of	Damaged piping	Possible environmental contamination	Pipeline Inspection	D	I		
Direction of rotation	Different from	Installation error	Solid phase separation failure	Check the direction of rotation set by the manufacturer	B	II		
Liquid Layer Depth	Bigger	Equipment adjustment	Low solids content	Check the setting according to the expected results	C	I		
	Minor	Equipment adjustment	High Solids Theory	Check the setting according to the expected results	C	I		

Source: Prepared by the authors, 2025

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NODE 5

Chart 13 presents the results of Node 5, which involves the cleaning of the sludge with the addition of hydrated lime, which aims to eliminate the pathogenic organisms contained in the sludge from the WWTP, in addition to the transport and final disposal of the sludge with the use of trucks to the ASA.

Table 13. Spreadsheet with HAZOP analysis for Node 5

Hazard Analysis and Operability (HAZOP)								
Sewage Treatment Plant								
Sector (Area)	Sanitation, Transport and Final Disposal of Sludge							
Knot	5		Date	23/12/2023				
Parameter	Detour	Cause	Effect	Safeguards	Frequency	Severity	Risk	Recommendations
Quantity (Cal)	Minor	Operator Fault	Failure to sanitize the sludge	Check quantity required for process	And	II		
Leakage during transport	Occurrence of	Inadequate packaging	Possible environmental contamination	Use of suitable equipment for transport	D	I		
		High moisture content		IN				
Accident (truck)	Occurrence of	Mechanical failure	Risk to the driver	Truck maintenance	C	IV		Installation of speed limiters on trucks
			Possible environmental contamination		D	II		
		Driver fault	Risk to the driver	Driver training	C	IV		Defensive driving courses for drivers.
			Possible environmental contamination		D	II		
		Animals on the track	Risk to the driver	IN	C	IV		
			Possible environmental contamination		D	II		
Quantity (Sludge)	Bigger	Absence of a Sludge Management Plan	Reduced ASA Life	Reuse	And	II		Appendix 1 - Technical Note No. 01/2024/EAS2019/UEPA

Source: Prepared by the authors, 2025

A total of 65 scenarios were analyzed, 35 of which were classified as acceptable risk (54%), 30 undesirable (46%) and none unacceptable (0%), as shown in figure 10.

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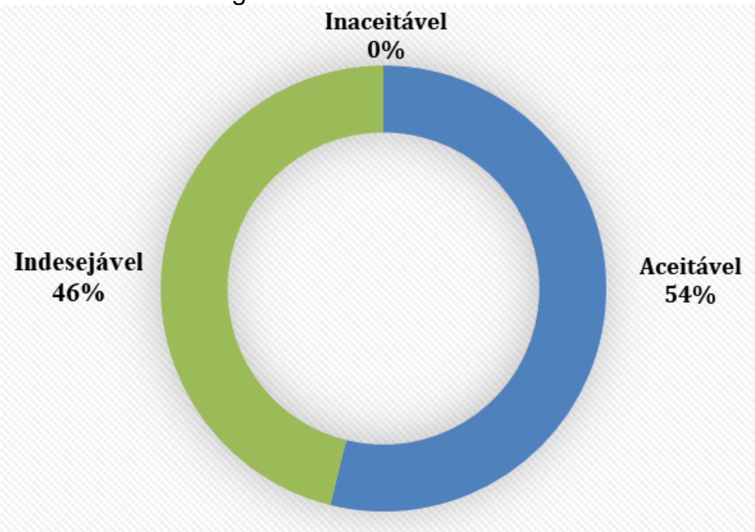
Figure 10. Risk classification



Source: Prepared by the authors, 2025

In a research based on a hypothetical scenario of an industrial effluent treatment plant, Corrêa (2014) concluded that, of the 71 scenarios analyzed, 91.5% were categorized as undesirable, 8.5% as acceptable, and none as unacceptable. The high percentage of undesirable risks contrasts with the values found in this study. This is because, according to CETESB (2011), the risk associated with the activities of an enterprise depends on the characteristics and quantities of the chemical substances handled, as well as the level of vulnerability and susceptibility of the region where the enterprise is located.

Regarding the frequency with which each event can occur, the Probable (D) and Unlikely (C) categories, as shown in Table 2, represent about 92% of the events analyzed. However, the events that were more likely to occur result in consequences of a low degree of severity, which configures a risk considered acceptable or undesirable.

As for severity, the Marginal (I) and Negligible (II) categories represent 94% of the events analyzed, because the effects caused by deviations have little potential to affect personal safety, the integrity of the facilities as well as the environment.

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Table 2. Risk assessment matrix

Severidade	Frequência					Total
	A	B	C	D	E	
V	0	0	0	0	0	**0**
IV	0	0	3	0	0	**3**
III	0	0	0	1	0	**1**
II	0	2	13	23	3	**41**
I	0	1	4	15	0	**20**
Total	**0**	**3**	**20**	**39**	**2**	**65**

Cor	Legenda
Vermelho	Inaceitável, Mudanças devem ser feitas
Amarelo	Indesejável, faça alterações se possível
Verde	Aceitável sem revisão

Source: Prepared by the authors, 2025.

The categorization of risks through the evaluation matrix provides valuable information for their management. According to Galante, Bordalo and Nóbrega (2014), this information facilitates the understanding of the unit's operation and highlights the need to manage risks, given the potential effects that a simple deviation can cause. In addition, it clarifies the way events are triggered from failures or operations performed improperly.

As it is an automated WWTP, in most processes there is less susceptibility to events that pose risks to the installation, the health of the worker and the environment. However, as stated by Ponte Junior (2014) there is no absolute security, despite all the resources employed, the risks are not completely eliminated. In this sense, in order to minimize the risks, 15 recommendations were presented, which, if implemented, can reduce the frequency with which events can occur or the severity of the consequences resulting from deviations, thus changing the risk classification.

CONCLUSION

Following what was defined in the general objective of this study, which was to apply the HAZOP method in the stage of treatment and disposal of sludge in a sewage treatment plant in the city of Altamira-PA, the HAZOP methodology proved to be effective in the identification, analysis and evaluation of the riches, due to a thorough verification carried out throughout the sludge treatment process.

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A total of 65 scenarios were examined, in which the risks classified as acceptable (35) and undesirable (30) stand out, with none being considered unacceptable. Thus, 54% of the risks identified in the process are classified as acceptable. However, part of the risks initially classified as undesirable may be reclassified as the recommendations indicated in the study are implemented to reduce the frequency or severity of the consequences of the events.

High automation in the facility results in a reduced demand for employees for the operation, facilitating safety at work by minimizing workers' exposure to risks. In addition, automation contributes to the minimization of dangerous events resulting from human error, making the process less susceptible to the materialization of dangers.

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ATTACHMENTS

APPENDIX I - TECHNICAL NOTE No. 01/2024/EAS2019/UEPA

I. REPORT

1. This is a technical study carried out by undergraduate students Haroldo Oliveira e Silva Junior and Jovânio Carvalho do Rosário, from the Environmental and Sanitary Engineering course – UEPA, Campus IX Altamira, in the light of the guidelines of Profa. Dr. Hebe Simone Sousa Ripardo (http://lattes.cnpq.br/6711509760901899) and Profo. Msc. Glauber Epifanio Loureiro (http://lattes.cnpq.br/2678297764211806), which aims to propose a mechanism to improve the disposal of residual sewage sludge originating from the secondary treatment of the Altamira Sewage Treatment Plant, while it also seeks to present a solution to the recovery of degraded or disturbed areas, in order to mitigate the environmental and economic impacts intrinsic to this process, considering the consolidated techniques for the treatment of sludge and its potential agricultural use and restructuring of the microfauna and the physicochemical characteristics of the soil.
2. This study seeks to fulfill the role of universities in the production of scientific knowledge to support decision-making by the public authorities in facing issues that impact the ways of life and daily life of citizens, for example, problems of an economic nature, public health, basic sanitation and environmental, among others. With this attitude, the UEPA institution fulfills its purpose of promoting the universalization of knowledge for the harmonious benefit that permeates the physical limits of its structures, in order to achieve the fulfillment of social purposes.
3. That said, we present the arguments that support this Technical Note.
4. It is the report.

II GROUNDS

5. The University of the State of Pará – UEPA, with headquarters and jurisdiction in the city of Belém – PA, was created on May 18, 1993 by State Law No. 5,747. It has a special regime autarchic organization and a multi-campus structure. It is governed by its Statute, which establishes the general rules of the University and by the General Regulation, which regulates the functioning of teaching, research and

extension activities, of university units and bodies, both created by Resolution 069/94 of March 17, 1994 of the State Council of Education.

6. Article 6 of Resolutions 2910/15 and 2911/15 – CONSUN deals with the purposes of the University of the State of Pará. In the Statute and General Regulations of UEPA, among which we highlight:

> Article 6. These are the purposes of the University of the State of Pará.
> I - **to contribute to the creation of rights** and new forms of social existence and **to the cultivation of citizenship**;
> [...]
> III - **to promote and stimulate research considered as a scientific**, educational and political principle, aiming at the development of philosophy, science, letters, arts and technology;
> [...]
> V - **To carry out studies and debates** for the discussion of regional and national issues with the purpose of contributing to the **solution of problems**, as well as enabling the creation of new knowledge, **in the perspective of the construction of a democratic society**. (emphasis added).

7. In addition, these resolutions address in Article 9 the fundamental principles that govern UEPA's actions and commitments, which we highlight:

> Article 9. The fundamental principles of the University of the State of Pará are:
> [...]
> III- **development** of philosophy, **science**, **technology**, letters and arts, **committed to the** humanization of the human being and **society**; (emphasis added).

8. In this vein, it is to be considered that UEPA has the competence and capacity to assist decision-makers in understanding aspects of the protection of collective rights, especially the preservation and conservation of natural resources and the duty to sustainable consumption consolidated in Article 225 of our Magna Carta. That is to say, sustainability perfuses the environmental regulation without separating itself from it.

9. In addition to this proposition, it should be noted that the environmental law that intervenes in the duties and rights of the sustainable use of natural resources, among several other regulations, is the National Solid Waste Policy (PNRS) Federal Law No. 12,305/2010, which determines that States and Municipalities must promote actions with the purpose of achieving efficiency in the management of solid waste (Article 7).

10. Note that the PNRS imputes to the States and Municipalities the responsibility of implementing environmental safeguard actions that enable – with the participation of

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society – the preservation, conservation, defense, recovery and improvement of the natural and artificial environment and the work environment, in a way that is harmonized with socioeconomic and environmental development.

11. For the clarity of the concepts, the National Council for the Environment (CONAMA), through Resolution 498 of August 19, 2020, presents the definitions for degraded area, sewage sludge, biosolids, and recovery of degraded area:

> Article 2. For the purposes of this Resolution, the following definitions are adopted:
> IV – Degraded area: any area that, by natural or anthropic action, had its original characteristics altered beyond the limit of natural recovery of the soils, thus requiring the intervention of human beings for its recovery;
> ...
> XIII – Sewage sludge: solid waste generated in the sanitary sewage treatment process, by primary, biological or chemical decantation processes, not including solid waste removed from desanders, grating and screening;
> XIV – Biosolids: product from the treatment of sanitary sewage sludge that meets the microbiological and chemical criteria established in this Resolution, thus being able to be applied to soils;
> ...
> XXI – Recovery of degraded area: recovery of the physical, chemical and/or biological integrity and productive capacity of an area, whether for the production of food and raw materials or in the provision of environmental services;

12. For the Brazilian Association of Technical Standards (ABNT), the sludge generated strictly in a Domestic Sewage Treatment Plant – that is, without significant traces of industrial sewage – is not classified as waste with pathogenic characteristics (Class I – Hazardous), but as being Class II A – Non-Inert, containing properties of water solubility, combustibility and biodegradability.

13. The PNRS classifies sludge as solid waste from sewage treatment systems, categorized as waste from public basic sanitation services, according to its origin. Due to its characteristics, which include a basically organic composition and rich in nutrients, it makes it a beneficial source for vegetables, as well as a soil recovery and/or conditioner. The sludge is in line with the standards of recycling and reuse of waste, promoting the sustainable development recommended by the PNRS.

14. The discarded sludge is usually directed to specific treatment aiming at its final disposal. This stage, in the operation of sewage treatment plants, constitutes the most expensive phase of treatment, and can represent up to 60% of the operational budget dedicated to the control of wastewater pollution.

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III ANALYSIS

15. Although the sanitary landfill is an accepted route of destination for by-products in Brazil, it is common sense that it is not the most appropriate, due to the potential environmental impacts that may occur in the soil and groundwater. Altamira has a municipal landfill, where for the year 2023 1,000,452 tons of sewage sludge were disposed of (which corresponds to 100 trucks with a capacity of 10 m³), and solid waste was deposited in the cells, waterproofed with a 2 mm thick geotextile blanket (Municipal Secretariat for Environmental Management of Altamira/SEMMA, 2023).

16. Another aspect that needs to be presented refers to the amount of 12,261.65 km² (7.68% of the Altamir territory) of areas subject to environmental recovery (5,816.58 km² by the year 2007 – consolidated deforestation; 6,445.07 km² referring to the period from 2008 to 2023), which are distributed in rural properties located in the municipality (SEMMA/INPE/PRODES/2023).

17. It is widely recognized that the by-products (notably, sludge) of sewage treatment have considerable potential for use. However, efforts in this direction are limited and, when implemented, tend to be uncoordinated, often exploring only a few of the diverse possibilities available.

18. In this regard, the Environmental Company of the State of São Paulo (CETESB), the State Government agency responsible for environmental management and a member of the set of 16 United Nations (UN) reference centers for environmental issues, validates this understanding as highlighted in Technical Note No. P4,230. of May 2021 when revising its First Edition (year 1999):

> In technical terms, **there are reports of several possibilities** for the final disposal of sludge generated in effluent treatment plants found **in the American, Australian and New Zealand experiments**, to indicate the most cited (page 2).

19. It should also be noted that the studies conducted by the National Institute of Science and Technology in Sustainable Effluent Treatment Plants (INCT ETEs) resulted in the production of approximately 50 technical notes. These notes address issues related to the valorization and use of by-products from sewage treatment, contributing to improve efficiency and existing processes, in addition to consolidating the knowledge already available.

20. Thus, considering the benefits of sewage sludge, the Ministry of Agriculture and Livestock – MAPA recognizes its application as an agricultural product, whether as a

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soil conditioner, substrate for plants, organic fertilizer or even as a raw material in the manufacture of these inputs, emphasizing the safety criteria for application in agriculture.

21. Due to its characteristics, as an essentially organic material rich in nutrients and, therefore, a source of nutrients for plants, a soil recovery and/or conditioner, sludge fits well into the principles of recycling and reuse of waste and sustainable development of the PNRS.

22. Therefore, for these reasons, the use of sewage sludge in soils can be an environmentally sustainable form of final disposal, which is in line with the PNRS, as it stipulates that, when addressing the management and management of solid waste, it is imperative to prioritize actions such as the reduction, reuse, and recycling of solid waste (Brasil, 2010).

IV CONCLUSION

23. That said, it is suggested that the Municipal Executive carry out a technical-financial feasibility study, in light of the exegesis of CONAMA Resolution No. 498/2020, for the planning of public policies aimed at supporting farmers in the application of biosolids, aiming to promote the conversion of this valuable by-product of sewage treatment into a resource for agricultural use and for the recovery of degraded areas, aligning with a circular economy perspective.

24. To the office of His Excellency Mr. Mayor of Altamira Claudomiro Gomes and to the office of His Lordship Municipal Secretary of Environmental Management Mr. Antônio Ubirajara Bogea Umbuzeiro Junior, for science and further actions.

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