Engineering Faculty

Master's Program in Health, Safety and Environment

Evaluation of the Water Quality of the Infulene River Basin

Dissertation Submitted to the Faculty of Engineering in Partial Fulfillment of the Requirements for the Degree of Master of Science in Health, Safety and Environment

Name of student:

Mery Beatriz Marcelino Rodrigues

Maputo, March 2023

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Declaration of originality of the project

I declare that the present dissertation with the subject **"Assessment of the Water Quality of the Infulene River Basin"** was never presented for obtaining any degree or other scope and that it constitutes the result of my individual work. This dissertation is presented in partial fulfillment of the requirements for obtaining the degree of Master's in Health, Safety and Environment of Eduardo Mondlane University.

Maputo, March 2023

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(Mery Beatriz Marcelino Rodrigues)

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Dedication

To my husband Victor Hugo for his love, companionship and understanding, I love you. To my parents Marcelino Rodrigues and Beatriz Massuanganhe, and my brother Venâncio Rodrigues for the love and unconditional support, I love you. I dedicate this work especially to my beloved daughter Christabelle Mery Hugo João for the love and light, you are the reason of my achievements, I LOVE YOU ♥.

‘‘Science begins with curiosity.’’

Aristóteles

Contents

Abstract

Climatic events and increased agricultural activity impact negatively the water quality of the Infulene River endangering public health and aquatic biodiversity. The river exposed to pollution from defuse and punctual sources, that include: (1) discharges from Infulene and Zimpeto wastewater treatment plants, (2) discharges of industrial wastewater from brewery and paper industry, (3) discharge of water from Maputo drainage systems, that collected water from informal settlements with poor sanitation, and (4) runoff from urban agriculture land, while it is a source of water for domestic use and irrigation for urban agriculture that supplies vegetables for Maputo and Matola. The trophic and water quality status of the river is not well established, so it is important to assess the level of pollution of the river, to allow appropriate planning of actions to avoid the further pollution of the river, thus protecting the ecosystem and public health. Physical-chemical and biological parameters were measured in six selected monitoring points along the river and the results were compared with national and international legislation. Additionally, the Trophic State Index (TSI) and the Water Quality Index (WQI) were calculated and compared for dry seasons. To get additional information, on the causes water pollution and its possible effects on public health additional surveys was implemented for the farmers working in the riparian area of the river, from which it was observed that fertilized agriculture, agricultural waste dumps and open-air fecal dumping contribute to the pollution of the river. Water pollution is considerable high in the middle and downstream points of the river and the pollution sources identified significantly influence the water quality, with [PO_4^{3-}], [NO_{3-}] and [*Escherichia coli*] being the parameters above the standards. The trophic status of the water varied from super- to hypereutrophic and the water quality varied from poor to very poor, showing that the river water is not suitable for irrigation and recreation as it constitutes a danger to public health and compromises aquatic biodiversity. Aiming to minimize the pollution it is suggested control the use of fertilizers and agricultural wastes, as well as the installation of waste containers and public toilets. It is also recommended the replanting of riparian vegetation, treatment, and regular monitoring of domestic and industrial wastewaters. Finally, nevertheless difficult, it is also recommended to improve sanitation in informal settlements to reduce contamination of drainage waters.

Keywords: Physical-chemical and biological water quality, Trophic State Index and Water Quality Index.

Resumo

Os eventos climáticos e o aumento da actividade agrícola afectam negativamente a qualidade da água do Rio Infulene, colocando em risco a saúde pública e a biodiversidade aquática. O rio exposto a poluição por fontes difusas e pontuais, que incluem: (1) descargas das estações de tratamento de água residual de Infulene e Zimpeto, (2) descargas de água residual industrial das indústrias de cerveja e de papel, (3) descarga da água do sistema de drenagem de Maputo, que recolhe água de assentamentos informais com saneamento precário e (4) escoamento de terras de agricultura urbana, enquanto o rio é fonte de água para uso doméstico e irrigação para agricultura urbana que fornece vegetais para a Cidade de Maputo e Matola. O estado trófico e de qualidade da água do rio não está bem estabelecido, por isso é importante avaliar o nível de poluição do rio, para permitir o planeamento adequado de acções para evitar a poluição adicional do rio, protegendo assim o ecossistema e a saúde pública. Parâmetros físico-químicos e biológicos foram medidos em seis pontos de monitoramento selecionados ao longo do rio e os resultados foram comparados com a legislação nacional e internacional. Além disso, o Índice de Estado Trófico (TSI) e o Índice de Qualidade da Água (IQA) foram calculados e comparados para as estações secas e chuvosas. A fim de obter informação adicional, sobre as causas da poluição da água e possíveis efeitos para a saúde pública, foi implementado um questionário para os agricultores que trabalham na área ribeirinha do rio, a partir do qual se observou que os fertilizantes agrícolas e fecalismo a céu aberto também contribuem para a poluição do rio. A poluição da água é considerável nos pontos médio e a jusante do rio e as fontes de poluição identificadas influenciam significativamente a qualidade da água, sendo [PO_4^{3-}], [NO_3^-] e [*Escherichia coli*] os parâmetros acima dos padrões. O estado trófico da água variou de super a hipereutrófico e a qualidade da água variou de má a muito má, mostrando que a água do rio não é adequada para irrigação e recreação, pois constitui um perigo para a saúde pública e compromete a biodiversidade aquática. Visando minimizar a poluição sugere-se o controle do uso de fertilizantes e despejo de resíduos agrícolas, bem como a instalação de lixeiras e casas de banho públicas. Recomenda-se também o replantio da vegetação nas margens do rio, o tratamento e monitoramento regular de efluentes domésticos e industriais. Finalmente, apesar de difícil, também é recomendado melhorar o saneamento em assentamentos informais para reduzir a contaminação das águas de drenagem.

Palavras-chave: Qualidade da água físico-química e biológica, Índice de Estado Trófico e Índice de Qualidade da Água.

List of Abbreviations and Acronyms

[ ]- Concentration of.
ARA-Sul- Southern Regional Water Administration of Mozambique.
BOD- Biochemical Oxygen Demand.
cF- constraints Functions.
CFU- Colony Forming Units.
Chl- Chlorophyll.
CMCM- Maputo City Municipal Council.
DNGRH- National Directorate of Water Resources Management of Mozambique.
DO- Dissolved Oxygen.
E. coli- *Escherichia coli*.
F- Flexibility (acceptability of negotiating levels)
FAO- Food and Agriculture Organization.
FMECA- Failure Modes, Effects and Criticality Analysis.
FTA- Failure Tree Analysis.
IQA- Water Quality Index.
ISO- International Organization for Standardization.
K- Level of importance.
KW- Kruskal-Wallis.
MADeR- Ministry of Agriculture and Rural Development of Mozambique.
mg/L- milligrams per liter.
MITA- Ministry of Land and Environment of Mozambique.
MPN- Most Probable Number.
NO_3^-- Nitrate.
NTU- Nephelometric Turbidity Unit.
ºC – Degree Celsius.
PCA- Principal Components Analysis.
pH- Hydrogen potential.
PO_4^{3-}- Phosphate.
sF- services of Functions.
TDS- Total Dissolved Solids.
Temp- Temperature.
TSI- Trophic State Index.
USEPA- United States Environmental Protection Agency.
W- Wilcoxon.
WWTP- Wastewater Treatment Plant.
WW- Wastewater.

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1. INTRODUCTION

Rivers constitute a very small amount of freshwater with about 0.1% coverage of the earth's surface where only 0.01% of the earth's water occurs in river channels (Wetzel, 2001). Despite their low quantity, rivers play an important role in providing goods and services such as fishery, recreation, transport, use in domestic and industrial activities, agriculture, among others (Wetzel, 2001; Singh & Gupta, 2016).

While these anthropogenic activities contribute to economic development, they also pose a potential threat to rivers natural function through alteration of their physical, chemical, and biological quality caused by discharge of untreated domestic and industrial effluent.

In Mozambique the lack of adequate sanitation has resulted in the discharge of untreated wastewater into some rivers (Matsinhe & Coellho, 2020). Water from these rivers is subsequently used for irrigation and, consequently, a vector for transmission of chemical (Machado *et al.*, 2016) and biological agents (Molina-Guzmán & Ríos-Osório, 2020).

Agricultural production in areas associated with contaminated rivers constitutes a vector of exposure and contamination in the agricultural supply chain, from the production process, processing, storage (Uyttendaele *et al.*, 2015; Dhananjayan & Ravichandran, 2018), sale and subsequent consumption of agricultural products (Truchado *et al.*, 2018).

The use of contaminated rivers for irrigation constitutes a problem to Public Health, since most diseases are caused by the consumption of crops contaminated by chemical (Machado *et al.*, 2016) and microbiological agents (Molina-Guzmán & Ríos-Osório, 2020). The main diseases associated with microorganisms found in irrigation water include gastroenteritis caused by *Escherichia coli* (Uyttendaele *et al.*, 2015).

Knowledge of water quality and awareness of the risks of chemical (Groot & Van't Hooft, 2016) and biological agents are important for a detailed assessment of health effects (Meima *et al.*, 2020). Chemical and biological agents in the river from industrial discharges, surface runoff can increase water turbidity (Zhou *et al.*, 2015), and due to high nutrient levels, mainly nitrogen and phosphorus compounds can cause blooms of cyanobacteria-producing cyanotoxins (Thronson & Quigg, 2008) that can result in economic damage (fisheries) and cause adverse Public Health effects (Best *et al.*, 2002).

Although rivers are a key raw material for various economic activities, bad management of the river is a threat to Public Health and aquatic biodiversity, studies quantifying the level of contamination of the river from upstream to downstream region are scarce, particularly in Mozambique. The present study aims to understand the level of pollution associated with anthropogenic activities from Infulene river Basin in Maputo.

1.1. Problem Statement and Justification

Mozambique presents an urban development characterized by some informal and industrial settlements that more often do not respect the environmental protection laws. The informal settlements are characterized by problems of sanitation and access to water which contribute to the contamination of water resources such as rivers (Matsinhe & Coellho, 2020).

The rivers associated with agriculture and human settlements lead to their contamination by chemical and microbiological agents, as is the case of the Infulene river (Nhantumbo *et al*., 2023). Adjacent areas of this river are characterized by vegetable irrigation system and, vegetables produced in these areas are sold in markets of Maputo and Matola. This river has been the target of discharges of domestic effluents without prior treatment, also receiving effluents from industries and diffuse sources, which contributes to the contamination of the river, since these discharges contain chemical agents and microorganisms that constitute public health hazard (Mussagy *et al.*, 2018; Nhantumbo *et al*., 2023).

The chemical and biological contaminations of water could negatively impact the environment as well as the people health, especially farmers who have direct contact with the water during their daily activity and from the ingestion of agricultural products contaminated by the river.

The consumption of vegetables contaminated by pathogenic bacteria (Truchado *et al.*, 2018; Molina-Guzmán & Ríos-Osório, 2020) constitutes a risk for public health. The high number of bacterial agents, for example, total bacteria > 100.000MPN /100mL (Decree no 18/2004) or *E.* coli > 100MPN/100mL (USEPA, 1986) can cause gastroenteritis (Uyttendaele *et al.*, 2015).

Contamination, in addition to causing adverse effects on public health, also causes harmful effects on the ecosystem due to the increase in nutrients such as nitrogen and phosphorus from domestic and industrial discharges that can cause eutrophication in the river and consequent increase in turbidity, oxygen deficit due to increased decomposition of organic debris and the cyanobacteria-producing cyanotoxins that may contribute to the reduction of fish (Thronson & Quigg, 2008).

The Infulene river is subject to punctual discharges of water from the Zimpeto WWTP, Maputo Drainage Systems (without prior treatment), the Mozambique brewery factory and is a direct water supply source for irrigation of the agricultural sector in Maputo and Matola. At the moment few studies have been conducted in this river and the aim of the present study is to evaluate the pollution levels of punctual and diffuse source discharges through agricultural activity. Results from this study could be used to design an action plan to improve the use and management in this hydrographic basin. Nevertheless, no study has been reported on the trophic state of the Infulene river and the knowledge of the current water quality of the Infulene river from the Water Quality Index (WQI) as well as the main factors influencing its deterioration are unknown.

This study may contribute with information on nutrient limitation as a management tool in experimental work and programs for the sustainable use of human activities in the basin, particularly in the management of domestic and industrial effluents, good practices for agricultural activities to safeguard Public Health and the aquatic ecosystem.

1.2. Research Questions

The main questions addressed in the present study are:

I- What are the main sources of pollution of the Infulene river?

II- What are the levels of water pollution at the discharge points and along the Infulene river according to national and international standards?

III- How to minimize the causes that constitute risks for the pollution of the Infulene river Basin?

1.3. Objectives

1.3.1. General objective

To evaluate the water quality of Infulene river.

1.3.2. Specific objectives

a) To identify the main sources of pollution of the river;
b) To determine and correlate the water pollution levels along the river;
c) To compare the water quality physical-chemical and biological results with national and international legislation; and
d) To correlate the causes that constitute risks of the Infulene river basin and propose an action plan to minimize the causes of the river water pollution following the ISO 9001: 2015 standard.

1.4. Hypotheses

Punctual discharges are sources of pollution that deteriorate the water quality of the river since these are rich in phosphates, nitrates and pathogenic microorganisms constituting a threat to Public Health and the ecosystem (USEPA, 2020; Andrade *et al.*, 2021; Halecki *et al.*, 2022).

H0: The [PO_4^{3-}], [NO_3-] and [*E. coli*] do not differ between unpolluted, polluted without punctual discharges and polluted with punctual discharges.

H1: Not all [PO_4^{3-}], [NO_3-] and [*E. coli*] are equal among the unpolluted, polluted without punctual discharges and polluted with punctual discharges points.

H0: The physical-chemical parameters, TSI and WQI do not vary between dry and rainy season.

H1: Not all physical-chemical parameters, TSI and WQI differ between seasons.

H0: The relationships between the causes identified for the risk analysis do not differ.

H1: There is no relationship between the causes identified for the risk analysis.

2. LITERATURE REVIEW

The theoretical framework described was based on bibliographic review and synthesis of scientific articles, books, national and international legislation on water quality of river.

2.1. River pollution sources

In small watersheds, anthropogenic action combined with the effects of natural components influence the deterioration of surface water (Alamdari *et al.*, 2020). However, the main source of pollution is of anthropogenic origin due to poor water and effluent management and overuse of agricultural fertilizers (Honisch *et al.*, 2002; Arreghini *et al.*, 2005; Sinha & Michalak, 2016; Andrade *et al.*, 2021; Halecki *et al.*, 2022). Sources of water pollution include: (1) The excess of agricultural fertilizers and pesticides influences the increase of organic compounds and nutrients (such as nitrates and phosphates) in the soil (Loss *et al.*, 2019) that with the action of rainfall, the soil surface is saturated and generates surface runoff that carries contaminants to rivers (Arreghini *et al.*, 2005; Halecki *et al.*, 2022); (2) The deficiency of basic sanitation mainly in developing countries (McGrane, 2016) makes the population around the river contaminate the surface water through the disposal of liquid and solid waste on the ground (or in the water body) that contains toxic substances, pathogenic microorganisms (Boechat *et al.*, 2017) and nutrients that through surface runoff contaminates the surface water (Andrade *et al.*, 2021; Halecki *et al.*, 2022); (3) Globally, more than 80% of wastewater is discharged directly into the receiving body without proper treatment (UN WATER, 2017), which influences for water contamination by organic compounds, nutrients, and pathogenic microorganisms (USEPA, 1986, 2020); and (4) Industrial wastewater, when not treated efficiently can cause water pollution from contamination by organic and inorganic matter, nitrate, and water-soluble phosphorus (Simate, 2015; Khumalo *et al.*, 2022).

2.2. Methods for assessing water quality of the river

In recent years, the Trophic State Index and Water Quality Index methods have been widely used to assess water quality from chemical and biological parameters (such as phosphorus and chlorophyll) (Lamparelli, 2004) and physical-chemical and biological parameters (McClelland, 1974; Pimenta *et al.*, 2009) respectively. The physical-chemical and biological parameters used in water quality assessment include temperature, total dissolved solids, turbidity, pH, nitrates, phosphates, dissolved oxygen, biochemical oxygen demand and coliforms (*Escherichia coli*).

The physical parameters include: temperature, which is responsible for heat transfer in a medium and influences the speed of chemical reactions, the solubility of substances and the activities of organisms (Andrade *et al*., 2016); total dissolved solids, consists of particles with diameter less than 10^{-3} µm and turbidity, is a measure of the degree of interference to the passage of light through the liquid, influenced by suspended particles from domestic and industrial wastewater, and can affect the visibility of water to aquatic organisms during locomotion and feeding and to humans during recreational activities (USEPA, 1986).

The chemical parameters are: pH, a measure of the acid-base balance achieved by various dissolved compounds, salts and gases regulated by the carbonate system, is important for the chemical and biological systems of natural waters, levels below 4 and above 9 can harm aquatic organisms and agricultural produce (USEPA, 1986); nitrate and phosphate are essential nutrients for primary producers and are responsible for cyanotoxin-producing cyanobacteria blooms (Thronson & Quigg, 2008).

The main point sources of input include municipal and industrial effluents, and diffuse sources of are agricultural fertilizers, animal wastes, leachate from waste disposal in waste dumps or landfills, and atmospheric precipitation (USEPA, 1986, 2006, 2020); dissolved oxygen is a limiting factor for the maintenance of aerobic aquatic organisms and self-depuration processes in natural aquatic systems, and biochemical oxygen demand, assesses the amount of oxygen required to occur the oxidation of biodegradable organic matter under aerobic conditions, both used to assess water quality (Andrade *et al*. , 2016).

The biological parameters include: coliforms such as *Escherichia coli*, it is an indicator bacterium of contamination by the faecal-oral route, found in the human and animal intestinal tract (WHO, 2017) responsible for causing disease in humans from consumption of contaminated water or food (Uyttendaele *et al*., 2015; Dhananjayan & Ravichandran, 2018); and chlorophyll, is an indirect measure of algal biomass, at high concentrations it indicates excess algae present in the aquatic environment which occurs due to excess nutrients such as phosphate in the water (Huszar *et al*., 2006; USEPA, 2020).

2.3. Regulations on Environmental Quality Standards

The Decree No. 18/2004 and the United States Environmental Protection Agency establish water quality standards for recreation, irrigation, and the aquatic ecosystem (Table 1) to ensure effective control and enforcement over the quality of the environment and natural resources.

Table 1. The National (Decree No. 18/2004) and international (USEPA, 1986) legislation on permissible limits for recreational, irrigation and receiving water bodies.

Parameters	Recreation		Irrigation		River/ RWB	
	Nacional	**Internacional**	**Nacional**	**Internacional**	**Nacional**	**Internacional**
Temperature (ºC)	NE	-	NE	-	NE	-
TDS (mg/L)	NE	-	500	-	-	250
Turbidity (NTU)	Nule	-	NE	-	VA	1
pH	NE	-	6.5-8.4	4.5-9.0	6.5-8.5	6.5-9.0
PO_4^{3-} (mg/L)	NE	-	2	-	NE	0.03
NO_3- (mg/L)	NE	-	30	-	10	10
DO (mg/L)	NE	-	NE	-	≤ 6	> 4
BOD (mg/L)	NE	-	NE	-	NE	5
Escherichia coli (Nº/100mL)	100 MPN	126 CFU	100.000 MPN	-	NE	-
Chlorophyll (µg/L)	NE	-	NE	-	NE	15*

RWB= Receiving Water Bodies.
NE= Not Evaluated.
VA= Virtually absent.
* ANZECC-AMCANZ (2000).

Decree No. 18/2004 establishes water quality standards for emission of domestic and industrial liquid effluents (Table 2) to ensure effective control and enforcement over the quality of the environment and natural resources.

Table 2. Permissible limits for emission of domestic and industrial (brewery) liquid effluents.

Parameters \ Emission sources	Domestic	Industrial
Temperature (ºC)	35	≤ 3
TDS (mg/L)	NE	NE
Turbidity (NTU)	NE	NE
pH	6-9	6-9
PO_4^{3-} (mg/L)	3	NE
NO_3- (mg/L)	15	NE
DO (mg/L)	NE	NE
BOD (mg/L)	NE	30
Escherichia coli (Nº/100mL)	NE	400
Clorofila (µg/L)	NA	NA

2.4. Use of polluted river water

The contamination of river water leads to problems for aquatic organisms and the trophic chain, as the excess of nutrients, mainly phosphate and nitrate, causes algal blooms. Algae blooms, mainly cyanobacteria, have been considered a potential problem to aquatic ecosystems due to some genus that are responsible for producing cyanotoxins that are harmful to aquatic organisms (as fish), humans and other animals (Thronson & Quigg, 2008).

Excess organic matter in water increases water turbidity and causes a reduction in the concentration of dissolved oxygen for aerobic bacteria, which can compromise the life of aerobic aquatic organisms such as fish (USEPA, 2020). On the other hand, the excessive consumption of oxygen by aerobic bacteria will influence the reduction of its concentration, which may favour the oxidation of organic matter by anaerobic bacteria leading to the production of unpleasant-smelling substances that interfere with recreational activities (USEPA, 1986, 2020).

Any water source can become contaminated by pathogenic microorganisms, this fact is extensively reported worldwide due to studies done with drinking water and is the reason why efforts have been made over millennia to separate wastewater containing human and animal faecal matter from drinking water sources (Uyttendaele *et al.*, 2015).

Microbiological contamination is currently one of the main problems affecting water quality, the agricultural sector has been one of the vectors for the spread of human diseases (Eshed *et al.*, 2010). The pathogenic bacteria that can be found in irrigation water include *E. coli* (Nhantumbo *et al.*, 2023), the consumption of vegetables contaminated is harmful to public health.

2.5. Risk Analysis

Risk assessment is a product or process that collects information and assigns values to risks for the purpose of identifying priorities, developing, or comparing courses of action and informing decision makers while, risk management involves a process of identifying, analyzing, evaluating, and communicating risk and accepting, preventing, or controlling risk at an acceptable level and cost (Rausand, 2013) (Fig.1).

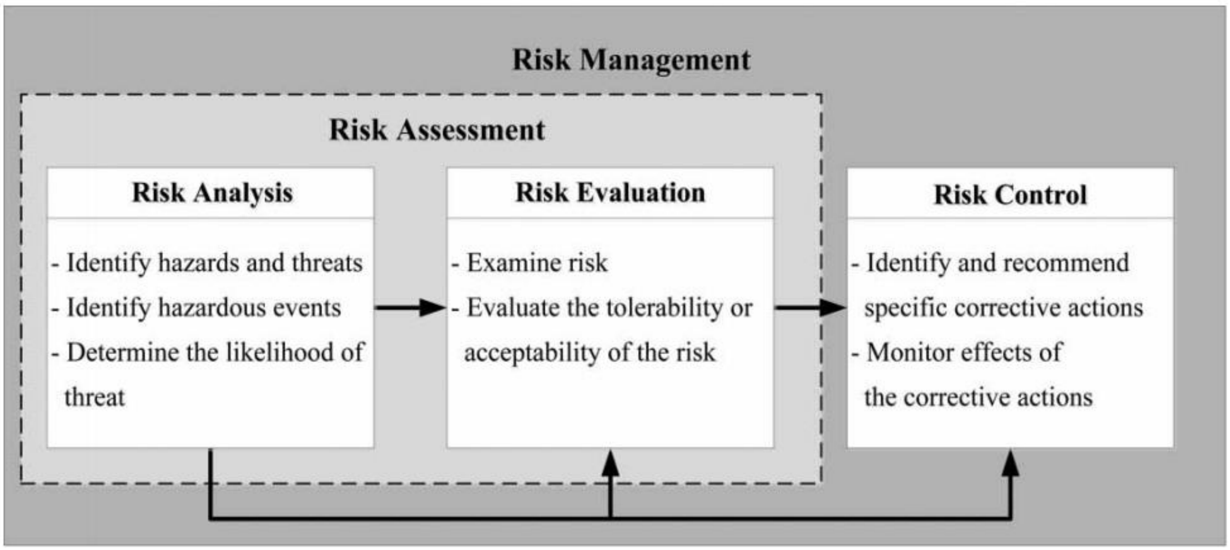

Figure 1. Risk management process (Rausand, 2013).

The engineers and decision makers apply risk management techniques to identify possible failure modes (events) and expose possible losses, so that decision makers can rank and prioritize the possible failure conditions of a system through a risk assessment. The risk analysis techniques include FMECA failure mode effects and criticality analysis, fault tree analysis (FTA), Markov analysis methods (Fredriksen *et al*., 2002) and finally an action plan aimed at reducing risks.

FMECA is composed of two separate analyses, the Failure Mode, and Effects Analysis (FMEA) and the Criticality Analysis (CA). The FMEA is an inductive method that analyses different failure modes and their effects on the system, while the CA ranks or prioritises their level of importance based on the failure rate and the severity of the failure effect. The fault tree is a logic diagram (Fig. 2) performed in a deductive manner, based on the principle of multicausality, which traces all the branches of intermediate events and root causes that may contribute to an accident or failure of a system (Vesely & Goldberg, 1981; Wessiani. & Yoshio, 2018).

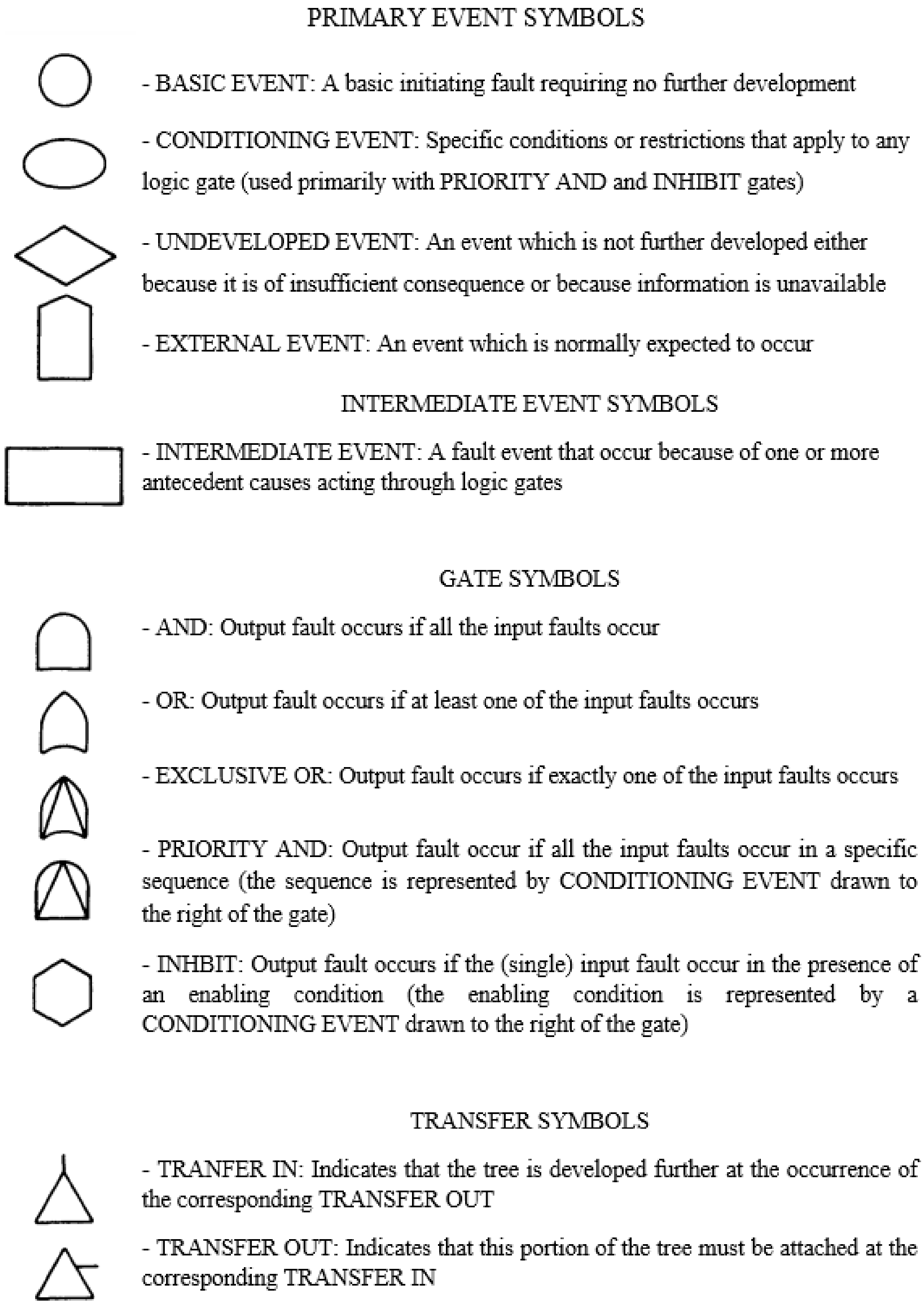

Figure 2. Fault Tree Symbols (Vesely & Goldberg, 1981).

3. STUDY AREA

Infulene river is located in Maputo province and borders the municipalities of Maputo and Matola. The Infulene river runs from north to south in Maputo province and flows into the Espírito Santo estuary. This is considered a small river (Fig. 3), about 20 km long, with an average width of 500m, an area of 130 km^2, and a total discharge that varies between 0.2-7m^3/s, with a large influence of the return water from industries and the WWTP (ARA-SUL, 2008).

Infulene river is the natural source of running water with an almost permanent flow that benefits about 2904 farmers, organized in 15 associations, occupying 422 hectares of land, whose agricultural production represents 40% of consumption in Maputo city. Agricultural activities on Infulene river take place mainly in cold and dry season (between April and July), because temperature in this season is suitable for horticulture. In hot and rainy season, due to heavy rain that causes flooding, the population move and cultivates in the high zone (Sitoe, 2008).

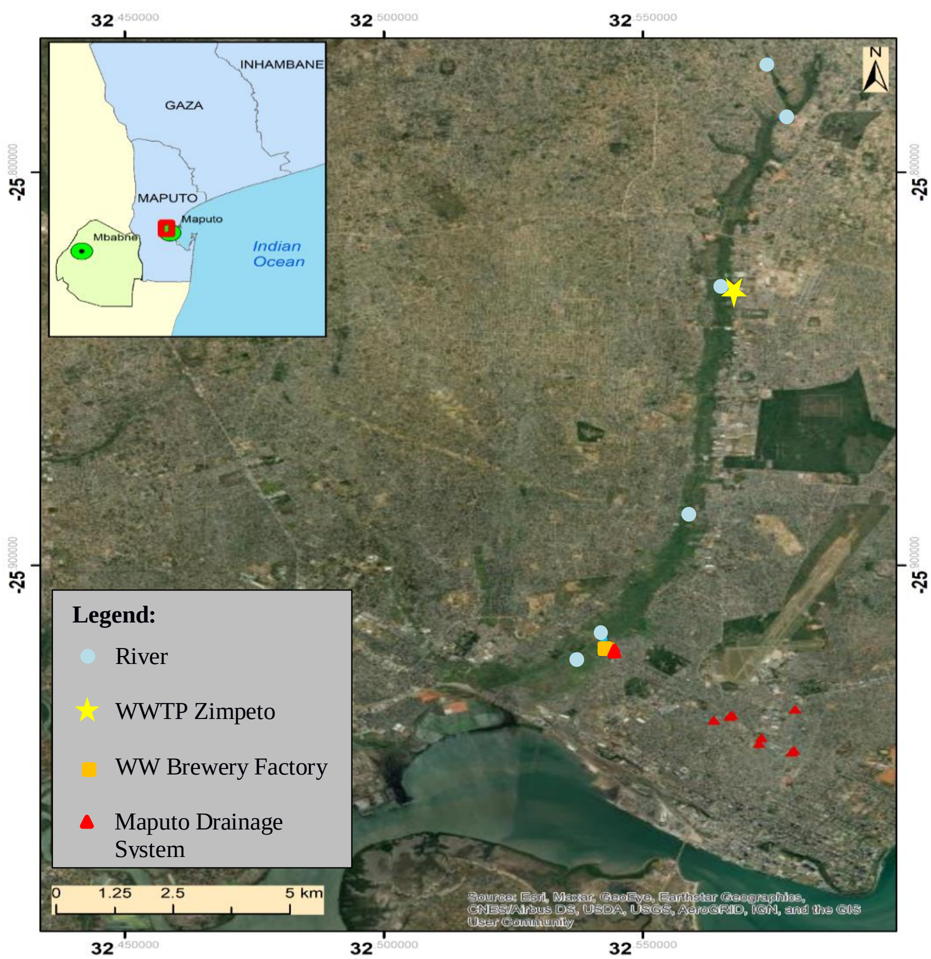

Figure 3. Map of the sampling sites of the Infulene river basin (Mery Rodrigues, 2023).

4. METHODS

The present work was divided into five phases: (1) literature review and fieldwork preparation, (2) fieldwork, (3) laboratory analysis, (4) analysis and discussion of results and (5) final report writing. The first phase, the literature review included consulting scientific papers and books, reports, official documents, and other relevant documents to identify and characterize the potential pollution sources to the river; selection of parameters to be included in the study and selection of sampling points (Appendix 1); as well as the elaboration of a surveys for farmers (Appendix 2). The second phase was field work where the surveys was administered to farmers, field water quality parameters were measured *in situ*. In the third phase, water samples collected in the field were determined in the laboratory. In the fourth and fifth phases, the results of the surveys, the water quality parameters were analyzed and synthesized, the Trophic State Index (TSI) and the Water Quality Index (WQI) for dry and rainy seasons were calculated and compared. After analyzing the results, the present report was compiled.

4.1. Potential Sources of Pollution

To describe the sources of pollution in the Infulene river (Table 3), a visit was made along the river to identify the potential sources of river pollution, from agriculture area around the river, WWTP's, Factories located near and drainage systems that discharge into the Infulene river.

Table 3. Potential pollution sources identified in the Infulene river Basin.

Potential source of pollution	Type of pollution
Zimpeto WWTP	Contamination by organic matter, phosphorus, and nitrogen
Domestic Effluent	Contamination by fecal matter, nitrogen, and phosphorus
Industrial Effluent – Brewery Factory	High pollution potential due to its organic load, suspended solids content and presence of phosphorus and nitrogen
Maputo WWTP	Currently not in operation
Old paper Factory	The industry recycled paper
Rainwater Drainage System	Contamination by organic matter, phosphorus, and nitrogen
Agricultural Activities	Contamination by organic matter, organic and chemical fertilizers (nitrogen and phosphorus)

4.2. Sampling

The sampling was stratified, and the strata were divided into neighborhoods along the river, from Marracuene neighborhood (upstream region) to Infulene neighborhood (downstream region) during the dry season in July and rainy season in October of 2022. Nine sampling points were selected, of which six points were in the river and three were at the river pollution sources namely Zimpeto Wastewater Treatment Plant, drainage systems and brewery factory. To better understand the quality of the water that is discharged to the river, a parallel study was conducted at nine more points in the Maputo City drainage system (Appendix 1, table 1). The criteria for the selection of the sites were based on the proximity of the sites where water is withdrawn for urban agriculture, recreation, domestic use by some residents and the proximity of the river to sources of water contamination suspected of altering the water quality of the river (Appendix 1, table 2). The water samples were analyzed *in situ* (n=3) and afterwards 2.5L of water was collected and transported in a thermal box to the Sanitary Hydraulic Laboratory of the Civil Engineering Department, the Water Laboratory of the Chemical Engineering Department of the Faculty of Engineering, and the Fisheries Inspection Laboratory of Maputo.

4.3. Procedures

4.3.1. Socio-demographic, occupational, and sanitation profile of the farmers

To describe the demographic, occupational and sanitation (personal hygiene) profile of the farmers, surveys were administered to 10% of the farmers in Infulene river (Appendix 1). In demographic profile personal data of the farmers such as gender, age, education level was obtained. In occupational profile, data on main crops grown, type of fertilizer used, knowledge on care during irrigation and water collection sites was obtained. On sanitation, data on the source of water for drinking and personal hygiene, sanitary conditions of the site and the place for depositing agricultural waste. Before data collection, participants were informed about the objectives and procedures of the study and only farmers who agreed to participate were involved. National and international ethical requirements established for research involving human subjects to respect participants individual autonomy, maximize benefits and minimize risks and protect the integrity and maintain the confidentiality of all research participants were met.

4.3.2. Physical-chemical and biological characteristics

a) Physical-chemical characteristics

In each sampling point, the water was collected in triplicates with the help of a 20L plastic bucket and later determined *in situ* the physical-chemical parameters of the water (temperature in ºC, Hydrogen potential (pH), dissolved oxygen in mg/L, total dissolved solids in mg/L from a multiparameter instrument (Hach HQ 40d) and turbidity in NTU from a field turbidimeter (TURB 430 T) previously calibrated. In the Laboratory, PO_4^{3-}, NO_3- and BOD in mg/L were analyzed following the procedures of the manual *Standard Methods for the Examination of water and wastewater* (APHA, AWWA & WEF, 2017).

b) Biological characteristic (chlorophyll and thermotolerant coliform- *Escherichia coli*)

The chlorophyll concentration analysis was done *in situ*, where a water sample was taken into a cuvette for analysis in the AQUA FLUOR apparatus, where results of the fluorescence of the water were obtained in ppb for later conversion into µg/L.

For the identification of bacteriological agents present in the water in the dry season, a 250mL sample for each sampled point was collected in a previously sterilized flask. These samples were placed in a thermal box and transported, for less than three hours, to the laboratory of the Faculty of Engineering of the Eduardo Mondlane University.

In the laboratory, before the analyses, aseptic conditions were guaranteed. For the samples diluted with Colilert (Fig 4), which contained a high number of microorganisms, the technique of successive dilutions was applied, which allowed the counting of microorganism colonies on the Quanti Tray card (Fig 4). The card (Fig 4) was sealed and conditioned in a Water Bath at 45ºC for 10 minutes for subsequent incubation in an incubator at 44ºC for 24 hours, with the aid of an Ultraviolet light, the *Escherichia coli* present on the card was quantified using the Quanti Tray Table. In the rainy season, 1000ml of water was collected into a previously sterilized flask, subsequently the samples were packed in a thermal box and transported for less than three hours to the Fish Inspection Laboratory in Maputo to proceed with the analysis of thermotolerant coliforms (*Escherichia coli*).

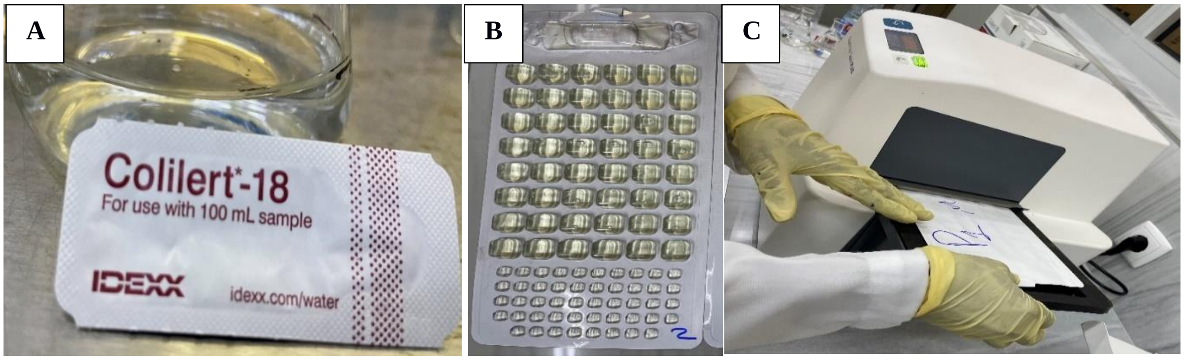

Figure 4. Some items for *E. coli* analysis: Colilert (A), Quanti Tray card (B) Quanti Tray Sealer (C).

4.3.3. Risk Analysis

To estimate the risk of the Infulene river system, first the octopus's diagram and the specifications of the river functions were drawn through the previous knowledge of the possible interactions existing in the river, subsequently the levels of importance (K) and Flexibility- F (acceptability of negotiating the levels) for each function were classified. The Infulene river basin system was constructed and described, and then the FMECA (Failure Modes, Effects and Criticality Analysis) technique was used for the identification of possible failures in the Infulene river system to later propose a preventive action plan for river management. After the knowledge of the feared event with the highest criticality in the FMECA, the failure tree analysis (FTA) was performed to draw the critical path from causes with the highest percentage weight (Johnson & Niezgoda, 2004).

4.4. Data Analysis

To quantify the influence of agricultural activity to river pollution, data from the surveys were organized and analyzed in the statistical program IBM SPSS version 20. The data from the physical-chemical and biological charts were organized and summarized in Excel 365 software. To spatially correlate the physical-chemical and biological characteristics, Principal Component Analysis (PCA) was performed in R Core Team 2021 program. To test whether the regions with punctual discharges to the river influenced its quality, the Kruskal-Wallis test was used because the data did not present normal distribution, for the graphic representation the Boxplot was constructed in R program. Seasonal comparison was done using Wilcoxon test, for graphical representation Boxplot was constructed, for subsequent comparison of the medians with the standards stipulated in the national legislation (Decree 18/2004) and/or international (Environmental Protection Agency- EPA of the United States) on water quality.

To evaluate the trophic state of the river, the Trophic State Index (TSI) (Table 4) was determined and for the calculation the formula 1, modified by Lamparelli (2004) was used, considering phosphates and chlorophyll in µg/L.

$$\boldsymbol{TSI}\left(\frac{\mu\mathbf{g}}{\mathbf{L}}\mathbf{P}\right)=\frac{10*\ [6-((0.42-0.36*(\text{Ln P}))]}{\text{Ln }2}-20$$

$$\boldsymbol{TSI}\left(\frac{\mu\mathbf{g}}{\mathbf{L}}\mathbf{Chl}\right)=\frac{10*\ [6-((0.7-0.6*(\text{Ln P}))]}{\text{Ln }2}-20$$

$$\boldsymbol{TSI}\,(\mathbf{T})=\frac{[\text{TSI (P)}+\text{TSI (Chl)}}{2} \qquad (\mathbf{1})$$

Where:

TSI= Trophic State Index.

P= Phosphate.

Chl= Chlorophyll.

Table 4. Trophic State Index classification.

Range	Classification
≤ 47	Ultraoligotrophic
47 < IET ≤ 52	Oligotrophic
52 < IET ≤ 59	Mesotrophic
59 < IET ≤ 63	Eutrofic
63 < IET ≤ 67	Supereutrophic
IET > 67	Hypereutrophic

To evaluate water quality through physical-chemical and bacteriological variables, the National Sanitation Foundation Water Quality Index (NSF-WQI) was determined, which is calculated by the weighted product of the scores obtained by nine water quality variables, namely: DO, thermotolerant coliforms, pH, BOD, PO_4^{3-}, NO_3-, temperature, turbidity, and TDS (McClelland, 1974; Pimenta *et al.*, 2009). The Index can be applied using formula 2.

$$\mathbf{WQI}=\prod_{i=1}^{n} q_i^{w_i} \qquad \mathbf{(2)}$$

Where:

WQI: Water Quality Index (WQI), ranging from 0 to 100 (Table 5).

qi: quality of the i th variable, obtained through the mean variation curve.

wi: weight attributed to the parameter, as a function of its importance in quality, between 0 and 1 (Table 3).

Table 5. WQI classification and the weights for each parameter (Wi).

Range	Classification		i	Wi
0-25	Very Bad		DO	0.17
26-50	Bad		Coliform	0.16
51-70	Acceptable		pH	0.11
71-90	Good		BOD	0.11
91-100	Very good		NO_{3-}	0.10
			PO_4^{3-}	0.10
			Temperature	0.10
			Turbidity	0.08
			TDS	0.07

To define the level of importance of the hierarchy between the functions (K) and the level of negotiability of the levels (F) the classification for function analysis was used (Table 6).

Table 6. Classification of K and F.

K	Importance	F	Flexibility
1	Useful	0	Not negotiable
2	Necessary	1	Could be negotiable
3	Important	2	Negotiable
4	Very important	3	Very negotiable
5	Vital		

To calculate the Criticality of FMECA (Bowles, 2003), the formula 3 was used. The formula is calculated based on the product of three ordinal scale values (each ranging from 1 to 10) of severity (S), probability of occurrence of failure (O) and detectability (D) (Table 7). In FMECA, it is assumed that failure modes with higher criticality result in more severe and critical damage than lower ones (Johnson & Niezgoda, 2004) and require a quick response.

$$\mathbf{C} = S * O * D \qquad \textbf{(3)}$$

Where:
C= Criticality;
S= Severity (higher values indicate a more severe consequence associated with the failure);
O= Occurrence (higher values indicate severe consequence associated with a higher probability of failure);
D= Detectability (higher values indicate lower probabilities of failure detection).

Table 7. Failure Modes, Effects and Criticality Analysis classification (Stamatis, 1997).

Range of Severity and Occurrence	Range of Detectability	Classification
1	10	Almost never
2	9	Remote
3	8	Very slight
4	7	Slight
5	6	Low
6	5	Medium
7	4	Moderate high
8	3	High
9	2	Very high
10	1	Almost certain

To estimate the risk of the river basin failure tree (FTA) the specific Excel software for risk analysis was used, where first the mathematical model laws for the risk cause distributions were defined, namely: Beta 1 and Gamma. Subsequently, the risk law was identified based on the distribution curve obtained from Pearson's Correlation. To calculate the probabilities of the intermediate and top events, formulas 4 and 5 were used for events with 2 and 3 probabilities respectively.

$$P\ (A\ U\ B) = [P(A) + P(B)] – [(P(A) * P(B)] \quad \textbf{(4)}$$

$$P\ (A\ U\ B\ U\ C) = [(P(A) + P(B) + P(C)] – [P(A) * P(B)] – [(P(B) * P(C)] – (P(A) * P(C)] + [(P(A) * P(B) * P(C)] \quad \textbf{(5)}$$

To better propose an action plan to minimise the risks causes of the river, a survey was carried out of the farmers comments on aspects to be improved in the river, the critical causes of the river for risks analysis were identified, and the results of river quality were compared with current legislation and a literature review was carried out on recommendations to improve contaminated areas with values above those stipulated in Decree No. 18/2004.

5. LIMITATIONS OF THE STUDY

In the present study it was not possible to obtain the data from rainy season drainage systems due to lack of reagents and it was not possible to make the comparison of *Escherichia coli* concentration between the seasons as different counting techniques were used, MPN in the dry season and CFU in the rainy season (a technique which is usually applied in the Fisheries Inspection Laboratory of Maputo).

6. RESULTS

In the following subsections results of the study are presented.

6.1. The main sources of pollution of the river

6.1.1. Agricultural activity (Diffuse source of pollution)

Out of the 303 surveys, 65% are Male and 35% are Female. The main vegetables grown include lettuce, cabbage, spring onion, onion, parsley, beetroot, and spinach, where the most used fertilizer with about 97% is animal manure and the other 3% includes rice husks, ash, and leaves. The water for irrigation is abstracted from Infulene river (87.5%), Infulene river and pond (7.3%), pond (2.3%), Infulene river and drain (3%). Besides irrigation the river is used for hand washing (105 individuals), hand and foot washing (41), hand and face washing (06), food washing (02), Body and food washing (01), construction (01) and consumption (0) (Fig. 5).

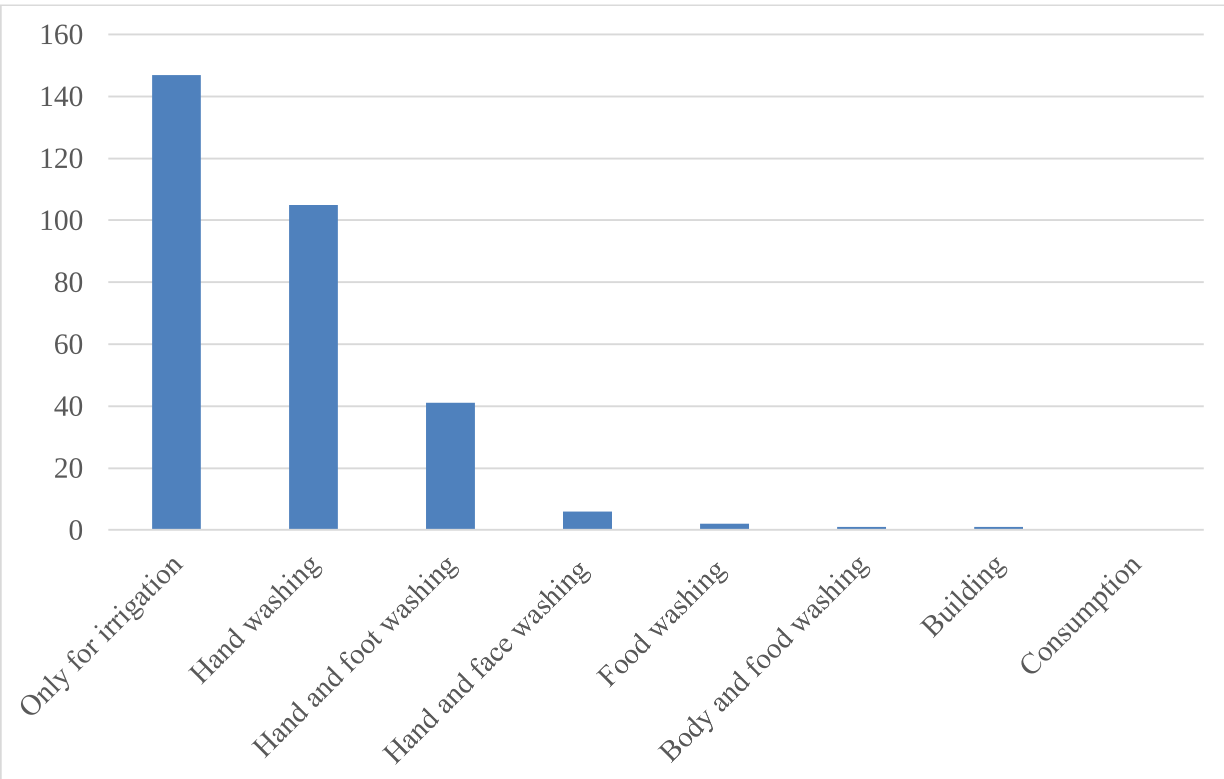

Figure 5. Different uses of Infulene river water besides irrigation.

From the observations made, none of the sites along the river have waste containers and public toilets. Of the agricultural waste disposal, 78% discards on the ground, 21% buries, 1% directly into the river, 0% reuses as fertilizer (Fig 6). Discarded items include crop residues only (68.6%), crop residues and plastics (29.7%), crop residues, plastics, and papers (1.6%). Of the human waste disposal, about 36.0% perform in the open, 33.7% in neighboring houses, 26.7% at home and 3.6% in the river (Fig 6). The number of farmers who do not deworm is about 90.8%, and at least 9.2% deworm at least once a year, the justifications given were: lack of knowledge (87.1%), lack of interest (3.6) and lack of financial resources (1.3%).

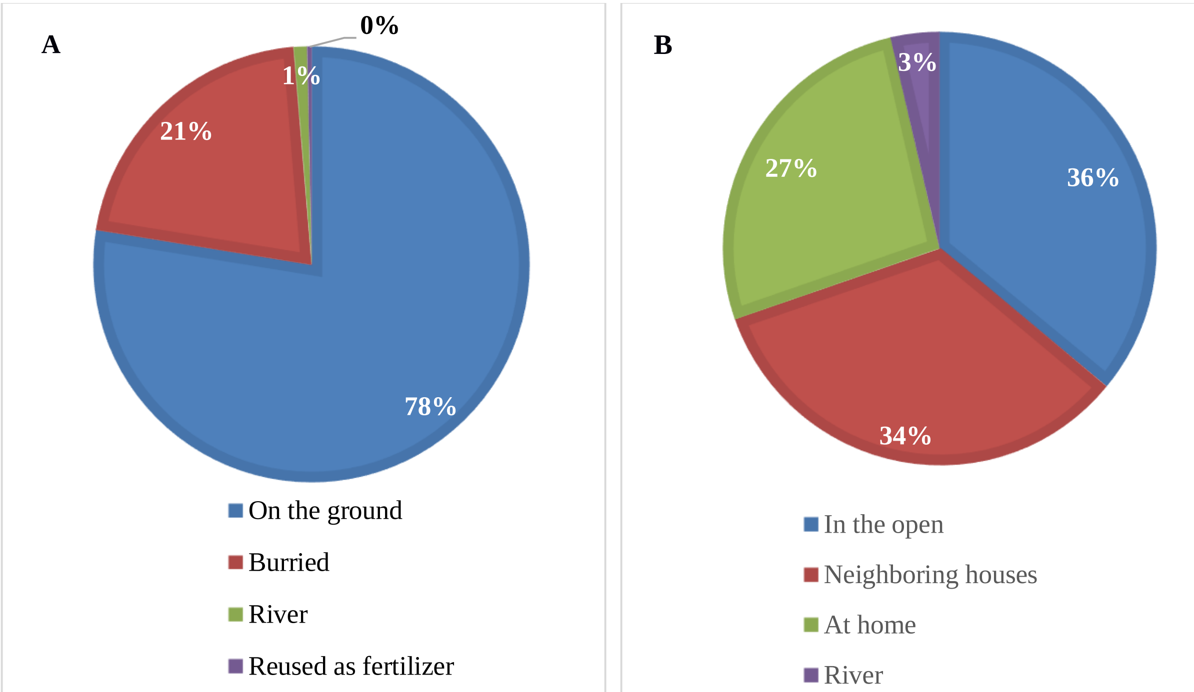

Figure 6. Places for disposal of: agricultural waste (A) and human dejects (B).

6.1.2. Punctual source of pollution

The sampled points of the Maputo City Drainage System were at Malhangalene (point 2), Maxaquene (points 1 & 3) Xipamanine (point 4), Mafalala (point 5) and Aeroporto (points 6 to 9) neighbourhoods (Fig 7). The temperature ranged from 25.33 to 29.33°C, DO from 0.79 to 7.12 mg/L, BOD from 22.21 to 238.69 mg/L, PO_4^{3-} from 0.26 to 0.71 mg/L, pH and [TDS] with little variation from 7.07 to 7.36 and 2251 to 3130 mg/L respectively. All points were highly contaminated by pathogenic bacteria with concentrations above 150,000 MPN/100ml of *E. coli*. The point that presented the highest [*E. coli*] was point 4 (Xipamanine) with 2,802,500 MPN/100ml. The drainage system also shows high [NO_3-] ranging between 3 and 20.3 mg/L.

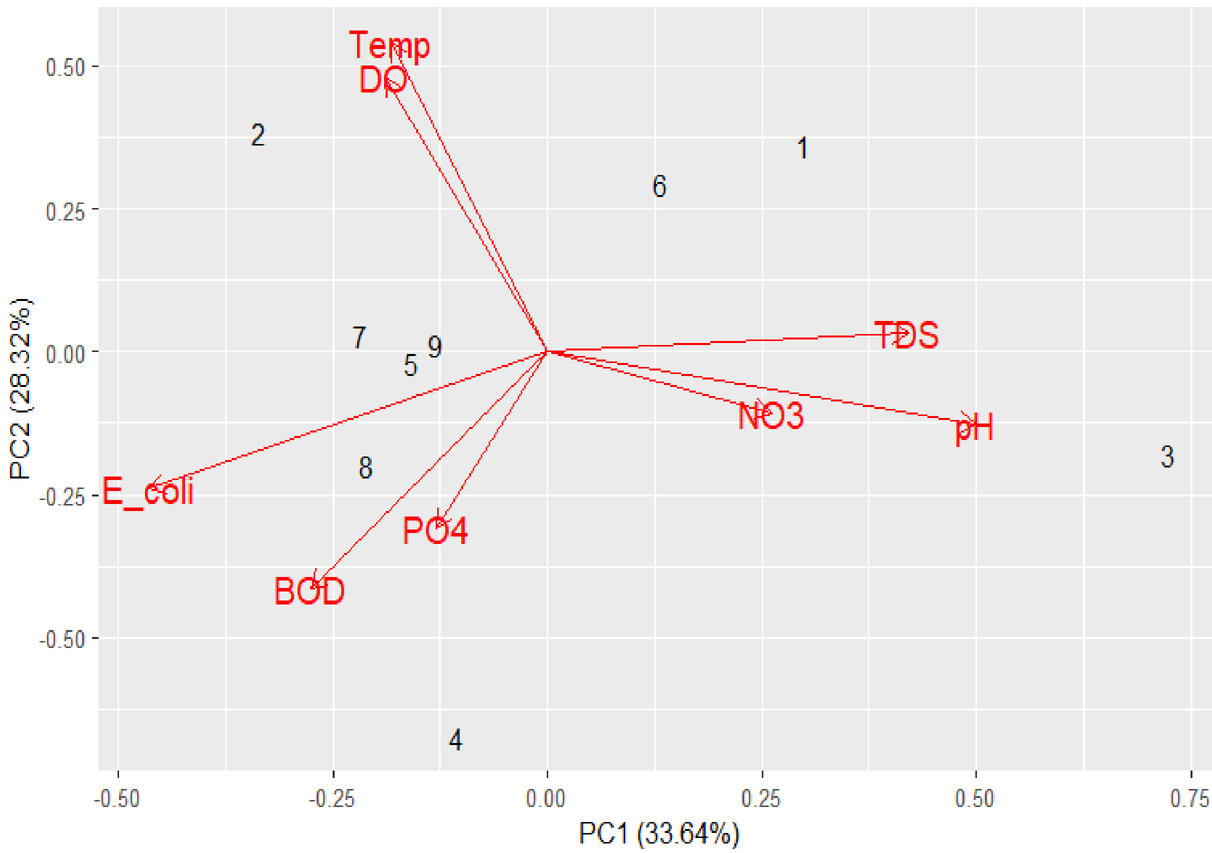

Figure 7. PCA of average physical-chemical and biological parameters of the drainage system in the dry season.

Point 1 corresponds to Zimpeto WWTP, point 2 to Maputo City Drainage System and point 3 to brewery factory wastewater (Fig 8). Point 1 presented high values of temperature (25.23ºC), PO_4^{3-} (3.28 mg/L), BOD (42.57 mg/L) and *E. coli* (35.900.000MPN/100mL) however it obtained low [TDS] (2050 mg/L), [DO] (2.09 mg/L) and [NO_3-] (1.67 mg/L). Point 2 obtained high [DO] (7.06 mg/L) and [NO_3-] (16.73 mg/L), however, temperature (20.67ºC), turbidity (15 NTU), [BOD] (20.52 mg/L), [PO_4^{3-}] (1.55 mg/L) and [*E. coli*] (1.000.000MPN/100mL) presented lower values. Point 3 can be considered an intermediate area, with neither low nor high concentrations of chemical and biological pollutants. The results showed the highest [TDS] (4053 mg/L), Turbidity (60 NTU) and [PO_4^{3-}] (3.50 mg/L). The pH obtained very little variation with 7.05±0.02. The domestic effluent emission results were within the emission standards of Decree 18/2004 for pH, temperature, [PO_4^{3-}] (only at point 2), [NO_3-] (except point 2). The brewing factory showed that it emitted some parameters outside the standards stipulated by the Decree as is the case of [BOD] (>30 mg/L) and [E-Coliforms] (>400/100ml).

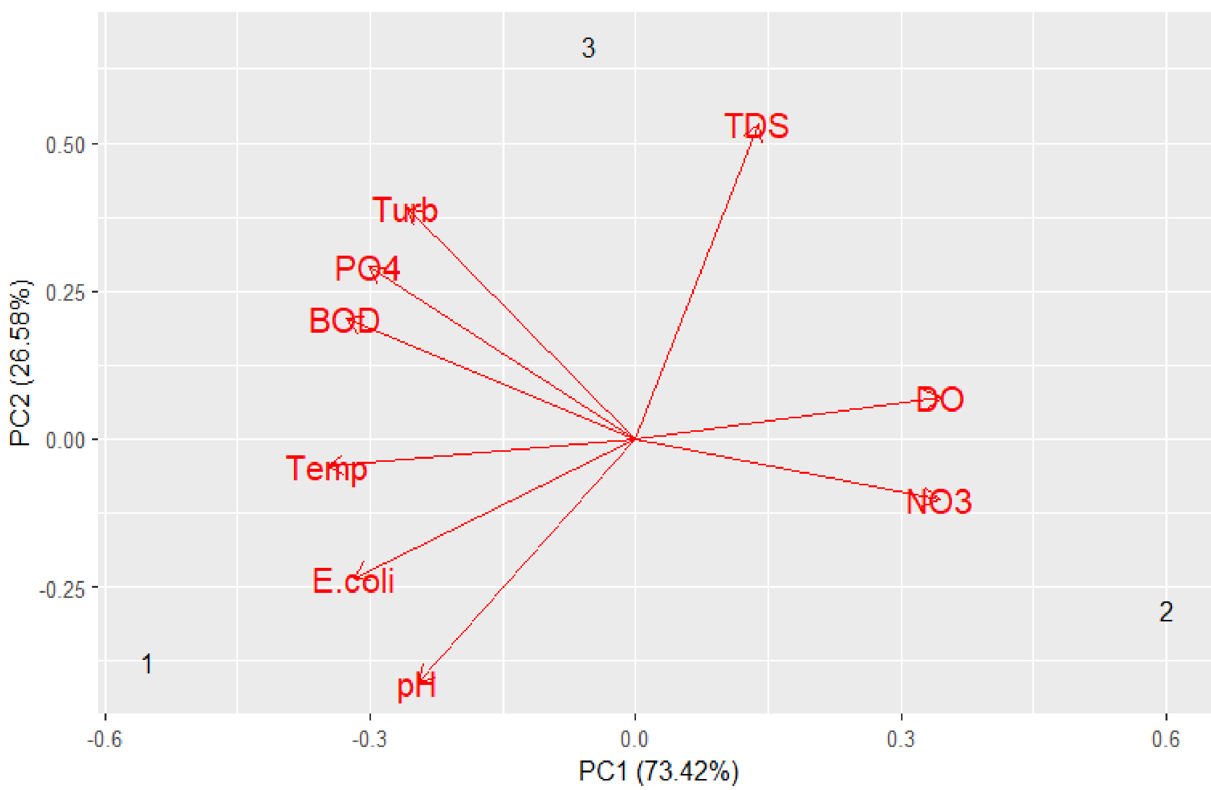

Figure 8. PCA of average physical-chemical and biological parameters of punctual pollution sources of the river in dry season.

Point 1 corresponds to Zimpeto WWTP, point 2 to Maputo Drainage System and point 3 to brewery factory wastewater (Fig 9). Point 1 presented high values of temperature (30.80ºC), [PO_4^{3-}] (8.39 mg/L), however it obtained low [TDS] (1544 mg/L) and [NO_3-] (3.03 mg/L). Point 2 obtained high [DO] (8.32 mg/L), [NO_3-] (22.49 mg/L), and [*E. coli*] (82,000 CFU/100mL), however, turbidity (35 NTU), [BOD] (25 mg/L) and [PO_4^{3-}] (1.94 mg/L) presented lower values. Point 3 showed higher [TDS] (5248 mg/L), Turbidity (100 NTU), [NO_3-] (22.87 mg/L), [BOD] (62 mg/L), and lower values of Temperature (28.77ºC), [DO] (0.65 mg/L) and [*E. coli*] (57.500 CFU/100mL). The results of domestic effluent emission showed to be within the emission standards of Decree no. 18/2004 for pH, temperature, [PO_4^{3-}] (only in point 2), [NO_3-] (except point 2). The brewing factory showed that it emitted some parameters outside the standards described in the Decree as it is the case of [BOD] (>30 mg/L) and [E-Coliforms] (>400/100ml).

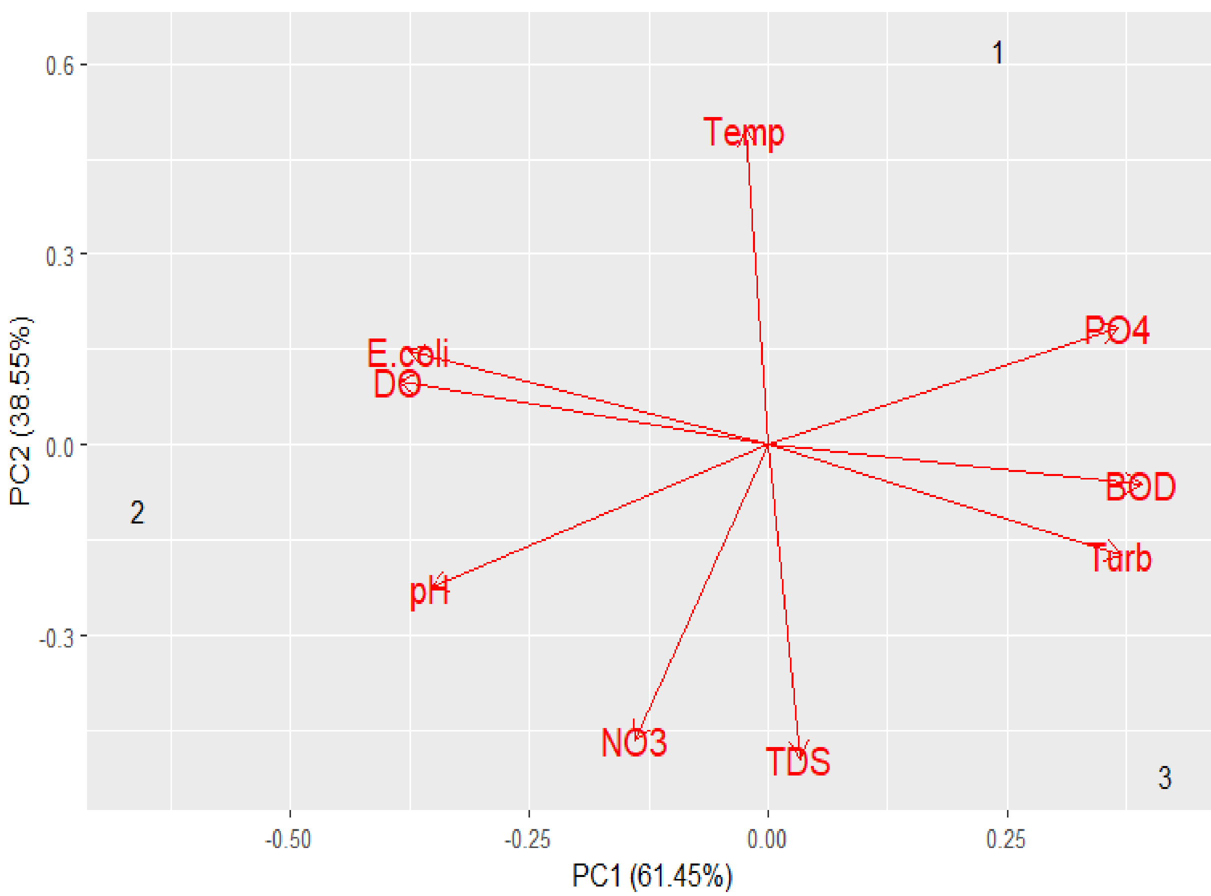

Figure 9. PCA of average physical-chemical and biological parameters of punctual pollution sources of the river in rainy season.

6.2. Water pollution levels of the river

Points 1 and 2 which correspond to Marracuene and Zimpeto respectively (upstream), obtained overall low values of physicochemical and biological parameters. Point 3 (Zimpeto- Centre) presented high level of Temperature (24.77ºC), Turbidity (35 NTU), [PO_4^{3-}] (4.0 mg/L), [*E. coli*] (4.000.000MPN/100mL) and [Chl] (45.91 µg/L), and it was also the point that presented the lowest [DO] (1.29 mg/L). The point 4 (Benfica- Centre) demonstrates to be in an intermediate area, not presenting the lowest and neither high value. Points 5 and 6 (Infulene- downstream) had high values (Fig 10), and the last point had 2.65 mg/L of DO, 3217 mg/L of TDS and 14 mg/L of NO_3-. The pH obtained a very small variation with 7.05±0.03. The [Chl] showed a strong correlation (R2=0.88) with the [PO_4^{3-}]. Comparing the results with the Decree 18/2004 for irrigation purposes, the points are within the stipulated standards for pH, [PO_4^{3-}] (except Zimpeto) and [NO_3-], however, none of the points presents [TDS] less than 500 mg/l, as for [total bacteria] (<100,000/100ml MPN) only the upstream zones are within the standards. Regarding the standards for recreation, the only point that indicated being within the standards was Intaka regarding the values of turbidity (null) and coliforms (<100 /100ml).

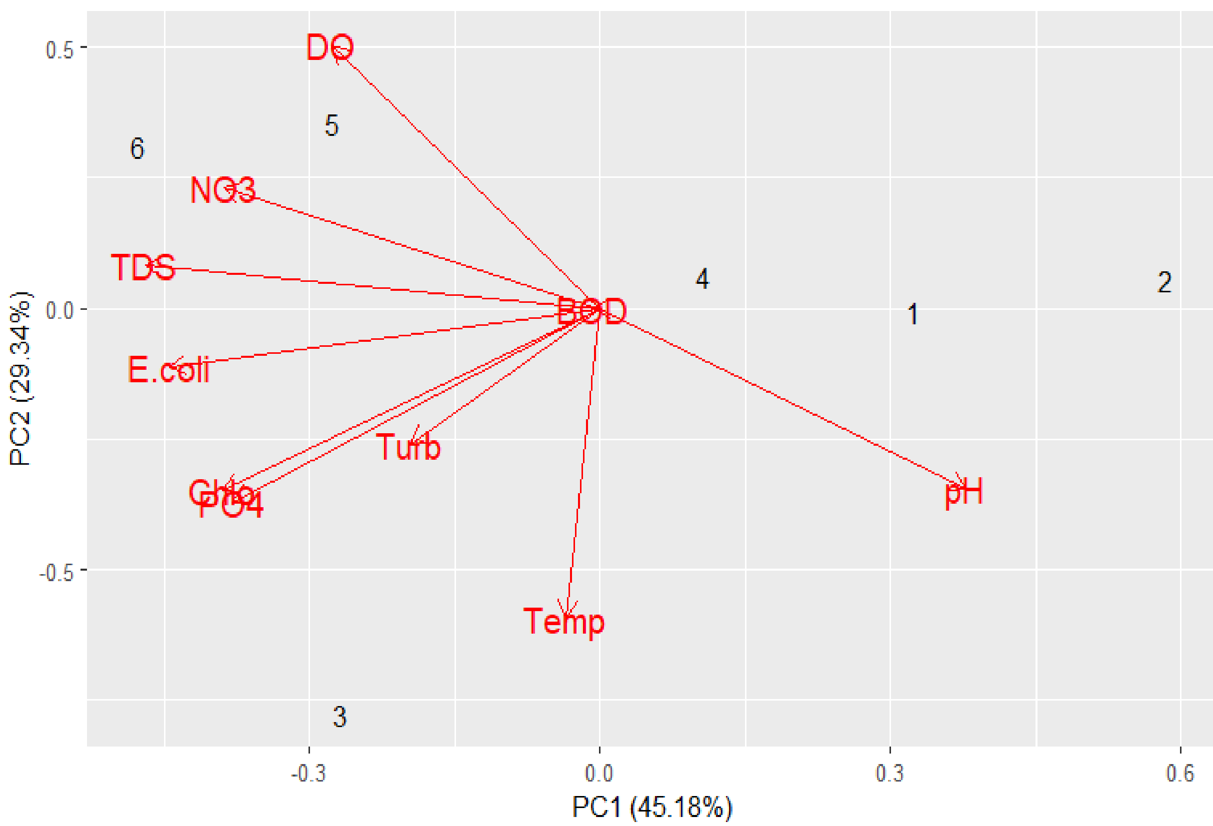

Figure 10. PCA of average physical-chemical and biological parameters of the river in the dry season.

Points 1 and 2 which correspond to Marracuene and Zimpeto respectively (upstream) (Fig 11), obtained overall low values of the parameters, however they presented high [DO] (2.0 mg/L). Point 3 (Zimpeto - Centre) showed high values of Temperature (30.01ºC), Turbidity (50 NTU), [PO_4^{3-}] (6.57 mg/L), [BOD] (8.70 mg/L), [*E. coli*] (67.200CFU/100mL) and [Chl] (42.60 µg/L) and showed low [DO] (1.46 mg/L). Point 4 (Benfica- Centro) indicated to be in an intermediate area in the values obtained. Downstream (Infulene) obtained high [TDS] (2955 mg/L), [BOD] (8.40 mg/L) and [NO_3-] (6.04 mg/L), however, indicated low [DO] (1.42 mg/L) and [PO_4^{3-}] (2.41 mg/L). The pH obtained very little variation with 7.28±0.31. The [Chl] showed weak correlation (R2=0.33) with the [PO4], however the [PO4] obtained strong correlation with the Turbidity. Comparing the results with Decree No. 18/2004 for irrigation purposes, all points are within the stipulated standards for pH (6.5-8.4) and [NO_3-] (<30 mg/L) levels, however none of the points presented acceptable [PO_4^{3-}] (<2 mg/L), [TDS] (<500 mg/L). Regarding the standards for recreation, the only point that indicated to be within the stipulated was Intaka regarding the values of turbidity (null) and coliforms (<100 /100ml).

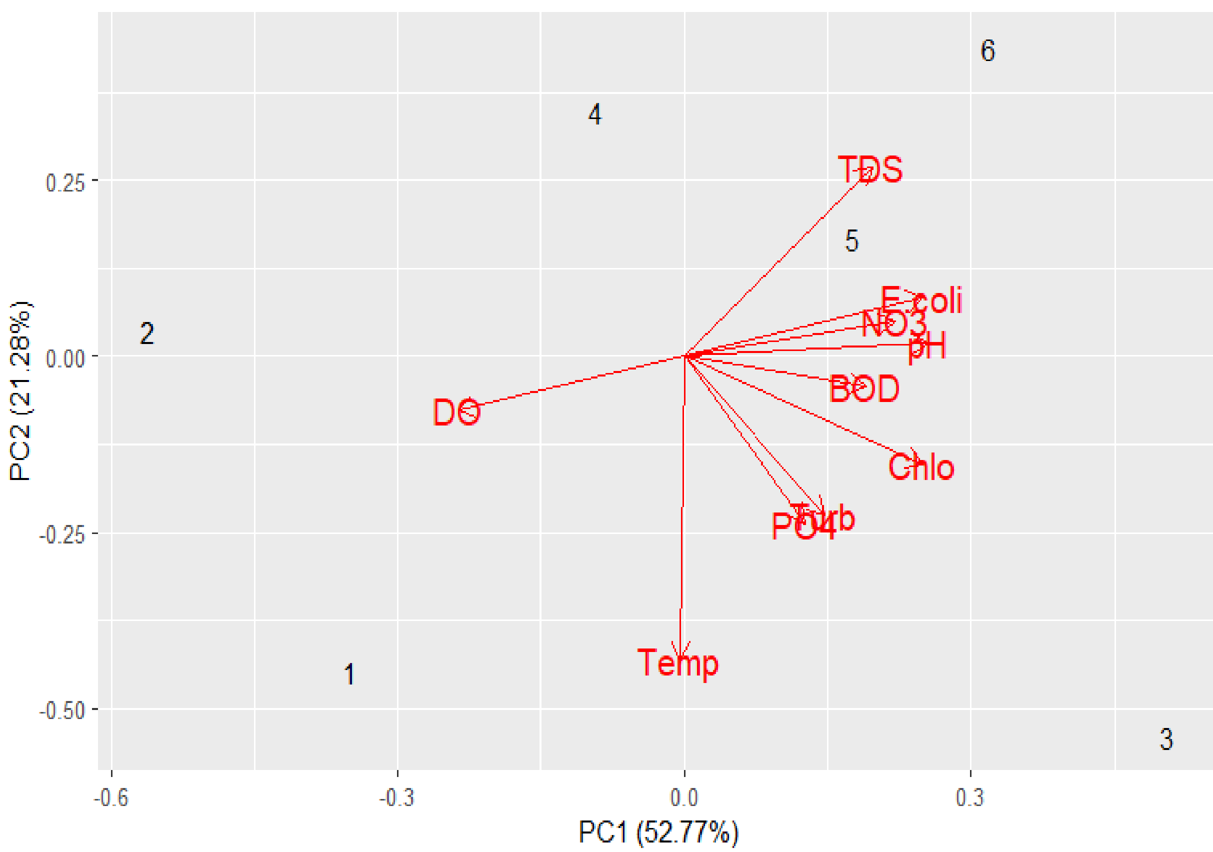

Figure 11. PCA of average physical-chemical and biological parameters of the river in the rainy season.

The comparison carried out of [PO_4^{3-}], [NO_3-] and [*E. coli*] with the different unpolluted and the polluted points with and without punctual discharges (Fig. 12) for the dry season reject the null hypothesis, showing that there are significant differences with [(KW=15. 2; p=0.001); (KW=12.4; p=0.002); (KW=12.6; p=0.002)] respectively and for the rainy season only [PO_4^{3-}] does not show evidence to reject the null hypothesis [(KW=0; p=1.0); (KW=14.9; p=0.001); (KW=12.6; p=0.002)] respectively. Overall, the points with punctual discharges presented high values, thus showing that they significantly influence the deterioration of water quality.

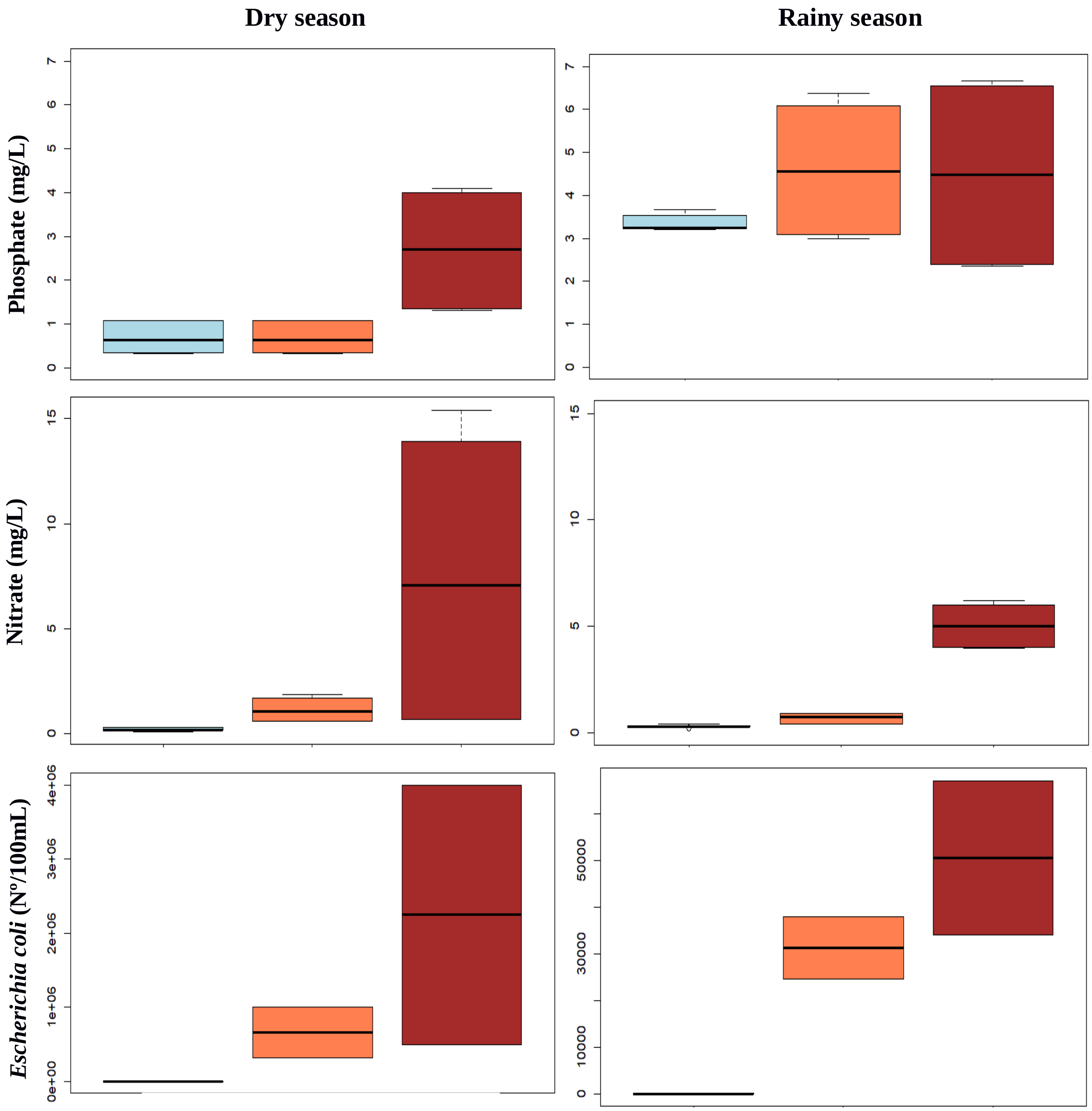

Figure 12. Comparison of [PO_4^{3-}], [NO_3-] and [*E. coli*] with the points: unpolluted (blue), polluted without point discharge (orange) and with point discharge (brown) in the dry (on the left) and rainy (on the right) seasons.

6.3. Comparison of the water quality physical-chemical and biological with national and international legislation

The physical parameters (Fig. 13), presented seasonal variations, in dry season presented lower values compared to rainy season. The temperature was the only parameter that showed statistically significant differences (W=2; p-value= 0.0000004). The [TDS] (W= 158; p-value= 0.90) in both seasons did not follow the national standard for irrigation water and the international limit for domestic use. Turbidity values (W= 108; p-value= 0.09) oscillated, with the median in both seasons not showing acceptable levels in both legislations (> 5 NTU).

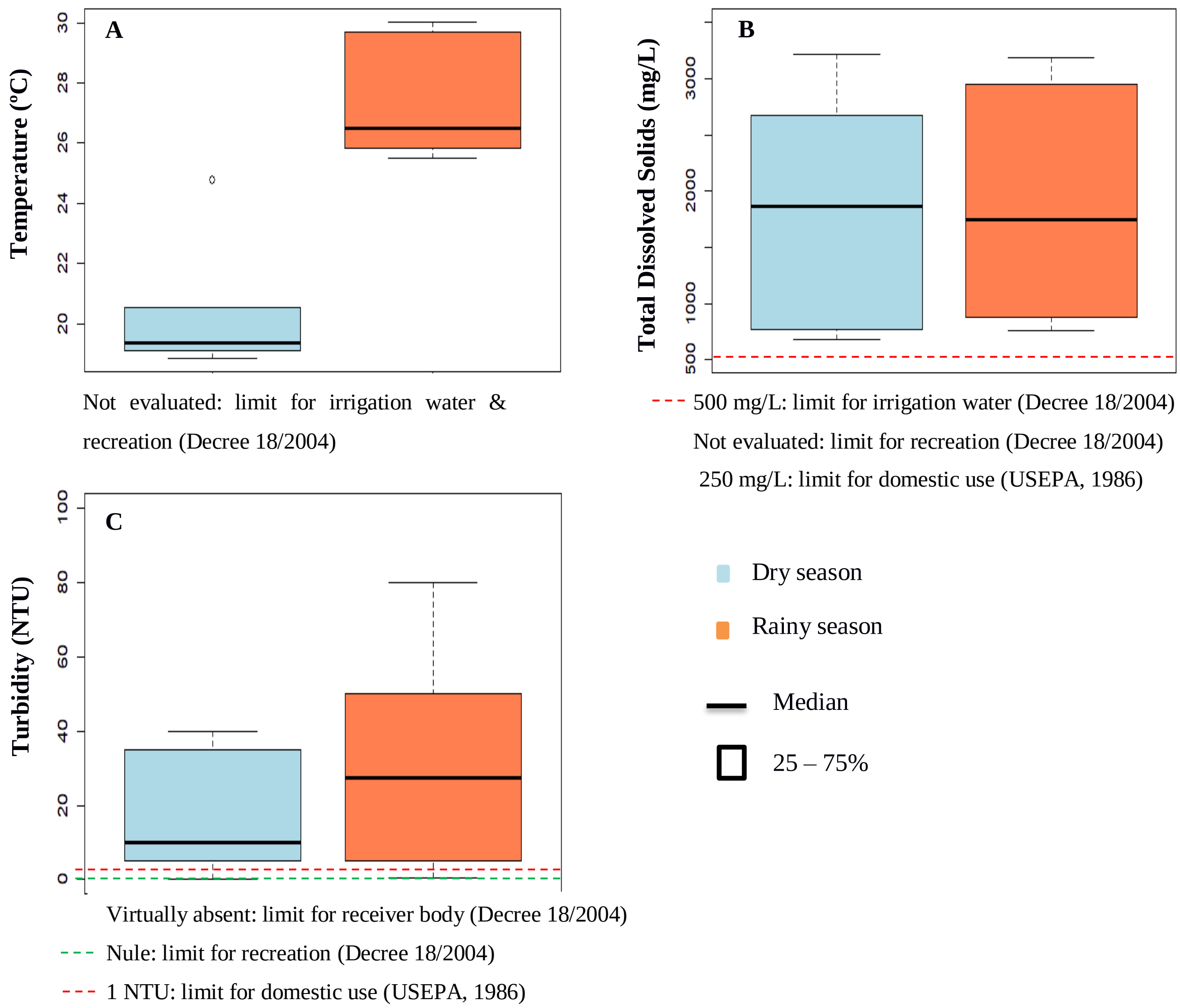

Figure 13. Temporal variation of physical parameters (A- Temperature; B- [TDS]; C- Turbidity) during the dry and rainy seasons and national (Decree No. 18/2004) and international (USEPA, 1986) standards.

The chemical parameters (Fig 14) illustrated oscillations during both seasons. The [DO] (W=202; p-value= 0.22), presented in both seasons values within the standards stipulated in the national legislation on the limit for receiving bodies (≤ 6 mg/L), however presented values below the internationally recommended for aquatic life (> 4 mg/L). The [BOD] (W= 198; p-value= 0.26) demonstrated that the median in the first season was above the recommended in both legislations (6.58 mg/L) and in the second season, the median was within the standards (3.96 mg/L). The [NO_3-] (W= 150; p-value= 0.73) had a small variation, the results in both seasons denote being within the standards of the national and international level. The [PO_4^{3-}] (W= 36; p-value= 0.00007) presented values above the stipulated in the international legislations on limit for unpolluted rivers (< 0.03 mg/L) and national on water for irrigation (< 2 mg/L) in rainy season.

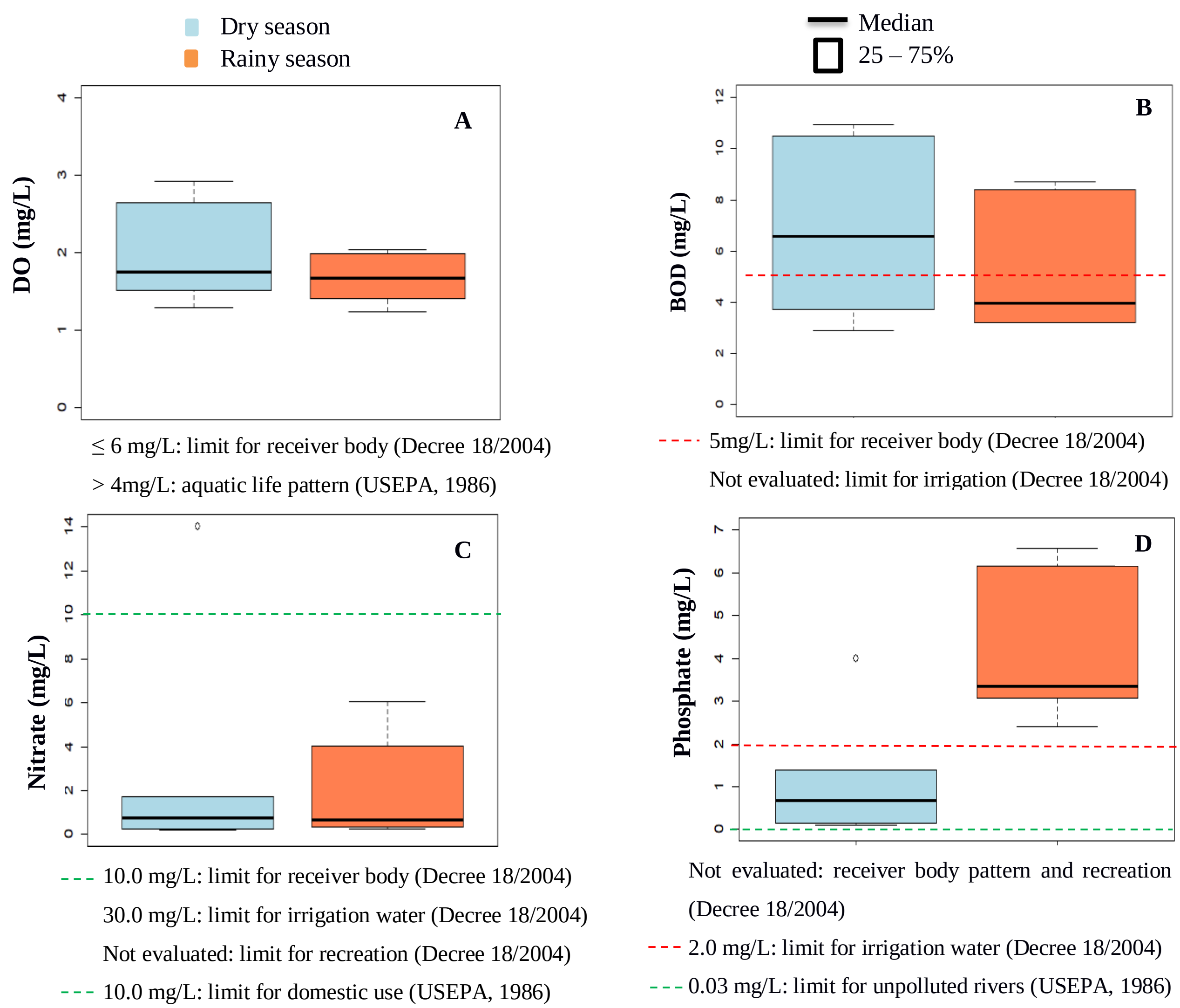

Figure 14. Temporal variation of chemical parameters (A- [DO]; B- [BOD]; C- [NO_3-]; and D- [PO_4^{3-}]) during dry and rainy seasons and national (Decree No. 18/2004) and international (USEPA, 1986) standards.

The biological parameters (Fig 15) illustrated oscillations between the seasons. The results of bacteria [*Escherichia coli*] in both seasons indicated being above the national and international standards stipulated for recreational water. The [Chl] (W= 170; p-value= 0.81) obtained little variation, the results in both seasons denote being beyond the standards stipulated at international level (ANZECC-AMCANZ, 2000) on [Chl] in aquatic ecosystems and the corresponding trophic state, the median being approximately 19 µg/L considered as eutrophic with notable water turbidity.

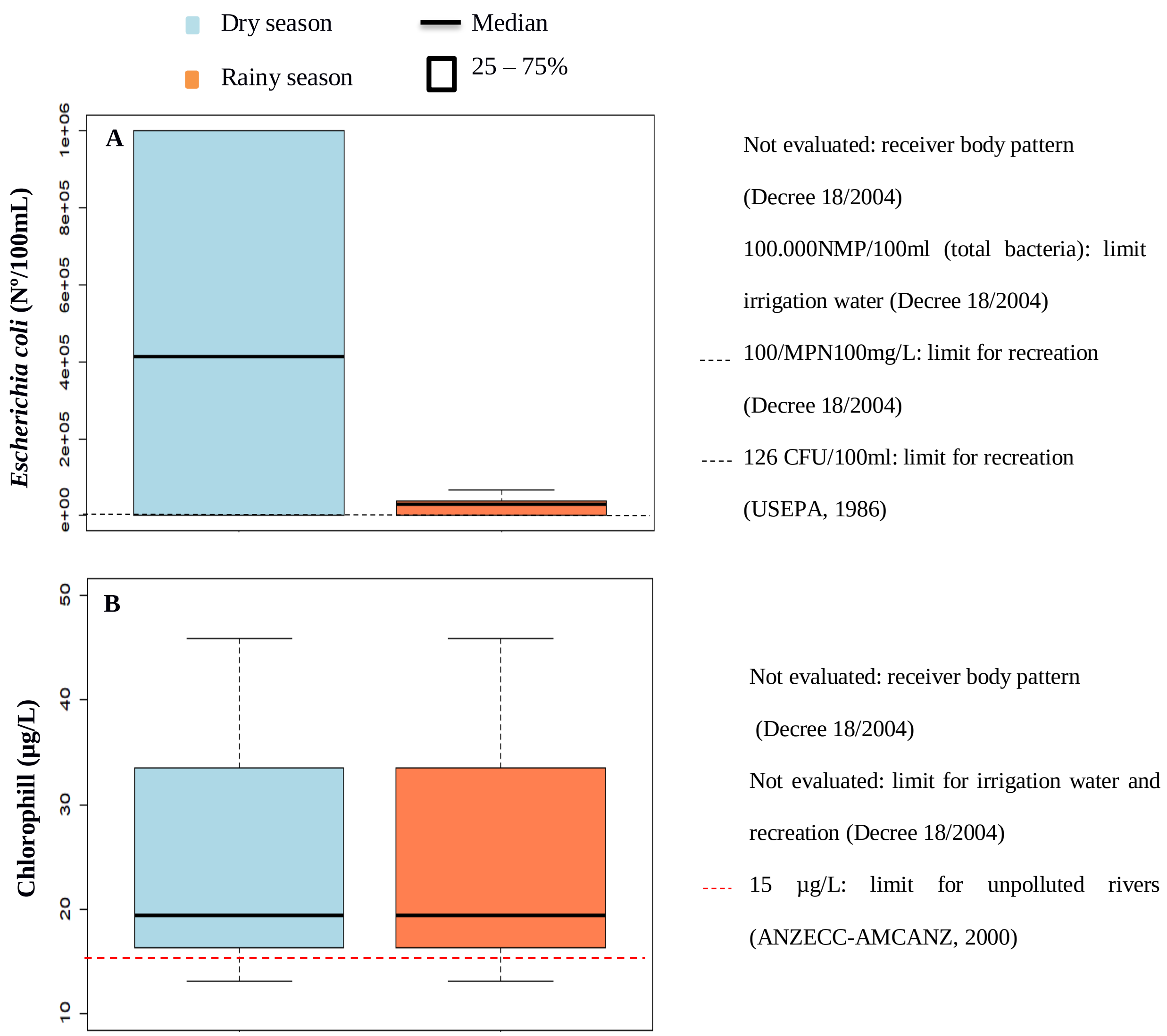

Figure 15. Temporal variation of biological parameters (A- [*E. coli*]; B- [Chl]) during dry and rainy seasons and national (Decree nº 18/2004) and international (ANZECC-AMCANZ, 2000) standards.

6.4. The Trophic State Index (TSI) and Water Quality Index (WQI)

The TSI of the river varied spatially and temporally, in dry season it showed lower values from 65 to 80 classified as Supereutrophic and Hypereutrophic respectively, and in rainy season higher values from 74 to 80 categorized as Hypereutrophic (Fig. 16). The TSI did not show statistically significant differences (W= 7.5; p-value= 0.11), failing to reject the null hypothesis. The upstream region (Marracuene and Intaka) showed lower TSI, and the central region (Zimpeto) showed higher TSI in both seasons.

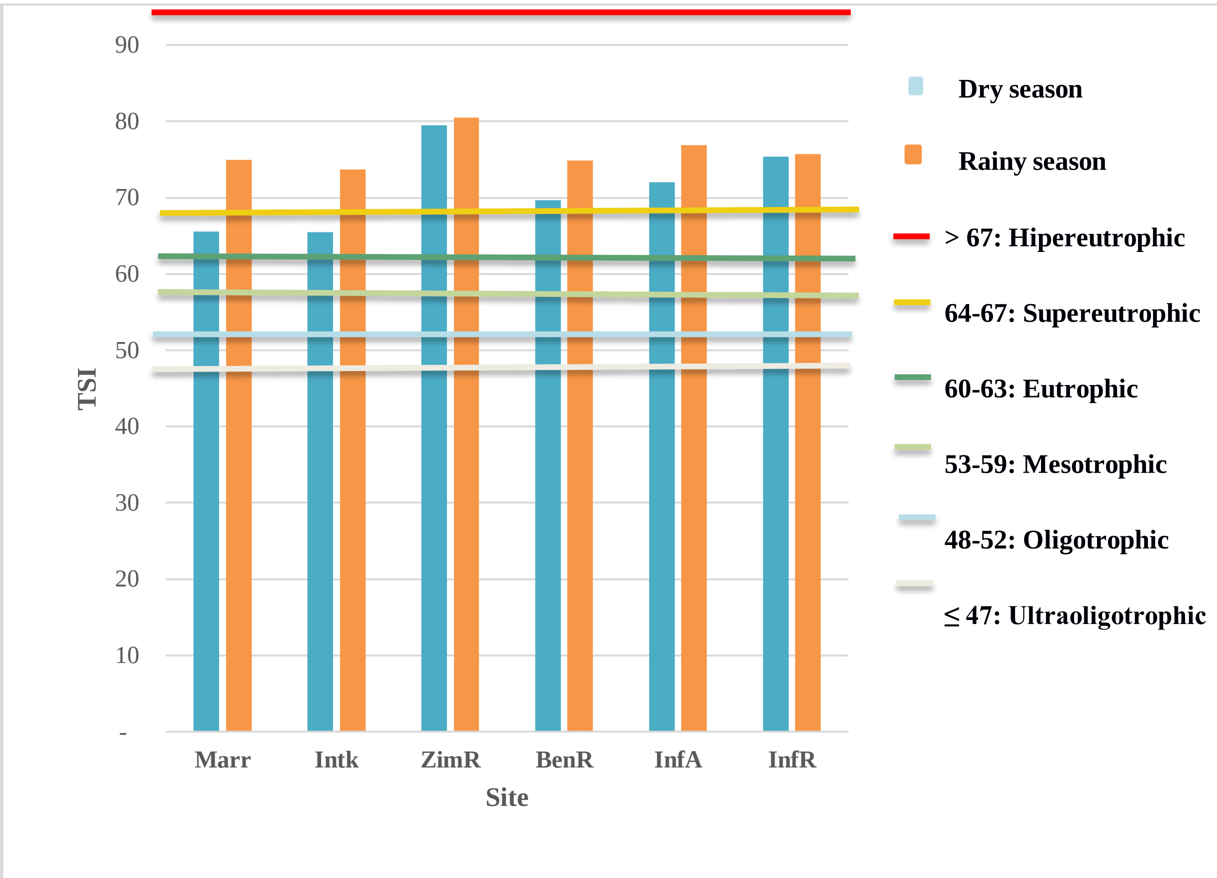

Figure 16. Temporal variation of the Trophic State Index during the dry and rainy seasons.

The WQI in the sampled points varied spatially and temporally (Fig. 17), where in dry season it showed higher values from 24 to 42 categorized as very bad and bad water quality respectively, and in rainy season it showed lower values from 19 to 41 classified as very bad and bad quality water respectively. The WQI did not present statistically significant differences (W= 26.5; p-value= 0.20), failing to reject the null hypothesis. The upstream region (Marracuene and Intaka) showed higher WQI and the central region (Zimpeto) lower WQI at both stations.

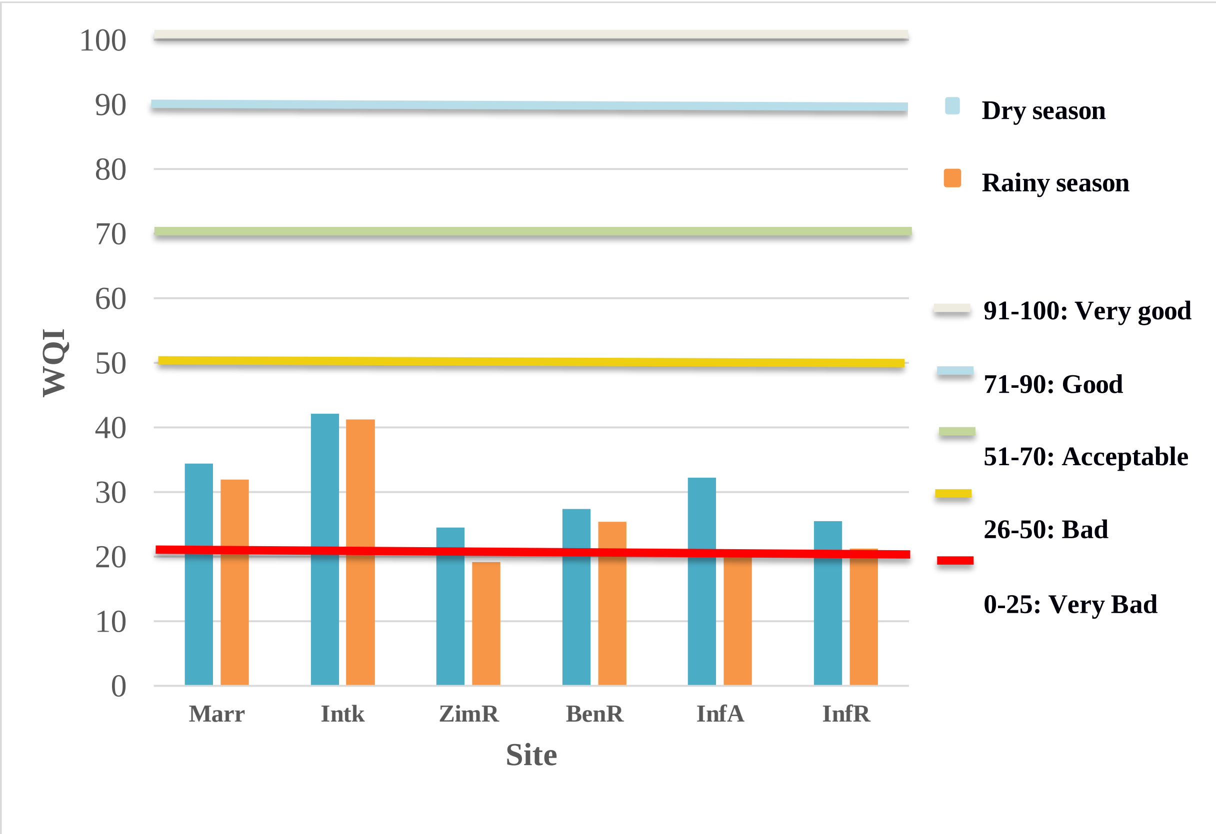

Figure 17. Temporal variation of the Water Quality Index during the dry and rainy seasons.

6.5. Risk Analysis

6.5.1. Infulene river basin management system

Anthropogenic activities have contributed to the deterioration of the river's water quality, altering its transparency, smell through the increase of untreated liquid waste rich in nitrogen compounds, phosphates, and pathogenic microorganisms.

A management system for the Infulene river basin (Fig. 18) must identify those responsible for its management (environment) (Table 10), consider the legislated standards on environmental quality and effluent emissions, potential sources of river pollution that includes the drainage system, wastewater from WWTP's and factory, and fertilized agriculture. The interface shows that there must be a connection or interdependence between the water quality control subsystem with the drainage and agricultural production subsystems to guarantee the integrity of the river.

For an efficient functioning of the Infulene river system, it is necessary to know the functionality, ecosystem services and possible failure modes of the river (Fig. 20) to guarantee the sustainable use of the river and minimize the costs involved in the process of controlling and monitoring well such as cleaning or treating river water.

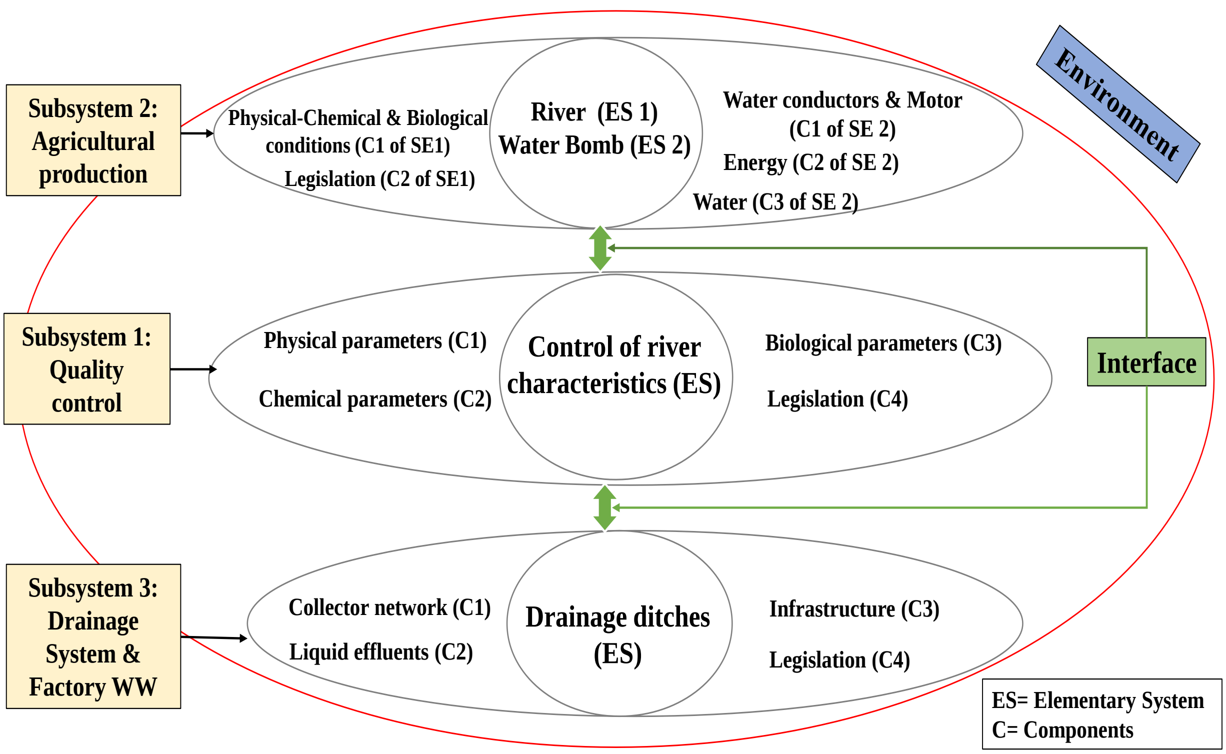

Figure 18. The representation of Infulene river basin system.

6.5.2. Functional Analysis

The function diagrams are represented in the Octopus diagram (Fig. 19), where function services are represented by sF and restricted functions by cF and their specifications (Table 8). The external components of the river include the land, drainage systems, water from the Zimpeto WWTP, agricultural activity, wastewater from the brewery factory, climate events such as rainfall, wind and storm, water monitoring equipment and materials and water pump.

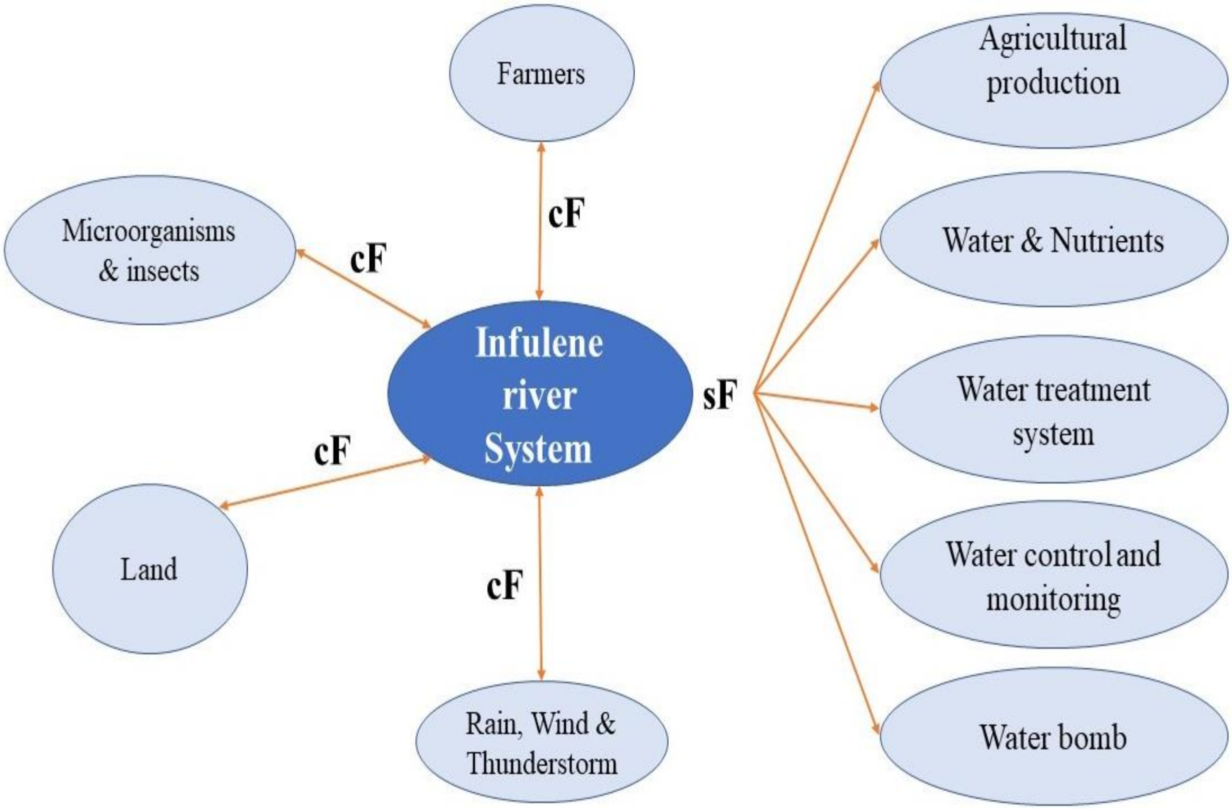

Figure 19. Octopus diagram.

Table 8. Function specifications.

Function		Criteria	K	Level	Flexibility
sF 1	The river is the source of water for agricultural production	Quantity in Litres	3	<20L/day /farmer	F1
sF 2	The river is enriched with water and nutrients through rainfall, drainage systems, agricultural activity, and brewery factory	Quantity in Litres	5	>120.000L /day	F1
sF 3	The river must be connected to a water treatment system to ensure adequate water for irrigation as well as the final recipient (sea)	Biannual maintenance	5	100%	F0
sF 4	The equipment used for control and monitoring of the river must be calibrated to avoid incorrect results	Monthly monitoring	4	100%	F0
sF 5	The river is efficient when it meets legislated water quality standards	Monthly Monitoring	5	100%	F0
sF 6	The use of the water pump avoids ergonomic problems for farmers	Biannual Maintenance	2	100%	F2
cF 1	The river is stable on the ground	Three-monthly monitoring	4	100%	F0
cF 2	The river is visible to all	Biannual maintenance	1	100%	F1
cF 3	The river system is resilient to nutrients and microorganisms	Monthly monitoring	4	100%	F0
cF 4	The river system can withstand climatic variations such as rain, wind, and storms	Biannual maintenance	2	100%	F0
cF 5	The water in the river must guarantee quality for users, such as farmers	Monthly monitoring	5	100%	F0

6.5.3. Failure Mode, Effects & Criticality Analysis (FMECA)

From the FMECA analysis it was identified that pollution in the Infulene River System was the cause with the highest criticality (Table 9) and a preventive action plan was proposed (Table 10).

Table 9. Criticality levels of the failure modes identified.

Failure Mode	**Effects**	**S**	**O**	**D**	**C**
Air pollution around the Infulene River	Increased emission of contaminants on the air and consequently in the soil and river	1	1	9	9
Pollution at Infulene river Basin	**Increased contaminants into the river, reduction of basic sanitation can cause disease in users (surrounding people and farmers)**	**10**	**10**	**1**	**100**
Soil pollution around the Infulene river	Increased emission of contaminants on the soil and consequently into the river	8	10	1	80
Lack of garbage container and public toilet around the Infulene river	Reduction of basic sanitation and diseases in the surrounding people	8	10	1	80
Lack of environmental education projects for the community	Reduction of basic sanitation	5	8	2	80
Lack of training of farmers in the use of fertilizers	Diseases in users, river, and soil contamination	8	9	1	72
Lack of inspection and supply of agricultural materials	Increased emission of contaminants to soil and river	7	8	1	56

6.5.4. Failure Tree Analysis (FTA)

The FTA of the highest criticality identified in the FMECA (Pollution in the Infulene river System) illustrates that punctual and diffuse discharges constitute a threat to the Infulene river. About 48% of punctual discharges corresponded to loss of functionality of the Zimpeto and Maputo WWTP (3rd cause) and about 52% of diffuse discharges corresponded to surface runoff and soil erosion (7th cause), thus indicating that these were the causes with the greatest impact on risk analysis, making it possible to draw the critical paths shown in red (Fig. 20).

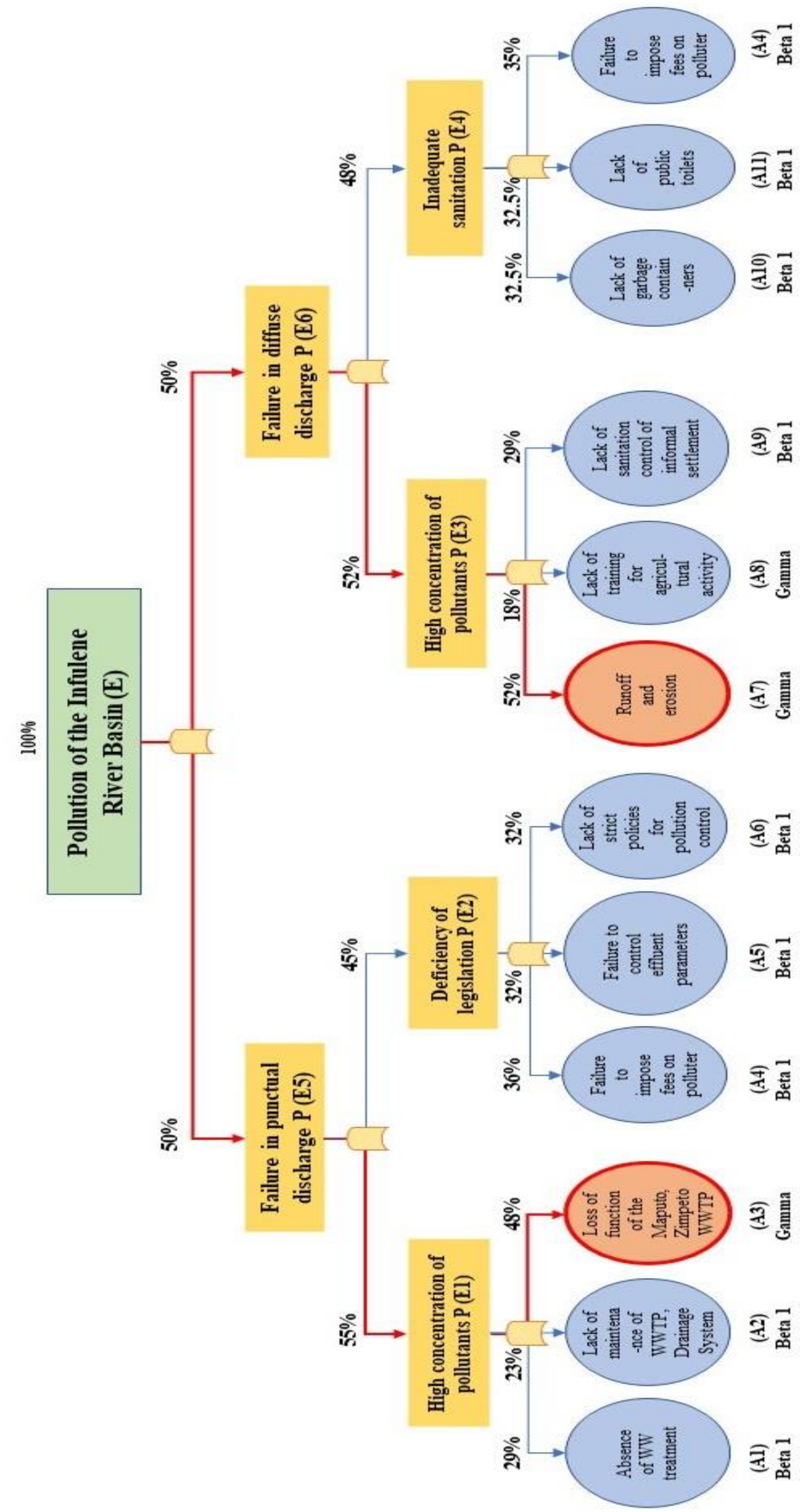

Figure 20. Failure Tree Analysis of Infulene river basin.

The feared event illustrates a correlation coefficient of 96%, validating the analysis since there is a strong correlation between causes identified for the risk analysis. The sample is homogeneous because the point cloud can be modeled by a curve with an upward concavity curve (Fig. 21), that is, the point cloud is spread out quite homogeneously and can be modeled by a 96.26% in straight line). This curve corresponds to the BETA 1 distribution law for this risk, meaning that the main factor that regulated the risk analysis was the human factor.

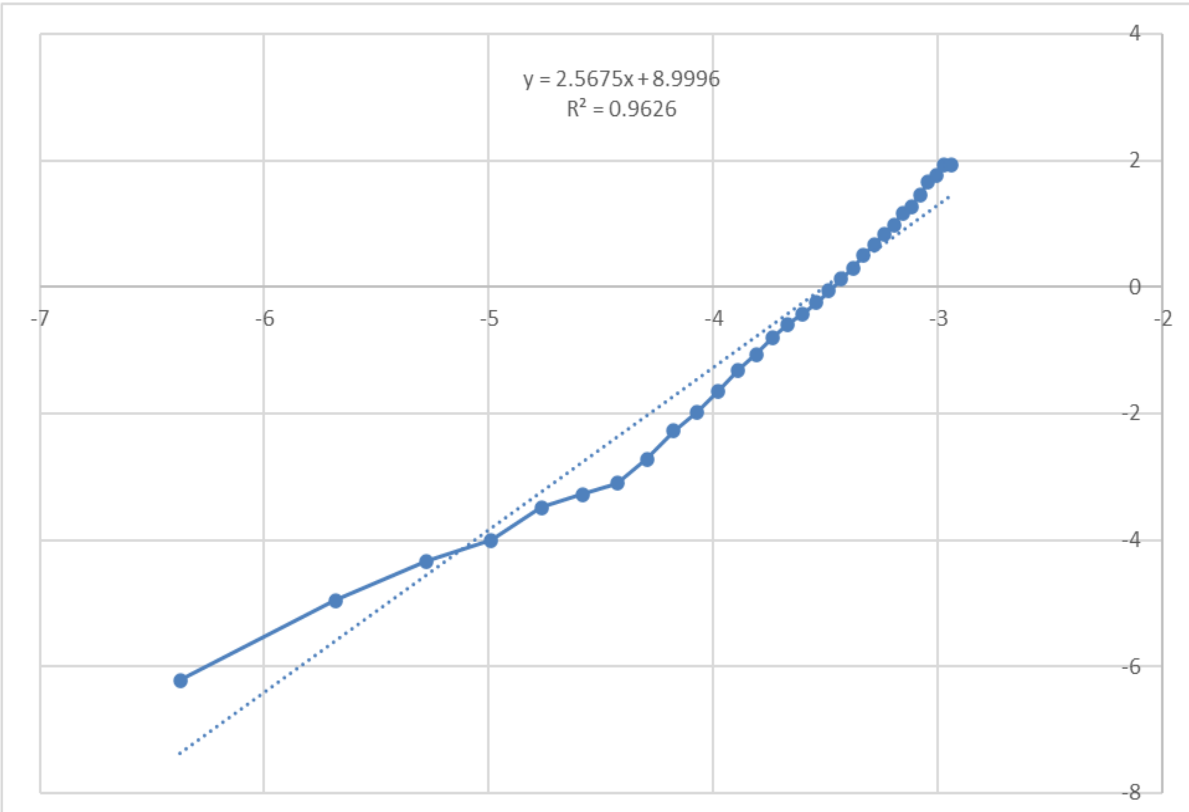

Figure 21. Correlation of the causes identified for the risk analysis of the Infulene river.

The action plan (Table 10) described above ensures the control and monitoring of water quality in the river basin, including punctual and diffuse sources of pollution; provides for the application of sanctions and fines (Polluter-Pays) to those responsible for polluting the river; ensures that there is basic sanitation in the region; cleans up the river basin; provides strict policies for the emission of liquid waste into the Infulene river; promotes environmental protection awareness in the community, farmers and the general public; and increases the sense of responsibility of the entire population to protect the ecosystem.

Table 10. Action plan for the management of the Infulene river basin following ISO 9001:2015.

What (Aspect)	Quality impact	How (Action)	When (duration)	Who (Responsible)
Lack of liquid waste treatment before discharge into the river	- Increase of pollutants (physicochemical and pathogenic microorganisms) in the river. - Reduced food security due to contaminated agricultural products that may result in diseases. - Threat to aquatic biodiversity	To install a Wastewater treatment plant to threat liquid waste before discharge	Whenever there is wastewater	- Wastewater treatment plant under the jurisdiction of CMCM - collective effluent - Individual effluent: septic tank method - Brewery factory: Industrial effluent
		Monitoring the quality of wastewater	Monthly	DNGRH
		Imposing sanctions and fines on polluters	Monthly	
		Revision of decree no. 18/2004 in the section on the quality of effluent emissions	Where necessary	DNGRH
Lack of maintenance of the drainage systems and WWTP's or loss of their functionality	- Increase of pollutants in the river. - Flooding in the systems and dispersion of pollutants in the watershed. - Reduced longevity.	Define procedures and responsibility for the periodic control of the systems including cleaning programs for both	Where necessary	CMCM
Lack of control of polluters in the basin and lack of environmental education programmes	Increase of pollutants in the soil and river	Imposing sanctions and fines on polluters	Monthly	DNGRH
		Deliver environmental education programs for river users	Trimestral	
Lack of control of the quality parameters of the river and the wastewater discharged into the river	- Increase of pollutants in the river - Lack of knowledge of pollutant emission levels - Reduction of food security	Control and monitoring of water quality	Monthly	DNGRH

Table 10. Action plan for the management of the Infulene river basin following ISO 9001:2015 (cont.).

What (Aspect)	Quality impact	How (Action)	When (duration)	Who (Responsible)
Lack of strict policies for water quality control	Increased emission of pollutants	Revision of Decree No. 18/2004 in the section on effluent emission quality standards, restricting the emission standards for [*E. coli]* to 100MPN/100mL, [PO_4^{3-}] to 0.03mg/L; [NO_3-] to 5mg/L. Addition of quality control of river parameters such as [Chl] to up to 15µg/L.	Where necessary	DNGRH
Lack of control and planning of land use in the river Basin	- Increase in informal settlements that have clandestine pipelines and pollute the river basin. - Intense fertilized agriculture can saturate the soil and increase erosion into the river, increasing nutrient levels. - Increased development has reduced the ability of rainwater to infiltrate into the soil, increasing surface runoff that will wash into the river from the soil.	Resettlement of populations living in informal settlements near the riverbanks or improvement of basic sanitation	Where necessary	MITA
		Planting of riparian vegetation	Where necessary	DNGRH
		Crop rotation (avoiding monoculture)	Always	MADeR
		Regular cleaning of the soil, pavement, drainage system and river	Weekly	CMM
Lack of control and sanitary conditions for agricultural activity	- Increased pollutants in soil and river - Increased open-air faecal dumping	Allocation of rubbish dumps and public toilets along the river	Where necessary	CMCM
		Deliver environmental education programs for schools, communities, and farmers	Quarterly	DNGRH
		Implement a training process for farmers and monitor the activity	Where necessary	MADeR

7. DISCUSSION

The type of agriculture used in the Infulene river is fertilized agriculture, with the majority of farmers (97%) using animal dung that is usually rich in phosphorus, nitrogen, among others, this aspect may have contributed to the increase of nutrients such as phosphates and nitrates in the river water (probably from surface runoff and erosion of the soils enriched with fertilizers), especially in Infulene where agriculture is intense and obtained high concentration of nitrates and phosphates. The increase in nitrogen and phosphorus and the consequent groundwater contamination is associated with agriculture fertilized by animal manure (Girotto *et al.*, 2013; Couto *et al.*, 2017; Loss *et al.*, 2019).

Apart from the contribution of fertilizers in the contamination of the river water, the other aspect that may pose a threat to the health of the Infulene river are the various uses by farmers which include: sanitization of different parts of the body such as the face, hands and feet; sanitization of the food eaten during the activity; for the deposit of agricultural waste and farmers' droppings, which contribute to the increase in nitrates, phosphates, turbidity, pathogenic microorganisms, among others. Soil waste dumping, open air faecal dumping and urbanisation also pose a threat to the river as during surface run-off the waste from the soil is carried into the river.

The disposal of waste in agricultural soils may contain toxic substances, pathogenic microorganisms (Boechat *et al.*, 2017) and nutrients that with the action of rainfall, the soil surface is saturated and generates surface runoff that carries these contaminants to the river contributing to the deterioration of water quality (Sinha & Michalak, 2016; Halecki *et al.*, 2022).

The drainage system of Maputo City receives domestic effluent from informal settlements with high concentration of Nitrates, BOD and *Escherichia coli* whose values can be considered as polluted water. The Although neighbourhoods Xipamanine, Malhangalene, Maxaquene, Mafalala and Aeroporto was considered to have very poor sanitation conditions. These results may be related to the excess organic matter and human waste discharged directly into the drainage system, which due to the lack of domestic effluent collectors, residents make clandestine connections of pipes for domestic effluents that are conducted into the storm drainage system without prior treatment, combined with the deficiency of basic sanitation in the neighbourhoods studied that have latrines in informal settlements whose effluents are also directed into the Infulene river.

The drainage system of Maputo is part of an area in which most of the population lives in about 20 neighbourhoods with informal settlements such as the areas studied, areas prone to flooding due to the high-water table and reduced infiltration of water into the soil. Flooding can pose a risk to public health as some areas have latrines in very poor sanitary conditions that are managed on an individual basis, which contributes to an increased likelihood of residents contracting waterborne diseases such as cholera and malaria (CMM, 2021).

Factors influencing water quality include air pollution through precipitation, urban runoff contaminated by sediments, organic matter and metals, urban waste carried into the storm drainage system. The water quality of the rainwater network also depends on the frequency of urban cleaning, the intensity of precipitation and its temporal and spatial distribution, the time of year and the type of use of the urban area (Tucci, 2004).

The deficiency in basic sanitation may be associated with lack of efficient urban planning, the lack of an effective treatment system for individual and collective effluents, the lack of rigorous policies described in decree no. 18/2004 and the lack of control of solid and liquid waste.

The Maputo WWTP is currently being rehabilitated and there is no alternative system to reduce the load of pollutants from urban runoff, domestic and industrial effluents, which may explain the high organic load of the neighbourhood of Infulene. Globally, more than 80% of wastewater is discharged directly into the environment without adequate treatment (UN WATER, 2017), especially in developing countries where access to sanitation is limited and regularization policies are precarious (McGrane, 2016).

Vegetation cover has the function of protecting the soil and facilitates water infiltration, when it is removed due to the development of cities, it reduces the rate of evapotranspiration and infiltration of the soil, increasing the volume that runs off the surface (USEPA, 1998; Tucci, 2004) which could cause soil erosion and transport of contaminants such as sediment and nutrients, to the river (Arreghini *et al.*, 2005; Sinha & Michalak, 2016; Andrade *et al.,* 2021; Zak *et al.,* 2019).

In Maputo City, two types of drainage and sanitation infrastructures stand out: 1) open ditches, for rainwater runoff; and 2) buried collectors, which depending on the situation, drain domestic or rainwater effluents or both. There are only two pumping stations that convey part of the effluent to the Maputo WWTP located in Infulene, the rest is directed to Maputo Bay (Jane, 2017).

The high concentrations of the parameters studied in dry and rainy seasons showed that the emission of wastewater from Zimpeto WWTP (TDS of 2050 and 1544mg/L; turbidity of 40 and 60NTU; BOD of 42.57 and 47.95mg/L; $PO_4^{3-}$of 3.28 and 8.39mg/L; *E. coli* of 35.900.000MPN and 67.200CFU/100mL), Drainage System (TDS of 2821 and 3052mg/L; turbidity of 15 and 35NTU; BOD of 20.52 and 25.00mg/L; NO_3- of 16.73 and 22.49mg/L; *E. coli* of 1.000.000MPN and 82.000CFU /100ml) and the brewery factory (TDS of 4053 and 5248mg/L; turbidity of 60 and 100NTU; BOD of 36.65 and 62.00mg/L; PO_4^{3-} of 3.5 and 6.15mg/L; NO_3- of 3.4 and 22.87mg/L; *E. coli* of 2.000.000MPN and 57.500CFU /100ml) are the punctual sources that contribute to the pollution of the river water since they obtained values far above the standards stipulated in Decree No. 18/2004.

The high concentration of contaminants from domestic effluents can be justified by the fact that there is no proper wastewater treatment system, causing the discarded waste to remain rich in NO_3-, PO_4^{3-} and pathogenic bacteria as *E. coli* from human waste. The industrial effluent showed high pollution potential by the high concentration of *E. coli*, TDS, presence of phosphates and nitrates that can justify high turbidity values of the water.

Studies by Moccellin (2006) and Enitan *et al.* (2015), associated high ionic concentration to the discharge of industrial effluent in the aquatic ecosystem. Studies by Calijuri *et al.* (2008), Enitan *et al.* (2015) and Khumalo *et al.* (2022), pointed out high concentrations of phosphorus and nitrogen respectively, to the discharge of industrial effluents into the aquatic ecosystem.

The brewery factory in Mozambique produces several types of beer and uses various raw materials such as water, maize (Chibuku) and cassava (Impala), wheat (Mafalala), barley malt (Manica, Laurentina) and sugar (2M, Manica) (CDM, 2023). The brewery factory requires large volumes of water (primary raw material) for its production since this element constitutes the main ingredient in production, and requires the water for cooling and washing floors, packaging, and cleaning the production sectors. Therefore, the amount of effluent generated after beer production comes from the various sectors of the factory (Simate, 2015; Kumar *et al.*, 2022).

Industrial effluents contain organic and inorganic matter, nitrate and water-soluble phosphorus that can cause environmental pollution problems (Enitan *et al.*, 2015; Simate, 2015) and one of the ways to mitigate pollution is through control and monitoring of liquid effluents discharged to aquatic ecosystems (Baig *et al.*, 2010; Kovoor *et al.*, 2012; Khumalo *et al.*, 2022).

The WQI was categorized from poor to very poor quality, where the upstream region (Intaka) was considered as a bad quality water and in the center and downstream as a very bad quality water for aquatic ecosystems, with Zimpeto showing the worst quality. The main variables that may have influenced for the deterioration of water quality include low dissolved oxygen concentration and high [PO_4^{3-}], [*E. coli*], [TDS] and Turbidity from the studied punctual and diffuse sources, showing that the water of this river is not suitable for irrigation of vegetables most of them consumed raw, recreation and aquatic life, the use endangers Public and Environmental Health.

Overall there were no statistically significant differences in the parameters between the seasons, with the exception of temperature and phosphates. The temperature presented differences probably due to the change of seasons, where the first season was in July considered as winter characterized by low temperatures and the second season was in October framed in the summer season represented by generally high temperatures and high rainfall indices.

Mozambique is characterized by having a tropical to subtropical climate and is vulnerable to climate change, with large areas of the country exposed to tropical cyclones, droughts (every three to four years) and river/coastal flooding (FAO, 2016). The seasons are divided into two, namely hot and rainy (October to March) with average annual temperatures in the southern region ranging from 24°C to 26°C also categorized as summer, and cold and dry (April to September) with average annual temperatures ranging from 20°C to 22°C also classified as winter (WBG, 2021).

Average annual rainfall varies between 800 and 1200 mm, with the peak rainy season being in January/February. Tropical cyclones from the Indian Ocean usually hit Mozambique in summer and are associated with heavier rainfall (FAO, 2016), which can cause flooding and increases the risk of waterborne disease outbreaks (WBG, 2021). These climate risk factors join other risk factors that contribute to poor health, such as low access to adequate sanitation, improved water sources and health facilities. The recent heavy rainy observed in Maputo in 2023 showed this situation almost everywhere in Maputo, particulary in the poor settlement areas where floods carry a lot of sediments and organic material and water stay in that areas even in the houses for a long period.

Phosphate showed statistically significant differences, this can be justified by the samples being collected after the fall of rains, where there was an increase in organic matter in the water due to surface runoff and soil erosion.

Studies by Andrade *et al.* (2021), Halecki *et al.* (2022), Shou *et al.* (2022) and Zheng *et al.* (2023), reported that the occurrence of rainfall can increase the nutrient load to the aquatic ecosystem. The occurrence of rainfall can cause increased turbidity due to the input of organic matter and soil particles that transport nutrients to the aquatic system (Arreghini *et al.*, 2005; Zhou *et al.*, 2015; Sarkar & Majumder, 2021). Increased nutrients from agricultural land runoff and soil erosion negatively affect freshwater quality (Zak *et al.*, 2019), as it favours algal growth and increases the risk of eutrophication (USEPA, 2020; Liu *et al.*, 2022).

Riparian vegetation was converted into agricultural land and under the pressure of population increase, some lands were converted into residential and industrial areas, causing the form of surface water contamination to be through contaminants associated with soil after erosion (Honisch *et al.*, 2002). Rainfall in non-urbanized areas with vegetation, water penetrates the soil and slowly infiltrates to the groundwater, however, in urbanized areas, much of the stormwater ends up in canals and waterways (Jebamalar *et al.*, 2021).

Severe water erosion increases the risk of nutrient leaching in soils prone to surface runoff and because of low soil permeability and urbanization, the holding capacity is reduced in areas with low soil permeability (Halecki *et al.*, 2022). Soil erosion usually occurs in unprotected soils, as is the case in the region downstream of the Infulene River probably due to intense agricultural activity. This finding can be justified by the study by Michael *et al.* (2005), who concluded that soil erosion can increase with increasing land cover.

The points upstream of the river showed lower concentration of nitrates, phosphates and *E. coli* compared to the midstream and downstream, thus determining that the polluted sites in the river were the midstream and downstream points that were influenced by the agricultural activity (mainly in the downstream region), and the punctual discharges from Zimpeto WWTP, Drainage System and brewery factory wastewater that indicated significant influence on water pollution. This finding can be justified by the fact that points with the influence of effluents and intense agricultural activity present high concentration of Total Solids, Turbidity, Phosphates, Nitrates, thus increasing organic matter in water, consequently, increases BOD and the reduction of DO.

In small watersheds, the anthropic influence on surface water deterioration is combined with the effect of natural components (Alamdari et al, 2020), however, the main source of pollution is of anthropogenic origin due to poor water and effluent management, excessive use of fertilizers (Andrade *et al.*, 2021; Halecki *et al.*, 2022).

The manuscripts by Honisch *et al.* (2002) and USEPA (2020), described agricultural fertilizers and wastewater (Halecki *et al.*, 2022) as the main sources of nitrogen, and the reports by USEPA (1986, 2006 and 2020), reported agricultural runoff and domestic effluent (Halecki *et al.*, 2022) as the main sources of phosphates. Studies have indicated a relationship between increasing total solids concentration and decreasing water transparency (Smith, 2003; Huszar *et al.*, 2006; USEPA, 2020) and increasing organic matter and decreasing dissolved oxygen (USEPA, 2020).

Although the chlorophyll concentration peaks followed the phosphate peaks in both seasons, it was possible to observe that the biological response measured by chlorophyll concentrations showed significant and strong relationship in dry season compared to rainy season. This weak relationship can be justified by the fact that phosphate concentration exceeded the tolerable limit in phytoplankton until it reached stress levels. The strong relationship of chlorophyll with phosphorus was described by Smith (2003), Huszar et al. (2006) and USEPA (2020), and the weak relationship by Dodds *et al*. (2002) and Calijuri *et al*. (2008).

Nitrogen and Phosphorus are essential nutrients found naturally in the environment, their excess can negatively affect water quality and biology. High concentrations of these nutrients can favour the overgrowth of macrophytes and algae reflecting in high concentrations of chlorophyll (an indirect measure of algal biomass), which can reduce the aesthetic pleasure of the water and interfere with swimming due to increased total solids in the water which will reduce water transparency (Smith, 2003; USEPA, 2020). Excessive algal growth can result in the proliferation of cyanobacteria producing cyanotoxins that can be harmful to human and animal health, and consequently low dissolved oxygen concentrations and compromise aquatic life (USEPA, 2020).

The weak relationship of chlorophyll concentration to phosphate increase was probably restricted by physical factors such high turbidity that influences light intensity for photosynthesis and low water residence time (Calijuri *et al*., 2008). In rivers there is an apparent decrease in chlorophyll production per unit of phosphorus when total phosphorus exceeds approximately 0.3 mg/L, showing that nutrient limitation is overcome when there is excess nutrients in the water column (Dodds *et al.*, 2002).

Nitrogen can come from different sources such as agricultural fertilizers (Honisch *et al.*, 2002), wastewater and atmospheric deposition (USEPA, 2020). Sources of phosphorus in rivers include eroded riverbanks, agricultural runoff, domestic effluent, detergents, and animal waste (USEPA, 1986, 2006, 2020).

The Infulene river water is mostly used for irrigation and recreation, as stipulated in Decree 18/2004. The results obtained, except for the upstream region, show above-described values for phosphate, total dissolved solids and *E. coli* concentration for irrigation water and turbidity and *E. coli* levels for recreational water, showing an urgent need for proper river management.

The presence of *E. coli* in water indicates inadequate hygienic-sanitary conditions and/or faecal contamination from mammalian intestines, as river water is used for irrigation, it contaminates the agricultural supply chain (Uyttendaele *et al.*, 2015; Dhananjayan & Ravichandran, 2018) from water as raw material to the final consumer, thus constituting a threat to Public Health of consumers especially foods eaten raw like lettuce. Water used in agriculture is considered as one of the risk factors for contamination of fresh produce with pathogenic microorganisms (Decol *et al.*, 2017; Truchado *et al.*, 2018), leading to subsequent outbreaks of diseases transmitted by leafy vegetables consumed raw (Allende & Monaghan, 2015).

The world's water resources have significant ecological and socioeconomic importance, however, sustainable use and restoration are matters of utmost importance to the economy and society. The management of these resources is very complex, as it depends on reconciling the uses of water such as human consumption, irrigation, and industrial uses (Calijuri *et al.*, 2008).

As for the ecosystem, the river presents water quality above recommended, which can compromise aquatic life, with the central and downstream regions presenting high concentrations of nutrients such as phosphate that promotes primary productivity, a fact notable by the high chlorophyll present in the river (13-46 µg/L) whose chlorophyll peaks followed the phosphate peaks. The excess organic matter as well as senescence of organisms increased water turbidity and the rate of decomposition of organic matter by aerobic bacteria, which contributed to the reduction of dissolved oxygen, this can harm aerobic organisms like fish.

Phosphorus concentration >25 µg/L can stimulate the growth of algae and macrophytes that impart undesirable taste and odour to water and interfere with swimming (USEPA, 1986, 2020). According to Hutchinson (1957) and Wetzel (2001), rivers containing phosphorus concentration above 0.03 mg/L and 0.05 mg/L respectively are considered polluted, as is the case of this river. The decomposition of algae and macrophytes causes the reduction of dissolved oxygen, causing additional stress to aquatic life (USEPA, 2020). Dissolved Oxygen concentration <4 mg/L is not suitable for aquatic life for tropical waters (USEPA, 1986).

The TSI ranged from Super-Hypereutrophic, the overall water quality suggests high nutrient concentration, which may favour the proliferation of primary productivity. This result shows there is a high potential of causing impacts to the water quality and consequently the aquatic biota by not presenting acceptable levels of eutrophication. The results may be related to the fact that the river is close to brewery factory, urban centres where effluent treatment is not carried out, and to the fact that there is intense agricultural activity along the river mainly in the downstream area, an activity where most farmers lack training and basic sanitation, which increases the amount of phosphate from the droppings and direct waste disposal by farmers.

Zimpeto showed a higher index compared to the other points probably because it receives phosphate-rich domestic effluent from waste and detergents without prior treatment from the broken down Zimpeto WWTP.

Agricultural and urban land contribute varying amounts of diffuse sources of phosphorus in stream drainage from rainfall runoff or irrigation return flow. Phosphorus in the form of phosphate is one of the major nutrients required for primary productivity. Excessive increase in primary productivity has been pointed out because of increased phosphorus supply causing the phenomenon associated with a eutrophication condition (USEPA, 1986).

The eutrophication process is characterized by an increase in phosphorus concentration from domestic effluents or urban runoff and fertilizers from agricultural areas (Wetzel, 2001; Smith, 2003; Wood *et al.*, 2005; USEPA, 2020). This addition triggers a chain of events starting with an excessive increase in the growth of primary producers such as algae (USEPA, 2020), as these are generally phosphorus-limited in aquatic ecosystems. Currently, eutrophication constitutes one of the biggest environmental challenges (Zak *et al.*, 2019).

Risk analysis indicated that both punctual and diffuse pollution sources contribute to the water quality of the Infulene river, and two critical causes for the pollution of the river were identified, namely: the loss of functionality of the WWTP and surface runoff and soil erosion. These causes may justify the high load of physicochemical and biological pollutants found in the Infulene river Basin, since the Zimpeto WWTP is not in operation and effluents are discharged into the river without prior treatment, coupled with the fact that the high land occupation (due to the increase in informal and industrial settlements and intense agricultural activity) contributes to increased surface runoff and consequent soil erosion of agricultural land near the river.

The main sources of nutrient inputs into aquatic systems are punctual and diffuse pollution sources (Ding & Feng, 2022). Small stream catchments are more prone to pollution due to human influences associated with agricultural activities (Loss *et al.*, 2019; Halecki *et al.*, 2022), settlements, developments (Halecki *et al*., 2022), factories (Simate, 2015; Khumalo *et al.*, 2022) and surface runoff (Andrade *et al.*, 2021) as is the case of the Infulene river.

8. CONCLUSION AND RECOMMENDATIONS

Infulene river displayed regions with high level of pollution, especially in Zimpeto and Infulene. The poor water quality of the river is explained by the presence of diffuse and punctual pollution sources, that include: (1) discharges of domestic wastewater from Zimpeto wastewater treatment plant, industrial wastewater from brewery factory, (2) water discharge from Maputo's drainage system, contaminated by runoff form informal settlements with poor sanitation and (3) runoff from urban agricultural areas in the riparian area of the river contaminated by fertilizers.

The water of Infulene river is unsuitable for irrigation (mainly for products eaten raw) and recreation as it presents concentration of *Escherichia coli* above the stipulated standards, constituting a danger for Public Health. This water is also a danger to aquatic organisms because it contains high concentration of nutrients such as phosphates and nitrates that compromise the aquatic organisms.

The measures to improve the water quality of the Infulene river basin include: (1) controlling the use of fertilizers and agricultural wastes; (2) installation of waste containers and public toilets; (3) replanting of riparian vegetation, treatment, and regular monitoring of domestic and industrial wastewaters; and (4) improving sanitation in informal settlements to reduce contamination of drainage waters.

It is recommended that for future studies, the water quality of the Infulene river basin should be analysed monthly for at least one year and that the same methods should be used during the analysis to compare water quality during the dry and rainy seasons. It is also recommended that pesticide and aquatic biodiversity analyses of the river and also soil quality analyses of the Infulene river basin be carried out.

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10. APPENDICES

10.1. Geographical Location of Sampling Sites

Sampling points in the Infulene river basin (Tables 1 and 2).

Tabela 1. Geographical location of the points in Drainage system.

Nr	Details	Latitude	Longitude
1	Acordos de Luzaca Avenue / Joaquim Chissano Avenue	-25.94710	32.57920
2	Acordos de Luzaca Avenue / Joaquim Chissano Avenue	-25.94753	32.57878
3	Maxaquene neighborhood outlet	-25.93664	32.57944
4	Xipamanine	-25.94386	32.57291
5	Angola Avenue / departure from Mafalala neighborhood	-25.94534	32.57248
6	Exutory of the Xipamanine neighborhood / Airport B	-25.93845	32.56677
7	Airport A	-25.93806	32.56720
8	Airport B: conduct	-25.93939	32.56372
9	Airport B: main channel	-25.93940	32.56374

Table 2. Geographical location of the points in the river and the potential sources of pollution.

Nr	Details	Latitude	Longitude
1	Marracuene- Upstream	-25.771676	32.57433
2	Intaka- Bridge near Intaka village (Upstream)	-25.78613	32.57709
3	Zimpeto- Zimpeto WWTP (potential source of pollution)	-25.828888	32.56677
4	Zimpeto river- Midstream	-25.829313	32.56605
5	Benfica river- Midstream	-25.88739	32.55876
6	Infulene-before contamination of drainage system and and brewery factory (Downstream)	-25.918748	32.54245
7	Infulene- Outlet of Drainage System (potential source of pollution)	-25.920833	32.54445
8	Infulene- Waste water from brewery factory (potential source of pollution)	-25.920992	32.54319
9	Infulene- After Contamination of Drainage System and and brewery factory (Downstream)	-25.92328	32.53698

10.2. Surveys to Farmers

a) Socio-Demographic Profile

i. Code: ________________________________ Age:____ Gender: ________

ii. Level of education: _________ Reading: ____ Writing: ______ Counting: ____

iii. How long have you practice this activity: ___________________________________

iv. Alternative sources of income: ____

b) Occupational Profile

i. Production plots: _____ Main products grown:____________:____________________

ii. What type of fertilizer do you use:____________________ Frequency:______________

iii. Do you have any knowledge of care during irrigation? What kind?

____

iv. Have you had any training: ____ When:_____ What institution: __________________

v. What days of the week do you work: ______ Holidays: ____ Duration (h):__________

i. Where and How you collect water for irrigation:_________ and:___________________

ii. Deworming:____________Frequency:____ If not, Why:__________________________

iii. What are the aspects you would like to see improved in the work?

____

c) Sanitation

i. What is the source of water for washing hands, food, and consumption: ____/____/ __

ii. Is there a public toilet:_______Where do you defecate:__________________________

iii. Do you use the water from the river for another purpose: ___ Which: _______________

iv. Where is the solid and liquid waste generated disposed of: _______________________

v. Are there garbage containers in the are: ____ Do you use: ____Who disposes of: ____

vi. Has the municipality been cleaning the river: _____ Frequency: __________________

Observations:____

____

____

____