Variability in Salinity and Other Variables in the Santa Inês Creek and Ourém Creek from July 2023 to February 2024

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DECLARATION BY STUDENT

I hereby declare that the data presented in this Dissertation report entitled, "Variability in salinity and other variables in the Santa Inês Creek and Ourém Creek from July 2023 to February 2024" is based on the results of investigations carried out by me in the M.Sc. Environment Science at the School of Earth, Ocean and Atmospheric Sciences, Goa University under the Supervision of Dr. Joshua Rosario D'Mello and the same has not been submitted elsewhere for the award of a degree or diploma by me. Further, I understand that Goa University or its authorities will not be responsible for the correctness of observations / experimental or other findings given the dissertation.

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COMPLETION CERTIFICATE

This is to certify that the dissertation report "Variability in salinity and other variables in the Santa Inês Creek and Ourém Creek from July 2023 to February 2024." Is a bonafide work carried out by Mr. Thoudem Roshan Singh under my supervision in partial fulfilment of the requirements for the award of the degree of Masters of Science in the Discipline of Environmental Science at the School of Earth, Ocean and Atmospheric Sciences, Goa University.

Date: 22nd of April, 2024

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PREFACE

The intricate dynamics of coastal ecosystems demand a thorough understanding of their variability to mitigate potential environmental impacts. This research delves into the variability of salinity and other variables within the Santa Inês Creek and Ourém Creek, located in the scenic region of Goa, India. Spanning from July 2023 to February 2024, this study scrutinizes the intricate interplay of factors influencing these water bodies. The coastal areas of Goa harbor diverse ecosystems crucial for both ecological balance and human sustenance. However, these ecosystems face burgeoning threats from anthropogenic activities and natural fluctuations. The creeks under investigation witnessed significant alterations in their water quality due to anthropogenic interventions, and natural phenomena, which contribute to the variability observed in the studied creeks. By meticulously analyzing data collected from both creeks, this research aims to unravel the variability in salinity levels and other variables in these creeks. Such insights are paramount for informed decision-making concerning conservation efforts, resource management, and sustainable development along the coastal regions. This preface sets the stage for an in-depth exploration of the variability of Santa Inês Creek and Ourém Creek during the specified timeframe.

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Thoudem Roshan Singh

April 2024

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LIST OF ABBREVIATIONS, ACRONYMS, SYMBOLS AND UNITS

Abbreviation, Acronym, Symbol or Unit	Full-form
‰	per mille (parts per thousand)
BIS	Bureau of Indian Standard
BOD	Biochemical Oxygen Demand
Ca	Calcium
CPCB	Central Pollution Control Board
CCP	Corporation of the City of Panjim
CGWB	Central Ground Water Board
CO_2	Carbon Dioxide
CZMP	Coastal Zone Management Plan
DO	Dissolved Oxygen
EBT	Eriochrome Black T
EDTA	Ethylenediamine Tetraacetic Acid
ESG	Entertainment Society of Goa
GCZMA	Goa Coastal Zone Management Authority
GMC	Goa Medical College
GSPCB	Goa State Pollution Control Board
LiDAR	Light Detection and Ranging
M	Molar
m	Meter
Mg	Magnesium

mg/L	Milligram per Litre
ml	Milliliter
$NaNO_2$	Sodium Nitrite
NaOH	Sodium Hydroxide
NBS	Nature Based Solution
NH_3	Ammonia
NIO	National Institute of Oceanography
NO_2	Nitrite
NO_3	Nitrate
OD	Optical Density
PULL	Project Urban Living Lab in Panjim
SAPCC	State Action Plan for Climate Change
SoI	Survey of India
SW	Surface Water
TERI	Transitions Research and the Energy and Resources Institute
WHO	World Health Organization
WQMS	Water Quality Monitoring and Surveillance

ABSTRACT

The amount of information available on the salinity and physico-chemical parameters of Santa Inês Creek and Ourém Creek in Goa is currently limited. This study aimed to assess the salinity and physico-chemical parameters of both these creeks using the Water Quality Monitoring and Surveillance (WQMS) framework and Bureau of Indian Standards (BIS) guidelines. Santa Inês Creek's salinity fluctuated monthly, influenced by precipitation and tides. During monsoon, most stations recorded zero salinity due to rainwater influx, contrasting with post-monsoon levels of 10 ‰ to 20 ‰ in October 2023 and February 2024 respectively, signifying saline water presence in Santa Inês Creek. Ourém Creek experienced a similar trend, with increasing salinity from July 2023 to February 2024, demonstrating greater saline influence. Physico-chemical analyses revealed fluctuating parameters. Both creeks exhibited acceptable pH levels during monsoon and post-monsoon, but conductivity, total dissolved solids (TDS), and turbidity exceeded permissible limits, particularly post-monsoon. High TDS concentrations, exceeding 500 mg/L, rendered the water unsuitable for drinking. Total hardness, phosphate, and nitrite levels varied spatially and temporally, influenced by proximity to pollution sources. Conclusively, Ourém Creek remained saline throughout most months, while Santa Inês Creek's salinity varied seasonally. Monsoon months exhibited relatively acceptable pollutant levels, but post-monsoon saw a significant rise, especially in Santa Inês Creek. Continuous monitoring and mitigation efforts are crucial to preserve both creeks' ecological integrity and prevent further pollution-induced damage.

KEY-WORDS

Santa Inês Creek; Ourém Creek; Salinity; Physico-chemical parameters; monthly; seasonal; Pollution

CHAPTER 1

INTRODUCTION

CHAPTER 1: INTRODUCTION

1.1 General

Creek water, sometimes referred to as stream water, is an essential part of our natural surroundings because it is the main supply of fresh water for a large number of ecosystems and communities across the globe. Often thought of as tiny streams or brooks, creeks are vital to the ecosystem and provide several advantages to communities, societies, and ecosystems. Understanding the importance of creeks encompasses their ecological, hydrological, social, and economic significance. According to the Cambridge Dictionary (https://dictionary.cambridge.org/dictionary/english/creek), a creek is a narrow area of water that flows into the land from the sea, river, lake, etc. and according to the Collins Dictionary, a creek is a narrow place where the sea comes a long way into the land (https://www.collinsdictionary.com/dictionary/english/creek).

Numerous aquatic and riparian species, such as fish, amphibians, insects, birds, and plants, call creeks home. Rich biodiversity is supported by these habitats, which offer many species home, food, and breeding grounds. The resilience and general ecological balance of the surrounding landscapes are enhanced by healthy creek ecosystems. Since they move water from higher elevations to lower ones, replenish groundwater reserves, and maintain downstream flows in rivers and lakes, creeks are essential to the hydrological cycle. They lessen flooding by absorbing excess runoff after heavy rains, control local and regional water supply, and preserve steady streamflow patterns that are vital to aquatic life and ecosystem health.

Creeks help regulate climate by absorbing carbon dioxide (CO_2) from the photosynthesis of aquatic plants and riparian vegetation. Creek-related wetland regions act as carbon sinks by accumulating organic matter and gradually sequestering carbon. Reducing greenhouse gas emissions and increasing ecosystem resilience to extreme weather events are two ways that healthy stream ecosystems help mitigate the effects of Climate Change. However, creek water quality can be harmed by a variety of human activities and natural processes, posing serious dangers to the environment and public health. As a result, the examination of creek water's chemical, physical, and biological properties to guarantee its sustainability and safety has emerged as a crucial field of research.

The devastation of water resources due to recent unplanned industrialization, increasing urbanization, and their usage as trash disposal sites, depletion of water resources are some challenges in maintaining water quality. The sewage or the water that has been utilized is known as wastewater. It originates from industrial, domestic, and agricultural processes that bring hazardous chemicals, sludge, metals, and solvents into the water bodies, degrading the water quality and causing harm to humans and the ecosystem.

Water can dissolve more materials than any other liquid on the planet, that's the cause why contaminating water is so simple. Water becomes contaminated when toxic substances from factories, towns, and farms mix and dissolve easily. These toxins, which are harmful to aquatic life, move up the food chain as predators devour prey. This shortens the life span of organisms and impairs their capacity to reproduce.

The examination of creek water is necessary for a number of reasons, including environmental monitoring, keeping an eye on the water quality in creeks can assist detect possible contaminants and comprehend how human activity affects aquatic ecosystems. It makes it possible to put suitable management plans into place to safeguard and maintain these priceless resources. Analysing creek water is crucial for locating pollutants that could endanger human health when consumed or when engaging in recreational activities like fishing and swimming. The detection of hazardous materials allows authorities to take the appropriate action to protect public health.

To safeguard aquatic habitats and public health, governments, and regulatory organizations set water quality standards and regulations. Analysing creek water makes it easier to evaluate how well these standards are being followed and pinpoint areas that require improvement to comply with regulations. To learn more about the biological variety, nutrient cycling, and overall functioning of aquatic ecosystems, researchers examine the water in creeks. The creation of successful conservation and management plans is aided by this knowledge.

To determine the overall quality of creek water, several physical, chemical, and biological criteria are evaluated. Information about the state of creek water and its surroundings can be gained by examining physical attributes like temperature, turbidity, conductivity, and flow rate. They affect the movement of contaminants and the dispersal of aquatic life. Determining the amounts of different elements in creek water, such as dissolved oxygen, pH, nitrates, phosphorus, hardness, heavy metals, and different chemical pollutants is part of the chemical analysis process. These compounds, which have a major impact on ecosystem health and water quality, might come from natural sources or human activity. The ecological health of a watercourse is evaluated using biological indicators, such as bacteria, algae, etc.

Water quality monitoring is getting increasingly difficult because of the numerous pollutants we use daily and in trade that may wind up in aquatic environments. Analysis of water quality is widely utilized in environmental observation. The environment and marine life are both impacted by low water quality. The present study was conducted to assess the physicochemical parameters of Santa Inês Creek and Ourém Creek using the Water Quality

Monitoring and Surveillance (WQMS) framework and the Bureau of Indian Standards (BIS) for water quality standards.

For the Santa Inês Creek development, numerous studies and projects have been created however, for a variety of reasons, they have not yet been put into action. One of the primary obstacles to its renewal is the rehabilitation of the stream is the result of the divided governance of the states and the city of Goa. Essentially, the many government agencies, some of which have overlapping jurisdictions, are in charge of various aspects of the creek's maintenance, there is no single institutional owner.

The creeks are home to a variety of plants and animals, but they also serve as a location for tidal flushing, which is the process by which water is constantly replaced by the tides. For example, when the tide is high, seawater from the Mandovi Estuary enters the city and brings with it a rich biodiversity, including a variety of fish. A mangrove ecosystem is also supported by tidal flushing. The creeks are vital to the city, but they are getting more and more contaminated, silted up, and sluggish. Sewage tankers from casinos, high-rise buildings, informal settlements, and the Tonca Sewage Treatment Plant along with water flowing from CCP’s composting-cum-storage centre at Patto are among the sources of the contamination throwing rubbish into the creeks. The creek's issues extend beyond Panaji since the area's connected wells and water bodies are impacted by pollution from the creeks.

As described by B. M. Gomes (2005), Large stretches of the Ourém Creek, which lives true to its name by becoming a golden-orange colour at dusk, are still surrounded by lush mangroves. A few artisanal fishermen are still pursuing some of Goa's most beloved seafood, including mud crab, shrimp, mangrove red snapper, jack, and Asian seabass, in these waters. The smooth-coated otter, which is playful, continues to feed in these waterways. Additionally, even in the most contaminated area of Santa Inês Creek near Camarabhat, you can be fortunate enough to see the occasional marsh crocodile lazing on its banks. Taleigão's lush fields continue to provide the city with some of the best veggies in the state (Gomes, 2005). In contrast, there hasn't been the same awareness in current urban development. Driven by a sharp rise in the number of people living in Goa, urbanization has spread to the surrounding rural areas of the creeks in response to demand from the real estate market. The Ministry of Housing and Urban Affairs projects that Goa's urban population will increase from its present 62.5 % to 88 % in 2036.

As repurposed Khazan farmlands on the city's periphery have turned into a concrete jungle along major arterial routes heading to the city, it is not surprising that this sprawl has reduced the amount of green space in the city and directly affected the biodiversity near and within the creeks in Panjim. All of this might lead to an increase in stormwater runoff from impermeable surfaces, which would eventually result in isolated flooding. For instance, Santa Inês Creek, which has been allowed to flow unhindered for the past 200 years, is today neglected. Now, silt pushed in by the Mandovi Estuary into which it drains, along with solid trash and sludge deposited from different sections of the city, choke it in different places. The situation is exacerbated by the now-polluted and stagnant rivers, which provide support to invasive and quickly spreading floating vegetation such as water hyacinths. All it takes for the creek to overflow is a prolonged period of heavy rain, which floods roads in various parts of the city and carries sewage and rubbish with it.

Water from CCP's composting/ storage centre in Patto has been gradually contaminating Ourém Creek over the past few years. In addition to the plant's offensive stench, locals claim that wastewater spills straight into the creek, endangering the body of water, because there is no collection tank for the water. The creek's waters flow into the Mandovi Estuary, which is only a few kilometres from the location of CCP's composting-cum storage facility. Despite the lack of an analysis of the Ourém Creek's water quality, residents and environmentalists are of the opinion that the water is becoming contaminated. There has not been any evidence of quality analysis work being done in this creek. Hence it is crucial to conduct a quality analysis to indicate the creek's current status and its pollution susceptibility.

The Santa Inês Creek and Ourém Creek, are indeed worthy of serious attention due to their ecological significance and the roles they play in the local environment. Both the creeks support diverse ecosystems, including various flora and fauna. These creeks may serve as habitats for fish, birds, and other aquatic life, contributing to the overall biodiversity of the area, they play crucial roles in regulating water flow, reducing flooding risks, and maintaining water quality. They also help in groundwater recharge and provide a source of water for irrigation and other purposes. These creeks can offer recreational opportunities like fishing, boating, birdwatching, and hiking along their banks. Additionally, they contribute to the aesthetic appeal of the landscape, enhancing the overall beauty of the region. Creeks often hold cultural significance for local communities, sometimes featuring in folklore, traditions, and historical narratives. Preserving these water bodies helps maintain connections to the past and fosters a sense of identity and belonging among residents. However, like many natural waterways, Santa Inês Creek and Ourém Creek face threats from pollution, habitat destruction, encroachment, and improper waste disposal.

Protecting and restoring these creeks is essential for safeguarding their ecological integrity and ensuring the well-being of both human and non-human inhabitants. Giving serious attention to Santa Inês Creek and Ourém Creek is crucial for their preservation and sustainable management. These water bodies contribute significantly to the ecological, social, and cultural fabric of Panjim, Goa, and warrant proactive conservation efforts.

1.2 Location and study areas

Goa state lies along the west coast of the Indian subcontinent and encompasses an area of 3702 square kilometres, the North Canara district of Karnataka is located on the south, and the Tiracol (Terekhol) River, which divides Goa from Maharashtra, passes along its north. The Western Ghats are to the east, and the Arabian Sea is to the west. Mandovi and Zuari are the main rivers. Around eleven separate rivers drain the Goa region, mainly flowing from the east (the Western Ghats) to the west (the Arabian Sea). The Sal River in south Goa is an outlier, flowing from northeast to southwest as a result of the west coast fault. The important rivers in Goa include the Tiracol, Arambol, Mandrem, Chapora (Kaisuv), Baga, Mandovi, Zuari, Sal, Saleri, Talpona and Galgibaga. The 42 tributaries on these rivers have a major impact on the lives of people living in the state. The combined drainage of the Mandovi and Zuari rivers accounts for 2553 square kilometres or around 69 % of the total land area of Goa.

The rivers of Goa have the distinction of being both rainfed and tidal. The influence of tides extends far inward from the mouths of all the rivers. The tides' ebb flows can occasionally be seen 40 kilometres inland. The river's salinity factor fluctuates significantly between the monsoon and non-monsoon seasons, as does the water quality in wells along the banks, which tends to get saltier as summer approaches.

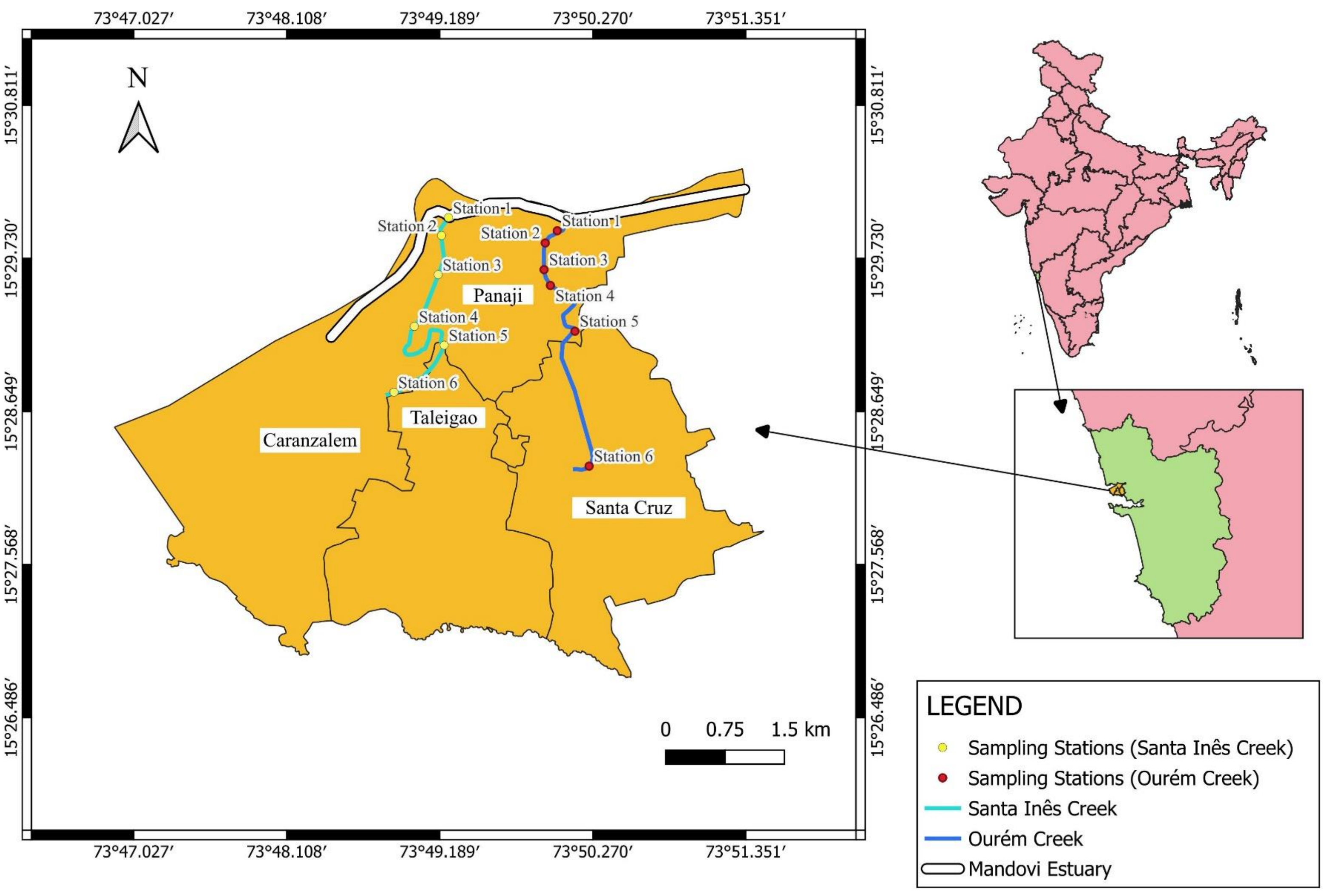


Figure 1.1 Study area Map (Santa Inês Creek and Ourém Creek)

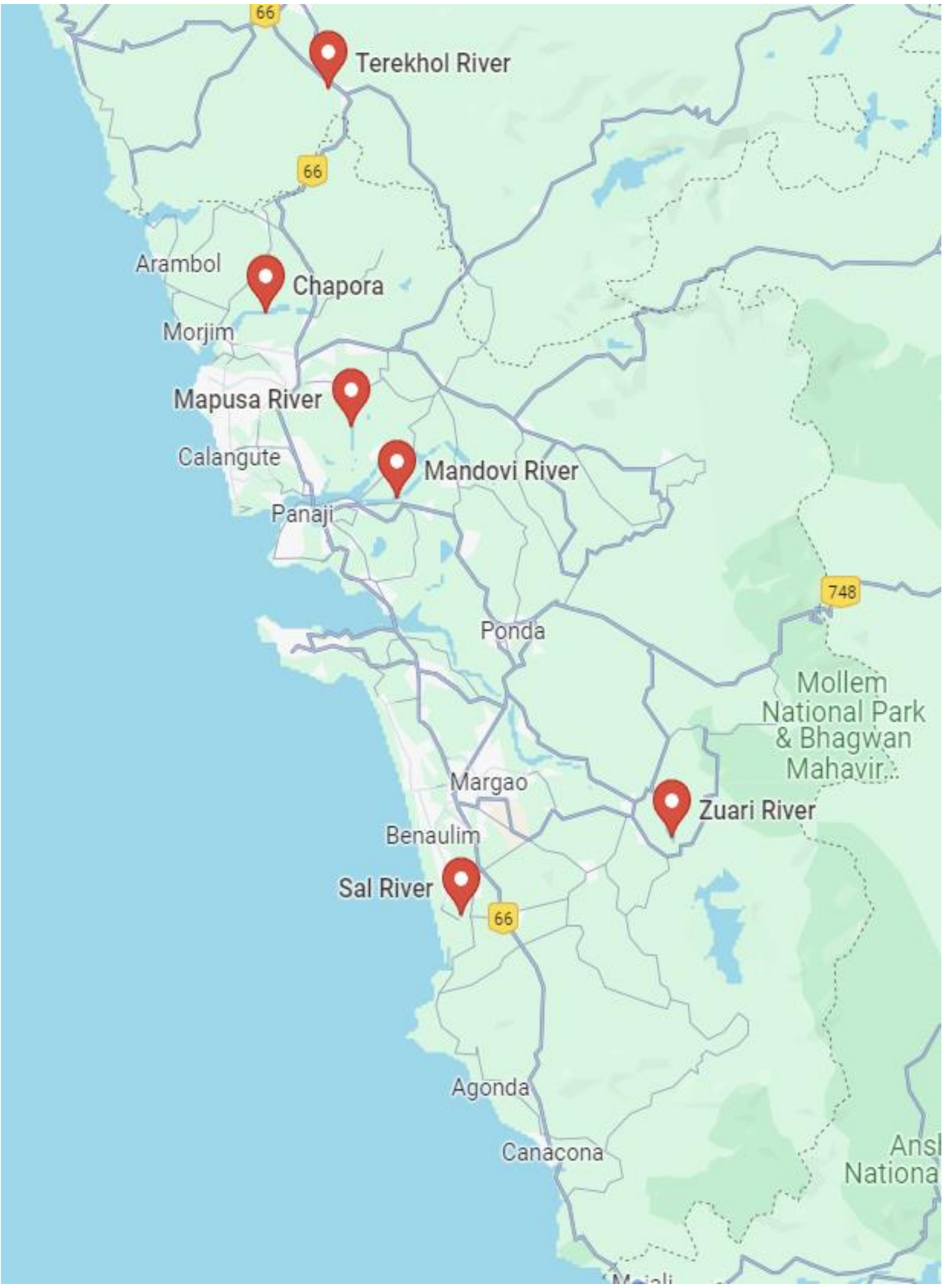


Figure 1.2 Important Rivers of Goa

1.3 Santa Inês Creek

The Santa Inês Creek cut across the city of Panjim, extending from (15°30'01.0" N, 73°49'15.2" E) to (15°28'47.1" N 73°48'52.0" E). It originates at the marshland in Taleigão and is fed by rainwater from the Altinho and Nagalli hills. In Panaji, it passes through Camarabhat, Tambddi Mati, Tonca, flowing behind the Military Hospital, Don Bosco School and by the old Goa Medical College (G.M.C.). It opens up into the Mandovi Estuary, opposite the old GMC/ Maquinez Palace complex, and is a few kilometres upstream to the area where the Mandovi Estuary opens into the Arabian Sea. The existence of the Creek is dated back to 1829 as seen on the Portuguese plaque still visible on one of the 12 culverts (Minerva Bridge) running over the Creek, even though, Historian Percival Noronha dates it back to 1647 (Annual Report 2013– 2014, Goa State Pollution Control Board).

The creek is 3.7 kilometres in length, with a surface area of 65,750 square meters with an average width of 12.6 meters. St. Inez Creek was a tidal waterbody near Panaji, Goa, with ecological purposes. St. Inez Creek's cultural, sociological, and biological significance make it one of the city's most significant freshwater bodies. However, due to a combination of anthropogenic and natural factors, such as eutrophication, weed growth, sedimentation, collapsed embankments, raw sewage release from nearby informal settlements, and the disposal of construction waste, the creek's ecological functionality has recently been seriously jeopardized.

Figure 1.3 Map of sampling locations of Santa Inês Creek

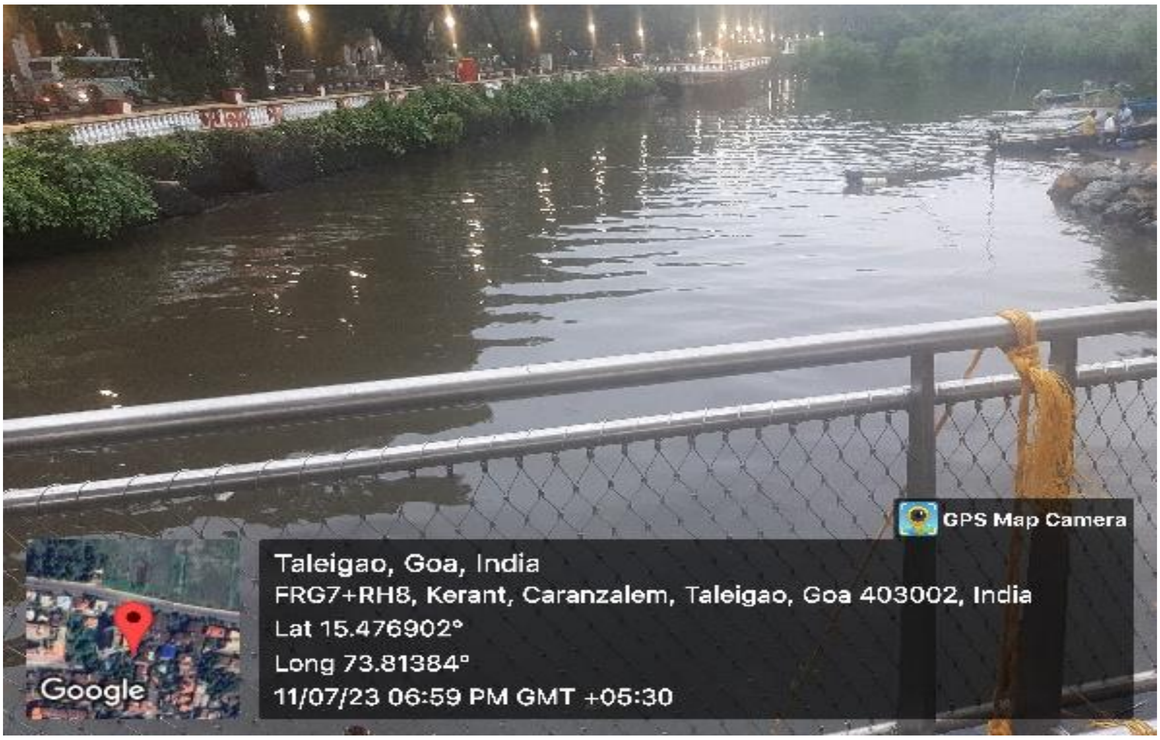


Figure 1.4 Photograph of the first station on Santa Inês Creek

Figure 1.5 Photograph of the second station on Santa Inês Creek

Figure 1.6 Photograph of the third station on Santa Inês Creek

Figure 1.7 Photograph of the fourth station on Santa Inês Creek

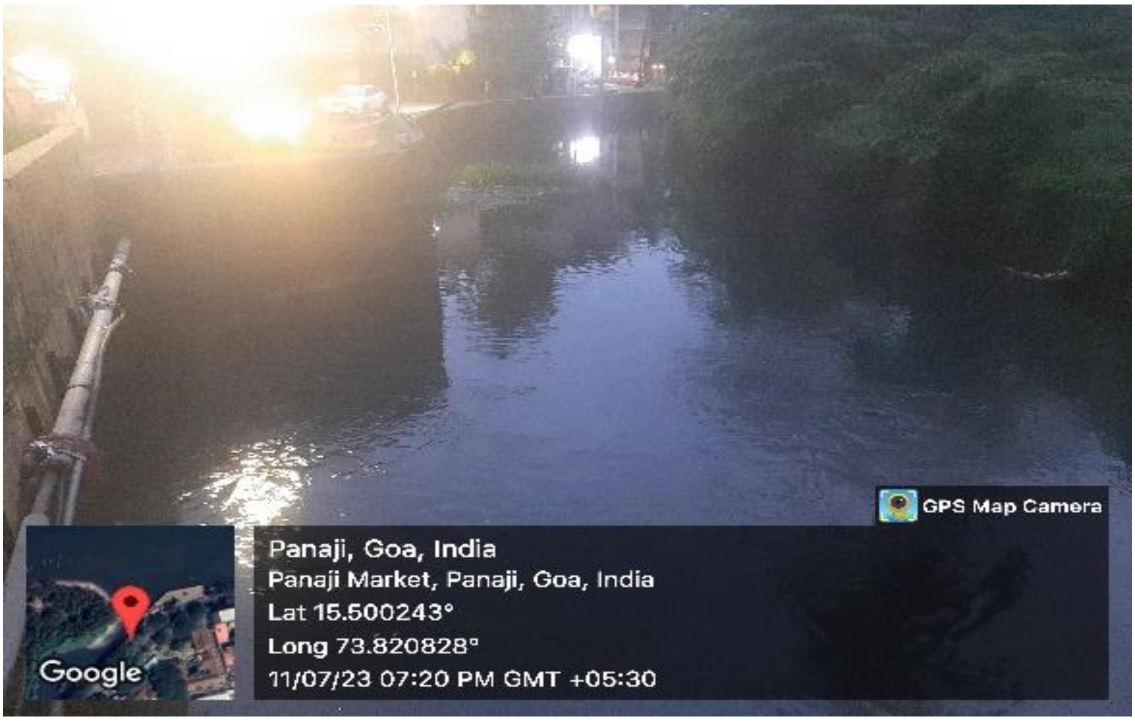


Figure 1.8 Photograph of the fifth station on Santa Inês Creek

Figure 1.9 Photograph of the sixth station on Santa Inês Creek

1.4 Terminology used for the Santa Inês Creek

Over time, the Santa Inês Creek's situation has evolved. For instance, the creek was governed by the local government and categorized as a "nullah" or drain for some years before 2010. The creek might consequently be built upon as a "nullah," and portions of it were even intended to be concretized. Based on evidence of tidal flushing, a subcommittee of the Jawaharlal Nehru National Urban Renewal Mission's urban project voted in 2010 to reclassify the Santa Inês Nullah as a creek, which it was originally. Next, the Goa State Pollution Control Board (GSPCB), members of the Panaji Legislative Assembly, and other interested parties classed the creek as a nullah during a workshop in 2015. The Goa Coastal Zone Management Authority (GCZMA) was particularly instructed by the National Green Tribunal in 2019 to investigate reclassifying Santa Inês Creek as a creek by altering its classification in the state's Coastal Zone Management Plan (CZMP), based on scientific findings.

1.5 Ourém Creek

The Ourém Creek is a tributary of the Mandovi Estuary, meeting it in Panjim, extending from (15°29'55.5" N, 73°50'01.2" E) to (15°28'15.7" N, 73°50'14.7" E). The creek flows through agricultural landscapes called the Khazan lands, which were reclaimed from the mangroves (Gomes, 2005). Ourém Creek originates from Santa Cruz wetlands, passing via the *Band* from Santa Cruz to Taleigão, flowing through Chear Khambe (Four Pillars) on the Panjim-Santa Cruz old-highway road. Further downstream, the Ourém Creek has the Portais, Mala, Fontainhas areas of Panjim on its left bank and the Morombi O Pequeno and Patto areas on its right bank. The Ourém Creek then meets the Mandovi Estuary.

It is thought that Panaji derives its name from the term Panaz, which means an area that gets waterlogged (Gomes, 2005). The majority of the city was low-lying marshlands in the

Mandovi's flood plains before it was made the capital of Goa in 1843, with a few fishing villages strewn around the river's banks. The phrase "Ouro" which means "like gold" is the source of the creek's name, suggesting that it was once a bustling stream that sustained a large artisanal fishery (Gomes, 2005).

Ourém Creek is located near a variety of mangrove cover, which contributes to the creek's enormous biodiversity and bird species. Originating in the wetland of Santa Cruz, it holds great ecological significance in the surrounding region.

Figure 1.10 Map of sampling locations of the Ourém Creek

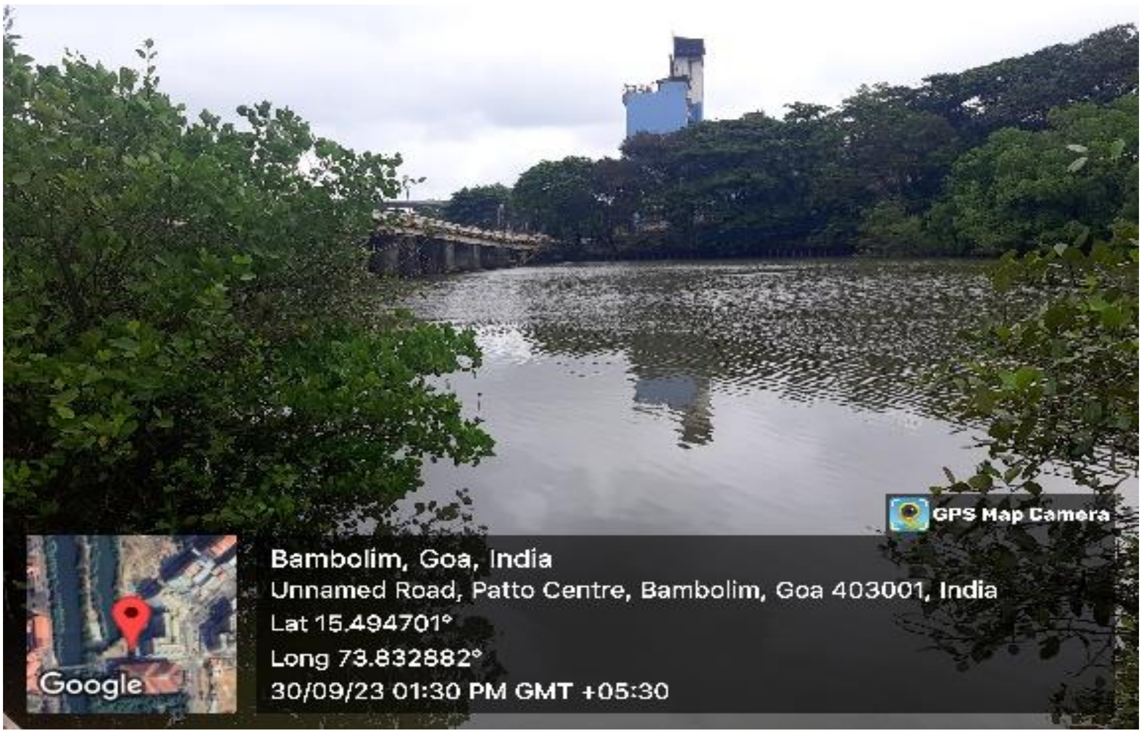


Figure 1.11 Photograph of the first station on Ourém Creek

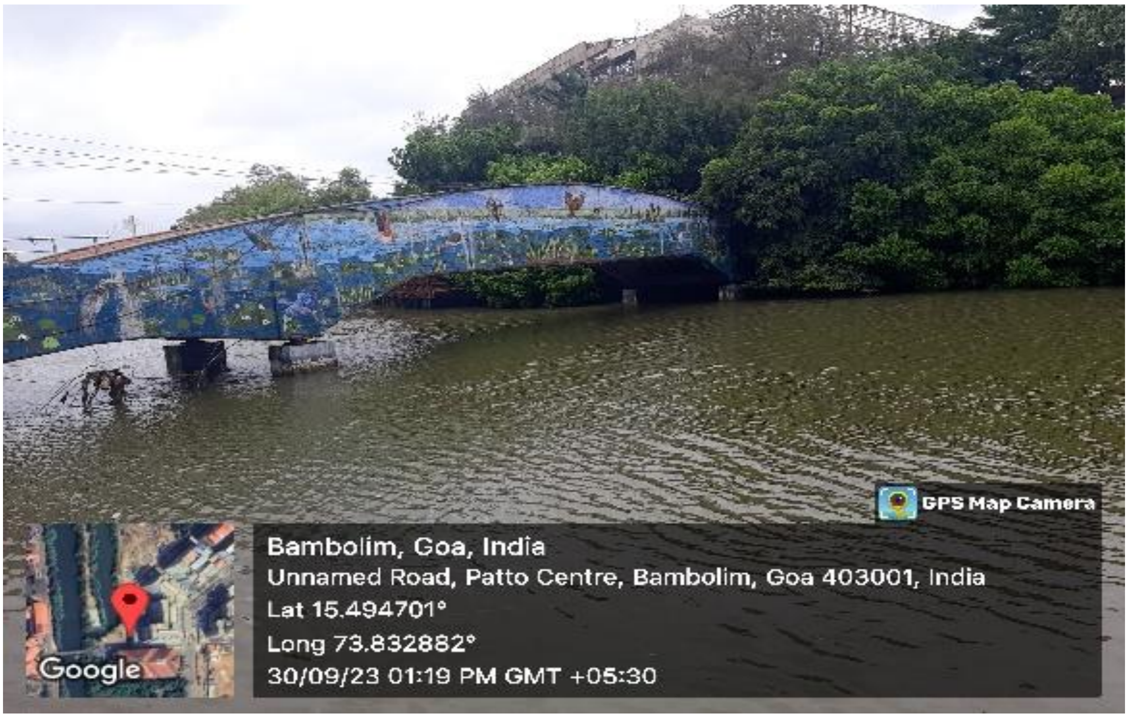


Figure 1.12 Photograph of the second station on Ourém Creek

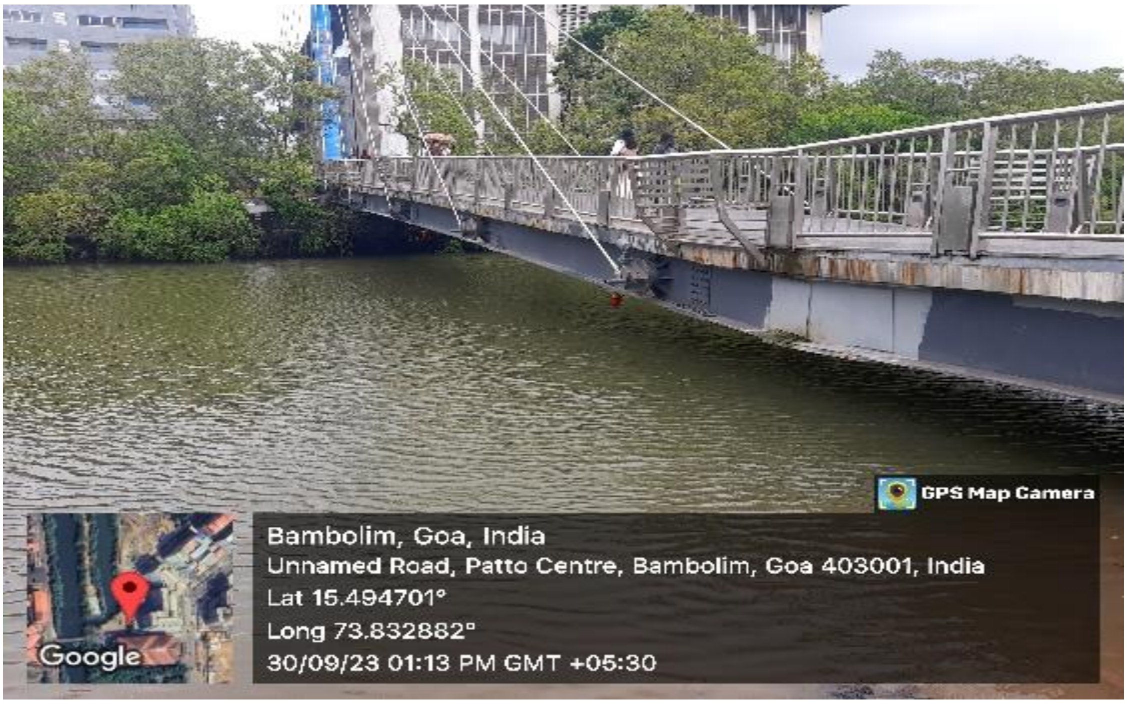


Figure 1.13 Photograph of the third station on Ourém Creek

Figure 1.14 Photograph of the fourth station on Ourém Creek

Figure 1.15 Photograph of the fifth station on Ourém Creek

Figure 1.16 Photograph of the sixth station on Ourém Creek

1.6 Climate

Goa enjoys a hot and humid environment for most of the year due to its tropical location close to the Arabian Sea. Goa receives the majority of its yearly rainfall during the monsoon season, which runs through late September. In March 2008, Goa had intense rainfall and gusty winds. It had rained in March in Goa for the first time in 29 years (Department of Information and Publicity, Government of Goa, 2024).

Goa is one of the wettest states of India which receives an average rainfall of 3483 mm. Monsoon from the southwest contributes to 90 % of the rainfall in the state. The state has a tropical, warm, and humid kind of climate. Goa State is blessed with a tropical monsoon climate. The majority of the year in Goa is hot and humid due to its tropical location close to the Arabian Sea.

The warmest months are April and May when high humidity and daytime highs of above 35 °C are common. Early June marks the start of the monsoon season, which lasts until September and provides the majority of Goa's yearly rainfall. The winter season in Goa lasts just from mid-December to mid-February. During these months, days average approximately 28 °C with moderate humidity and temperatures of about 21 °C. Due to the altitudinal gradient, the nights are a few degrees colder farther inland.

1.7 Physiography

Panjim, the capital of Goa, in south-western India, lies on the left bank of the Mandovi Estuary, a few kilometres upstream from where the Mandovi Estuary opens into the Arabian Sea. Panjim is located in Ilhas. The longitude and latitude of Panaji are 73.5 degrees east and 15.25 degrees north, respectively. The town occupies a mere 36 square kilometres. Situated on an island, in the Taluka of Tiswadi, the city is nearly at sea level. It rises to an elevation of 60 meters. The area of Altinho in Panjim is on a hill. The backwaters and creeks that make up Panaji's main topographical features serve as defining characteristics of the city.

Tiswadi, a taluka in the district of North Goa in Goa, is also referred to as Ilhas. Panjim is located on a part of an estuarine island that is situated between the Zuari and Mandovi Estuaries. Geographically, it is comprised of several small riverine islands that are bounded by the Zuari River to the south, the Mandovi River to the north, and the Cumbharjua Canal to the east. Besides the large island on which Panjim is situated, this sub-district comprises the following smaller islands, as suggested by its native name: Chorão, Divar, Sto. Estevam, Cumbharjua and Vanxim. Additionally, there are some little sandbars and mangrove islands.

The study area is located in Tiswadi taluka of the North Goa district. The geographical area of the North Goa district is 1736 square kilometres and the taluka cover is 193.64 square kilometres. The North Goa district is bordered to the north by the district of Sindhudurg in the state of Maharashtra to the east by the districts of Belgavi (Belgaum) and Uttara Kannada (North Canara) in the state of Karnataka, to the south by the district of South Goa, and the west by the Arabian Sea.

Santa Inês Creek and Ourém Creek are tidal-creeks which traverse Panjim, and these tidal-creeks comprise the research area. Panjim's storm-water drainage system are connected to these creeks and these creeks in-turn are connected to the Mandovi River, which in-turn is connected to the Arabian Sea. These storm-water drains were built to help in the preventing of flooding in Panjim– as most of Panjim was said to be low-lying marshlands along the flood-plains of the River Mandovi (Bhandari et al., 2022).

1.8 Aim and Objectives

The main aim of the dissertation is to determine the variability in salinity and other variables in Santa Inês Creek and Ourém Creek from July 2023 to February 2024. The objectives of the work include

- To study the monthly variability of salinity of Santa Inês Creek and Ourém Creek from July 2023 to February 2024
- To study the seasonal variability of other physical and chemical parameters at different locations in Santa Inês Creek and Ourém Creek, in the period from July 2023 to February 2024.
- To estimate the extent of the tidal effect in Santa Inês Creek and Ourém Creek.
- Quality analysis and pollution estimation of both the creeks (monsoon and post-monsoon).

1.9 Hypotheses

- The surface salinity in each of the creeks is inversely proportional to the amount of monthly precipitation.
- During monsoon, intense rainfall and run-off will reduce surface salinity in the creek to almost freshwater conditions (0 ‰) in most of the locations.
- Mangroves are observed in both the creeks. During the post-monsoon season, the surface salinity level may rise inside the creek for a few kilometres due to the tidal influx of saline water from the Mandovi Estuary.
- Based on the colour of the observed water in Santa Inês Creek, it might have higher levels of pollutants.

- While Ourém Creek is expected to have lower pollutant levels than Santa Inês Creek, the higher probability of escape of contaminated water from surrounding treatment plants and composting and storage centres at Patto, may occasionally increase the pollutant levels in the former.
- During the monsoon season, the pollution level is likely to be lower compared to the post-monsoon period in both creeks.

CHAPTER 2
LITERATURE REVIEW

CHAPTER 2: LITERATURE REVIEW

The Goa State Pollution Control Board in 2013-2014 conducted a study entitled "Status Study of St. Inez Creek to check the extent of Environmental Degradation as a result of Anthropogenic Activities, Civic Infrastructure, and Natural Causes" with the following objectives

1. To attempt to explore and establish the sources responsible for the degradation of the Creek.

2. To determine the extent of environmental degradation of the Creek as a result of reported indiscriminate disposal of wastes and natural runoffs.

In their study, the entire Creek and its sources of discharge are included in their study's scope. To identify seasonal fluctuation, a one-year study was started by them in November 2013. The full length of the creek has been mapped on the Google map following an initial survey of the entire creek. A total of 22 locations were chosen for sample collection throughout the survey, and in December 2013, those locations were narrowed down to 18 in number (Annual Report 2013 – 2014, Goa State Pollution Control Board).

During the surveys, the following observations were made in the Santa Inês Creek: The Creek appeared to be heavily silted. Raw sewage discharge was seen at many locations along the entire stretch of the Creek. Heavy hyacinth growth was observed at a number of places including Camara Bhat pond and near the Tonca STP (Annual Report 2013 – 2014, Goa State Pollution Control Board). Samples were collected during low tide in November 2013, high tide in January 2014, and December 2013, the samples were then analysed in the Board laboratory. Several parameters have been examined, nevertheless, the following table presents the specifics of some of the parameters. The parameters shown in the table show the concentration range throughout the Creek's length. Generally speaking, as per the Annual Report 2013 – 2014 of the Goa State Pollution Control Board the range's minimum value represents the concentration upstream, while the range's maximum value represents the concentration at the extreme downstream (Annual Report 2013 – 2014, Goa State Pollution Control Board).

Table 2.1 Parameters indicating concentration range over the entire stretch of the Santa Inês Creek (Source: Annual Report 2013 – 2014, Goa State Pollution Control Board)

Month of Monitoring	**pH**	**Conductivity (µS/cm)**	**TDS (mg/l)**	**Chlorides (mg/l)**	**DO (mg/l)**	**BOD (mg/l)**	**Total Coliform (MPN/100 ml)**	**Faecal Coliform (MPN/100 ml)**	***E. coli***
November 2013	6.41 – 7.23	123.08 – 7160	73 – 2146	300	1 – 4.1	1.3 – 50	5400 – 9800000	2200 – 3500000	Present
December 2013	6.0 – 8.0	139.27 – 34420	78 – 15248	22 – 11741	1 – 2.7	3.2 – 26	13000 – 3500000	7800 – 1700000	Present
January 2014	6.87 – 7.77	—	326 – 37312	10 – 15473	0 – 4.3	3.3 – 96	330000 – 3500000	130000 – 1700000	Present

Their laboratory study indicates that the pH is within the normal range in the Santa Inês Creek, exhibiting no notable change, and is measured at most places in the range between 6.25 and 7.23. Seawater is present in the Creek up to its centre point during high tide, based on the readings of conductivity. When the tide is low, conductivity decreases, signalling a receding tide and an influx of seawater up to the creek's centre point when it is high. Because of the significant organic load from sewage and decomposing waste, dissolved oxygen ranges from low to 0 or 1 mg/L in the majority of sample locations. Furthermore, supporting this is the BOD range, which varies from 1.3 mg/L to 50 mg/L at low tide and 3.2 mg/L to 96 mg/L at high tide (Annual Report 2013 – 2014, Goa State Pollution Control Board).

A publication produced as part of the Project Urban Living Lab in Panaji (PULL), with the financial support of the Danish Ministry of Foreign Affairs, Royal Danish Embassy, New Delhi, by Oxford Policy Management, Transitions Research, and The Energy and Resources Institute (TERI) named "St. Inez Creek Rejuvenation Plan (2021)" lays out a broad framework for developing a shared vision for the revitalization of the Santa Inês Creek and highlights important challenges in the planning and management of the creek. It establishes particular objectives that, if met, will allow the water body to be restored to its intended purpose. It highlights certain actions that should be taken by the creek's body in the short and medium term to accomplish particular objectives. Some initiatives and measures must be carried out in the watershed as well as along the creek's body to sustainably improve the creek's health. Using best techniques from Danish experience and those that have achieved significant impact from the Indian context of using natural-based solutions (Ramanathan et al., 2021).

To gather topography data for the city, the PULL carried out a ground-based survey and an airborne drone-based Light Detection and Ranging (LiDAR) survey. Cross-sectional information on Santa Inês Creek and its visible outfall pipes that drain into it was gathered during the survey. In addition to the survey, the PULL explored the stream and engaged in interactive mapping activities to better understand its current state. Knowledge Partner Ramboll was in charge of the data analysis. The following are some of the analysis's primary conclusions: (1) The creek's cross-sectional area varies from 6 to 42 square meters; (2) the cross-sectional area increases as one moves downstream from upstream; and (3) identification of local encroachments and shallow parts (Ramanathan et al., 2021).

The Santa Inês creek has an average slope of only 0.5 % and exhibits obvious encroachment, obstruction, and siltation. Sudden decreases in cross-sectional flow areas cause flow bottlenecks that are not normal. Culvert structures, bridges and overpasses, are likely to further restrict the flow, especially if the creek receives little upkeep and cleaning. This is because silt, sludge, and solid waste can accumulate in the stream and obstruct the flow. The stream segment at 1900 meters from the mouth indicates obvious obstructions or incursions, as evidenced by the sharp decline in cross-sectional area from 18.6 square meters at 1800 meters to 7.8 meters at 1900 meters (Ramanathan et al., 2021).

At the outflow where the Santa Inês creek joins the Mandovi River, sedimentation is a problem which is clearly evident. This may be the result of silts from the main river being deposited. The areas where water may collect after heavy rainstorms is indicated by blue regions on the map (Ramanathan et al., 2021). Howerver, their map does not take any drainage infrastructure into account or presume that it is full or clogged.

Ramanathan, D., Padmanabhan, V., Lassen, U., Fuentes Dellepiane, G., Holm, B., Sulejmani, M. (2021). St. Inez Creek Rejuvenation Plan-Panaji. Project Urban Living Lab

Figure 2.1 Surface flow lines in the Santa Inês Creek area based on elevation data (Source: Ramanathan et al., 2021)

These results highlight the significance of preserving natural flows, either by rebuilding the natural cross-sectional flow area in proportion to the catchment area or by using engineered solutions, such as lining creeks and diverting flows, to boost the drainage system's total capacity. Furthermore, when high water levels at the outlet exceed or otherwise restrict the creek's conveyance, the catchment's water balance may be enhanced with storage capacity to control peak flows. In order to restore the ecosystem to its pre-development state, peak flows into the creek would need to be limited. This might be done by adding storage volumes to the watershed through the use of Nature-based Solutions (NBS) or more conventional flood control structures like basins and multipurpose areas that also offer side benefits like leisure areas and enhanced microclimate conditions that lessen the effects of Climate Change (Ramanathan et al., 2021).

According to O Heraldo newspaper about fifteen years ago, Manohar Parrikar, the then-leader of the opposition, led a high-powered committee at the state level that attempted to address many ecological problems that the city of Panjim was suffering. One of the goals was to bring Santa Inês Creek back to life. Dr. Antonio Mascarenhas (former Scientist, NIO, Goa) was invited to multiple meetings by the active member Nandakumar Kamat. Parrikar received unquestionable proof that the 1964 Survey of India (SoI) toposheets showed the presence of a saline tidal incursion about two kilometres inside, past the current fire station. One of the significant results of these discussions was that the saltwater stream affected by tides would henceforth be called Santa Inês Creek rather than "nallah," as the corporations were attempting to do (Mascarenhas, 2022). Sand deposition has led to a beach formation at the mouth of the Santa Inês Creek leading to blockage of water flow between the Santa Inês Creek and the Mandovi River (SAPCC for the State of Goa, 2023). Presently, there is sand deposition which extends from the Dayanand Bandodkar Road near Children’s Park and extending towards the east in the Mandovi Estuary to opposite Maquinez Palace. This has occurred in the last couple of decades leading to a slight extension of the length of Santa Inês creek. No earlier data, results, or studies have been found on the salinity and water quality of Ourém Creek.

CHAPTER 3

METHODOLOGY

CHAPTER 3: METHODOLOGY

3.1 Introduction

An essential tool for assessing the level of contamination in water bodies is water monitoring and analysis. In addition to their colour, taste, and odour, the amount of minute components in the water also determines the level of pollution. The elements present in soil, rocks, discharged debris, and raw sewage determine the concentration of major, minor, and trace inorganic constituents in creek water. The waterways are generally contaminated due to the flow of raw sewage, chemicals from agricultural activities, and contamination from neighbouring homes. It is expensive and difficult to clean up the contaminated water.

An exact amount of a sample serves as a representation of the contamination in the surrounding area. The samples are collected from desired sites, stored, and then examined for several parameters. For the study to produce reliable results that accurately reflect both the environment and the environmental concern, the standard analytical process must be followed. Therefore, the supplies, procedures, and methods must meet internationally recognized standards.

3.2 Pre-field preparation

The study area is located in Tiswadi taluka of Goa state's North Goa district. The latitudes and longitudes (GPS coordinates) of both creeks were noted before sample collection. Before the field visit the pH meter, and electrical conductance meter were calibrated, and the required reagents were prepared for certain parameters that have less than 24-hour holding periods. Plastic bottles with capacities of 1000 ml and 125 ml BOD bottles were washed and rinsed with distilled water and set up for sampling. The labels and thermometer for measuring the temperature were prepared ahead of time.

3.3 Sampling

The water samples were carefully collected in plastic bottles from various locations (Figures 1.3 and 1.5) from both the creeks during monsoon and post-monsoon for quality analysis of different parameters and every month from July 2023 to February 2024 for salinity determination. 6 stations each were chosen from both the creeks for sampling. After taking a field temperature reading, the samples were brought to the lab for additional examination. The materials were handled very carefully before examination to prevent contamination.

Figure 3.1 Water sampling for salinity analysis

Table 3.1 The locations of sampling sites (Santa Inês Creek and Ourém Creek)

Sampling Stations	**Santa Inês Creek**			**Ourém Creek**		
	Landmark	Coordinates	Sampling point	Landmark	Coordinates	Sampling point
Station 1	Yog Setu bridge, Opposite Maquinez Palace, Mandovi River	15°30'01.0"N 73°49'15.2"E	Downstream to the right side of the bank of the creek	Old Patto Bridge, Mahatma Gandhi Road, Panjim	15°29'55.5"N 73°50'01.2"E	Downstream to the left side of the bank of the creek
Station 2	Minerva bridge, Near Don Bosco Hostel, General Bernardo Guedes Road	15°29'53.5"N 73°49'12.2"E	Downstream on the middle of the bridge	Patto pedestrian bridge, Patto-Fontainhas, Panjim	15°29'50.3"N 73°49'56.1"E	Upstream to the left side of the bank of the creek
Station 3	Ponte de Portugal, Near Military Hospital, Campal- Santa Inês	15°29'37.0"N 73°49'10.7"E	Upstream to the left of the bank of the creek	Gyan Setu, Patto-Mala	15°29'39.0"N 73°49'55.6"E	Upstream to the left side of the bank of the creek
Station 4	Near Dr. T. B. Cunha Government Higher Secondary School, Campal- Santa Inês	15°29'14.9"N 73°49'00.5"E	Upstream to the left of the bank of the creek	Mala Patto bridge, Morambi-O-Pequeno	15°29'32.3"N 73°49'58.3"E	Downstream to the left side of the bank of the creek
Station 5	Tambddi Mati, Santa Inês	15°29'07.0"N 73°49'13.3"E	Downstream to the right side of the bank of the creek	Chear Khambe (Four Pillars), Panjim-Santa Cruz old highway road, Panjim	15°29'12.9"N 73°50'08.7"E	Upstream to the left side of the bank of the creek
Station 6	Near Café Basil, Tonca-Taleigão Marshland	15°28'47.1"N 73°48'52.0"E	To the left of the bank of the creek	Santa Cruz wetland, Band, Santa Cruz- Taleigão	15°28'15.7"N 73°50'14.7"E	Variable

3.4 Analysis of physical and chemical parameters

3.4.1 Temperature

A laboratory thermometer was used to measure the temperature of the water at each of the 6 stations for both the creeks at the sites. The thermometer was inserted into the obtained water sample and was held in the sample for two minutes before the readings were taken.

Figure 3.2 Laboratory thermometer

3.4.2 pH

A pH meter was used to determine the pH of the collected water samples. The pH meter was calibrated using a buffer solution of pH 4, pH 7, and pH 10 just before use. The electrode was thoroughly rinsed with distilled water and carefully wiped with tissue paper. A measurable amount of water sample approximately 40 ml of water sample whose pH is to be determined was transferred to a beaker and placed on the magnetic stirrer, the electrode was placed in the water sample whose pH is to be determined and waited for a steady reading, the reading displayed was noted. The same was followed for all the other samples.

Figure 3.3 pH meter

3.4.2 Conductivity

An electrical Conductivity meter was used to determine the conductivity of the water samples. The Conductivity meter was calibrated using 0.01 M KCl solution to 1.546×10^{-3} S/cm at 30 °C. After the calibration, the probe of the Conductivity meter was rinsed with distilled water and wiped thoroughly with tissue paper. A measurable amount of water sample of approximately 40 ml each was taken for the measurements.

Figure 3.4 Conductivity meter

3.4.3 Hardness (Ca, Mg and total hardness)

Water hardness can be measured using a procedure known as complexometric titration by adding a known concentration of the chelating agent EDTA (Ethylenediamine tetraacetic acid) through a burette to a sample containing an unknown amount of calcium and magnesium ions. For the determination of Calcium, a water sample along with NaOH buffer and Patton and Reeder's indicator was used and titrated against 0.01 M EDTA. At the endpoint, the last of the pinkish tinge disappears, and pure blue colour is left. The amount of EDTA added is measured. Similarly for determining Calcium and Magnesium, NH_3 buffer and (Eriochrome Black T) EBT indicator are used. The volume of EDTA consumed for Mg is calculated by subtracting the volume of EDTA consumed by Ca from the volume of EDTA consumed by Ca and Mg.

To determine Calcium

1 M of EDTA is equivalent to 1 M of Ca

The atomic weight of Ca is 40.008 g

Therefore 1 M of EDTA is equivalent to 40.008 g of Ca

$$\textbf{Concentration of Ca (g/L)} = \frac{\textbf{Volume of EDTA} \times \textbf{Normality of EDTA} \times \textbf{40.008}}{\textbf{Volume of water sample}}$$

To determine Magnesium

1 M of EDTA is equivalent to 1 M of Mg

The atomic weight of Mg is 24.31 g

Therefore 1 M of EDTA is equivalent to 24.31 g of Mg

$$\textbf{Concentration of Mg (g/L)} = \frac{\textbf{Volume of EDTA} \times \textbf{Normality of EDTA} \times \textbf{24.31}}{\textbf{Volume of water sample}}$$

Total Hardness = Concentration of Ca and Concentration of Mg

3.4.4 Phosphate

For the analysis of Phosphate, Murphy and Riley's Molybdenum blue method forms the basis of most methods. It involves the reaction of orthophosphate with ammonia molybdate under conditions to form 12-molybdophosphate, a yellow-coloured complex. This complex is reduced by either ascorbic acid or Stannous chloride in the presence of antimony to a blue colour complex (molybdenum blue). The light absorption of this is measured in a spectrophotometer at the wavelength of 880 nm.

Blank (0), 2, 4, 6, 8, 10, and 12 ml of working solution (Potassium dihydrogen phosphate) are taken in 50 ml graduated tubes and diluted to the marks with distilled water and 50 ml of the water sample is taken in the graduated tubes. 1 ml of the Mixed reagent and 1 ml of ascorbic acid is added and mixed well. After 30 minutes the absorbance is measured at the wavelength of 880 nm.

Concentration of phosphate (μ mol / L) = Average Factor × Optical Density

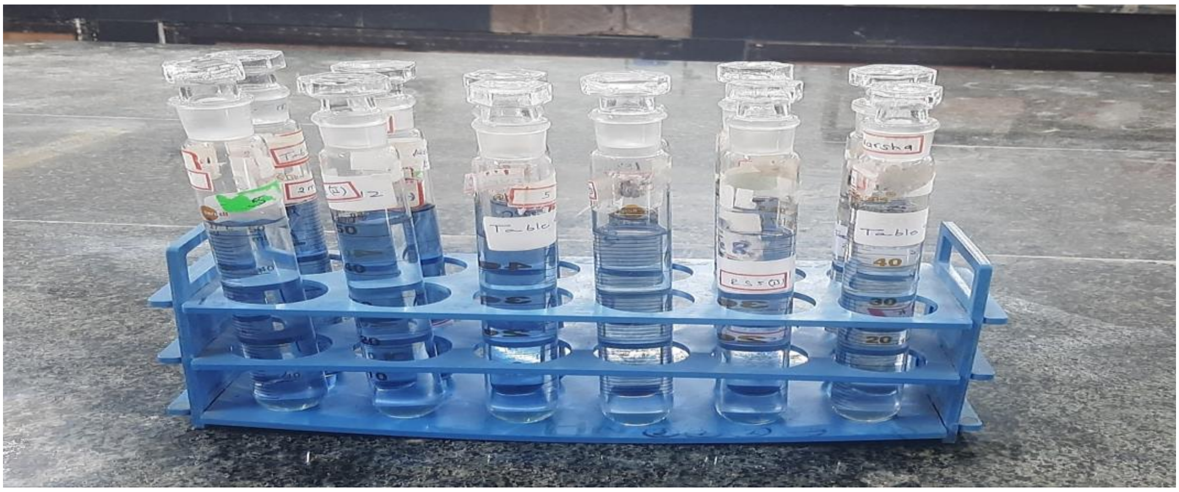


Figure 3.5 Graduated tubes with water samples for phosphate analysis

3.4.5 Nitrite

The determination of Nitrite is based on the method of Strickland and Parsons (1968). Nitrite reacts with sulfanilamide in an acid solution resulting in a diazonium compound. This is then coupled with N-(1-Naphthyl)-ethylenediamine dihydrochloride to form a coloured azo dye, the extinction of which can be measured spectrophotometrically at the wavelength of 540 nm.

Blank (0), 1, 2, 3, 4, and 5 ml of the working solution ($NaNO_2$) are taken in 50 ml graduated tubes and diluted to the marks with distilled water. 50 ml of the water sample is taken in the graduated tubes. 1 ml of sulfanilamide and 1 ml of diamene is added and shaken well. The absorbance of this is measured after 20 minutes in a spectrophotometer at the wavelength of 540 nm.

Note: The dye should not be exposed to sunlight.

Concentration of Nitrite (μ mol / L) = Average Factor × Optical Density

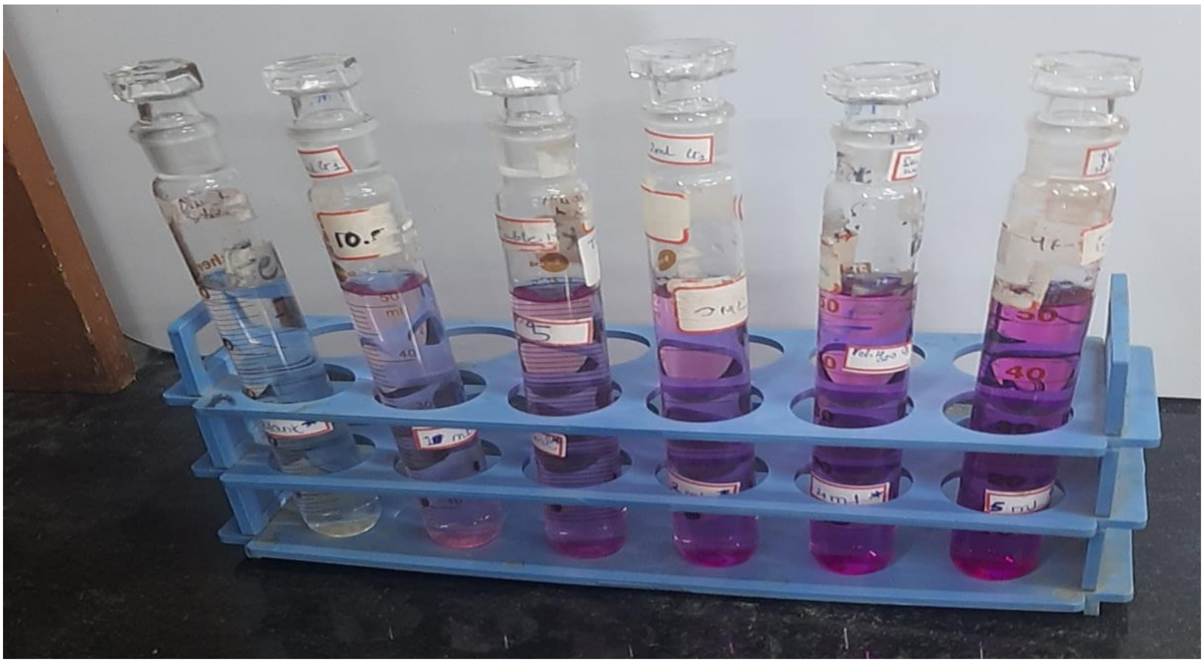


Figure 3.6 Graduated tubes with water samples for nitrite analysis

3.4.6 Acidity

For the determination of acidity of wastewater and natural water, methyl orange acidity (pH 3.7) and phenolphthalein acidity (pH 8.3) are used. Thus, in determining the acidity of the sample the volumes of standard alkali required to bring about colour change at pH 8.3 and at pH 3.7 are determined. 50 mL of sample is pipette into a flask. 2 to 3 drops of methyl orange indicator are added. These contents are titrated against 0.02 N NaOH. The endpoint is noted when colour changes from orange-red to yellow thus this is the Methyl orange acidity (V1). Then two drops of phenolphthalein indicator are added and titration continued till a pink colour just develops. The volumes of the titrant used are noted down giving the total acidity (V2). Phenolphthalein acidity is calculated by subtracting the Methyl orange acidity from the total acidity. (V3 = V2 – V1)

$$\textbf{Methyl orange acidity (mg / L as } \mathbf{CaCO_3}\textbf{)} = \frac{\mathbf{V1 \times \text{Normality of NaOH} \times 50 \times 1000}}{\textbf{Volume of water sample}}$$

$$\textbf{Total acidity (mg / L as } \mathbf{CaCO_3}\textbf{)} = \frac{\mathbf{V2 \times \text{Normality of NaOH} \times 50 \times 1000}}{\textbf{Volume of water sample}}$$

Phenolphthalein acidity (mg / L as $CaCO_3$) = Total acidity - Methyl orange acidity

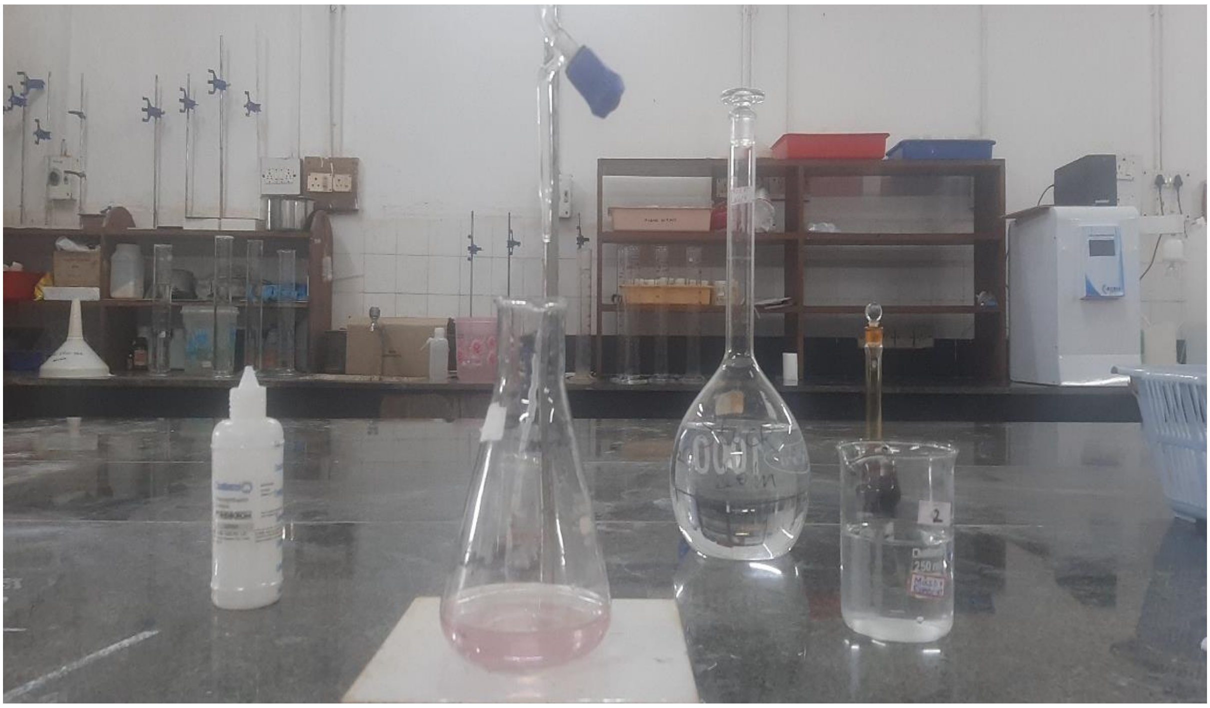


Figure 3.7 Titration for determination of acidity in water samples

3.4.7 Alkalinity

The alkalinity of water can be determined by titrating the water sample with Sulphuric acid of known values of pH, volume, and concentrations. Based on the stoichiometry of the reaction and the number of moles of Sulphuric acid needed to reach the endpoint, the concentration of alkalinity in water is calculated. 100 ml of water sample is taken and 2 drops of phenolphthalein indicator are added, this is then titrated with 0.02 N Sulphuric acid until it becomes colourless. Add a few drops of methyl orange indicator and titrate with 0.02 N Sulphuric acid until the colour changes from yellow to orange. Note down the readings.

$$\textbf{Alkalinity (mg / L as CaCO}_3\textbf{)} = \frac{\textbf{Volume of } H_2SO_4 \times \textbf{Normality of } H_2SO_4 \times 50 \times 1000}{\textbf{Volume of water sample}}$$

3.4.8 Fluoride

Fluoride concentration in water is estimated using a spectrophotometer at a wavelength of 622 nm. Blank (0), 0.5, 1, 1.5, 2, 2.5, and 3 ml of sodium fluoride working solution are taken in 50 ml graduated tubes, this is diluted to 15 ml with distilled water, to this 8 ml of lanthanum alizarin complex and 0.4 ml acetic acid is added. This is then diluted to 25 ml with distilled water. The pH should be between 4.5 to 0.02. Take 15 ml of water sample into a graduated tube, add 8 ml of lanthanum alizarin complex and 0.4 ml acetic acid, and dilute this to 25 ml with distilled water. A calibration curve is constructed by taking the optical density against concentration.

Concentration of fluoride (mg / L) = Average Factor × Optical Density × 1.667

3.4.9 Turbidity

A turbidity meter was used to measure the turbidity of water. The turbidity meter was calibrated before use using the solution of 0.02 NTU, 20 NTU, 100 NTU, and 800 NTU.

Figure 3.8 Turbidity meter

3.4.10 Nitrate

The Nitrate concentration in water samples was estimated spectrophotometrically. The standard concentrations of 0, 1, 3, 5, 7, and 9 g/L were prepared using KNO_3 stock solution along with the unknown concentration of the water samples. These solutions were diluted into 50 ml graduated tubes with distilled water and the absorbance was measured.

3.4.11 Total dissolved solids

The total dissolved solid can be calculated with the help of Electrical Conductance values. The correlation of these parameters can be estimated by the following equation.

TDS (mg / L) = k × Electrical Conductance (µg / L)

Where k =0.64 (CGWB, 2021)

3.4.12 Biochemical Oxygen Demand (BOD)

The Winkler procedure of the Biochemical Oxygen Demand (BOD) test involves filling a 125 ml BOD bottle with a sample and placing it in a controlled environment at a designated temperature for a period of five days. The initial and final levels of dissolved oxygen (DO) in the sample are measured both before and after the five-day incubation period.

The BOD can be determined by subtracting the initial DO from the final DO. The initial DO is recorded immediately, and any subsequent oxygen consumption during the measurement period is considered in the calculation of BOD. For day 0, The water sample is added with 1 ml of Winkler A and 1 ml of Winkler B and then mixed and left to settle to form precipitation. Once the precipitation is formed 1 ml of 50 % H_2SO_4 is added and mixed till the precipitation dissolves. 50 ml of the sample is taken in a conical flask and titrated against sodium thiosulphate solution until a pale yellow colour appears, add 1 ml starch solution in the conical flask and continue the titration until the blue colour disappears. Note down the burette reading for BOD calculation. Repeat the same for the 5th day DO estimation.

$$\mathbf{DO\ (mg / L)} = \frac{\textbf{Titrant value} \times 0.01 \times 1000 \times 8}{49.2}$$

$$\mathbf{BOD\ (mg / L)} = (DO)_{0^{th}\ day} - (DO)_{5^{th}\ day}$$

Figure 3.9 BOD bottles

3.5 Salinity Analysis

The salinity of the water samples was determined using an instrumental method i.e. using a refractometer. A refractometer is a sensor that measures the salinity (saltiness) of a water sample. Salinity is determined by measuring how much light refracts (bends) when it passes through the sample. The more salt there is in water, the more the light is bent. This refractometer measures salinity in parts per thousand (ppt or ‰).

Figure 3.10 Refractometer

3.5.1 Calibration of the Refractometer

1. Lift the plastic cover plate from the prism, or wedge-shaped end, of the refractometer.
2. Use a pipette to put 2 or 3 drops of distilled water on the blue surface of the prism.
3. Close the cover plate.
4. The distilled water should almost fill the entire rectangular outline on the cover plate.
5. Hold the refractometer horizontally underneath a light so that the light is shining straight down on the refractometer. (Alternative: hold the refractometer horizontally and point towards a window.)
6. Turn the eyepiece until the scale is as clear as possible.
7. If the shadow line is not at zero, remove the black rubber cap from the knob next to the prism. Use the tiny screwdriver to turn the knob until the shadow line is at 0.
8. After calibration, clean the distilled water from the prism and cover the plate with a soft cloth or with a tissue

3.5.2 Measurement of Salinity using Refractometer

1. Lift the cover plate and use a pipette to put 2 or 3 drops of the liquid sample on the blue surface of the prism.
2. Close the cover plate and check that the liquid almost completely fills the rectangular outline on the cover plate with no air bubbles. Add another drop of liquid if needed.
3. Wait 30 seconds.
4. Hold the refractometer horizontally underneath a light so that the light is shining straight down on the refractometer.
5. Look through the eyepiece.
6. Turn the eyepiece until the scale is as clear as possible.

7. To measure salinity, find where the shadow line crosses the scale on the right. This scale is marked from 0 to 100 and has the ppt symbol (‰) next to it.
8. Record your salinity measurement.

CHAPTER 4

RESULTS, ANALYSIS AND DISCUSSIONS

CHAPTER 4: RESULTS, ANALYSIS AND DISCUSSIONS

4.1 Salinity Variations

4.1.1 Santa Inês Creek

The monthly salinity levels of the Santa Inês Creek at different stations are given below. Water samples were collected monthly from July 2023 to February 2024 at high tide, except for the November sample (collected at low tide of 0 meters). The samples were collected from 6 stations across the creek, with the sampling beginning from the creek's source at Taleigão marshland (Station 6) and ending at the station near the mouth of the Creek near Mandovi Estuary (Station 1).

Table 4.1 Monthly-values of salinity data at various stations in the Santa Inês Creek, in the period from July 2023 to February 2024

Months	**Salinity (‰)**					
	Station 1	**Station 2**	**Station 3**	**Station 4**	**Station 5**	**Station 6**
11 Jul. 2023	2	1	0	0	0	0
21 Aug. 2023	2	1	0	0	0	0
30 Sept. 2023	3	0	0	0	0	0
26 Oct. 2023	10	10	1	0	0	0
25 Nov. 2023	2.5	2	2	1	0	0
28 Dec. 2023	13	10	3	2	0	0
10 Jan. 2024	13	11	4	2	1	0
8 Feb. 2024	20	15	5	2	2	1

Table 4.2 Panjim tidal data for the sampling months (Santa Inês Creek) (Source of data: https://www.tideschart.com/)

Date	1st Tide	2nd Tide	3rd Tide	4th Tide	Sampling time
11 Jul. 2023	6:30 a.m. (1.4 m)	11:31 a.m. (0.8)	5:44 p.m. (1.7 m)	–	6 p.m. – 7 p.m.
21 Aug. 2023	–	–	–	–	4 p.m. – 5 p.m.
30 Sept. 2023	5:29 a.m. (0.3 m)	11:45 a.m. (2 m)	5:54 p.m. (0)	–	3 p.m. – 4 p.m.
26 Oct. 2023	2:48 a.m. (0.4 m)	9:20 a.m. (1.8 m)	3:33 p.m. (0.3 m)	10:02 p.m. (1.7 m)	11 a.m. – 12 p.m.
25 Nov. 2023	3:20 a.m. (0.7 m)	9:15 a.m. (1.8 m)	3:49 p.m. (0 m)	10:48 p.m. (1.8 m)	5 p.m. – 6 p.m.
28 Dec. 2023	12:43 a.m. (1.9 m)	6:15 a.m. (0.8 m)	11:30 a.m. (1.6 m)	6:03 p.m. (0 m)	4 p.m. – 5 p.m.
10 Jan. 2024	4:20 a.m. (0.9 m)	9:33 a.m. (1.6 m)	4:22 p.m. (- 0.1 m)	11:46 p.m. (1.9 m)	12 p.m. – 1 p.m.
8 Feb. 2024	4:09 a.m. (0.9 m)	9:28 a.m. (1.6)	4:09 p.m. (0 m)	11:25 p.m. (1.9 m)	11 a.m. – 12 p.m.

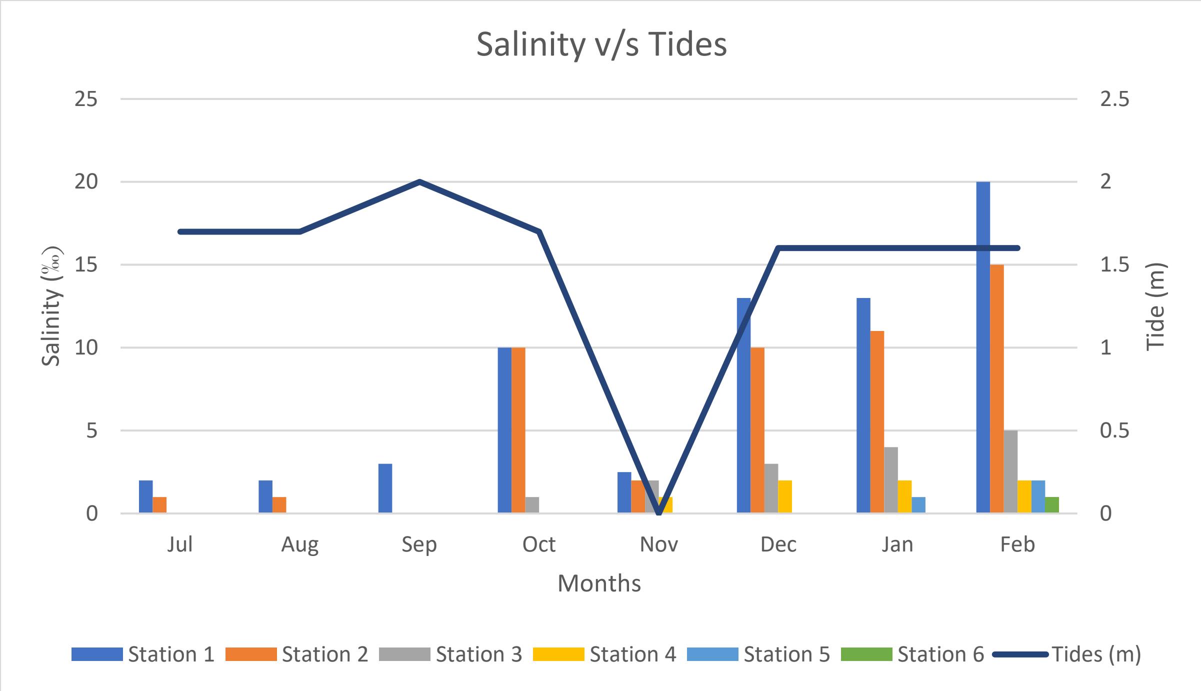


Figure 4.1 Monthly salinity variation in the Santa Inês Creek from July 2023 to February 2024 along with tidal data

The Figure 4.1 gives the monthly salinity level in different locations (Table 3.1) for Santa Inês creek. As seen in the above figure, the salinity of Santa Inês Creek varies monthly at different stations. These variations are according to the amount of precipitation and are also dependent on the phase of the tidal cycle. The samples were collected during high tide except for November when the sampling was done at low tide. During the monsoon season (July, August, and September), the salinity level of Santa Inês Creek is zero at most of the sampling stations except at the mouth of the creek (Station 1) at 2 ‰ (parts per thousand), 2 ‰ and 3 ‰ for July, August, and September 2023 respectively. This is evident due to the influx of fresh water in the form of precipitation. However, once the monsoon recedes the salinity of the creek at Station 1 is in the range from 10 ‰ (October 2023) to 20 ‰ (February 2024). There is a sharp increase in salinity from September to October 2023 at Station 1 and Station 2 and a gradual increase from October 2023 to February 2024, except for the month of November when the sample was collected at low tide. This indicates the tidal influence on the creek and on its salinity level. Although there is a sharp increase in the salinity level in Station 1 and Station 2 from October to November 2023, a gradual increase in salinity is observed in Station 3 and Station 4 during the same months. This explains why the creek is far more influenced by the tides at the mouth compared to the other locations within the creek. The tide is not the only factor influencing the salinity of the creek, the amount of precipitation and how far is the sampling station from the source of salinity– in this case the Mandovi Estuary which is in close proximity to the Arabian Sea– also play a major role.

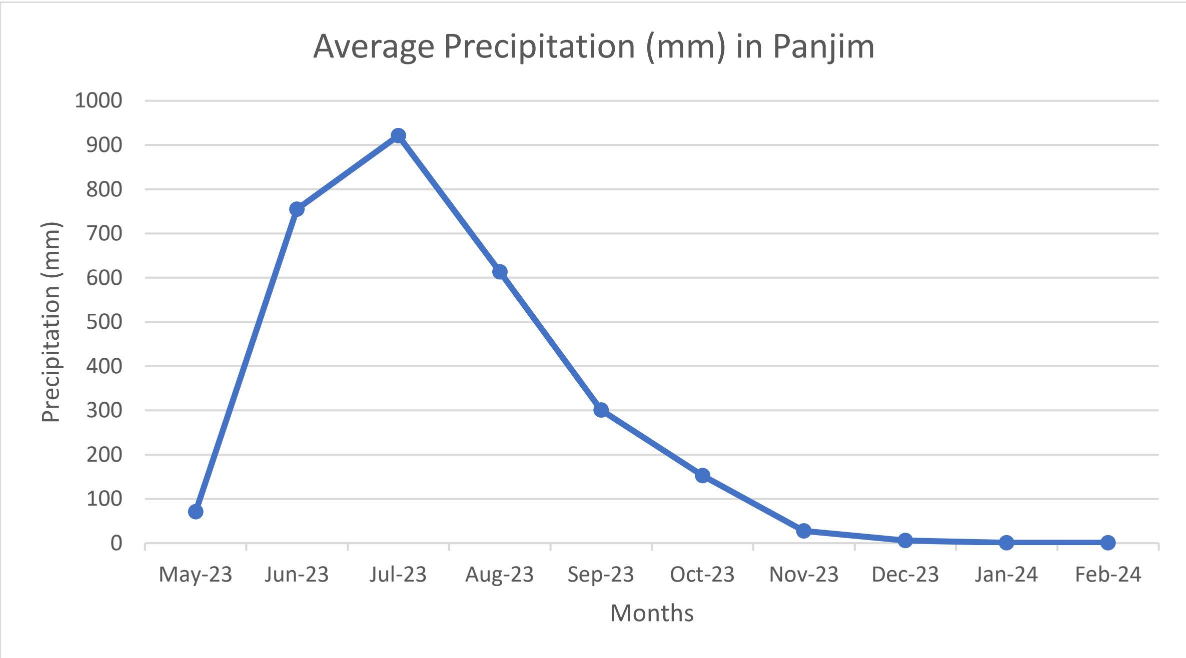


Figure 4.2 Average monthly precipitation over the year in Panaji (Goa), 2023-24 (Source of data: https://weather-and-climate.com/average-monthly-precipitation-Rainfall,panaji,India)

On average, July is the wettest month with 921 mm of precipitation, and Panaji has a drier period from October to May. On average, February is the driest month with 1 mm of precipitation. From Figure 4.2, it is seen that Panjim received the heaviest precipitation in the month of July and the least rainfall was received in the month of February. This affects the salinity of the creek. The salinity was the lowest in July 2023 and the highest in February 2024. The more the precipitation the more the freshwater influx into the creek, and lesser the salinity level in the creek and vice versa. There is an inverse relationship between the two varaibles.

In July 2023, only Station 1 and Station 2 located near the Mandovi Estuary (the source of saline water) were found to have salinity levels of 2 ‰ and 1 ‰ respectively, while all other stations registered a salinity of 0 ‰ [Figure 4.3(a)]. This is apparent from the high precipitation occurring in July in Panjim, where freshwater mixing is notably pronounced and the influx of freshwater toward the river surpasses the flow of saline water within the creek. The proximity of the Mandovi Estuary to the Arabian Sea maintained elevated salinity levels within the river near the sea, consequently impacting the salinity levels of the adjoining creek that flows into it. The Santa Inês Creek joins the Mandovi Estuary around 3 kilometres from where the Mandovi Estuary opens into the Arabian Sea (between Cabo in Dona Paula and Aguada). Similarly, August yields comparable outcomes to those observed in July [Figure 4.3(b)]. In September, only Station 1 exhibited a rise in salinity to 3 ‰, whereas no other stations registered any salinity levels [Figure 4.3(c)]. In October, there was a notable surge in salinity levels at Station 1 and Station 2, rising from 3 ‰ in September to 10 ‰. This significant elevation in salinity can be attributed to the prevailing monsoon, which resulted in an influx of more saline water into the creek. Meanwhile, Station 3 recorded a salinity level of 1 ‰ during the same period, while the remaining three stations exhibited no indication of saline water presence [Figure 4.3(d)]. The November sample was obtained during a low tide (of 0 meters), resulting in observed salinity levels of 2.5 ‰, 2 ‰, 2 ‰, and 1 ‰ for Station 1, Station 2, Station 3, and

Station 4, respectively [Figure 4.3(e)]. The notable decline in salinity from 10 ‰ in October to 2.5 ‰ in November at Station 1 illustrates the impact of tidal fluctuations on creek salinity.

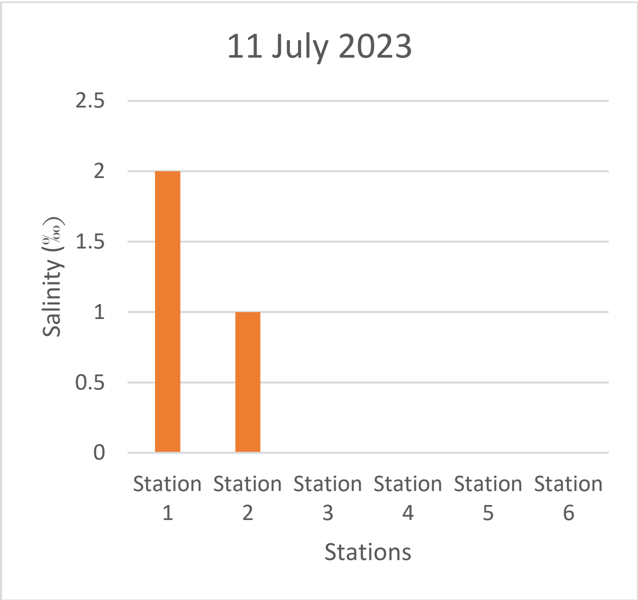


Figure (a)

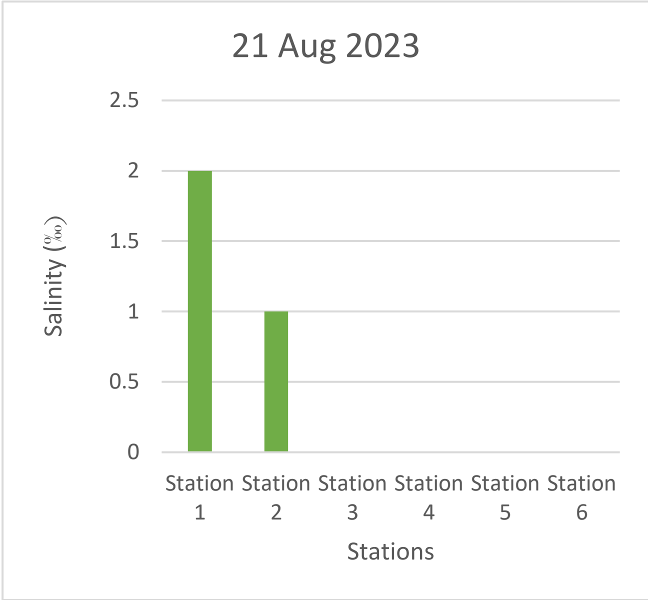


Figure (b)

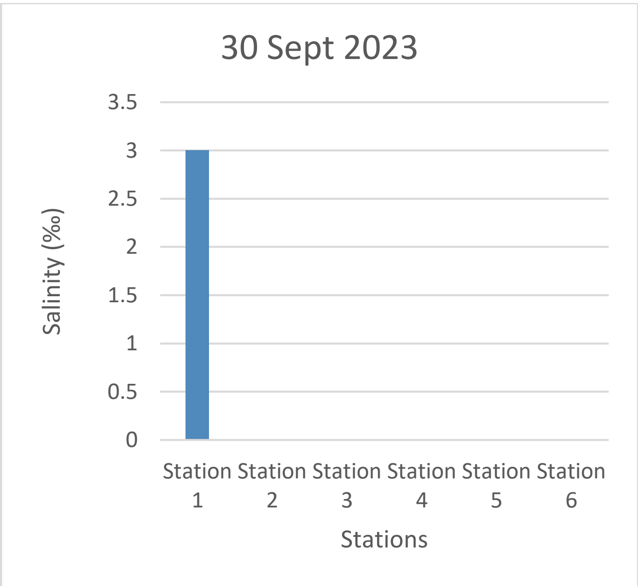


Figure (c)

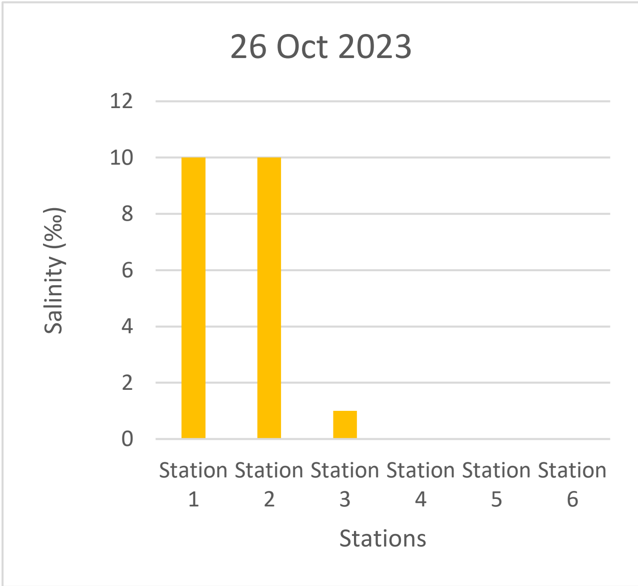


Figure (d)

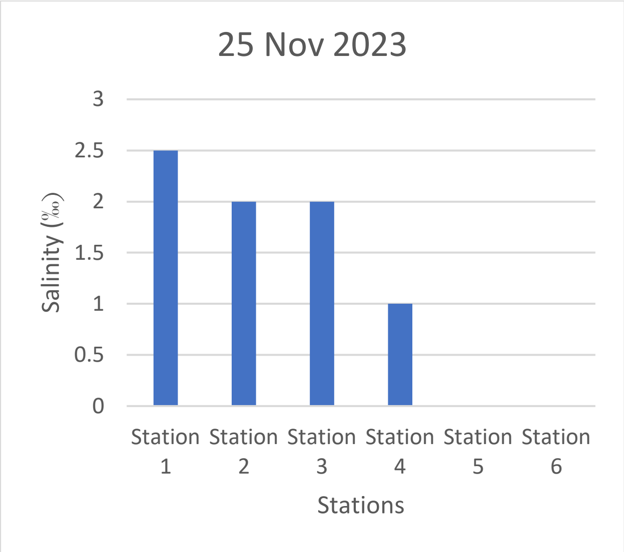


Figure (e)

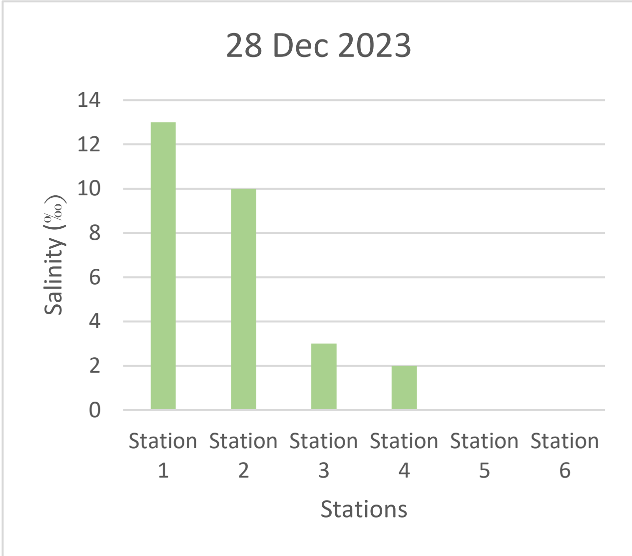


Figure (f)

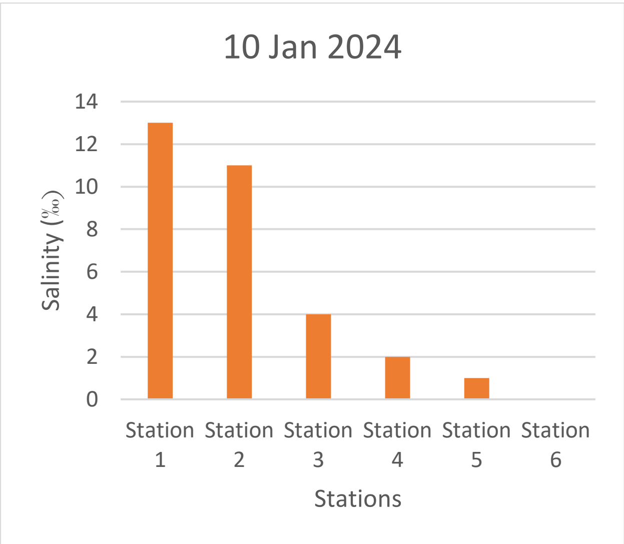


Figure (g)

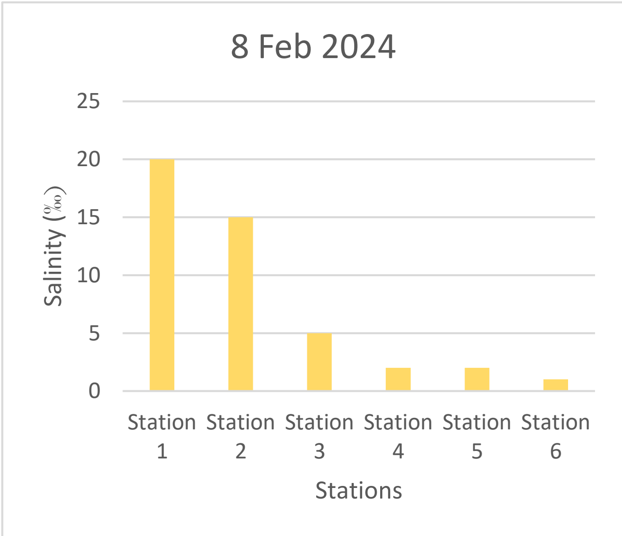


Figure (h)

Figure 4.3 Graphical representation of salinity variation in Santa Inês Creek at different stations from July 2023 to February 2024 respectively in (a) July, (b) August, (c) September, (d) October, (e) November, (f) December, (g) January and (h) February.

Interestingly, the November sample revealed a salinity of 1 ‰ at Station 4, marking the first occurrence of salinity since July in this location.

The salinity levels observed in December 2023 [Figure 4.3(f)] and January 2024 [Figure 4.3(g)] are quite similar across Station 1 through Station 6. Specifically, Station 1 records 13 ‰, Station 2 has 10 ‰, Station 3 shows 3 ‰, Station 4 indicates 2 ‰, Station 5 registers 0 ‰, and Station 6 notes 0 ‰ for December 2023; while for January 2024 the readings are 13 ‰, 11 ‰, 4 ‰, 2 ‰, 1 ‰ and 0 ‰ for Stations 1 through 6, respectively. However, there is a notable surge in salinity at Station 1 from January 2024 to February 2024, jumping from 13 ‰ to 20 ‰. This elevation in salinity is particularly significant because February exhibits the driest conditions of the season in Panjim, with only 1 mm of precipitation. Notably, February marks the first instance where Station 6, situated upstream in the Santa Inês Creek near café Basil in the Taleigão marshland, records a salinity level of 1 ‰ [Figure 4.3(h)]. This finding suggests that Santa Inês Creek could be classified as a seasonal tidal body as the creek is influenced by the tides. Furthermore, in February 2024, the entire creek experienced salinity levels exceeding 0 ‰, indicating the intrusion of saline water into the entire creek, extending all the way to the marshland of Taleigão (Station 6). The impact of the salinity is seen in the entire Santa Inês Creek, atleast in the month of February. It is thus a tidal body affected water-body.

Observing the data presented in Figure 4.4, it's evident that the salinity exhibits a consistent monthly rise from July 2023 to February 2024, with the exception of November, which experiences a dip due to low tide. Specifically, at Station 1, the salinity increases from 2 ‰ in July 2023 to 3 ‰ in September, further to 10 ‰ in October, peaking at 13 ‰ in December, and reaching its highest point at 20 ‰ in February 2024. Likewise, Station 2 demonstrates a similar trend of increasing salinity, except for September when it drops to 0 ‰. The salinity levels, at Station 3 and Station 5, also show a progressive rise over the months.

However, Station 4 maintains a consistent salinity level of 2 ‰ throughout December 2023, January 2024, and February 2024.

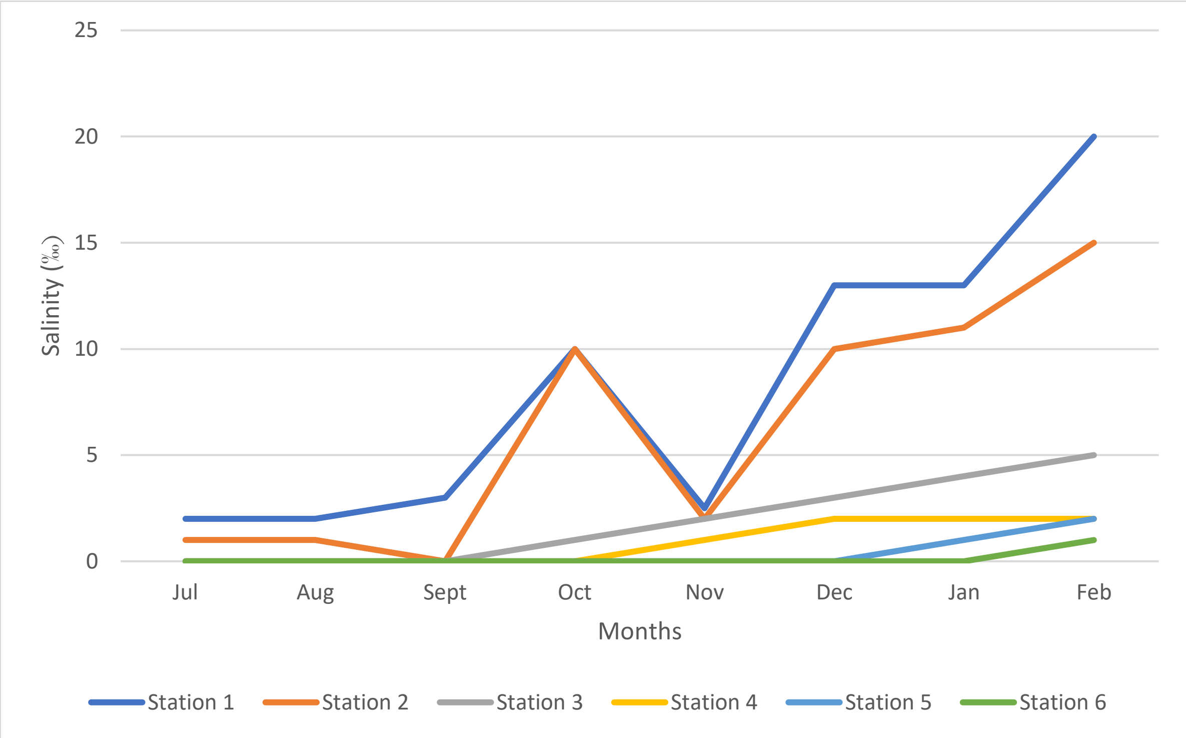


Figure 4.4 Salinity trend from July 2023 to February 2024 at different stations in the Santa Inês Creek

4.1.2 Ourém Creek

The monthly salinity levels of the Ourém Creek at different stations are given below. Water samples were collected monthly from July 2023 to February 2024 at high tide, except for the November sample (collected at low tide of 0 meters) from 6 stations across the creek. Every month sampling was done in the order from the creek's upstream station at Santa Cruz wetland (Station 6) to the downstream opening of the creek's mouth near Mandovi Estuary (Station 1).

Table 4.3 Monthly-values of salinity data at various stations in the Ourém Creek, in the period from July 2023 to February 2024

Months	**Salinity (‰)**					
	Station 1	**Station 2**	**Station 3**	**Station 4**	**Station 5**	**Station 6**
11 Jul. 2023	1	0	0	0	0	0
21 Aug. 2023	5	4	3	1	0	0
30 Sept. 2023	7	5	3	1	0	0
26 Oct. 2023	20	19	18	17	14	1
25 Nov. 2023	23	21	20	22	20	6
28 Dec. 2023	30	30	30	30	29	23
10 Jan. 2024	30	30	30	30	30	25
8 Feb. 2024	30	29	29	30	30	25

Table 4.4 Panjim tidal data for the sampling months (Ourém Creek) (Source of data: https://www.tideschart.com/)

Date	1st Tide	2nd Tide	3rd Tide	4th Tide	Sampling time
11 Jul. 2023	6:30 a.m. (1.4 m)	11:31 a.m. (0.8)	5:44 p.m. (1.7 m)	–	7 p.m. – 8 p.m.
21 Aug. 2023	–	–	–	–	5 p.m. – 6 p.m.
30 Sept. 2023	5:29 a.m. (0.3 m)	11:45 a.m. (2 m)	5:54 p.m. (0)	–	4 p.m. – 5 p.m.
26 Oct. 2023	2:48 a.m. (0.4 m)	9:20 a.m. (1.8 m)	3:33 p.m. (0.3 m)	10:02 p.m. (1.7 m)	12 p.m. – 1 p.m.
25 Nov. 2023	3:20 a.m. (0.7 m)	9:15 a.m. (1.8 m)	3:49 p.m. (0 m)	10:48 p.m. (1.8 m)	6 p.m. – 7 p.m.
28 Dec. 2023	12:43 a.m. (1.9 m)	6:15 a.m. (0.8 m)	11:30 a.m. (1.6 m)	6:03 p.m. (0 m)	5 p.m. – 6 p.m.
10 Jan. 2024	4:20 a.m. (0.9 m)	9:33 a.m. (1.6 m)	4:22 p.m. (- 0.1 m)	11:46 p.m. (1.9 m)	1 p.m. – 2 p.m.
8 Feb. 2024	4:09 a.m. (0.9 m)	9:28 a.m. (1.6)	4:09 p.m. (0 m)	11:25 p.m. (1.9 m)	12 p.m. – 1 p.m.

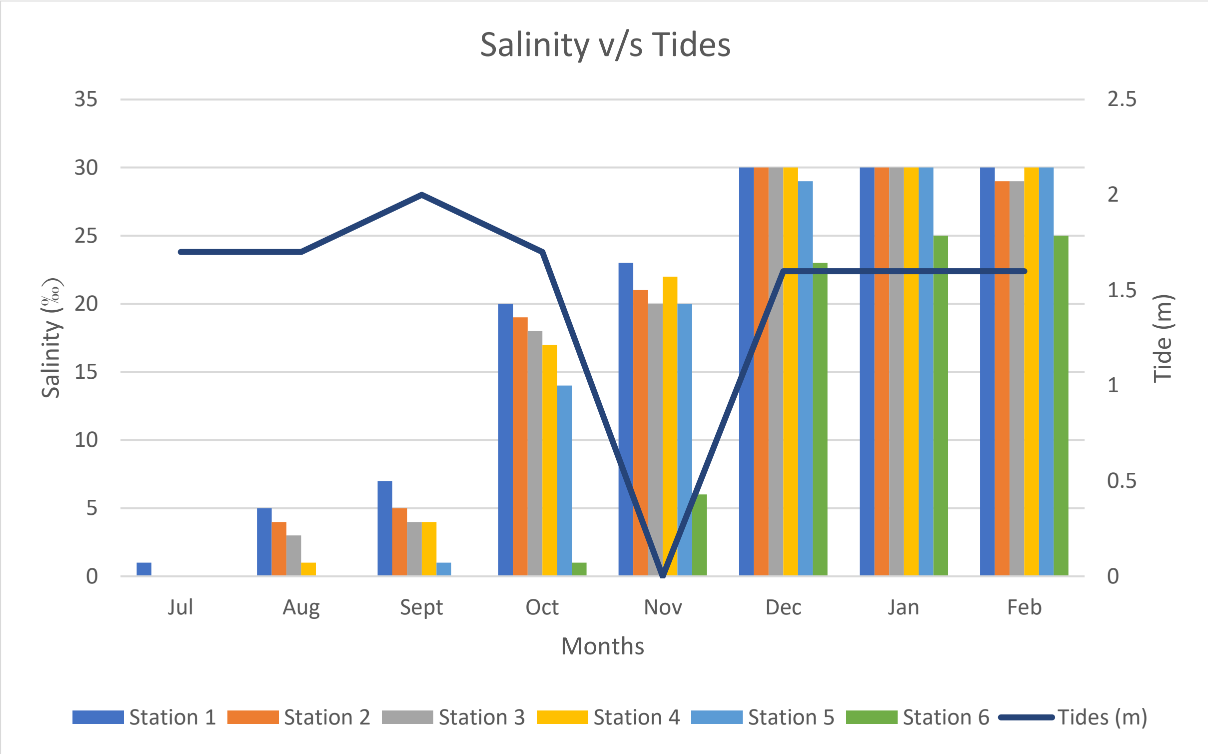


Figure 4.5 Monthly salinity variation in the Ourém Creek from July 2023 to February 2024 along with tidal data

In July 2023, Station 1 in Ourém Creek situated close to the Mandovi River – the source of saline water – exhibited a salinity level of 1 ‰, while all other stations maintained a salinity of 0 ‰ [Figure 4.6(a)]. This occurrence aligns with the highest precipitation recorded in July in Panjim, intensifying freshwater mixing and outweighing the influx of saline water into the creek. The proximity of the Mandovi Estuary to the Arabian Sea perpetuated heightened salinity levels near its mouth, subsequently impacting the creek's salinity levels. As precipitation gradually decreased in August following the peak in July, salinity became discernible in all stations except for Station 5 and Station 6. Similarly, in September, barring Station 6, all stations displayed an uptick in salinity [Figure 4.6(c)].

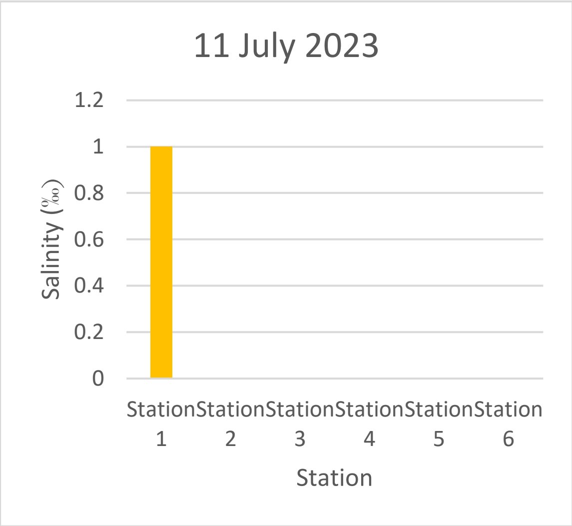


Figure (a)

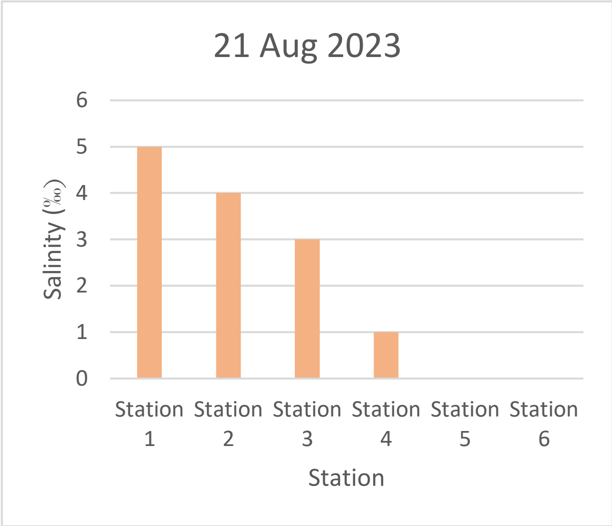


Figure (b)

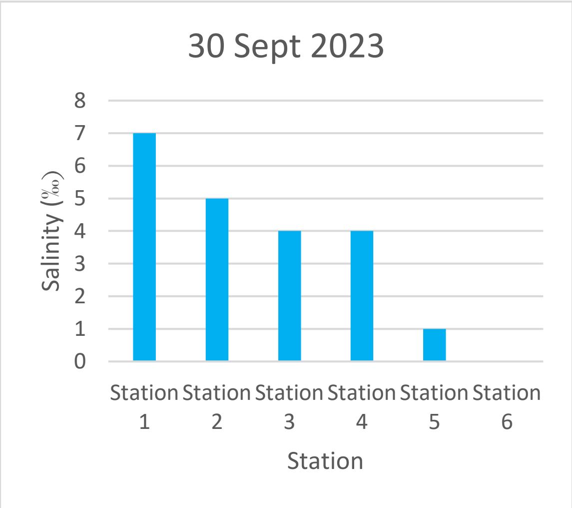


Figure (c)

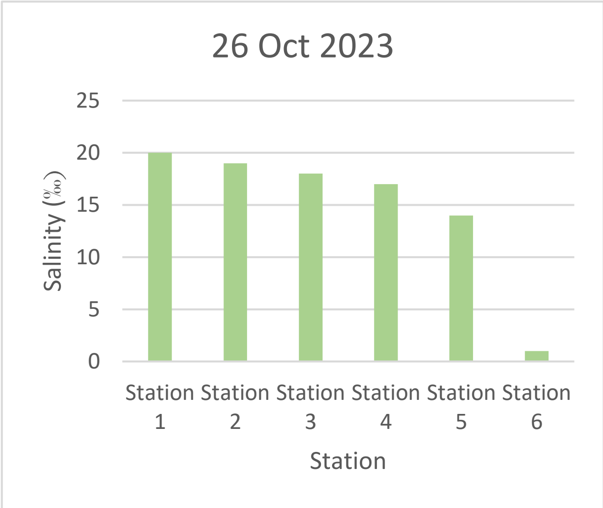


Figure (d)

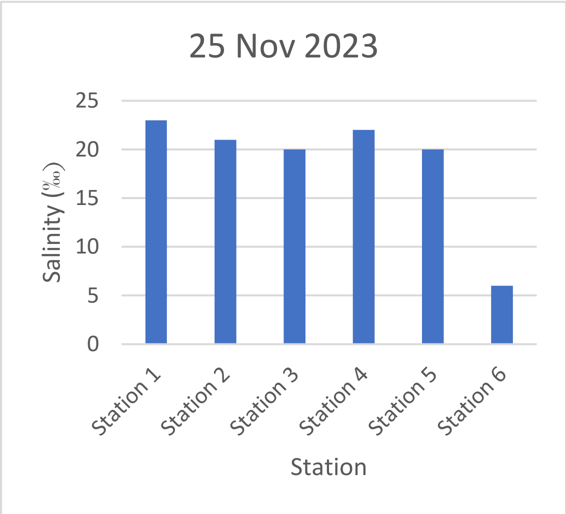


Figure (e)

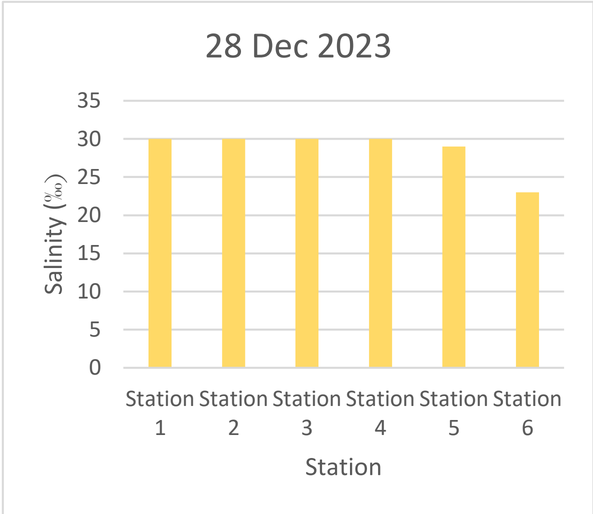


Figure (f)

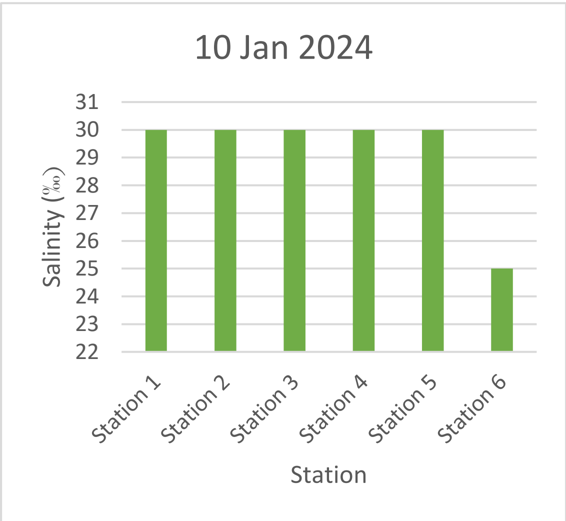


Figure (g)

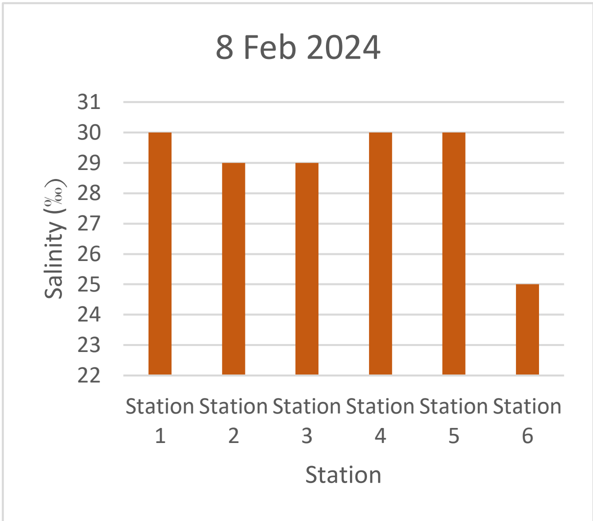


Figure (h)

Figure 4.6 Graphical representation of salinity variation in Ourém Creek at different stations from July 2023 to February 2024 respectively in (a) July, (b) August, (c) September, (d) October, (e) November, (f) December, (g) January and (h) February.

In October, a notable surge in salinity levels transpired at Station 1, Station 2, Station 3, Station 4, and Station 5, escalating from 7 ‰, 5 ‰, 4 ‰, 4 ‰, and 1 ‰ respectively in September to 20 ‰, 19 ‰, 18 ‰, 17 ‰, and 14 ‰. This substantial rise in salinity correlates with the prevailing monsoon, resulting in an increased influx of saline water into the creek. Conversely, Station 6 recorded a salinity level of 1 ‰ during October, marking its initial occurrence of salinity in the entire creek since July in this location [Figure 4.6(d)]. Despite the November sample being acquired during a low tide of 0 meters, observed salinity levels were markedly high, almost parallel with October samples at 23 ‰, 21 ‰, 20 ‰, 22 ‰, 20 ‰, and 6 ‰ for Station 1, Station 2, Station 3, Station 4, Station 5, and Station 6 respectively [Figure 4.6(e)].

Salinity levels in December 2023 [Figure 4.6(f)] and January 2024 [Figure 4.6(g)] remained relatively consistent across all stations. Specifically, Station 1, Station 2, Station 3, and Station 4 recorded 30 ‰ in both months, while Stations 5 and 6 noted 29 ‰ and 23 ‰ for December 2023, and 30 ‰ and 25 ‰ respectively for January 2024. However, the February sample exhibited a slight decline in salinity at Station 2 and Station 3 by 1 ‰ from the previous month [Figure 4.6(h)]. Notably, the highest salinity recorded at Station 6 occurred in January and February 2024, reaching 25 ‰, indicating a significant intrusion of saline water from the Mandovi Estuary. The entire creek maintains a saline nature, surrounded by mangrove cover across most regions. Unlike Santa Inês Creek, Ourém Creek's salinity isn't as dependent on the tidal cycle but rather on extremely high precipitation, as evidenced by the reduction in salinity solely during such instances. This finding underscores the perennial saline nature of Ourém

Creek, reaffirming its classification as a coastal water body. Additionally, from October 2023 to February 2024, the creek experienced consistently high salinity levels exceeding 0 ‰, indicative of widespread intrusion of saline water throughout the creek, extending to the Santa Cruz wetland (Station 6).

4.2 Physical and Chemical Parameters

4.2.1 Santa Inês Creek

The seasonal variation of physical and chemical parameters of Santa Inês Creek at all 6 stations is given below (Table 4.3 and Table 4.4). The physical and chemical parameters were analysed for two seasons (monsoon and post-monsoon). The water samples in the monsoon were collected on 30th September 2023 and for post-monsoon on 12th January 2024 at high tide from all 6 stations across the creek starting from the opening mouth near Mandovi Estuary (Station 1) to the creek's source at Taleigão marshland (Station 6). The obtained data is compared with the BIS standards and SW II standards (CPCB 1993).

The pH of the Santa Inês Creek ranges from 6.56 to 6.79 in monsoon and 7.13 to 7.67 in post-monsoon [Figure 4.7(a)] which is within the limit of the Bureau of Indian Standard (B.I.S) (Table 4.5). In all of the stations during that season, the pH is essentially constant. As pH has an impact on the chemical characteristics of water and how it interacts with other substances, it is significant. For instance, high-pH water can lead to the formation of mineral deposits, whereas low-pH water can dissolve metals and other minerals. Additionally, pH is essential to biological activities, even slight variations in pH can affect the health of aquatic life and indirectly also human life. Thus, maintaining a pH range of 6.5 to 8.5 is crucial in keeping the water free of various contaminants. When the creek opens into the Mandovi Estuary, which is near the Arabian Sea, the conductivity is at its highest there and diminishes upstream towards the creek's source. With the maximum conductivity at station 1 during post-monsoon at 27.4

mS/Cm, the conductivity is much higher during this time. High conductivity in water is caused by an increase in the amount of dissolved ions in the water. The ability of water to carry electrical current is measured by its conductivity. This capacity is directly proportional to the ion concentration in the water.

Table 4.5 Physical and chemical parameters of Santa Inês Creek at different stations (Monsoon sample)

Parameters	**Station 1**	**Station 2**	**Station 3**	**Station 4**	**Station 5**	**Station 6**
pH	6.56	6.74	6.78	6.84	6.79	6.93
Turbidity (NTU)	10.86	12.27	20.2	49.2	69.9	8.48
Conductivity (mS/Cm)	9.83	0.972	0.922	0.989	0.833	0.681
TDS (mg/L)	6291.2	622.08	590.08	632.96	533.12	435.84
Total Hardness (mg/L)	243.1	128.636	177.256	177.256	225.876	257.272
Calcium (mg/L)	0	80.016	80.016	80.016	80.016	160.032
Magnesium (mg/L)	243.1	48.62	97.24	97.24	145.86	97.24
Phosphate (mg/L)	0.8902	1.0193	1.0136	0.5789	0.6017	0.3189
Nitrites (mg/L)	0.0094	0.0027	0.0054	0.0121	0.0067	0.0664
Nitrate (mg/L)	1.1244	1.5592	1.5742	1.8140	2.1289	1.5892
Alkalinity (mg/L)	148	170	164	172	182	160
Acidity (mg/L)	22	22	22	22	20	16
Fluoride (mg/L)	0.0128	0.0289	0.0032	0.1221	0.0032	0.0514

Station	pH	Turbidity (NTU)	Conductivity (mS/cm)	TDS (mg/l)	Total Hardness (mg/l)	Ca (mg/l)
Station 1	7.23	1.85	27.4	17536	437.667	248.049
Station 2	7.13	8.69	23.3	14912	379.628	224.044
Station 3	7.25	7.97	7.58	4851.2	329.395	96.019
Station 4	7.31	15.76	2.44	1561.6	151.528	64.012
Station 5	7.14	24.3	2.28	1459.2	112.632	64.012
Station 6	7.67	13.99	0.783	501.12	98.352	40.008

Table 4.6 Physical and chemical parameters of Santa Inês Creek at different stations (post-Monsoon sample)

Parameters	**Station 1**	**Station 2**	**Station 3**	**Station 4**	**Station 5**	**Station 6**
pH	7.23	7.13	7.25	7.31	7.14	7.67
Turbidity (NTU)	1.85	8.69	7.97	15.76	24.3	13.99
Conductivity (mS/Cm)	27.4	23.3	7.58	2.44	2.28	0.783
TDS (mg/L)	17536	14912	4851.2	1561.6	1459.2	501.12
Total Hardness (mg/L)	437.667	379.628	329.395	151.528	112.632	98.352
Calcium (mg/L)	248.049	224.044	96.019	64.012	64.012	40.008
Magnesium (mg/L)	189.618	155.584	233.375	87.516	48.62	58.343
Phosphate (mg/L)	1.1205	1.6100	2.2075	2.4215	2.3564	0.1954
Nitrites (mg/L)	0.0185	0.0353	0.0473	0.0566	0.0668	1.3787
Nitrate (mg/L)	0.8270	2.4360	3.0676	4.4511	4.3909	1.6541
Alkalinity (mg/L)	168	192	278	308	294	210
Acidity (mg/L)	24	24	40	44	44	18
Fluoride (mg/L)	0.9271	0.9080	0.3492	0.3778	0.3079	1.1779
BOD (mg/L)	3.577	4.227	4.065	4.065	—	14.959

Station	pH	Turbidity (NTU)	Conductivity (mS/cm)	TDS (mg/l)	Total Hardness (mg/l)	Ca (mg/l)
Station 1	7.23	1.85	27.4	17536	437.667	248.049
Station 2	7.13	8.69	23.3	14912	379.628	224.044
Station 3	7.25	7.97	7.58	4851.2	329.395	96.019
Station 4	7.31	15.76	2.44	1561.6	151.528	64.012
Station 5	7.14	24.3	2.28	1459.2	112.632	64.012
Station 6	7.67	13.99	0.783	501.12	98.352	40.008

Table 4.7 BIS and WHO standards

Sr. No.	Water quality Parameters	BIS, 2012		WHO, 1999	
		Acceptable	**Permissible**	**Acceptable**	**Permissible**
1	pH	6.5 – 8.5	—	7 – 8.5	6.5 – 9.2
2	Conductivity (μS/Cm)	—	—	—	—
3	TDS (mg/L)	500	2000	500	1500
4	Turbidity (NTU)	1	5	—	—
5	Total Hardness (mg/L)	200	600	100	500
6	Calcium (mg/L)	75	200	75	200
7	Magnesium (mg/L)	30	100	30	150
8	Phosphate (mg/L)	—	—	0.1	1
9	Nitrites (mg/L)	1	—	3	—
10	Nitrate (mg/L)	45	—	45	100
11	Total Alkalinity (mg/L)	200	600	—	—
12	Fluoride (mg/L)	1	1.5	—	—

Table 4.8 Panjim tidal data for the sampling days for physical and chemical analysis (Santa Inês Creek and Ourém Creek) (Source of data: https://www.tideschart.com/)

Date	1st Tide	2nd Tide	3rd Tide	4th Tide	Sampling Time in Santa Inês Creek	Sampling Time in Ourém Creek
30 Sept. 2023 (Monsoon)	5:29 a.m. (0.3 m)	11:45 a.m. (2 m)	5:54 p.m. (0 m)	—	3 p.m. – 4 p.m.	4 p.m. – 5 p.m.
12 Jan. 2024 (post-Monsoon)	12:23 a.m. (2 m)	5:53 a.m. (0.8 m)	11 :20 a.m. (1.7 m)	5:50 p.m. (-0.1 m)	2 p.m. – 3 p.m.	3 p.m. – 4 p.m.

These conductive ions are produced by inorganic substances such as carbonate compounds, chlorides, sulfides, and alkalis as well as dissolved salts. The conductivity of seawater is extremely high. Therefore, a high concentration of salt content is the cause of the high conductivity at Station 1 near the estuary. The finding that the conductivity increases with proximity to the estuary makes this clear.

The total dissolved solids (TDS) exhibits a similar pattern as observed from Figure 4.7(d), with the mouth having the maximum concentration (6291.2 mg/L) for monsoon samples and 17536 mg/L for post-monsoon samples, respectively. The water nearer the sea has a higher salt concentration, which may be the cause of elevated TDS near the estuary. The TDS in Santa Inês Creek is way beyond the prescribed BIS standards in all the stations except for Station 6 of the monsoon season. In comparison to the post-monsoon sample, the monsoon sample has the lowest TDS due to the dissolution caused by the mixing of freshwater from the precipitation.

Since the TDS concentration is far higher than the permissible limit of 500 mg/L, it is not appropriate for drinking. A high total dissolved solids content in drinking water is a major cause for worry. The most concerns include the possibility of kidney stones resulting from high total dissolved solids, particularly in cases where hard water levels exceed 500 mg/l, as well as other health-related conditions like diabetes and heart disease (https://quenchwater.com/blog/total-dissolved-solids/).

A tiny quantity of organic materials and inorganic salts make up TDS. Water frequently contains inorganic salts such as anions such as carbonates, nitrates, bicarbonates, chlorides, and sulfates, and cations such as calcium, magnesium, potassium, and sodium. These minerals can originate from a number of sources, both natural and as a result of human activities. Salt, industrial wastes, wastewater discharges, and runoff from agriculture and cities can all introduce excess minerals into water sources (https://www.knowyourh2o.com/indoor-6/total-dissolved-solids). The high level of TDS in monsoon season in Santa Inês Creek except near the estuary is not likely caused by salt content as the salinity of Santa Inês Creek in September is zero in all stations except the mouth near the estuary (Table 4.1), but rather by raw sewage and wastewater discharged from the nearby settlement and city, as reported by the Goa State Pollution Control Board's Annual Report 2013–2014. High levels of TDS also give rise to hard water. Soaps and detergents do not produce as much lather with hard water as with soft water.

It is also evident from Table 4.5 above that the turbidity is higher than its acceptable and permissible limit of 1 mg/L and 5 mg/L. In comparison to post-monsoon samples, turbidity is higher during the monsoon. The station with the darkest water (station 5), in the monsoon sample had the highest turbidity, measuring 69.9 NTU. The estuary's turbidity is lower than the other places during the post-monsoon season. One way to describe a liquid's turbidity is its clarity. In general, water with a high turbidity level is less clear than one with a low turbidity level. Solid particles suspended in a liquid are the source of turbidity. Light can be scattered by these particles, giving the water an impression of cloudiness or murkiness.

Turbidity is often used to test water quality heuristically. Turbidity in water can be caused by a variety of factors, such as debris or runoff, wastewater containing leftover particles, or the decomposition of plant and animal matter. Because bottom-feeding fish and other organisms, together with algae, are active in a body of water, sediment and other bio-organic debris may float to the surface. Soil erosion occurring as a result of logging operations, construction projects etc can cause high turbidity. Rain, erosion, and the presence of aquatic plants and animals can all cause turbidity to rise (https://aosts.com/what-causes-turbidity-in-water-importance/). Station 1, Station 5, and Station 6 of the monsoon samples show a higher level of total hardness more than the acceptable limit of 200 mg/L than that of the other stations. The highest total hardness was observed in Station 1 of the post-monsoon sample with 437.667 mg/L (very hard) and decreased to 98.352 mg/L (moderately hard) at Station 6.

The hardness varies as per the location and is due to the presence of calcium and magnesium ions in water. Hard water is created when water filters through deposits of limestone, chalk, or gypsum, primarily composed of calcium and magnesium carbonates, bicarbonates, and sulfates. When soap interacts with hard water, it doesn't produce lather as readily as it does with soft water. Water hardness can be classified into two types: temporary and permanent.

Temporary hardness arises from the presence of calcium and magnesium bicarbonates, while permanent hardness stems from soluble salts of calcium and magnesium such as sulfates and chlorides of calcium and magnesium. Boiling effectively eliminates temporary hardness by converting magnesium and calcium bicarbonates into their carbonate forms.

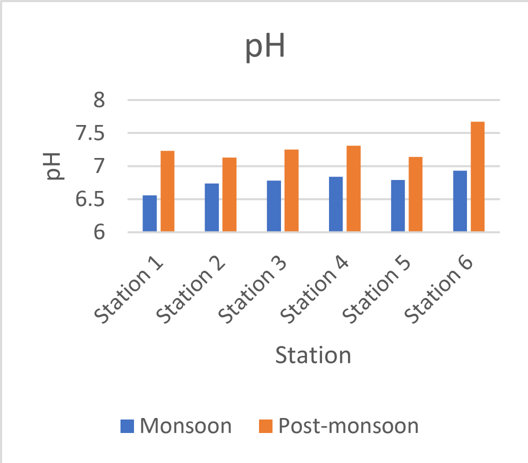
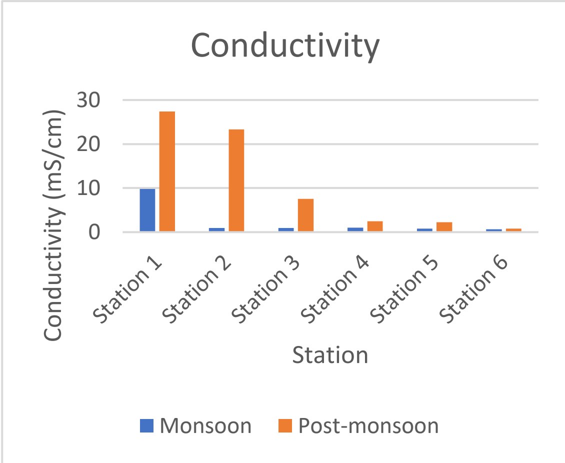


Figure (a)



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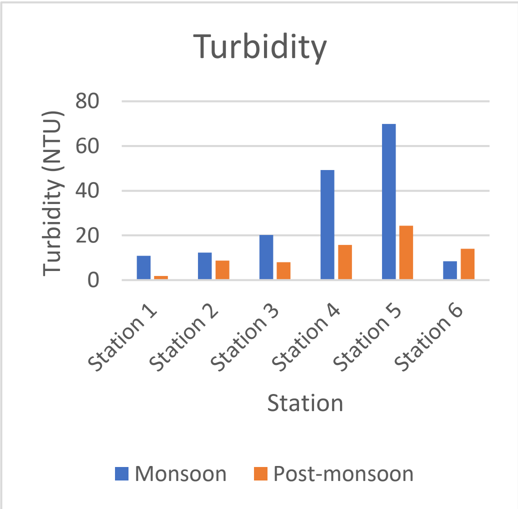

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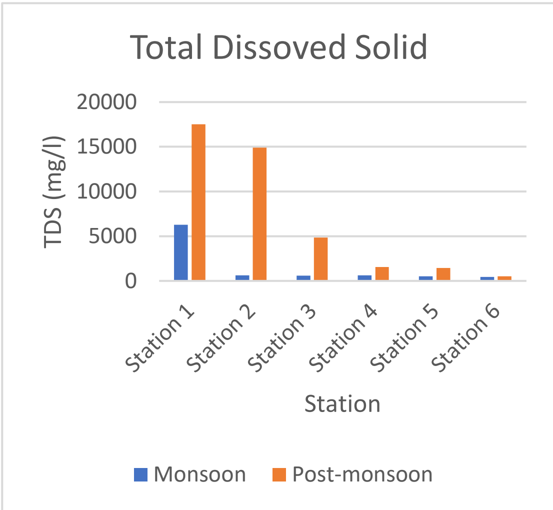

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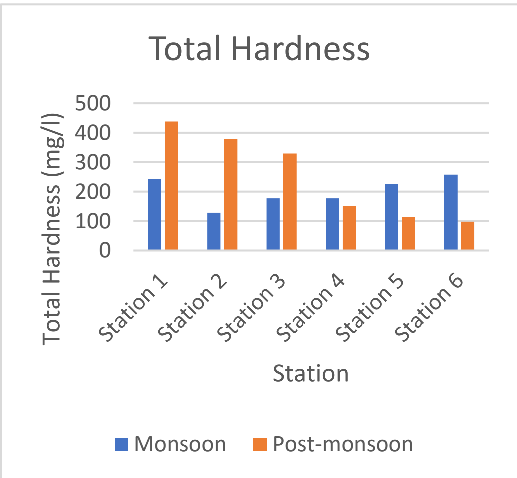

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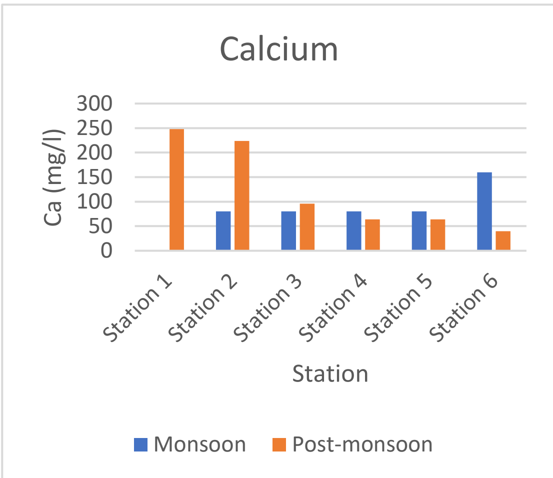

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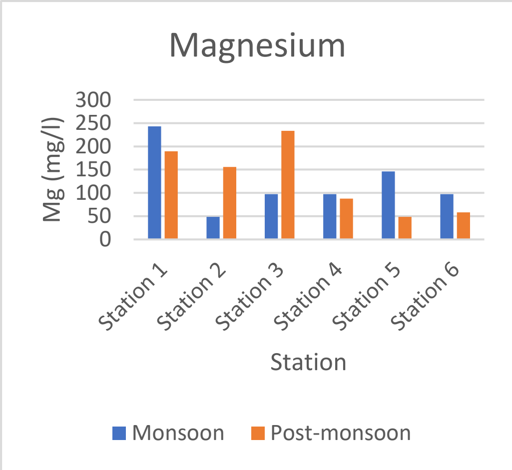

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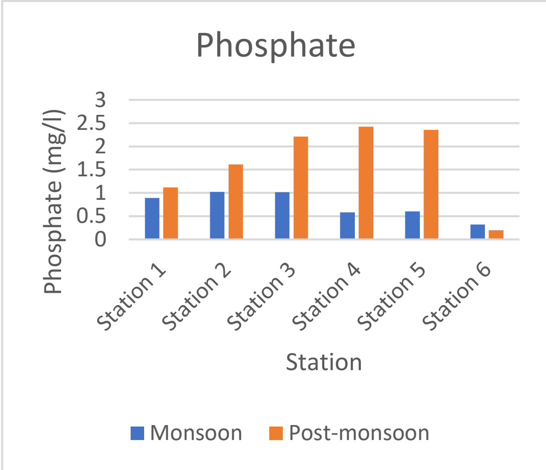
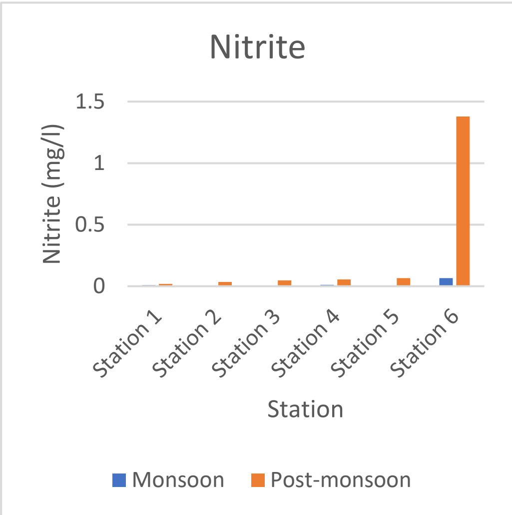


Figure (h)



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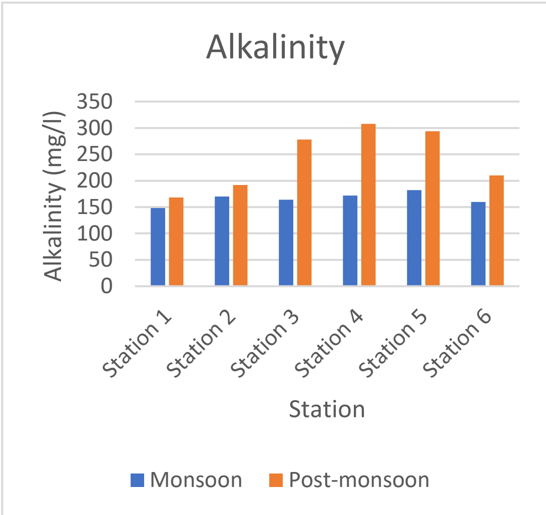

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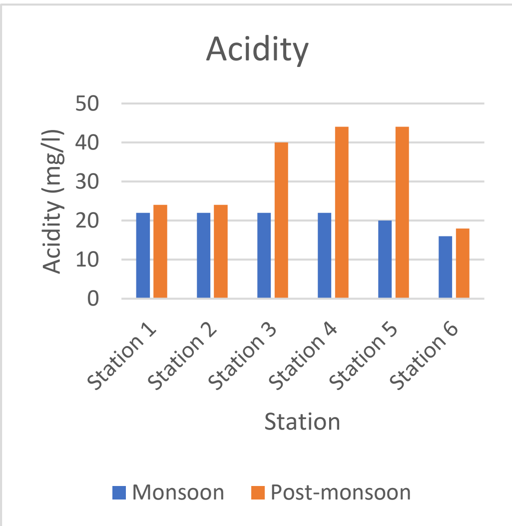


Figure (k)

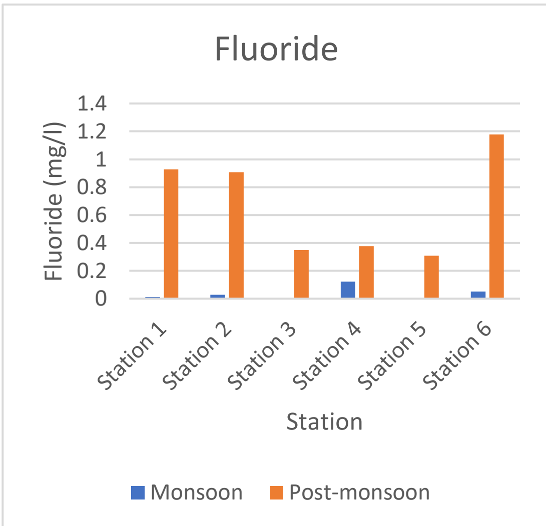


Figure (l)

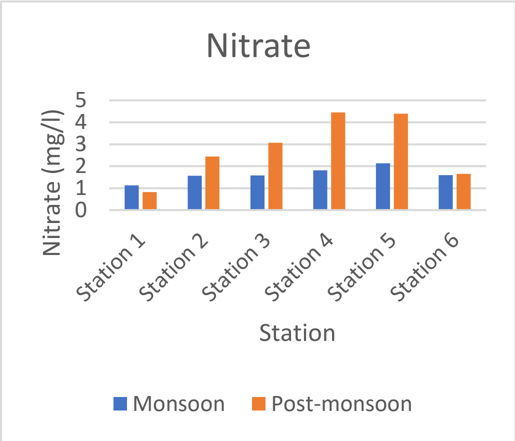


Figure (m)

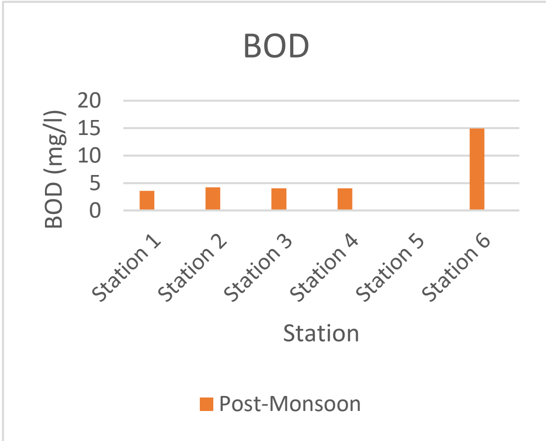


Figure (n)

Figure 4.7 Graphical representation of physical and chemical parameters in Santa Inês Creek at different stations (Monsoon and post-Monsoon) (a) pH, (b) Conductivity, (c) Turbidity, (d) Total dissolved solids, (e) Total hardness, (f) Calcium, (g) Magnesium, (h) Phosphate, (i) Nitrite, (j) Alkalinity, (k) Acidity, (l) Fluoride, (m) Nitrate, (n) BOD

With the exception of Station 1 in Santa Inês Creek of the monsoon sample, all of the stations have calcium concentrations above the acceptable limit of 80 mg/L [Figure 4.7(f)]. Station 6 has the highest concentration of calcium in the monsoon sample, this could be because of runoff from adjacent construction projects. Only the first, second, and third stations surpass the acceptable limit for the post-monsoon sample. All of the stations for the monsoon and post-monsoon samples have magnesium levels that are higher than acceptable limits, the monsoon sample's station 6 has the highest level, at 257.272 mg/L.

The phosphate concentration is lesser in monsoon as compared to post-monsoon samples, exceeding acceptable limits at Station 2 and Station 3 in monsoon and all the stations except for Station 6 for post-monsoon samples. The highest phosphate concentration found was 2.421 mg/L at Station 4 and the least at Station 6 with 0.195 mg/L in the post-monsoon sample [Figure

4.7(h)]. Phosphates are chemical compounds that contain phosphorous, phosphorous is a key nutrient that both plants and animals use for growth and development. While phosphate is essential for plant and animal life, too much of it can cause a form of water pollution known as eutrophication. Phosphorous is a common constituent of agricultural fertilizer as it is essential for plant growth, pollution from septic systems and sewers can cause excess phosphorous to occur in bodies of water, and human sewage is the most prevalent urban source of nutrient pollution. Contamination with manure and organic waste will also cause levels of phosphorous to increase, municipal and industrial sources are considered to be "point sources" of nutrient pollution as they discharge nutrients directly into surface and groundwater (Stones 2017). The high concentration of phosphate in the post-monsoon sample indicates the mixing of organic wastewater with the creek water.

In both monsoon and post-monsoon, the amount of Nitrogen-Nitrite present in Santa Inês Creek is within the acceptable limit having the highest at the source of the creek with 1.378 mg/L at Station 6 of the post-monsoon sample. As nitrite is easily oxidized to nitrate, nitrate is the compound predominantly found in groundwater and surface waters. Similarly, the concentration of nitrate in both monsoon and post-monsoon is within the acceptable limit having the highest at Station 4 of the post-monsoon sample with 4.451 mg/L [Figure 4.7(m)].

Nitrate level increases once the precipitation reduces in Santa Inês Creek. Many agricultural chemicals, including pesticides and herbicides, contain nitrates. These chemicals may leach nitrates into surface water sources through runoff. Industrial waste and leaking septic tanks and septic systems also release nitrates and nitrites into water. Additionally, rainwater may carry manure containing nitrates into lakes and streams. Nitrites (NO_2) are made from one nitrogen atom and only two oxygen atoms which are more toxic than nitrates (NO_3). The creek's lower nitrite concentration could be the result of its conversion to nitrates.

During the monsoon, the creek's total alkalinity is observed to be within acceptable limits, but following the monsoon, stations 3, 4, 5, and 6 report somewhat higher than the limit [Figure 4.7(j)]. With a value of 308 mg/L, Station 4 of the post-monsoon sample had the highest alkalinity. Rather than being a chemical, alkalinity is a feature of water that depends on other chemicals, such as hydroxides, carbonates, and bicarbonates, being present. The definition of alkalinity would be "the buffering capacity of a water body, a measure of the ability of the water body to neutralize acids and bases and thus maintain a fairly stable pH level" (https://www.usgs.gov/special-topics/water-science-school/science/alkalinity-and-water). In more simple terms, water with high alkalinity will experience less of a change in its acidity, for instance, when acidic water, such as acid rain or an acid spill, is introduced into the water body.

The Total Acidity ranges from 16 mg/L to 44 mg/L. Dissolved carbon dioxide (CO_2) is the main source of acidity in unpolluted waters. Acidity from sources other than dissolved CO_2 is not commonly encountered in unpolluted natural waters and is often an indicator of pollution. The overall fluoride concentration is below the acceptable limit of 1 mg/L, except for station 6 of the post-monsoon sample at 1.17 mg/L. Higher concentrations of fluoride are often associated with underground sources. In seawater, a total fluoride concentration of 1.3 mg/litre has been reported (Slooff et al., 1988). In areas rich in fluoride-containing minerals, well water may contain up to about 10 mg of fluoride per litre. Fluorides may also enter a river as a result of industrial discharges (Slooff et al., 1988). In groundwater, fluoride concentrations vary with the type of rock the water flows through but do not usually exceed 10 mg/litre. Fluoride primarily produces effects on skeletal tissues (bones and teeth). Low concentrations provide protection against dental caries, especially in children, fluoride can also have an adverse effect on tooth enamel and may give rise to mild dental fluorosis. The Biochemical Oxygen Demand (BOD) was analysed only for post-Monsoon samples. With the highest BOD at Station 6 with 14.959 mg/L and the lowest at the mouth (Station 1) with 3.577 mg/L. The BOD for all the analysed samples were found to be above the acceptable limit of 3 mg/L as specified by SW II standards (CPCB 1993) indicating a high level of organic waste content. High BOD levels can deplete oxygen concentrations, leading to hypoxic or anoxic conditions. This oxygen depletion can harm fish, invertebrates, and other aquatic organisms, affecting their survival, growth, and reproduction. Pollution is a major contributor to increasing the BOD of water bodies.

In addition to the BIS limit, the creek water is also compared to SW II standards (CPCB 1993) for Bathing, Contact Water Sports and Commercial Fishing. The pH was within the acceptable limit in all the stations in both seasons. The turbidity exceeds its acceptable limit in Station 4 and Station 5 of the monsoon sample with 49.2 NTU and 69.9 NTU respectively. The Turbidity of the Santa Inês Creek in post-monsoon is within the SW II Standards. However, the BOD exceeds its acceptable limit in all stations having a significantly high value in Station 6 (14.959 mg/L) indicating high pollution.

Table 4.9 Primary water quality criteria for class SW-II waters

Sr. No.	**Parameters**	**Standards**
1	pH	6.5 – 8.5
2	Turbidity (NTU)	30
3	BOD (mg/L)	3

4.2.2 Ourém Creek

The seasonal variation of physical and chemical parameters of Ourém Creek at all 6 stations is given below (Table 4.7 and Table 4.8). The obtained data is compared with the BIS standards and SW II standards (CPCB 1993).

The pH of the Ourém Creek ranges from 6.71 to 6.99 and 7.55 to 7.61 for monsoon and post-monsoon samples respectively which is within the limit of the Bureau of Indian Standard (B.I.S). The Ourém Creek is neutral to moderately alkaline. The conductivity is maximum at the mouth and decreases towards the source of the creek as the mouth of the creek opens at the Mandovi Estuary which is near the Arabian Sea. The conductivity is significantly higher during post-monsoon having an approximately constant level of 35 mg/L in all the stations and the least at the source at 33.1 mg/L. The highest conductivity during monsoon is at Station 1 with 19.05 mS/Cm and the least at Station 6 with 0.302 mS/Cm. Similarly, the total dissolved solids follow the same trend where the highest is at the mouth with 12192 mg/L and 22848 mg/L for monsoon and post-monsoon samples respectively. The reason is the high salt content of the water closer to the sea. The TDS concentration is way beyond the acceptable limit of 500 mg/L hence is not suitable for drinking purposes.

The turbidity also exceeds its acceptable and permissible limit of 1 NTU and 5 NTU as can be observed from the above table. All the stations except Station 6 of the monsoon samples show a higher level of total hardness more than the acceptable limit of 200 mg/L. The highest total hardness was observed in Station 3 of the post-monsoon sample with 483.649 mg/L. The post-monsoon sample had a higher hardness than the monsoon sample in all 6 stations. The major contribution of the total hardness in this creek is the calcium ions. Typical seawater contains 400 mg/L of calcium and the post-monsoon samples of the creek water also showed approximately 400 mg/L of calcium concentration [Figure 4.8(f)].

Table 4.10 Physical and chemical parameters of Ourém Creek at different stations (Monsoon sample)

Parameters	**Station 1**	**Station 2**	**Station 3**	**Station 4**	**Station 5**	**Station 6**
pH	6.99	6.79	6.75	6.71	6.76	6.76
Turbidity (NTU)	11.21	13.27	9	12.6	6.76	3.4
Conductivity (mS/Cm)	19.05	16.46	12.38	11.87	4.87	0.302
TDS (mg/L)	12192	10534.4	7923.2	7596.8	3116.8	193.28
Total Hardness (mg/L)	305.892	305.892	257.272	225.876	208.652	97.24
Calcium (mg/L)	160.032	160.032	160.032	80.016	160.032	0
Magnesium (mg/L)	145.859	145.859	97.24	145.86	48.619	97.24
Phosphate (mg/L)	0.1176	0.1063	0.0721	0.0683	0.0569	0.0531
Nitrites (mg/L)	0.0271	0.0108	0.0027	0.0013	0.0013	0.0067
Nitrate (mg/L)	0.6896	0.6896	0.5697	0.3448	0.4647	0.3148
Alkalinity (mg/L)	98	66	56	68	50	38
Acidity (mg/L)	16	12	10	10	12	8
Fluoride (mg/L)	0.8359	0.2218	0.1253	0.1929	0.0996	0

Table 4.11 Physical and chemical parameters of Ourém Creek at different stations (post-Monsoon sample)

Parameters	**Station 1**	**Station 2**	**Station 3**	**Station 4**	**Station 5**	**Station 6**
pH	7.56	7.55	7.58	7.57	7.61	7.59
Turbidity (NTU)	25.5	19.13	11.29	19.6	2.15	3.43
Conductivity (mS/Cm)	35.7	35.7	35.3	35.4	35.5	33.1
TDS (mg/L)	22848	22848	22592	22656	22720	21184
Total Hardness (mg/L)	421.555	400.995	483.649	398.968	378.408	414.164
Calcium (mg/L)	368.073	328.065	328.065	360.072	320.064	312.062
Magnesium (mg/L)	53.482	72.929	155.584	38.895	58.344	102.108
Phosphate (mg/L)	0.0241	0.0390	0.0279	0.0316	0.0483	0.0186
Nitrites (mg/L)	0.0659	0.0510	0.0399	0.0585	0.0464	0.0250
Nitrate (mg/L)	0.6466	0.7218	0.4661	0.5413	0.4210	0.7067
Alkalinity (mg/L)	124	124	124	126	126	104
Acidity (mg/L)	18	14	14	14	14	12
Fluoride (mg/L)	1.4161	1.3145	1.197	1.3843	1.3875	0.273
BOD (mg/L)	0.651	1.464	4.227	1.301	8.13	6.341

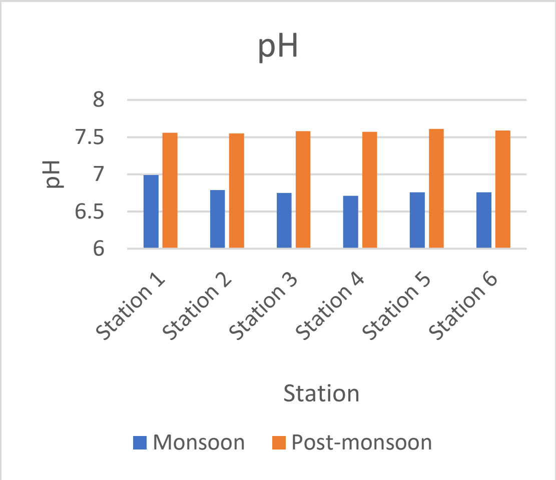
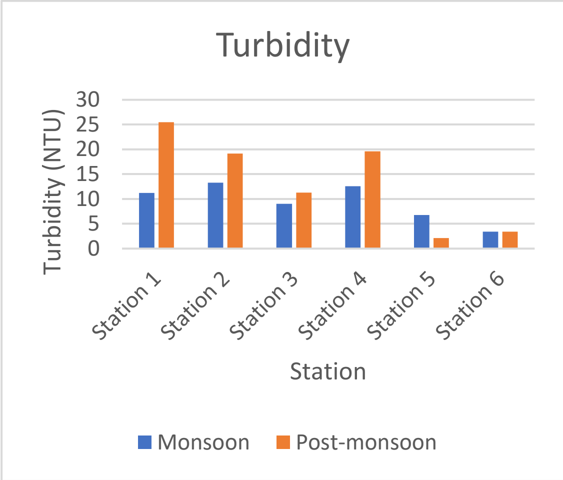


Figure (a)



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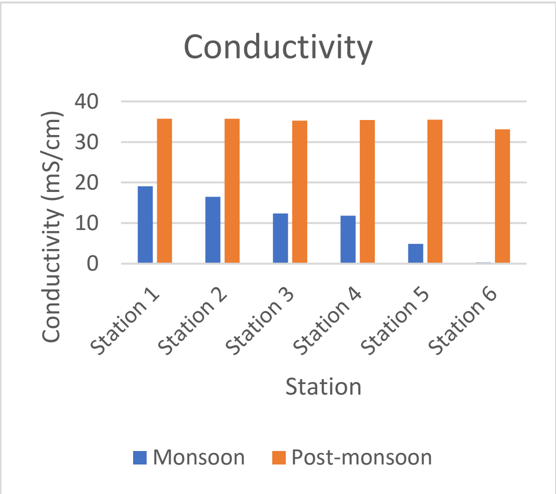


Figure (c)

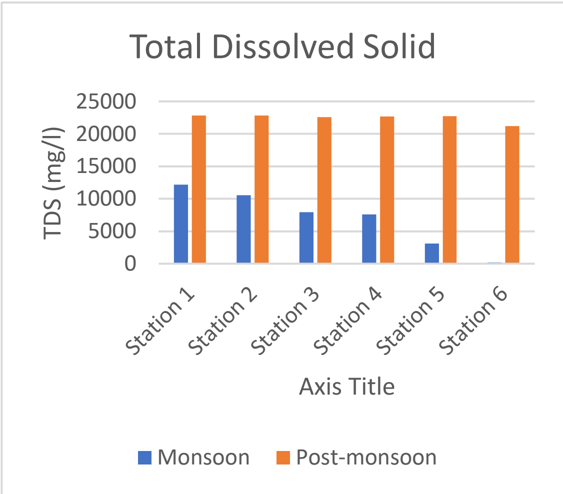


Figure (d)

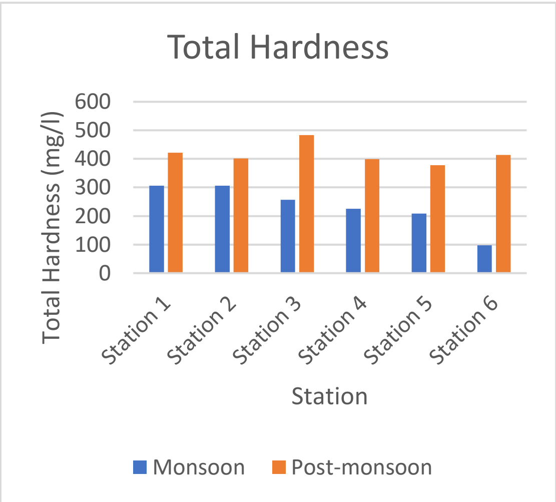
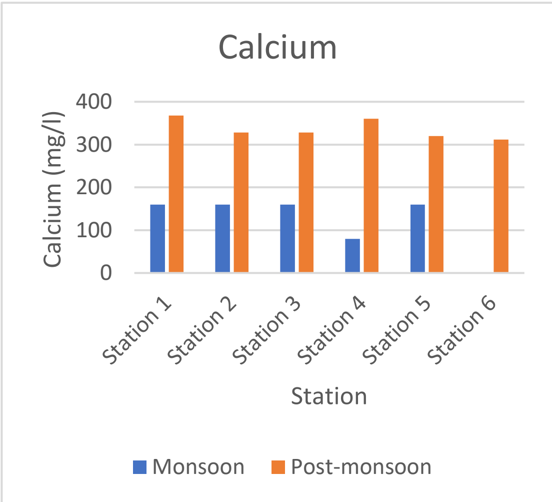


Figure (e)



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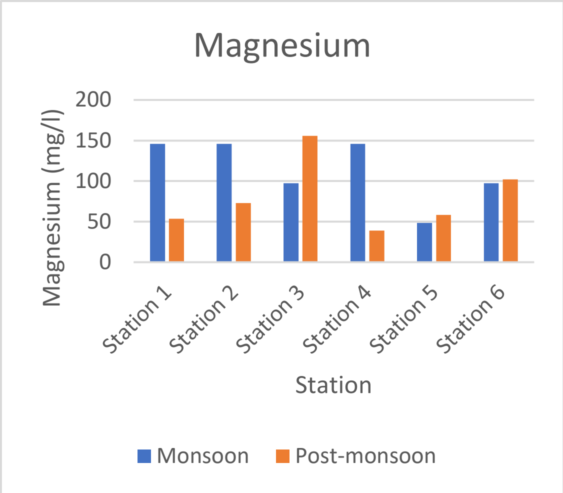


Figure (g)

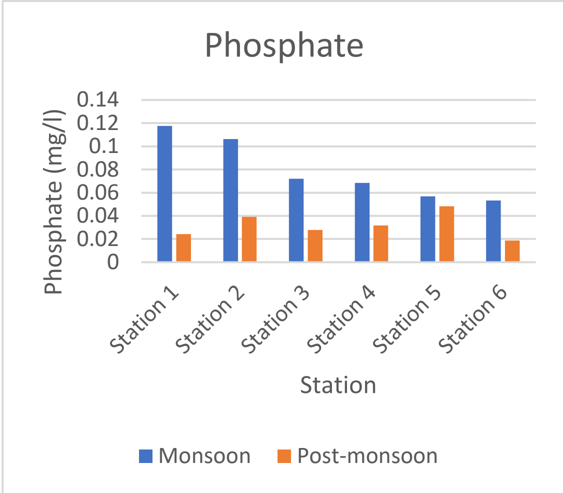


Figure (h)

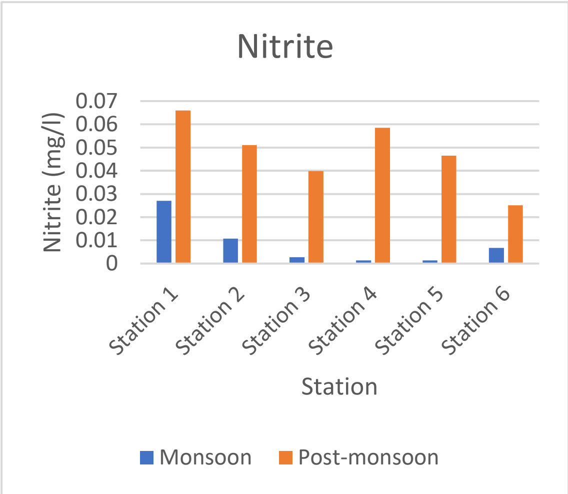


Figure (i)

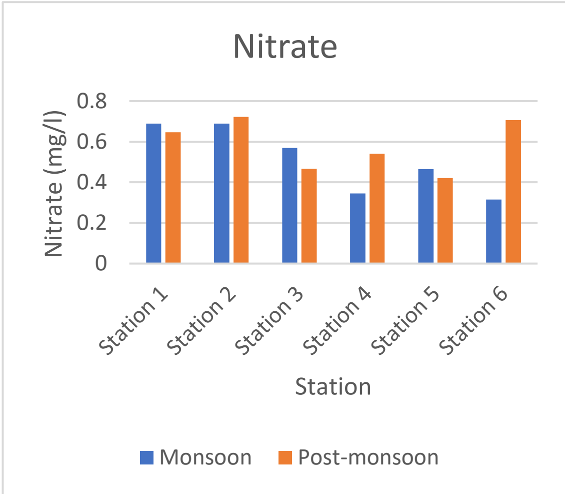
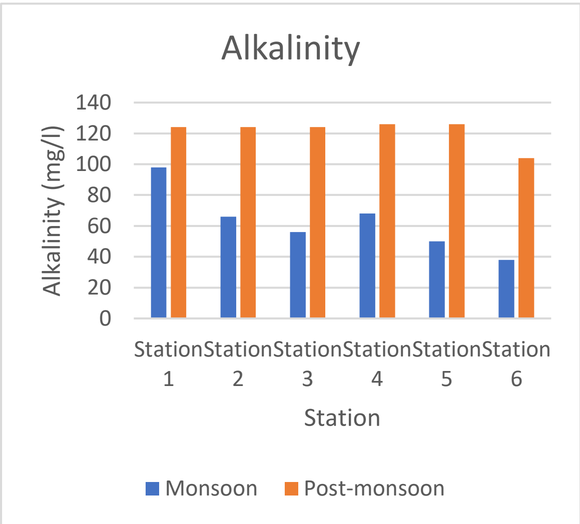


Figure (j)



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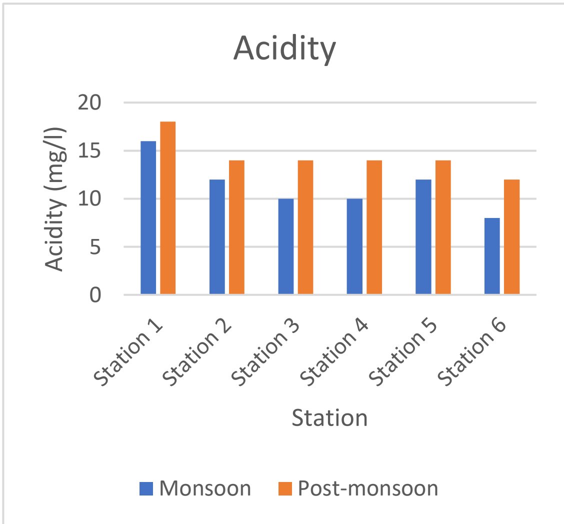

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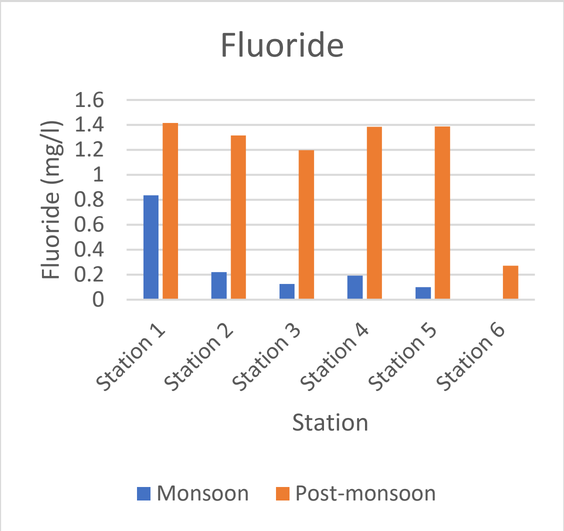

Figure (m)

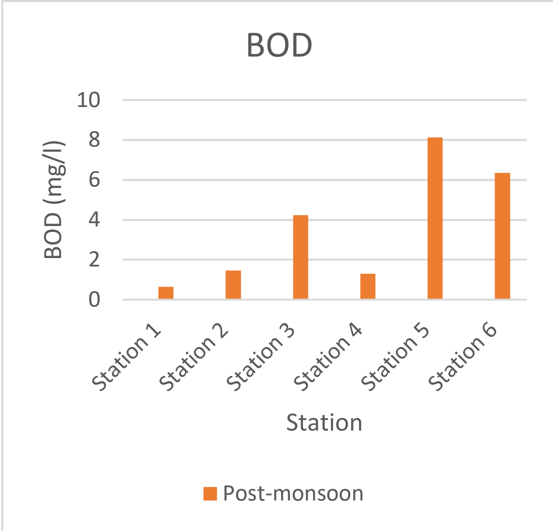

Figure (n)

Figure 4.8 Graphical representation of physical and chemical parameters in Ourém Creek at different stations (Monsoon and post-monsoon) (a) pH, (b)Turbidity, (c) Conductivity, (d) Total dissolved solids, (e) Total hardness, (f) Calcium, (g) Magnesium, (h) Phosphate, (i) Nitrite, (j) Nitrate (k) Alkalinity, (l) Acidity, (m) Fluoride, (n) BOD

In comparison to the monsoon sample, the post-monsoon sample has the highest concentration of calcium, and the monsoon sample has the highest concentration of magnesium, with stations 1 and 2 having the highest concentrations at 145.859 mg/L. The phosphate concentration is lesser in post-monsoon as compared to monsoon samples and is way within the acceptable limits of 1 mg/L. The highest phosphate concentration found was 0.1176 mg/L at Station 1 of the monsoon sample and the least 0.0186 mg/L at Station 6 of the post-monsoon sample. The reason for higher phosphate concentration during monsoon samples as compared to the post-monsoon samples may be due to the runoff of water from nearby fields.

In both monsoon and post-monsoon, the amount of Nitrogen-Nitrite present in Ourém Creek is within the acceptable limit of 1 mg/L. The creek is observed to have an acceptable amount of total alkalinity during both monsoon and post-monsoon. The fluoride concentration decreases from 0.8359 mg/L at Station 1 to 0 mg/L at Station 6 of the monsoon sample and is below the acceptable limit of 1 mg/L; whereas, for the post-monsoon sample, the fluoride concentration is above the acceptable limit except for Station 6 where the concentration is 0.273 mg/L [Figure 4.8(m)]. Higher concentrations of fluoride are often associated with underground sources. The higher concentration of fluoride in the Ourém Creek may be due to the geology of the region as well as the influx from Mandovi Estuary. Similar to Santa Inês Creek, the Biochemical Oxygen Demand (BOD) was analysed only for post-monsoon samples. With the highest BOD at Station 5 with 8.13 mg/L and the lowest at the mouth (Station 1) with 0.651 mg/L. The BOD for Station 3, Station 5 and Station 6 were found to be above the acceptable limit of 3 mg/L indicating a high level of organic waste content [Figure 4.8(n)].

In addition to the BIS limit, the creek water is also compared to SW II standards (CPCB 1993) for Bathing, Contact Water Sports and Commercial Fishing (Table 4.6). The pH was within the acceptable limit in all the stations in both seasons. The turbidity is also within the acceptable limit of 30 NTU in both seasons. However, the BOD exceeds its acceptable limit in Station 3 (4.227 mg/L), Station 5 (8.13 mg/L) and Station 6 (6.341 mg/L).

The entire research reveals that Ourém Creek is less contaminated than Santa Inês Creek. However, the salty water from the Mandovi Estuary intrudes more into Ourém Creek than Santa Inês Creek does. The Ourém Creek is wider and relatively more linear as compared to the Santa Inêz Creek. The sampling was done in the period from July 2023 to February 2024. There were large-scale civil-infrastucture works in Panjim during this period. The civil works involved digging of soil in areas and roads of Panjim around the Santa Inês Creek. Certain areas like Tonca Bridge over Santa Inês Creek were not easily accessible and samples were not taken there.

4.3 Variation in temperature in Santa Inês Creek and Ourém Creek

Santa Inês Creek and Ourém Creek have monthly and station-specific temperature fluctuations. Figures 4.9 and 4.10, show the temperature variations between 28 °C and 31 °C in Santa Inês Creek and 28 °C and 31.5 °C in Ourém Creek.

Table 4.12 Monthly temperature variation in Santa Inês Creek

Months	**Temperature (°C)**					
	Station 1	**Station 2**	**Station 3**	**Station 4**	**Station 5**	**Station 6**
11-Jul-23	28.9	29.7	29.5	29.5	29.4	29.4
21-Aug-23	28.9	29.4	29.5	29.5	29.4	29.3
30-Sep-23	29.3	29.3	29.4	29.4	29.4	29.3
26-Oct-23	30	30	29.5	31	29	29
25-Nov-23	31.5	31	31	31.5	30	29
28-Dec-23	30	30	29	28	30	30
10-Jan-24	29	29	29	28	28	29
08-Feb-24	28	28	29	28	28	29

Table 4.13 Monthly temperature variation in Ourém Creek

Months	**Temperature (°C)**					
	Station 1	**Station 2**	**Station 3**	**Station 4**	**Station 5**	**Station 6**
11-Jul-23	28.9	29.9	29.7	29.7	29.6	29.6
21-Aug-23	28.8	29.8	29.7	29.7	29.6	29.6
30-Sep-23	28.9	28.8	28.8	28.9	28.7	28.7
26-Oct-23	30	30.5	31.2	31	31.5	31
25-Nov-23	32.5	32	32	32	32	31
28-Dec-23	29	29	30	29	30	30
10-Jan-24	30	29	29	30	30	29
08-Jan-24	27	28	28	28	29	29

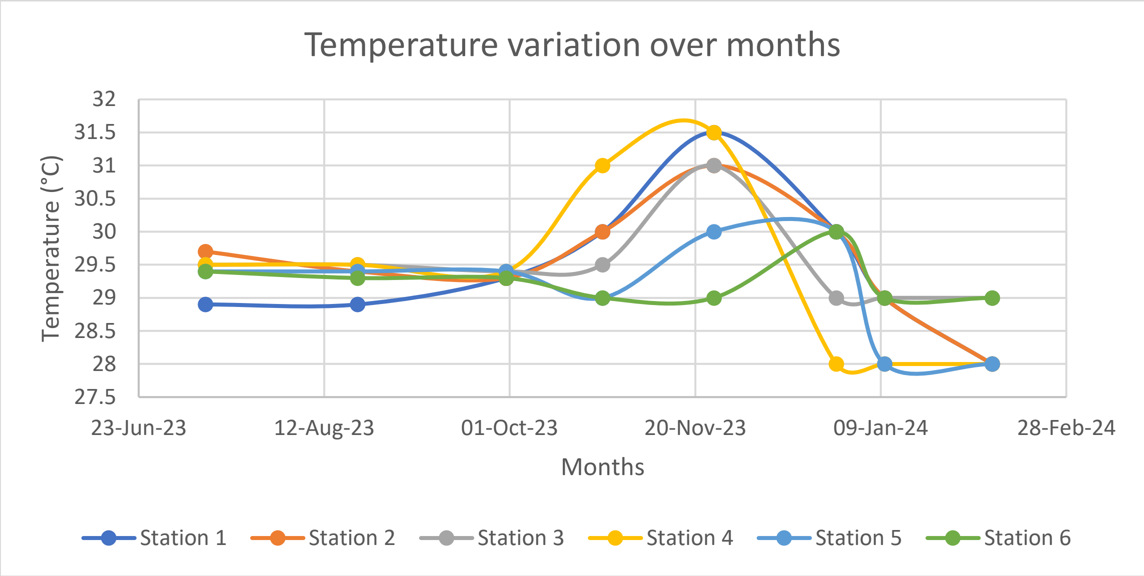

Figure 4.9 Graphical representation of monthly temperature variation in Santa Inês Creek

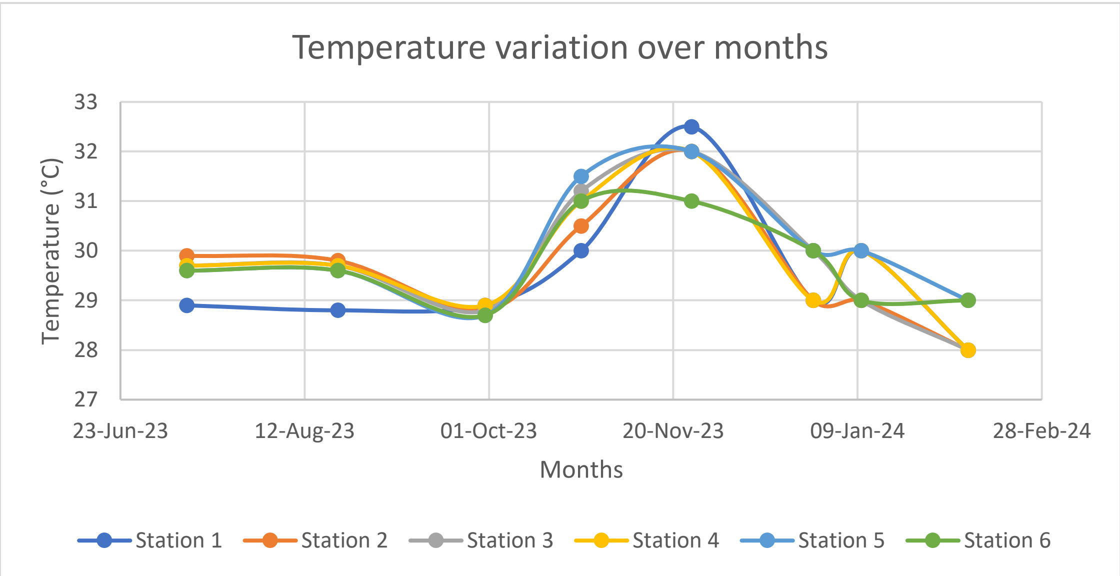

Figure 4.10 Graphical representation of monthly temperature variation in Ourém Creek

The highest recorded temperature in Santa Inês Creek occurred in November at 31.5 °C at Station 1 and Station 4 and 32.5 °C in Ourém Creek. November was the month with the biggest rise in temperature in both creeks. Figure 4.9 shows that Santa Inês Creek experienced a significant rise in temperature between October 2023 and November 2023, followed by a subsequent decline to a minimum of 28 °C for Stations 1, 2, 4, and 5 in February 2024.

However, in the Ourém Creek, the temperature decreased from August 2023 to October 2023 and then increased in November 2023 [Figure 4.10]. Station 1 recorded the maximum temperature there, at 32.5 °C, before sharply dropping to 28 °C in February 2024 for Stations 1, 2, 3, and 4. At Stations 1, 2, 3, 4, 5, and 6, the average temperature of the Santa Inês Creek throughout the months under study is 29.4 °C, 29.5 °C, 29.4 °C, 29.3 °C, 29.1 °C, and 29.2 °C respectively. At Stations 1, 2, 3, 4, 5, and 6, the average temperature for the months under study in the Ourém Creek is 29.5 °C, 29.6 °C, 29.8 °C, 29.7 °C, 30 °C, and 29.7 °C, respectively.

CHAPTER 5
CONCLUSIONS

CHAPTER 5: CONCLUSIONS

The study conducted on the monthly salinity levels of Santa Inês Creek and Ourém Creek provides valuable insights into the dynamics of these water bodies, their seasonal variations, and the impact of environmental factors on their chemical and physical parameters. Through a comprehensive analysis of data collected from various stations over multiple months, several significant findings have emerged, shedding light on the intricate relationship between precipitation, tidal cycles, geographical features, and water quality.

Santa Inês Creek exhibits distinct patterns of salinity variation influenced by seasonal changes, tidal fluctuations, and proximity to the Mandovi Estuary and Arabian Sea. During the monsoon season, the influx of freshwater from heavy precipitation reduces salinity levels significantly, particularly at stations closer to the source and away from the Estuary. However, as the monsoon recedes, salinity gradually increases, reaching its peak in February when dry conditions prevail. Tidal effects are also evident, with stations closer to the estuary experiencing sharper fluctuations in salinity compared to those further upstream. Notably, February marks the first instance where Station 6, situated at the source of the Santa Inês Creek near café Basil in the Taleigão marshland, records a salinity level of 1 ‰ [Figure 4.3(h)]. This finding suggests that Santa Inês Creek could be classified as a seasonal tidal body as the creek is influenced by the tides indicating the intrusion of saline water into the entire creek, extending all the way to the marshland of Taleigão (Station 6). This emphasizes the complex interplay between freshwater input, tidal movements, and geographical proximity to saline sources in shaping the salinity dynamics of the creek.

Contrastingly, Ourém Creek exhibits relatively stable salinity levels, with fluctuations primarily driven by seasonal variations in precipitation rather than tidal cycle. Being influenced by the Mandovi Estuary, which contributes saline water, the creek maintains higher salinity levels compared to Santa Inês Creek. This suggests a high degree of intrusion of seawater into the Ourém Creek.

The analysis of physical and chemical parameters further elucidates the water quality status of both creeks. The study presents a comprehensive analysis of the seasonal variations in the physical and chemical parameters of Santa Inês Creek and Ourém Creek, focusing on six stations along each creek during the monsoon and post-monsoon periods. The data collected includes pH, conductivity, total dissolved solids (TDS), turbidity, total hardness, calcium and magnesium concentrations, phosphate levels, nitrite and nitrate concentrations, total alkalinity, acidity, fluoride concentration, and biochemical oxygen demand (BOD).

In Santa Inês Creek, pH levels were within acceptable limits throughout both seasons, indicating a stable environment for aquatic life. However, conductivity, TDS, and turbidity exceeded permissible levels, particularly near the estuary, suggesting high salt content and pollution from nearby settlements. Total hardness, calcium, and magnesium concentrations also surpassed acceptable limits, with implications for soap effectiveness and water quality. Elevated phosphate concentrations, especially during the monsoon, indicate potential nutrient pollution, while Nitrite and Nitrate levels remained within acceptable limits. BOD levels exceeded standards in all stations, indicating high organic waste content and potential harm to aquatic organisms.

Similarly, Ourém Creek exhibited pH levels within acceptable limits, but conductivity, TDS, turbidity, total hardness, calcium, and magnesium concentrations exceeded BIS standards. Phosphate concentrations were higher during the monsoon samples as compared to post-monsoon’s likely due to agricultural runoff, while Nitrite levels remained within acceptable limits. Fluoride level exceeded the BIS limit during post-monsoon at all stations except for station 6. BOD levels exceeded standards in several stations, suggesting organic waste contamination.

Comparing the two creeks, Santa Inês Creek appeared more contaminated, with higher TDS, turbidity, Phosphate and BOD levels, likely due to salt content runoff, sewage and wastewater discharge. Ourém Creek fares relatively better, albeit still showing signs of pollution, particularly in terms of organic waste content. Also, Ourém Creek exhibited higher levels of salts intruding from the estuary. Both creeks pose risks to aquatic life and human health, emphasizing the need for pollution control measures. The comparison with SW II standards highlights areas of concern, particularly regarding parameters such as turbidity and biochemical oxygen demand (BOD), which exceed acceptable limits in certain stations and seasons. Overall, the study highlights the complex interplay of natural and anthropogenic factors in shaping water quality in these coastal ecosystems, underscoring the importance of continued monitoring and management efforts to ensure the health and sustainability of these vital water resources.

Furthermore, the study reveals significant temperature variations in both creeks, with distinct seasonal trends observed. While Santa Inês Creek experiences a gradual rise in temperature from October to November followed by a decline in January and February, Ourém Creek shows a drop, rise and drop fluctuations. These temperature variations reflect the interplay of climatic conditions, geographical features, and anthropogenic influences on water bodies. In conclusion, the study provides valuable insights into the seasonal dynamics and water quality status of Santa Inês Creek and Ourém Creek. By analysing a comprehensive dataset encompassing multiple parameters and stations, the study enhances our understanding of the complex physical and chemical characteristics of these creeks. The findings underscore the importance of integrated water resource management strategies to ensure the sustainability and resilience of coastal ecosystems in the face of changing environmental conditions and anthropogenic pressures. Continued monitoring and conservation efforts are essential to preserve the ecological integrity and ecosystem services provided by these valuable natural resources.

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IMAGE REFERENCE

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