TALLINN UNIVERSITY OF TECHNOLOGY
SCHOOL OF ENGINEERING
Department of Civil Engineering and architecture

Effect of wastewater discharge location on the distribution of metal pollution in the Gulf of Finland

Reovee ärajuhtimise koha mõju metallireostuse levikule Soome lahes

MASTER THESIS

Student: Behzad Bashiri
Student code: 214155EABM
Supervisor:

Urmas Raudsepp, LM - Department of Marine Systems

Supervisor:

Arvo Iital, Professor Emeritus - School of Engineering

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(*On the reverse side of title page*)

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20.05. 2023
Author: Behzad Bashiri

Thesis is in accordance with terms and requirements.

20.05. 2023
Supervisor: Urmas Raudsepp
/signature/

20.05. 2023
Supervisor: Arvo Iital
/signature/

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Department of Civil Engineering and architecture

THESIS TASK

Student: Behzad Bashiri, **214155EABM**

Study programme: EABM, Environmental Engineering and Management

Supervisor(s):

Urmas Raudsepp, LM - Department of Marine Systems

Arvo Iital, Professor Emeritus - School of Engineering

, (position, name, phone)

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Student: Behzad Bashiri

Supervisor: Urmas Raudsepp, LM - Department of Marine Systems

co-Supervisor: Arvo Iital, Professor Emeritus - School of Engineering

Consultant:

Head of study programme:

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Table of Contents

LIST OF ABBREVIATIONS

ADT	Air-dried metric ton
BAT	Best available techniques
BPT	Best possible techniques
RMSE	Root-mean-square deviation
SPM	Suspended particulate matter

PREFACE

The marine environment is a fragile ecosystem that plays a vital role in sustaining life on Earth. However, various human activities have led to the introduction of pollutants into our oceans, posing significant threats to marine life and ecosystem health. Among these pollutants, heavy metals from wastewater discharge have emerged as a growing concern. The Gulf of Finland serves as an important water body shared by Finland, Estonia, and Russia. With increasing urbanization and industrialization in the region, the discharge of wastewater containing heavy metals from municipal and industrial sources has raised alarm bells regarding potential risks to human health and ecological systems.

The primary objective of this study is to identify a suitable location for wastewater discharge of the planned bioproduct factory by Viru Keemia Grupp AS and to investigate the spatial patterns of metal contamination associated with the outlet of the factory in the Gulf of Finland in order to minimize its impact on the marine environment. Two alternative locations of the wastewater outlet were preselected, one coastal and the other offshore. By examining the distribution of metal pollution in relation to different discharge locations, this research aims to provide valuable insights into the environmental consequences of wastewater discharge and aid in the development of sustainable management strategies.

This master's thesis endeavors to shed light on the effect of wastewater discharge location on the distribution of metal pollution in the Gulf of Finland. By comprehensively examining the spatial patterns of metal contamination and assessing the most suitable discharge location for the environmental well-being of the Gulf, this study strives to contribute to the preservation and sustainability of this precious marine ecosystem.

1. INTRODUCTION

The Viru Keemia Grupp AS bioproducts production complex is a planned facility that aims to produce cellulose, soluble cellulose, biochemistry, green energy, and biofertilizers. This production will be achieved through the utilization of modern KRAFT technology, involving the chemical treatment of wood pulp. The establishment of this factory necessitates an appropriate land area of approximately 160 hectares. In the designated area, there will be raw wood and wood chip warehouses, production units dedicated to cellulose and biochemical production, a combined heat and power plant, as well as a raw water and wastewater treatment plant. The complex has been designed in accordance with the stringent standards of the best possible technique (BPT). Furthermore, the production complex is committed to adhering to the highest environmental standards set by the European Union, specifically in regards to air and water treatment and usage.

1.1. Oceanography And Environment

The scientific study of the physical, chemical, and biological properties of the ocean is known as oceanography (Thurman, H. V. 2019). The marine environment refers to the entire ocean system, comprising both living and non-living elements, as well as their interactions. In order to comprehend the complexity of the ocean system and how it impacts our world, it is crucial to understand the link between oceanography and the marine environment. (Kaiser, M. J., et al., 2011).

One important area of study within oceanography and marine environmental research is the analysis of heavy metal concentrations in regional seas. Heavy metals are metallic elements that have high atomic weights and are toxic to living organisms at certain concentrations. They can originate from natural processes, such as weathering of rocks and volcanic eruptions, but human activities, such as industrial and agricultural practices, have significantly increased heavy metal inputs into the oceans. Ocean currents can influence the variability of heavy metal concentrations in regional seas through their role in transporting and redistributing pollutants. Currents can carry heavy metals from their source regions to other areas, leading to spatial variability in concentrations. Additionally, ocean currents can cause vertical mixing of water masses, which can affect the distribution and cycling of heavy metals in the water column, further contributing to their variability

(Wang, L., Luo, X., & Fan, Y. 2018). Metal content is a crucial component of saltwater chemistry. Iron, zinc, and copper are examples of trace metals that are important nutrients for marine life and play crucial roles in several biological processes. However, high levels of metals can have negative ecological effects and be poisonous to marine life (Wu et al., 2017). Metal pollution is a significant problem caused by human activities such as urbanization and industrial processes, which can release large amounts of metals into the ocean. This pollution can have detrimental effects on marine life as the metals can accumulate in the water and sediments. For instance, mercury pollution can lead to neurological and reproductive issues in marine mammals and fish (Mason et al., 2012). Additionally, metal pollution can also impact human health, particularly through the consumption of contaminated seafood. Seafood is a crucial source of protein and nutrients worldwide, but ingesting contaminated seafood can lead to metal poisoning and severe health consequences (Tang et al., 2022).

Understanding the chemical properties of seawater, including metal distribution and the impacts of pollution, is critical for protecting marine ecosystems and human health. By studying the ocean's chemistry, oceanographers can provide valuable insights into the impacts of human activities on the marine environment and help develop effective strategies for pollution control and mitigation.

1.2. Coastal Dynamics

Coastal water dynamics play an essential role in the distribution of metals from inland water to the sea. Coastal waters are dynamic systems that are influenced by various factors, including tidal cycles, wind patterns, and freshwater inputs from rivers and streams. Understanding these dynamics is critical for predicting how metal pollution from inland sources can impact the coastal environment. When freshwater from rivers and streams enters the coastal zone, it can bring with it large amounts of dissolved and particulate matter, including metals, which can have significant impacts on the chemistry and ecology of coastal waters. High levels of metal pollution, for example, can cause toxic algal blooms that can lead to the death of fish and other marine organisms (Lv et al., 2021). Human activities such as dredging, construction, and urbanization can also impact coastal water dynamics and lead to increased metal pollution. For instance, the construction of ports and marinas can cause sedimentation and metal pollution in nearby coastal waters (Calvache and Pulido-Bosch,1997). In conclusion, the movement of metals from inland water to the sea is significantly influenced by coastal water dynamics. Foreseeing how metal pollution may affect coastal ecosystems and creating efficient measures for pollution control and mitigation require an understanding of these processes.

1.3. Wastewater Discharge

Wastewater discharge to the sea involves the release of treated or untreated wastewater, including domestic, industrial, and agricultural waste into the ocean. This practice introduces a wide range of pollutants such as nutrients, pathogens, organic and inorganic chemicals, and heavy metals into marine ecosystems, potentially causing significant environmental and ecological impacts. This discharge can occur through various pathways, such as outfalls, pipelines, or direct release from ships or offshore platforms. Coastal cities and industrial facilities commonly adopt this practice as a means of managing and disposing of wastewater effectively (Wu et al., 2022).

Water circulation patterns can influence the movement and distribution of wastewater discharged into the sea. Discharging wastewater in areas with strong water circulation patterns can result in pollutants being transported to other areas or concentrated in certain regions, potentially affecting local marine ecosystems and organisms (Nilsson et al., 2008). In conclusion, wastewater may be an important cause of metal contamination in coastal areas, and the dynamics of coastal water can be crucial in determining how these metals are distributed. Understanding these processes is essential for forecasting metal pollution's destiny and effects in coastal environments as well as for creating efficient pollution management and mitigation techniques.

However, the impact of wastewater discharge on marine environments depends on the type and quantity of pollutants in the wastewater, the treatment processes employed, "the location and depth of discharge", and the characteristics of the receiving marine environment.

1.3.1. Location Of Discharge

The location of wastewater discharge can vary between near-coastal areas and offshore areas, and this can affect how the discharged wastewater is distributed in the sea (Kvesić et al., 2021). Wastewater discharged near the coast can then spread along the coastline or be influenced by coastal currents, tides, and other local hydrodynamic processes. Near-coastal discharges are generally shallower and may result in higher pollutant concentrations near the surface, as well as in the near-shore marine environment. On the other side, wastewater discharged offshore is typically released in deeper waters. Offshore discharges can be influenced by regional ocean currents and other large-scale hydrodynamic processes. The discharged wastewater can mix and disperse in the water column, and pollutants can be transported by ocean currents over longer distances. In total the location of the wastewater discharge point can affect the dispersion and dilution of pollutants in the receiving marine environment (Liet al., 2019). Discharging wastewater close to sensitive areas, such as coral reefs, seagrass beds, or marine protected areas, can pose a higher risk of ecological impacts. It is important to carefully select discharge locations to minimize potential impacts on vulnerable ecosystems and marine habitats. In addition, it is crucial to carefully consider the location and depth of wastewater discharge into the sea, along with other factors, to minimize potential impacts on marine ecosystems and protect the health of the marine environment. Compliance with regulations, monitoring of discharge practices, and ongoing assessment of potential impacts are essential to ensure the sustainability of marine ecosystems and coastal communities. (Burke et al., 2011)

1.3.2. Depth Of Discharge

The depth at which wastewater is discharged can also affect its diffusivity in the water column and consequently its distribution over the discharge basin. Discharging wastewater at shallower depths can result in higher pollutant concentrations near the water surface, potentially impacting marine life that inhabits the surface or near-surface waters. On the other hand, discharging wastewater at greater depths can result in better dispersion and dilution of pollutants, reducing their potential impact on the surface or near-surface marine organisms. (Kwon et al., 2005).

However, selecting the optimal discharge location and depth can be different in different parts of the world depending on the regional environments and local oceanographic and climatic conditions. In the meanwhile, monitoring and modeling studies can help to assess the fate and transport of pollutants from wastewater discharge, taking into consideration the location and depth of discharge, as well as other environmental factors. This information can be used to inform decision-making and ensure that wastewater discharge practices are optimized to minimize potential impacts on marine environments (Iqbal et al., 2018)

The effect of wastewater discharge on the distribution of metals in the sea has been the subject of several research. For instance, research by Wang et al. (2019) found that metal concentrations in a nearby river and coastal region significantly increased as a result of wastewater discharge from a sewage treatment facility. Additionally, the study discovered that the discharge pipe's placement affected the geographical distribution of metals, with larger amounts being detected nearer the discharge site. Similarly, a study by Xu et al. (2017) investigated the impact of a wastewater discharge pipe on the distribution of metals in a coastal bay. The study discovered that the placement of the discharge pipe had a major impact on the spreading of metals, with larger concentrations of metals being seen close to the discharge point and lower concentrations farther away. The efficiency of pollution control techniques can also be greatly influenced by the placement of the discharge pipe. For instance, research by Yin et al. (2015) showed that a wastewater treatment plant's deployment and the relocation of the discharge pipe led to a considerable decrease in metal contamination in a river estuary.

1.3.3. Spatial And Temporal Variabilities

Although the discharge of wastewater into the sea takes place in the first place at a fixed point with specific location and depth, as it mentioned in the previous section, the dynamic nature of a basin always causes changes in the spatial and temporal condition of the materials discharged into the basin. In other words, the concentration of pollutants in the sea is usually spread with specific and variable temporal and spatial patterns.

It is essential to know how metals are distributed in a particular area over time to effectively manage and treat metal pollution. Having precise information about metal distribution can help identify sources of pollution and its potential effects on the environment and human health. Furthermore, comprehending how metal distribution changes over time can assist in developing effective pollution control methods and evaluating their success.

The significance of monitoring metal contamination in marine systems both spatially and temporally has been shown in several research. For instance, Wang et al. (2019) study discovered that metal contamination in a river system in China fluctuated dramatically across time and place, underscoring the significance of extensive monitoring and long-term evaluations. In a shallow coastal bay in China, research by Xu et al. (2017) showed the geographical and temporal variability of metal pollution, with high concentrations of metals found in regions impacted by anthropogenic activity. Furthermore, evaluating the danger of exposure to human populations can be aided by understanding the regional and temporal distribution of metals. A research by Yin et al. (2015) highlighted the need for efficient pollution management and remediation measures by highlighting the significant risk of metal exposure for populations living near a polluted river.

Understanding the spatial and temporal distribution of metals in a basin is essential for effective management and remediation of metal pollution. Comprehensive assessments and long-term monitoring are crucial for identifying sources and potential impacts on the environment and human health, developing effective pollution control strategies, and assessing their effectiveness.

1.4. Metals

In this research, it is important to note that the discharges from industrial processes can include a wide variety of metals, such as cadmium and its components, mercury, nickel, lead, arsenic, barium, chrome, tin, zinc, copper, aluminum, boron, iron, manganese, and antimony. The presence of these metals in the environment can have significant negative impacts on both human health and the ecosystem (Agency for Toxic Substances and Disease Registry, 2021).

Cadmium is a toxic metal that can accumulate in the body and cause serious health problems such as kidney damage, osteoporosis, and cancer (Järup, 2003).
Mercury is a highly toxic metal that can damage the brain, kidneys, and other organs, and can also cause developmental and reproductive problems in humans and wildlife (Clarkson et al., 2006). Nickel can cause skin allergies and asthma, while lead can lead to developmental and neurological problems, particularly in children (Grandjean et al,. 2006). Arsenic is a carcinogenic metal that can cause skin, lung, and bladder cancer (National Research Council, 2014). Barium is toxic and can cause cardiovascular

problems, while chrome is carcinogenic and can cause lung cancer (International Agency for Research on Cancer, 2012). Tin, zinc, copper, and aluminum are all essential metals that are required by the body in small amounts but can become toxic in larger quantities (Institute of Medicine, 2001). Boron is also an essential metal but can cause reproductive problems in high concentrations (National Research Council, 1993). Iron and manganese are essential metals that can become toxic in large amounts, causing neurological problems (Sandyk et al., 1984). Finally, antimony can cause respiratory problems and skin irritation (Agency for Toxic Substances and Disease Registry, 2021).

Therefore, it is crucial to monitor and control the discharge of these metals into the environment to minimize their negative impacts on human health and the ecosystem. This can be achieved through the implementation of appropriate regulations and policies, as well as the development and use of advanced technologies for the treatment and disposal of industrial waste (Chen et al., 2019).

2. DATA AND METHODS

2.1. Study Area: Importance and Significance

The Gulf of Finland, which is located in the northeastern region of the Baltic Sea, is the subject area for this thesis. Due to its strategic position, economic activity, and ecological value, the Gulf of Finland is a significant body of water. The region has a complicated hydrodynamic regime, which is impacted by the flow of salty water from the North Sea and the entrance of freshwater from various rivers (Soomere and Tarmo 2013)
The Gulf of Finland's coastal region is highly populated and developed, with several cities, ports, and industrial facilities situated there. On the other hand, the offshore region of the Gulf of Finland is farther away and has been less affected by human activity. Numerous features of the Gulf of Finland have been studied in the past, including its physical and chemical qualities, hydrodynamic regime, and biological traits.
The Gulf of Finland is an essential region of research for figuring out the effects of environmental stresses on marine ecosystems since it is a dynamic, complex ecosystem that is extensively impacted by both natural and manmade influences.

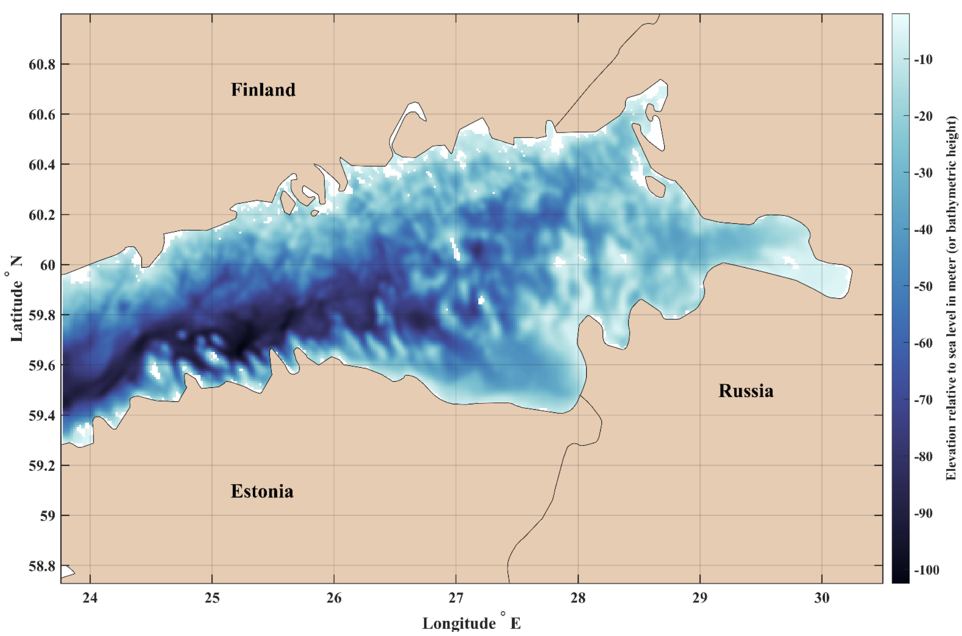

Figure 2.1. Bathymetric Map of the Gulf of Finland

The map of the Gulf of Finland reveals the intricate bathymetry of the seafloor in this region, showcasing varying water depths through its color scheme (Figure 2.1.). Dark blue hues signify deeper waters, while lighter shades represent shallower areas. Along the Estonian coast, the depth appears relatively high, characterized by a range of light and dark blue tones indicative of depths between 50 and 100 meters. Conversely, the bathymetry near the Finnish coast appears somewhat shallower, displaying white and light blue shades denoting depths of 20 to 50 meters. These variations in the map illustrate the diverse topography of the Gulf of Finland, with deeper areas near Estonia and Finland potentially featuring underwater formations like ridges or trenches contributing to their higher depth, while other regions of the gulf exhibit shallower waters, suggesting flatter or gradually sloping seafloors farther from the coastlines. Overall, the map illustrates the complexity of the Gulf of Finland's underwater landscape and highlights the need for continued exploration and study of this important marine ecosystem.

2.2. Literature Review

The Gulf of Finland is an important marine ecosystem that is under threat from anthropogenic activities, particularly from the discharge of wastewater. The discharge of wastewater into the Gulf of Finland can significantly affect the distribution of metal pollution in the marine environment. Understanding the spatial and temporal variability of metal concentrations in the Gulf of Finland is crucial for assessing the impacts of wastewater discharge on the marine ecosystem.

Several studies have investigated the spatial and temporal variability of metal concentrations and pollution in the Gulf of Finland. Gubelit et al. (2016) focuses on anthropogenic pollution along the coastline of the eastern Gulf of Finland and employs various methods to analyze metal contamination in different environmental components. The main pollutants in water were identified as copper and manganese, with the nearby Nuclear Power Plant significantly influencing adjacent areas by contributing high concentrations of molybdenum, nickel, copper, and other elements to the water. The research (Gubelit et al., 2016) indicates that sediments in the studied area contain relatively high concentrations of copper, lead, and zinc. It was observed that microbial tolerance levels were correlated with the metal concentrations in the sediments, with higher tolerance levels found in more polluted stations. The study also found that macroalgae, which experienced mass development in the coastal zone, exhibited high levels of metal bioaccumulation.

Kurilenko et al. (2015) presents research findings on the contamination of coastal waters in the Gulf of Finland, specifically focusing on Kotlin Island and its various pollution sources, such as industrial and municipal wastewater, ship and vehicle traffic, aerosol deposits, dredging activities, and metal leaching from soils. Overall, this study provides valuable insights into heavy metal pollution in the area, its impact on the surroundings, and potential remediation strategies.

Emelyanov et al. (2017) reviews on heavy metals in sediment of the Gulf of Finland highlights the presence and distribution of anthropogenically derived heavy metals in the region. Analyzing sediment chemistry data from past decades, including information from the Nord Stream project, the study identifies distinct patterns in heavy metal enrichment. Zinc, copper, and chromium are found to be enriched in the eastern part of the Gulf, while mercury, cadmium, and lead show higher concentrations in the north-eastern region. Anomalies in heavy metal distribution are influenced by metal sources, such as the Kymijoki and Neva rivers, as well as local physico-chemical conditions. Understanding these patterns is vital for effective monitoring and management of heavy metal pollution in the Gulf of Finland.

2.3. Objectives

The planned pulp production of the production complex is 500,000 ADt/a. This corresponds to a daily water consumption of approximately 35,000 m^3 and an annual water consumption of 12.5 million m^3/a. The intention is to use groundwater from mines in the area as the raw water for production. In order to manage the wastewater generated during production, a (pre-)treatment plant will be constructed. The treated

wastewater will be discharged into the Gulf of Finland through a deep-sea collector. It is expected that the construction of the production complex will not commence before 2027.
In order to design the sea-based outlet effectively, it is essential to conduct a study that evaluates the impact of the additional pollution load on the coastal water body of Narva-Kunda Bay, as well as the water quality indicators of Narva Bay. These indicators include water chemistry, oxygen conditions, and biota. The document titled "European Commission implementing decision of September 26, 2014, establishing the best available technique (BAT) conclusions for the production of wood pulp, paper, and cardboard based on Directive 2010/75/EU of the European Parliament and of the Council'' specifies the emission level ranges according to the BAT. The BAT conclusions provide a range of emission levels, and the stringency of requirements should be determined based on the existing environmental conditions. In this case, the environmental tolerance of the Gulf of Finland becomes decisive. According to both the water management plans and the requirements of HELCOM, the overall reduction of nutrient pollution load is set as the goal. For pollutants that are not regulated by BAT conclusions, the requirements stated in Regulation No. 61 of the Minister of the Environment, dated 08.11.2019, "Requirements for wastewater treatment and discharge, precipitation, mining, quarry and cooling water management, measures for assessing compliance with requirements and limit values for pollutant content," must be followed.

When assessing the environmental impact of a complex, it is necessary to consider the interaction with the existing deep-sea discharge from the Kohtla-Järve regional wastewater treatment plant, owned by the private limited company JÄRVE BIO PUHASTUS.

The primary focus of this study is to simulate metal transport, which is intricately tied to ocean dynamics, then determine the preferred location of the wastewater outlet. Furthermore, the study aims to examine the distribution patterns of metal concentrations in Narva Bay, encompassing the surface, bottom, and various depth layers.

The study will particularly focus on evaluating the branches of discharge location and depth. It is crucial to acknowledge that the configuration of the mixing zone, which represents the area where discharged wastewater and the surrounding seawater blend, can significantly influence the impact of wastewater on marine ecosystems. By designing appropriate mixing zones, effective mixing and dilution of pollutants can be achieved, thereby minimizing their potential adverse effects on marine organisms.

The thesis is divided into four main chapters: Data and Methods, Results, Discussion, and Conclusion. The Data and Methods chapter will describe the methodology used to collect and analyze data, while the Results chapter will present the findings of the study. The Discussion chapter will analyze and interpret the results, and the Conclusion chapter will summarize the main outcomes of the project. Through this approach, the thesis aims to provide insights into the best practices for location of wastewater disposal.

2.4. Model Description

This study employed the hydrodynamical model GETM (General Estuarine Transport Model) by Burchard and Bolding (2002) for the Gulf of Finland. The model was coupled with the FABM (The Framework for Aquatic Biogeochemical Models) water quality framework by Bruggeman and Bolding (2014) to apply a passive tracer model with basic sedimentation dynamics.

The computational domain over the Gulf of Finland was discretized horizontally on a spherical grid with a resolution of 0.5 arcminute (~1 km). The water column was vertically divided into 30 adaptive terrain-following layers, with layer thickness adaptation tuned to follow the vertical density gradient to reduce numerical dissipation. The model used a timestep of 10 s for maintaining barotropic stability and 100 s for the baroclinic mode, where advection-diffusion terms were solved.

The western boundary of the model's computation domain was defined along 23.75-degree longitude/meridian and was forced with hourly sea-level and daily salinity and temperature data from the CMEMS reanalysis obtained at the SMHI (Swedish Meteorological and Hydrological Institute) using the NEMO-Nordic setup by Tuomi et al. (2017) and Stepanova et al. (2022). The initial fields for salinity and temperature were adopted from the CMEMS reanalysis of 1st December 2014, and a three-step spin-up procedure was performed from 2nd to 31st December 2014 by gradually applying open boundary and atmospheric forcing.

Meteorological forcing was derived from the ERA5 database by Hersbach et al. (2020). The model used hourly fields of single-level reduced parameters of 10m wind speed components, 2m air temperature, sea level pressure, 2m relative humidity, total cloud coverage, and total precipitation as atmospheric input. Additionally, the atmospheric momentum- and heat flux between air and sea were calculated according to Kondo et al. (1987). The daily river runoff was calculated as the daily mean climatology over the period of 2005-2012 from the GREEN model output by Grizzetti et al. (2021).

2.4.1. Validation

To validate the model output in this thesis, sea level height datasets from available tide gauges within the study area were utilized. Tide gauges are instruments that record sea level at specific locations, typically with an hourly time-step. The data spanned the year 2015, and a total of 10 tide gauge observations were obtained, as presented in Table 2.1. This study has been conducted using E.U. Copernicus Marine Service Information; https://doi.org/10.48670/moi-00032

However, since the model output in this study was generated on a daily basis, the daily mean of the observed values was calculated for comparison. Sea level fluctuation serves as a valuable indicator of basin dynamics, making sea level height validation crucial for gaining insights into how well the model simulates the basin's dynamics. The sea level elevation was then compared between the available tide gauges and the model outputs, as shown in Figure 2.2.

Validating the sea level height is essential, aligning with the study's defined objectives. Although it would have been beneficial to compare the observation data for metals with the model outputs, unfortunately, no such data for metals in the study area during the year 2015 was accessible.

The mean of the root mean square error (RMSE) between the model output and the observed sea level heights was calculated to be 9 mm. The RMSE serves as a measure of the overall agreement between the model and the observed data, with lower values indicating a better fit. In this case, the average RMSE of 9 mm suggests that, on average, the model's sea level height predictions deviate from the observed values by approximately 9 mm.

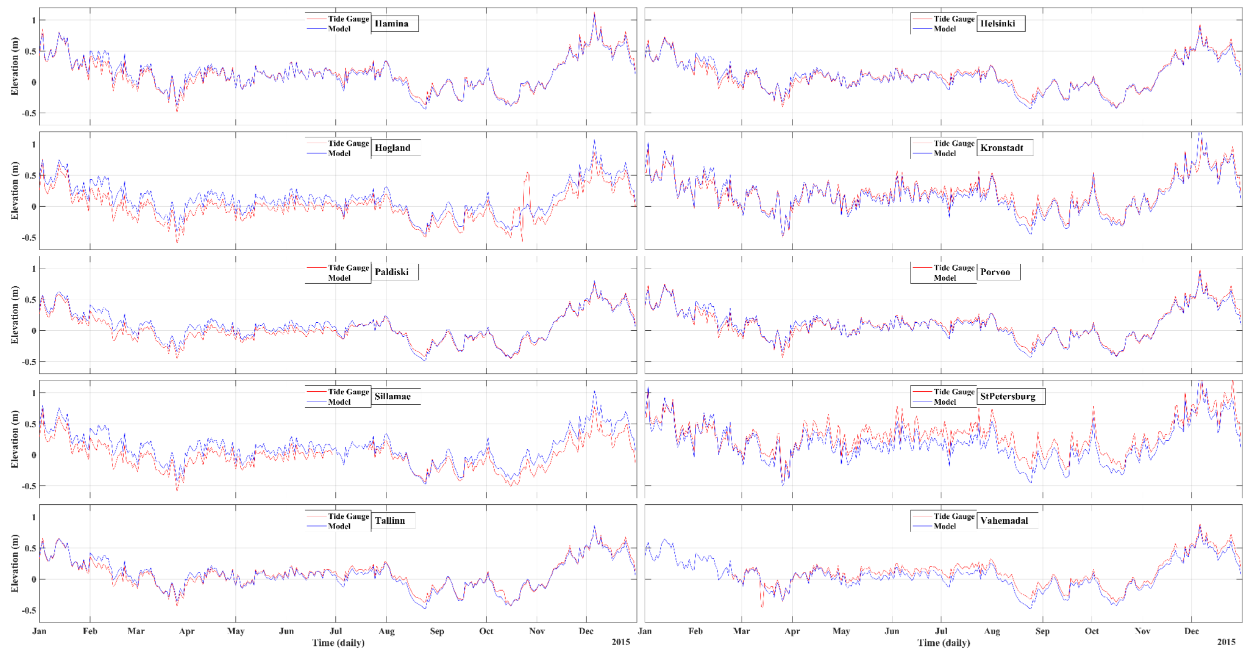

Figure 2.2. Sea level elevation comparison between available tide gauges and the model outputs

	Location	Longitude °E	Latitude °N	RMSE	Correlation Coefficient	P-value
1	Hamina	27.1792	60.5628	0.0025166	0.98312	7.5675e-270
2	Hogland	27	60.0167	0.020849	0.93947	6.0897e-171
3	Paldiski	24.0796	50.3349	0.0046097	0.97627	2.6913e-243
4	Sillamae	27.7401	59.4227	0.021994	0.97817	1.9808e-235
5	Tallinn	24.7637	59.4444	0.0026434	0.97883	1.6582e-251
6	Helsinki	24.9562	60.1536	0.0021455	0.98289	8.1293e-269
7	Kronstadt	29.75	59.9667	0.0062295	0.97035	5.7096-226
8	Porvoo	25.6251	60.2058	0.0022212	0.98265	1.0228e-267
9	StPetersburg	30.2667	59.9333	0.0228	0.95615	1.0951e-195
10	Vahemadal	24.6662	59.5102	0.0066258	0.97698	1.0684e-208

Mean of RMSE	0.00926347

Table 2.1. Location of Tide gauges with information ,https://doi.org/10.48670/moi-00032

2.4.2. Tracer Model for Heavy Metals

In this study, the 15 heavy-metal tracers were initialized with zero-concentration fields, meaning there were no background values. The source of the metals was OÜ Järve Biopuhastus and the VKG outlet. The latter had prescribed constant loads (as shown in Table 2-2).

						Ref				Case1 = Ref + Plan			
					Q	6603000	m3/a	12500000	Q	19103000	m3/a		
					q	0.20938	m3/a		q	0.60575	m3/a		
Subjects to be assessed		decay	Sedimentation [m /d]			Load t/y	conc, g/m3	Load t/y		Load t/y	conc, g/m3		conc %
Cadmium and its components		5	0.23			0.0099	0.0015	0.0625	72.4	0.0724	0.00379		1.53
Mercury		55	2.48			0.0001	0.0000151	0.0125	12.6	0.0126	0.0006596		42.55
Nickel		27	1.22			0.027	0.00409	0.425	452	0.452	0.02366		4.79
Lead		47.6	2.14			0.0092	0.00139	0.175	184.2	0.1842	0.00964		5.92
Arsenic		0	0			0.0198	0.003	0.125	144.8	0.1448	0.00758		1.53
Barium		0	0			1.5	0.22717	1.25	2750	2.75	0.14396		-0.37
Chrome		66.6	3			0.0066	0.001	0.625	631.6	0.6316	0.03306		32.08
Tin		95	4.28				0	0.0375	37.5	0.0375	0.00196		#DIV/0!
Zink		59.3	2.67				0	0.625	625	0.625	0.03272		#DIV/0!
Copper		29.2	1.31			0.0297	0.0045	0.438	467.7	0.4677	0.02448		4.44
Aluminum		20	0.9				0	2.125	2125	2.125	0.11124		
Boron		50	2.25				0	0.65	650	0.65	0.03403		
Iron		74	3.33				0	9.75	9750	9.75	0.51039		
Manganese		37.5	1.69				0	35	35000	35	1.83217		
Antimony		0	0				0	0.022	22	0.022	0.00115		

Table 2-2 VKG outlet

Various absorption coefficients have been compiled from different sources by Edward et al. (1987), Dominika et al. (2022), Farajnejad et al. (2017), Shima et al. (2013), Gregg et al. (2003), Montserrat et al. (2002), Savenko et al. (2014).

The heavy metals were subject to various chemical fates, including absorption into suspended particulate matter (SPM). The SPM was assumed to be approximately 0.2mm sand/silt particles, giving a vertical settling velocity of around 4 m/day. It can be expressed that the fraction of absorption into constantly settling SPM is a function of the SPM's vertical sedimentation velocity applied to the heavy metal tracer concentration. Once the heavy metals reach the seafloor, they accumulate on the seabed.

The 3D conservation equation for tracer is

$$\frac{\partial c}{\partial t} + u\frac{\partial c}{\partial x} + v\frac{\partial c}{\partial y} + (w + w_s)\frac{\partial c}{\partial z} = \frac{\partial}{\partial x}\left(\mathcal{A} \frac{\partial c}{\partial x}\right) + \frac{\partial}{\partial y}\left(\mathcal{A} \frac{\partial c}{\partial y}\right) + \frac{\partial}{\partial z}\left(\mathcal{K} \frac{\partial c}{\partial z}\right)$$

w_s is settling velocity of fraction p of metal that is absorbed on settling particulate matter.

2.5. Scenarios and reference state

To evaluate the dispersion of effluent from the BTT discharge in the Gulf of Finland, the following model calculations are conducted for a duration of one year, based on the following scenarios:
1) The existing situation or reference state, where the marine environment is affected only by the wastewater from the Kohtla-Järve deep-sea reservoir of OÜ Järve Biopuhastus, denoted as R2.

2) Scenario I, the existing situation with the planned VKG BTT load discharge of waste water from the same location as the current OÜ Järve BiopuhastusKohtla-Järve deep sea discharge (Table 2.2), taking into account the highest permitted pollutant concentrations, denoted as R5 (scenario I; 59.4575 ^{o}N, 27.2000 ^{o}E; depth: 13.2 m).

3) Scenario II, the existing situation with the planned VKG BTT load with a discharge of waste water from a different location than the current OÜ Järve Biopuhastus Kohtla-Järve deep sea discharge (Table 2.2), taking into account the highest permitted pollutant concentrations, denoted as R8 (scenario II; 59.4742 ^{o}N, 27.2000 ^{o}E; depth: 20.6 m).

The goal is to assess the extent to which the scenarios align with the existing situation, and which one is closer to this. The evaluation of these scenarios with respect to the reference will provide valuable insights into the performance and accuracy of each scenario. By comparing the results obtained from each scenario to the reference, it will be possible to identify any strengths or weaknesses in the approach taken in each scenario. Furthermore, it may also provide insights into the environmental conditions and factors that may have affected the data collected for each scenario. Overall, the precise location and depth of each scenario are critical factors that must be considered when interpreting the results obtained.

2.6. Approaches for find the best state

The model in this study was run separately for each scenario for the year 2015, and the daily mean model outputs for each tracer/metal concentration were extracted. The subsequent step involved analyzing the temporal and spatial distribution of metal concentration for each scenario. In order to determine the overall metal concentration, the data underwent a normalization process, considering the presence of multiple metals with distinct numerical ranges. This step was necessary to ensure accurate and meaningful comparisons among the prepared data values.

To choose the best scenario, the final result of each scenario was compared with the reference state in the second stage. The algorithm used in the thesis is illustrated in Figure 2.3.

Two distinct locations, each represented by a four-dimensional matrix: R5 for the coast, and R8 for the offshore region, were considered. The goal is to identify the best scenario that is closest to the reference mentioned as R2.

To accomplish this, we propose an algorithm that involves first extracting the differences between the scenarios and the reference matrix, resulting in two matrices, A and B. We then create a new matrix by comparing the entries of A and B and selecting the one closest to zero, with the entry marked with the letter C if the corresponding values in A and B are equal.

The resulting matrix will contain entries marked with A, B, or C. Finally, we count the number of occurrences of A and B and declare the scenario with the most letters as the closest to the source and the best scenario.

By following this approach, we can effectively determine the optimal scenario for the given location and time based on its proximity to the source matrix.

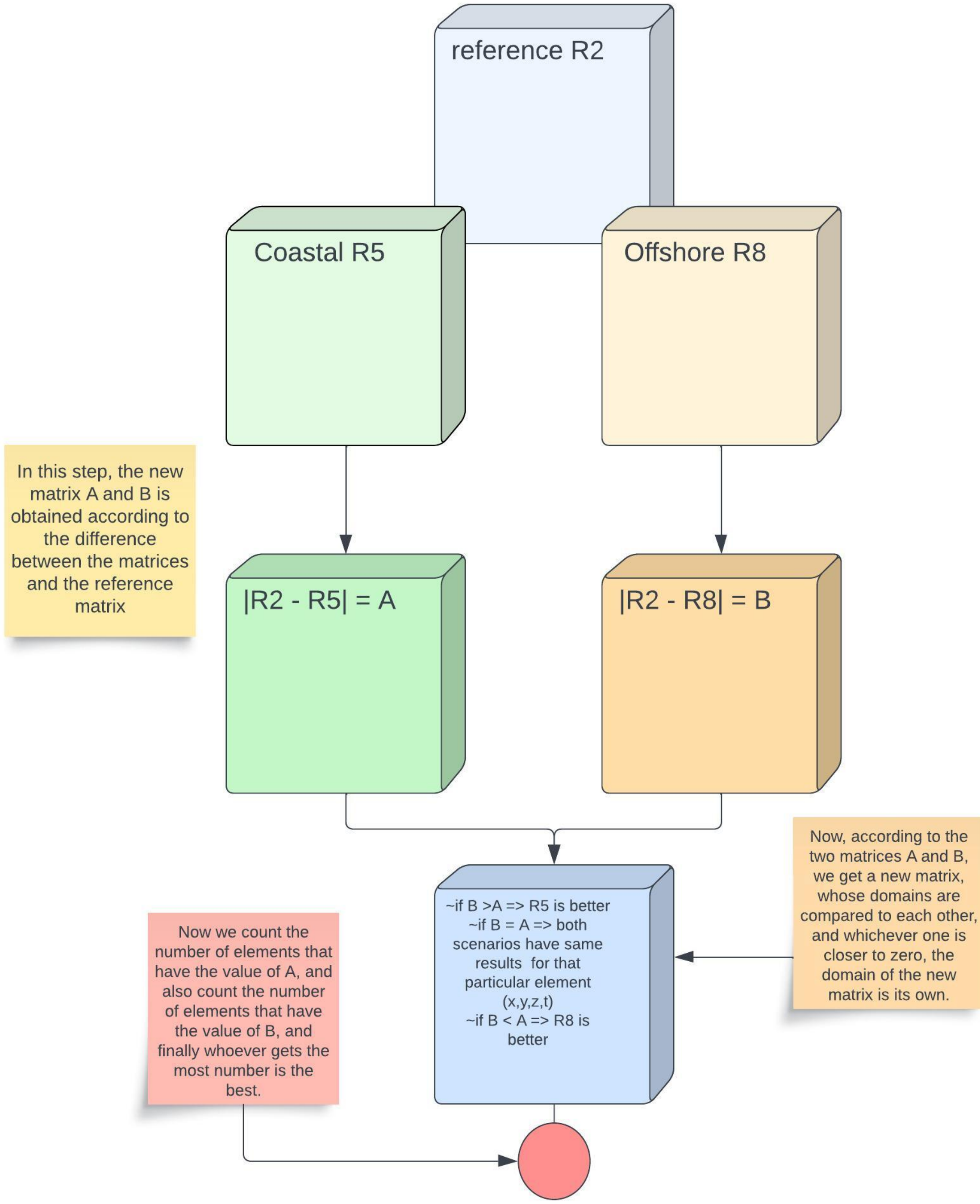

Figure 2.3. Algorithm for Selecting the Optimal Scenario

3. RESULTS

3.1. Mean Of Metal Concentration

The spatial distribution of metals in the Gulf of Finland was investigated in this study. For each scenario, the mean map of concentrations throughout the entire study period (from January 1, 2015, to December 31, 2015) was presented. It is worth mentioning that the focus of this study was on the total concentration as an indicator of pollution distribution in the Gulf of Finland. Therefore, the total concentration of all metals was considered for investigating the spatial distribution in each scenario. However, the numerical ranges of values for each metal concentration varied. This means that the metal with the highest value range could introduce a significant bias when attempting to sum all concentrations to derive the total concentration at each time and location. To address this issue, a normalization process was applied to each metal in each scenario. During the normalization process, all values of each metal in each scenario were divided by the maximum values of that metal in that particular scenario. As a result, all values were transformed to a range between 0 and 1. Subsequently, the total values were computed by summing all normalized values and dividing them by the number of metals in a specific scenario. It is important to note that this normalization procedure was solely used to demonstrate the overall distribution of metals in the Gulf of Finland. However, for the other part of the present study, which involved comparing each scenario with the reference case, the original values of each metal were used separately.

The mean maps have been evaluated for surface layer, bottom layer and the mean of all vertical levels except surface and bottom. So, as we had 30 levels in the model outputs, the surface layer is representing level 1, bottom level representing level 30 and a mean over level 2 to 29 representing the mean of vertical profiles except surface and bottom.

Figure 3.1. shows the normalized distribution of metal concentration in the Gulf of Finland for the reference scenario. It should be mentioned that, in this figure and also next similar figures, the normalized values below 0.1 are eliminated for better visualization because it is assumed that the normalized values below 0.1 do not represent the significant concentrations. In general, the figure 3.1. illustrates that the metal will be horizontally distributed more in the surface layer and toward the bottom the diffusion of

metals in the Gulf of Finland will decrease. For better visualization Figure 3.2. showing a zooming of results in the Narva Bay that is the location with existing significant normalized values. In the Narva Bay, the reference scenario at the surface shows the significant part of metals distributed along the Estonian coasts from ~26.6°E to 27.6 °E. In the bottom the metal concentrations are focused on the discharge location but with a significant value. Also, the horizontal distribution will decrease for mean vertical layers in comparison with surface.

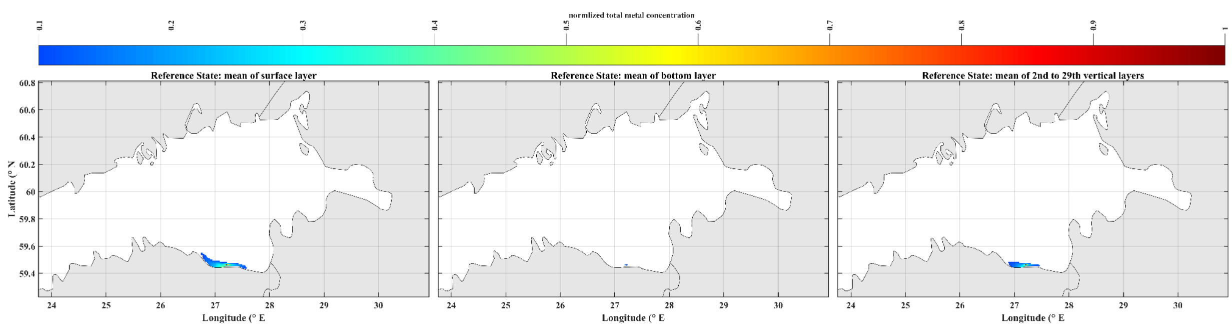

Figure 3.1. "Normalized Mean Metal Concentrations for reference R2 "

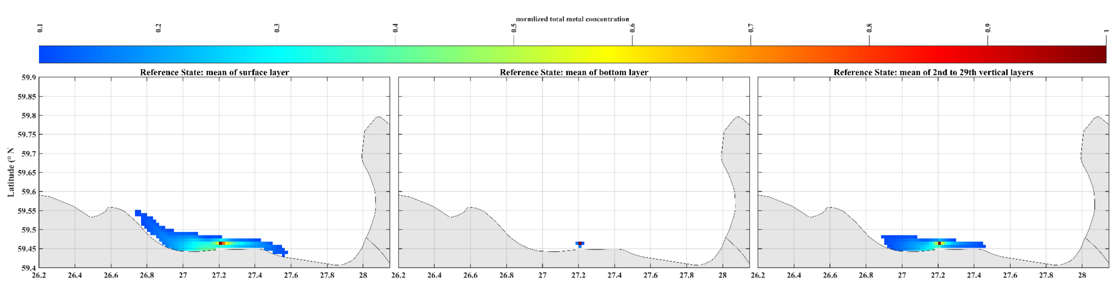

Figure 3.2."Normalized Mean Metal Concentrations for reference R2 , focusing on Narva Bay”

Similar to reference for the rest of scenarios zoomed figures have been used, Figure 3.3. shows the normalized distribution of metal concentration in the Gulf of Finland for coastal scenario. Same as reference the normalized values below 0.1 are eliminated for better visualization. In general, the figure 3.3. illustrates that the metal will be horizontally distributed in the surface layer., Like in the reference case the diffusion of metals in the Gulf of Finland will decrease toward the bottom. The coastal scenario at surface shows the significant part of metals distributed along the Estonian coasts from ~26.8 °E to 27.5°E. In the bottom the metal concentrations are focused on the discharge location in 27.2°E with a significant value. The horizontal distribution will decrease for mean vertical layers in comparison with surface.

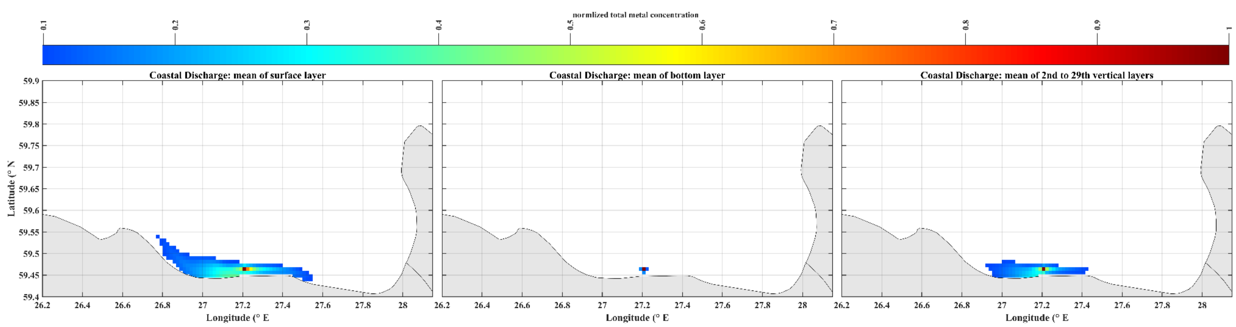

Figure 3.3. "Normalized Mean Metal Concentrations for Coastal R5 scenarios focusing on Narva Bay”

Figure 3.4. shows the normalized distribution of metal concentration in the Gulf of Finland for offshore scenario. For improved visualization, any normalized values below 0.1 have been removed. Figure 3.4 visually demonstrates the horizontal distribution of metal within the surface layer. It illustrates that as we descend towards the bottom, the diffusion of metals in the Gulf of Finland gradually decreases, as similar to other scenarios. The offshore scenario shows the significant part of metals distributed along the Estonian coasts from ~26.2 °E to higher than 27.5°E at the surface. In the bottom the metal concentrations are the same as other scenarios with high concentration at 27.2°E. Figure 3.4 demonstrates a similar pattern for mean vertical layers in comparison to the surface layer. However, it is worth noting that the horizontal diffusion of metal concentration is stronger than in the other scenarios.

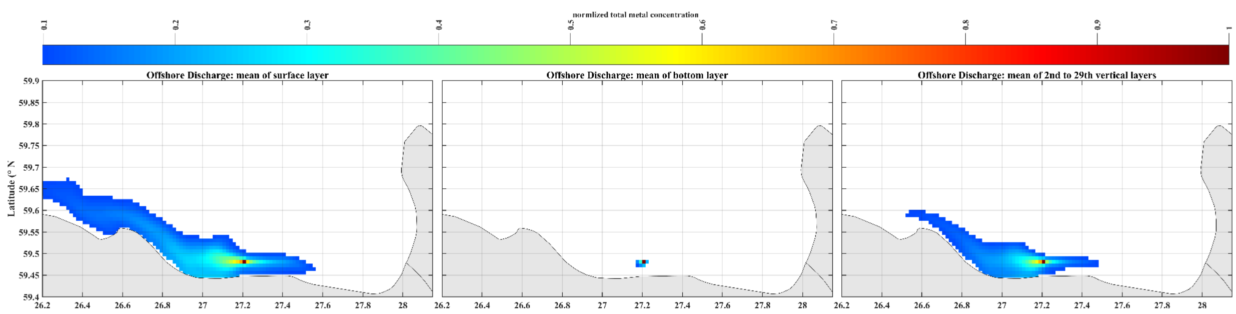

Figure 3.4. "Normalized Mean Metal Concentrations for Offshore R8 scenarios focusing on Narva Bay"

3.2. Monthly Mean Of Metal Concentration For Each State

Figure 3.5, showing the monthly mean of concentrations at surface in reference scenario. As all the mean maps show the significant concentration at Narva Bay, the figure will focus on the area. At first glance, Figure 3.5 illustrates different concentrations in each month. Generally in Jan, the surface concentration is similar to the mean map in the surface with high value at the location of the discharge. But in February the concentration will be distributed more to the east and also west along the Estonian coast. Totally the highest distribution is in February, but in March again there is decrease in total horizontal distribution however it is more tendency for metal transporting to the west and also the values are not that high around the discharge location. This tendency will go through the east in April. In May again the distribution will decrease but in June however the decrease will continue but metals significantly tend to gather at the east of the discharge location. In the Summer, the horizontal distribution will reach its minimum but in autumn start increasing with high values in November but with a tendency to the east.

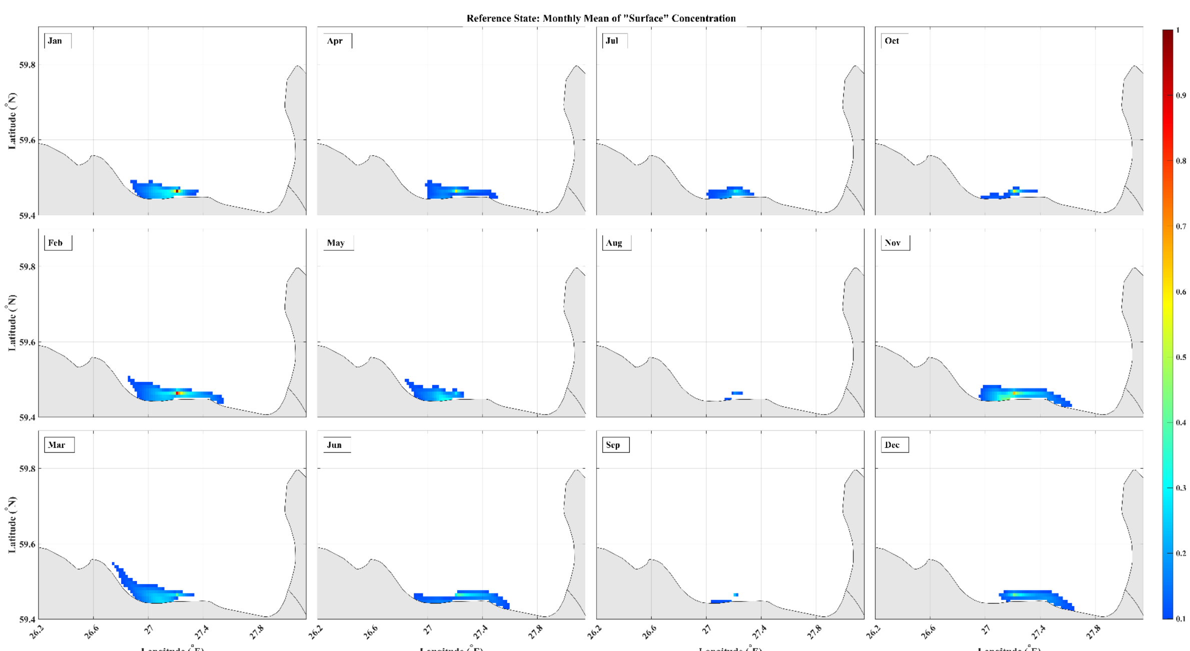

Figure 3.5. Monthly Mean Of "surface" concentration for Reference R2

Figure 3.6 presents the monthly mean concentrations at the surface in the coastal scenario. Similarly to the reference scenario, all the mean maps indicate significant concentrations in Narva Bay. Therefore, the figure focuses on this particular area. In January, the surface concentration is similar to the mean map, with high values observed around the discharge location. The highest distribution occurs in February, but there is a decrease in total horizontal distribution in March. However, there is a greater tendency for metal transport towards the west, and the values at the discharge location are not as high. This tendency continues towards the east in April.

In May, the distribution shifts back towards the west. In June, metals tend to accumulate significantly in the coastal area, moving from west to east of the discharge location. During the summer, the horizontal distribution decreases and reaches its minimum in August. However, in autumn, it starts to increase again, with high values in November and a tendency towards the east.

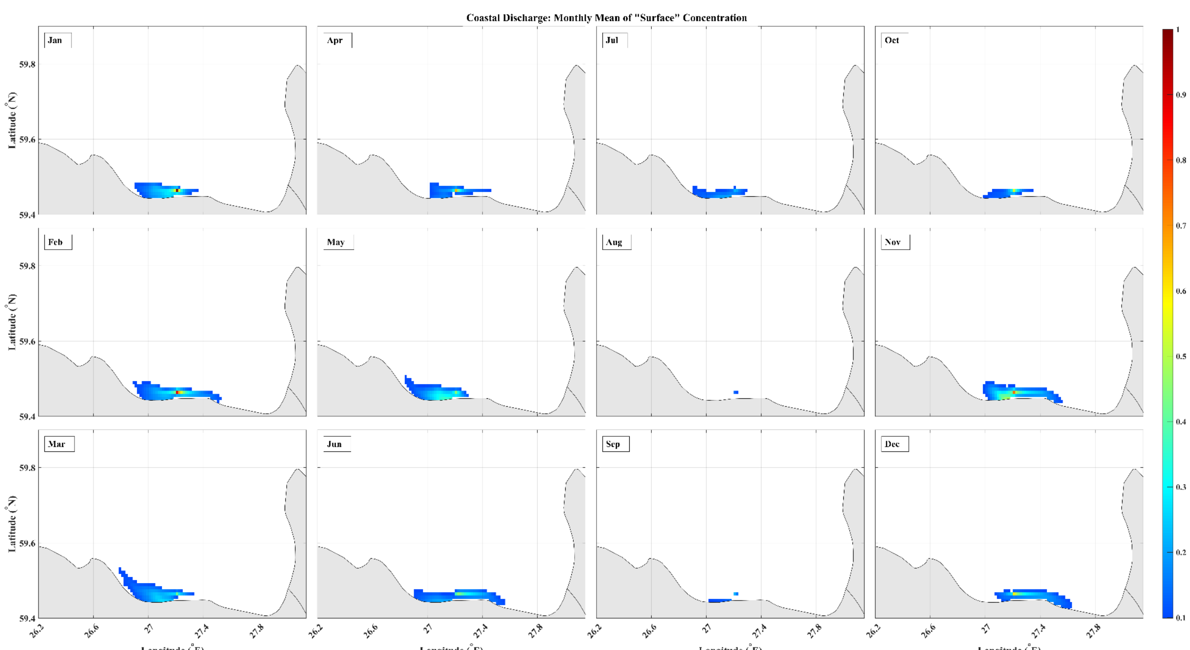

Figure 3.6. Monthly Mean Of "surface" concentration for Coastal R5

Figure 3.7 illustrates the monthly mean concentrations at the surface in the offshore scenario. Like the other scenarios, all the mean maps highlight significant concentrations in Narva Bay. Thus, the figure specifically centers around this area. In January, the surface concentration closely resembles the mean map, with high values observed at the discharge location, without reaching the coast. The distribution of metals increases in February, with a tendency for transport towards the West. This pattern continues in March, although the metal concentration at the discharge location decreases. In April, metal concentrations shift towards the discharge location and its eastern part. In May, there is a decrease in total horizontal distribution as metals are transported eastward. This decrease in metal pollution concentration continues in the following month, with no significant distribution of metal concentrations during summer. However, in October, the distribution of metal concentrations starts to increase. In November and December, metals tend to accumulate significantly in the coastal area, moving towards the east of the discharge location.

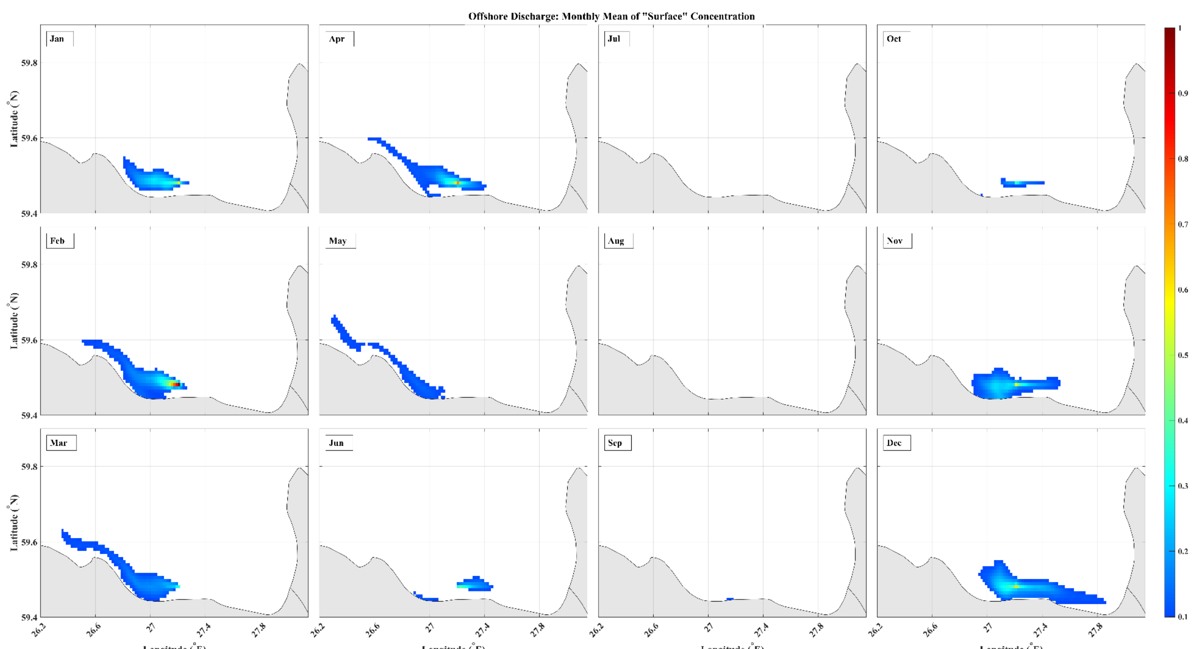

Figure 3.7. Monthly Mean Of “surface” concentration for Offshore R8

Figures 3.8, 3.9, and 3.10 show the monthly average concentrations at the bottom in the reference, coastal, and offshore scenarios, respectively. Generally these figures illustrate that the normalized mean metal concentration follows a similar pattern in monthly mean across all scenarios. The distribution in depth primarily centers around the discharge location, approximately at 27.2°E. It is noteworthy that in all scenarios, the highest metal concentration is observed during summer, especially in July. However, for the offshore discharge scenario, the metal concentration at the bottom is more distributed around the discharge location.

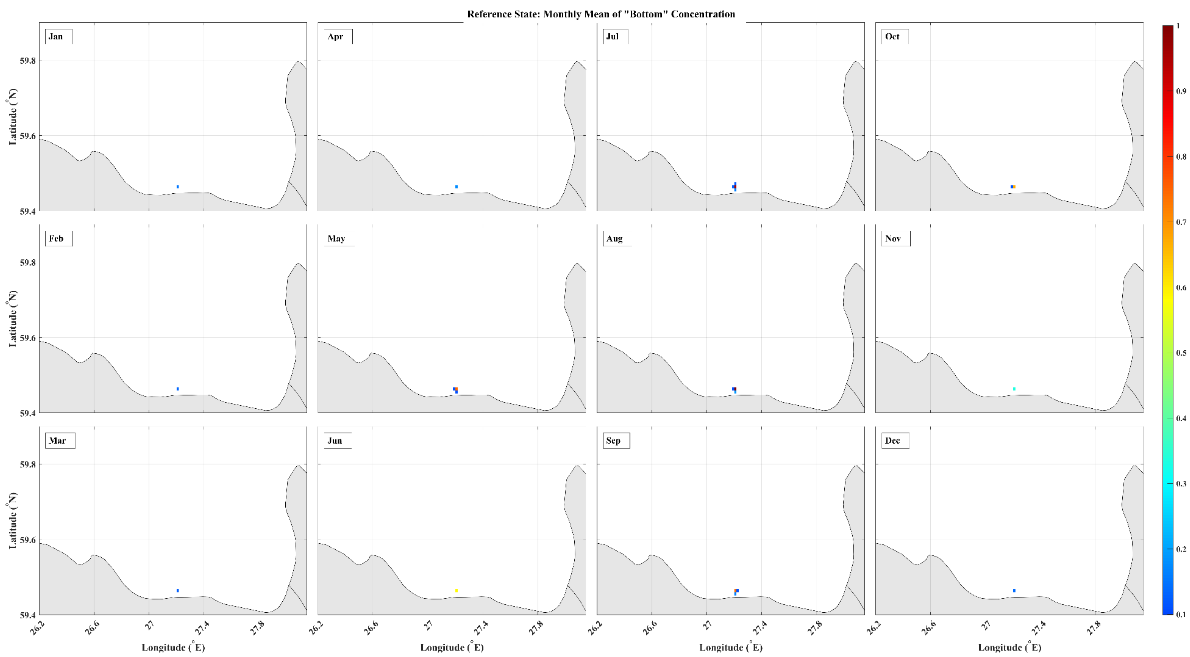

Figure 3.8. Monthly Mean Of “bottom” concentration for Reference R2

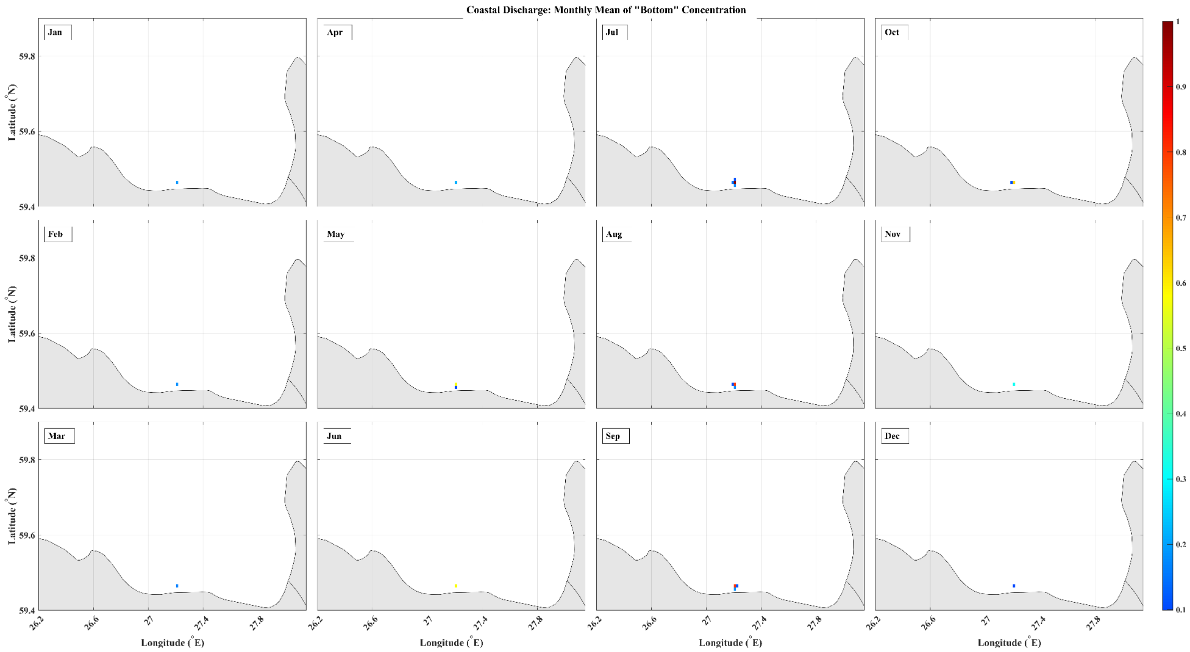

Figure 3.9. Monthly Mean Of "bottom" concentration for Coastal R5

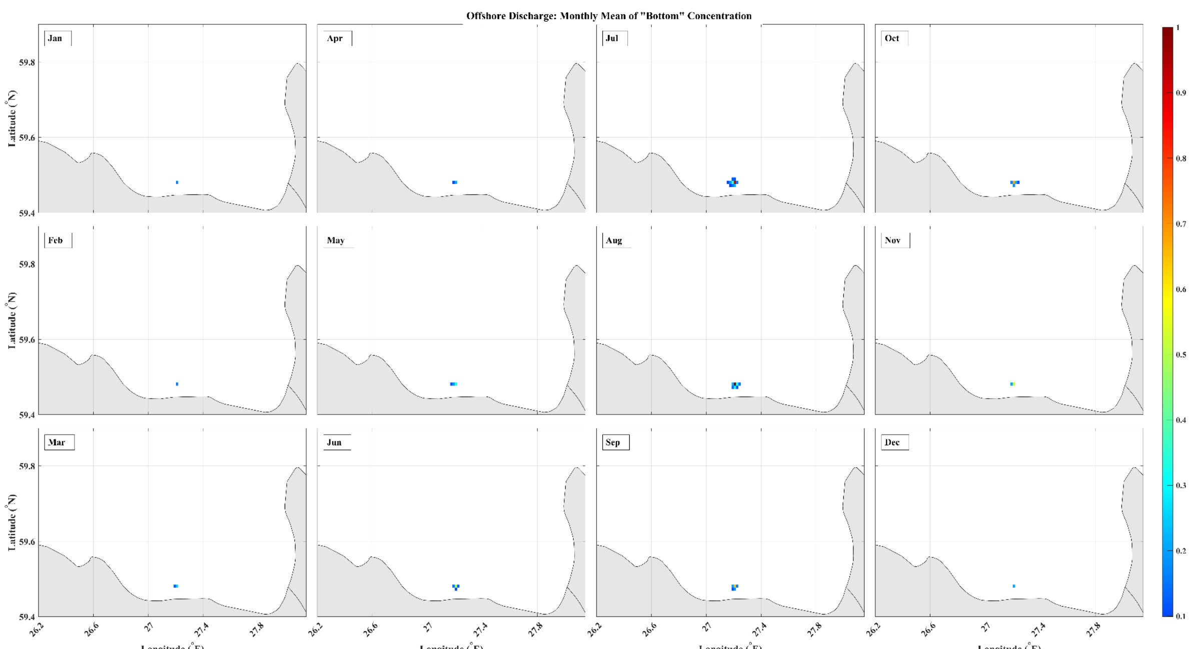

Figure 3.10. Monthly Mean Of "bottom" concentration for Offshore R8

Figure 3.11 presents the monthly mean concentrations at the vertical profile in the reference scenario. The figure focuses on Narva Bay. Figure 3.11 displays varying concentrations for each month. In January, the vertical concentration is similar to the mean map, with high values observed at the discharge location, distribution toward the west.for the next month, The significant increase of metals distributed along the Estonian coasts from ~26.9ºE to 27.6 ºE. but there is a decrease in total distribution in March. However, there is a greater tendency for metal transport towards the east, in April. In May, the distribution shifts back towards the west. In June, metals tend to accumulate significantly in the coastal area, moving from west to east of the discharge location from 26.9 ºEto 27.5ºE. During the summer, the horizontal distribution decreases and reaches its minimum in September. However, in autumn, it starts to increase again, the same pattern as surface concentration, with high values in November and a tendency towards the east.

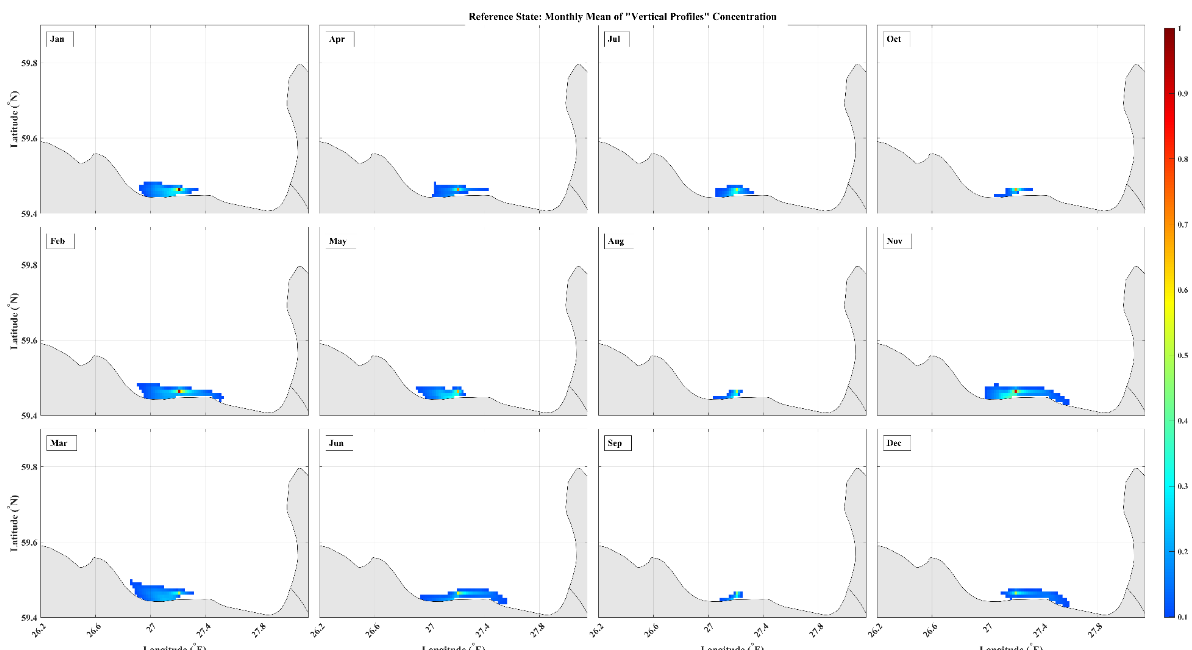

Figure 3.11. Monthly Mean Of "Vertical profile" concentration for Reference R2

The monthly mean concentrations at the vertical profile in the coastal scenario are depicted in Figure 3.12. In January, the vertical concentration is similar to the pattern in the reference scenario, with high values observed at the discharge location, distribution toward the west. The following month exhibits a notable increase in metal concentrations along the Estonian coasts, spanning approximately from ~27ºE to 27.5ºE. However, in March, there is a decrease in the overall distribution. Notably, April demonstrates a stronger tendency for metal transport towards the east.

In May, the distribution shifts back towards the west, while in June, metals tend to accumulate significantly in the coastal area, moving from the west to the east of the discharge location, specifically from 26.9ºE to 27.5ºE. During the summer, the distribution decreases, reaching its lowest point in September. Nevertheless, in autumn, it begins to rise once again, following the same pattern as the surface concentration. High values are observed in November, accompanied by a tendency towards the east.

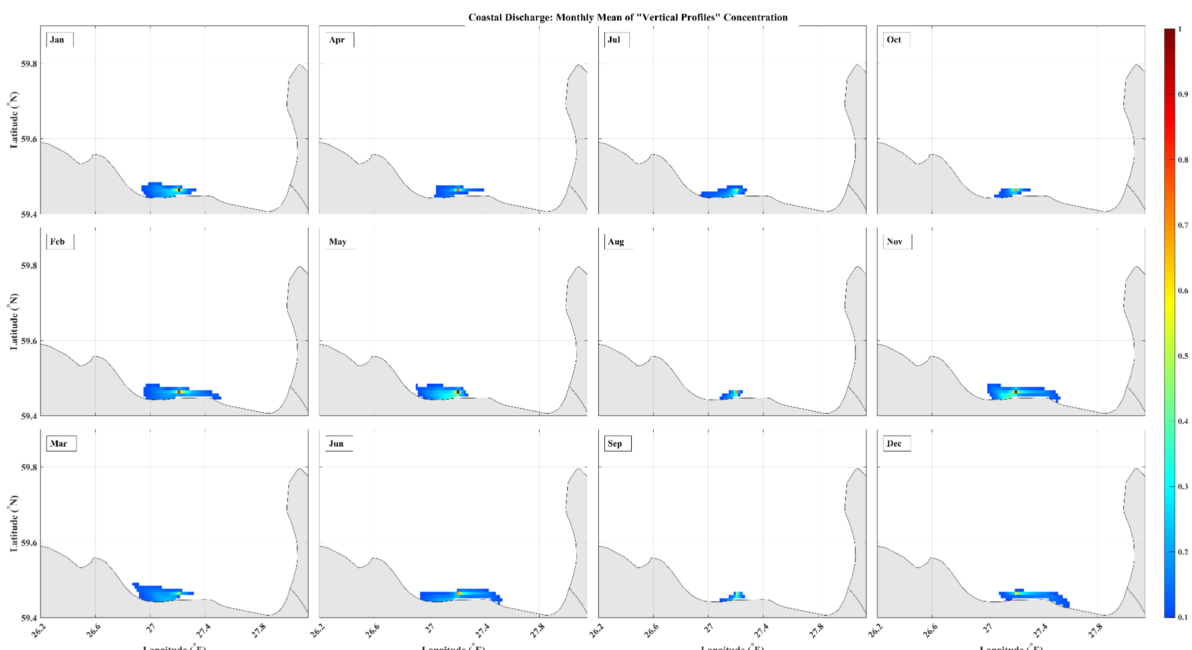

Figure 3.12. Monthly Mean Of “Vertical profile” concentration for Coastal R5

Figure 3.13 illustrates the monthly mean concentrations at the vertical profile in the Offshore scenario. In January, the vertical concentration acted similarly to the reference scenario to the west of the discharge location with high concentration of metal distribution, The following month an increase in metal concentrations to the west, spanning approximately from ~26.7ºE to 27.2ºE. However, in March, there is a decrease in the overall distribution without connection to the coast. In April concentration metal distribution increased around the discharge location which tended to west. In May, the distribution connected to the coastal area toward to west of the discharge location, while in June, metals tend to accumulate significantly in the coastal area, moving the east, specifically from 26.9ºE to 27.5ºE. During the summer, the distribution decreases, reaching its lowest point in July. same as the other scenarios, in autumn, it begins to rise once again, following the same pattern as the surface concentration. High values are observed in December, accompanied by a tendency towards the east of the discharge location approximately from 27ºE to 27.8ºE .

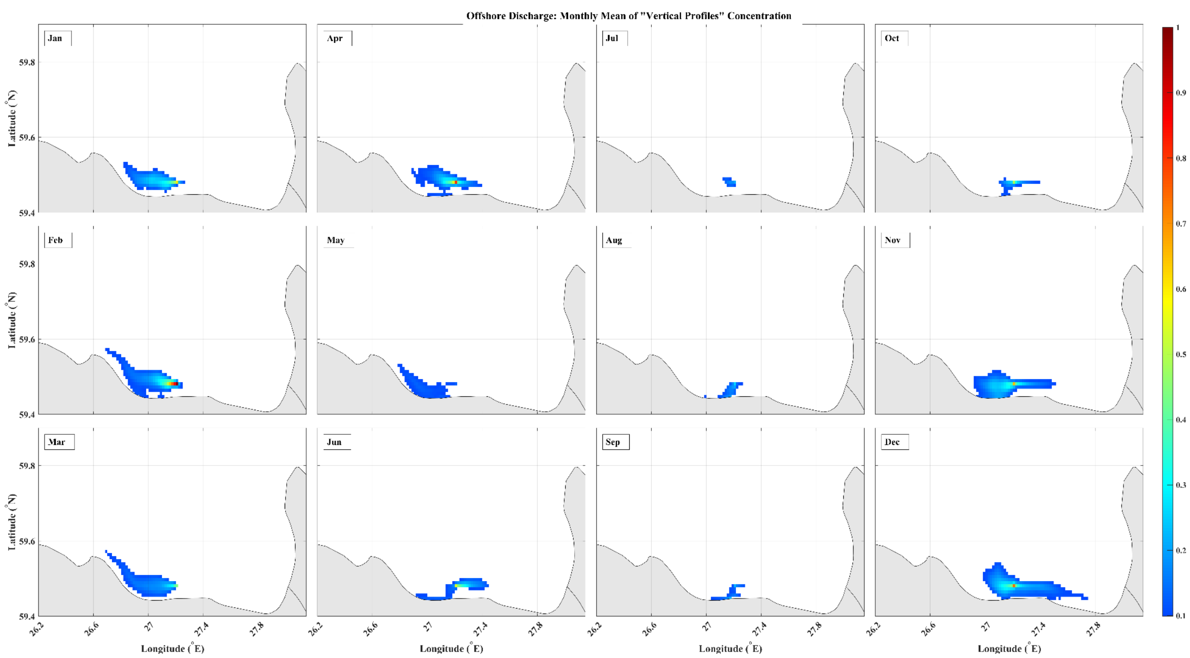

Figure 3.13. Monthly Mean Of “Vertical profile” concentration for Offshore R8

3.3. Performance Of The Two Scenarios

Table 3.1 presents the main results comparing the scenarios in this study to the reference state. The analysis considers 15 different metals, and based on the data analyzed in Table 3.1, it becomes apparent that the offshore discharge scenario (R8) exhibits a relative advantage in terms of metal distributions throughout the entire Gulf of Finland. Overall, the offshore discharge scenario causes smaller deviations from the reference state compared to the coastal discharge scenario (R5). The average final percentage indicates that the offshore discharge scenario is approximately 5% better than the coastal discharge scenario. While the previous plots suggest that the coastal discharge scenario may be closer to the reference state in Narva Bay, Table 3.1 confirms that with a comprehensive survey of the entire study area, the offshore discharge scenario results in less pollution in the Gulf of Finland.

Var/Headers	elm_r2~r5	elm_r2~r8	elm_r5=r8	sum_elm	best	betterness %
cd	144036963	181832992	16262795	342132750	r8	55.8
hg	146035716	179593079	16503955	342132750	r8	55.15
ni	136611836	189337443	16183471	342132750	r8	58.09
pb	143591925	182250822	16290003	342132750	r8	55.93
ar	152314323	173621371	16197056	342132750	r8	53.27
ba	159285350	166837807	16009593	342132750	r8	51.16
cr	150088879	175819786	16224085	342132750	r8	53.95
sn	156904427	168739268	16489055	342132750	r8	51.82
zn	147921575	177986308	16224867	342132750	r8	54.61
cu	137343651	188604357	16184742	342132750	r8	57.86
al	134742936	191331971	16057843	342132750	r8	58.68
bo	144515029	181417641	16200080	342132750	r8	55.66
fe	152390329	173702893	16039528	342132750	r8	53.27
mn	140196483	186034356	15901911	342132750	r8	57.03
sb	151739471	174065139	16328140	342132750	r8	53.43
SUM	2197718893	2691175233	243097124	5131991250	r8	55.04733333

Table 3.1. Final Matrix: Count of Elements by Category

4. DISCUSSION

4.1. Mean Of Concentration

The reference mean map distribution implies that the significant diffusion of metal concentration will remain around the discharge location. However, around the discharge location, at the surface layer the metals will be distributed along Estonian coasts from 26 oE to 27 oE and this distribution extension will reduce toward the bottom. In addition, however the bottom layer does not contain a large horizontal distribution, the metal concentration below the discharge location is still very high that can be due the metals settling downward. Both the coastal and offshore scenarios exhibit the same pattern as the reference scenario in terms of surface, bottom, and vertical layers. However, it is important to note that the offshore scenario causes more extended horizontal distribution in the Narva Bay and its neighboring areas. This difference in horizontal distribution can be attributed to variations in the distances between the different discharge locations in each scenario.

4.2. Monthly Means

The monthly mean surface concentration in the reference state shows a noticeable seasonal cycle, with an increase during autumn and winter followed by a decrease in summer. However, when considering the eastern and western regions of the discharge location, there is a distinct difference in the distribution of metal concentrations. This variation can be attributed to seasonal and monthly fluctuations in coastal water circulations. Despite this regional difference, both the coastal and offshore scenarios highlight the significant impact of the wastewater discharge location on the high concentration zone of metal pollution.

4.3 Wastewater discharge scenarios

In Section 3.3, it becomes evident that the offshore discharge scenario exhibits a relative advantage of approximately 5% for all metals across the entire Gulf of Finland. This suggests that, when accounting for temporal and spatial variations within the study area, the offshore discharge scenario shows smaller deviations from the reference state compared to the coastal discharge scenario. However, this finding contradicts the observed metal concentration distribution in the Narva Bay. Additionally, it is worth noting that for approximately 10% of the data elements, both scenarios yield equal values. Considering the metal concentration maps, it is expected that these data elements are spatially more clustered away from the Narva Bay.

5. CONCLUSION

The distribution of metal pollution in the Gulf of Finland is influenced by the depth and location of wastewater discharge, as well as various environmental factors such as water temperature, salinity, and wind speed. Understanding the spatial and temporal variability of metal concentrations in the Gulf of Finland is crucial for assessing the impacts of wastewater discharge on the marine ecosystem. Modeling techniques can be used to simulate the transport and fate of metals in the marine environment, providing valuable insights into the distribution of metal pollution in the Gulf of Finland.

In conclusion, this master thesis has provided insights into the impact of metal pollution on the environment and the comparison of different scenarios for wastewater discharge location and depth and the important results concluded as below:

- Horizontal distribution in each scenario is higher at surface and will reduce toward depth. However the most significant distribution due to wastewater discharge will remain in the eastern part of the narva bay. By the way, however the horizontal distribution is higher at surface but a significant amount of metals will settle down the discharge location.
- The monthly means in all scenarios confirm that the spatial distribution of metal pollution in the Gulf of Finland follows a seasonal cycle. The concentration is significantly higher in Narva Bay, decreasing in summer and increasing in autumn and winter. Furthermore, the horizontal distribution of metal pollution indicates that as the discharge location moves towards the offshore area, the interaction with coastal areas decreases. This suggests that it is the most favorable scenario for human health, particularly for swimming and recreational activities. Additionally, the results of this study highlight the importance of diligent monitoring and management of metal pollution in the upper layers.
- The comprehensive analysis conducted for comparing wastewater discharge scenarios leads to the conclusion that the offshore scenario is the most suitable option. It exhibits favorable advantages for all the metals examined. The findings of this study offer valuable guidance for decision-making processes and emphasize the significance of prioritizing the offshore scenario in environmental planning efforts.

Overall, our findings offer valuable insights into the impact of wastewater discharge location in the Gulf of Finland. The study highlights the temporal variability of metal pollution distribution and the concentration dominance near the discharge area. These findings can be beneficial not only for environmental researchers, but also for chemical oceanographers and ecology researchers interested in comprehending the effects of various modeling scenarios on metal pollution concentration distribution and its impacts. Future research in this field can expand upon the knowledge generated by this study, contributing to a more comprehensive understanding of the complex interplay between ocean modeling and environmental factors.

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SUMMARY

(In English)

This master's thesis examines the relationship between wastewater discharge location and the distribution of metal pollution in the Gulf of Finland. The study is motivated by concerns regarding the detrimental effects of wastewater discharge, containing heavy metals, on the marine environment and its potential risks to human health and ecological systems. The primary objective is to identify a suitable location for wastewater discharge from a planned bioproduct factory and analyze the spatial patterns of metal contamination associated with the factory's outlet in the Gulf of Finland. Two discharge locations, coastal and offshore, are compared to determine the optimal distribution pattern for minimizing the impact of metal pollution on the marine environment.

This study aims to provide valuable insights into the environmental consequences of wastewater discharge by analyzing the spatial patterns of metal contamination. The findings will inform the development of sustainable management strategies and contribute to the preservation and sustainability of the Gulf of Finland's marine ecosystem. Totally, it focuses on the impact of wastewater discharge location on metal pollution distribution in Narva Bay. By evaluating the spatial patterns of metal contamination and identifying the most suitable discharge location, the study aims to contribute to the understanding and management of wastewater pollution, ultimately ensuring the long-term health and sustainability of the marine ecosystem. The research shows that the offshore discharge can be the closest scenario to the reference scenario.

(In Estonian)

See magistritöö uurib reovee äravoolu asukoha ja metallireostuse jaotuse vahelist seost Soome lahes. Uuringut motiveerib mure reovee äravoolu kahjulike mõjude pärast, mis sisaldavad raskemetalle, merekeskkonnale ja nende potentsiaalsetele ohtudele inimese tervisele ja ökoloogilistele süsteemidele. Peamine eesmärk on leida sobiv koht biotoodete tehase kavandatavale reovee äravoolule ja analüüsida metallireostuse ruumilisi mustreid seoses tehase väljundiga Soome lahes. Võrdleme kahte äravoolukohta - rannikulähedast ja avamereäärset - selleks, et kindlaks teha optimaalne jaotusmuster metallireostuse mõju minimeerimiseks merekeskkonnale.

Selle uuringu eesmärk on anda väärtuslikke teadmisi reovee äravoolu keskkonnamõjudest, analüüsides metallireostuse ruumilisi mustreid. Uurimustulemused aitavad kaasa säästva majandamise strateegiate väljatöötamisele ning Soome lahe mereökosüsteemi säilimisele ja jätkusuutlikkusele. Uurimuse fookuses on reovee äravoolu asukoha mõju metallireostuse jaotusele Narva lahes. Hinnates metallireostuse ruumilisi mustreid ja leides kõige sobivama äravoolukoha, püüab uuring kaasa aidata reovee saastamise mõistmisele ja juhtimisele, tagades lõppkokkuvõttes mereökosüsteemi pikaajalise tervise ja jätkusuutlikkuse. Uuring näitab, et avamereärane äravool võib olla kõige lähedasem olukorrale, mis vastab referentsstsenaariumile.

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