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MORALITY BEFORE KNOWLEDGE

Spatial analysis of zinc (Zn) heavy metal distribution in the waters of Staring Bay, Southeast Sulawesi

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ABSTRACT
Background: A spatial study of the distribution of heavy metal zinc (Zn) in the waters of Staring Bay, Southeast Sulawesi, has been conducted. This research aims to determine the spatial distribution of heavy metal Zn in the waters of Staring Bay. **Methods:** Sampling was carried out at 12 stations in the bay using a purposive sampling method. The concentration of heavy metal Zn in seawater samples was determined using an Atomic Absorption Spectrophotometer (AAS). Spatial analysis was performed using the Inverse Distance Weight (IDW) interpolation method (power = 2) with data processing software (ArcGIS 10.1). **Findings:** The results of the study indicate that the Zn metal concentration at the 12 research stations ranges from 0.0141 to 0.2085 ppm, with an average of 0.0668 ppm. The highest concentration of Zn metal is found at station 1. The results of the spatial analysis, with 12 stations, show that the area from the open sea to the coast of Tanjung Tiram Village has been contaminated with Zn heavy metal, ranging from 0.0132 to 0.2085 ppm. The same contamination is observed in the northern part of Wawosunggu Island, from the river mouth near Rumbia-rumbia Village to Lara Island, which has also been contaminated with a range of 0.0572 to 0.2085 ppm. **Conclusion:** Based on the contaminant factor (CF) values, the highest contamination by Zn metal occurs at station 1. Environmental variables (salinity, pH, temperature) show no significant effect on the concentration of Zn heavy metal. **Novelty/Originality of this article:** This study provides a comprehensive spatial analysis of zinc (Zn) contamination in Staring Bay, highlighting critical areas of pollution. It uniquely employs the Inverse Distance Weight interpolation method, revealing significant contamination patterns with minimal influence from environmental variables.

KEYWORDS: heavy metal Zn; spatial analysis; staring bay; inverse distance weight (IDW); contaminant factor (CF).

1. Introduction

Waters are very important for human survival and provide a significant source of livelihood. The ocean is generally known as a "dumping area," serving as the final disposal site for waste from all human activities around the world. The waste discarded can include household, industrial, and construction waste. Every form of waste eventually enters the water, posing a threat to aquatic ecosystems and, if left unchecked, causes pollution. Pollution is a threat to the sustainability of life within an ecosystem. Santika (2024) states that the primary cause of pollution is the dominant influence of human activities on the environment. The causes of pollution are highly varied, one of which is pollutants such as

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heavy metals. Heavy metals are a type of contaminant that raises significant concern for the environment. Heavy metals have garnered global attention due to their toxic nature, persistence, and tendency to accumulate in living organisms (Bosch et al., 2016).

The presence of heavy metals within the water can pollute the environment and impact health as well as decrease water quality standards. If the amount of waste dumped into water bodies exceeds their natural ability to neutralize it, the water quality will decline, making the water less effective or even unable to serve its original purpose. Although water bodies can partially recover on their own, there is a limit to their capacity to do so (Fismawati, 2010). The metabolism of organisms living in aquatic environments will be disrupted due to waste that is difficult to decompose, causing it to settle at the mouths of water bodies. The bioaccumulation of heavy metals in marine organisms has significant implications for human health, considering that humans consume seafood. This can lead to numerous health conditions in the body. Therefore, the issue of heavy metal waste becomes an important concern due to its significant effects on living organisms (Rachmawati et al., 2013). One of the heavy metals that is particularly dangerous to the human body is zinc (Zn). According to Susanto et al. (2015), excess Zn can cause liver damage and acute kidney failure. Measuring dissolved metals in seawater is much more difficult than detecting metals in sediments or other forms. This is largely due to the very low concentrations of metals in seawater and the impact of the seawater matrix effects. Until now, only a limited number of studies have been conducted on the distribution and risks of metal elements in seawater in the field (Zhang et al., 2017a; 2018; Li et al., 2017; 2019; Wang et al., 2018). Teluk Staring is a marine zone that extends inland, located in the North Moramo District, Moramo, and Laonti, Konawe Selatan Regency, Southeast Sulawesi Province, Indonesia. This bay is situated very close to residential activities that are utilized for tourism, transportation, fishing, and developing industries along the coast. Teluk Staring is also used for capture fisheries and industrial ports, which are closely related to the quality of seawater, sediments, and other marine biota concerning the concentration of metals due to waste disposal.

According to Armid et al. (2014), previous research on the distribution of heavy metals found that monitoring data only represented conditions at individual stations and did not provide a representative overview. Therefore, it is crucial to utilize spatial methods to analyze the presence of heavy metal zinc (Zn) to determine the patterns or distribution of heavy metals comprehensively, covering the entire Teluk Staring area in Southeast Sulawesi. This examination aims to ascertain whether the levels of heavy metal Zn are below hazardous limits. Excessive concentrations of heavy metals can result in the death of certain aquatic organisms. The spatial analysis method is used to determine the condition of an object in relation to a particular area, taking into account the geographic distribution. The spatial method employs Geographic Information Systems (GIS) to map the specified water areas using the Inverse Distance Weight (IDW) interpolation method. Through this interpolation method, the results of spatial analysis of polluted water conditions can be presented by mapping the targeted regions. The concentrations of heavy metals in Teluk Staring, Southeast Sulawesi, can be quantified using one of the instruments, namely the Atomic Absorption Spectrophotometer (AAS). The principle of AAS is the absorption of light energy by an atom or element at a specific wavelength. The AAS method is specific and nearly free from interference because the frequency of radiation absorbed is characteristic for each element, and absorbance is directly proportional to the length of the flame through which light passes and the concentration of atomic vapor in the flame. Based on the above background, this study is conducted to evaluate the distribution of heavy metal Zn representatively using spatial methods in the waters of Teluk Staring, Southeast Sulawesi, to observe the prevalence of heavy metals around the water areas in the world.

2. Methods

This research combines field activities and laboratory work. The field activities involve the collection of seawater samples in the waters of Teluk Staring, Southeast Sulawesi, at the coordinates 4°02'40"–4°08'53" S – 122°40'03"–122°48'02" E. The seawater samples obtained are brought to the Laboratory for Soil Testing, Fertilizers, and Plant Tissues at the Faculty of Agriculture, Halu Oleo University (UHO).

2.1 Tools and materials

The tools used in this research include: Global Positioning System (GPS) (Garmin Montana, Germany), portable pH-salinometer (Germany), 20 mL syringe, 0.45 μm filter, Iwaki Pyrex volumetric flasks of 50 mL, 100 mL, and 1000 mL, Iwaki Pyrex measuring pipettes of 10 mL and 25 mL, 5 mL volumetric pipette, filler, plastic bottles, dropper pipettes, spray bottles, cool box, and Atomic Absorption Spectrophotometer (AAS) (Hitachi Z-2000). The materials used in this research consist of seawater samples from the waters of Teluk Staring, Southeast Sulawesi, hydrochloric acid (HCl) p.a solution, 1% and 70% nitric acid (HNO3) solutions, 1000 ppm zinc (Zn) stock solution, and distilled water.

2.2 Research procedure

2.2.1 Sample collection

Field research was conducted by determining the sampling points for seawater in the waters of Teluk Staring, Southeast Sulawesi, using the Global Positioning System (GPS) at the coordinates 4°5'14" S and 122°43'34" E. pH measurements were performed directly at 12 stations using a portable pH-salinometer, as shown in Figure 1.

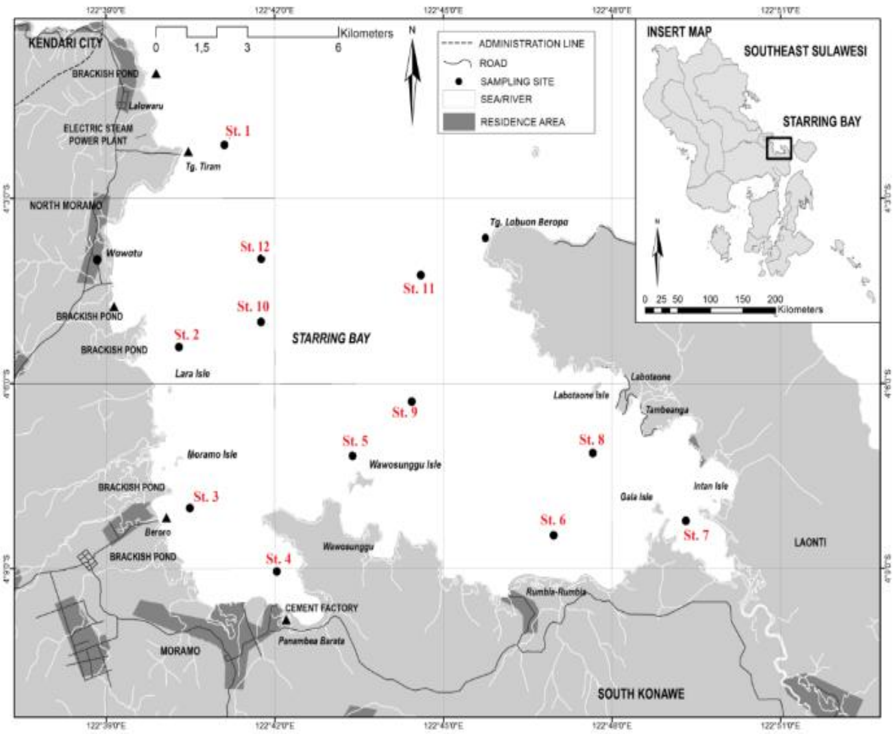

Fig. 1. Sampling station

The environmental parameters measured in the water are pH, temperature, and salinity. The samples, once placed in plastic bottles, were treated with a drop of concentrated hydrochloric acid (HCl p.a), sealed, shaken, and labeled with the station identifier before being placed in an ice box to prevent evaporation. They were then stored in a freezer prior to further analysis. Table 1 shows the coordinates of the sampling points.

Table 1. Coordinates of the 12 sampling stations

Station	Coordinate	
	BT	LS
#1	122°41'6.44"	4° 2'7.79"
#2	122°40'17.68"	4° 5'24.39"
#3	122°40'29.26"	4° 8'0.95"
#4	122°42'2.19"	4° 9'2.77"
#5	122°43'23.20"	4° 7'10.34"
#6	122°46'57.83"	4° 8'27.56"
#7	122°49'18.90"	4° 8'13.66"
#8	122°47'39.56"	4° 7'7.75"
#9	122°44'26.20"	4° 6'17.44"
#10	122°41'45.48"	4° 5'0.16"
#11	122°44'35.97"	4° 4'14.46"
#12	122°41'45.70"	4° 3'58.80"

2.2.2 Preparation of seawater samples

The preparation of seawater samples was conducted at the Laboratory of Soil, Fertilizer, and Plant Tissue Testing, Department of Soil Science, Faculty of Agriculture UHO. The seawater samples were filtered using a syringe with a filter paper of 0.45 μm pore size, collecting 50 mL, and then placed into polyethylene bottles. The samples were then diluted with 1% HNO3 solution and prepared for analysis (Reichelt-Bruchett and Mcorist, 2003).

2.2.3 Sample preparation

2.2.3.1 Zn standard solution

The Zn standard solution was prepared with varying concentrations of 0 ppm, 0.025 ppm, 0.050 ppm, 0.075 ppm, 0.100 ppm, and 0.150 ppm from a 1000 ppm Zn stock solution. The prepared Zn standard solutions were analyzed using AAS to obtain data for the calibration curve, which would be used to determine the concentration of Zn metal at each seawater sampling station.

2.2.3.2 Zn metal concentration

To measure the concentration of the heavy metal Zn in the seawater samples, 5 mL of each sample solution was taken and diluted with 1% HNO3 in a 10 mL volumetric flask and homogenized. Each sample was then analyzed using AAS with an air-acetylene flame (Reichelt-Bruchett and Mcorist, 2003).

2.3 Data analysis

After the data were collected, they were analyzed in several stages, including linearity testing using the absorbance of the standard solution series measured at a wavelength of 213.9 nm (Zn metal), determining the limit of detection (LOD), establishing the quantification limit, and assessing the precision of the research samples. After all stages of sample analysis were conducted, the next step was to perform spatial distribution analysis by inputting all data using MS Excel, Office 2016, which was then converted into a database and delimited text format for compatibility with the software during the digitization process. The location map was digitized using ArcGIS 10.1 to produce a digital map with coordinates. This map was combined with a 2018 Google Earth imagery map. The registration process included digitizing the distance between sampling stations. The digital map was then clipped with a polyline (defining the spatial distribution parameter area) to obtain the land range corresponding to the spread of heavy metals. The add table process was performed based on the processed data with MS Excel data* text in the ArcGIS 10.1

program. Subsequently, data interpolation was conducted using the Inverse Distance Weight (IDW) method, a technique that yields interpolation results more similar to sample data that are closer in distance rather than those further away. The weights would change linearly based on their distance from the sample data. Meanwhile, the Contamination Factor (CF) in seawater can be calculated to describe the contamination process caused by toxic substances in the environment, with the following equation:

$$CF = Cx/Cbackground(Bn) \quad (Eq.1)$$

Where CX is the concentration of Zn metal in the seawater sample being studied. Cbackground (Bn) is the average normal concentration of Zn metal in nature (Wardhani et al. 2016). The average normal concentration for Zn metal is 0.05 ppm (KMNLH, 2004). The final step is to conduct a descriptive analysis using the purposive sampling method.

3. Results and Discussion

3.1 Analysis of Zn metal concentration in Staring Bay

The regression equation of the calibration curve obtained is calculated using the least squares method from the absorbance measurement results plotted against the concentrations of the standard zinc (Zn) solutions. The average absorbance values from the measurements can be seen in Table 2.

Table 2. Measurement Data of absorbance for standard Zn solutions

Concentration of standard solutions (ppm)	Absorbance
0	0,0001
0,025	0,0238
0,050	0,0566
0,075	0,0805
0,100	0,1096
0,150	0,1694

Based on the average absorbance data of the standard Zn solution measurements, the calibration curve is presented in Figure 2.

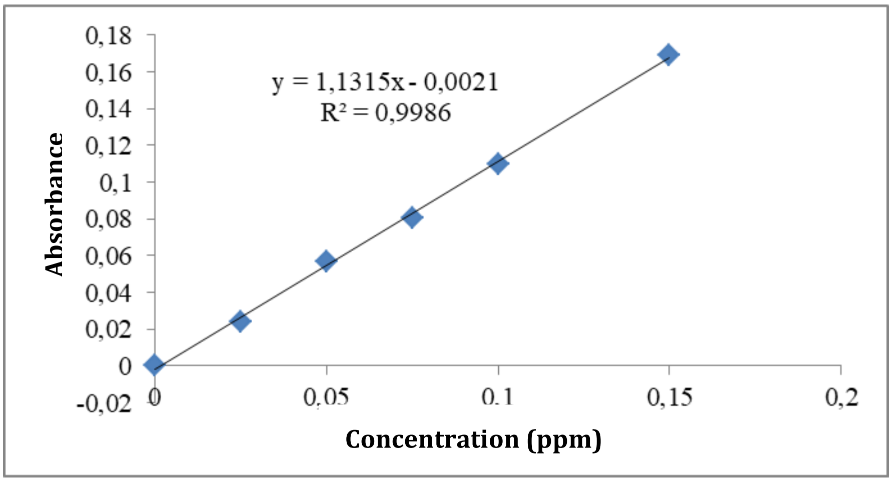

Fig. 2. Calibration curve of standard Zn solution

According to the regression analysis results of the curve shown in Figure 2, the average results from the three repetitions of the standard zinc solution measurements represent the best analysis, with a slope value of 1.1315 and a curve intercept of 0.0021. Thus, the regression equation for the standard curve for zinc (Zn) is obtained as $y = 1.1315x - 0.0021$ with a correlation coefficient (R^2) of 0.998. Based on this regression equation, the concentration of zinc (Zn) in each analyzed sample can be calculated using the regression equation. The limit of detection (LOD) for this measurement is 0.0016 ppm.

Meanwhile, the linearity test in this study was conducted by measuring six series of standard zinc solutions three times, resulting in the calibration curve presented in Figure 2. The linear equation and correlation coefficient of the series of standard zinc solutions are $y = 1.1315x - 0.0021$ and $R^2 = 0.998$. The analysis of the correlation coefficient (R^2) of the standard solution series was averaged to obtain the best correlation coefficient value of R^2= 0.998. This result indicates that the absorbance obtained and the concentration of the standard solution series meet the acceptance criteria of the method, where good linearity will yield a correlation coefficient close to 1 with $R^2 > 0.997$ (Chan, 2004).

According to the analysis conducted, the LOD obtained was 0.0016 ppm. This indicates that the AAS (Hitachi Z-2000) instrument used can detect heavy metal Zn at the lowest concentration in the seawater samples. On the other hand, based on the analysis conducted, the limit of quantification (LOQ) obtained is 0.005226 ppm. This shows that the AAS (Hitachi Z-2000) instrument can detect heavy metal Zn with the lowest analyte concentration in the seawater samples. The precision test shows the closeness of the measurement results according to the established standards from several repetitions on the homogeneous samples (Riyanto, 2014). The method used to determine the precision value is repeatability. Based on the analysis conducted, the %RSD value is 0.8099. This indicates that the method used has a high precision level, thus meeting the acceptance criteria for the analytical method.

3.2 Analysis of Zn metal content

The linear regression equation obtained from the calibration curve is subsequently used to calculate the zinc (Zn) concentration at the 12 sampling stations to be analyzed. The absorbance measurements of the samples from the 12 stations were conducted three times, with two dilution factors, resulting in average absorbance values. The concentration values of Zn are presented in Figure 3.

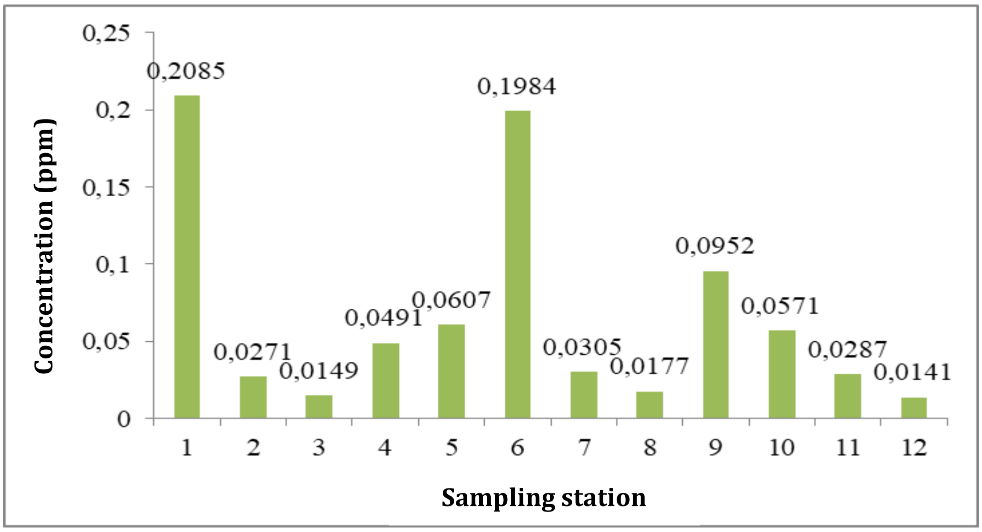

Fig. 3. Concentration of Zn at 12 sampling stations in Teluk Staring

Based on Figure 3, the concentration of dissolved Zn metal measured at the 12 stations in this study ranges from 0.0141 to 0.2085 ppm. Zinc (Zn) has a standard quality benchmark of 0.05 ppm (KMNLH, 2004). This indicates that the concentrations at stations 1, 5, 6, 9, and 10 have exceeded the allowable normal limit. Station 1 has the highest concentration of Zn metal at 0.2085 ppm. The high concentration of Zn at station 1 is attributed to input sources from the Steam Power Plant (PLTU), stemming from coal combustion waste, as Zn is typically used as an additive in fuel oil (Wardhani et al., 2012). Stations 2 and 3 have Zn concentrations of 0.0271 ppm and 0.0149 ppm, respectively, both located in the estuary area, which is the confluence of freshwater and seawater.

Station 4, with a Zn concentration of 0.0491 ppm, is suspected to be influenced by inputs from the cement factory, where Zn is used in the mixing of building materials, for example, as a catalyst in the cracking process for producing concrete tiles (Darmono, 2001). Stations 5, 9, 10, 11, and 12 have Zn concentrations of 0.0607 ppm, 0.0952 ppm, 0.0571 ppm, 0.0287 ppm, and 0.0141 ppm, respectively. Four of these sampling station locations are situated in open seawater. The contamination of Zn at these locations is suspected to result from the distribution of water carried by currents from contaminant sources.

The same is true for station 6, which has a Zn concentration of 0.1984 ppm, quite high after station 1. The sampling location is in open seawater, influenced by currents from a large river estuary. Stations 7 and 8 have Zn concentrations of 0.0305 ppm and 0.0177 ppm, respectively, situated near residential areas that are also influenced by currents from a large river estuary and domestic wastewater.

3.3 Spatial distribution of heavy metal Zn in Teluk Staring Waters

Geographic Information System (GIS) modeling is used to distribute the spatial distribution of heavy metal parameters of Zn concentration from the study at twelve stations in Teluk Staring waters. The map source used is derived from Google Earth imagery from 2018, with boundary coordinates matching the sampling coordinates, utilizing ArcGIS 10.1 software, which is released by the Environmental Systems Research Institute (ESRI).

The modeling in this study employs the Inverse Distance Weight (IDW) interpolation method, which is a relatively simple model compared to other interpolation methods. According to Ningsih (2013), this model assumes that the value of a point will be influenced by the values of nearby points spatially. The software measures the distance from an observation point to the observed points, where the Z value for each point is generally weighted by the square of the distance, such that values closer spatially tend to influence the value at the observed point. This process begins with the registration of the base map, digitization of the map, attribute data input and editing, interpolation of the sampling station grid, followed by layout creation and map storage. IDW interpolation has two parameters that can be studied: power and sample size. The power parameter can be used to determine the significance of the sample data values in the interpolation calculation. Local interpolation can be converted into global interpolation by altering the power. A higher power will reduce the influence of surrounding sample data, resulting in more detailed interpolation outcomes. However, in the interpolation of Zn distribution, the focus is not on varying the power in IDW but rather using a fixed power value of 2. The distribution of Zn, obtained from the digitization and interpolation of the 12 sampling stations in Teluk Staring waters, can be seen in Figure 4.

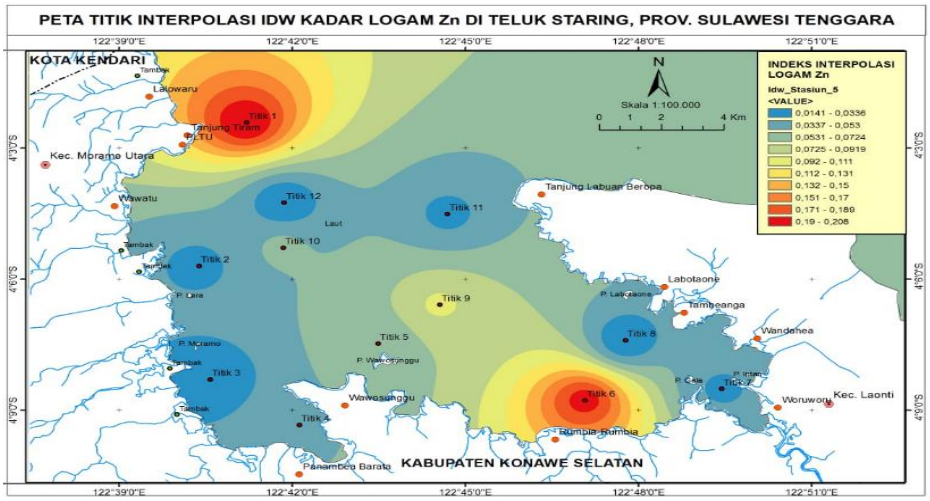

Fig. 4. Distribution of Zn metal across 12 stations after interpolation

Based on the spatial analysis data presented in Figure 4, the locations contaminated with Zn metal are situated at the estuary of the open sea near Tanjung Tiram Village, the northern part of Wawosunggu Island, the river mouth near Rumbi-rumbia Village, and Lara Island, with concentration levels ranging from 0.0571 to 0.2085 ppm. Meanwhile, locations not contaminated by Zn metal are found in the open sea near Labuan Beropa Village, Lara Island, Moramo Island, the open sea between Wawosunggu Island and Labotaone Island, Labotaone Island, and Laonti, between Intan Island and Gala Island, with concentrations ranging from 0.0141 to 0.0491 ppm. According to the interpolation index, the highest Zn metal concentration is located at stations 1 and 6, with a range of 0.19–0.2085 ppm, marked by a red color gradient. The lowest Zn metal concentration is found at stations 2, 3, 7, 8, 11, and 12, with concentrations ranging from 0.0141 to 0.0336 ppm, marked by a blue color gradient. The red color indicates Zn levels above the normal quality standards, while the blue color represents Zn levels below the normal quality standards.

3.4 Contamination factor (CF) analysis

The Contamination Factor (CF) analysis of seawater is conducted to determine the contamination process caused by toxic substances in the environment. The contamination factor values for the 12 observation stations are shown in Appendix 9. According to Hakanson (1980), the contamination factor for Zn metal is 1. The following criteria are used to describe the contamination conditions: $CF < 1$ indicates low contamination, $1 \leq CF < 3$ indicates moderate contamination, $3 \leq CF \leq 6$ indicates high contamination, and $CF > 6$ indicates very high contamination. The contamination factor analysis for the 12 sampling stations is presented in Figure 5.

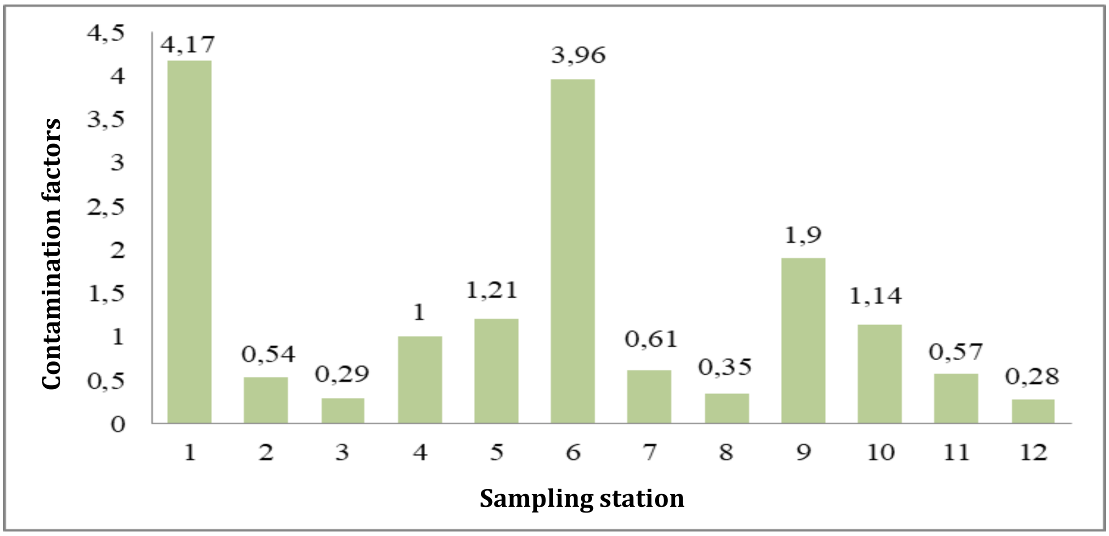

Fig. 5. Contamination factor (CF) of Zn heavy metal in the waters of Staring Bay, Southeast Sulawesi at 12 sampling stations

Based on Figure 10, referring to contamination factor criteria, it can be observed that 2 out of 12 sampling stations have CF values in the range of $3 \leq CF \leq 6$, specifically between 3.96 and 4.17, indicating that these locations are highly contaminated with Zn heavy metal. Moderate contamination levels, where $1 \leq CF < 3$, are found at stations 4, 5, 9, and 10, with CF values between 1 and 1.9. Low contamination levels, where $CF < 1$, are recorded at 6 stations—namely stations 2, 3, 7, 8, 11, and 12—with CF values ranging from 0.28 to 0.61.

3.5 Influence of environmental parameters (pH, temperature, and salinity) on Zn metal levels in the waters of Staring Bay

Staring Bay receives a high volume of waste load from various activities along its coastal and river basin areas, which flow into the bay. The measured values of pH, temperature, and salinity were recorded. Based on the research findings, several environmental parameters were measured at the study site, supporting factors in the bioaccumulation of Zinc (Zn) heavy metal in seawater within the waters of Staring Bay, Southeast Sulawesi. These environmental parameter values and the standard seawater quality criteria for marine biota can be seen in Table 3.

Table 3. Measurement results of environmental parameters based on seawater quality standards for Marine Biota

Parameter	Staring Bay	Quality standard
Salinity (%)	33.86	33–34
Temperature (ºC)	28.6	28–30
pH	7.85	7–8.5

(MENLH, 2004)

3.5.1 Salinity

Salinity is the level of saltiness or the concentration of dissolved salts in water. The measured salinity level in the waters of Staring Bay, Southeast Sulawesi, was 33.86%. This value remains within the seawater salinity quality standard for marine biota, set by MENLH (2004), which ranges from 33–34%. A decrease in salinity is related to marine biota, as lower salinity levels in waters can lead to higher bioconcentration of heavy metals in marine organisms. Staring Bay is part of an estuary habitat, a semi-enclosed river mouth that connects freely with the sea, allowing high-salinity seawater to mix with freshwater. Based on Table 3, salinity impacts on seawater were observed at 12 stations, with results varying depending on local marine conditions and natural influences such as freshwater runoff, storms, and rain, which can cause salinity to range from 17.5% to 52.2% (Vaughan 1919; Wells 1932 in Supriharyono, 2000). Previous studies have shown that increased salinity negatively affects heavy metal concentration; the higher the salinity, the lower the heavy metal concentration. The highest salinity value measured was at station 10, at 36.3%, while the lowest was at station 7, at 24.8%, located in the industrial cement plant area.

3.5.2 Temperature

The average temperature obtained from measurements in the waters of Staring Bay, Southeast Sulawesi, was 28.6°C. According to Table 3 and MENLH (2004), this temperature value meets the seawater quality standard for marine biota, which ranges from 28–30°C. However, if the temperature exceeds the seawater quality standard, it can increase heavy metal bioaccumulation in organisms. Water temperature directly affects the solubility of heavy metals in water. According to research by A. Firmansyaf et al. (2013), the solubility of heavy metals in water increases with rising temperatures.

3.5.3 pH (degree of acidity)

The natural pH of seawater makes heavy metals difficult to dissolve and present in particle or suspended solid (TSS) forms. Increased salinity raises pH, reducing metal solubility in water as stability shifts from carbonate to hydroxide forms, which bond with particles in the water, forming sludge deposits. The concentration of heavy metals in sediment sludge is positively correlated; the higher the sludge content in sediment, the higher the heavy metal content, resulting in lower metal levels in the surface water (Bangun, 2005). The pH measured in the waters of Staring Bay, Southeast Sulawesi, was 7.85. This value is within the seawater quality standard for marine biota according to MENLH (2004), which ranges from 7 to 8.5, while the basic pH of seawater ranges from 7.5 to 8.3 (Sanusi, 2005). A decrease in pH levels in a body of water can increase heavy metal toxicity, disrupting marine biota life.

3.5.4 Impact of environmental variables on Zn metal concentration

The impact of environmental variables is shown in Figure 6, with average values for salinity, temperature, and pH tending to meet the quality standards set by MENLH (2004). Zn levels at the 12 stations indicate no significant effect on heavy metal concentrations in the waters of Staring Bay. This may be due to varying environmental conditions at each station, such as the inconsistent tidal movement in the estuary area and the variability in source input, also influenced by irregular rainfall during the sampling and measurement period.

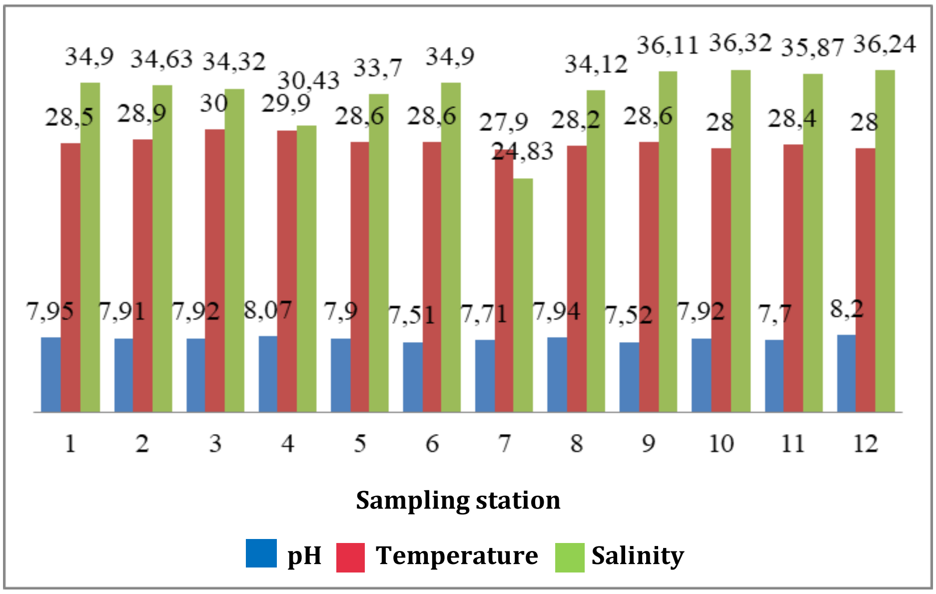

Fig. 6. pH, temperature, and salinity values at 12 sampling stations

4. Conclusions

Based on the research conducted, it can be concluded that the analysis of zinc (Zn) heavy metal concentration using the Atomic Absorption Spectrometry (AAS) method at 12 stations in the waters of Staring Bay, Southeast Sulawesi, yielded an average Zn concentration of 0.0668 ppm. The highest zinc concentration was found at station 1, at 0.2085 ppm, and the lowest concentration was at station 12, at 0.0141 ppm.

The spatial distribution of Zn in the waters of Staring Bay, Southeast Sulawesi, shows that the highest interpolated Zn concentration index was at stations 1 and 6, with concentrations ranging from 0.19 to 0.2085 ppm, marked by a red color gradient. The lowest interpolated Zn concentration index was found at stations 5, 2, 3, 7, 8, 11, and 12, with Zn concentrations ranging from 0.0141 to 0.336 ppm, marked by a blue color gradient. Pollution status, based on contamination factor (CF) criteria, indicates that 2 out of the 12 sampling stations had CF values of $3 \leq CF \leq 6$, ranging from 3.96 to 4.17, indicating high levels of Zn contamination at those locations. Moderate contamination, with values of $1 \leq CF < 3$, was observed at stations 4, 5, 9, and 10, ranging from 1 to 1.9. Low contamination, with $CF < 1$, was recorded at 6 stations: 2, 3, 7, 8, 11, and 12, with CF values between 0.28 and 0.61.

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Author Contribution

Conceptualization, W., A., A.T.; Methodology, W., A., A.T.; Software, W., A., A.T.; Validation, W., A., A.T.; Formal Analysis, W., A., A.T.; Investigation, W., A., A.T.; Resources, W., A., A.T.; Data Curation, W., A., A.T.; Writing – Original Draft Preparation, W., A., A.T.; Writing – Review & Editing, W., A., A.T.; Visualization, W., A., A.T.; Supervision, W., A., A.T.; Project Administration, W., A., A.T.; and Funding Acquisition, W., A., A.T.

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Conflicts of Interest
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Open Access

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