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DISTRIBUTION OF SALINITY AND TEMPERATURE IN MUSI ESTUARY: USING VERTICAL SALINITY GRADIENT FOR ESTUARY CLASSIFICATION ZONE

DISTRIBUSI SALINITAS DAN SUHU DI MUARA MUSI: MENGGUNAKAN GRADIEN SALINITAS VERTIKAL UNTUK ZONA KLASIFIKASI MUARA

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ABSTRACT

Musi estuary is the mouth of the Telang and Musi rivers directly adjacent to the Bangka Strait. During flood (ebb) we see the distribution of salinity increases (decreases) which is known through the vertical distribution using CTD. The TS diagram is used to see the water mass characteristics the study area. Data-Interpolating Variational Analysis (DIVA) method is used to interpolate and visualize data from vertical and spatial temperature, salinity and density data. The classification of the Musi estuary zone is identified based on the value of the distribution of salinity, which considers the exchange of circulating salinity at flood and ebb. The density of the water mass is significantly affected by the proven graded salinity. While the temperature distribution does not change significantly with depth, the spatial distribution indicates that the temperature in the estuary is lower than in the upstream and ocean areas. The spatial distribution of salinity indicates that high salinity enters the estuary towards the river further at flood than at ebb. Salinity distribution ranges from 0.5 to 30 psu and temperatures between 29 and 33 °C from horizontal and vertical sections. The pattern of salinity distribution in the Musi river estuary was identified, consisting of three zones representing salinity conditions in the study area, namely the Polyhaline, Mesohaline, and Olygohaline zones.

Keywords: estuary, salinity zone classification, stratification, tidal exchange

ABSTRAK

Muara Musi merupakan muara sungai Telang dan Musi yang berbatasan langsung dengan Selat Bangka. Pada saat pasang (surut) kita melihat distribusi salinitas meningkat (menurun) yang diketahui melalui distribusi vertikal menggunakan CTD (Conductivity Temperature Depth). Diagram TS (Temperature-Salinity) digunakan untuk melihat karakteristik massa air di daerah penelitian. Metode DIVA (Data-Interpolating Variational Analysis) digunakan untuk interpolasi dan visualisasi data dari data vertikal dan spasial temperatur, salinitas dan densitas. Klasifikasi zona muara Musi diidentifikasi berdasarkan nilai sebaran salinitas yang memperhitungkan pertukaran salinitas yang bersirkulasi pada saat pasang dan surut. Densitas massa air secara signifikan dipengaruhi oleh salinitas yang terbukti bergradasi. Sementara distribusi suhu tidak berubah secara signifikan dengan kedalaman, distribusi spasial menunjukkan bahwa suhu di estuari lebih rendah daripada di daerah hulu dan laut. Distribusi spasial salinitas menunjukkan bahwa salinitas tinggi memasuki muara menuju sungai lebih jauh pada saat pasang dari pada saat surut. Distribusi salinitas berkisar antara 0,5–30 psu *dan suhu antara 29–33 °C dari bagian horizontal dan vertikal. Pola sebaran salinitas di muara sungai Musi diidentifikasi, terdiri dari tiga zona yang mewakili kondisi salinitas di daerah penelitian, yaitu zona Polyhaline, Mesohaline, dan Olygohaline.*

Kata kunci: *klasifikasi zona salinitas, muara, pertukaran pasang surut, stratifikasi*

I. INTRODUCTION

The estuary is a transitional area between freshwater and marine environments. Water characteristics are highly dependent on fresh water inflows, tides, and weather variables. (La Peyre *et al.,* 2016). River discharge, winds and tides play an important role in the cycle of water mass movement in the estuary (Uncles & Stephens, 2011; Bolanos *et al.,* 2013). During flood, higher saline water from the sea enters the river causing dilution of water mass and at ebb the river discharge pushes the sea water mass back out of the estuary (Heltria *et al.,* 2021). This continuous phenomenon causes the formation of low-salinity water masses along with the river flow from the estuary.

The distribution of salinity in the Musi estuary is very interesting to study because it is located directly opposite the Bangka Strait and is the estuary of two main rivers in South Sumatra, namely the Telang river and the Musi river. Previous research at this location has not comprehensively classified zones based on salinity. The effect of tides on the exchange of water masses at the Musi Estuary is significant. The salinity distribution model made by Sari *et al.,* (2013) shows the salinity distribution in the river and causes low salinity to form around Payung Island, while the wind does not significantly affect the movement of the water masses. The type of tide at this location is diurnal, in one daily cycle, there is one high tide and low tide with a flow rate of 19.3 $cm.s^{-1}$ (Surbakti, 2012). The tidal range at Musi Estuary at the neap tide is 1.07 to 2.03 m during spring tide (Heltria *et al.,* 2021).

Research on the salinity zone in the Musi estuary itself has not been conveyed. Samuel & Adjie (2007) previously divided the zones along the Musi river into three zone based on the physical-chemical water characteristics, where the Musi estuary was included in the downstream zone (sungsang village as the end of the zone) with a salinity range of 0-6 psu. Information about this zone is important to illustrate a general understanding of the physical oceanography patterns of the environment, sea water intrusion and the biota suitability zone of the Musi estuary.

The research aims to investigate the Musi estuary based on the salinity values in the range 0-30 psu. The data in this study are in-situ measurements in 2016 consisting of salinity, temperature, density and tides. The salinity zone will be classified based on its diurnal changes from the spatial and vertical distribution. The pattern of temperature and density in the study area is also delivered.

II. RESEARCH METHODS

2.1. Location and Time of Research

CTD data was carried out in the waters of the Musi estuary on September 4th and 7th, 2016, to compare the date of collection of tidal observation data with the Hijri calendar. September 4th includes the new moon phase and the 7th is the first quarter phase of the rising moon. The research location is at the mouth of the Musi river which is directly adjacent to the Bangka Strait with the coordinates between 2.1˚ - 2.5˚LS and 104.8˚ - 105.1˚LU (Figure 1).

2.2. Data Collection

Data were taken using CTD instruments at 25 station points with different depths. The stations are located around the Musi River, Telang River and the Musi Estuary. The process of taking using a CTD instrument is a “snapshot” once taken at each station. CTD is lowered to the bottom waters and raised back to the surface. The acquired raw CTD data included temperature and salinity data. On September 4th, CTD data were collected during flood tide conditions, while on September 7th during ebb tide conditions (Figure 2). The density value obtained from calculations referring to TEOS-10 (IOC *et al.*, 2010).

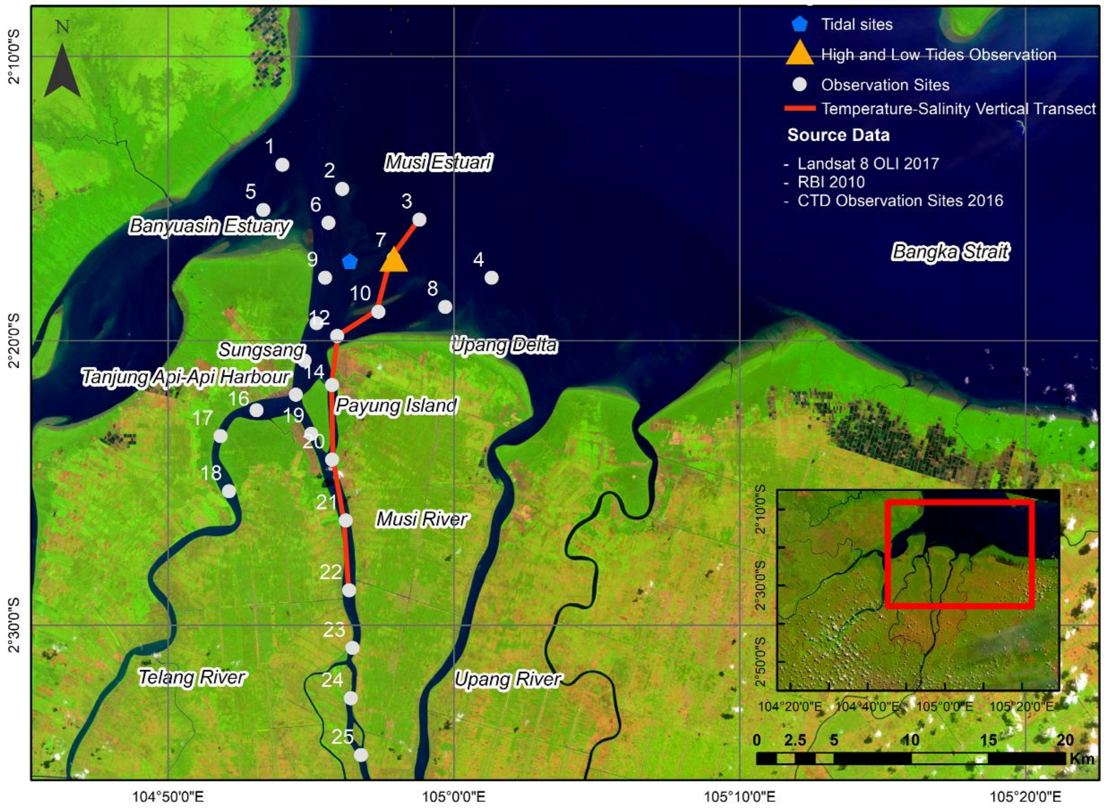

Figure 1. The Musi Estuary, East Coast of South Sumatera. The 25 white dots represent CTD observation sites that took temperature and salinity (T-S) data Red line shows the vertical transect of those data. The yellow triangle is the location of tide observation site to compare with T-S CTD Data between high and ebbs condition. The blue rectangular symbol indicates the tide observation site.

Potential density ($\theta\rho$) is the density that a fluid field has if its pressure is converted to a fixed reference pressure (Pr) by isentropic and isohaline means. For in situ density:

$$\rho = \rho(SA, \theta, p) \qquad \text{.................................} \ (1)$$

where SA is the absolute salinity, θ is the potential temperature and p is the pressure. The potential density anomaly ($\theta\sigma$) is the potential density - (minus) 1000 kg.m^{-3}. Written with the following equation:

$$\theta\sigma = \rho\ (SA, \theta, \rho) - 1000\ \mathrm{kg.m^{-3}} \qquad \text{. . . . .} \ (2)$$

Tide data were obtained from the Geospatial Information Agency (BIG) (http://tides.big.go.id/). The tidal data used is the hourly time series data from 1st – 30th September 2016 from 00:00 to 23:00 local time. Then observations were made on the tidal data adjusted for the CTD data recording period. CTD data collection during neap tide, namely during flood was carried out on 4th September 2016 and at ebb on 7th September 2016. At neap tide, flood and ebb have elevations that are not significantly different. So that they can represent the state of the mass distribution of water during flood and ebb conditions with minimal salinity intrusion.

2.2. Data Analysis

Analysis, visualization and data computation use Ocean Data View (ODV) version 5.2.0 software and Python 3.8

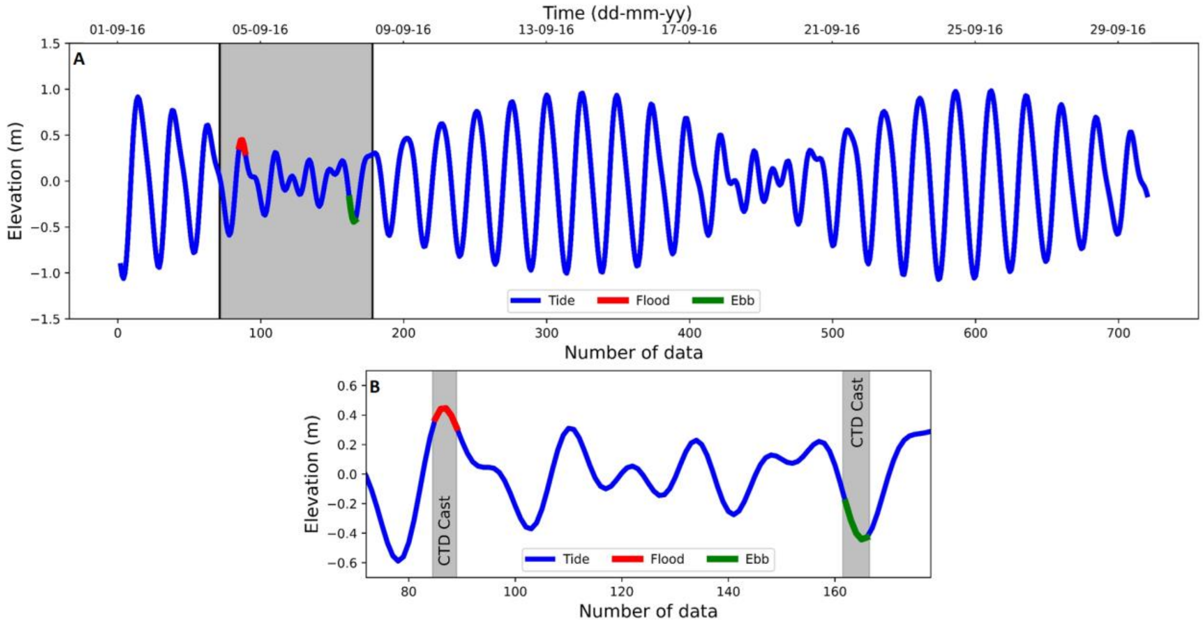

Figure 2. Tidal elevation in Musi Estuary. (A) tidal elevation during September. The gray blocks represent in situ data on 4th – 7th September 2016 during high and ebb conditions. (B) CTD data retrieval, red line when flood and green line when ebb. The tidal type at the Musi estuary is diurnal with a tidal range of 1.03 m at ebb and 2.05 m at flood.

(Jupyter Notebook). The program is used to display tidal data, vertical and spatial profiles on water columns and TS diagrams according to a predetermined estuary zone. Analysis of water mass characteristics using TS (Temperature-Salinity) diagrams. TS Diagram illustrates the temperature and salinity profile observed vertically in the water column. TS diagrams are used to identify the characters and sources of the water mass. TS diagrams can be used as a method for studying water mass mixtures (Emery & Thomson, 1998). Multidimensional variational analysis using the Data-Interpolating Variational Analysis (DIVA) method. This method allows interpolation and analysis of observations on a curved orthogonal grid in dimensional space. This method is useful in oceanography, where the water masses observed using instruments at one point often have different physical properties at another point and time. with this method will make it easier to visualize and analyze (Barth *et al.*, 2014).

The determination of salinity zone is based on the classification of Venice System (1958) and McLusky (1993) which divides the upstream area to the estuary (sea) for Limnetic <0.5 psu, Oligohaline 0.5-5 psu, Mesohaline 5-18 psu, Polyhaline 18-30 psu and Euhaline 30-40 psu. In this study, the division of the estuary zone was visualized using ArcGIS 10.4. Station 7, which is in front of the Musi River, is used as a point to see the difference in temperature and salinity values at flood and ebb. This observation station serves as a representation to see the existence of a strong tidal influence on estuary Musi waters. The determination of the cross transect is based on the entry route of freshwater intrusion or sea water flowing from the direction of the river or sea. Cross transects are represented by stations 3, 7, 10, 11, 14, 20, 21 and 22 located at the mouth of the Musi River and the Musi River with a transect length of 27.3 km.

III. RESULTS AND DISCUSSION

3.1. Temperature-Salinity Profiles at High and Ebb

The difference in temperature and salinity values at flood and ebb at station 7 can be seen in Figure 3. Measurement of temperature and salinity at Musi estuary shows a significant difference in values at the two observation times. At flood, the salinity value ranges from 17-29 psu with a pattern of salinity values increasing with depth. The temperature value at flood is between 29.7-30.4 °C. At flood, sea water masses with high salinity and low temperature enter the Musi estuary.

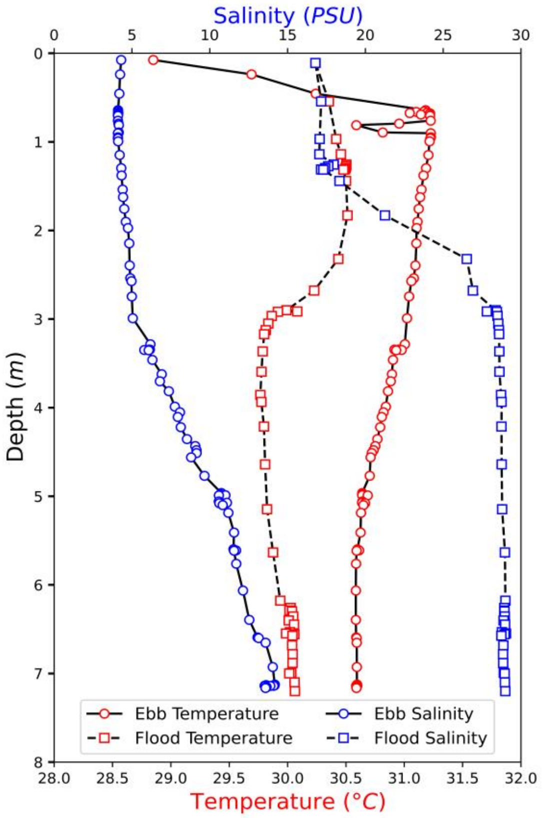

Figure 3. Vertical profiles of temperature (red) and salinity (blue) were recorded on September 4 under flood conditions (dotted line box) and September 7 at ebb condition (solid circle line) during the CTD cast taken at the Muara Musi estuary (Station 7).

Based on the results obtained, higher salinity is at the bottom and indicates seawater intrution from the bottom of the waters due to the large discharge of the Musi river. Seawater intrusion with a high salinity value is below because of the higher density value. At ebb the temperature of the water column is warmer between 30.6-31.2 °C and low salinity values range from 4-13 psu. The change in salinity value during the tidal period and ebb phase reaches a maximum of 25 psu at a depth of 3 meters. While the temperature changes in value reaching 1.5 °C. The salinity value has a significant change compared to the temperature value. Water masses of low salinity and high temperature are characteristic of water originating from land.

The high difference in the range of values for both temperature and salinity indicates that tidal dynamics strongly influence the influence of water mass. At ebb the water mass from the river which has warmer and fresher characteristics is more dominant because at ebb the tidal energy moving from the sea is minimal and the river discharge continues to flow towards the sea. while at flood the water mass from the sea is more dominant with greater energy entering the estuary area and intruding the river so that the waters are more saline and cold (Sorgente *et al.*, 2020). In addition, the depth in the Musi estuary area also has a major influence on the high and low values of temperature and salinity, namely the temperature value decreases with increasing depth and conversely the salinity value increases with increasing depth.

3.2. Vertical Characteristic of Water Mass

The results of the vertical distribution of temperature, salinity and density at ebb are presented in Figure 4a, Figure 4b, and Figure 4c. The flood is shown in Figure 5a for temperature, Figure 5b for salinity and 5c for density. The temperature value at ebb (Figure 4a) ranges between 28-32 ºC. It can be seen that several high- temperature cores with a maximum value of 32 ⁰C are located at the mouth of the Musi river. This high temperature is found at stations with shallow depths, so that the intensity of the irradiation that occurs is more intensive than other stations and causes a significant increase in temperature values in a certain range. The significance of surface temperature variations on the intensity of irradiation in these waters is still in the range that is not drastically different. This difference is not drastic because the water is a small-scale area. At flood, the water coming from the river looks stuck with an uneven temperature distribution. The water mass of water with a warm temperature is limited by the mass of water with a cooler temperature. The warm water mass has a range of 30.5 ⁰C while the cooler water mass is in the 30 ⁰C range. Furthermore, the warm water mass returns to the station which has shallow water depth. Several meteorological factors have a role in the high and low temperatures in a waters. Estuary waters in coastal areas are complex environments where hydrodynamic processes, exchange of matter and energy between land and sea and the atmosphere occur (Geyer & MacCready, 2014; Canuel & Hardison, 2015). The estuary area of the Musi River is a gathering point for several river flows with a fairly high discharge with a peak value reaching 555.28 m^3/s (Heltria *et al.,* 2021). These waters are also directly affected by the tides. At high tide the entry from the Bangka Strait to the mainland and at low tide from the mainland to the Bangka Strait with asymmetrical time (Surbakti, 2012).

The salinity at ebb (Figure 4b) at the mouth of the Musi River shows clear stratification. The surface layer has a lower salinity value than the bottom of the water. The mass of water with higher salinity originating from the sea is in the lower layer. This results in an isohaline slope that tends to be pushed to the surface from below with a lower stratified value towards the surface. Mixing of water that enters from the bottom of the waters by bringing higher salinity values and out to the surface can occur in these waters. Based on the observations (Figures 4 and 5), it can be identified the type of estuary in these waters. Mixing of water occurs due to the confluence of water masses from rivers and seas that enter from the bottom of the water and exit through the surface can occur in these waters. This condition indicates that partially mixed stratification has occurred in these waters. Partially mixed waters are characterized when tides encourage mixing in the estuary partially mixed causing some stratification of sea water below and fresh water above with variations in gradient in various estuary areas.

The salinity distribution between flood and ebb is seen to have a significant difference in value. Focusing on isohaline 15 and 2.5 psu shows that the intrusion between sea water and fresh water is much different. During ebb isohaline at 15 psu, the surface layer is 3 km from the mouth of the estuary (transect boundary) and the bottom layer is 6 km. Meanwhile, during the isohaline tide the surface layer pushes deep into the river until it reaches 11 km and the base layer reaches 14 km. The distribution of salinity values in the water column has a difference of up to 8 km in each layer. At isohaline 2.5 psu, which is at ebb, fresh water intrusion on the surface layer reaches 15 km from the upstream (transect boundary) and the bottom layer is still dominated by fresh water. Meanwhile, at flood, the range of fresh water intrusion on the surface layer with the same isohaline value is reduced to 8 km and 2 km at the bottom layer. The reach of freshwater intrusion is clearly on the surface layer with a difference of up to 7 km. These high fluctuations can cause significant differences between samples obtained at different tidal conditions (Cereja *et al.*, 2021).

The density at flood and ebb is quite significant and is proportional to salinity. The isopycnal gradient at ebb is at the river

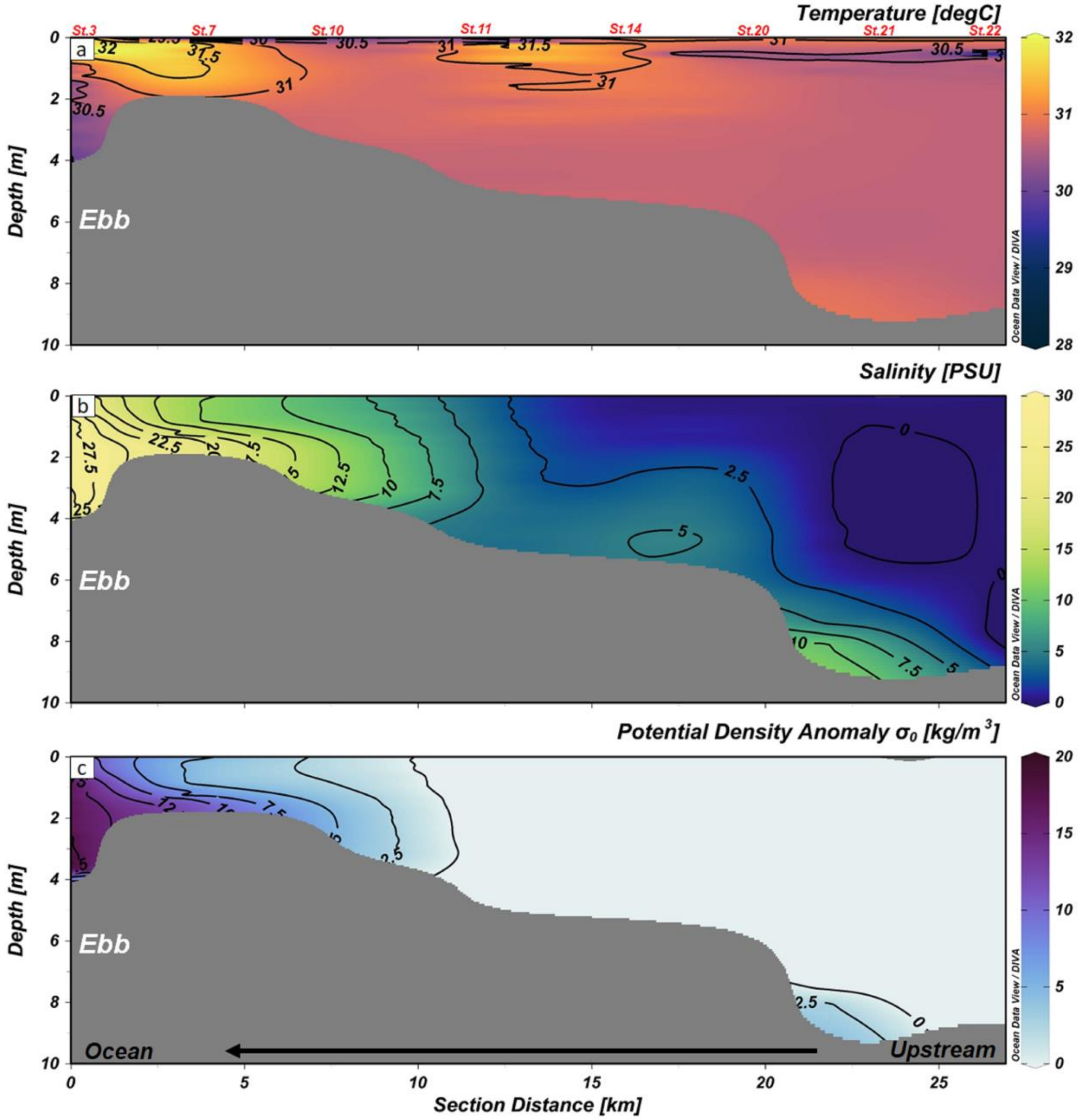

Figure 4. Cross section of (a) temperature (°C), (b) salinity (psu), and (c) potential density anomaly (kg.m^3) in Musi Estuary during ebb condition (7th September). The grey pattern in the bottom of the layer represents batymetry and the distance starts measuring from the Ocean to Upstream.

mouth with tight contours. This condition indicates a decrease in the density value when the mass of sea water enters the river due to the weak tidal currents so that the sea water is unable to reach further towards the river. The density at ebb is stuck at the mouth of the river estuary when it starts to enter the middle of the river. Meanwhile, the isopycnal gradient at flood looks more tenuous. This is due to the strong tidal forces that bring water with a high salinity character from the sea to the mid-river area (Guenther & MacDonald, 2012).

The cross-distribution of density along the transect from upstream to the sea tends to follow the pattern of salinity

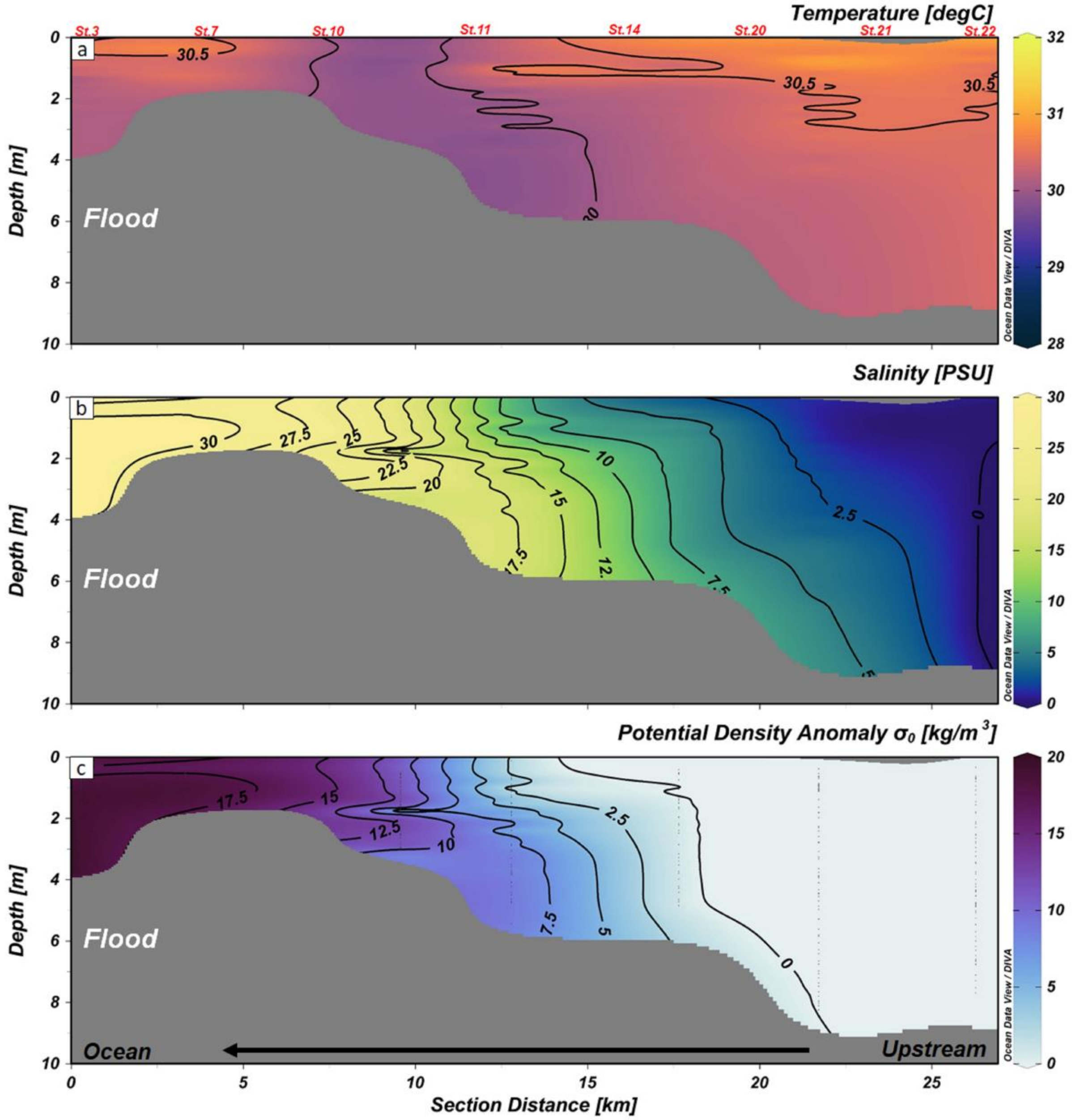

Figure 5. Cross section of (a) temperature (^{o}C), (b) salinity (PSU), and (c) potential density anomaly (kg.m^{3}) in Musi Estuary during flood condition (4th September). Grey pattern in the bottom of layer represents batymetry and the distance starts measuring from the Ocean to Upstream.

distribution. This condition occurs because the distribution and density values in the mouth of the Musi River are strongly influenced or controlled by the salinity value. Circulation in the estuary region forms a vertical salinity (density) gradient stratification that can be stronger than the temperature stratification in lakes and oceans. When the flow enters the river and the value of the salinity gradient increases, so does the intensity of the density stratification that forms a pattern of a certain type of estuary. Given the strength of the fresh water discharge relative to the tides, a partially mixed estuary type will be formed (Geyer & MacCready, 2014). The former is characterized by a high vertical thermal stratification, with a decrease in temperature starting from the surface downwards. Temperature is the main driver of density distribution along the entire water column.

3.3. Spatial Characteristic of Water Mass

Figure 6 shows the distribution of temperature, salinity and density spatially at ebb. The temperature distribution from the river to the sea has a fairly large range, 27.13 - 33.97 ⁰C. In estuaries tides are the main force of water circulation. According to the tidal regime, the inflow and outflow of water are unidirectional along the water column (Biguino *et al.*, 2021). This is related to the variability of temperature and salinity. The distribution pattern formed is not linear, the temperature in the estuary mouth area is lower than in the upstream and sea areas. The distribution of salinity formed shows the mass of seawater dominating the front of the estuary which is indicated by high salinity values. The salinity value decreases with increasing distance from the sea. The salinity value got weaker when it arrived upstream at 0.052 psu. The salinity distribution pattern formed is directly proportional to the density pattern, which means that variations in salinity control the water mass density in the Musi estuary. Low salinity in the upstream area is characterized by lighter water mass and heavier water mass in the estuary mouth and sea area characterized by increasing salinity values.

The water temperature variability in the estuary is also strongly influenced by tidal exchange (Biguino *et al.*, 2021). The estuary of the Musi River is strongly influenced by tides because it can be seen from the distribution pattern of the water mass that follows the tidal cycle. At high tide the salinity is high and at ebb tide the salinity is low. At flood (Figure 7) the temperature in the river is higher than the sea, while the estuary area has the lowest temperature, which is 27.44 ⁰C. The salinity distribution due to the influence of tide causes high salinity to enter deeper into the estuary than during ebb. This condition can be seen in the 15 psu salinity gradient which is outside the mouth of the estuary at ebb and enters the estuary approaching the Payung island at flood. The increasing water mass density in the Musi estuary at flood also confirms the increase in the salinity value at that location.

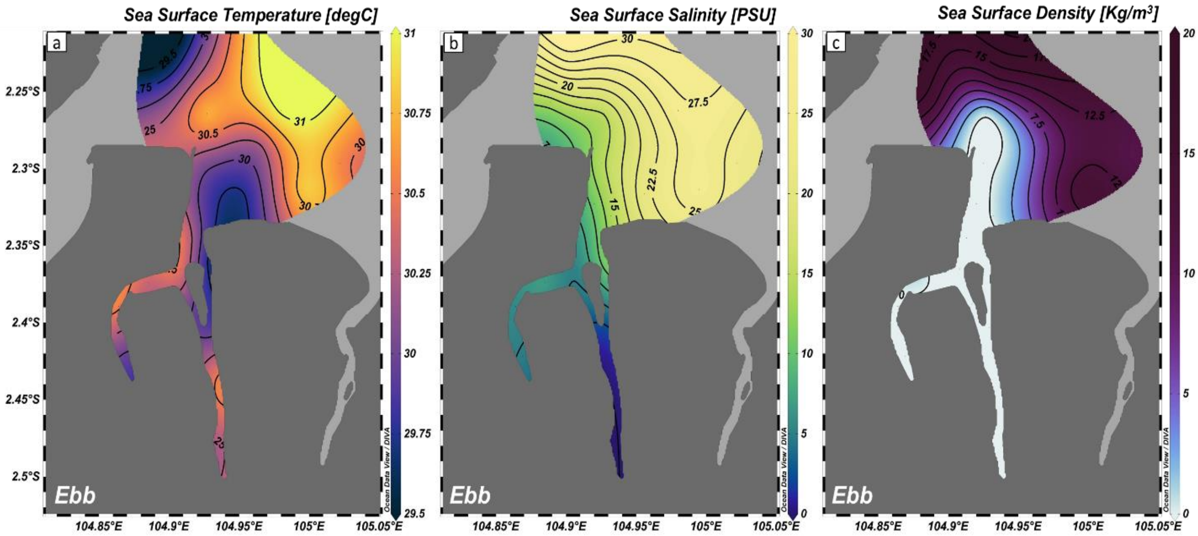

Figure 6. Spatial distribution of (a) temperature (b) salinity, and (c) density in Musi Estuary in ebb conditions.

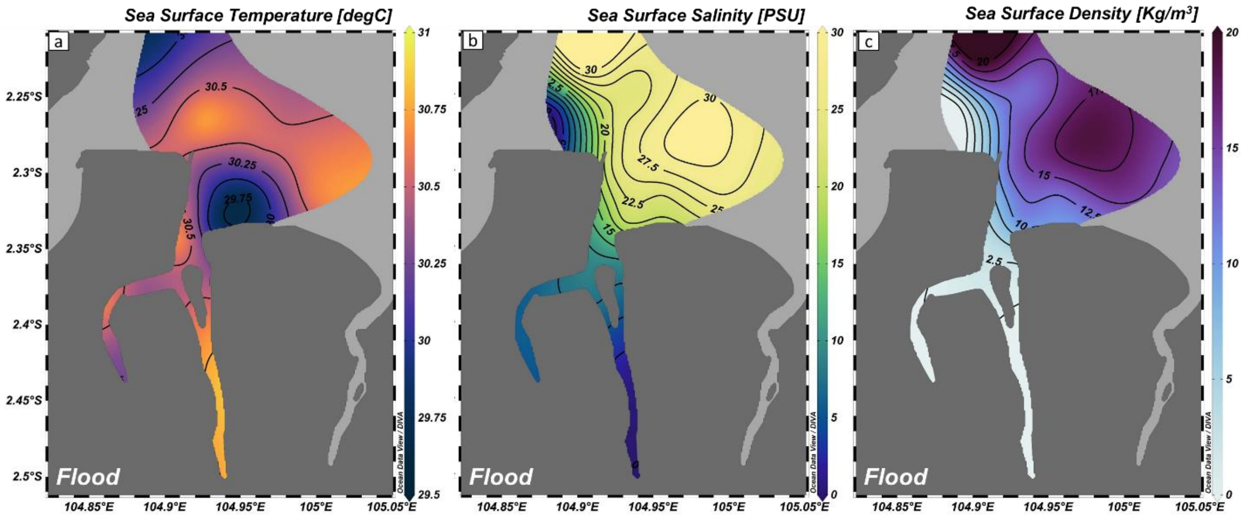

Figure 7. Spatial distribution of (a) temperature (b) salinity, and (c) density in Musi Estuary in flood conditions.

3.4. Salinity Zone Classification

The mixing of freshwater and seawater causes vertical movement of water masses. This is influenced by variations in temperature and salinity in the waters. The mass of water with low density is above sea water of high density. The effect of salinity on water mass density is more dominant than the temperature in estuary Musi as indicated by the presence of salinity stratification, while the vertical temperature gradient did not change significantly. Salinity variations can provide an overview and physical spatial patterns and variability over time in estuaries. Changes in salinity values are categorized into four zones by Supriatna *et al.* (2018) based on organisms living in the estuary and three zones by Geawhari *et al.* (2014) based on the characteristics of the vertical gradient of salinity.

Based on the observations in this study, we divided the area of the Musi estuary, which lies between the mouths of the Banyuasin and Upang rivers with a length of 25 km upstream from the estuary, into three zones based on the distribution of salinity gradients. Based on the variation of salinity in the Musi estuary, we propose three salinity zones which can be seen in Figure 8. The identified zones starting from the Musi river are at station 23 (Figure 1), the Musi estuary to the sea. Zone 1 is dominated by tides located from the mouth of the estuary to the sea with a high salinity range starting from >18 - 30 psu. The vertical gradient of salinity formed is quite dense, that is, low salinity is on the surface and increases with increasing depth. The push of water mass entering from the sea brings high salinity to the mouth of the estuary which causes the density of the water mass to increase. This zone is categorized as a polyhaline zone, which is the outermost zone in the Musi estuary. Hydrodynamics in estuary waters is a complex condition due to the interaction between fresh water from rivers and coastal waters from ocean waves (MacDonald *et al.*, 2013; Horner-Devine *et al.*, 2015). Hydrodynamics in estuary waters is a complex condition because of the interaction between freshwater from rivers and coastal waters from ocean waves. In the estuary area there may be significant cross-coastal currents and substantial mixing (Horner-Devine *et al.*, 2015).

Zone 2 is identified as being around the branch of Payung Island. This zone extends from the Musi and Telang rivers to the estuary with a distance of 10.48 km and 19.20 km. Zone 2 is formed longer than the

Telang river, which is thought to be due to the curving topography of the Telang river so that the water masses do not easily mix. The spatially large distribution of salinity formed in this zone has a large range, > 5-18 psu categorized as a mesohaline zone. The vertical salinity gradient indicates the presence of discharge pressure against tides both at flood and ebb. Zone 3 is identified as predominantly fresh water with a very low vertical salinity gradient. This zone is located on the Musi River (Station 23) until it meets Payung Island with a total distance of 13.75 Km. This zone is formed when the salinity is 0.5 - 5 psu which is categorized as the olygohaline zone. Data collection during flood and ebb conditions has a time gap of about 4 hours. With the time gap in CTD data collection, temperature and salinity transformations are not observed comprehensively. However, with the taking still with the same phase period, both flood and ebb, the temperature and salinity characteristics can still be seen quite clearly. There is a fairly homogeneous variation of salt (saltier) at the mouth of the river near the ocean and salinity stratification whose intrusion is strongly influenced by tides. Stratification in these waters has been observed mainly in the circulation near the outflow of rivers and the shifting of onshore/offshore plumes due to wind and tides (Kelsey-Wilkinson, 2014; Cole & Hetland, 2016).

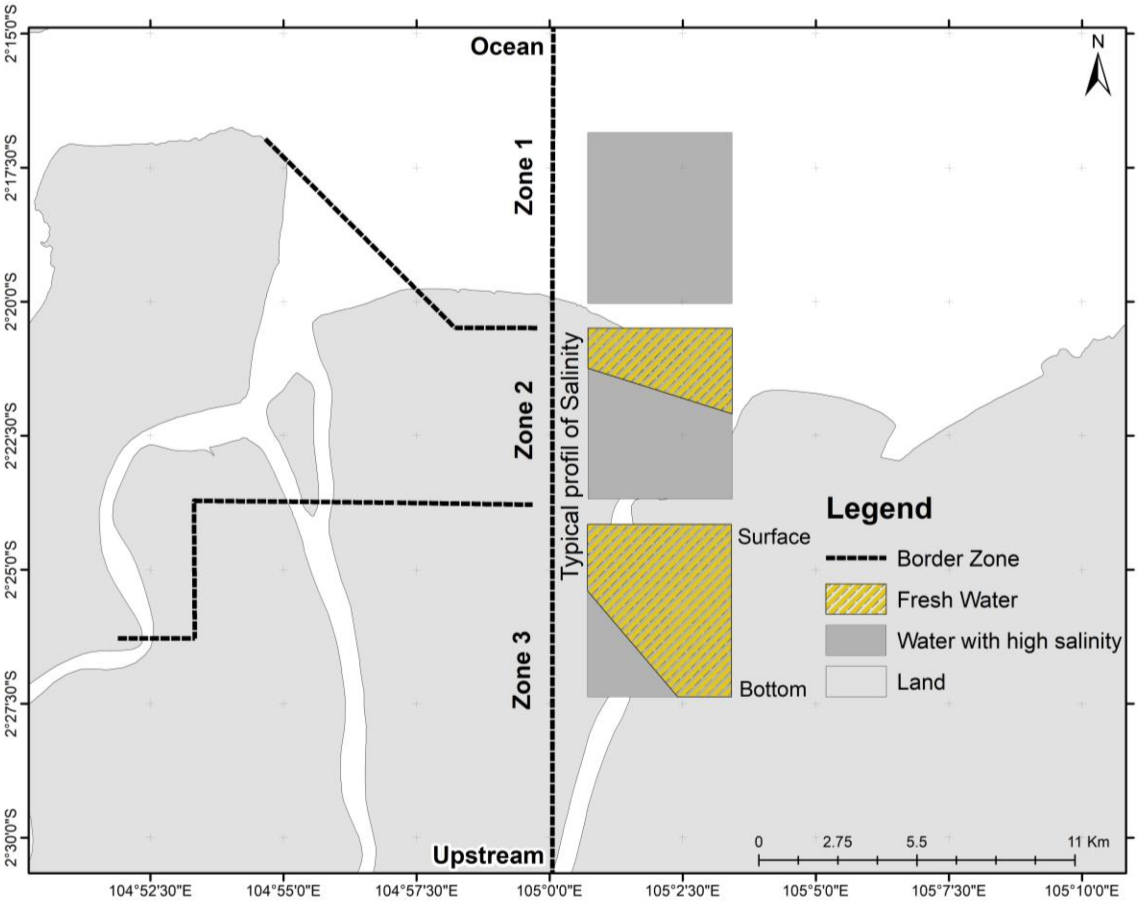

Figure 8. The salinity zone of the Musi Estuary is based on the vertical gradient of salinity, with the typical salinity profiles for each zone. There are three zones: zone 3 is in the upstream area dominated by fresh water, zone 2 is in mid-estuary having stratification dominated by seawater in the bottom layer, and zone 1 starts in the mouth estuary dominated by high salinity.

3.5. T-S Digrams at Flood and Ebb

The TS diagram of the polyhaline zone (Figure 9c) shows a different pattern between flood and ebb. It has a wider distribution at low tide than at high tide, both the temperature and salinity values. At low tide, the temperature values ranged from 33.1 C - 29.6 ºC, salinity values ranged from 29 - 18 psu. Meanwhile, at high tide, the water mass has a salinity value range between 29.5 - 21.5 psu and a temperature value between 30.75 - 27.5 ºC. The characteristic difference between the mass of sea water and mass of fresh water is visible. Seawater masses have high salinity characteristics with low temperatures and freshwater masses have low salinity characteristics with high temperatures. The distribution of salinity and temperature in river areas with the estuary partially mixed type is influenced by tidal dynamics, bathymetry, and discharge. Freshwater discharge from rivers strongly influences the length of the intrusion range. These waters also have a lower density and carry a large amount of dissolved and suspended river material. These clumps also contribute to horizontal redistribution over long distances (Slinger, 2017). The spread and impact of estuary material along the coast and overshelf depends on the inertial interaction of the outflow (Jovanovic *et al.*, 2019). A plume estuary is a river flow that can be observed directly near the mouth of the estuary with a significant color difference between the estuary and adjacent marine waters (Mendes *et al.*, 2016).

In the mesohaline zone (Figure 9b) the flood and ebb have similar temperature characters ranging from 29.75 to 31 ºC with a maximum value at ebb in the temperature range of 31 ºC. The salinity has a significant difference in values, at flood the salinity range is 5 to 14.1 psu while at ebb it is between 5 to 18 psu. The salinity values at ebb are concentrated in a lower salinity range than at flood. At flood, the sea water mass with high salinity values enters the mesohaline zone with a high concentration reaching a value of 18 psu. Meanwhile, at ebb, salinity distribution does not reach its maximum value because freshwater masses dominate the mesohaline zone. Several stations are included in the mesohaline zone in the middle. These stations are located on a winding river route and there is a significant difference in salinity values. The mesohaline zone has a significant effect on the salinity distribution.

According to Akter (2021), silting in estuaries and river bends significantly

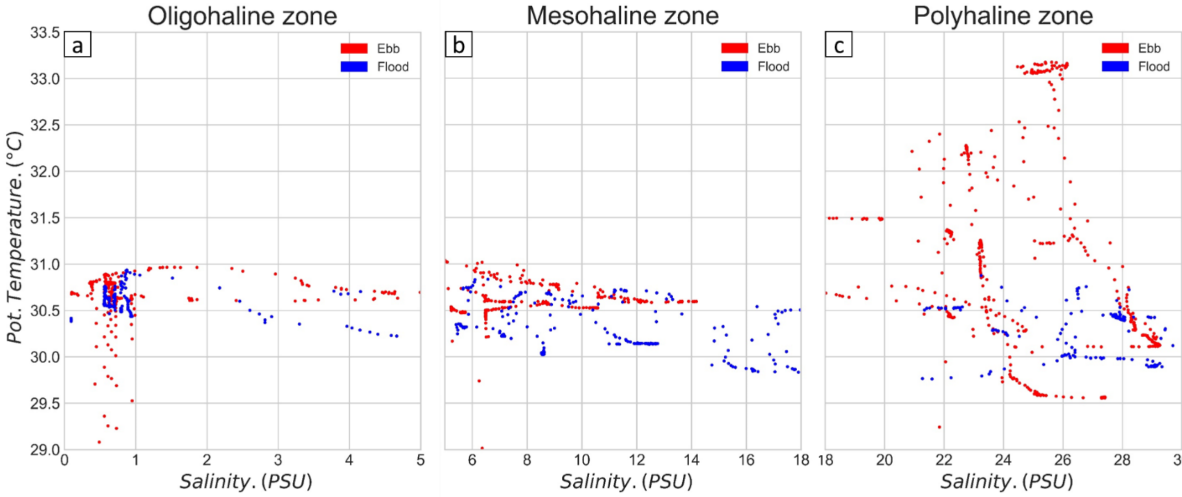

Figure 9. Diagram T-S (a) olygohaline zone (b) mesohaline zone, dan (c) polyhaline zone. The red dot represents ebb time and blue dot represent flood time.

reduces salinity values when heading upstream. Tidal asymmetric effect influences the salinity dynamics in the estuary. In this study, the tidal pattern has a significant effect on decreasing salinity values. The major contribution of this tide is dominated by the movement of water masses in and out of the estuary area. The asymmetric effect of the tide causes the dynamics of salinity exchange when the tide has a higher salt flux than at ebb and as a control for periodic salinity stratification. The olygohaline zone (Figure 9a) is a zone that classifies areas with minimum salinity values. The mass characteristics of sea water and fresh water have the same distribution of salinity values. The distribution of temperature values at a salinity of 2.5 to 5 psu has little difference between at flood and ebb. At flood the temperature has a lower value than at ebb. The olygohaline zone still has tidal influence but is not as strong as the polyhaline and mesohaline zones. Tidal circulation has a significant contribution to salt transport to land in deeper channels (Wei *et al.,* 2016)

IV. CONCLUSION

Tides play an important role in the exchange of water masses in the estuary Musi. The bathymetry influence between Musi river, which is deeper than the Musi estuary, shows the presence of high salinity water masses that are trapped and difficult to dilute both at flood and ebb. The TS diagram shows the salinity character which is visualized based on the identification zone of the salinity distribution value. There are three zones of salinity identified in the Musi estuary, zone 1: olygohaline which is dominated by low salinity, zone 2: mesohaline, which is indicated by strong salinity stratification and zone 3: polyhaline which is characterized by high salinity and is outside the mouth of the estuary.

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