20200604_IJARET_11_05_044.pdf

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International Journal of Advanced Research in Engineering and Technology (IJARET)
Volume 11, Issue 5, May 2020, pp. 420-431, Article ID: IJARET_11_05_044
Available online athttp://www.iaeme.com/IJARET/issues.asp?JType=IJARET&VType=11&IType=5
ISSN Print: 0976-6480 and ISSN Online: 0976-6499
DOI: 10.34218/IJARET.11.5.2020.044

NUMERICAL MODELING OF WATER MASS STRUCTURE DISTRIBUTION AT THE ESTUARY JENEBERANG RIVER, MAKASSAR

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ABSTRACT

This study aims to model the distribution pattern and stratification of water mass structures by the influence of hydrodynamics using a two-dimensional numerical model. Data recording was performed in spring tide and neap tide conditions for 18 days at the Stuary Jeneberang River in Makassar. 2D numerical models with flexible mesh bases are used in this study. This model can configure the coastline and bathymetry and applied in the estuary. Model validation shows the error rate of water level elevation at stations 1 and 2 of 2.26% and 5.47%. Likewise, the model validation of the measurement results of current, u-velocity of 9.7% and v-velocity of 4.8%. The simulation results show the pattern of salinity and temperature distribution follows the flow pattern so that it affects the distribution of the structure of water mass in the estuary waters of the Jeneberang River. The interaction that occurs between the mass structure of water with the hydrodynamic factor results in a moving current carrying a number of water masses, namely salinity and temperature. Well-mixed occurs at a distance of 400 m - 1000 m from the mouth of the estuary.

Key words: Spring tide, neep tide, numerical modeling

Cite this Article: Riswal Karamma, Muhammad Saleh Pallu, Muh. Arsyad Thaha and Mukhsan Putra Hatta, Numerical Modeling of Water Mass Structure Distribution at the Estuary Jeneberang River, Makassar, *International Journal of Advanced Research in Engineering and Technology (IJARET),* 11(5), 2020, pp. 420-431.
http://www.iaeme.com/IJARET/issues.asp?JType=IJARET&VType=11&IType=5

1. INTRODUCTION

In planning the development of coastal areas need to pay attention to various factors such as wind, currents, tides, river mouths, erosion, abrasion, sedimentation, and so forth [1][2][3]. Coastal waters around the Jeneberang River estuary are areas that have long been used by surrounding communities for transportation, fisheries and so on. These waters are transitional areas between the mainland and the high seas, so there is interaction between the two [3]. The existence of the Jeneberang River which empties into the coast of Makassar City has an important role in the supply of raw water, shipping and flood control Makassar City and Gowa Regency. Estuary condition are very dynamic due to influences such as river currents and strong sea tides, thus affecting the pattern of circulation flow, salinity, the level of mixing of salt water and fresh water and sedimentation [4][5][6][7][8][9][10]. This of course affects the process of mixing and shifting density in the layers of the water column. The value of electrical conductivity will vary greatly depending on tidal strength and river discharge [11]. Efforts to determine the dynamics of the waters about the distribution of salinity caused by the effects of tides and river physical parameters can be brought closer to numerical modeling [12][13][14]. Models can provide a picture of the real system to help approach the situation that occurs in nature and solve a problem [15][16]. Equations that describe streams in rivers, estuaries and bodies of water are based on the concepts of conservation of mass and momentum. 2D horizontal flow equation depth averaged is derived by integrating the three-dimensional equation of mass transport and momentum with respect to the vertical coordinates from the base to the surface of the water, assuming that vertical velocity and acceleration are ignored and the salinity concentration is the same for each depth (two-dimensional flow averaging depth by the finite element method)[8][15][16]. 2D flexible mesh numerical model with flexible mesh base provides easy settlement in configuring coastlines and bathymetry. 2D incompressible Reynolds numerical solutions on the average *Navier-Stokes* equations consist of the basic equations of conservation of mass and conservation of momentum[8], temperature, salinity and density, at 2D settlement using sigma coordinate transformation used in this study, which aims to model the distribution pattern of water mass structures with 2D numerical models [13][17][18] at the Jeneberang River estuary and see the effect of hydrodynamics on the distribution and stratification of water mass structures.

2. METHOD

2.1. Research Location and Time

The location of the study was conducted at the etury of the Jeneberang River, located at the coordinates of the UTM 50S UTM 763000 mE – 767000 mE and 9426000 mS (figure 1). Data was collected on October 26, 2019 - November 10, 2019.

Figure 1 Domain of the area of measurement investigation, estuary of the Jeneberang Rive

2.2. The Tools used

Research survey investigation instruments are equipment including hardware and software used in research. These instrument sets include acoustic devices, electrical sensors, hardware, and software, used to acquire data, extract data, filter data, to display multiple graphs of display results and support the implementation of research activities. Investigation instruments needed for research studies shows in table 2.

Table 2 Instrument sets for carrying out the Jeneberang River research survey investigation**.**

No.	Nama Alat	Ketelitian	Satuan	Use
1	ADCP (*acoustic doppler current profile) Argonaut SonTek XR*	0.01 *cm/det*	*cm/det*	Acoustics are used for measurements of tidal currents, wave height, water base temperature.
2	*Tide logger RBR Virtuoso*	0.01 *cm*	*cm*	Recording changes in water level elevation
3	*Echosounder* 0.1 *mGarmin 585 map*		° ' "	Rating depth
4	CTD	-	-	Salinity, Density and Temperature waters profile data recording

2.3. Flow Speed Data Retrieval

Retrieval of water flow data by eulerian method. Measurement using ADCP Argonaut SonTek XR with 0.75 mhz wavelength *sensor beam* and *autonomous multi-cell system*. The Euler method is the working principle of ADCP in measuring currents with the concept of following the motion of water particles by firing a *single beam* at a certain depth with the arranged layer division. ADCP Argonaut SonTek XR at each location is placed at a depth of ± 3.6 meters for station 1 and forms an angle to the upright axis of 20o upwards and forms a Cartesian coordinate system of current components in the direction u (west-east / E), v (north-south / N), and z (vertical water column / U). The location of the ADCP (*acoustic rural doppler current profile*) Argonaut SonTek XR is as follows.

Table 3 Coordinates of current measurement locations

No.	Nama	Koordinat Lokasi	Kedalaman	Layer
1	ADCP St.1	765587.163 9425503.83	±3.6 m	0,8 m /layer, 3 layer
2	ADCP St.2	766610.002 9425445.39	±2.7 m	0,8 m /layer, 3 layer

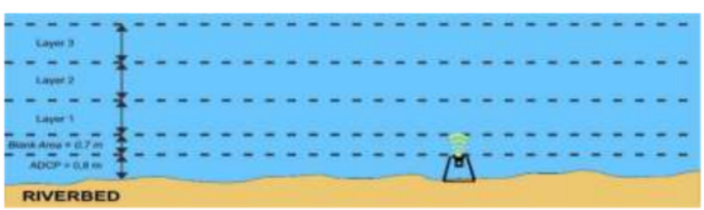

Figure 2 Sketch of layer division on ADCP performance

Current measurements at 3 layers of depth each layer has a distance of 0.8 meters. The current recording interval is 10 minutes with the recording time at the location is 360 hours. This tool uses acoustic waves emitted through a transducer that propagates along the water column, in a layer of water whose current velocity is measured, the waves will be reflected back towards the transducer. According to Poerbondono and Djunasjah (2005) the *Doppler effect* is the phenomenon of equality of changes in the frequency of a sound with changes in the speed of the sound source [19]. According to Gordon (1996) in Poerbondono and Djunasjah (2005) ADCP terminology, the layers of water measured along the measurement column are called bin, while the thickness of the column is called *ensemble* [19][20][21][22].

2.4. Measurement of Water Mass Structure

Measurement of the water mass structure at a specified station using 2 units of CTD as shown in table 2. Data obtained from the CTD measurement results are downcast data that is the measurement of the profile when the CTD is lowered to depth, the acquisition of CTD data is done with a logger interval is per 0.1 meter. Data that can be acquired in measurements using CTD devices are temperature (^{o}C), salinity (PSU), depth (m), pressure (PSI), density, sound velocity (m/s) and some technical requirements such as power.

Table 2 Coordinate point of salinity and temperature measurement

NO	Stasiun	Koordinat		Interval Sampling (m)
		X	Y	
1	ST - 01	764201.537616	9425558.346350	0.10
2	ST - 02	764200.061688	9425460.992690	0.10
3	ST - 03	764196.429911	9425380.242480	0.10
4	ST - 04	764842.201038	9425440.868740	0.10
5	ST - 05	764841.355094	9425510.572590	0.10
6	ST - 06	764839.387416	9425576.961580	0.10
7	ST - 07	765435.091652	9425595.730680	0.10
8	ST - 08	765450.226475	9425491.675200	0.10
9	ST - 09	765462.092313	9425403.121170	0.10
10	ST - 10	766050.486790	9425541.399900	0.10
11	ST - 11	766061.851341	9425613.270730	0.10
12	ST - 12	766072.123487	9425689.571190	0.10
13	ST - 13	766694.797895	9425506.868040	0.10
14	ST - 14	766671.240051	9425437.256130	0.10
15	ST - 15	766650.988723	9425362.099790	0.10
16	ST - 16	767149.521149	9425203.096610	0.10
17	ST - 17	767167.478856	9425258.347000	0.10
18	ST - 18	767186.583702	9425323.550410	0.10

2.5. Tide Recorder

Tide recording for 360 hours with sample intervals of 5 minutes, and depth variations ranging from 0 - 3 meters, at 2 measurement stations on the Jeneberang River, Makassar. Recording is done by Virtuoso loggerRBR instrument which is placed along with the ocean current recording device. The laying of the RBR Vituoso tide logger is located ± 150 meters from the coastline, and the distance between station 1 and station 2 is recording tidal data logers as far as 950 meters. It runs from 26 October 2019 - 10 November 2019.

2.6. Bathymetry

Bathymetry targeting aims to determine the basic shape of the estuary in the area of the water area from the downstream of the Jeneberang river dam to the outer area of the Jeneberang river estuary with the measured area in the outer area of the river mouth is 1 km2. Bathymetry data retrieval is performed with the Garmin Echo Sounder 585, as shown in figure 3.

Figure 3 Bathymetric investigations using the Garmin Echo Sounder 585 and transducer

2.7. Hydrodynamic Model

2D flexible mesh numerical model is a numerical settlement model with a flexible mesh base with ease of completion and advantages in configuring coastlines and bathymetry. The completion of this numerical calculation can be applied to oceanographic, beach and estuary environmental studies. The numerical solution of 2D incompressible Reynolds on the average Navier-Stokes equation which consists of the basic equations of mass conservation and conservation of momentum, temperature, salinity and density, on 2D settlement using sigma coordinate transformation. Given the following equation for 2D settlement [23]. The equation of continuity is given:

$$\frac{\partial h}{\partial t} + \frac{\partial h\vec{u}}{\partial x} + \frac{\partial h\vec{v}}{\partial y} = hs \quad (1)$$

And the two momentum horizontal equations for the component x and component y are:

$$\frac{\partial h\vec{u}}{\partial t} + u\frac{\partial \vec{u}}{\partial x} + v\frac{\partial \vec{u}}{\partial y} = F_{\vec{v}h} - gh\frac{\partial \eta}{\partial x} - \frac{h}{\rho_0}\frac{\partial \rho}{\partial x} - \frac{gh^2}{2\rho_0}\frac{\partial \rho}{\partial x} + \frac{\tau_{sx}}{\rho_0} - \frac{\tau_{bx}}{\rho_0} + \frac{1}{\rho_0}\left(\frac{\partial s_{xx}}{\partial x} + \frac{\partial s_{xy}}{\partial y}\right) + \frac{\partial}{\partial x}(hT_{xx}) + \frac{\partial}{\partial y}(hT_{xy})\ hu_s s \quad (2)$$

$$\frac{\partial h\vec{v}}{\partial t} + u\frac{\partial \vec{v}}{\partial x} + v\frac{\partial \vec{v}}{\partial y} = -F_{\vec{u}h} - gh\frac{\partial \eta}{\partial y} - \frac{h}{\rho_0}\frac{\partial \rho}{\partial y} - \frac{gh^2}{2\rho_0}\frac{\partial \rho}{\partial y} + \frac{\tau_{sy}}{\rho_0} - \frac{\tau_{by}}{\rho_0} + \frac{1}{\rho_0}\left(\frac{\partial s_{yx}}{\partial x} + \frac{\partial s_{yy}}{\partial y}\right) + \frac{\partial}{\partial x}(hT_{xy}) + \frac{\partial}{\partial y}(hT_{yy})\ hv_s s \quad (3)$$

Where the settlement indicates the value of the average depth, where $\vec{u}$ $\vec{v}$ is the velocity at the average depth given by:

$$h\vec{u} = \int_{-d}^{\eta} u dz, \qquad h\vec{v} = \int_{-d}^{\eta} v dz \quad (4)$$

η is the water level elevation; $h = \eta + d$ is the total depth of the waters; $f = 2\Omega sin\phi$ is the Coriolis parameter; g is the acceleration of gravity; ρ is the density of water; ρ_0 is the density at the initial conditions; s is magnitude discharge; τ_{sx}, τ_{sy} is surface stress in the x and y directions; τ_{bx}, τ_{by} is basic stress in the x and y directions; u_s, v_s is velocity in ambient water conditions. The lateral stresses T_{ij} include viscous friction, turbulent friction and differential advection. They are estimated using an eddy viscosity formulation based on of the depth average velocity gradients.

$$T_{xx} = 2A\frac{\partial \bar{u}}{\partial x}, T_{xy} = A\left(\frac{\partial \bar{u}}{\partial y} + \frac{\partial \bar{v}}{\partial x}\right), T_{yy} = 2A\frac{\partial \bar{v}}{\partial y} \quad (5)$$

Integrating transport equations for salt and temperature over depth the following two-dimensional transpoert equations are obtained. Where $\bar{T}$ and $\bar{s}$ is the depth average temperature and salinity

$$\frac{\partial h\bar{T}}{\partial t}+\frac{\partial h\bar{u}\bar{T}}{\partial x}+\frac{h\bar{v}\bar{T}}{\partial y}=hF_T+h\hat{H}+hT_sS \tag{6}$$

$$\frac{\partial h\bar{s}}{\partial t}+\frac{\partial h\bar{u}\bar{s}}{\partial x}+\frac{h\bar{v}\bar{s}}{\partial y}=hF_s+hs_sS \tag{7}$$

3. RESULTS AND DISCUSSION

3.1. Validation Analysis

The results of the validation analysis of 2D flexible mesh numerical modeling can be seen in Figure 4 and Figure 5. The RMSE (root mean square error) calculation results show the magnitude of the model error on tidal measurement / recording at station 1 is 2.26%, and station 2 has an error rate of 5.47%. The magnitude of the error value of the value of current measurement and 2D mesh flexible numerical modeling results, for each component of the current, *u-velocity* 9.7% and *v-velocity* 4.8%.

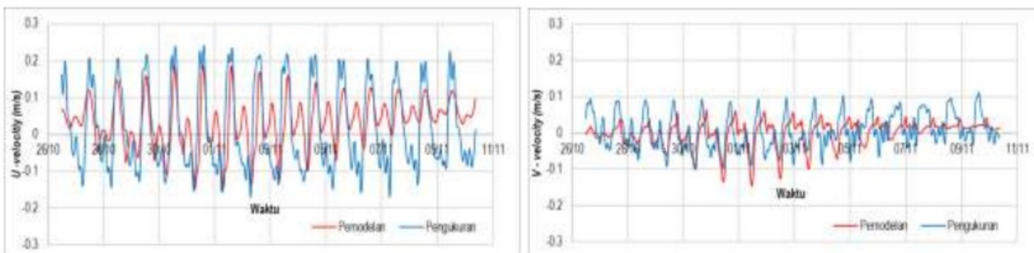

Figure 4 Validation analysis graphs of u-velocity and v-velocity, velocity components modeling and recording at the Jeneberang River location, Makassar

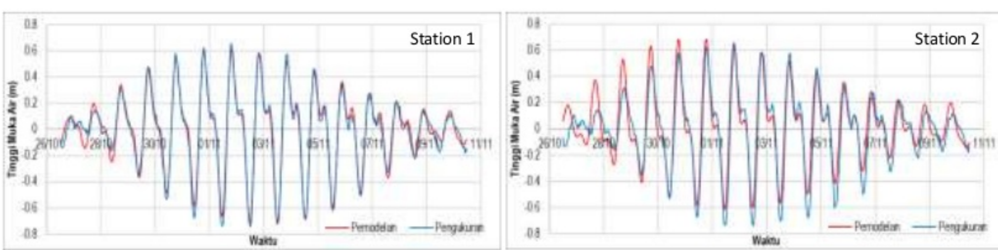

Figure 5 Graphic analysis of water level elevation validation on modeling and measurement at the Jeneberang River location, Makassa

3.2. Bathymetry Analysis

The results of bathymetry data analysis of the maximum depth are -6.5 meters located in the downstream of the weir and the Southwest coast waters the mouth of the Jeneberang River. The average depth of the Jeneberang River ranges from -2 meters to -4 meters. The most dominant depths are located in the north along the Jeneberang River. Seeming is happening at the mouth of the Jeneberang River, with depth in the mouth of the Jeneberang River ranging from -0.5 meters to -1.5 meters. The depth contours of the Jenenang River can be seen in Figure 6.

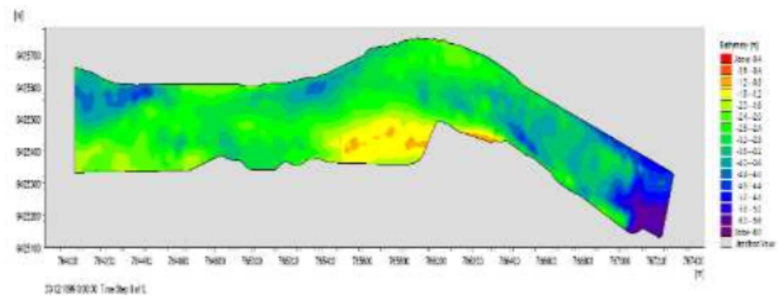

Figure 6 Bathymetry of the results of a triangular flexible mesh interpolation, the Jenebarang River model domain dengan range kedalaman 0 hingga -0.6

3.3. Flow Modeling

Based on the results of modeling in the Jeneberang River estuary waters, the maximum current velocity obtained is 0.33 m / s. The average current speed in the station 1 area is 0.15 m /s with a maximum speed of 0.30 m / s. The average current speed in the station 2 area is 0.17 m / s with a maximum speed of 0.33 m / s. The current movement at station 1 and station 2 at high tide is westward and the current at low tide toward tide is east. Modeling of currents in the neap tide and spring tide conditions are shown in Figure 11. When the elevation is low tide to high tide and when the tide is low tide to neep conditions, the maximum current speed ranges from 0.06 m /s - 0.2 m /s. The maximum current speed at elevation conditions is low tide to high tide and high tide to low tide, ranging from 0.06 m/s - 0.25 m/s.

3.4. Salinity Pattern Modeling Results

2D flexible mesh numerical modeling simulation is done with the salinity parameter as one of the components of water mass, with two time conditions, namely: the condition when the Janeberang River was dammed so that the fresh water salinity value (~ 0 PSU) still exists in the channel (t = 0), and conditions during the simulation after mixing along the Janebarang River canal, until spatial stratification along the river canal (t = 1). The condition t = 1 is the condition when the mass of water enters the upstream of the Janebarang River, so the salinity value is the same as the condition of the open waters in the Makassar Sea waters. The simulation is continued from t = 1 to t = n, so that it meets the existing conditions. Figure 7b and Figure 8b. shows at low tide to high tide with each spring tide and neap tide conditions. Salinity during the condition of t = 0 experiences the same conditions, causing trapping salinity in the upstream of the Janebarang River. At low tide to high tide conditions when the spring tide shows the salinity in the upstream area is 36.75 PSU - 37 PSU that moves in due to current transport from downstream to upstream (figure 13b). The same thing with lower magnitude is found in the condition of the elevation of the tide to the tide when facing the figure 8b. Tidal conditions are receding with events at spring tide and neep tide (figures 7a and 8a). Currents moving towards ebb make a number of current vectors indicate downstream movements that result in a number of salinity moving outward from the channel body of the Janebarang River, Makassar. Salinity with values ranging from 35 PSU - 36 PSU is located downstream of the Janebarang River. This is due to the force of transport that drives the mass of water to spread downstream of the Janebarang River canal, Makassar (figure 7a).

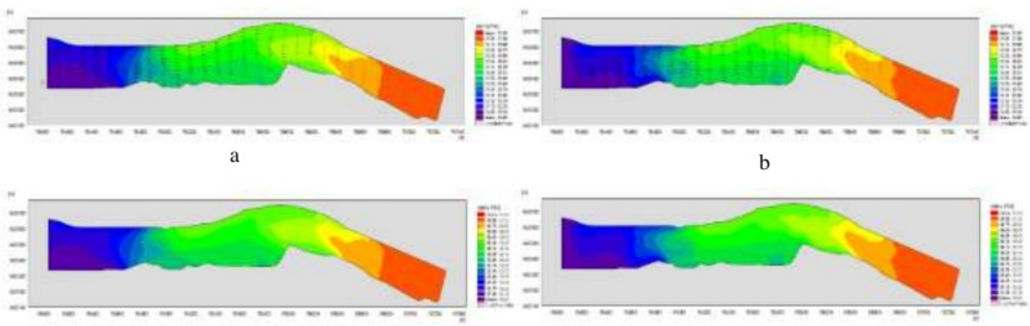

Figure 7. **(a)** Profile of the salinity distribution plot at t = 1 condition of tidal elevation to recede at spring tide. **(b)** The profile of the salinity distribution plot at t = 1 elevation conditions recedes towards the tide during spring tide. The top panel shows the current vector and the bottom panel is the salinity distribution

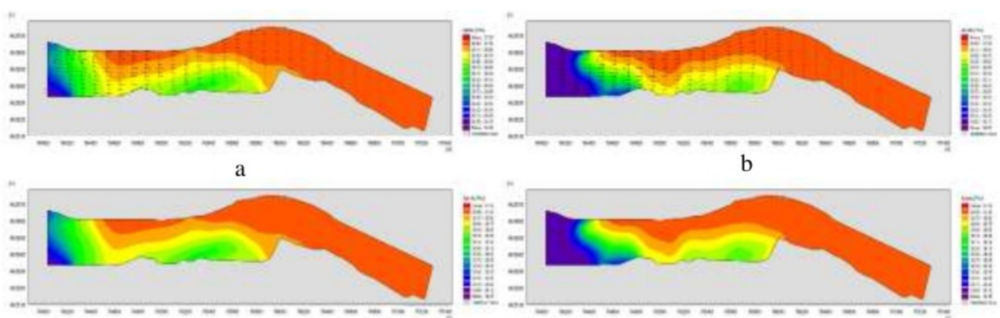

Figure 8. **(a)** The profile of the salinity distribution plot at time t = 1, the condition of the tide elevation to ebb when at tide. **(b)** The profile of the salinity distribution plot at t = 1 elevation conditions recedes towards the tide when neep tide. The top panel shows the current vector and the bottom panel is the salinity distribution

3.5. Pattern of Spatial Temperature Distribution Modeling Results

The results of the 2D flexible mesh numerical modeling simulation of the Janebarang River, Makassar are shown in Figure 9a - 9d which is the scenario of events at t = 1 is the event after equilibrium between the downstream and along the Janebarang River, Makassar for water temperature. Figure 9a shows the spatial temperature distribution under conditions of tidal elevation to ebb during spring tide. This condition shows the movement of the current at high tide to ebb carrying a number of masses of water including the temperature out of the river body, so that the downstream has a temperature variation of 30°C - 30.5°C. The upstream part still has a relatively higher temperature with a value of 31°C - 33°C. Figure 9b is the event of back momentum from high tide to low tide, that is receded to high tide. At low tide towards the tide the movement of current from downstream to upstream of the river carries a number of periods of water including temperature. Temperatures with variations of 30°C - 30.5°C begin to spread in due to the current vector impulse (Figure 9b). The middle part of the river begins to experience a mixture of water temperature indicated by the value of a short gradation of temperature 31.2°C - 31.4°C. Figure 15c-15d is a distribution spatial profile which refers to the temperature conditions in the waters of the Janebarang River in neep tide conditions. During high tide (figures 9a and 9c) the conditions at both the neep tide and spring tide have the same pattern, the difference is the magnitude of the velocity of the water moving period, shows the temperature moves towards the downstream with temperature variations in the downstream area is 29 ^{o}C - 30 ^{o}C, the upstream still has a higher temperature. Figures 9b and 9d are conditions at low tide to the tide. Current movement moves upstream. This results in temperatures below 29^{o}C coming from downstream moving into the waters due to the current transport force. Mixing layer can be seen in the temperature degradation section with a short area with a temperature variation of 30.9^{o}C - 31.5^{o}C.

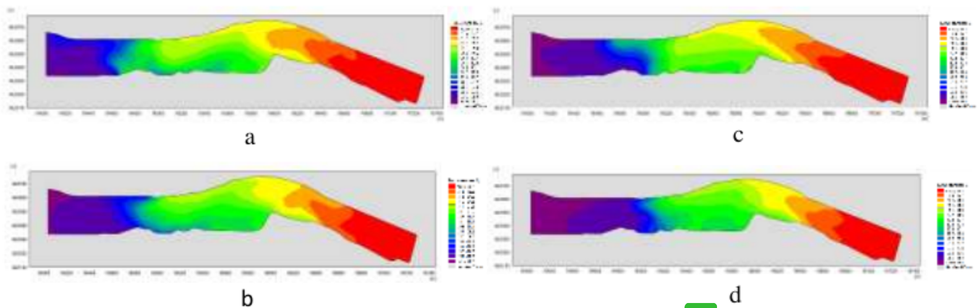

Figure 9. Plot profile of temperature distribution at t = 1 condition of spring tide and neap tide. The location of the Jeneberang River estuary **(a)** tide elevation to ebb during spring tide. **(b)** elevation recedes to high tide during spring tide. **(c)** tide elevation to low tide when unable to tide. **(d)** elevation recedes to high tide when steady

3.6. Stratification of Modeling Salinity

Horizontal distribution results (spatial dispersal) show stratification of salinity (water mass) results of 2D numerical modeling shown in Figure 10a and Figure 10b. Figure 16a is the result of a horizontal distribution with salinity stratification during high tide conditions showing three stratification points on S1, S2 and S3 from estuary to channel bodies on the Janebarang River. S1 is the salinity with values derived from the channel body is the result of mixing with incoming salinity, while S3 is the salinity from the mouth of the estuary. From these points, variations in salinity in elevated to receding conditions are known. Salinity stratification of S1, S2, and S3 appears to be displaced as shown in figures 10a and 10b. This condition shows the existence of lateral mixing (lateral mixing) can be seen in spatial distribution. One edge of the water has a higher salinity value compared to the other edge, this is also strengthened by the current vector. The middle part is an area of lateral mixing, lateral mixing induces horizontal residual circulation, leading to horizontal variations in estuary salinity (halocline) gradations as shown in Figures 10a and 10b.

The profile of vertical stratification is shown in Figure 10c and Figure 10d shows there are vertical variations at the time of tide to ebb and at low tide to tide. At high tide, the salinity varies vertically and starts to be pushed from the body of the river channel downstream. The salinity gradient with a value of 35.5 PSU starts to enter and salinity with a value of 35.0 PSU is approaching downstream. At a depth of 2m - 3m, salinity indicates a well-mixed layer, the high elevation direction of the river body places the water mass condition moving downstream of the Janebarang River channel, due to the progressive attenuation of the halocline line which shows the reciprocal relationship of tidal influences that are starting to increase. Vertical distribution profile (vertical stratification) for the receding tide, resulting in the movement of currents from the river mouth to the river body upstream of the Janebarang River. The current that moves in carries a certain amount of water mass, salinity. Vertical stratification was also seen to have a salinity range of 34.8 PSU - 35.6 PSU aimed at well-mixed.

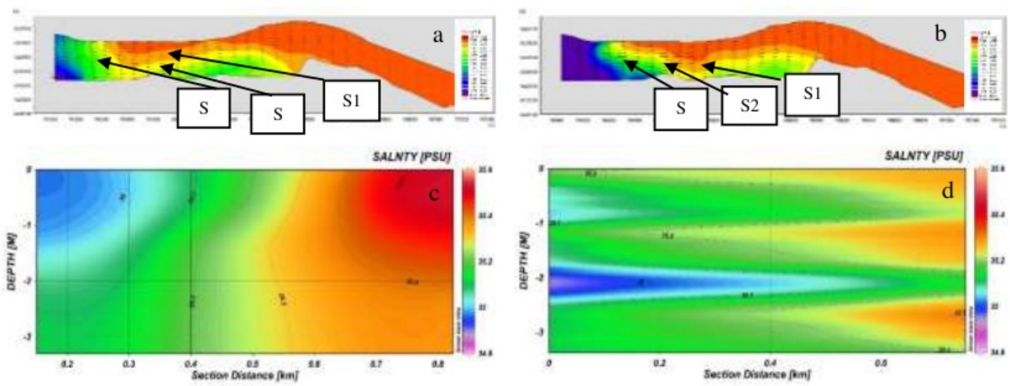

Figure 10. (a) The horizontal distribution of salinity stratification points at the surface layer at low tide conditions. **(b)** Horizontal distribution of salinity stratification points at the surface layer at low tide to tide conditions. **(c)** Profile of salinity vertical distribution in the stratification point area (s_1, s_2, and s_3) of the Janebarang River channel at high tide. **(d)** Profile of salinity vertical distribution in the stratification point area (s_1, s_2, and s_3) of the Janebarang River channel at low tide to high tide

4. CONCLUSION

Hydrodynamic modeling by applying the calculation of changes in temperature and salinity will affect the speed of the components that occur. The salinity and temperature equation functions will work on the momentum function in shallow waters, resulting in changes in water height and surface temperature directly proportional to changes in forces and salinity values.

This result shows that salinity starts to enter the river body to the part of the river that has deeper contours so that there is a mixture at the beginning in this section, the mass of water has a weight so that the vertical profile will dominate the waters with deeper contours. The basic friction force which is small due to depth causes the current to move bigger and faster. The frictional force acting on the fluid is inversely proportional to the mass transfer of water. The profile of the vertical mass distribution of water or vertical stratification at low tide to the tide shows the elevation of the water downstream quite high so that it causes the movement of currents from the river mouth to the river body upstream of the Janebarang River. The current that moves in carries a certain amount of water mass, salinity. Vertical stratification was also seen to have a salinity range of 34.8 PSU - 35.6 PSU aimed at well-mixed, this occurred at a distance of 400 m to 1000 m from the mouth of the estuary.

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