The Effect of Tides on Water Salinity and Acidity in the Main Channel of Anjir Serapat Lowland Irrigation Area, Central Kalimantan

S Revina[1] Istiarto[2,*] E P A Pratiwi[2]

[1] *Master Student, Department of Civil and Environmental Engineering, Universitas Gadjah Mada*
[2] *Department of Civil and Environmental Engineering, Universitas Gadjah Mada*
[*] *Corresponding author. Email: istiarto@ugm.ac.id*

ABSTRACT

Water salinity and acidity are two water quality parameters that are important for the success of crop cultivation in the Anjir Serapat Lowland Irrigation Area, Central Kalimantan. The interrupted tidal flow between Kapuas Murung River and the irrigation drainage system prevents fresh-saline water exchange. Tide is one factor determining the change in flow and water quality. This study aims to analyze the influence of tides in the Kapuas Murung River on pH and salinity in the main channel of the Anjir Serapat Lowland Irrigation Area. pH and salinity are measured simultaneously with the water level. Salinity, pH, and water level data were collected at Sta 0, Sta 10, and Sta 14 of the main channel during spring and neap tide for 27 hours. The effect of tides on pH and salinity at Sta 0 and Sta 14 is shown in the relationship between the rate of change of the water level to the rate of change of pH and salinity, and also the relationship between the slope of the water to the rate of change of pH and salinity. When heading towards the flood or the ebb, fresh water from the river can lower salinity and increase pH, and vice versa can also increase salinity and lower pH in the main channel. Changes in water level significantly influence only salinity at Sta 0, while changes in salinity at Sta 14 and changes in pH at Sta 0 and 14 are not so significant because other unmeasured variables affect pH and salinity. The pH quality of the freshwater source from the Kapuas Murung River is not much different from that of the water in the main channel. When mixing occurs, the pH change is insignificant. It is suggested to do further study of other factors that affect the pH and salinity of irrigation water in the main channel of Anjir Serapat Lowland Irrigation Area.

Keywords: Lowland irrigation, tidal effect, acidity, salinity

1. INTRODUCTION

The Ex Peatland Clearing (ex-PLG), which has an area of nearly 165,000 ha, is suitable for developing agricultural activities to support *The Food Estate* program. Improvement of water management and auxiliary channels and buildings is still needed to support agricultural activities. The ex PLG area includes freshwater tidal areas, although some parts include brackish tides[1]. Food security can be achieved if water is available at the right place, time, and water quality [2].

The development of agriculture in swamplands has various obstacles and problems [3,4]. Several aspects hinder the implementation of swamp development, including water aspects, include water management, floods, droughts, pH and salinity, soil aspects include pyrite, peat, weeds, nutrient-poor, socio-cultural aspects of the economy include settlements, marketing, cultivators, means of transportation, limited capital, isolation, and environmental aspects [4].

Anjir Serapat Lowland Irrigation Area (DIR Anjir Serapat) is one of the ex-PLG areas located in block D, which will be used as the location of *The Food Estate* program. DIR Anjir Serapat is located in Kapuas Regency, Central Kalimantan Province. DIR Anjir Serapat has a potential area of 17,609 ha, divided into a functional area of 10,115 ha and a potential area to be functionalized of 7,494 ha [5]. Anjir Serapat is the main channel in the DIR Anjir Serapat connects two major rivers, namely the Kapuas Murung River in Central Kalimantan Province with the Barito River in South Kalimantan Province, with a length of 28.5 km [6].

Good water quality is one of the requirements in the irrigation water supply. High salinity and acidity are fundamental problems in the Anjir Serapat Lowland Irrigation Area, Central Kalimantan. The interrupted tidal

A. D. Saputro et al. (Eds.): ICOSEAT 2022, ABSR 26, pp. 179–189, 2023.
https://doi.org/10.2991/978-94-6463-086-2_24

flow between Kapuas Murung River and the irrigation drainage system prevents fresh-saline water exchange is suspected to be the cause of this problem.

DIR Anjir Serapat utilizes rainfall for agricultural water supply. Rainfall is collected dan held using a sluice and opened during leaching. In the rainy season, the water is held in the "handil" to raise the water level in the channel so that it spills into the field. Handil comes from the Banjar language, a canal that supplies irrigation water from Anjir at high tide and drains irrigation water to Anjir at low tide.

In the use of rainfall, in higher areas, later pyrite in the channel will flow to a lower area, coupled with non-optimal tissue conditions, there will be spooling, and the water becomes retained longer, which results in a relatively lower pH so that in some lower areas the land becomes abandoned which eventually becomes shrubs. Water with a low pH cannot be used to irrigate irrigated land because it will affect the absorption of nutrients by plants [7]. The Factors that determine the flow change are the tides, the channel length, and the tidal pool [8].

This study aims to analyze the influence of the tides of the Kapuas Murung River on pH and salinity in the main channel of the Anjir Serapat Lowland Irrigation Area. The influence of tides entering the main channel is expected to increase the volume of fresh water, improving water quality in meeting water needs in irrigated land. Proper water supply management using tidal movements at high tide or rainwater is needed to meet water needs for washing and diluting acidity [9].

2. MATERIAL AND METHOD

2.1 Study Area

DIR Anjir Serapat is one of the lowland irrigation areas for former peatland development located in Block D of Kapuas Regency, Central Kalimantan. DIR Anjir Serapat, as seen in Figure 1, is spread across two districts, namely Kapuas Timur District and Bataguh District [10]

Figure 1 Location of Anjir Serapat Lowland Irrigation Area and Measurement Station (Source: Modified Open Street Map using QGIS)

Anjir Serapat, the main channel on DIR Anjir Serapat has a length of 14 km. The secondary channel/handil on the right of the system consists of 16 handils with lengths varying from 2.9 km to 7.8 km, while on the left, the system consists of 17 handils with lengths varying from 1.9 km to 7.7 km.

Plantations are the most extensive land use in the DIR Anjir Serapat, covering an area of 6852 ha (38.91%). Rice fields cover an area of 6167 ha (35.02%), spread over low land blocks around the Kapuas Murung River. Shrubs are relatively large land-use after rice fields, covering an area of 3769 ha (21.41%). Some of this area is thought to be a former rice field or field that was long abandoned, so it is now an abandoned land.

2.2 Data Collection

pH and salinity data are measured in conjunction with water level measurements in the rainy season. PH, salinity, and water level are measured at Sta 0, Sta 10, and Sta 14 in the main channel. Measurements on the neap tide condition were carried out on March 21-22, 2022, while the spring tide condition was carried out on March 28-29, 2022, for 27 hours, starting at 07.00 until 10.00 Central Indonesian Time on the next day. Instantaneous measurement of pH and salinity was also carried out on March 10, 2022, at 18 points (3 at the main channel point, 15 secondary/handil channel points to find out an overview of the pH and salinity at the site.

Water level measurement is carried out by reading the height of the water level on the staff gauge that has been installed at all three measurement points. The readings then need to be tied to the connective points around the site. The tie point is in the form of the nearest Benchmark (BM) stake, namely BM AJS 01, which is ± 0.70 km from Sta 0, BM AJS 05, which is ± 3.90 km from Sta 10, and Sta 14. pH and salinity measurements are carried out using measuring instruments in conjunction with water level readings. Every 27 hours, a water sample was taken at each measurement point and immediately recorded pH and salinity readings.

2.3 Data Analysis

The effect of tides on pH and salinity is shown in the relationship between the rate of change in water level per hour to the rate of change in pH and the rate of change in salinity per hour at Sta 0 and Sta 14 and the relationship between the slope of the water level per hour between Sta 0 and Sta 14 to the rate of change in pH and hourly rates of salinity change at Sta 0 and Sta 14.

The rate of change in the water level that is positive indicates the condition toward the flood tide, while the rate of change in the water level that is negatively valued indicates the condition towards the ebb tide. A positive water level slope indicates a flow supply to the channel, while a negative slope indicates an outflow towards the river. The rate of change in pH and salinity that is positively valued indicates an increase in pH and Salinity, while the rate of change in pH and salinity that is negatively valued indicates a decrease in pH and salinity.

3. RESULT AND DISCUSSION

3.1 Existing Condition of Anjir Serapat Lowland Irrigation Area

The development of swamplands needs serious attention to several things, including the depth of the pyrite layer, the thickness and nutrients in peat, the hydro topography of the land, the duration and depth of inundation, and the type of soil layer [11].

In tidal irrigation, there is a known relationship between the elevation of the ground level, the height of the tide level, and the damping of the tide level in the system of channels between river and land. This relationship is known as hydro topography and is very important in assessing the development potential of agricultural land. The Ministry of Public Works and Housing divides the classification of land hydro topography into Hydrotopography A, B, C, and D (Figure 2).

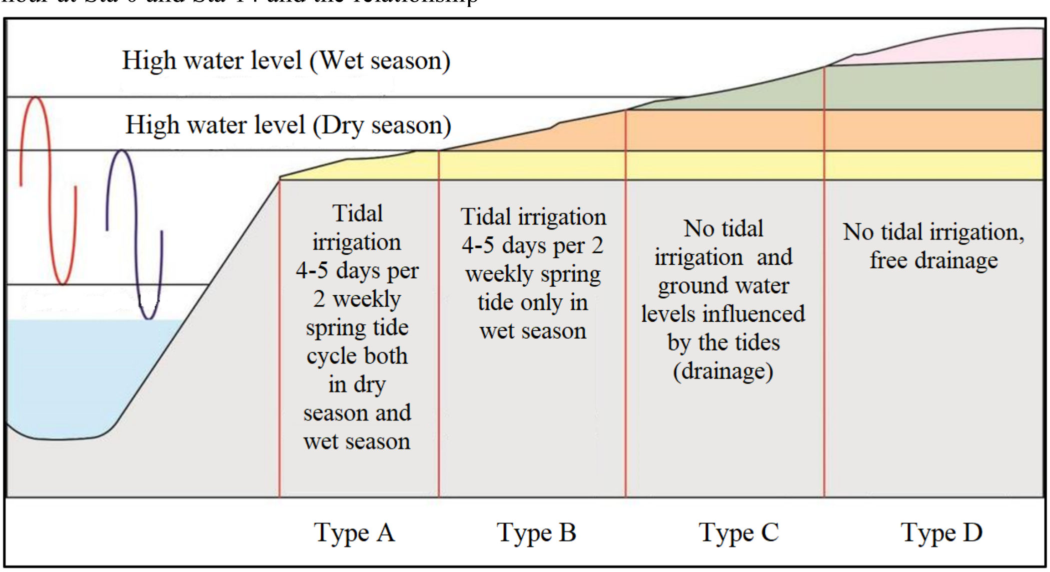

Figure 2 Tidal swamp hydro-topography schematic (Ministry of PUPR, 2017)

In type A, overflows are arranged in a one-way flow system, while in type B, overflows are regulated with a one-way flow system and dam overflow because high tides in the dry season often do not enter the land map. The water system on land types C and D overflows is intended to store water because the water source only comes from rainwater. Therefore, waterways in water systems in fields of overflow types C and D need to be sealed with stop log doors to maintain groundwater levels to suit the needs of plants and allow rainwater to be accommodated in the channel [12].

Almost all the sluices in the secondary channel are not functioning optimally (Figure 3) due to the loss of the beam on the door, so control of the flow out is also disturbed, and several secondary channels in DIR Anjir Serapat show sedimentation and the presence of vegetation that inhibits the flow (Figure 4). The obstructed flow of water in the channel will cause the pH of the water to decrease so that the water becomes acidic [7]. Acidity is an obstacle to the development of agriculture in acidic sulfate lands [13].

Figure 3 The existing condition of the sluice in Handil Dumanap (left) and Handil Setuju (right)

Figure 4 The existing condition of Handil Dumanap, which is still functioning (left), and Handil Gardu, which has been overgrown with vegetation (right)

3.2 Tidal Dynamics on Main Channel

Tides are fluctuations in sea level as a function of time due to the force of attraction of celestial bodies, especially the sun and moon, to the masses of seawater on earth. Although the moon's mass is much smaller than that of the sun, because of its closest distance to the earth, the influence of the moon's pulling force is more significant than that of the sun's pulling force [14]. The influence of incoming tides will help maintain water quality [15].

The water level looks higher at the spring tide than at the neap tide. The tides' amplitude is getting smaller farther from the main channel estuary. The maximum water level at the spring tide is 1.01 m, while the maximum water level at the neap tide is 0.49 m. The tidal amplitude is sequentially at the time of neap tide at Sta 0, Sta 10, and Sta 14 is 0.93 m, 0.54 m, and 0.48 m, while at the time of spring tide is 1.70 m, 0.98 m, and 0.87 m. P. Tidal impacts entering the main channel network are expected to increase pH and decrease salinity in the channel.

In the spring tide curve, the water level is not only affected by the influence of tides because it does not describe one tidal and ebb cycle as at the time of the neap tide. It is suspected that there is an influence of discharge from the upper reaches of the Kapuas Murung River, which supplies the flow to the channel so that when the water in the channel recedes, the flow becomes restrained, and the water level increases. The results of tidal measurement are shown in **Figure 5**.

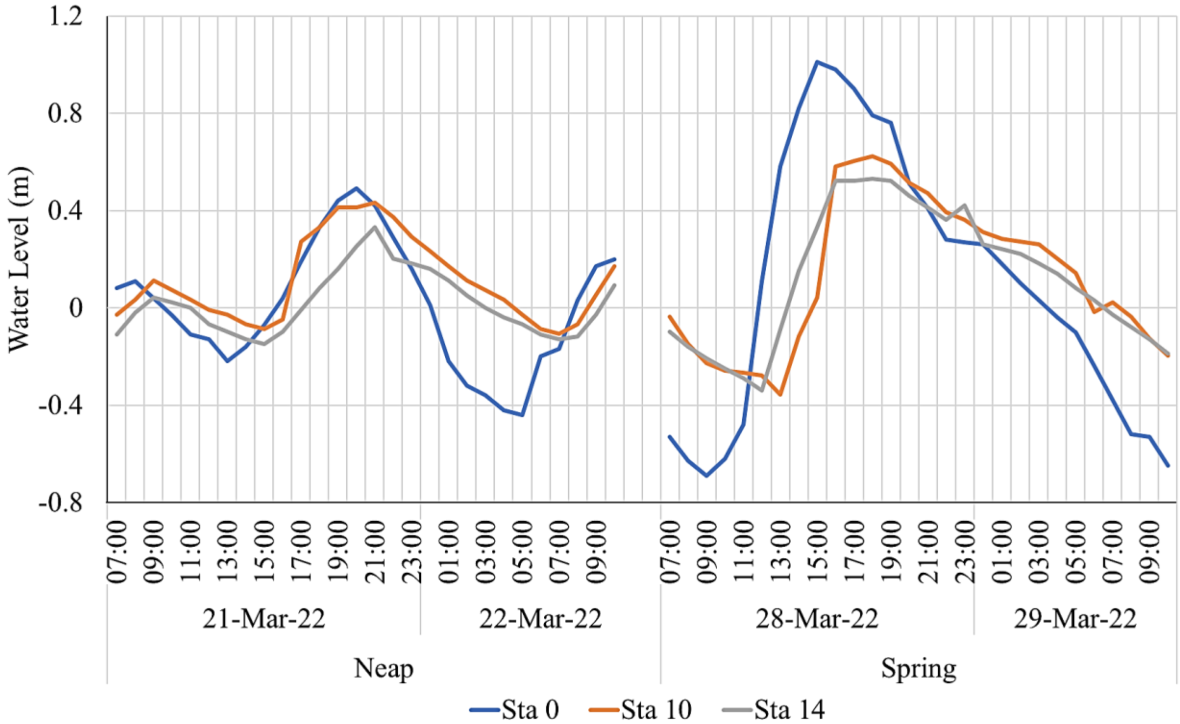

Figure 5 Measured water level in the main channel during the neap and spring tide periods

3.3 Water Quality Dynamics in Main Channel

The quality of water for agricultural purposes is determined by the chemical content as well as the content of garbage and sludge in it. Water quality is rated by its physical and chemical properties parameters. Physical properties such as color, water brightness, and smell can be observed directly in the field. In comparison, the chemical properties are determined by analysis in the laboratory. The parameters of the measured chemical properties are usually Electrical Conductivity (DHL/ electrical conductivity), water pH, suspended solids, Sodium Adsorption Ratio (SAR), and some anions and cations contained in water [16]. Rainfall, tides, and distance from the mouth of the river will affect the quality of tidal irrigation water [15].

A comparison of pH in the neap tide and spring tide periods is shown in Figure 6. The pH at the spring tide is higher than at the neap tide because, during the spring tide, the tidal energy to push fresh water from the river is much higher than during the neap tide, thus causing the cyclical amplitude for pH to be greater during spring tides compared to neap tides [17]. Sta 0 has higher pH fluctuations than Sta 10 and Sta 14. The best pH quality at Sta 0 is obtained at the tide's peak. Meanwhile, at Sta 10 and Sta 14, the tide's peak does not necessarily produce the best water quality compared to other hours, and the change in pH is not too significant. The pH in the main channel in the neap tide condition ranges from 2.26 to 4.82, while in the spring tide condition, it ranges from 2.6 to 5.52. Local rice can live and grow with this pH. The pH of the water must be improved for planting the superior rice. The recommended pH for irrigation water is in the range of 6-9 [18].

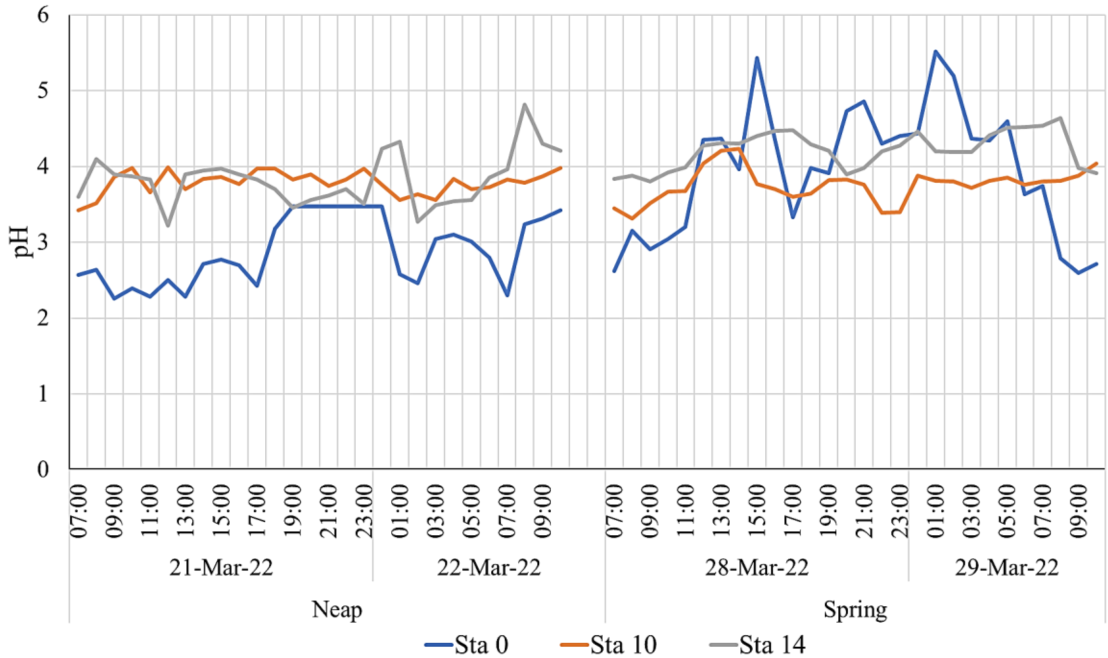

Figure 6 Measured pH in the main channel during the neap tide and spring tide periods

The salinity comparison at the time of neap and spring tide is shown in Figure 7. At Sta 0, it is seen that salinity is relatively lower at the spring tide than the neap tide, inversely proportional to Sta 14, where salinity is lower at neap tide than spring tide. At Sta 10, salinity did not change significantly in the neap tide and spring tide periods.

At the neap tide, the lowest salinity occurs at Sta 14, while at the time of spring tide, the lowest salinity occurs at Sta 0. Salinity in the main channel ranges from 30 to 284 ppm in the neap tide and 13 to 318 ppm in the spring tide. The critical value of salinity for rice cultivation is 4 dS/m or 2650 ppm, so salinity meets the criteria for rice cultivation [19].

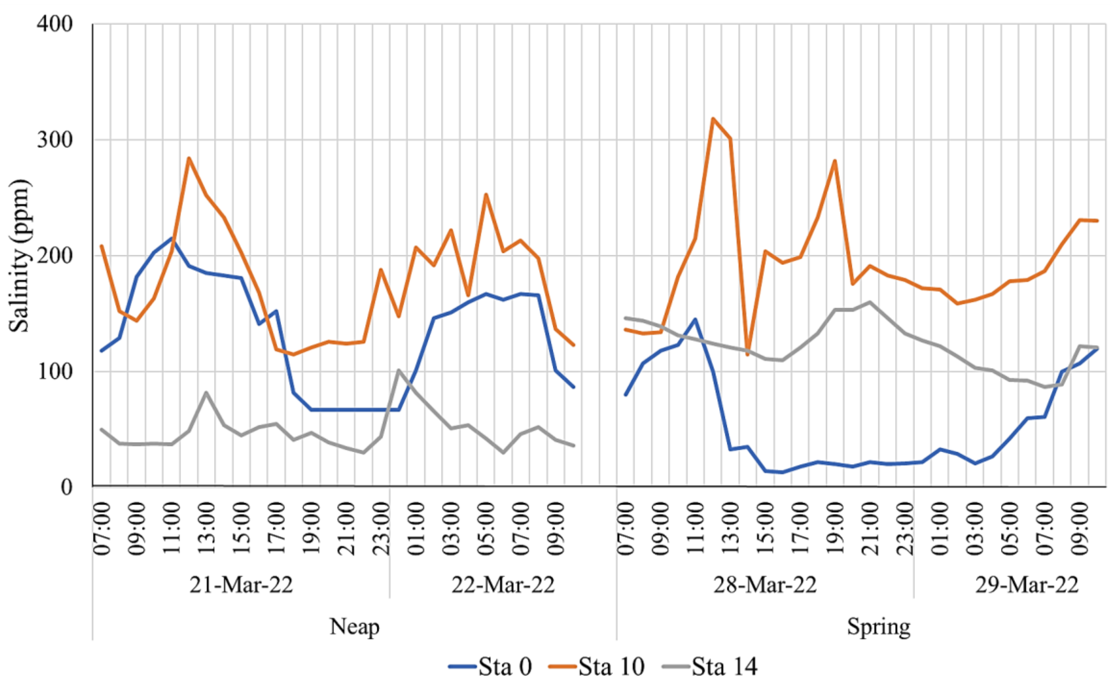

Figure 7 Measured salinity in the main channel during the neap tide and spring tide periods

In addition to simultaneous measurements, instantaneous measurements of pH and salinity were also carried out spread across 18 points in DIR Anjir Serapat. A few hours before the measurement, there was rain. The average pH is 5, while the salinity is 160 ppm (Table 1). Higher pH and lower salinity indicate that rain affects the main channel's irrigation water quality.

Table 1. Instantaneous measurement of pH and salinity

No	Measurement Point	pH	Salinity (ppm)
1	Primer Sta 0	3.93	229
2	Handil Karang Paci	6.07	30
3	Handil Dotoi	5.92	107
4	Handil Hidup Baru	4.93	189
5	Handil Pejantai/Hikmat	5.05	241
6	Handil Enon	5.3	191
7	Handil Mulia	6.01	303
8	Handil Murni	5.57	263
9	Handil Lencong	5.47	269
10	Handil Habib	5.61	164
11	Primer Sta 10	3.48	205
12	Handil Perwira	5.51	239
13	Handil Sinjung	3.27	31
14	Handil Mantat	7.01	38
15	Handil Dahlan	5.64	225
16	Handil Cempaka	7.34	21
17	Handil Kaderi	6.21	93
18	Primer Sta 14	5.98	67

3.4 Tidal Effect on pH and Salinity

3.4.1 Rate of Change of pH to Rate of Change of the Water Level

The rate of change of pH to the rate of change of the water level at Sta 0 and Sta 14 during the neap tide and spring tide periods is shown in Figure 8. The increase in pH at Sta 0 in neap tide conditions happens more often at the flood, while the pH decrease is more common at the ebb. The decrease in pH towards the flood and the increase in pH towards the ebb are insignificant. In spring tide conditions, when heading to low tide, the pH can increase or decrease so that changes in water level do not affect the pH. Changes in pH are influenced by anthropogenic eutrophication and environmental influences [20]. Different results are expressed by Leidonald et al. [21] that pH is more sensitive to tidal changes.

At Sta 14, the range of pH at both spring tide and the neap tide is smaller than the range of pH at Sta 0. The farther from the estuary of the channel, the water quality will decrease [15]. When neap tide, the increase in pH is more frequent at the ebb, while the decrease in pH occurs more often when going to the flood. During spring tide, the increase and decrease in pH are more frequent when conditions are heading to the ebb than when heading towards the flood. In Sta 0, the highest pH increase was 1.47, which occurred in spring tide, while in Sta 14, the highest pH increase was 0.86, which occurred in the neap tide.

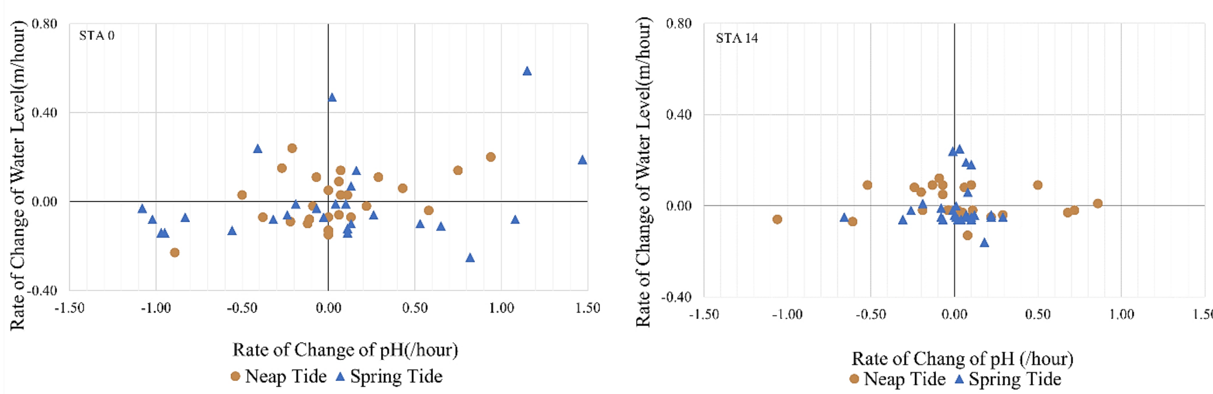

Figure 8 Rate of change of pH at Sta 0 (left) and Sta 14 (right) during the neap tide and spring tide periods against the rate of change of the water level

3.3.1 Rate of Change of Salinity to Rate of Change of the Water Level

The rate of change of salinity to the rate of change of the water level at Sta 0 and Sta 14 at the neap tide and spring tide periods is shown in Figure 9. In neap tide, salinity decreases in Sta 0 are more frequent at the time of the flood, while salinity increases are more frequent at the ebb tide. Other studies have also revealed that salinity at the ebb will be higher than when heading towards the flood tide [15,22]. An increase in salinity at the time of going to the flood and a decrease in salinity at ebb also occur, but the frequency is minor. In spring tide, salinity correlates well with tides [17,21]. Changes are frequent at ebb, with salinity increasing quite a lot compared to salinity reductions.

The decrease in salinity in the neap tide and spring tide periods in Sta 14 is more frequent than the increase in salinity, where the declining frequency occurs more at the ebb. In Sta 0, the most significant decrease in salinity is 70 ppm, which occurs during the neap tide, while in Sta 14, the most significant salinity decrease is 28 ppm which also occurs during the neap tide.

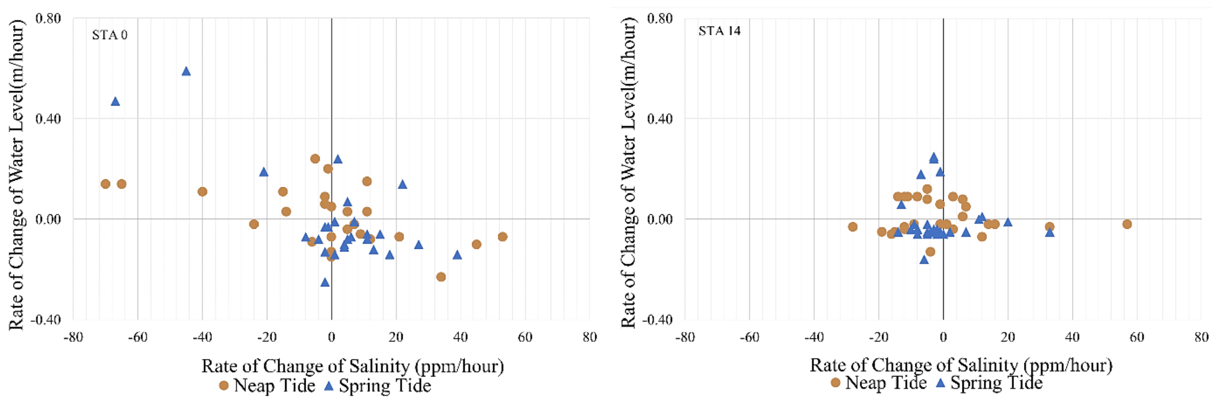

Figure 9 Rate of change of salinity at Sta 0 (left) and Sta 14 (right) during the neap tide and spring tide periods against the rate of change of the water level

3.4.2 Rate of Change of pH to the Water Level Slope

The rate of change of pH to the slope of the water level at the neap tide and spring tide periods at Sta 0 and Sta 14 is shown in Figure 10**.** The slope of the positive water level at the neap tide at Sta 0 did not significantly affect the increase or decrease in pH. The change in pH is more influenced by the slope of the water level when it is negative, with the frequency of occurrence of an increase in pH and a decrease in pH equally a lot. In contrast to Sta 14, the slope of the positive water level has a more significant influence on the decrease in pH, while at the time of the slope of the negative water level, the pH more often increases.

At the spring tide, the pH range is more significant at Sta 0 than Sta 14 either at the time of increase or decrease in pH. At Sta 14, the pH did not change significantly to the slope of the water level, even though the slope of the water level changed rapidly. The variation of pH and tidal fluctuation is not synchronized [23]. Change in pH is not always linear with changes in water level [15].

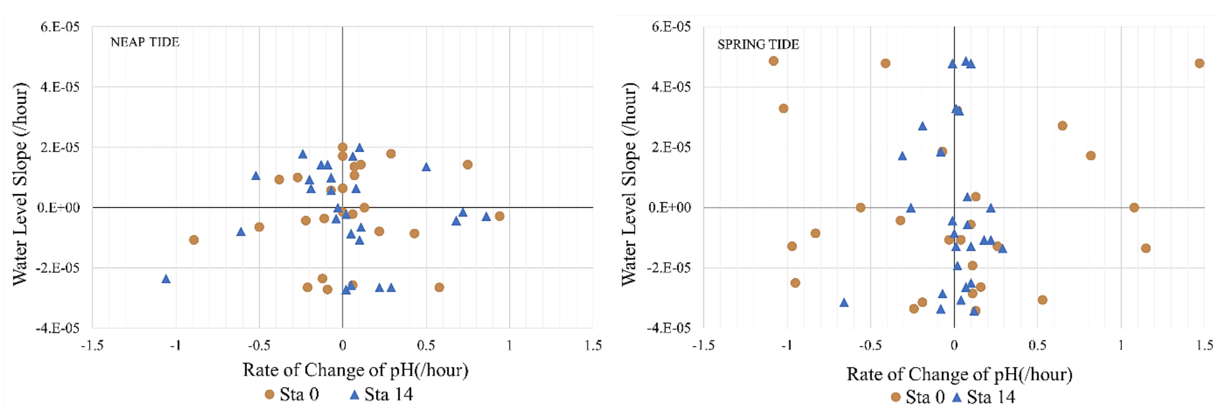

Figure 10 Rate of changes of pH during the neap tide period (left) and spring tide period (right) at Sta 0 and Sta 14 against the slope of the water level

3.4.3 Rate of Change of Salinity to the Water Level Slope

The rate of change of salinity to the slope of the water level during the neap tide and spring tide periods at Sta 0 and Sta 14 is shown in Figure 11. At Sta 0 and Sta 14, when neap tide indicates that either the slope of the water level is positive or the slope of the face becomes negative, both can increase and reduce salinity so that the change in the slope of the water level does not affect the change in salinity.

In spring tide conditions, the range of change in salinity rate is smaller than during neap tide. Changes in salinity are significant when the slope of the water level is negative. When the slope of the water level is negative, in Sta 0, there is a threefold increase in salinity more often than a decrease in salinity, inversely proportional to Sta 14, where there is a decrease in salinity three times more often than an increase in salinity.

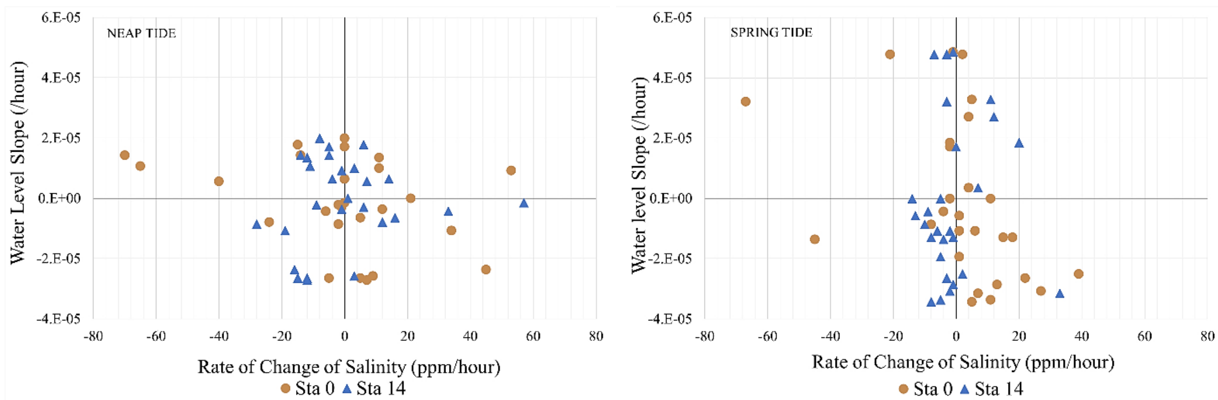

Figure 11 Rate of changes of salinity during the neap tide period (left) and spring tide period (right) at Sta 0 and Sta 14 against the slope of the water level

4. CONCLUSION AND SUGGESTIONS

4.1 Conclusions

When heading towards the flood or the ebb, fresh water from the river can lower salinity and increase the pH, and vice versa can also increase salinity and lower the pH in the main channel. The effect on pH and salinity changes is more common when the flow is going to low tide because it is prone to more prolonged ebb and flow in one tidal cycle.

Changes in water level significantly influence only salinity at Sta 0, while changes in salinity at Sta 14 and changes in pH at Sta 0 and 14 are not so significant because other unmeasured variables affect pH and salinity. The pH quality of the freshwater source from the Kapuas Murung River is not much different from that of the water in the main channel. When mixing occurs, the pH change is insignificant

4.2 Suggestions

Improvement of water quality at high tide is expected to increase the quantity and quality of water in meeting water needs in irrigated land. It is suggested to do further study of other factors that affect the pH and salinity of irrigation water in the main channel of Anjir Serapat Lowland Irrigation Area. Furthermore, it is necessary to simulate the extent of the influence of the tidal range on the system in order to be able to apply water regulation patterns and the correct type of infrastructure so that it can increase the agricultural index in the Anjir Serapat Lowland Irrigation Area.

AUTHORS' CONTRIBUTIONS

The first author contributed to data collection, analysis and editing of the manuscript. The second and third authors as mentors who provide ideas on how to process and display data as well as data interpretation and drawing conclusions.

ACKNOWLEDGMENTS

The author would like to thank The Ministry of Public Works and Housing, BWS Kalimantan II, Balai Teknik Rawa, for supporting and assisting this research.

REFERENCES

[1] S. Marwanto and F. Pangestu, "Food Estate Program in Central Kalimantan Province as An Integrated and Sustainable Solution for Food Security in Indonesia," IOP Conf. Ser. Earth Environ. Sci. 794(1) (2021). doi: 10.1088/ 1755-1315/794/1/012068.

[2] E. P. A. Pratiwi, E. L. Ramadhani, F. Nurrochmad, and D. Legono, "The Impacts of Flood and Drought on Food Security in Central Java," J. Civ. Eng. Forum 6(1) (2020) 69. doi: 10.22146/ jcef.51872.

[3] M. Alwi, "Prospek Lahan Rawa Pasang Surut untuk Tanaman Padi [Tidal Swamp Land Prospects for Rice Plants]," 2007, pp. 45–59, [Online]. Available: http://kalsel.litbang.pertanian.go.id/ind/images/pdf/ semnas2014/6alwi.pdf.

[4] R. Sjarief, Dukungan Teknologi untuk Pengembangan Lahan Rawa [Technol Support for Swampland Development].

Jakarta: Research and Development Agency of the Department of Settlement and Regional Infrastructure, 2006.

[5] Directorate of Irrigation and Swamp, 2020.

[6] A. A. Sulaiman, Y. Sulaeman, and B. Minasny, "A Framework for the Development of Wetland for Agricultural Use in Indonesia," Resources 8(1) (2019). doi: 10.3390/resources8010034.

[7] L. Huang, X. Liu, Z. Wang, Z. Liang, M. Wang, M. Liu, D. L Suarez, "Interactive effects of pH, EC and nitrogen on yields and nutrient absorption of rice (*Oryza sativa* L.)," Agric. Water Manag. 194(3) (2017) 48–57. doi: 10.1016 /j.agwat. 2017. 08.012.

[8] R. Riduan and B. Utomo, "Compilation of Numerical Models for the Movement of Toxic Materials in the Unrestricted Reclamation Channel," J. Env. Eng vol. 2 (2016) 51–61, 2016.

[9] B. S. Wignyosukarto, "Leaching and flushing of acidity in the reclamation of acid sulfate soil, Kalimantan, Indonesia," Irrig. Drain. 62(S1) (2013) 75–81. doi: 10.1002/ird.1777.

[10] Yodya Karya, "Laporan Ringkasan Survey Investigasi dan Desain (SID) Rehabilitasi dan Peningkatan Jaringan Irigasi Rawa Wilayah Kerja Blok D (Paket 4) DIR Unit Anjir Serapat [Summary Report of Investigation and Design Survey (SID) Rehabilitation and Improvement of Swamp Irrigation Network in Block D Working Area (Package 4) DIR Unit Anjir Serapat]," 2020.

[11] H. Subagyo, "Karakteristik dan Pengelolaan Lahan Rawa [Swampland Characteristics and Management]," in Tidal Swamp Land, Center for Research and Development of Agricultural Land Resources, 2006, pp. 23–98.

[12] D. Nazemi, A. Hairani, and Nurita, "Optimalisasi Pemanfaatan Lahan Rawa Pasang Surut Melalui Pengelolaan Lahan dan Komoditas [Optimization of Tidal Swamp Land Utilization Through Land and Commodity Management]," Agrovigor 5(1) (2012) 52–57.

[13] M. Noor, Lahan Rawa: Sifat dan Pengelolaan Tanah Bermasalah Sulfat Masam [Swamplands: Nature and Management of Acid Sulfate Problematic Soils], 1st ed. Jakarta: Raja Grafindo Persada, 2004.

[14] B. Triatmodjo, Perencanaan Pelabuhan [Port Planning]. Yogyakarta: Beta Offset, 2009.

[15] Z. Multazam, S. N. H. Utami, A. Maas, and K. Anwar, "The impact of seasonal changes on tidal water quality in acid sulfate soils for rice cultivation and water management strategies in South Kalimantan, Indonesia," IOP Conf. Ser. Earth Environ. Sci. 1005(1) (2022). doi: 10.1088/1755-1315/1005/1/012023.

[16] S. Najiyati, L. Muslihat, I. Nyoman, and N. Suryadiputra, Pengelolaan Lahan Gambut Untuk Pertanian Berkelanjutan [Peatland Management for Sustainable Agriculture]. 2005.

[17] S. Proum, J. H. Santos, L. H. Lim, and D. J. Marshall, "Tidal and seasonal variation in carbonate chemistry, pH and salinity for a mineral-acidified tropical estuarine system," Reg. Stud. Mar. Sci. vol. 17 (2018) 17–27. doi: 10.1016 /j.rsma. 2017. 11.004.

[18] Peraturan Pemerintah Nomor 22 Tahun 2021 tentang Pedoman Perlindungan dan Pengelolaan Lingkungan Hidup [Government Regulation Number 22 of 2021 concerning Guidelines for Environmental Protection and Management], vol. 1, no. 078487A. 2021, p. 483.

[19] S. Ritung, Wahyunto, A. Fahmuddin, and H. Hidayat, Land Suitability Evaluation with Case Map of Aceh Barat District. Bogor, Indonesia: Indonesian Soil Research Institute and World Agroforestry Centre, 2007.

[20] C. F. Cerco, T. Threadgill, M. R. Noel, and S. Hinz, "Modeling the pH in the tidal fresh Potomac River under conditions of varying hydrology and loads," Ecol. Modell. vol. 257 (2013) 101–112. doi: 10.1016/j.ecolmodel.2013.02.011.

[21] M. H. Abdullah, M. B. Mokhtar, S. H. Tahir, and A. B. Awaluddin, "Do tides affect water quality in the upper phreatic zone of a small oceanic island, Sipadan Island, Malaysia?," Environ. Geol. 29(1-2) (1997) 112–117. doi: 10.1007/ s00254 0050109.

[22] R. Leidonald, A. Muhtadi, I. Lesmana, Z. A. Harahap, and A. Rahmadya, "Profiles of temperature, salinity, dissolved oxygen, and pH in Tidal Lakes," IOP Conf. Ser. Earth Environ. Sci. 260(1) (2019) 1–8. doi: 10.1088/1755-1315/260/1/012075.

[23] Y. Liu, J. J. Jiao, and W. Liang, "Tidal Fluctuation Influenced Physicochemical Parameter Dynamics in Coastal Groundwater Mixing Zone," Estuaries and Coasts 41(4) (2018) 988–1001. doi: 10.1007/s12237-017-0335-x.