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# SEASONAL VARIATIONS AND TIDAL INFLUENCE ON WATER QUALITY PARAMETERS IN SUNGAI PENGKALAN DATU, KELANTAN

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**Abstract:** The study of water quality mainly on salinity and ammoniacal nitrogen was carried out to strategize the pumping water intake to the desalination plant located at Pantai Senok, Bachok, Kelantan. The intake point was strongly influenced by seasonal variations of monsoon and drought as well as tidal conditions. This study aimed to evaluate the salinity and ammoniacal nitrogen concentration at the plant intake in relation to rainfall impact. As a result, the salinity concentration is extremely high during the dry season and high tide (28 to 31 ppt) while very low during the wet season and low tide (1 to 15 ppt). In contrast, the ammoniacal nitrogen concentration is quite high during the wet season and low tide (0.10 to 0.30 mg/L) whereas rather low during the dry season and high tide (0.04 to 0.10 mg/L). In conclusion, to overcome the above problems, a balancing reservoir or tank should be installed to stabilize the salinity and ammoniacal nitrogen within the range of 15 to 24 ppt and below 0.15 mg/L respectively.

Keywords: Water quality, desalination, water intake, estuary.

## Introduction

An estuary is located near to river mouth and permanently vulnerable to seawater and measurably diluted by freshwater obtained from land drainage. Estuaries are probably the most attractive coastal environments for human occupation since they have major potential for the development of various activities, especially in agriculture, aquaculture, harbor and touristic activities (Monteiro *et al*., 2016) nutrients and thermotolerant coliforms input is intensified by the absence of a public sanitation system and by mangrove outwelling. This input is more accentuated in the upper sector of the estuary where 90% of the local population is concentrated and a high incidence of commercial activities (public markets, ice factories and boat repairing among others. However, estuaries recently have been affected by rapid population growth leading to unregulated urbanization development and several anthropogenic human activities (Monteiro *et al*., 2016) nutrients and thermotolerant coliforms input is intensified by the absence of a public sanitation system and by mangrove outwelling. This input is more accentuated in the upper sector of the estuary where 90% of the local population is concentrated and a high incidence of commercial activities (public markets, ice factories and boat repairing among others). As a consequence, the anthropogenic input waste from the land such as agriculture, aquaculture, urbanization, coastal and industrial products have contributed to river contaminations for which the pollutions being transported within the river or the estuary (Jayachandran *et al*., 2012). Anthropogenic pollutants related to land use can cause major deterioration to the aquatic system in a watershed (Al-Badaii *et al*., 2013). The effect of land use and land cover on the hydrology is a global issue which influences the entire catchment of the river basin (Desta *et al*., 2019). In addition, hydrological conditions and fluctuating tides play a major role in affecting water quality.

Water quality plays a vital role in determining both the ecological environment and public health. Clean, safe and freshwater can be a major source of human social and economic developments (Xu *et al*., 2019) public health and social and economic development. This study analyzed the spatial and seasonal differences in surface water quality in the Dan River basin based on three monitoring sections over the period of 2009–2015. The main influencing factors and their contributions to water quality in different seasons were determined using statistical analysis, hurst exponent and redundancy analysis. Results indicated that vegetation coverage in the Dan River basin increased substantially from 2009 to 2015, particularly forested land. Higher concentrations of major water pollution indicators were recorded in the downstream monitoring sites. Nitrate nitrogen (NN). In the case of Sungai Pengkalan Datu, the river water close to the estuary has been influenced by both marine and freshwater from the catchment. Recently, the river water within Pantai Senok represents the substantial source of water used for daily water supply. However, the quality of the river was suspected to be contaminated due to the presence of various types of nutrients, sediment and pathogen from upstream catchments. Regarding this matter, the variety of land use within these districts including commercial, industrial and agriculture are the contributing factors to river water contamination. Such changes in land use can significantly affect the environment of a watershed as they amend the hydrological processes via infiltration, groundwater recharge, baseflow and surface runoff (Sajikumar & Remya, 2015) which in turn, affects the surface and groundwater availability of the area and hence leads to further change in LCLU. This forms a vicious circle. Hence it becomes essential to assess the effect of change in LCLU on the runoff characteristics of a region in general and of small watershed levels (sub-basin levels. Understandably, the surface runoff will carry all sorts of nutrients, sediments, pesticides and particles into the river system. On the other hand, the source of river contamination such as nutrients pollution, sediment, decomposing material, algae, bacteria, fertilizer and pesticides are the potential factors in river pollution. On top of that, the physical state for the water is considered as cloudy and currently presenting poor water quality intake before being treated into the desalination treatment plant.

For that reason, the prevention and the monitoring of the river contamination and reliable assessment of water quality are crucial for effective management (Al-Badaii *et al*., 2013). Furthermore, the reliable methods for water quality and quantity data are the two most important monitoring factors which are closely related to each other despite not often measured simultaneously. Water quantity is measured by water level, discharge and velocity, whereas water quality is regularly determined by analyzing samples of collected water in a laboratory or by conducting in-situ testing. Usually, water quality parameters are determined by comparing data analysis from the previous studies and the present study to obtain a clear vision of how the surrounding environment affects water quality. In addition, understanding the relationships between water quality conditions and natural landscapes, hydrologic processes and human activities that occur within a river basin are still lacking particularly in developing countries especially Malaysia (Kailasam, 2006).

The objective of the present study is to determine the relationship between the variations of water quality in temporal conditions and raw water intake sources for the desalination treatment plant. Besides, this study also aims to identify the effective and suitable pumping strategy for better water intake quality flow into the desalination treatment plant. The findings are intended to contribute a better understanding of quantifying the influence of possible natural and anthropogenic sources on the water quality parameter.

## Materials and Methods

### *Study of Catchment Area*

Sungai Pengkalan Datu is located in the east of Kelantan state and close to the capital state Kota Bharu as shown in Figure 1. Sungai Pengkalan Datu basin lies between the coordinate of 6°03'13.6"N and 6°09'58.6"N latitude and 102°17'47.9"E and 102°20'38.4"E longitude. Besides, this river has a total length of about 16 km from Kampung Gong Dermin to Pantai Senok before its discharge into the sea. Sungai Pengkalan Datu catchment also consists of 38 $km^2$ area draining surface runoff water from Kota Bharu, Pengkalan Chepa and Bachok as illustrated in Figure 1. Apparently, the land-use variation within this area comprised residential, industrial, agricultural commercial and forestry areas. Therefore, Sungai Pengkalan Datu has been polluted by various types of sediments and nutrients from the upstream catchment due to the active transport of soil from the land surface into the river basin especially during the monsoon period. Moreover, the geomorphological settings of the Sungai Pengkalan Datu catchment are Quaternary rocks where the majority of the rocks are marine continental deposits, clay, silt, sand and peat soil with minor gravel.

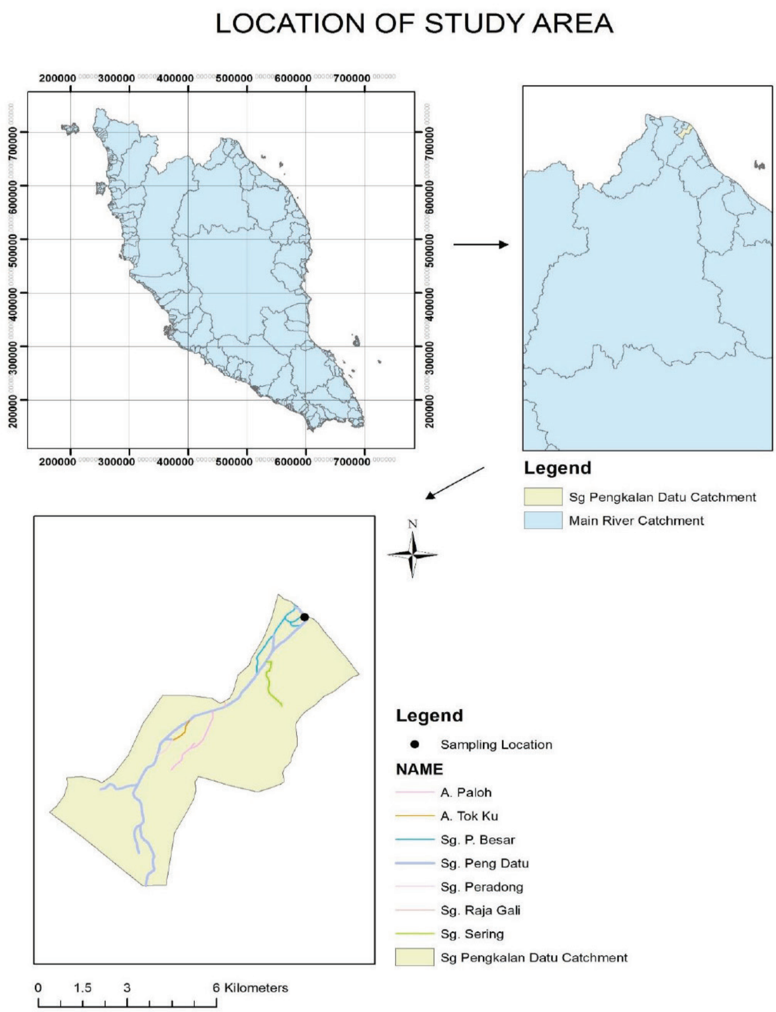


Figure 1: The map of Sungai Pengkalan Datu catchment area

### *The Status of Rainfall*

Sungai Pengkalan Datu area received three different seasons annually which were wet, dry and intermediate seasons. Based on the record, the wet season was expected to be from October until January whereas the dry season started from February to April and the intermediate season might be from May until September. Apart from that, the average seasonal rainfall in this area was approximately 450 mm monthly during the wet season, 29 mm during the dry season and 190 mm during the intermediate season as illustrated in Table 1.

### *River Water Quality Monitoring*

Under normal water quality monitoring conditions, the water samples were collected during the wet, the dry and the intermediate seasons. For this study, the temporal data was collected only at the downstream area, Pantai Senok, Sungai Pengkalan Datu from 8.00 am to 11.00 pm with two hours interval. The recorded coordinate for the sampling point was 6°09'58.6"N latitude and 102°20'38.4"E longitude. The water parameters that were monitored in situ is salinity. The concentrations of salinity were measured using the YSI Professional Plus Multiparameter. The river water level was measured using Aquasonde. On the other hand, the ex-situ experiment analysis such as ammoniacal nitrogen particularly, was analyzed in the laboratory by applying analytical technique following the standard method (Barakat *et al*., 2016).

The concentration of ammoniacal nitrogen ($NH_4^+$-N) was determined based on Phenate Method adapted from the Standard Methods of Examination of Water and Wastewater by using an ultraviolet-visible spectrophotometer double beam spectrophotometer (Shimadzu UV-1800, Japan) (APHA, 1915). All instruments were calibrated before conducting the sampling activity.

### *Statistical Analysis*

The correlation coefficient indicates how strong a relationship is between the two variables. In this case, the Pearson's correlation coefficient analysis was carried out in the study in order to investigate the relationship between rainfall event with water quality parameters such as salinity and ammoniacal nitrogen by using IBM SPSS Statistics 22. Pearson's correlation coefficient (r) lies between the range +1 and -1. The correlation between parameters was classified as strong when the range is ±0.8 to ±1.0, moderate range in ±0.5 to ±0.8 and weak in the range of 0.0 to ±0.5 (Zribi *et al*., 2015).

Table 1: The average seasonal rainfall at Sungai Pengkalan Datu

| Month | Year | Total Monthly Rainfall (mm) | Average Seasonal Rainfall (mm) | Season |
|---|---|---|---|---|
| October | 2018 | 236.0 | 448.25 | Wet |
| November | 2018 | 534.5 | | |
| December | 2018 | 802.5 | | |
| January | 2019 | 220.0 | | |
| February | 2019 | 49.5 | 28.67 | Dry |
| March | 2019 | 10.0 | | |
| April | 2019 | 26.5 | | |
| May | 2019 | 178.0 | 187.88 | Intermediate |
| June | 2019 | 358.5 | | |
| July | 2019 | 60.0 | | |
| August | 2019 | 155.0 | | |

The correlation coefficients were calculated based on different pairs of water parameters and the p-value was applied in order to calculate the significance correlation is significant ($p<0.05$, $p<0.01$) or non-significant ($p>0.05$).

### *A Storm Hydrograph on Rainfall-runoff Relationship*

The method used to determine the rainfall-runoff relationship was using the design flood hydrograph estimation equation. The equation described the total accumulated storm rainfall volume for a particular storm event and the direct runoff derived from the rainfall. The equation derived for Peninsular Malaysia catchment is illustrated as in Equation 1 (JPS, 2010).

$$Q = 0.33P \quad (1)$$

$$Q = \frac{p2}{(P + 150)} \quad (2)$$

where
P = total storm rainfall in mm
Q = direct runoff in mm

For rainfall amount smaller than 75 mm, the linear relationship in Equation 1 was recommended whereas Equation 2 was used for total rainfall that reached above 75 mm.

## Result and Discussion

### *Rainfall Trends in the Study Area*

The rainfall data through the sampling period was provided by the Department of Irrigation and Drainage Malaysia (DID) from 2017 to 2019. The selected rainfall station was at Kg Binjai, Kelantan which is near to the Pengkalan Datu catchment area. Figure 2 shows trends data of average monthly rainfall at Kg Binjai rainfall station from 2017 to 2019. As can be seen from Figure 2, the analysis shows that the high precipitation typically occurred in January, November and December, considered as a wet season in Sungai Pengkalan Datu. It can be seen from the data in Figure 2, the dry season commonly appeared in February, March and April due to the lower rainfall recorded. On top of that, an intermediate season can be found within May, June, July, August, September and October.

### *Residential and Municipal Sewage Management System in the Study Area*

The concept of the sewage management system used in Kota Bharu and Bachok districts was an onsite sewage management system. The system generally described as a decentralized treatment

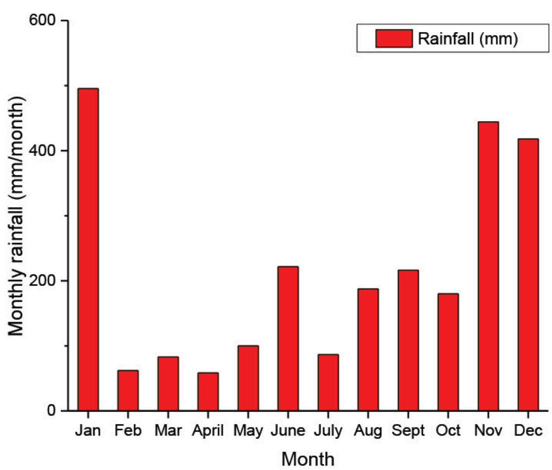


Figure 2: The average monthly precipitation of Kg Binjai rainfall station from 2017 to 2019

is where the treatment plant is not connected with any central treatment system. There were three types of sewage systems used in the study area namely pour-flush, individual septic tank system (IST) and community septic tank system. These systems were majorly used by the residential areas in Kota Bharu and Bachok districts, where more than 60% used the pour flash system in the Bachok district and over 50% used the individual septic tank (IST) system in Kota Bharu. Without proper installation, well planned and constructed sewage system, the wastewater could easily be brought to nearby water bodies due to the effluent discharge and the drainage system of wastewater and finally connected to the river. As a result, these problems released harmful pollutants to aquatic life and produced excessive algal growth that definitely caused distraction to water quality uncontrollably. Moreover, the solids and scums also may easily flow into the drain field if the septic tank is not properly maintained with adequate treatment. Therefore, several mitigation measures should be implemented and applied for better sewage treatment system involving residential areas especially in the study areas.

### *Seasonal Variation and Tidal Influence on Water Quality Parameter*

The water quality monitoring was conducted regularly at Pantai Senok located in the downstream area of Sungai Pengkalan Datu. In this research, the salinity and pollution such as ammoniacal nitrogen dynamically changed, depending upon the seasonal factor including a wet, dry and intermediate season as well as tidal effect.

Data in Figure 3 shows that the salinity of the river was generally low during the wet season and was driven by heavy rainfall that occurred a few days before the surveillance period. The massive precipitation during the wet season majorly has altered the sustainability of salinity due to the high dilution factor by the freshwater influx and consequently declining the salinity in the river (Suratman *et al*., 2016). In contrast, the salinity concentration appeared to be higher during the dry season. Limited precipitation during the dry season has led to an increase of salinity in the river due to the limited freshwater discharge from the upstream region (Kennedy, 2018).

Apart from that, the tidal effects also induced the fluctuation of river salinity. Data in Figure 3 recorded that the salinity during the wet season varied from 1 ppt during low tide up to 15 ppt during high tide. As the seawater constantly moved into the river during high tide, the salinity concentration has consequently increased. Meanwhile, during low tide, the salinity tends to decrease due to the intrusion of water run-off discharge from the upstream region (Monteiro *et al*., 2016) nutrients and thermotolerant coliforms input is intensified by the absence of a public sanitation system and by mangrove outwelling. This input is more accentuated in the upper

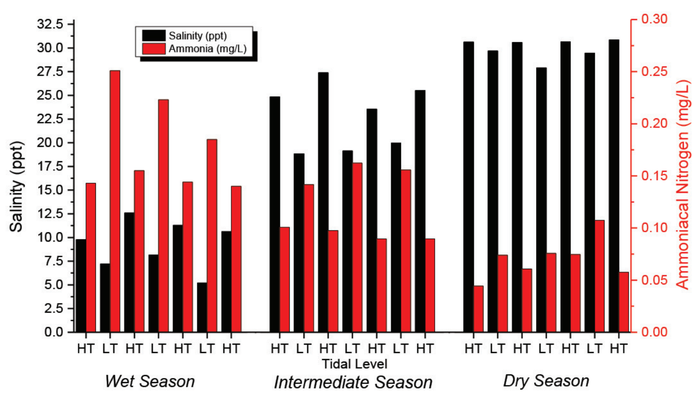


Figure 3: The salinity and the ammoniacal nitrogen concentration in Sungai Pengkalan Datu

sector of the estuary where 90% of the local population is concentrated and a high incidence of commercial activities (public markets, ice factories and boat repairing among others). Furthermore, the salinity recorded during the dry season ranging from 28 ppt during low tide up to 31 ppt during high tide as illustrated in Figure 3. The Figure below also shows the result of medium-range salinity which varied from 19 ppt during low tide and 27 ppt during high during the intermediate season. The results recorded have shown that the higher salinity typically emerged at high tide during wet, dry and intermediate seasons.

On the other hand, the ammoniacal nitrogen in the river was high during the wet season. The stormwater runoff caused by precipitation ultimately flowed from the land into the river carrying all sorts of pollutants such as pesticide, fertilizer, nutrients, organic matter and sediment and eventually increased the ammoniacal nitrogen during the wet season. On the other hand, the low ammoniacal nitrogen generally appeared during the dry season. The low concentration of ammoniacal nitrogen rose during the dry season as the river water was diluted by saline water intrusion from seawater into the river (Fan *et al*., 2012). Moreover, the storm event that occurred during the dry season was very limited perhaps minimizing the presence of foreign substances such as nutrients to flow into the river.

In addition, the ammoniacal nitrogen during the wet season showed a higher range for both high and low tides which were 0.1 mg/L and 0.3 mg/L respectively. However, the ammoniacal nitrogen during the dry season emerged to have a lower range than the wet season that recorded 0.04 mg/L during high tide and 0.1 mg/L during low tide. This study recorded that the ammoniacal nitrogen significantly decreased during high tide because the seawater moved into the river and diluted the ammoniacal nitrogen concentration. In contrast, the intermediate season showed the medium range of ammoniacal nitrogen concentration for both high and low tides which varied from 0.03 mg/L and 0.2 mg/L respectively, as illustrated in Figure 3.

Based on the result from the Figure 3, the salinity and ammoniacal nitrogen fluctuated due to the seasonal variation. The inconsistency of salinity and ammoniacal nitrogen in the river, however, will degrade the performance and quality of RO membrane easily. Due to the standard requirement of the membrane's specification, the optimum range of salinity and ammoniacal nitrogen as feedwater should be achieved in order to prevent damage and operation failure to the membrane. Therefore, suggestion of the pumping strategy at the water intake should be carried out to obtain the optimum rate of water parameters.

As can be seen from Figure 3, the appropriate time of pumping operation within the wet season is during high tide. This is due to the condition of salinity that should be greater than 10 ppt and ammoniacal nitrogen with less than 0.15 mg/L. Whereas the appropriate time within the intermediate season is during low tide, preferably with salinity in the range of 15 to 24 ppt and ammoniacal nitrogen at the range of below 0.15 mg/L. For a long-term solution, the desalination plant should be equipped with an equalizing tank in order to regulate the salinity and ammoniacal nitrogen at the appropriate range of 10 to 25 ppt of salinity and below 0.15 mg/L for ammoniacal nitrogen. Therefore, the membrane can appropriately be used in different seasons and when the waters are tidal.

### *The Relationship of Precipitation on Water Quality Parameters*

Since the correlation coefficient gives the interrelationship between water quality parameters, the Pearson correlation coefficients were calculated. The correlation matrix for water quality parameter and precipitation is depicted in Table 2. The result of the correlation analysis shows that the precipitation shared a high negative correlation with salinity (r = -0.89). It is also interesting to observe a strong negative correlation between salinity and ammoniacal nitrogen (r = -0.87). This indicates that a negative increase in correlations between precipitation, salinity and ammoniacal nitrogen could be attributed to the dilution effect during the wet and dry seasons. The analysis conducted by Ouyang *et al*. (2006), found negative correlations in salinity during the wet summer season. However, the correlation coefficients between precipitation and ammoniacal nitrogen ($r = 0.63$) and water level ($r = 0.60$) shared positive correlation indicating a relatively moderate correlation. Thus, it can be concluded that the water quality parameters significantly correlated with the precipitation.

### *Hydrological Factors and Characteristics*

There were various hydrological factors which ultimately affected the water quality parameters in the river at the desalination plant near to Pantai Senok, Sungai Pengkalan Datu. In this case, the hydrological factors, primarily rainfall event, played a significant role in determining the flow discharge rate which eventually caused the fluctuation of water quality parameter in the river. For instance, after the heavy rainfall, the discharge rate of the river tended to be higher due to the excessive water entering the river by surface runoff. This phenomenon can be represented clearly with a graph called hydrograph which illustrates how a river discharge responds to the precipitation period. The relationship between rainfall and discharge rate in hydrograph generated various shapes of hydrograph depended on the seasonal changes and the storm event.

The present study demonstrated the hydrograph shape in the wet season was 'peaky' with steep rising and recessional limbs which occurred from October until December 2018, as shown in Figure 4. In this case, the lag time was likely to be greater during the wet season and possibly vulnerable to flooding events due to the massive precipitation with a peak rainfall of 26 mm as the monthly maximum average rainfall. Figure 4 shows the hydrograph pattern known as the rising limb as the rainfall event caused the discharge rate to be increased rapidly. This study recorded approximately the base flow from 103 $m^3/s$ up to 109 $m^3/s$ as illustrated in Figure 4. Furthermore, the peak rainfall generated the peak discharge to reach approximately 109 $m^3/s$. The higher discharge rate indicated the high exposure of contaminants to the river due to the large surface runoff. Therefore, the concentration of the pollutants shows higher value during the wet season.

In contrast, the discharge rate during the dry season was lower than the in the wet season. The amount of precipitation was significantly lower during the dry season resulting in a low amount of surface runoff into the river and also discharge rate (Roa-García *et al*., 2011). For instance, the discharge rate recorded from February to April 2019 varied from 100.11 $m^3/s$ up to 100.6 $m^3/s$. Hence, the water parameters such as ammoniacal nitrogen, turbidity and suspended solids were lower during the dry season due to low foreign particles and contaminants from the land precipitated into the river carried by surface runoff. On top of that, the discharge rate showed gentle slope during the intermediate season from May until August 2019 as seen in Figure 4.

Table 2: Pearson correlation matrix for water parameters and precipitation of Sungai Pengkalan Datu obtained from experimental plots

| | **Precipitation** | **Salinity** | **Ammoniacal Nitrogen** | **Water Level** |
|---|---|---|---|---|
| Precipitation | 1.00 | | | |
| Salinity | -0.89** | 1.00 | | |
| Ammoniacal Nitrogen | 0.63** | -0.87** | 1.00 | |
| Water Level | 0.60** | -0.42* | 0.1 | 1.00 |

** Correlation is significant at the 0.01 level (2-tailed)
* Correlation is significant at the 0.05 level (2-tailed)

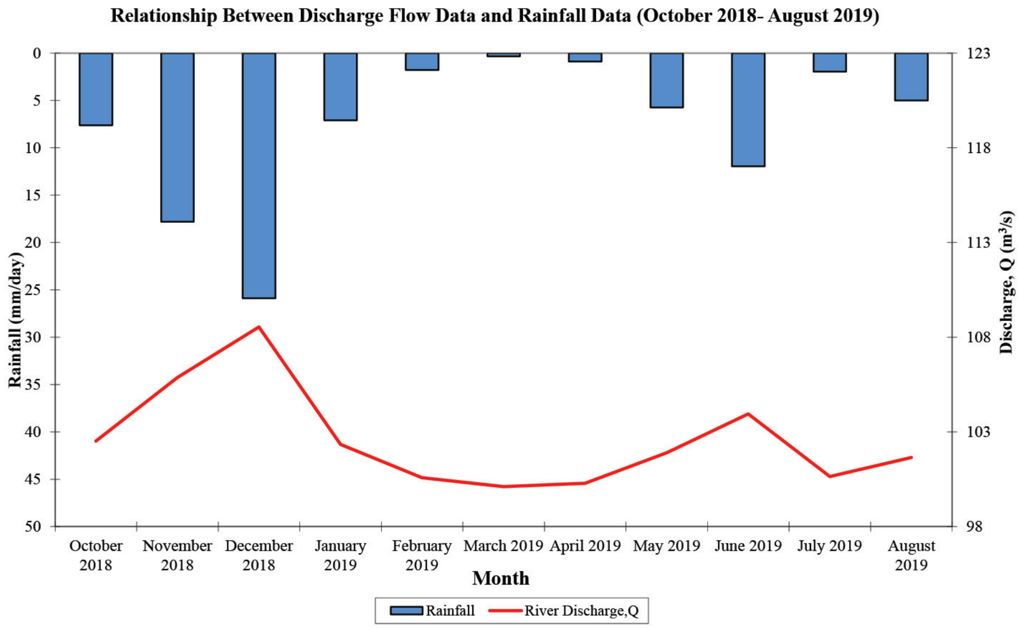


Figure 4: A storm hydrograph in Sungai Pengkalan Datu

### *Water Intake Problem*

The result from the analysis of the water quality parameter collected from Sungai Pengkalan Datu indicates that water quality fluctuations were affected by the seasonal and tidal impacts. However, attention should also be paid to the water intake of the desalination plant at Pantai Senok. The intake point of the desalination plant was currently installed at the bottom section of the river which provides low-quality raw water for the desalination process system. Moreover, inconsistent salinity and ammoniacal nitrogen in the river are found to be risky that can cause damage to the membrane system. Therefore, strategies for the water intake pumping and equalizing tank are the solutions to overcome balancing the salinity and ammoniacal nitrogen based on the standard range of membrane specification. Figure 5 shows the location to install the Equalizer Tank.

## Conclusion

The result from the analysis of water collected from the Sungai Pengkalan Datu showed that the water quality parameters were impacted by the seasonal variations and tidal impact. Based on the result, the dry season recorded the high salinity which is not suitable to run the treatment through the membrane. Hence, the appropriate time of pumping operation was during the wet season at the high tide. The condition of salinity should be greater than 10 ppt and ammoniacal nitrogen with less than 0.15 mg/L. Whereas the appropriate time within the intermediate season is during low tide preferably with salinity in the range of 15 to 24 ppt and ammoniacal nitrogen in the range of below 0.15 mg/L. As a conclusion, the placement of the intake point should be placed correctly to maintain the sustainability of the treatment plant. It is suggested for inlet water to be as close as possible to the water surface to obtain the best water quality. In order to stabilize the river water in terms of salinity and pollutant as well as to pre-treat the intake water, it is recommended to have a temporary reservoir prior to desalination treatment.

## Acknowledgements

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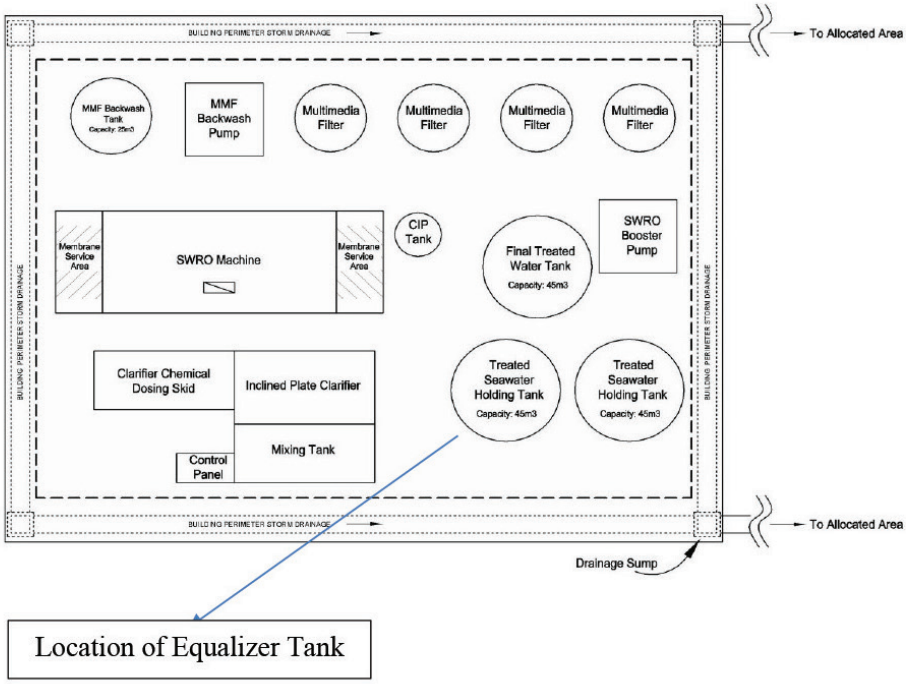


Figure 5: The figure shows the location of Equalizer Tank at Pantai Senok desalination plant

supply of rainfall data used in the testing and sampling applications. The study conducted in this paper is a part of the research project proudly funded by the Internal Translational Research Grant (TRG) from Universiti Malaysia Terengganu (UMT).

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