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Modeling the Influence of River Flow and Salt Water Intrusion in the Terengganu Estuary, Malaysia

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Abstract. Salinity intrusion is a major concern when the freshwater extraction station is located in the estuary. This paper attempt to predict the salt intrusion length in the upper stretch of estuary, by applying different magnitudes of freshwater discharge at the river regime. The integrated two dimensional hydrodynamics model associated with advection dispersion model was performed to investigate the salinity intrusion. The model was well calibrated and verified by the measured data undertaken during dry season. The maximum salt intrusion length to the threshold of salinity density is 1.00 ppt on the existing condition was predicted at 9.97 km from the river mouth. Moreover, with the magnitude of 100.00 m³s⁻¹ and 30.00 m³s⁻¹ freshwater discharges at the upstream boundary (Kpg Tanggol), it was predicted the maximum salt intrusion length was 11.84 km and 21.41 km, respectively, from the river mouth. Therefore, it was determined the minimum freshwater discharge of approximately 100.00 m³s⁻¹ is required at the Kpg Tanggol river gauging station, in order to maintain the acceptable salinity levels at the Pulau Musang freshwater pump house. However, the actual water discharge at the Kpg Tanggol boundary station should be higher, since the minimum discharge does not take into consideration the amount of water extraction by the Pulau Musang and SATU pump stations. Further analysis is required to execute the consequences of water extraction toward the salinity intrusion in the Terengganu estuary that coupled with projected sea level rise.

Keywords: numerical model, salinity intrusion, diurnal tide, high water level, hydrodynamic.

1. Introduction

River discharge, tidal forces and the estuarine geometry are the main key parameters determining the salt water intrusion in an estuary [1]. Decades ago, to meet the domestic demands, freshwater reservoirs are constructed; however it treated the saltwater intrusion during the dry season and enhanced the tidal excursion length further upstream [2]. The contaminated freshwater by the salt water from the sea, is no longer useable and could interrupt the function of water intake stations that located in the estuary for drinking or agricultural purposes [3].

Therefore, it is crucial to identify the minimal freshwater discharge's quantity from the reservoir into the estuary, to ensure all the facilities particularly water intake stations located at the upper stretches of the estuary, able to function well without interrupted by saline water. In the water resources plan and management strategies, the numerical mathematical modeling tools are often being used to derive hydrodynamics behaviors and advection dispersion characteristics for salinity intrusion in the estuary [4,5].

Sea salinity intrusion is major concerns in the study area, as there are freshwater extraction pump houses located in the estuary. Surprisingly, the salt intrusion length into upstream of estuary still not yet been scientifically investigated by any researcher at the study area. Therefore, in order to examine the salt intrusion in the Terengganu estuary, the mathematical numerical model was used. The simulation of two dimensional depth averages hydrodynamic (HD) and advection-dispersion (AD) module was performance, which associated with boundaries condition that driving forces into the model. The objective of this study is to execute hydrodynamic regime and salinity intrusion in the Terengganu estuary for identifying the minimum freshwater



discharge requirement at the river gauging station at Kpg Tanggol, for maintaining an acceptable salinity levels during highest high water spring tide near the water intake at the Pulau Musang pump houses.

2. Material and methods

2.1 Study area

The Terengganu estuary is located at 103.13° E and 5.34° N, with the river basin is approximately 4,600 km² (Figure-1a). The main tributary is the Terengganu river with the river length of 65 km. Upper catchment of the Terengganu river encompasses of hydroelectric power freshwater reservoir namely Kenyir Dam, while the middle catchments are engaged with plantation activities and the lower catchment with an urbanized and industrialized setting close to the estuary draining into the South China Sea. Analysis on 11 years river discharge records from river gauge station located at the Kpg Tanggol (data obtained from the Department of Irrigation and Drainage Malaysia (DID)), which is located in the Terengganu river and approximately 30 km upstream from the river mouth, the annual freshwater was calculated approximately $10 \times 10^9 \text{ m}^3 \text{ year}^{-1}$, while the maximum, average and minimum freshwater discharge was analysed as $2,808 \text{ m}^3 \text{ s}^{-1}$, $266.2 \text{ m}^3 \text{ s}^{-1}$ and $21 \text{ m}^3 \text{ s}^{-1}$, respectively. Higher freshwater runoff is discharged at the beginning and end of the year, with smaller volumes of river runoff is recorded from June to September. The study site is experiencing the wet season during end and early months of the year, where it is associated with the northeast monsoon [6,7,8], the average monthly rainfall during the wet season is ranging from 200 mm to 600 mm. Meanwhile, the dry season occurs from April to September with the average monthly rainfall ranging from 100 mm to 125mm. The tidal fluctuation at the study site is controlled by the diurnal tide, with the spring and neap tidal range approximately 3.07 and 0.7 m, respectively.

2.2 Data Collection

Bathymetry measurements on the shoreline and in the estuary were carried out by using Acoustic Doppler Current Profiler (ADCP) in both longitudinal and cross-sectional transects during the survey (Figure-1d). Water column current profiles were measured in the navigation channel located in the river mouth, by using a Nortek Aquadopp current profiler with a transducer head of 2 MHz during data campaign at July 2011 (Figure-1c). Meanwhile salinity levels at the Shah Bandar jetty and fisheries jetty was measured with XR-620 CTD sensor, the sensor were placed in a stainless steel pole and deployed at the bed layer at those stations from Dec 2011 to Sept 2012 (Figure-1c). All the equipment were calibrated and verified before been deployed at the site.

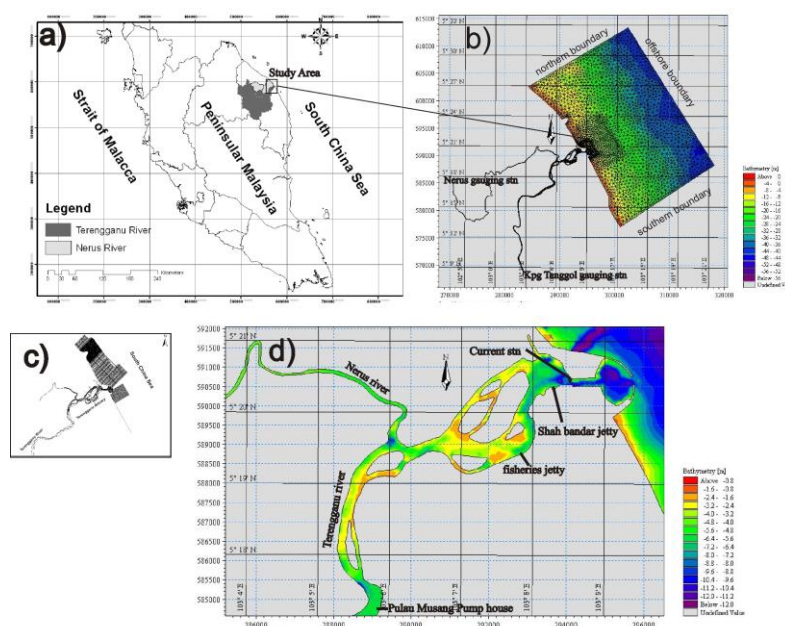


Figure 1. (a) Study area, (b) computational flexible mesh, (c) bathymetry survey data during data campaign and (d) bathymetry condition in the numerical simulation model.

2.3. *Hydrodynamic Module*

The integrated two dimensional models DHI's Mike 21 HD (hydrodynamics) and AD (advection dispersion) flexible mesh finite volume method was used to investigate the salinity intrusion in the estuary. The offshore bathymetry for the model was generated by digitizing the Malaysian Naval chart No: RMAL 654, while the stretches in the nearshore and the Terengganu estuary were measured during the bathymetry survey in the year 2011 and 2012 (Figure-1d). All the topographical data of the study area has been converted to local datum mean sea level (MSL) for HD and AD models uses. The water depths in the estuary vary from 1.57 m to 12.77 m from the MSL (Figure-1c). The triangulation pattern of mesh was kept from dense to course meshes from estuary to deep sea, with the total number for surface meshes were 5906 (Figure-1b). There were five boundaries, namely offshore boundary associated with two lateral boundaries north and south, to transfer tidal fluxes from offshore to the study area. While another two boundaries are located at the freshwater river gauging station at the Kpg Tanggol and Sg Nerus station respectively, for inducing river discharge fluxes from highland into estuary. Those fresh water inputs are obtained from river gauged station has been incharged by local river authority DID (Figure-1b). The hydraulic simulation is based on the two dimensional incompressible Reynolds averaged Navier-Stokes equations, subject to the assumptions of Boussinesq and of hydrostatic pressure solution [9].

3. Result And Discussions

3.1 *Model calibration: current speed, direction and water levels*

Model calibration is essential part in mathematical modeling and generally calibrated with the dynamic parameters, such as current speed, directions, salinity levels and water levels [10]. This study has calibrated the water level, current speed and current direction that were measured in the navigation channel during the data campaign in July 2011. The comparison of measured (dotted black color) and simulated (solid red in color) for the tidal currents, current directions and water levels are given in Figure 2a, 2b and 2c respectively, evidence of the simulated data was good agreement with the measured data. As, the measured location of current speed and direction was in the navigation channel (Figure-1c), the highest tidal and river current was observed during spring tide, with tidal current magnitude was higher than river current. This phenomenon, perhaps allows a better penetration of the saline water further upstream during high water spring (HWS) compared to neap tide. This finding agreed well with the empirical analytical formula constructed by the [11] for maximum HWS salinity intrusion.

3.2 *Hydrodynamic model simulations*

The integrated HD and AD model simulation was simulated for the existing condition of bathymetry. It was observed the study site dominated by diurnal tide, where in daily, approximately 30% of the tidal period was in flood tide and the remainder 70% of the tidal period was in ebb tide (Figure-3a and 3b). During the flood tide, offshore water bodies are flushed towards southern stretches of the shoreline and saline water is intruded into the Terengganu estuary (Figure-3a). Meanwhile during ebb tide, the brackish water from the estuary is flushed out from estuary and the entire coastal water bodies are flowed northwards with a longer duration of tidal period, approximately 17 hours (Figure-3b).

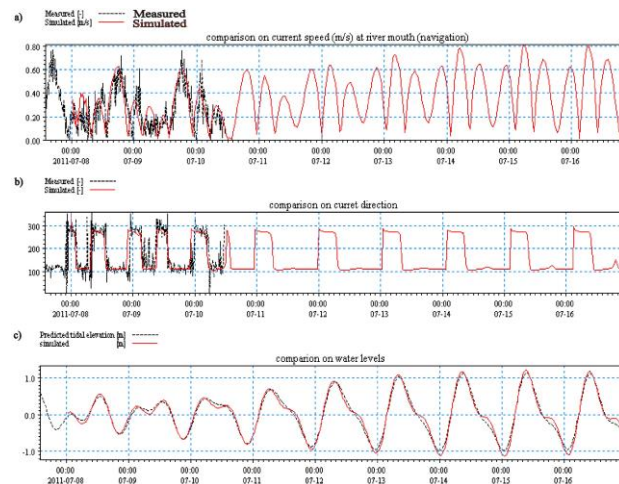


Figure 2. The solid red line represents the simulated results, while the solid black line illustrated the measured data. (a) is calibration for current speed, (b) is current direction and (c) is water levels at the study area.

Results on the maximum and mean current speed in a tidal cycle, which covered both neap and spring tide is shown in Figure-4. Maximum current speed was observed at the few stretches in the estuary, particularly at the navigation channel, the Manir village and the Kpg Cina areas with the magnitude approximately 0.8 ms^{-1} (Figure-4a). Meanwhile the highest mean current speed was defined in the navigation channel and the Manir village with magnitude of 0.3 to 0.4 ms^{-1} , in general the dominant mean current speed in the entire estuary was noted vary from 0.1 to 0.3 ms^{-1} as presents in Figure-4b.

3.3 AD model simulations

Analysis on the spatial salinity concentration at two fixed stations located at the Shah Bandar jetty and fisheries jetty as shown in Figure-5a and 5b respectively, illustrates the measured and simulated results for both stations were presented in good agreement with each other. The concentration of salinity was higher during spring tide compared to neap tide, this finding was consistence with current speed results (Figure-3a), where magnitude of tidal current was recorded higher during the spring tide compared to neap tide. Thus, this phenomenon enables saline water to penetrate further upstream and result in the high concentration of salinity inland (Figure-5a). This correlation has demonstrated that the model is a reasonably efficient tool for predicting salinity intrusion in the study area.

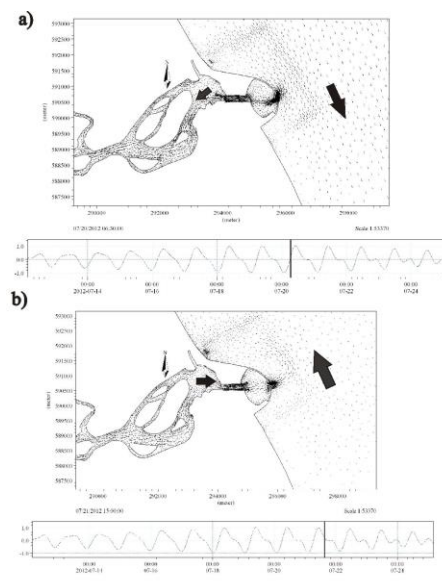


Figure 3. Current flow condition during flood tide (a) and ebb tide (b).

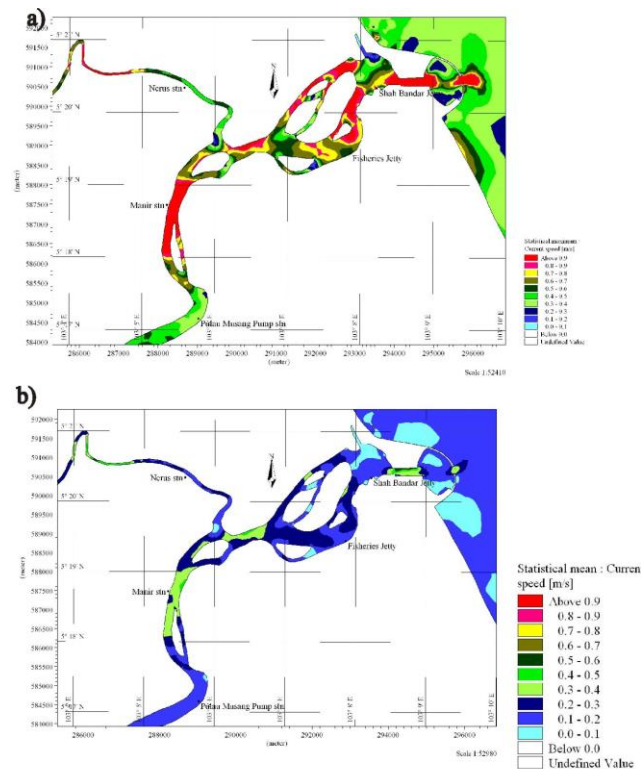


Figure 4. Maximum a) and mean b) current flow at the study area.

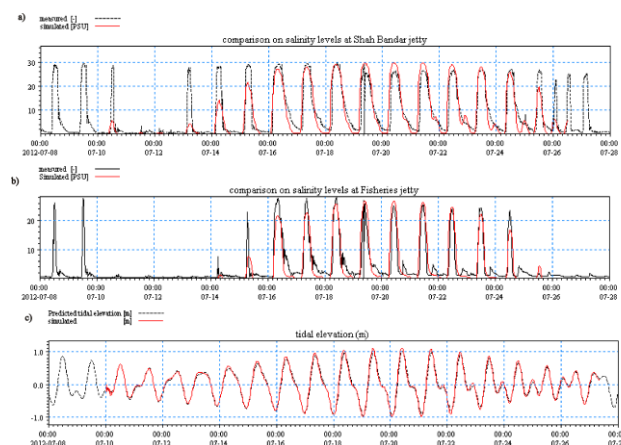


Figure 5. calibration for salinity at the Shah Bandar Jetty a) the fisheries jetty b) and water levels fluctuation c). The solid red line represents the simulated results, while the solid black line illustrated the measured data.

To predict the maximum salinity intrusion into upstream reaches of the study site, simulation has taken into consideration all the offshore boundaries that are subjected to the tidal during the highest high water spring (HHWS), while river discharge boundary condition for the Nerus river station was implied with existing condition during the HHWS. Nevertheless, for the Kpg Tanggol boundary condition, it was subjected to three scenarios, namely existing condition during HHWS, constant river discharge with $30 \text{ m}^3\text{s}^{-1}$ and $100 \text{ m}^3\text{s}^{-1}$ respectively. The predicted maximum salinity intrusion to the threshold of 1.00 ppt on the existing condition was predicted at 9.97 km from the river mouth (Figure-6a). Similarly, Savenije (2010) reported the typical length of the tidal excursion for diurnal tide is 10 km. Perhaps this is due to shorter duration of high water and longer period of low water, 30% and 70% (Figure-3) of daily tidal period respectively, which might contribute to shorter length of tidal excursion. Higher concentration of salinity was identified from the river mouth to the

fisheries jetty with concentration approximately 30.00 ppt. Salinity levels from the fisheries jetty to junction of the Nerus river was vary from 15.00 to 28.00 ppt. Finally, from the the Nerus junction to the Manir village was predicted 1.00 to 15.00 ppt. Salinity concentration of 1.00 ppt halocline was approximately 3.03 km downstream from the water withdrawal station for drinking and agricultural purposes at the Pulau Musang pump house. Thus, under the current situation, the withdrawal station is safe to extract the water from the Terengganu river for daily activities.

As analyzed previously, the minimum freshwater discharge was detected as low as $21 \text{ m}^3\text{s}^{-1}$. However, by performing freshwater runoff at the Kpg Tanggol station boundary condition with constant $30 \text{ m}^3\text{s}^{-1}$ magnitude of river runoff coupled with the highest high spring tide, the salinity intrusion able to penetrate 21.41 km from the river mouth. When this phenomenon takes place, it could interrupt the water intake station located at the Pulau Musang pump house due to high contamination of saline water, approximately 30.0 ppt (Figure-6b).

Result by applying constant freshwater discharge, $100 \text{ m}^3\text{s}^{-1}$, at the freshwater boundary in the Kpg Tanggol station, illustrated the halocline of 1.00 ppt was penetrated further inland with intrusion length was 11.84 km (Figure-6c). The Pulau Musang Pump house is predicted 1.16 km downstream of 1.00 ppt halocline; it is secured from salt contamination and is saved to extract river water for drinking and agricultural use. According to Shaha and Cho (2009) the recommended threshold values of salinity for drinking and agriculture purpose are less than 0.50 and 1.00 ppt respectively. It should be noted that freshwater discharge $100 \text{ m}^3\text{s}^{-1}$ was the minimum requirement of the river runoff at the Kpg Tanggol river gaging station, the actual water discharge upstream of the water intake should be higher, which should takes into considering the water extraction by the water intake stations located at the downstream and associated with the sea level rise factors [12,13,14].

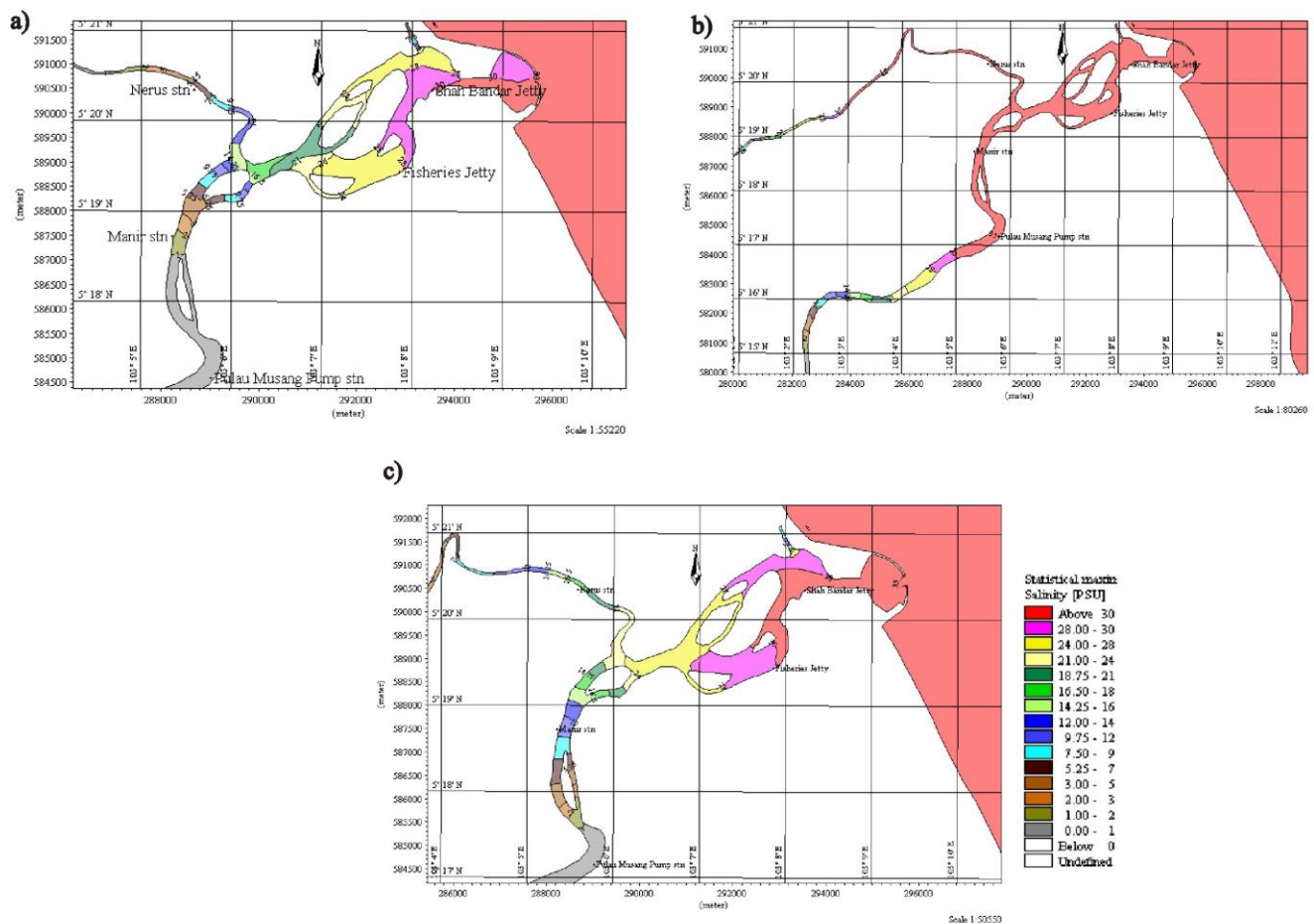


Figure 6. simulated salinity intrusion during HHWS at existing condition a), freshwater discharge at Kpg Tanggol boundary station with $30 \text{ m}^3\text{s}^{-1}$ b) and $Q=100 \text{ m}^3\text{s}^{-1}$ c)

4. Conclusions

An integrated two dimensional models HD (hydrodynamics) and AD (advection dispersion) flexible mesh numerical model were developed to predict the possible of the salinity intrusion in the Terengganu estuary. It was noted during the spring tide, higher tidal velocity with magnitude approximately 0.8 ms^{-1} manages to penetrate saline water further inland. The maximum salinity intrusion was observed at 9.97 km inland from the river mouth. The severity of saltwater intrusion was observed with magnitude of 21.41 km from river mouth, when $30 \text{ m}^3\text{s}^{-1}$ of freshwater discharge was applied constantly at the freshwater boundary at the Kpg Tanggol river gauging station. Nevertheless, when performed freshwater discharge with values of $100 \text{ m}^3\text{s}^{-1}$ at the freshwater boundary, it has identified the water intake station is secure from the salinity contaminant. However, it should be noted that the actual water discharge upstream of the water intake should be higher than $100 \text{ m}^3\text{s}^{-1}$, which takes into considering the water extraction by the water intake stations located at the downstream and associated with the sea level rise factors at the nearshore area.

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