

Impact of Flood Mitigation Project on the River Water Salinity

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Abstract

The impact of flood mitigation project in the Kemaman River Basin was assessed in this study. Salinity intrusion was simulated in the study area by 1D numerical model. A 1-D hydrodynamic model coupled with a salinity model was used to analyze the salinity intrusion within Chukai River after the implementation of the flood mitigation project. The model was calibrated and validated using the data measured in Chukai River at 3 points from January 2007 until August 2013. Water quality simulation of salinity has been carried out once an excellent hydrodynamic model was established. The simulated river flow was reasonably matched to the measured data with R^2 value 0.88, 0.92 and 0.82, respectively. Results suggest that after the realignment of Chukai River, the seawater intrudes further to the upstream river, causing the increasing salinity in the river about 10 - 15 ppt. However, with the floodway development, the channel would allow more water from Kemaman River being discharged into Chukai River. Increased in the volume of water in Chukai River has led to seawater dilution. Further, it invades the unique stretch of Chukai River and takes the salinity back to the initial state. Findings from the implementation of the flood mitigation project in the Kemaman river basin has benefitted the local society, watershed, and the surrounding biota ecosystems. Importantly, a greater prevention with the risk of repetitive flood damage to the buildings and structures in Kemaman area which has significantly achievable.

Keywords: Floodway, Hydrodynamic model, Intrusion, Water quality, Salinity

Introduction

Flood in Malaysia

Flood is a recurrent natural disaster and can bring misery to the country and inhabitants [1]. The most damaging natural disaster in Malaysia is flood [2]. The Malaysian Drainage and Irrigation Department has categorized floods in Malaysia into 2 groups, namely flash floods, and monsoon floods [3]. In Malaysia, the type of flood is categorized under the river flood category, where the entire East Coast region (the State of Pahang, Terengganu, and Kelantan) is combined with high tides under the impact of the Northeast monsoon season with high precipitation [4]. Apart from that, the frequency and intensity of flood events have significantly increased, as resulted in the expansion of the urban areas [5]. Urbanization has also exacerbated flooding problems due to a rise in impermeable areas such as highways, buildings, and parking spaces [6]. With the combination of monsoon seasons and urbanization, floods have become common among a large number of Malaysians.

Flood mitigation project

In an effort to avoid and mitigate the damage and loss of land, death, and spread of infectious disease due to the flood problem, the government of Malaysia has introduced various flood prevention or mitigation measures [7]. In Chukai River Terengganu, the vulnerability and exposure of urban dwellers to flooding have increased due to rapid industrial development [8]. Chukai city is witnessing rapid development as resulted from a high rate of growth in the Terengganu state economy. As a result, Chukai faces a significant setback in the regular flooding of many towns and the surrounding areas [9]. To tackle this challenge, through the Department of Irrigation and Drainage (DID), the government has taken the initiative to begin the project to mitigate flood with the assistance of Jurutera Perunding Zaaba Sdn bhd (JPZ) focus on Chukai city in particular. The project period was conducted for 10 years (2003 to 2013). The outstanding flood mitigation projects are as follow:

- 1) Construction of bund and structure along Kemaman River
- 2) Construction of floodway and 2 bridges
- 3) Repair and realignment of Chukai River.
- 4) Drainage in town

However, this study only focuses on implementing 2 components from the flood mitigation project (construction of floodway and 2 bridges, repair and realignment of Chukai River) that would affect the filtration of saltwater.

Water salinity model

Numerous studies reported salinity distribution and interference are the pivotal environmental factors influencing the survival and distribution of species in estuaries [10,11]. Since salinity is a conservative material, its time and space variance would be primarily due to its advection and flow dispersion [12,13]. Naturally, the seawater intrusion into river mouths mostly due to increasing sea levels, river discharge and breaching coastal areas [14,15]. However, this study believed that the changes in topography associated with the salinity intrusion into the river. The saltwater shifts affect the survival of trees and the habitat of fireflies along the river in Chukai River, as the trees require an optimum saltwater range to thrive [16]. The previous studies had proved that the salinity intrusion increase could be linked to dredging activities, allowing seawater to penetrate the system [17-19].

Salinity is of most importance in estuaries. Salinity is used as a longitudinal dispersion tracer in most water quality modelling exercises in estuaries [20]. Hydrodynamic models provide water quality models with important details, includes advection, dispersion, vertical mixing, temperature, and salinity [21]. A significant number of studies involved with the investigation of the spatial and temporal distribution of salinity in the estuary system [17], using a wide range of hydrodynamic models, including 1D [22], 2D [23, 24], and 3D models [10,25]. The study on saltwater intrusion for Chukai River has none carried out by any researcher. Therefore, this study aims to assess the salinity intrusion in the Chukai River using 1-D water quality (salinity model) after flood mitigation project implemented. The research focuses on the behaviour of salinity distribution before the project implementation and after the completion of the flood mitigation project. Thus, the hydrodynamic model's development was the backbone for the assessment and simulations on the impact. The excessive freshwater supply was found to dilute the concentration of salinity in the river significantly.

Research methodology

The topography of project location

In the Southern part of Terengganu, the Kemaman River Basin is situated on the east coast of Peninsular Malaysia. The Chukai River is a flat, slow-moving tidal river that crosses the Binjai Swamp. Chukai River's total length is around 33 km. Chukai River tributaries include Bungkus River, Ruang River, and Ibok River. Kemaman River is a large river with a total area of approximately 1800 km² and 100 km. The main tributaries of Kemaman River are Cherul River, Tebak River, and Jabor River (**Figure 1**).

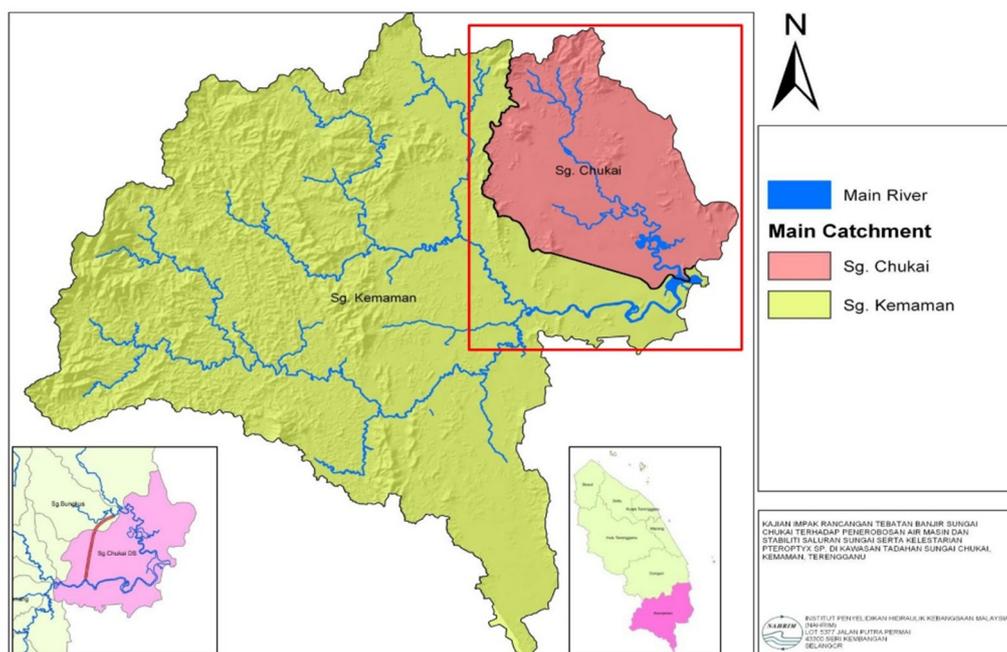


Figure 1 Study area within the Kemaman River Basin.

Preliminary data

The water quality preliminary study was based on the secondary data provided by the Department of Environment (DOE), Malaysia. A total of 8 monitoring stations in the study area, where are 4 stations in Kemaman River and 4 stations in Chukai River. (**Table 1**). From 2003 to 2012, the data were obtained at random 4 or 5 times a year to leave out any bias in the data. The water quality status dissolved oxygen saturated (DO%), dissolved oxygen (DO), mg/L, biochemical oxygen demand (BOD), mg/L, chemical oxygen demand (COD), mg/L, pH, suspended solids (SS), mg/L, ammonia nitrogen (AN), mg/L and salinity, ppt is among the most important variables in communicating water pollution.

Table 1 Location of water quality stations monitored by the Department of Environment.

Basin	River	Station No.	Longitude (X)	Latitude (Y)
Kemaman River	Ransan	4KM02	103.2444	4.3833
	Cherul	4KM04	103.1751	4.1319
	Kemaman	4KM11	103.2111	4.2694
	Kemaman DS	4KM12	103.3130	4.2149
Chukai River	Ibok	4CK02	103.3361	4.3750
	Chukai	4CK03	103.4342	4.2569
	Ruang	4CK04	103.4153	4.2727
	Bungkus	4CK06	103.3713	4.3040

Salinity model setup

The aims of the saltwater intrusion modelling in Sg. Chukai is linked to the ecosystem of the shown tree inhabited by the population of fireflies. In this study, the 1-D water salinity model developed consisting of water salinity model setup and water salinity model results and interpretation. The salinity intrusion within the Sg. Chukai will be assessed using a 1-D water quality model. To stimulate the 1-D water salinity model, a calibrated 1-D hydrological and hydrodynamic computer model of the Chukai River and Kemaman River system developed using Infoworks RS will be used. **Figure 2** shows the

process flow chart of the water salinity model using infoworks RS. This study proposes to perform a few simulations of numerical water quality consisting of:

1) Before flood mitigation works (involving dredging works done for Chukai River from CH 8330 to CH 11500).

2) After proposed flood mitigation works (involving floodway).

Inforworks water quality is used to model water quality in open channels. The quality simulation engine is separate from the hydraulic engine (which provides hydrodynamics), so water quality simulation requires 2 separate simulations. The hydraulic model is first performed, then the hydrodynamic data can be used for one more quality simulation. salinity models rely on hydrodynamics to explain the flow of water and the mixing phase. Knowledge of hydrology, meteorology and atmospheric physics is required to determine external loadings and conditions at the air-water interface. The model also draws on chemical kinetics and biochemistry to determine dissolved and particulate nutrients [26].

Water quality simulation of salinity was carried out once a successful hydrodynamic model has been developed. From 1 January 2011 to 31 December 2013, a simulation was carried out to demonstrate the pattern of saltwater intrusion 1) before the realignment of Chukai River, 2) after realignment of Chukai River, and 3) with the proposed floodway from Kemaman River into Chukai River. In the downstream, an input of salinity concentration was placed as 35 ppt while 0 ppt of salt in other catchments.

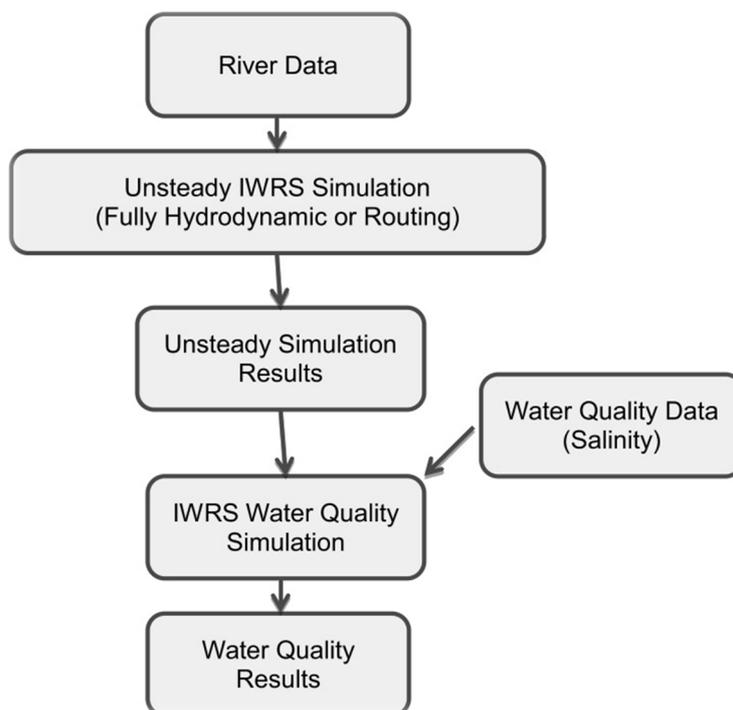


Figure 2 Process flow chart of salinity modelling using info works RS in 1-D mode.

Results and discussion

Water quality status in the Kemaman River Basin

The phenomena of saltwater intrusion into the Chukai River significantly affect water quality. The water quality index (WQI) was determined using the formula used to calculate by DOE. The index was derived from 6 sub-indices: DO per cent saturation, BOD₅, COD, pH, NH₃-N, and TSS. Overall, the WQI for the particular river (Chukai River Basin and Kemaman River Basin) from the year 2002 - 2012 in the range II and III. Based on the water quality index classification, the range of concentration for DO is 5 - 7 mg/L (Class II) and 3 - 5 mg/L (Class III). For BOD, the range concentration for Class II is 3 mg/L and

Class III is 6 mg/L, while COD range concentration for Class II is 25 mg/L and Class III is 50 mg/L. The acceptable pH value for Class II and III within the range 5 - 9. The concentration of NH₃-N for Class II and III is within the range 3 - 6 mg/L. The range concentration of TSS for Class II and III is 50 - 150 mg/L [27].

The data used to calculate the WQI for both rivers Chukai and Kemaman rivers are summarised in **Tables 2 and 3**.

Table 2 Summarization of water quality measured at Chukai River Basin (Sungai Bungkus).

River	Parameter	Average	Min	Max	Remarks (based on average)
Sg. Bungkus	DO%	50.8	3.57	93.3	Poor
	DO (mg/L)	4.16	3.23	7.23	Class III
	BOD (mg/L)	3.24	1.0	8.0	Class II
	COD (mg/L)	25.0	7.0	59.0	Class II
	TSS (mg/L)	14.58	1.0	58.0	Class I
	pH (mg/L)	6.44	4.68	7.91	Class I
	AN (mg/L)	0.24	0.03	3.40	Class I
	Salinity (ppt)	0.61	0.02	5.54	-
Sg. Ruang	DO%	43.0	4.5	99.1	Poor
	DO (mg/L)	3.5	1.1	7.5	Class III
	BOD (mg/L)	4.9	1.0	14.0	Class II
	COD (mg/L)	36.4	10.0	80.0	Class II
	TSS (mg/L)	21.0	2.0	102.0	Class I
	pH (mg/L)	6.7	5.6	8.4	Class I
	AN (mg/L)	1.1	0.0	5.4	Class III
	Salinity (ppt)	0.2	0.0	1.3	-
Sg. Chukai	DO%	74.4	5.8	96.7	Acceptable
	DO (mg/L)	5.5	2.7	7.3	Class II
	BOD (mg/L)	3.2	1.0	15.0	Class II
	COD (mg/L)	27.3	11.0	83.0	Class II
	TSS (mg/L)	32.4	1.0	191.0	Class I
	pH (mg/L)	6.9	5.7	8.0	Class I
	AN (mg/L)	0.2	0.0	1.2	Class I
	Salinity (ppt)	12.1	0.1	32.2	Tidal influence
Sg. Ibok	DO%	75.7	6.6	93.6	Acceptable
	DO (mg/L)	6.1	5.0	7.7	Class II
	BOD (mg/L)	2.1	1.0	10.0	Class I
	COD (mg/L)	17.5	5.0	39.0	Class I
	TSS (mg/L)	34.7	5.0	266.0	Class I
	pH (mg/L)	6.6	5.5	7.7	Class I

AN (mg/L)	0.1	0.0	0.4	Class I
Salinity (ppt)	0.0	0.0	0.1	-

Table 3 Summarization of water quality measured at Kemaman River Basin (Sungai Kemaman DS).

River	Parameter	Average	Min	Max	Remarks (based on average)
Sg. Kemaman DS	DO%	77.7	39.6	94.0	Acceptable
	DO (mg/L)	6.04	3.27	7.63	Class II
	BOD (mg/L)	2.30	1.0	5.00	Class I
	COD (mg/L)	20.43	5.0	174.0	Class I
	TSS (mg/L)	67.78	4.0	356.0	Class II
	pH (mg/L)	6.97	4.06	8.27	Class I
	AN (mg/L)	0.16	0.01	1.03	Class I
	Salinity (ppt)	3.63	0.01	28.5	Tidal influence
Sg. Kemaman	DO%	90.8	48.1	102.3	Excellent
	DO (mg/L)	7.3	4.0	9.6	Class I
	BOD (mg/L)	1.7	1.0	6.0	Class I
	COD (mg/L)	15.3	2.0	40.0	Class I
	TSS (mg/L)	33.5	2.0	160.0	Class I
	pH (mg/L)	7.0	5.7	8.1	Class I
	AN (mg/L)	0.1	0.0	0.2	Class I
	Salinity (ppt)	0.0	0.0	0.1	-
Sg. Cherul	DO%	87.0	48.3	99.6	Adequate
	DO (mg/L)	6.9	4.0	8.0	Class II
	BOD (mg/L)	2.0	1.0	6.0	Class II
	COD (mg/L)	15.8	5.0	35.0	Class II
	TSS (mg/L)	84.7	4.0	419.0	Class II
	pH (mg/L)	6.9	5.0	8.4	Class II
	AN (mg/L)	0.1	0.0	0.4	Class II
	Salinity (ppt)	0.0	0.0	0.1	-
Sg. Ransan	DO%	66.0	12.6	98.7	Acceptable
	DO (mg/L)	5.1	0.9	7.8	Class II
	BOD (mg/L)	14.1	1.0	102.0	Class IV
	COD (mg/L)	89.3	14.0	1250.0	Class III
	TSS (mg/L)	117.5	1.0	895.0	Class II
	pH (mg/L)	7.2	6.1	9.0	Class I
	AN (mg/L)	9.0	0.0	91.4	Class V
	Salinity (ppt)	0.0	0.0	1.9	-

Chukai River Basin demonstrated that water quality status in Ruang River was slightly lower compared to the other rivers. The deterioration of the river water quality contributed by the lowest value of DO in Ruang river, ranging from 1.1 - 7.5 mg/L compared to the acceptable value of the DO, usually ranging from 6 to 14 mg/L [28]. Meanwhile, the Ransan River within the Kemaman River Basin indicated the lowest water quality index which categorized as class III (62.2) (**Table 4**) with average DO% was 66 %.

Table 4 Water quality index for Kemaman River Basin from 2004 - 2012.

Year	Cherul	Kemaman	Ransan
2004	89	89	48
2005	86	87	74
2006	91	91	81
2007	89	87	62
2008	84	85	75
2009	89	88	58
2010	86	88	52
2011	87	86	60
2012	87	85	50
Average WQI	87.6	87.3	62.2
Class	II	II	III

Based on 6-parameter values, the water quality level of BOD, COD, and AN were the major factor loadings attributable to the deterioration of the water quality level in the study area. Apparently, the result obtained from this study was in line with the Malaysia environmental quality report (2016), which reported that the water quality of Ransan River was moderate [29]. Both rivers were classified under Class III of the Water Quality Standard. The Class III of Water Quality Standard was achieved as both Ruang River and Ransan River being surrounded by the residential, agricultural, and plantation areas [30]. These findings proved the evidence that anthropogenic pollutants, which include livestock wastes, human excrements, and fertiliser, have led to the deterioration of the river water quality [31].

Salinity model calibration

Model calibration is a process of adjusting parameters to suit the simulated results with the observed data with minimal errors [32]. A salinity model calibration was performed using the observed data taken from 16 March 2011 (before river realignment) and (after river realignment) 2 - 7 November 2013. The results of the observed and simulated flows at 3 calibration points were within the range of coefficient of determination (R^2) value, which are 0.88, 0.92 and 0.82, respectively. The comparison between the simulated and the observed data at Jeti Mini Zoo (CH400) and Jeti Bakau Tinggi (CH12150) have shown in **Figures 3a** and **3b**. CH400 and CH12150 were chosen for the calibration purpose based on the basis of the quality and accessibility of the data collected in the study area. The result shows the salinity model was well-calibrated when the simulated data was in good fit with the observed data. From the **Figure 3a**, the salt concentration indicates smooth reading and did not has significant changes during the calibration process. Moreover, the simulated data was under observed data instead of the salt concentration in **Figure 3b**.

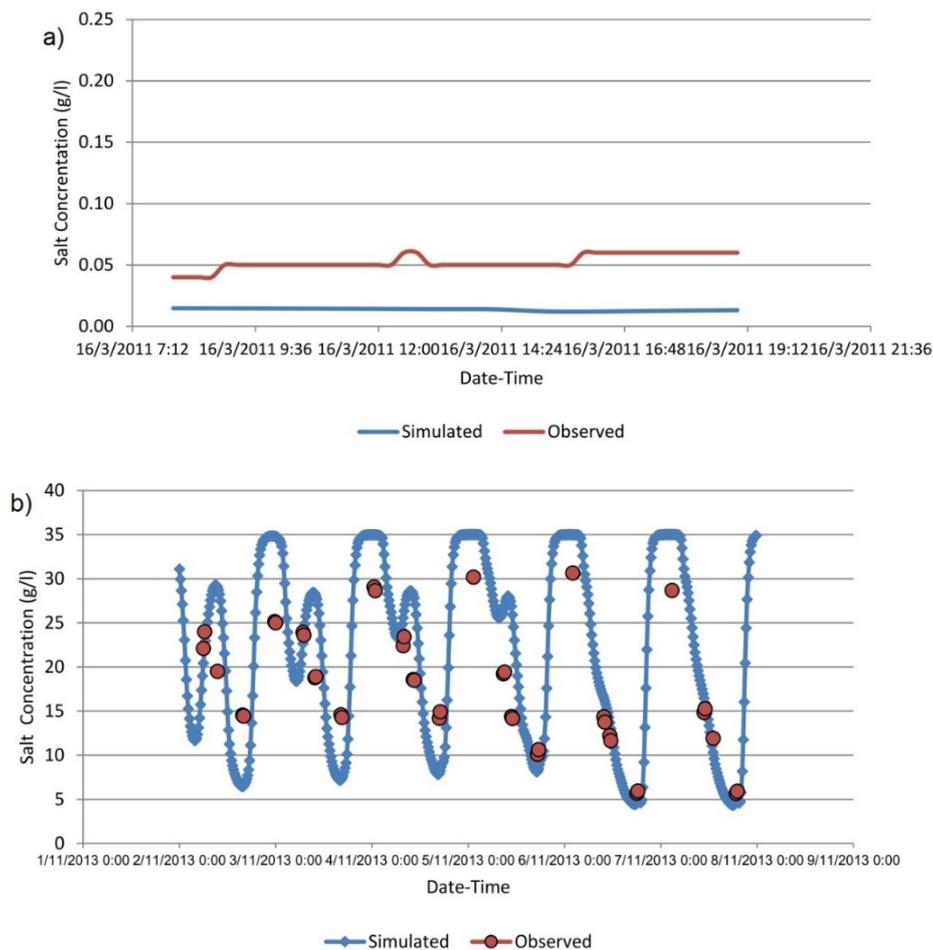


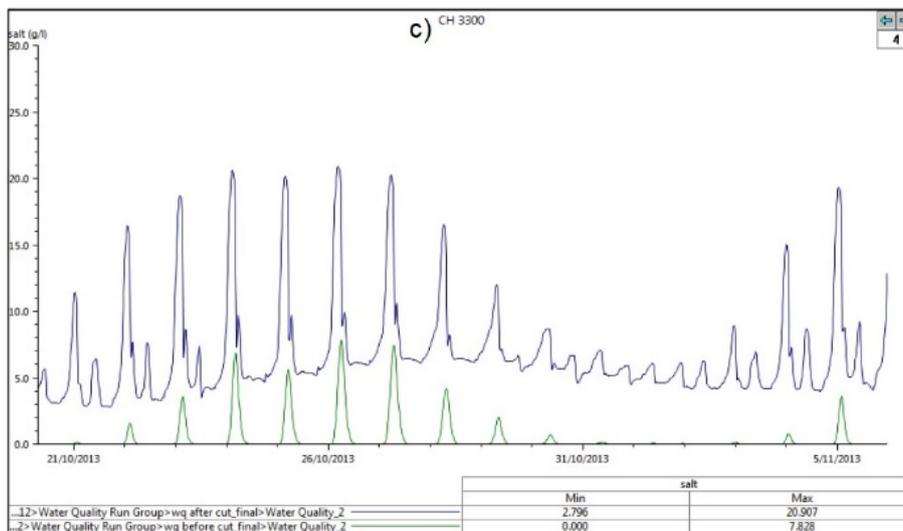
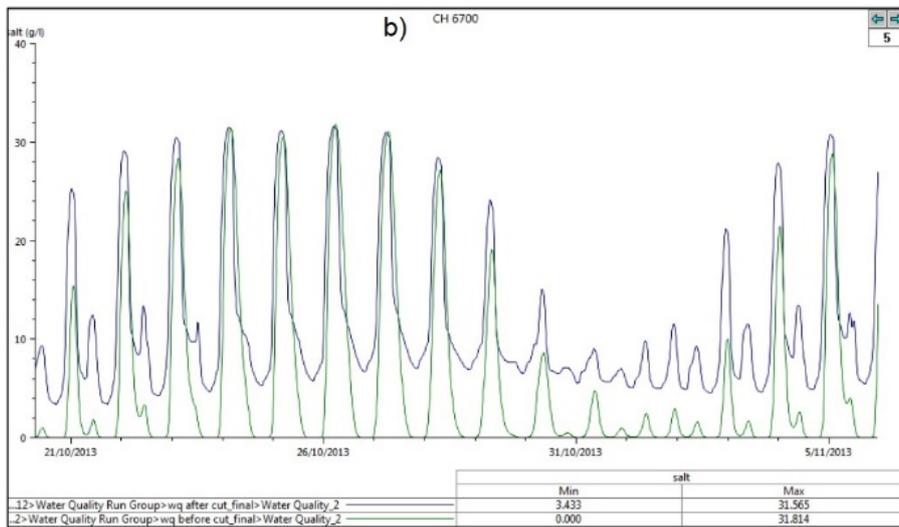
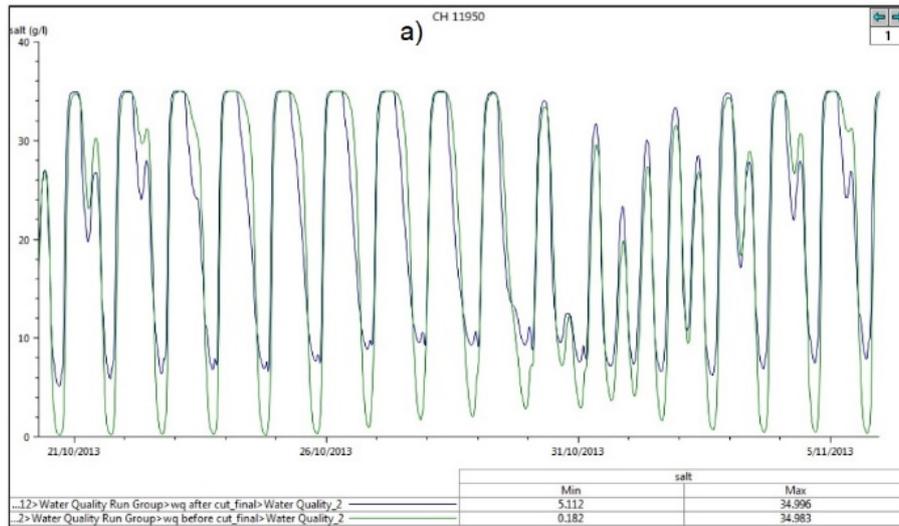
Figure 3 Comparison between simulated and observed data of salt concentration at a) Jeti Mini Zoo (CH 400) (before river realignment) and b) Jeti Bukit Tinggi (CH 12150) (after river realignment).

Model analysis

An analysis of saltwater intrusion has been made for a few scenarios; 1) before and after the realignment of Chukai River and 2) existing Chukai river and proposed floodway. The analysis of saltwater intrusion in Chukai River has been made at 5 points along the river.

Before and after a realignment of Chukai River

The comparison of salt concentration at 5 points along the Chukai River before and after the river’s realignment shows the salt concentration intrudes further upstream after the Chukai River has been realigned as shown in **Figures 4a - 4e**.



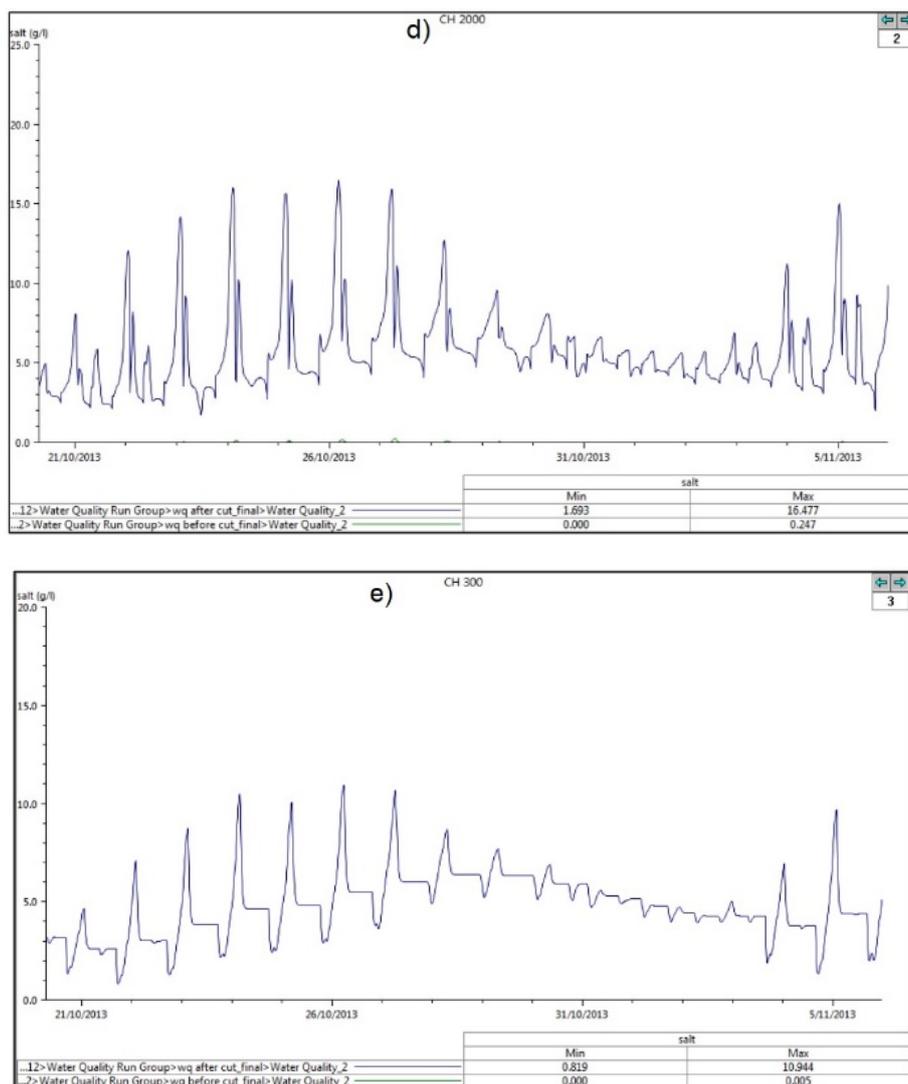


Figure 4 Comparison of salt concentration before (green line) and after realignment (blue line) of Chukai River at a) CH11950, b) CH6700, c) CH3300, d) CH2000 and e) CH300.

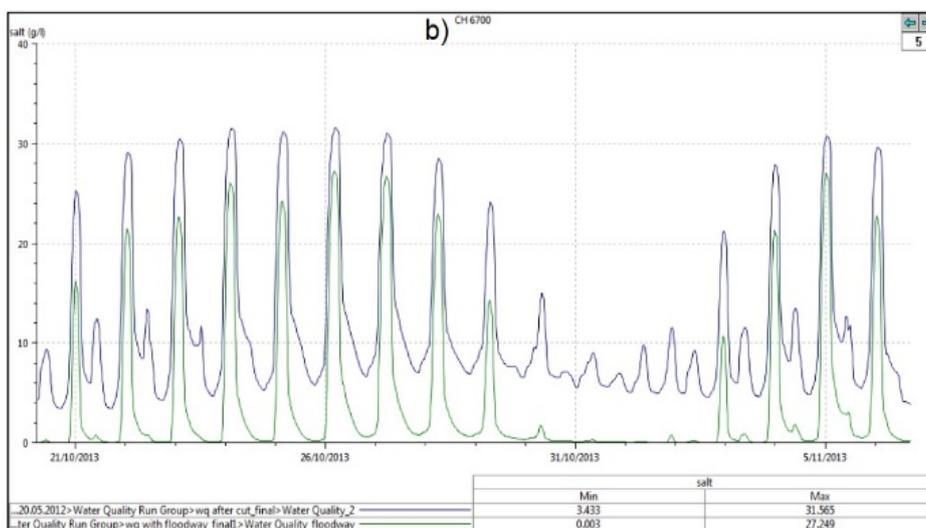
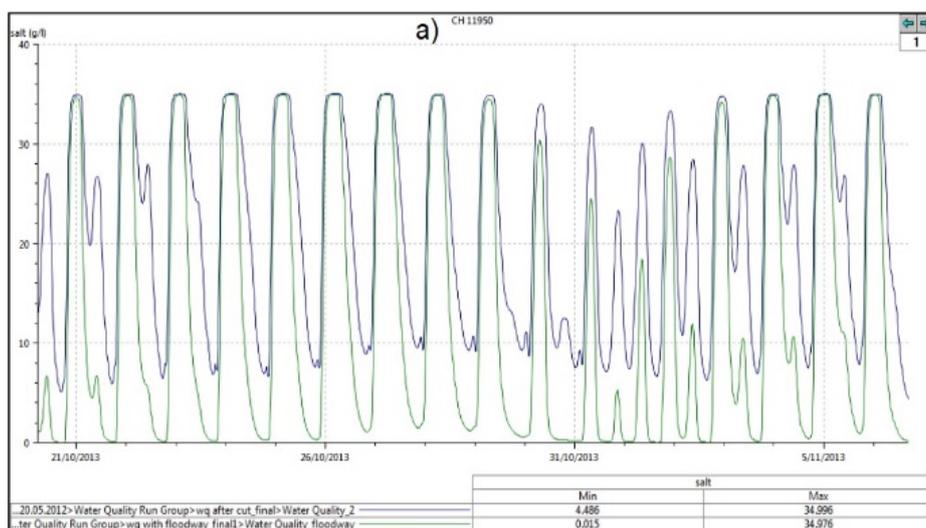
The saltwater intrusion phenomenon occurred when the Chukai River has (straightened) been aligned further upstream of Chukai River during the dry season. A comparison of the salt concentration indicates that there is less saltwater at this stage before the river is realigned, but after the river is realigned, saltiness increases. The saltiness trend appeared to be increased (**Figures 4d** and **4e**) ranges of 10 - 15 ppt. It was noticeable that the salinity level at the upstream (**Figure 4e**) freshwater supply was considerably lower than the downstream (**Figure 4a**). The lower level of salinity indicated a very low intrusion of seawater into the Chukai river [33]. Compared to upstream, the higher degree of salinity was clarified by the salt concentration caused by seawater intrusion due to the position of the river near to the shore. However, the influence of tidal waves during dry periods had increased the concentration of salinity in the estuaries and the movement of seawater towards the upstream [35]. In contrast, the impact of freshwater in the estuaries is reduced; thus, the salinity accumulation becomes greater [35]. Therefore, reducing the gradient forcing of surface elevation enables tidal rectification as a vital mechanism for saltwater intrusion [36], as shown in **Figure 4a** (CH11950). The location of the proximity of the river to shorelines experiencing the effect of both tides and river discharge associated with the salinity distribution [37].

The findings of this study implied that the river drainage activities could significantly influence the spatial distribution of river salinity. During the river realignment works, the dredging activities confounded the increased intrusion of saltwater. Dredging impacted seawater's water quality and

represents a potential risk to the environment, the prolonged seawater intrusion during tidal excursion upstream [38]. Similarly, the findings by Ijaz *et al.* [33] and Maren *et al.* [39] revealed that the channel deepening activities had increased the saltwater intrusion. Another study by Siles-Ajamil *et al.* [40], using the exploratory model, suggested that the channel deepening activities increases the salinity interference and pushes upstream maximum salt gradient.

The existing Chukai River and proposed floodway

The results show that the freshwater was diverted from Kemaman River to Chukai River, decreased the salt concentration in Chukai River through the floodway. **Figures 5a - 5e** compare the salt concentration along the Chukai River between the existing river system and the proposed floodway. This finding infers the influence of the freshwater discharge from the Kemaman River resulting in a rise in the water level upstream of the Chukai River. Thus, increasing river water discharge from Kemaman River, decreasing salinity in the Chukai River. As water flow carries salt, it is then not surprising since the increasing volume of river water will dilute the amount of salt in the water [18]. This study, however, in line with the previous studies conducted in the Amazon by Kosuth *et al.* [41] and the Yangtze by Zhang *et al.* [42]. It was found that much greater tidal effects on reversal discharge amplitudes. The tidal current impacted the river discharges level in the sense that it propagates the salinity intrusion and reversals the tidal current farther into the shore. As the salinity morphology pattern in the river is associated with freshwater discharge, however many studies applied the hydrological model for salinity intrusion control in the river through freshwater control [33,43,44].



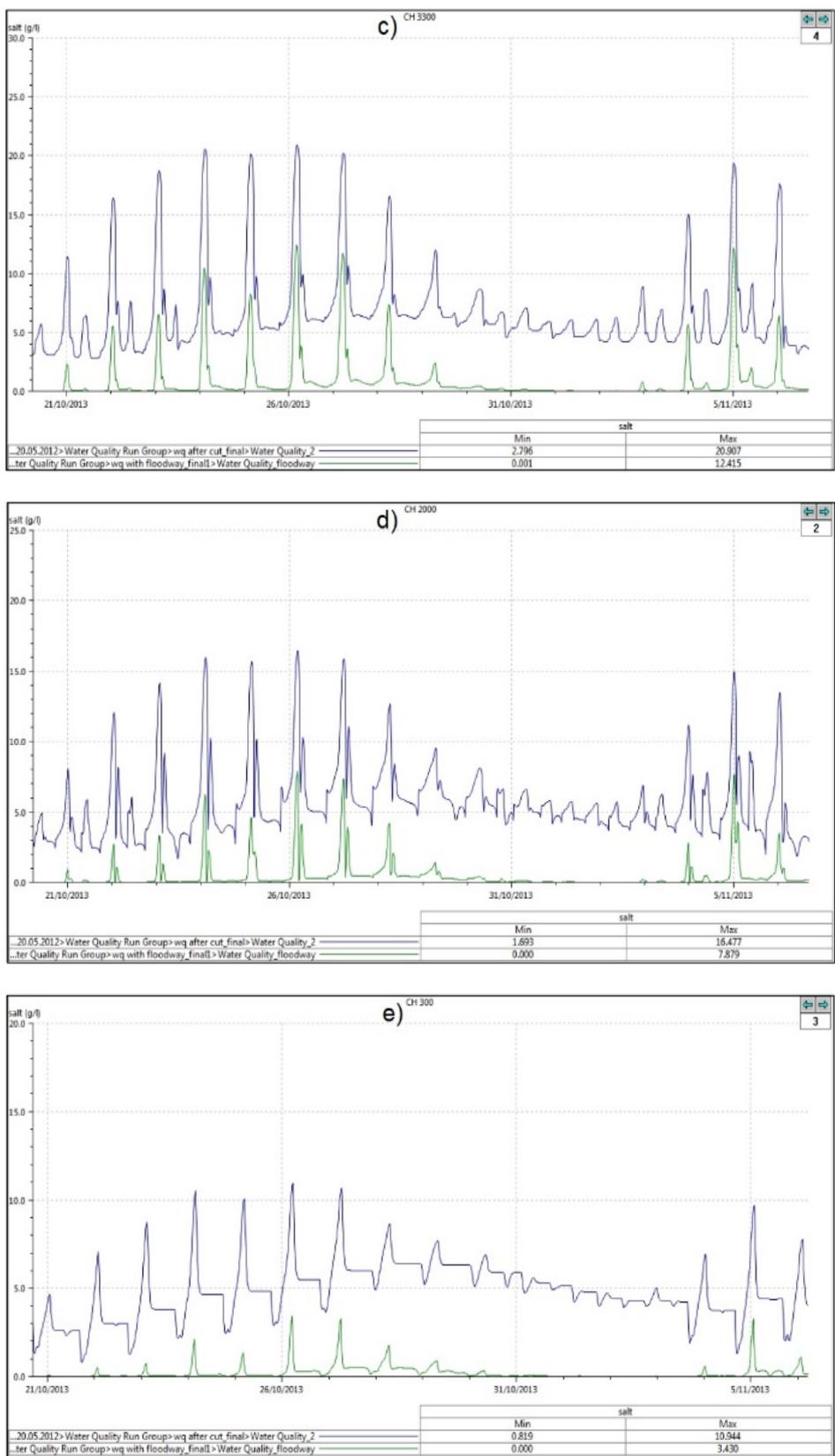


Figure 5 Comparison of salt concentration between existing river (green line) and proposed floodway (blue line) of Chukai River at a) CH11950, b) CH6700, c) CH3300, d) CH2000, and e) CH300.

Before realignment works of Chukai River, after realignment (existing Chukai River) and proposed floodway

A comparison was made on the above scenarios (before and after river alignment with the proposed floodway) at CH 300 to assess salt concentration changes (Figure 6). As shown in Figure 6, upon the straightening of the river, the salt concentration increased. However, after the floodway was completed, the level of salt concentration back to the original. There were not many changes in the velocity before and after river realignment works and the construction of floodway, and the tidal eddy variations were around 0.1 m/s. This study further demonstrated that before the proposed flood diversion, the existing condition of Chukai River, i.e., after river straightening, the salinity of Chukai River drastically increased and intruded further into the upstream river. Apparently, after the flood diversion and the straightening of Chukai River alone would trigger more saltwater intruding towards Chukai River fast. Subsequently, the salinity in Chukai River slightly increases—during the dry season. The channel would allow more water flows from Kemaman River with the proposed flood diversion channel. As a result, the volume of water in Chukai River increased. More water in Chukai River dilutes the seawater that invades the river's specific stretch and returns salinity to its original state. As a result, the straightening of Chukai River, coupled with the flood diversion channel, will have little impact on the biota region's salinity.

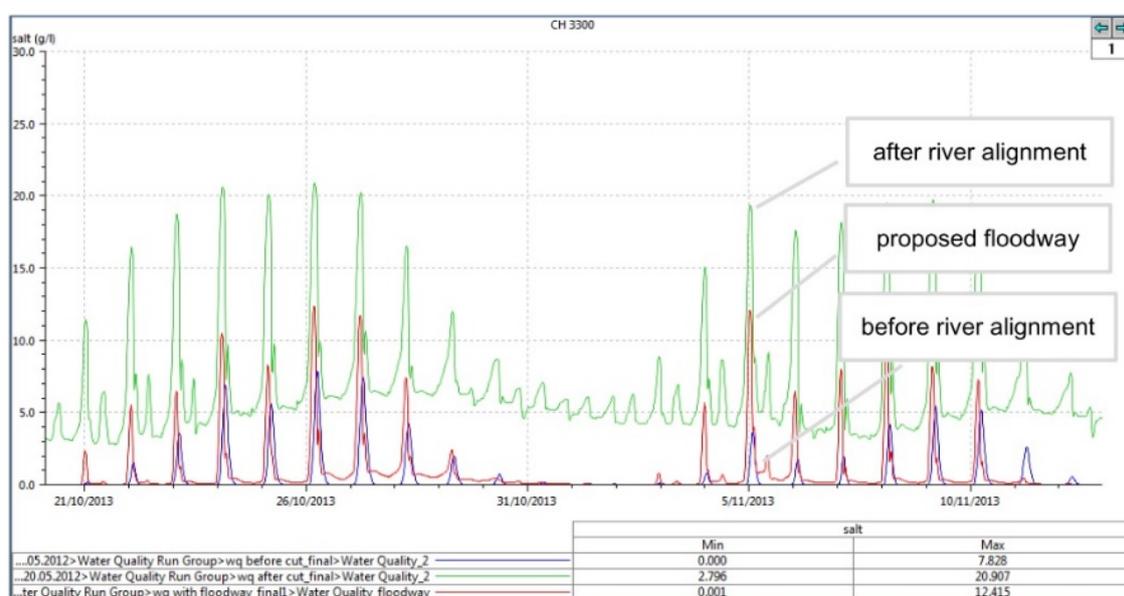


Figure 6 The Comparison of salt concentration in Chukai River(i) before river alignment (blue line), (ii) after river alignment (green line), and (iii) with proposed floodway (red line) at CH 3300.

Proposed floodway with 2 events; normal flow and 50-year ARI

The comparison of salt concentration at CH 3300 is shown in Figure 7, which represents 2 events; viz. natural flow and 50-year ARI. After flood mitigation, a simulation was carried out to run a 50-year ARI design flow for the scenario. For 50-year ARI, the flood peak discharge was 1947 m³/s, where the model simulates 1933 cu.m/s and gave approximately the same amount of discharge from Kemaman River before entering the floodway. In order to study the flood actions, an additional simulation for 10-year ARI and 5-year ARI were performed. The simulations show that the planned floodway can only cater for rainfall flows of up to 5-year ARI design (1348 m³/s at CH48, 885 m³/s at Floodway-FW CH0). Further, Figure 7 shows that salt concentration during the 50-year ARI case has been diluted significantly. As the amount of river water flow increases, the salinity decrease. The salt concentration level has taken approximately 1 week to return to normal conditions.

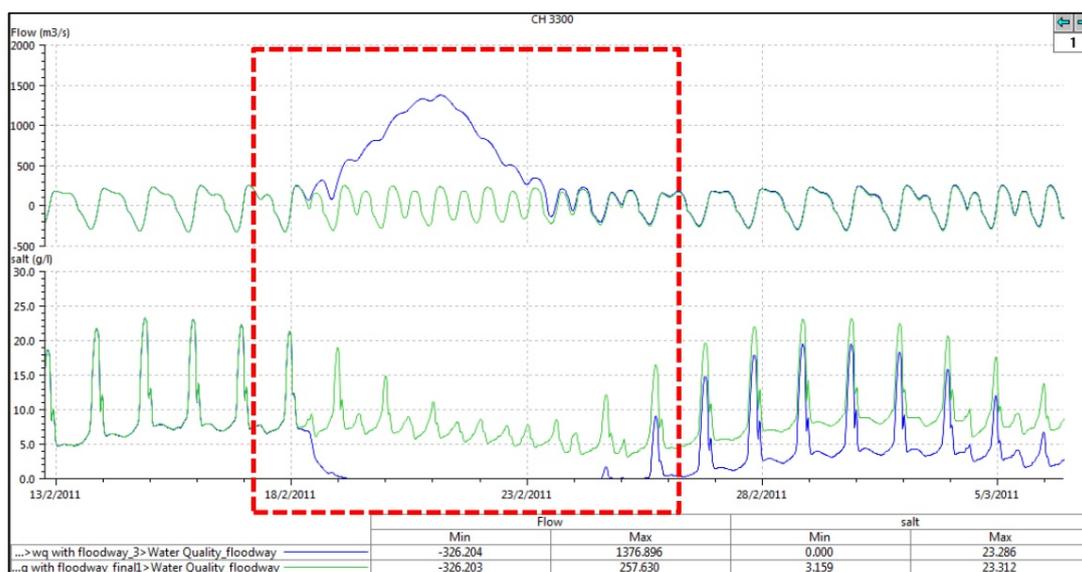


Figure 7 The Comparison of normal flow (green line) and 50-year ARI (blue line) with salt concentration at CH 3300.

Conclusions

The research findings are as follow:

- 1) The effect of salinity intrusions increases due to the construction of a floodway and 2 bridges and the repair and realignment of Chukai River.
- 2) The phenomenon of saltwater intrusion was observed during the alignment of Chukai River (straightened). The saltwater intrudes further upstream of Chukai River, particularly during the dry season.
- 3) The channel would encourage more water from Kemaman River flowing towards Chukai River with the development of floodway. The increased water volume of Chukai River gave a potential of seawater dilution that intrudes on a specific stretch of Chukai River and the salinity back to its original condition.
- 4) The flood mitigation project implemented in the Kemaman River Basin, however, did not significantly impact the changes in the river water quality. Obviously, the flood mitigation project did not affect the sustainability of the study area.
- 5) The project has provided a greater prevention with the risk of repetitive flood damage to the buildings and structures in Kemaman area has significantly achievable.

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