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Study on the Impact of Tidal Effects on Water Quality Modelling of Juru River, Malaysia

[1]Mohd Ekhwan Toriman, [2]Norbaya Hashim, [2]Abd. Jalil Hassan, [3]Mazlin Mokhtar, [4]Hafizan Juahir, [5]Muhamad Barzani Gasim and [5]Md Pauzi Abdullah

[1]School of Social Development and Environmental Studies, FSSK Universiti Kebangsaan Malaysia, 43600 Bangi Selangor, Malaysia
[2]Hydraulic Engineering Division, National Hydraulic Research Institute of Malaysia (NAHRIM), Jalan Putra Permai, 43300 Seri Kembangan, Selangor Darul Ehsan, Malaysia
[3]Institute of Environmental and Development (LESTARI), Universiti Kebangsaan Malaysia, 43600 Bangi Selangor, Malaysia
[4]Faculty of Environmental Studies, University Putra Malaysia, 43400 Serdang Selangor, Malaysia
[5]School of Environment and Natural Resource Sciences, FST, Universiti Kebangsaan Malaysia, 43600 Bangi Selangor, Malaysia

Corresponding Author: Dr. Mohd Ekhwan Hj Toriman, School of Social Development and Environmental Studies, FSSK. Universiti Kebangsaan Malaysia, 43600 Bangi, Selangor, Malaysia

ABSTRACT

This study on water quality modelling in Sungai Juru, Penang was undertaken as one of the most polluted rivers in Malaysia and is literally known as the 'dying river'. The research objectives are to assess the parameters that govern the amount of pollutants in the river and to identify appropriate measures to improve the river water quality. The main pollution sources are pig waste, discharge from agro-based industries, dumping of municipal and industrial waste. Due to its relatively flat bed gradient, Sungai Juru experienced tidal effect up to a distance of 13 km from the estuary. As a result, pollutants in the river are hardly discharged into the sea. This research on Dissolved Oxygen (DO) parameter has been carried out to develop a rehabilitation solution for Sungai Juru by using the numerical hydrodynamic modeling technique simulated by I-D Infoworks R.S software. The modeling involved two phases namely, development of a flow model followed by a water quality model. After the model has been successfully calibrated, the pollutant behaviour under various scenarios can be investigated. The hydraulic study of Sungai Juru revealed that the velocity at STJ02 ranging from -0.1 to +0.12 m sec^{-1} during high and low tide, respectively. Based on this velocity, traveling time from S TJ02 (Sungai Juru) to STJ01 (Sungai Rambai) (3.5 km) is approximately between 9-10 h. The duration provides ample time for photosynthesis to occur resulting high DO ranging from 4-10 mg at STJ01. The information is useful to determine pollution characteristics in Sungai Juru particularly related to tidal impacts. It is hoped that the modeling technique developed can be applied in other rivers in Malaysia which are subjected to tidal influences.

Key words: Sungai Juru, numerical modeling, pollution, tidal effect, water quality modeling

INTRODUCTION

Deteriorated water quality in Malaysia should be undertaken to improve current conditions and to protect human and environmental health. In the last decades, study on water-quality modeling has been an active aspect in environmental management (Toriman, 2010; Juahir *et al.*, 2004, 2010; Juahir *et al.*, 2004; Gasim *et al.*, 2006; Azzellino *et al.*, 2006). Malaysia, since 20 years ago, computer simulation often an integral part of the decision-making process particularly in water quality problems (Khalil *et al.*, 2004; Hassan, 2005; Toriman *et al.*, 2003; Toriman and Karim, 2008). Models and simulations allow rapid and varied evaluation of causes and effects and the principal advantage is that they enable an analysis of even long-term actions with limited investment costs. In this regards, mathematical models are always useful tools for water quality simulation and prediction. They can project consequences of alternative management, planning, or policy-level activities, such that effective management schemes can be identified (Einax *et al.*, 1998; Stambuk-Giljanovic, 1999). The Department of Environment (DOE) as the most polluted river in Malaysia has classified Sungai Juru. The water is so toxic that it is unsafe for drinking even after being boiled. Its Water Quality Index remains at Grade IV and V indicating that the river is excessively polluted and no fish would survive in such rivers. One of the main factors is urbanization which is the most forceful of all land use changes affecting the hydrology and water quality of an area. It reduces storage capacities and shortened concentration time resulting in high peak flows that could cause floods with increasing frequency and magnitude. As more lands in the basin of Sungai Juru are turning into urbanized areas, the river is at risk of becoming an open wastewater sewers. In Sungai Juru, the river has been deteriorating over the years. In 1991, this river has been classified by the Department of Environment (DOE) as one of six rivers in Malaysia in the much polluted category in terms of DOE Water Quality Index (WQI) (DEM, 1991). Meanwhile, in 2004, DOE classified Sungai Juru as the most polluted river in Malaysia with WQI value equal to 49 which is classified as Class IV (DEM, 2004). This has been brought about by indiscriminate discharge of industrial effluents, domestic and animal wastes into the river. This research has been carried out to develop a rehabilitation solution for Sungai Juru by using the numerical modeling technique. As this river receives pollutions from point and non point sources, the traditional method using simple monitoring and sampling are not adequate to describe the pollutant levels in relations to tidal impacts. Therefore the use of InfoWork R.S software (Wallingford Software, 2008) found to be promising in predicting water pollutions by simulating certain water quality parameters.

Concerns about the water quality modeling using InfoWork R.S have been expressed in a number of recent studies and reports (Toriman *et al.*, 2010; Law *et al.*, 2007; Mah *et al.*, 2007). These concerns surfaced both from Malaysia and worldwide perspectives particularly in urban and man made rivers (Devoldere *et al.*, 2009; Walling Software, 1992; Methods *et al.*, 2003).

The objectives of this study are to develop 1-dimentional water quality model for Sungai Juru basin in Malaysia using unsteady flow program, to investigate parameters, which influence the pollution in the river and to identify major sources contributing to pollution of the river. The information obtained from this model is useful in order to define pollution characteristics along the reach of Sungai Juru.

MATERIALS AND METHODS

Study area: Sungai Juru which is considered among the dense area is located in Seberang Perai in the state of Pulau Pinang, Malaysia with a total catchment area of 60.5 km^2 (Fig. 1). The river is called by different names, the upper part is known as Sungai Permatang Rawa, the middle part is Sungai Rambai while the downstream channel is called Sungai Juru. The river flows from Bukit

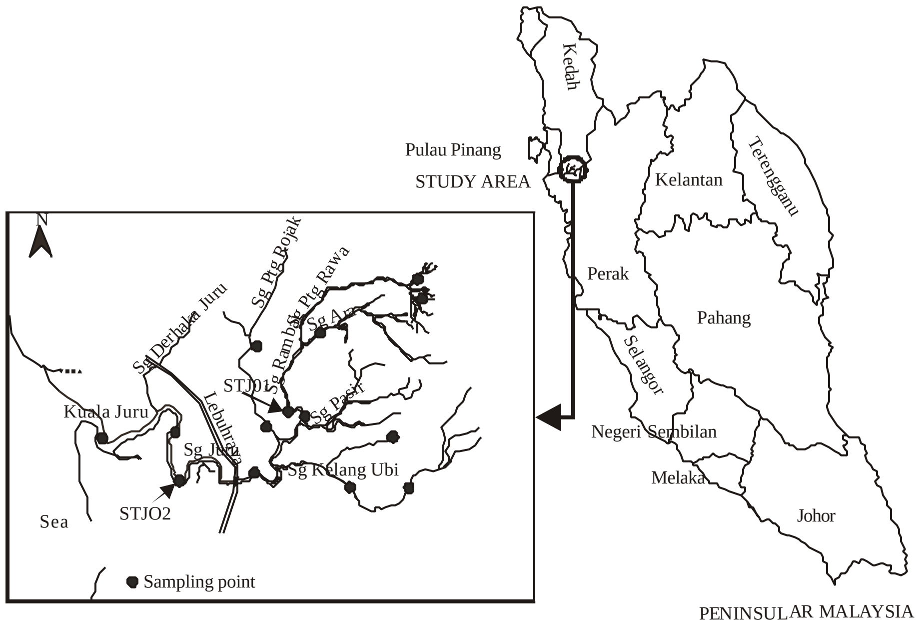

Fig. 1: Sungai juru basin and location of the sampling points

Minyak area towards the west and discharges into the Straits of Melaka. The total length of the river is about 15.62 km. It has three major tributaries, namely Sungai Ara, Sungai Kilang Ubi and Sungai Pasir, including one drain namely Parit 4. A large portion of the catchments is made up mainly of industrial and residential area. In 2006, the total population within the catchments is approximately 362,400.

This study involved field measurements, data collection and development of water quality model, which include hydraulic and water quality simulation from 2006 and 2007 in the selected water quality monitoring sites in the Sungai Juru, Seberang Perai Malaysia. The water quality model shall be able to describe the present situation, predict future trend and identify the major pollution sources. The water quality modeling process is shown in Fig. 2.

InfoWorks' water quality module is used to model water quality in open channels. As shown in Fig. 2, the two-way data input and output model adopted a hydrodynamic flow simulation to capture advection and diffusion due to different flow conditions. In this respect, the water quality module models the transport of pollutants along open channel reaches by the one-dimensional advection-diffusion equation. The transport of pollutants is modeled by a finite difference approximation to the one-dimensional advection-diffusion equation as below:

$$\frac{\delta(CA)}{\delta t} = -\frac{\delta(uCA)}{\delta x} + \frac{\delta}{\delta x}\left(DA\frac{\delta C}{\delta x}\right) + S,$$

where, C is pollutant concentration (kg m^{-3}), A is cross-sectional flow area (m^2), u is cross sectionally averaged flow velocity (m sec^{-1}), D is diffusion coefficient (m^2 sec^{-1}), x is distance (m), t is time (s), S is source/sink term; representing decay, growth, erosion and deposition (kg/m/sec).

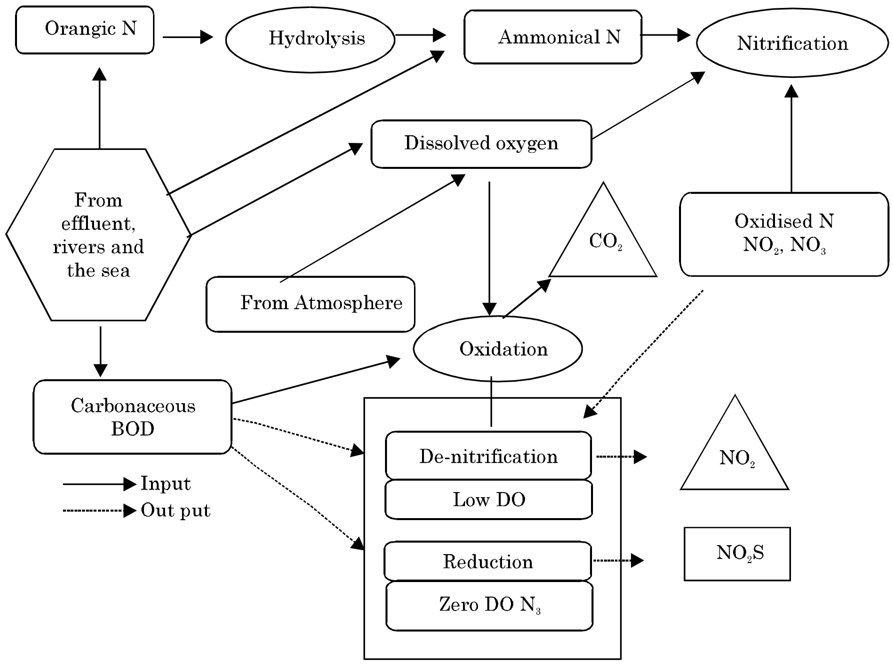

Fig. 2: Water quality processes

There are eight DOE water quality stations in Sungai Juru basin in 2004. The frequency of sampling is six times a year. The data available for this study is from 1997-2004. The data provided by DOE were used as baseline data, which gave insight into the water quality status of Sungai Juru that will be further supplemented by data collected under this study. Although the DOE water quality stations collected the data over a long period, there is still the need for more data to be collected under this study. The first continuous data collection activity was conducted from 25-28th March 2006. 72 samples of water were collected from 4 monitoring sites in the river (Fig. 1). The second sampling was conducted on 18-19 September 2006. 28 samples of water were collected from 28 selected sites. Other input parameters used to develop the model includes river discharge (m^3 sec^{-1}), water level (m) and river hydraulic. Discharge measurement was carried out at all the drains where sampling was taken. This information is used for the calibration of the water quality model. Water level data was taken at STJ 01, from 25 to 28th March 2007. The data covered period of both high and low tides. The water level observation is primary information used to calibrate the hydrodynamic model. Apart from that, river cross section data is also the main input to develop the hydraulic model. For hydraulic simulation, the cross section data of Sungai Juru were obtained from Drainage and Irrigation Department, Malaysia (DID) and covers the main river and major tributaries.

To establish spatial distribution of the study area, land use GIS layer was developed by using Ikonos satellite images taken in 2002. It is assumed that there is no change to the land use since then as the basin is already highly developed. Site inspections were also carried out to confirm the land use development pattern. River and road data layer were obtained from the Department of Survey and Mapping (JUPEM) whilst the Ikonos satellite image was obtained from Malaysian Centre For Remote Sensing (MACRES). The hydraulic calibration was carried out based on observed event on 25 to 28th March 2006. The observation location is located about 8 km from the river mouth.

RESULTS AND DISCUSSION

A one-dimensional hydrodynamic model called Infoworks RS which deployed the full St. Venant equation was used to study the behaviour of the pollution process in the river system. The modeling process involves two phases, namely the flow model and the water quality model. The model is capable of analysing unsteady flow in the river under tidal influence. The river model covers both of the main river and major tributaries from the river mouth up to 20 km upstream. The main data inputs are the river cross sections, details of hydraulic structure along the river such as weirs and bridges, flow from all tributaries and tidal constituents.

Calibration was carried out based on observed event on 25 to 28th March 2006. The observation location is located about 8 km from the river mouth. A comparison of the observed and simulated water levels is shown in Fig. 3. The correlation of the observed and simulated DO concentration at STJ 01 Station was 0.87. In this regard, the 20-day simulation to identify neap and spring tides are unnecessary as the calibration model shows good relationships between both observed and simulated. The model later can be used to predict water quality scenario in the study area. As shown in Fig. 3, the simulation result indicates that water level close to river mouth is fluctuated between minimum -0.22 m to the maximum 0.82 m. The average range between low and high tides in this area is estimated at 0.3 m.

Figure 4 showed the simulated water levels at river mouth and the other two stations namely Juru 8050 (STJ 01) and Rambai 1800 (STJ 02). For station STJ 01, the water level fluctuated from

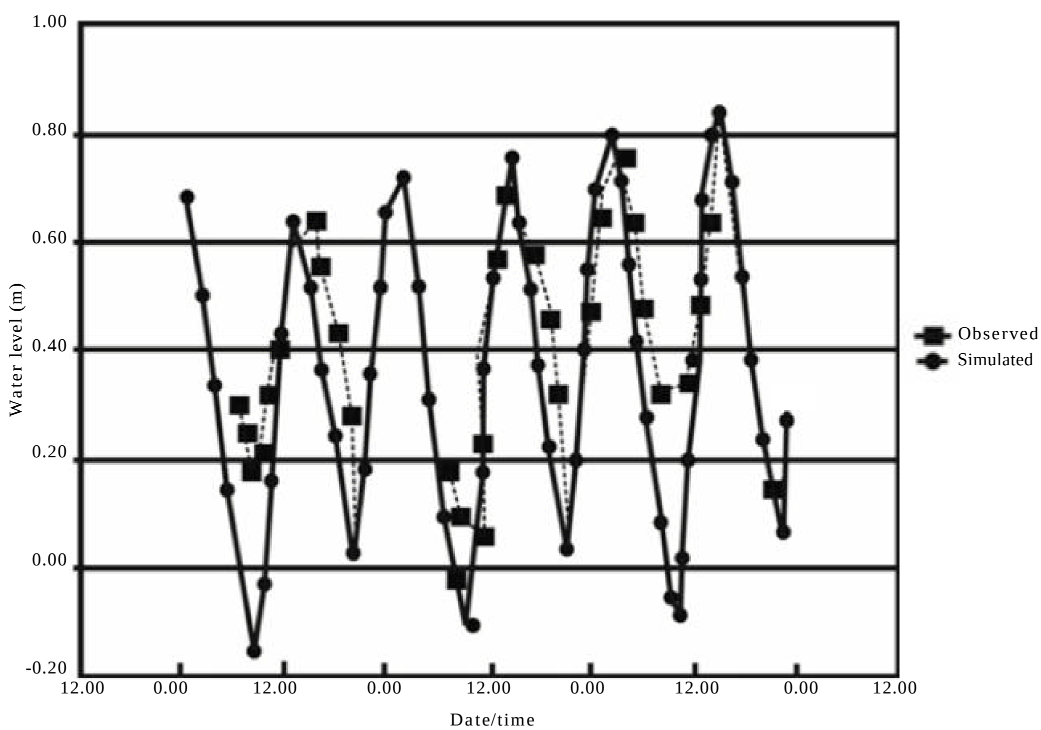

Fig. 3: Comparison between observed and simulated water levels grid at STJ01 approximately 8 km from the river mouth

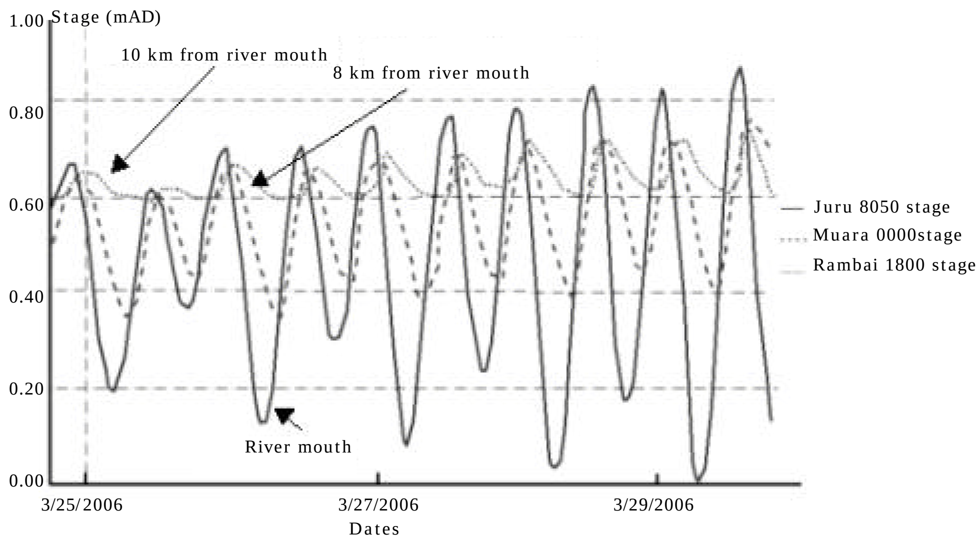

Fig. 4: Simulated water levels along the river at station Juru 8050 (STJ 01) and station Rambai 1800 (STJ 02)

0.01 to 0.84 m while 0.60 to 0.73 m was recorded in STJ 01. From the hydrodynamic simulation, the predicted water level, flow velocity and discharge can be obtained.

In this article, out of the pollution parameters studied, only Dissolved Oxygen (DO) will be discussed. DO concentration is often used as the main indicator of the health of a river. On the other hand, this parameter is also an important indicator of a water body's ability to support aquatic life. Oxygen enters the water by absorption directly from the atmosphere or by aquatic plant and algae photosynthesis. Oxygen is removed from the water by respiration and decomposition of organic matter. For example DO is vital to aquatic life, as it is needed to keep organisms alive. Coastal waters typically require a minimum of 4.0 mg L^{-1} and also do better with 5.0 mg L^{-1} of oxygen to provide for optimum ecosystem function and highest carrying capacity (Abowei, 2010). The amount of DO in water depends on several factors, including temperature, the volume and velocity of flowing water in the water body as well as the amount of organisms using oxygen for respiration. During the observation period, DO level in STJ 01 and STJ 02 were recorded between 0.9 to 10.5 mg L^{-1} and 0.5 to 10.5 mg L^{-1}, respectively. Although STJ 02 is located further upstream from the river mouth (11 km from river mouth), the DO values show slightly similar as recorded at STJ 01 (8 km from river mouth) indicating that no significant different in DO level between both locations. This is contrary to results of Jalal *et al*. (2010) who reported that DO values were higher at the upstream sampling stations in Kuantan River estuary than the downstream stations. The dissolved oxygen values were higher at the upstream sampling stations than the downstream stations with the highest of 9.6 mg L^{-1} observed in station 3 and the lowest 0.4 mg L^{-1} in station 6 probably due to the velocity and the more turbulent nature of the stream from anthropogenic activities occurring in between upstream and downstream.

Similar trend was also reported by Hart and Zabbey (2005) for Woji Creek. Ugwumba *et al*. (2008) also made similar report for the Trans-Amadi (Woji) creek, Port Harcourt. They attributed it to the effects of higher temperature and abattoir wastes. There was no significant ($p<0.05$) difference in the variation between the dry and wet seasons in the area. This is contrary to results

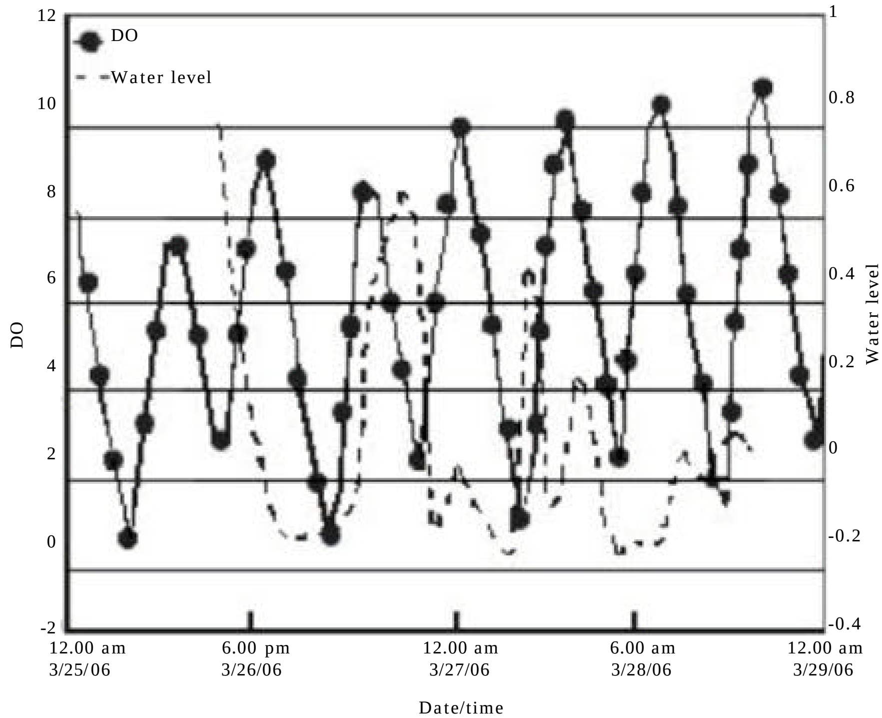

Fig. 5: DO reading at STJ 01 (8 km from river mouth) vs. water level

of (Plimmer, 1978; McNeely *et al*., 1979) who reported that at high temperature, which is usually observed in dry season, the solubility of oxygen decreases while at lower temperature (wet season) it increases. Ugwumba *et al.* (2008) also reported lowered dissolved oxygen (4.48 mg L^{-1}) in wet season than dry season (5.14 mg L^{-1}) and attributed it to be due to reduced photoperiod and photosynthetic activities of aquatic plants.

The higher mean dissolved oxygen value recorded in the dry season did not agree with the findings of Egborge (1971), who reported that dissolved oxygen is generally higher in the wet season in the tropics. A possible explanation for the lower mean dissolved oxygen values in the wet season could be the turbidity nature of the water at this period due to inflows from run-offs and decomposition of organic matter in the water.

To relate with river tidal scenario, the hypothetical flow conditions of high- and low-flow scenarios in the Juru River were tested against the advection and diffusion of the concerned pollutants. Figure 5 shows the DO reading (from 0.8 to 10.7 mg L^{-1}) at STJ 01 (8 km from river mouth) which is plotted against simulated water level while Fig. 6 shows DO reading at STJ 02 (11 km from river mouth) (from 0.1 to 12.8 mg L^{-1}), respectively. It is observed that DO value is dependent on tidal condition at both locations. For STJ 01, DO is increased during low tide which occurs in the evening (after photosynthesis). However for STJ 02, DO increases during high tide.

From the hydraulic simulation results, velocity at STJ 02 ranging from -0.1 m to +0.12 m sec^{-1} during high and low tide respectively. Based on this velocity, traveling time from STJ02 to STJ01 (3.5 km) will be approximately between 9-10 h i.e., pollution to travel between this two sampling point (Fig. 7). This duration is almost one tidal cycle for this river system. This duration will provide

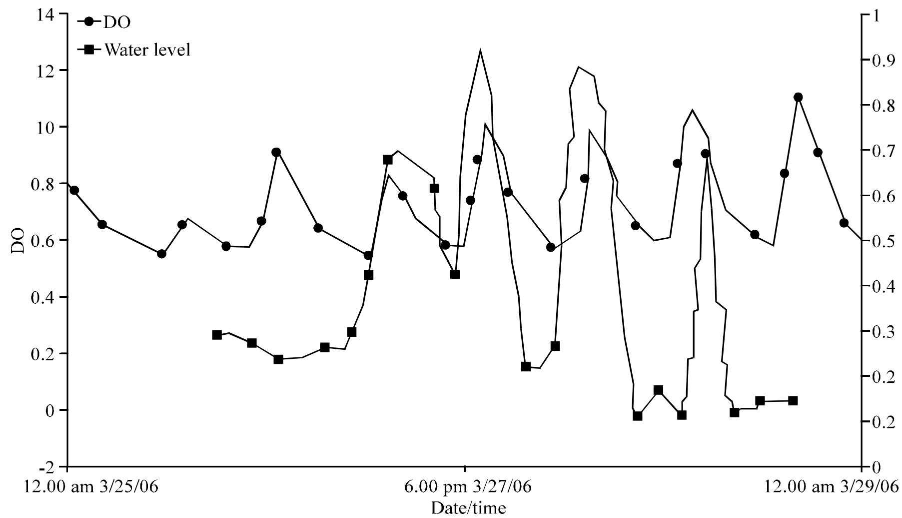

Fig. 6: DO and water level at STJ 02

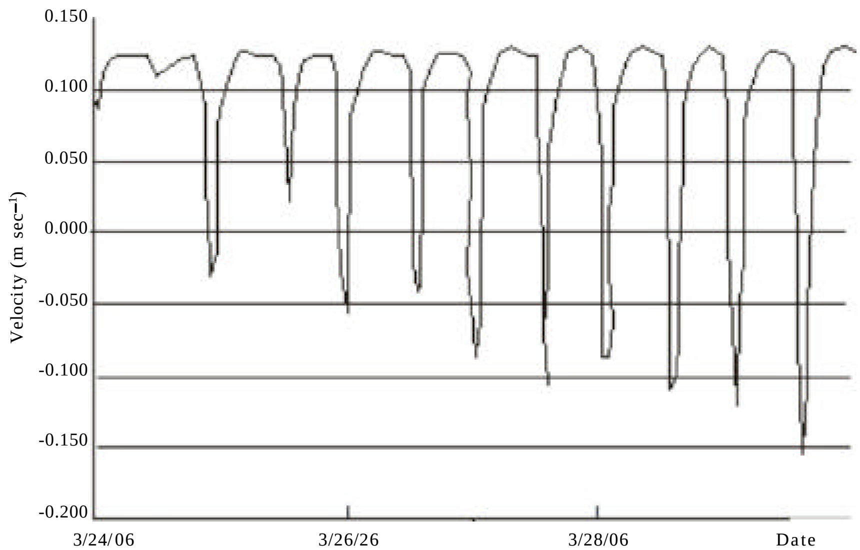

Fig. 7: Velocity at STJ 02

ample time for photosynthesis to occur within this stretch of the river. It explained the phenomena of high DO ranging from 4-10 mg L^{-1} at STJ01 during low tide which occurs late evening.

During high tide, water from some part of the river will travel back to STJ02. During this period of time, DO at STJ01 start to reduce as the samplings show that maximum value of DO drop to about 1.2 mg L^{-1}. The DO supply by upstream of the catchment is as low as 0 mg L^{-1} during low tide.

The simulation result and observation at STJ02 clearly shows the river flows in both direction which indicates that it is influence by tidal phenomena, whose flow towards upstream. Similar trend was also reported by Fan *et al.* (2007) for Keelung River, Taiwan. Tong and Chen (2002) also made similar report for the East Fork Little Miami River Basin. In this station, the difference between the depths of water at high and low tides are relatively large, leading to a marked difference between the speeds at which high and low tides move (Fig. 7). This behaviour will affect the speed of pollution flowing to the river mouth.

CONCLUSION

Water quality in Sungai Juru had been classified as Class IV and V. The pollution is mainly contributed by industry effluents, untreated domestic wastes and animal wastes such as pig waste. It has also shown that pollution in two thirds of the river is influence by tide. At present a hydrodynamic river model had been developed which is able to simulate the flow in the river including tidal zone. Development of the water quality model is ongoing by adding pollution parameters to the input of the hydrodynamic model.

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