Estimation of Tidal Stream Energy Resources at Sarawak Coastline and Their Potential Impact on Environment

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Abstract: The purpose of this study was to estimate the tidal stream energy resources in the Sarawak coastline and to assess the potential impacts of tidal structures on coastal environments. For that, a total of eight locations in the Sarawak coastline were selected for calculation of tidal stream energy resources. The sites were screened based on average peak tidal stream of more than 1.5 m/s. Tidal stream tables of selected sites were acquired from Sarawak Marine Department. On-site measurements of tidal stream speed were carried out at Pulau Triso (River mouth of Batang Lupar) with a current meter due to absence of tidal stream tables. The current meter was dipped 5 meter below the water surface and is scheduled to log a reading of the tidal stream speed for every 5 minutes. Power density was calculated based on depth-averaged speed instead of tidal stream speed at the water surface to prevent the overestimation of results. The mean monthly power density was determined by excluding the odd maximum and minimum values. Moreover, a survey was conducted from a sample of sixty people for predicting the potential impacts of tidal structures on coastal environment. In environmental assessment, six dependent variables namely water quality, mangrove forests, flooding, animals including birds, migratory species and fishes/ fishing industry were used with a close-ended questionnaire. The scale was consist of 5 restricted choices, which were “Highly detrimental”, “Detrimental”, “Neutral”, “Beneficial” and “Highly beneficial” for every question. It was revealed form the analysis that Pulau Triso was only feasible site for extraction of tidal stream energy followed by Off Kuala Igan among examined locations in the Sarawak coastline. The survey results showed that approximately seventy percent respondents were against the development of tidal energy systems because of possible reduction of fishing industry. Only sixteen percent respondents were in the favor of tidal energy systems. The literature review confirmed that the potential impacts include the variation in the level of nutrients, salinity, dissolved oxygen and sedimentation and threat of injury to marine and migratory species. However, the magnitude of impacts in the coastal environments is not known due to different physical, geographical and biological features.

Key words: Coastal zone, Ecosystems, Endangered species, Environmental impacts, Tidal energy systems.

INTRODUCTION

Global electricity demand is increasing much more rapidly since last five decades (Kadiri et al. 2012). It is expected that its growth will be around 33% up to 2035 (IEA, 2012). In spite of rapid developments in energy sector, still 1.3 billion people are living without electricity in the world (IEA, 2012). Although an obvious shift from oil and coal towards natural gas and renewable was made, yet fossil fuels remain the leading energy resources for power generation (IEA, 2012). However, the fossil fuels significantly contribute the emission of green house gases, including carbon dioxide, which is considered to be the major cause of global warming and climate change (Jakhrani et al. 2012a). The growing awareness and concerns over high crude oil and natural gas prices, emissions of carbon footprints, climate change and the rapid depletion of fossil fuel reserves, the generation of energy from renewable resources has become crucial (Jakhrani et al. 2011a and 2011b). Some potential solutions has evolved for the prevention of such impacts including energy conservation through improved energy efficiency, reduction in fossil fuel use and an increase in the green energy supplies (O’Rourke et al., 2010). Green energy sources are infinite, environment and nature friendly and produce less emission as compared to fossil fuels (Jakhrani et al., 2013). The tidal energy resources are one of the most predictable and reliable green energy sources. The tidal energy depends only on the gravitational pull of the moon and the sun and the centrifugal forces created by the rotation of the earth-moon system (Xia et al. 2010a and 2010b). Due to
these gravitational pulls, water levels follow periodic highs and lows and produce tidal currents or streams (Kirby and Retiere, 2009). Thus, the energy can be produced either through construction of a barrage over estuaries or using kinetic energy of tidal stream by installation of tidal in-stream turbines and generators.

1. Tidal Barrage:
Tidal barrage is usually a dam or offshore impoundment used to block the incoming and outgoing tides and then create a water head. The potential energy of water head in the barrage facilitates to produce power from different tidal conditions (Baker, 2006). Tidal electricity can either be generated by means of ebb or flood mode or both. A dam or barrage is constructed across an estuary or bay so as to allow water to flow into the basin as the tide comes in. The barrage has gates which let the water to pass through, thereby filling the basin. The gates are closed when the tide has stopped coming in, indicating the beginning of ebb. The water level outside the basin continues to drop during ebb while the water level inside the basin remains high. The difference of water level creates a head or fall. The water in the basin is then released into the sea through a set of turbines. Power is thereby generated by the turbines. This happens during ebb and continues until the tide floods and the rising water decreases the head to the minimum operating point. The water is then captured again and the process repeats. The generation of power takes place during the ebbs and therefore this mode of operation is called ebb generation. During the flood tide, the gates and turbines are kept closed until a considerable hydrostatic head is developed across the barrage. Once the adequate hydrostatic head is achieved, the turbine gates are opened allowing the water to flow through them into the basin. The electricity is generated by flood tide method is termed as flood generation. Flood generation is a less favorable method of generating electricity than ebb generation because the head created is usually less as compared to head created by ebb generation. Two-way generation method of operation employs both flood and ebb phases of the tide to generate electricity. The gates and turbines are kept closed until near the end of the flood cycle. After this point the water is allowed to flow through the turbines, generating electricity. When the minimum hydrostatic head for producing electricity is reached then the gates are opened. At high tide, the gates are closed and the water is trapped at the back of the barrage until a sufficient hydrostatic head is reached once again. Water is then allowed to flow through the turbines to generate power in the ebb mode. Two-way generation has the advantage of a reduced period of non-generation and a reduction in the cost of generators due to lower peak power. In general, the construction of tidal barrage requires a high capital and disturbs the environment. It is also less attractive scheme for the investors due to its long payback periods.

1.2. Tidal Stream Technology:
In tidal stream technology, the turbines are installed underwater at the locations in the sea where the high tidal stream exist (Hardisty, 2007). Tidal stream turbines make use of the kinetic energy of the tidal stream to power turbines, in a similar manner to the way in which windmills extract energy from the wind (Defne et al. 2011). Tidal stream method is gaining popularity because of the lower cost and lower environmental impact compared to tidal barrage method. This technology is less intrusive than tidal barrages and the installation and maintenance methods of tidal streams are simpler than barrage. The cost of building tidal streams will be very site specific and will depend on the technology used. However, maintenance costs will be the main cost during the life of the project. Tidal stream is the periodic horizontal flow of water associated with the rise and fall of the tide. This horizontal flow of water stores an enormous amount of energy that can be extracted and used for the purpose of power generation. The tidal stream technologies are more attractive than windmills due to more accurate predictability of tidal streams and the higher water density as compared to air. However, it is not a mature technology to be used as large scale electricity generation.

Moreover, the construction of barrages over estuaries has some environmental and ecological impacts. The change in water level and possible flooding would affect the ecosystems along the coast. The water quality in the basin would also be affected, and the turbidity may affect the animals that live in the water. In addition, the installation of tidal stream structure could change the tidal flow patterns in hydrodynamic regimes. These changes will be related in sediment transport, geo-morphological, ecological and water quality processes in the coastal zone (Shields, et al., 2011). In order to predict the extent and nature of ecological consequences there is a need for greater understanding of the distribution and level of the tidal energy resource. It is required to discover the species and biotopes which are vulnerable to the installations of tidal structures (Shields et al., 2011). In this study, the availability of tidal stream energy potential in the coastal zone of Sarawak was estimated and possible impacts of tidal structures on coastal environment were reviewed.

2. Impacts of Tidal Structures on Coastal Environments:
2.1. Impact of Tidal Installations on Water Quality:
The major issues in coastal resource utilization and management are the coastal erosion and river mouth siltation, resource depletion and degradation and water quality deterioration. The tidal streams are extensively affected by the tidal turbine arrays. The flow velocity field, suspended sediment and faecal bacteria levels is
increased on the side of the tidal arrays and decreased upstream as well as downstream of arrays (Ahmadian and Falconer, 2012). The installation of turbine arrays has several affects such as changes in the salinity profile of the estuary, rates of longitudinal dispersion and efficiency of oxygen absorption from the air and increased concentrations of nickel and cadmium (Defne et al., 2011). However, no significant changes were found in the number of bacteria near sewage outfalls and non-conservative pollutants behind any barrier (Henderson and Berd, 2010). Changes in the salinity profile of the estuary would result in the movement seaward of the freshwater/salt water interface by 5–30 km, depending on flow. Similarly, no significant change in the oxygen status was observed in spite of the reduced tidal mixing (Henderson and Berd, 2010). A reduction in the suspended sediment concentrations were found where water flows were reduced. The impact of tidal turbines on water quality in a coastline or an estuary is diverse, ranging from physical to biological and chemical parameters. The most important parameters include sediment transportation, salinity, dissolved oxygen, metals, nutrients and pathogens (Kadiri et al., 2012).

2.1.1. Sediment Transportation:

The construction of the tidal turbines across in an estuary is expected to have an influence on the pre-existing sediment transport capacity of the estuary. Such effects occur due to the changes in the level of tidal streams and sediment carrying capacity within the estuary (Falconer et al. 2009). A 50% reduction in tidal streams was noted in the Severn Estuary after the building of a barrage due to the decrease in the volume of incoming and outgoing water from an estuary (Xia et al., 2010). The reduction of tidal streams could change the sedimentation rates in certain locations (Falconer et al. 2009). However, the place of possible sedimentation will depend on the established source of sediment to the estuary. If the fluvial sources are dominant, then sedimentation is expected to be within the confiscated water column. If the sediments arrive mainly from oceanic sources, then sedimentation is likely to occur in the surrounding area immediately outside the turbines (ETSU, 1989). The speed of tidal streams could vary the sediment depositional patterns upstream as well as downstream of the devices (Ahmadian et al., 2012). The installation of tidal stream arrays could reduce the suspended sediment levels in the water column for up to 10 km downstream from the array. The changes in the passage of sediment transport could cause secondary effects on other hydro-environmental parameters in the estuary.

2.1.2. Salinity and Dissolved Oxygen:

Salinity is one of the major factors influencing on water quality in an estuary. It affects the sorption-desorption processes of metals, nutrients and dissolved oxygen (Turner, 1996). The presence of higher salinity enhances the metal and nutrient desorption of sediments. Therefore, higher concentrations of dissolved metal and nutrient concentrations in the water column will increase the competition of seawater cations (Rysgaard et al., 1999). Moreover, the salinity can modify the sediment-metal interactions in estuaries through insistent reactions of seawater ions. The major seawater cations are sodium, magnesium, calcium and potassium and anions are chlorides, and sulfates. These metals are efficient activators when associated with sediments (Millward and Liu, 2003). The lower salinity conditions lessen the competition between seawater cations and sediment-associated metals for cation replacement on the particle surfaces. The decrease of metal quantity in the water column will improve water quality and decrease the biological uptake and toxic effects on aquatic organisms.

The availability of dissolved oxygen is necessary to support marine flora and fauna in an estuary by balancing the input and output sources. The input sources of oxygen into an estuary comprise re-aeration from the atmosphere, freshwater flows from rivers, incoming seawater, in situ photosynthetic production and chemically bound oxygen in nitrates and sulfates (Hill et al., 1996). The most important phenomenon which results in the loss of dissolved oxygen is respiration by aquatic flora and fauna as well as the microbial decomposition of debris and sediment organic matter (Evans and Rogers, 1996). In the night time, the oxygen is also used by photosynthetic plants which reduce the amount of dissolved oxygen. The loss of dissolved oxygen is also became worse in eutrophic waters where dead algae sink onto the sediment bed after mass algal growth events as oxygen is used in the biodegradation process (Jahkran et al., 2009). The other potential cause of low dissolved oxygen levels in an estuary include inactivity of the water column, growth of organic matter and inputs of nutrients from storm sewers and industrial effluents. The increase of temperature can also reduce the dissolved oxygen levels. These factors lead to a significant demand of biological and chemical oxygen (Shackley and Dyrynda, 2006).

2.1.3. Heavy Metals:

The presence of metals in water bodies are a major environmental concern because of their wide spread use and possible toxic effects on marine species. The metals could not be easily degraded to harmless by-products (Kapustka et al., 2004). A few metals are vital for living organisms in trace amounts such as copper, zinc, cobalt and molybdenum. The metals such as lead, mercury, cadmium, nickel and arsenic have no metabolic role
The higher concentrations of these metals are very toxic to the organisms as these can damage health if enter in the food chain due to accumulation in the fishes (Jakhrani et al., 2012b and 2012c). The Minamata disease in Japan results the death of thousands of people due to mercury poisoning by the consumption of fish contaminated with methyl mercury discharged from a chemical factory into an estuary (Clarke, 2001).

There are several processes through which metals interact with the sediment. These processes include adsorption and desorption through ion exchange, precipitation and dissolution of carbonate-bound metals, formation and decomposition of organic matter-metal complexes, formation and dissolution of oxyhydroxides, sorption and co-precipitation of metals by iron and manganese oxides and precipitation and dissolution of metal sulfides (Caetano et al. 2002 and Spencer, 2002). The most of the metal inputs into the estuaries comes from sewage effluents, industrial discharge, agriculture, road run-off and ships (Turner and Millward, 2002). The majority of metals readily attach with sediments suspended in the water column (Eggleton and Thomas, 2004). It is because the sediments have a great ability to adsorb metals which are positively charged, due to their high surface area per unit mass and high percentage of reactive coating on particle surfaces (Filgueiras, 2002 and Couch et al. 2006).

2.1.4. **Nutrients:**

Nutrients are essential for all living organisms as they are vital components of nucleic acids and proteins which are the building blocks for plant and animal growth. The nutrients associated with sufficient illumination conditions excited the production of phytoplankton which forms the basis of the estuarine food chain (McLusky, 1989). Estuarine environments can provide appropriate habitat for various species of marine flora and fauna. The sources of nutrients in an estuary can be classified as autochthonous and allochthonous. The sources of autochthonous nutrients comprise nitrogen fixation, decay of organic matter by bacteria, precipitation, current of groundwater and chemical desorption from residues (Berelson et al. 1998). The most important sources of allochthonous nutrients are originated from earthly environments are transported by rivers into the estuaries. These include domestic and industrial effluents, agricultural run-off, leachates and soil erosion (Goulding, 1990). The direct nutrient inputs can also be takes place into the estuaries from atmospheric deposition (Yoshinari, 1990). The phosphates limit the biological productivity in freshwater and nitrates in marine environments (Morris et al. 2003).

Extreme amount of nutrient inputs into estuaries can cause the prolific growth of phytoplankton resulting in eutrophication. Eutrophication is defined as the nutrient enhancement of waters which leads to an array of indicative changes, such as increased production of algae and macrophytes, deterioration of fisheries and water quality (Connell, 2005). Other changes in the water column associated with the abundance of nutrients and eutrophication include a reduction in dissolved oxygen and pH, change in turbidity and decrease in the depth of sunlight penetration (Hinga, 2002). Eutrophication can speed up the biological processes and encourage the production of hydrogen sulfide as well as nitrous oxide (Eyre and Ferguson, 2002). These circumstances amplify the mortality of aquatic organisms, reduce the population of biodiversity and deteriorate the water quality (Jonas and Millward, 2010).

2.1.5. **Pathogens:**

The main distress associated with pathogens in water environments is their potential negative impact on aquatic organisms including fish and their hazard to human health (Crabill et al. 1999). Pathogens include faecal bacteria such as coliform, faecal coliform, faecal streptococci and intestinal enterococci. These organisms in water environments are mainly derived from discharge of sewage and industrial effluents either directly to sea or via rivers, urban run-off from adjacent land areas, particularly those used for livestock farming, inputs from birds especially in inter-tidal areas and agriculture-related diffuse pollution (Crowther et al. 2001). As pathogens are released into the water environment, either they can attach to the suspended sediments or survive as free-living forms in the water column (Gao et al. 2011). Attached pathogens travel with the suspended sediments, whereas, free living pathogens travel with the streams. The free-living pathogens in the water environment can die-out due to effects of salinity, temperature, nutrient deficiency and sunlight (Alkan et al. 1995). The mortality rate of bacteria in the water column due to sunlight is more severe than other factors (Kay et al. 2005). Usually, the level pathogenic bacteria can be 100–2000 times higher in the bed sediment as compared to the water column, because of deposition of pathogenic bacteria over the sediment layer. However, the bacteria may again move into the water column with sediment re-suspension process (Gao et al. 2011 and Kay et al. 2005). Therefore, the changes in the sediment movement results the variation of bacterial population in the water column of an estuary.

2.2. **Impact of Tidal Barrages on Inter-tidal Mudflats and Sandflats:**

Any application that reduces the magnitude of the tidal excursions will affect the area of exposed mud and sand (Henderson and Berd, 2010). It will reduce the tidal range upstream and could result in a loss of up to 30%
of the inter-tidal habitat (SDC, 2007). It might reduce the populations of benthic invertebrates on which many fish and birds rely. The reduced turbidity and resulting bed stability could cause a shift from hard to soft bottom communities and lead to an increase in the biomass of suspension-feeding invertebrates (DOE, 1989). This form of increased productivity has been observed in La Rance where there has been an increase in species diversity and abundance of invertebrates (Desroy and Retiere, 2004).

2.3 Impact of Tidal Barrages on Migratory Species:

The most significant concern about the impact of barrages and lagoons related to their potential impact on migratory species of fish and crustaceans. The increasing numbers of weirs and other barriers could decline the number of anadromous species including lampreys and shads (Henderson and Berd, 2010). Many aquatic estuarine opportunistic species are not anadromous. However, still some species could penetrate well into the estuary as part of their normal seasonal movements into suitable nursery areas. The common macro-crustaceans such as common shrimp, C. Crangon and a number of species of swimming crab undertake regular seasonal migrations within the estuary (Henderson and Berd, 2010).

2.4. Impact of Tidal Structures on Fishes and Fishing Industry:

The construction of the tidal barrages across an estuary or a bay may change the flow of the tidal currents, affecting the aquatic life within the estuary (Lim and Koh, 2010). The passing of fish and other aquatic animals through the turbines may be detrimental to these species (Henderson and Berd, 2010). However, there is little evidence that turbine-related deaths have been a significant problem. Migratory fish and cephalopods could pass through the turbines or sluice gates without injury (Retiere, 1994). In contrast, other evidence suggests that it could impact on trout migration (SAGE, 2004). Dadswell and Rulifson (1994) estimated the mortality of fishes can be between 20% and 80% per passage and Winter et al., (2006) reported from 16 to 26%. Since, the mortality rate depends on the type of fish species, their size and efficiency of the turbine operation (Dadswell and Rulifson, 1994). The typical approach to mitigate the impact of migratory barriers involves the construction of fish passes (SDC, 2007).

A little is known about the expected impacts of tidal energy systems on the fishing industry. However, three key issues were identified as loss of livelihood, shortage of skills and induced change of ecosystem due to installation of tidal structures (Alexander et al., 2013). The most important needs of fishers were security of employment and income. The compensation and longer-term alternatives should be considered as a mitigation measures for fishers. Furthermore, the larger issue of skills shortages in rural economies must be addressed to satisfy the fishing community.

3. Coastal Zone of Sarawak:

The coastal zone is generally defined as the region where the land and water meets. It includes the coastal plains, deltaic areas, coastal wetlands, estuaries and lagoons. It is difficult to draw a geographical boundary of the coastal zone due to the complex interaction and interdependence of fluvial and coastal processes. The coastal zone of Sarawak covers a land area of 2.25 million hectares, accounting for 18% of the land area based on fixed width of 5 km as the landward limit of the coastal zone. There are about 66 islands located in the coastal waters of Sarawak. The coastal region is almost equally divided between sandy beaches and mud coast (Abdullah, 1993). This region has a unique socio-economic and environmental significance. It supports a large percentage of the population and it is also the center of economic activities encircling urbanization, agriculture, fisheries, aquaculture, oil and gas exploitation, transportation and communication, recreation, etc (Abdullah, 1993).

Sarawak mangrove forest comprised of only 173,792 ha or less than 1.4% of the total land area. The mangrove forest refer to the highly adapted plants found in tropical inter tidal forests ecosystems (Hua, 1999). It is economically the third most important productive ecosystems of the State. Many important organisms can be found in the mangrove forests of Sarawak coastal area. The major habitats are located in Kuching Division (52,318 ha), Sarkei Division in the Rejang Delta (87,544 ha) and Limbang Division (8,359 ha) (Hua, 1999). There are important spawning, nursery and habitat areas for many economically important species of finfish and prawns (Abdullah, 1993). The biodiversity of mangrove forests include all different biotic elements of plants and animals in the mangrove (Hua, 1999). Mangrove swamps also support endangered species of wildlife such as the proboscis monkey, crocodile, stork, etc. The accreting mudflats of the Rejang delta represent the richest feeding grounds for migratory birds and resident water birds such as herons, egrets and storks. National parks, forest reserves and wildlife sanctuaries are announce as specific areas to protect the important ecological, wildlife and scientific resources. Many mangrove forests have been cleared and converted to aquaculture, housing and industrial development in recent years (Khan et al., 2008). Such activities could seriously destroy the coastal ecosystem.
3.1. Environmental Impacts on Sarawak Coastal Zone:

Environmental challenges in the coastal zones are related to deforestation and flooding, greenhouse gas emissions, and changes to water quality and river flow and downstream industrialization (Sovacool and Bulan, 2012). Deforestation and flooding were continually referenced as significant environmental impacts from Sarawak Corridor of Renewable Energy (SCORE). It is an economic corridor to inspire global and domestic investment in traditionally rural areas to create balanced development throughout the State. SCORE has a long coastline of more than 1,000 km, over 8 million hectares of forests, almost 5 million hectares of arable land and peat land suitable for agriculture. The corridor has 1.2 billion of known oil reserves, over 80 million tonnes of Silica sand and over 22 million tonnes of Kaolin of China clay, a key component of cosmetics, ceramics and, most recent, for combat area medical equipment. SCORE has an abundance of natural resources, including clean and safe renewable resources, such as hydropower, that offers commercial users clean energy at competitive rates (RECODA, 2013).

Bakun dam, with a catchment area of 1.5 million hectares logged and a reservoir area of about 70,000 ha cleared and then submerged, will destroy 50 million cubic meters of biomass home to 6 rare and endangered fish species, 32 protected bird species, 6 protected mammals, and more than 1600 protected plants as well as Herons, egrets, woodpeckers, Silvered Leaf Monkeys, Bornean Gibbons, Langurs, and Flying Squirrels (Choy, 2005). Murum dam, with a reservoir area of 24,500 ha and catchment area of 275,000 ha, will release 3.48 million tons of carbon, displace 755 people, and threaten 300 rare and engendered species (Choy, 2005). SCORE could have quite massive biodiversity and climate impacts. The construction of dams could negatively affect hydrology, water quality, and river flow. Consequently, such projects will impact the nearby Mulu National Park, which is the home of the world’s largest cave and a UNESCO World Heritage Site. Because the dams act as physical barriers within a river and change the concentration of dissolved oxygen, nutrient loads, and suspended sediments, and tidal encroachment could aggravate bank erosion (Sovacool and Bulan, 2012). Indirectly such dams would contribute to environmental degradation through waterlogging, clearing of the catchment area, and roads.

4. Methodology:

The survey of coastal zone of Sarawak was conducted to identify the types of tides and to record the tidal stream speed. The intention was to determine the extractable amount of energy for possible power generation. Furthermore, the environmental study of the area was conducted with the help of local people for identification of potential impacts of tidal projects.

Tidal energy mapping of potential sites was done after the analysis of tidal energy resource at eight locations of Sarawak coastline. The types of tides found in Sarawak coastline is shown in Figure 1. The depth-averaged speed ($\bar{u}$) of tidal stream with $1/10^8$ law is used to prevent from overestimation of results instead of using the surface speed. The term speed indicates average flood or ebb peak tidal stream. Site screening was carried out by selecting the sites with an average peak tidal stream of more than 1.5 m/s as adopted by Hagerman et al. (2006). The speed of the tidal stream for eight locations namely Off Tanjung Po (01° 48' 00” N and 110° 33’ 00” E), Off Kuala Paloh (02° 30’ 34” N and 111° 08’ 41” E), Off Kuala Rajang (02° 07’ 32” N and 111° 01’ 37” E), Off Tanjung Sirik (02° 55’ 00” N and 111° 30’ 00” E), Off Kuala Igan (03° 37’ 00” N and 111° 45’ 00” E), Bintulu Port (03° 15’ 46” N and 113° 00’ 04” E), Off Kuala Miri (04° 23’ 52” N and 113° 57’ 54” E) and Pulau Triso (Batang Luper) (01° 30’ 45” N and 110° 57’ 55” E) were evaluated. Sarawak tidal stream tables, hourly high and low tides tables, nautical charts and on-site measurements were used for tidal stream resource assessment and mapping of potential sites. Tidal stream tables acquired from Sarawak Marine Department (SMD) were used for the analysis. The tables illustrate the hourly tidal stream flows at the maximum rates (knots), the flows direction (degree) and the moon age (depicted by symbols). The speed of tidal streams for all locations except Pulau Triso (Batang Luper) from 2005 to 2006 was taken from the published data of the Directorate of Marine, Sarawak. On-site measurements were carried out only at Batang Luper due to the absence of data monitoring station near that location.

4.1. Tidal Stream Speed and Power Density:

The tidal stream speed at Off Tanjung Po and Off Kuala Paloh was observed for 36 days, at Off Kuala Rajang and Off Tanjung Sirik 31 days, at Off Kuala Igan 35 days, at Bintulu Port 14 days and Off Kuala Miri 20 days. The charts were used to characterize the physical features of the selected sites. Available tidal stream resources were calculated by obtaining the mean power density without accounting the cross-sectional area. Furthermore, 15% of extractable energy from gross tidal power was used for this assessment as proposed by Hagerman et al. (2006). The on-site measurements for the calculation of tidal stream speed at Pulau Triso (River mouth of Batang Luper) were carried out by means of a current meter. It was dipped 5 meter below the water surface and is scheduled to log a reading of the tidal stream speed for every 5 minutes. The first reading was taken in the afternoon of May 13, 2010 and the meter continuously logs for fifty hours. It was assumed that the speed of the tidal stream remains constant across the width of the channel (Hagerman et al., 2006). Furthermore,
the power density was calculated based on depth-averaged speed. The mean monthly power density was obtained by excluding the odd maximum and minimum.

![Fig. 1: Types of tides around Sarawak coastline.](image)

**4.2. Survey of Potential Environmental Impacts:**

The purpose of survey was to find out the opinion of local people regarding the construction tidal barrages and tidal in-stream turbines energy systems. For that, six dependent variables namely water quality, mangrove forests, flooding, animals including birds, migratory species and fishes/ fishing industry were selected for the assessment of potential impacts. A group of local people were approached for this analysis residing the coastal zone of Sarawak. It was intended to find out the view points of local people belongs to the area concerned and could be beneficiaries or affectees for the proposed project. The sample size of respondents was set up to 60 people. The study was conducted from voluntary participants, who wish to reply the quarries without any force and anxiety. In this analysis, evaluation test and close-ended questionnaire were used for achieving the objectives. The scale was consist of 5 restricted choices of answers, which were “Highly detrimental”, “Detrimental”, “Neutral”, “Beneficial” and “Highly beneficial” for every question. Microsoft Excel was used to analyze the obtained data about all depended variables and potential impact of proposed tidal energy systems.

**RESULTS AND DISCUSSION**

**5.1. Tidal Stream Speed and Power Density of Selected Sites:**

Peak speed is the highest speed of tidal streams at selected sites according to the predictions made in the tidal stream tables published by the Director of Marine, Sarawak. It was revealed from the analysis that no site was meeting the criteria of peak speed (more than 1.5m/s) requirements except for Pulau Triso at Batang Lupar. The highest speed recorded is 2.06m/s on May 15, 2010 at 08:52:29. It was found that approximately 28% of the readings logged throughout fifty hours period exceeded the 1.5m/s threshold limit. Almost 27.7% of the recorded readings exceeded the 1.5m/s speed requirements on May 14, 2010. The peak tidal stream at Off Kuala Igan, Off Kuala Rajang, Off Tanjung Po, Off Kuala Paloh, Off Tanjung Sirik, Off Kuala Miri and Bintulu Port was 0.51, 0.36, 0.36, 0.41, 0.36, 0.21 and 0.15 m/s respectively. The highest tidal streams speed was observed at Pulau Triso with 2.06 m/s and the lowest with 0.15 m/s at Bintulu port among the selected sites. The second highest tidal stream speed was found at Off Kuala Igan with 0.51 m/s.

The power potential of the sites was calculated in terms of power density. Power density does not carry the meaning of total kinetic energy flux. A total kinetic energy flux is a product of density and the cross-sectional area of the channel. Therefore, it was assumed that the physical power possessed by this site will be the largest among other locations. The amount of power density possessed by the month of February was found to be the least of all months. The power density of tidal stream at Pulau Triso was not calculated, because, the duration of the measured readings does not exceed to a period of a single month. It was found that Off Kuala Igan and Off Kuala Rajang possess the maximum extractable energy among eight selected locations, whereas, the lowest value was found at Bitulu port. The map of extractable annual power density at various sites in Sarawak coastline is shown ion Figure 2.
5.2. Environmental Impact of Tidal Energy Systems:

A total of sixty respondents were selected for assessment of environmental study of area. Six numbers of dependent variables namely water quality, mangrove forests, flooding, animals including birds, migratory species and fishes/fishing industry were used for this survey. A total of 162 (45%) responses were found to be highly disagreed, 95 (26.4%) agreed, 47 (13%) neutral, 42 (11.7%) agreed and 14 (3.9%) strongly agreed out of 360 responses for installation of tidal energy systems as shown in Table 1 and illustrated in Figure 3.

<table>
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<tr>
<td>Animals</td>
<td>28</td>
<td>17</td>
<td>9</td>
<td>6</td>
<td>0</td>
</tr>
<tr>
<td>Migratory Species</td>
<td>19</td>
<td>13</td>
<td>15</td>
<td>7</td>
<td>6</td>
</tr>
<tr>
<td>Fishes/Fishing Industry</td>
<td>42</td>
<td>15</td>
<td>3</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Total</td>
<td>162</td>
<td>95</td>
<td>47</td>
<td>42</td>
<td>14</td>
</tr>
<tr>
<td>Percentage</td>
<td>45</td>
<td>26.4</td>
<td>13</td>
<td>11.7</td>
<td>3.9</td>
</tr>
</tbody>
</table>

It was found from the analysis that the 70% responses were in a view that installation of tidal structures could be detrimental for environment and only 16% were positively taking the tidal energy as beneficial for local people. The negative responses of participants were due to experience of local people regarding previous projects. It was a fact that the maximum number of participants were belongs to the fishing industry. Therefore, 42 participants were replied that tidal energy systems could be highly detrimental, whereas, 15 numbers responded that it could be detrimental to the fishing industry. They were in a view that the installation of turbines could kill the fishes. Therefore, there is chance of unemployment of local fisherman. Second and third most threats in the mind of participants were destruction of mangrove forests and other animals and birds respectively. They were in a view that the mangrove forests are breading places andhabitat of various kinds of animals and birds could be highly affected.
Fig. 3: Survey results on potential environmental impacts of tidal energy systems.

6. Conclusions:
It is revealed from the review that tidal energy systems have significant potential impacts on hydro-ecological environment, although, the full extent of the impacts is still unknown. The installation of tidal structures could influence the salinity and dissolved oxygen levels as well as sediment transportation. These changes could lead to a decrease in suspended sediments and faecal bacteria concentrations in the water column. It was established that the some loss of livelihood may be occur due to the disturbance of species because of tidal structure deployments.

Moreover, the study of tidal energy resources revealed that the Pulau Triso is the only most practicable site for extraction of tidal stream energy followed by Off Kuala Igan among examined locations in Sarawak coastline. It was found from the survey that around seventy percent participants were against the development of tidal energy systems due to the threat of destruction of fishing industry and mangroves forests. In contrary, only sixteen percentages of participants were in the favor of tidal energy systems. They were in a view that the living standard may be enhanced due to the possible supply of electricity and new opportunities of jobs in the area.

It is recommended that further investigation may be carried out to determine the possible impact of tidal structures on environment. The process of gathering data should be stretched over a relatively long period of time using various data sources for comparison.

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