Effects of Bauxite Processing On the Aquatic Ecosystem: A Brief Review

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***Abstract*:** Uncontrolled bauxite mining activity in Kuantan, Pahang had been a hot issue in the media a few years back. In some parts of Kuantan, cars, homes and trees have accumulated a thick layer of red dust. Trucks and lorries transporting red soil could easily be seen on the roads and highways. Plants became damaged. The health of the local public is also affected due to the exposure to red dust particles in the air. The flat and arid red soils of bauxite mining could be clearly seen in aerial pictures of Kuantan and surrounding areas in Google Map. Several streams and coastal waters turned red due to the muddy flow of water from the open bauxite mines. Fish death cases were reported in several places. Given the fact that the effects of red dust to the aquatic environment and organisms are still a question mark for the stakeholders, this paper is prepared to specifically inform the effects of red dust on the aquatic ecosystem from the studies conducted including from Malaysia.

Keywords: Effect, bauxite, mining, aquatic, environment, organism

***Abstrak*:** Aktiviti perlombongan bauksit yang tidak terkawal di Kuantan, Pahang telah menjadi isu hangat di media masa beberapa tahun lepas. Di beberapa bahagian bandar pelabuhan Kuantan, kereta, rumah dan pokok-pokok diselaputi dengan debu merah. Trak dan lori yang membawa tanah merah sering dilihat di atas jalan dan lebuhraya. Tanam-tanaman menjadi rosak. Kesihatan penduduk setempat juga terjejas kerana terdedah debu merah yang berterbangan. Tanah merah yang rata dan gersang akibat perlombongan bauksit dapat dilhat dengan jelas dari gambar-gambar pemandangan udara sekitar Kuantan dalam *Google Map*. Beberapa sungai dan perairan pantai bertukar menjadi merah hasil dari aliran air yang membawa selut merah daripada lombong bauksit yang terbuka. Kes kematian ikan dilaporkan dibeberapa tempat. Memandangkan kesan spesifik debu merah kepada persekitaran dan organisma akuatik menjadi tanda tanya kepada pihak berkepentingan, maka kertas ini disediakan untuk meberi maklumat ringkas mengenai kesan debu merah hasil terhadap ekosistem akuatik hasil daripada laporan-laporan kajian yang telah dijalankan termasuk daripada Malaysia.

Introduction

Bauxite ore is the world's primary source of aluminum. Bauxite is typically found in topsoil located in various tropical and subtropical regions. According to Valeton (1972) the term bauxite ore is applied to bauxite which is economically mineable at present or in the foreseeable future containing not less than 40-50% Al_2O_3 and not more than 20% Fe_2O_3 and 3-5% combined silica (SiO_2). The iron oxide gives the ore and the red mud its reddish-brown colour. The proportion of iron oxide can vary from about 25% in French ores and 15% in Ghanaian ores to 2-3% in South American ores (Blackman, 1973). Other major impurities such as vanadium, arsenic, chromium and nickel may present in trace amount.

Most of the bauxite ore is acquired through open quarrying or strip mining although some underground mining is still being operated. The ore is crushed and followed by washing before processing. Red mud is a by-product in the 'reduction' of bauxite to alumina by the Bayer process, and its physical and chemical composition depends on the origin and treatment of the bauxite. Initially the red mud waste was stored inland in natural basins. However as the production of alumina increased, and the red mud started to accumulate, it was thus necessary to consider other methods for eliminating the residue including disposing it into the sea (Dauvin, 2010).

According to The Statistics Portal, Statista, Australia, China, and Brazil are among the most major bauxite producing countries generating 80 million, 60 million, and 35 million metric tons (MT) of bauxite, respectively in 2015. It is expected that global demand for aluminum to increase due to never ending demand from the construction industry worldwide. According to same portal, Malaysia produced only about 21,200 (MT) bauxite in 2015 compared to a mere 3,260 MT in 2014.

In 2015, bauxite mining in Kuantan, Pahang, Malaysia caused quite a stir. In some part of the port town of Kuantan, cars, homes and trees accumulated a thick layer of red dust kicked up by the trucks and ore-hauling trucks (Abdullah et al., 2016). Trucks and lorries transporting red soil could easily be seen on the roads and highways. Fruit orchards and small oil palm farms, sold to mining contractors, were transformed into giant red gashes in the earth. Red, arid and flat terrain, possibly from severe scarring caused by bauxite mining could be clearly seen from the aerial pictures of Kuantan from Google map. Some of the rivers in the state and coastal waters had gone from clear to red due to the washed down from the open-pit bauxite mines. Fish kills were reported in Sg. Balok and Sg. Tonggak in Kuantan, Pahang. The federal government decided to ban the bauxite mining activities which first came into effect in January 2016. The decision had been made in order to allow for existing stockpiles to be cleared and for mining operators to set their houses in order. Due to this, the production of bauxite from Malaysia declined drastically to about 1,000 MT in 2016 and 2017.

What is the effect of bauxite or red mud from bauxite processing to the aquatic ecosystem? In early 2017, search using keywords 'bauxite effect" through Science website resulted in more than 7000 hits. However only about 5% of the articles listed were about the effect of bauxite on the aquatic organisms or ecosystem. According to Dauvin (2010), there had been numerous environmental impact studies of the industrial alumina production activity since 1960's. However most of them are studies carried out in other countries. Reports on the same topic from Malaysia are very scarce. The Fisheries Research Institute (FRI) has been involved in the bauxite pollution investigation in Kuantan since it came into limelight in 2016. At the peak of the event, questions regarding the impact of the red mud to aquatic ecosystems were constantly posed to FRI. Hence this compilation of reports is prepared to present some of the findings from the studies carried out in other countries on the effects of bauxite, specifically the red mud, to the aquatic ecosystem. We also include works that have been carried out in Kuantan and surrounding areas which are related to bauxite mining activity.

Effects of red mud to marine organism

Table 1 presents some of the findings related to the effect of red mud to marine organism in the laboratory. According to Blackman (1973), mollusks (*Scrobicularia plana, Cardium edule, Mytilus edulis*), flatfish (*Solea solea*) and shrimps (*Crangon crangon*) survived although covered by a layer red mud for several days. Within days most of the original covering of red mud had worked into the substrate. Red mud was seen to be expelled from the opercula of the fish, filtered out by the mussels or bound with mucus into faeces or pseudo-faeces. This coating was gradually lost and after a few days animals were free from contamination. Other effects include the agglutination of the gills, adhesion of red mud particles to fish eggs; adhesion to various echinoderms and crustacean. Effects on growth were also reported in species of diatoms, dinoflagellates, algae and copepods.

There is also report that showed more damaging effect of the red mud. Red mud from Germany which was dumped experimentally into an area of the North Sea (55°5'N 05°30'E) where lower tidal currents (0.5 knots, 0.9 km/h) occur. Transient concentrations in the water column during this experiment were sufficient to kill caged cod (Dethlefsen, 1972).

Effects of red mud is also said to be dependent on the concentration and source or location it was obtained. In the case of Armed bullhead *(Agonus cataphractus)*, after being exposed to German red mud suspension at 33, 10 and 3.3 g/l for 72 h, the mortalities were 100%, 60% and 0% respectively. After a further 48 h the mortality at 10 g/l had reached 80%. Suspensions in UK red mud with the same concentrations resulted in less toxic cases with only 20% mortality occurred in after 72 h suspension of 33 g/l. At the time of transfer to clean sea water, all fish in all concentrations of red mud had a dense covering of red mud particles on the epidermis. The buccal cavity and pharynx were similarly affected and particles occurred throughout the alimentary canal, particularly abundant in the stomach. The gills were covered densely with fine particles on the lamellae. Although there was a significant loss of red mud after being transferred into clean sea water, red mud were still present on the body, the lamellae and in the buccal cavity several weeks after the experiment was completed (Blackman, 1973).

Effects of red mud on survival of eggs and embryos

A number of studies on the toxicological effects of red mud on marine invertebrates have been described. Dethlefsen and Rosenthal (1973) reported 40–50% reduction on the survival of artificially fertilized and induced eggs of Herring (*Clupea harengus*) embryos and larvae after exposure to various concentrations of suspended red mud. The mortality was due to a reduced oxygen exchange between egg and surrounding environment. Trieff et al. (1995) showed that high concentrations (150 μg/ml) of red mud could induce developmental and reproductive damage in embryos of the Sea urchin (*Paracentrotus lividus*). Later, Pagano et al. (2002) tested the effect of bauxite residue from four provenances (Turkey, France, Greece and Italy) on embryos of the sea urchin (*Sphaerechinus granularis*). The data indicated a highly variable toxicity in terms of both the analytical and toxicity outcomes. These results may be explained by the composition of the residue and the variable release of the main components (Al and/or Fe) and other minor components, such as Mn, Zn and Pb. The differences in sample toxicity also suggested a potentially variable toxicity due to the composition of the bauxite ore and to manufacturing processes.

On the other hand, toxicological tests performed on the sediment collected at Cassidaigne canyon, France were negative, except for the sea urchin larval development and the luminescence inhibition test (Ribera and Saint-Denis 2002). Similarly Brunori et al. (2005) reported absence of severe eco-toxicological effects of 3 different types of bauxite residue from the Eurallumina plants located in Sardinia, Italy. In particular, the sea urchin embryo toxicity test indicated no toxic effect, as there were no significant differences between the control and the samples. Compared to Pagano et al. (2002), Brunori et al. (2005) used seawater that has undergone neutralization treatment in his experiment and this could explain the effective reduction of red mud toxicity observed in his study. The larval malformation observed by Pagano et al. (2002) was probably due to using freshly collected residues from the alumina factory. Furthermore, the results of eco-toxicology experiments conducted to evaluate the potential dangers of red mud discharge in Cassidaigne canyon indicated that there were no effects on the oyster's larval development and on the luminescent bacterium *Vibrio fisheri* (Dauvin, 2010). These results indicate that the red mud sediments have neither genotoxic potential nor acute toxicity. Nevertheless, as mentioned above, the various test response observed could be due to the composition of the bauxite ore and likewise on the manufacturing and toxicological processes.

Effects of red mud on the marine habitat

France, Germany, Greece, Japan and the United Kingdom, have all used marine pipelines to dispose their bauxite processing waste. There have been a few environmental impact studies of this industrial alumina production and red mud disposal activity on the marine environment that we could refer to. Dispersion of red mud over a large area is the obvious effect of the red mud disposal into the sea. The red mud discharged through a submarine pipeline at Cassis, France resulted in the build-up of abiotic red mud zone at the end of the pipe (Bourcier, 1969). The disposal of red mud produced industrially in South Wales, Newport Deep of the Bristol Channel amounted to 300,000 tons in 6 years. However no accumulation of red mud in the sediments or damage to fisheries was reported (Blackman, 1973).

Furthermore, bauxite red mud discharged into the continental shelf of the central Gulf of Corinth (Greece) through a pipeline at a depth of 100 m resulted in red mud extending over the slope to distances over 18 km from the mouth of the pipeline and covered an area of 28 km^2 (Varvanas et al., 1986; Poulus et al., 1996). In this area, red mud was dispersed in the water column in the form of suspended material, and dispersal was controlled by current circulation. A comparable phenomenon happens in the Cassidaigne canyon. The red mud is concentrated along the canyon axis, and then extends into the abyssal plain up to over 50-60 km from the pipe. The mud spread along the canyon, on the lateral flanks and down to the abyssal plain, tainting the seabed with iron, titanium, vanadium and chromium (Dauvin, 2010; Fontainer et al., 2012). These elemental enrichments are related to bauxite-derived minerals and various amorphous phases. The width of the discharge diminishes from the canyon to the abyssal plain, where the red mud is mixed with the abyssal mud by mechanical and biological mechanisms.

Effect of red mud on the macrobenthic communities

The effect of the red mud on the macrobenthic fauna at Cassidaigne Canyon, France has been reported by Bourcier (1969). Boucier divided the investigated area into two zones; central zone near the mouth of the pipe with thick layer of red mud and the peripheral zone with only a thin layer of mud. Macrofauna was absence in the central zone while normal benthic fauna were still available in the peripheral zone. This observation suggests that the macrofauna in the central zone was eliminated by the mechanical effect of a thick fluid layer of the deposited mud. In addition Boucier et al. (1993) also investigated the macrobenthic fauna in Toulon Canyon, 50 km to the east of Cassidaigne Canyon. Fauna in Toulon Canyon were comprised of two main macrobenthic communities similarly as noted in Cassidaigne Canyon. Species richness declined greatly from 250 to 500 m (120-150 species for 0.375 m^2) and stabilizing between 1,000 and 2,000 m (around 30 for 0.375 m^2). In addition, Stora et al. (1999) stated that the macrobenthic density and biomass were particularly low in the Mediterranean, compared those observed in deep oceans around the world.

Later Dauvin (2010) reported an absence of macrofauna along the Cassidaigne canyon axis covered by a sizeable layer of red mud. However the sites outside of the red mud accumulation zones had a normal community structure, always composed of several species exclusively characteristic of the muddy-bottom bathyal community (VP). Species richness and abundance decreased with the bathymetric gradient their values exhibited long-term variability; for the same locations with the values observed in 1997 were lower than those observed during the three other campaigns in 1991, 2002 and 2007. Investigation by Fontainer et al. (2012) on the benthic foraminiferal faunas at 725 m and 1528 m depths along the axis of the Cassidaigne Canyon also described similar outcomes. At the shallowest station located very close to the pipe outlet, the benthic living foraminiferal community is characterize by a very low diversity and by an unusual dominance of *Gyroidina umbonata* and *Bulimina marginata*. The mechanical stress related to downslope transport of red mud is a possible source of hydro-sedimentary pollution precluding the settlement of diverse fauna. The living and dead foraminiferal faunas from the deepest site are typical of oligo-mesotrophic conditions as prevail in natural environments. At this site, bauxite residues have no obvious environmental impact on foraminiferal faunas.

Recently to Fabri et al. (2014) described a selective negative effect of not potentially lethal effect of red mud in the Mediterranean Sea. Megafauna diversity observed in 2009 was lower than that in 1971. Colonies of gorgonians (*Acanthogorgia hirsuta*) were smothered with red mud and showed clear signs of tissue necrosis and patches of mud flocs. The entire seabed along the canyon axis was covered by red mud below 350 m depth. The episodically severe up- and down welling current regimes may be the driving force for the complete spatial coverage of the natural seabed by man-made discharges. The burial of the rocky substrates suitable for the settlement of *Madrepora oculata* prevent them from expanding deeper than 350 m. The few *M. oculata* colonies observed deeper on blocks rising from the red mud bottom probably settled before the start of the disposal of the red mud. The highest abundances of *M. oculata* in the red mud environment were always observed on vertical walls where colonies were partly sheltered from silting. These colonies seemed to cope with the heavy sedimentation load but at a metabolic cost that remains to be investigated. However, it may point to a specific stress tolerance of *M. oculata*. The bauxite residue (red mud) expelled in the Cassidaigne canyon was seen to prevent fauna from settling at the bottom of the canyon and it covered much of the flanks.

Risk of red mud to seafood safety

The impact of red mud is also associated with the risk of tainting the seafood with minerals associated with bauxite. However there is not much evidence in this claim. Seafood samples *Merluccius merluccius*, *Pagellus bogaraveo*, *Trigla lucerna*, *Trigla gurnadus* and *Conger conger* has been analysed for aluminium, chromium VI, chromium III, copper, iron, lead, manganese, vanadium and zinc. The risk calculations for the measured concentrations of the above elements in fish did not identify any cumulated risk for women or children eating fish. The impact of the bauxite red mud on foraminiferal test chemistry is not straightforward suggesting that trace metals in the contaminated sites are not bioavailable for foraminiferal communities but merely bound in the solid phases. However, if the organic matter loading would change in the contaminated sites, it may induce releasing trace metals in solution from amorphous phases, making them bioavailable and causing toxicity to benthic life.

Bauxite mining in Malaysia and effect to the aquatic ecosystem

Bauxite deposits occur in several areas in Malaysia mostly in Rompin, Kuantan and Johor area. The deposits have been mined discontinuously since the first Japanese mining in 1936. The reserves of bauxite in Peninsular Malaysia are estimated to be 10 million tons, and potential bauxite resources, including low-grade bauxite, of 40 million tons are present. They are formed by the chemical weathering of igneous rocks of different compositions ranging from acidic to basic (Baioumy, 2016).

The existence of bauxite in Kuantan, Pahang was first recognized by the Geological Survey in 1937 (Rajah, 1986). Later, Fitch (1952) showed that its occurrence is confined to areas underlain by the Kuantan basalt. Chemical analysis of the bauxitic samples from Kuantan indicates a wide range of composition corresponding to low or medium grade bauxite. Some of the samples are lateritic with very high iron and silica content while others are high in iron only. Due to high content of ferric oxide, the bauxite in Kuantan could be categorized as ferruginous bauxite (Rajah, 1986). Baioumy (2016) later confirmed the relatively high contents of Fe_2O_3 in Kuantan bauxite.

So far there are very limited reports on the effects of red mud from bauxite mining to aquatic ecosystem or organisms in Kuantan and surrounding areas. Nevertheless there are several studies carried out on the determination of heavy metal pollution in the sediments from the river and coastal areas near Kuantan. River sediments are a major carrier of heavy metals in an aquatic environment and heavy metals are serious pollutants for aquatic life because of their toxicity and persistence in the environment.

Kamaruzzaman et al. (2011) studied on the heavy metal concentration in the surface sediment of Tanjung Lumpur Mangrove Forest in Kuantan. They reported a significant contamination of lead (44.41 µg/g dry weight) and moderate contamination of cuprum (32.79 µg/g) in this area. Contaminations of cobalt (5.79 µg/g) and manganese (117.73 µg/g) were minimal. The calculated enrichment factors (EF) for cobalt and manganese indicate that it could be from terrigenous sources while lead and cuprum from anthropogenic input. Later Mohd Zahari et al. (2015) investigated the presence of selected metal in Sungai (Sg.) Balok or Balok River sediment in order to evaluate the pollution status based on geoaccumulation index (Igeo) and EF. Sg. Balok is adjacent to Gebeng Industrial estate which is considered as one of the most developed industrial sites in Kuantan, Pahang. Since 1970s the area has increased its industrial activities involving mining, petrochemical, multifarious industries and the latest rare-earth processing. It is believed that Sg. Balok is receiving waste and discharge from Gebeng Indusrial estate. Mohd Zahari et al. (2015) reported that ferum and zinc were the two elements that dominated the surface sediment samples of the Sg. Balok. The existence of these two metals in the sediment could be from natural origin. Similar to previous study, cobalt was also recorded lowest in this study. The results of the Principal Component Analysis generally indicate that the metals in Sg. Balok sediment could have originated from two different sources, anthropogenic and natural. Ferum, manganese, cobalt, lead and cuprum were possibly related to the natural and agricultural origin, while nickel, vanadium, cadmium, chromium and zinc were contributed by industrial activities. However, the analysis of EF and Igeo suggests that no excessive metals were discharged into Sg. Balok by the industrial activities.

In 2016, after the bauxite pollution became big news in Malaysia, more studies were initiated in Kuantan, Pahang. Among the studies are by Shahunthala and Intan Nurlemsha, (2016); Kusin et al (2017) and Sharifah Norkhadijah et al (2017). There are also reports on the psychosocial and health impact to the communities surrounding the bauxite mining area (Hussain et al 2016; Abdullah et al, 2016). The majority of the studies still concentrate on the assessment of heavy metals in the soils, waters and sediment from the affected site. This could be due to the urgent need to determine the extent of pollution from the bauxite mining.

Rather comprehensive studies were carried out by the FRI Batu Maung, Penang. The studies focused on the i) examination of metal concentrations in riverine (Sg. Balok, Sg. Riau, Sg. Lembing, Sg. Mabuk, Empangan Kobalt, Sg. Pengorak and Sg. Padan) and coastal waters (Pantai Batu Hitam, Kuala Penur dan Tg. Lumpur) around Kuantan; ii) determination of metal concentration in fish and shellfish from affected areas to ensure no bio-accumulation of metals from a consumer perspective; iii) metal concentrations in riverbed sediments for long term impact assessments; iv) river water bioassays using freshwater fish for toxicity evaluations; and v) socio-economic impact of bauxite mining activity to fishers. Parts of the results were presented in Shahunthala and Intan Nurlemsha (2016). Results from the first part of the studies indicate that the levels of metals (magnesium, aluminum, chromium, manganese, cuprum, zinc, arsenic, selenium, cadmium. mercury and lead) are well below the maximum permissible limits for aquatic life conservation except for iron which is 0.3 ppm according to the Canadian Standard for protection of aquatic life which is used as reference in this study. Basically the locations around the mining areas (Bukit Goh, Bukit Sagu and Empangan Kobalt) and the two estuaries of Sg. Balok and Sg. Pengorak are contaminated with metals leached from the mined ore. Effects of high iron in water to fishes had been reported in laboratory bioassays.

The 96-h LC_{50} values for ferum, aluminum and manganese were 1.71, 1.53 and 5.71 mg/L for Cyprinidae *(R. sumatrana)* and 1.46, 6.76, and 23.91 mg/L for *P. reticulata*, (guppy; Poeciliidae) respectively. Based on the above numbers, we can infer that the iron concentration in Sg. Balok and Sg. Pengorak has exceeded the toxicity threshold for freshwater fish. Higher concentrations of metals (mercury, magnesium, arsenic, chromium and selenium) were recorded for marine and brackish water locations such as coastal waters and estuaries due to the natural presence of minerals and salts in saltwater. In addition, a total of 20 species of fish and 3 types of shellfish (crabs, bivalves and shrimps) were analyzed for metals. The results obtained demonstrated that the metal concentration in the fish examined was below the maximum permissible limit for consumption (Food Regulations 1985). Elevated levels were observed in some samples from locations nearby the mining areas, suggesting that the fish in the vicinity of mining operations at Sg Mabok, Sg. Padan and Sg. Riau were exposed to some of the metals leached from mined earth. Aluminum, magnesium, manganese, cadmium, chromium, selenium, cuprum and ferum were elevated in certain fish species (*Channa lucius* and *Mystus spp.*) from rivers in the vicinity of the mining site. Chromium, zinc, copper and arsenic were elevated in fish from estuarine locations due to marine inputs of the minerals. Metal concentrations in sediment collected from the same sites as water and fish were reflective of similar elevations as observed in water samples. The bioassay results are in very good agreement with the sediment EF results indicating areas near Bukit Goh (mining site), Bukit Sagu (mining site) and Empangan Kobalt as well as the estuary of Sg. Balok are being more contaminated than Sg. Mabok and Sg. Padan. Elevated metal data for Sg. Balok and Sg. Pengorak was most likely due to bauxite storage spillovers and other sources of pollution from upstream industrial activities.

Kusin et al. (2017) investigated the bauxite mining activities ecological impacts on water and sediment quality. Water and sediment samples were collected at seven sampling locations within the bauxite mining areas between June and December 2015. The water samples were analyzed for water quality index (WQI) and distribution of major and trace element geochemistry. Sediment samples were evaluated based on geochemical indices, i.e., the EF and Igeo. Potential ecological risk index was estimated to assess the degree to which sediments of the mine-impacted areas was contaminated with heavy metals. The results showed that WQIs of some locations were classified as slightly polluted with metal contents exceeding the recommended guideline values. The EFs indicated minimal to moderate enrichment of metals (lead, cuprum, zinc, manganese, arsenic, cadmium, chromium, nickel, cobalt and strontium in the sediments. Igeo showed slightly to partially polluted sediments with respect to arsenic at some locations. The potential ecological risk index (RI) showed that arsenic posed the highest potential ecological risk with RI of 52.35–60.92 at two locations, while other locations indicated low risk.

In addition, Sharifah Norkhadijah et al. (2017) studied the level of heavy metals in the soil samples from Kuantan Port and Bukit Goh as a basis to validate the health risk concern. A total of 36 elements from three categories, namely: (i) elements that can cause cancer or carcinogenic health effects; (ii) elements that cause non-carcinogenic health effects such as irritation, respiratory problems, kidney problem, etc.; and (iii) elements that have not been reported of their concern to human health were examined in the soil sample. Elements that can cause carcinogenic health effects were detected in the soil samples as follow: chromium > lead > nickel > arsenic > cadmium > selenium. The most prominent elements that can cause non-carcinogenic health effects detected were ferum > calcium > manganese > barium > molybdenum > zinc > mercury. Other traces elements highly detected in the samples were silicon > titanium > praseodymium > vanadium > cerium > neodymium. Most of the elements were highly detected in Kuantan Port, a bauxite stockpile area. The elements were derived from the crustal mineral, mine waste or residues as well as dust and aerosol emission from the extraction, transportation and deposits of soil particles in the mining area. Elements detected were possibly derived from the mine waste or residues as well as dust and aerosol emission from the mining operations.

Majority of the previous studies in and around Kuantan focus on heavy metals The primary impact of the red mud is relate to its presence or inputs into the surrounding waters. Therefore, changes in water quality (i.e water turbidity and total suspended solids (TSS) levels can be a good indicator of deteriorating water quality (and potentially detrimental to aquatic life). However, there seemed to be no report on this matter. Furthermore changes in the characteristics of bottom sediments can be a good indicator of potential adverse impact of red mud inputs. Without red mud inputs, the proportion of organic matter in the bottom sediments can be higher. Inputs of red mud will increase the inorganic proportion of the sediments.

Conclusion

In conclusion, findings from the studies elsewhere indicate that the effects of red mud in the ocean are different under different circumstances and depending on the physical properties (size, specific gravity, % solids) and chemical composition of red mud. The results also suggest red mud residues may be safely deposited in an area but not in another. From the table it can be concluded that the effect of red mud on ecosystems and marine animals is diverse and sometimes conflicting with each other.

The red mud furor in Kuantan recently is not from the alumina processing plant waste. It is from the spilled soil containing bauxite, the flying debris during transportation and washed down from the open-pit bauxite mines. Thus the effects of Kuantan red mud to aquatic ecosystems could be different than the findings from other countries as the red mud particles could be different in size and composition. For instance, the size of red mud particles in Kuantan could be bigger since they have not gone through any chemical process as in the industrial bauxite waste. Red mud from Pahang may also have minerals and impurities that are more complex than the rest of bauxite processed as in the above studies. Thus it was possible that the effect of red mud from Kuantan on the marine ecosystems or marine animals might differ from the results that have been observed.

From the works reported so far, we could conclude that the direct effects of red mud from bauxite mining to the aquatic environment and organisms in Kuantan and the surrounding areas are still uncertain. From the results, the main concern in Kuantan is the high iron concentrations in water as reported in most of the findings which may pose a risk to aquatic life especially at early stages of fish development. Monitoring of the changes in population and diversity of freshwater fish in the vicinity of mining areas is strongly recommended. This is important as the impact of red mud can be assessed and control measures could be taken to address this matter. Likewise, although metals in fish tissues are below permissible levels but they show elevations as compared to background levels. These should also be monitored. Sediment metal data shows enrichment in the vicinity of the mining areas as well as storage areas. Metals in sediment are bound to particulate material thus are not available for uptake by biota but long-term deposition of these metals in the estuaries poses a risk from resolubilisation and onto the food chain.

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