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Radiological Environmental Risk Associated with Different Water Management Systems in Amang Processing in Malaysia

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Abstract: The processing of amang (tin-tailing) for its valuable minerals have shown that it technologically enhanced naturally occurring radioactive materials, and has a potential of impacting the environment. Large volume of water is used to extract these valuable minerals from amang. Three types of water management systems are used by amang plants, i.e. Open Water System (OWS), Close Water System Man-made (CWS_{mm}) and Close Water System Natural (CWSn). A study was carried out to determine the radiological environmental risk associated with these different water management systems in amang processing in Malaysia. The parameters studied were pH of water, Water Quality Indices, and uranium ad thorium concentrations in water and sediments. Three different sampling locations were selected for each water management system, i.e. the source, the receiver and related reference water bodies. Results obtained showed that amang reduces the pH and contaminates the water. However, OWS appears have the least radiological environmental impact. On the contrary both CWS (man-made and natural) pose a potential environmental risk if great care are not given to the treatment of accumulated sediment and contaminated water before discharge into the environment..

Key words: amang, radiological, environmental, risk, water management

Introduction

Radiological risk associated with the processing of tin-tailing (or what is locally termed amang) processing containing naturally occurring radioactive materials (NORM)) for valuable minerals, have stirred a lot of interests and studies in Malaysia and countries in South East Asia. The studies were largely focused on immediate on-site radiological risk (AELB, 1991; Hewson, 1993; Kandar and Bahari, 1996 and Hu *et al*., 1995) and some potential radiological environmental impact (Ismail *et al*., 2001; Azlina *et al*., 2002). The risk associated with amang processing is not limited to radiological hazards but include non-radiological hazards as well. Other studies have shown that different types of amang soils are potentially cytotoxic to plants (Ismail *et al*., 1996 and Sarina *et al*., 1999), and water discharged from amang processing plant have been shown to reduced the Water Quality Index of water and has the potential of contaminating neighbouring water bodies.

Amang processing uses large volume of water in its wet gravity separation step. Currently amang processing plants in Malaysia employ three systems of water management in the wet gravity separation process. These systems may be classified as open water system, recycle water system (natural) and recycle water system (man-made). In the open water system, water is drawn from nearby river or stream, used in wet gravity separation and subsequently released into the river or stream. The close water system recycles the water used in wet gravity separation. The only different between man-made and natural systems is that the initial method uses large concrete pond to contain recycles water while the later uses natural pond or lake. Both man-made pond and natural lake sourced their water naturally. Preference for the use of either type of water management system is determined by the size of the plant operation and the availability of water. Whatever the system used there is a potential radiological environmental risk. A study was carried out to compare such risk associated with the different water management systems used by three amang processing plants. This paper reports the findings of this study.

Methods

Sampling locations: Three different amang processing plants employing three different water management systems (i.e. open water (OWS), close water (natural) (CWS_n), and close water (man-made) systems (CWS_{mm}) were used in this study. All plants were from the Kinta District, Perak, Malaysia. The plant employing the open water system draws its water from a nearby river. Three sampling stations (point of discharge, upstream and downstream) were identified. The upstream and downstream sampling stations were about 100 m from the point of discharge. The plant using the CWS_n sources its water from a flooded used open cast tin mine (about 6 acres in area). The source (s) of water from this pond is not fully understood but one sure source is from the rain. The pond is separated from a large river by a bund about 15 m wide at its nearest point. Three sampling stations, i.e. at the point of discharge, recycling pond and adjacent river were selected. The plant using the close water system (man-made) draws its recycle water from a concrete man-made pond. (6 m x 4 m x 6 m). Water used in this recycle concrete pond is periodically sourced from a nearby pond. At least once a year the recycle water from this pond is released into the environment. Three sampling points were selected, which were the point of discharge, man-made pond and the adjacent natural pond.

Samples and Parameters studied: For each sampling locations the following parameters were measured

pH: measured in-situ

Water Quality Index (WQI): WQI is an assessment on the levels of contamination based on the physical and chemical properties of water. WQI is calculated based on the Dissolve Oxygen (DO), Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), ammoniacal nitrogen (AN), suspended solids (SS), and pH of water. Each of these sub-parameters were determined using methods described in HACH (1996). These sub-parameters provide sub-indices that were accounted for to determine the WQI using the equation,

$$WQI = (0.22 \times SIDO) + (0.19 \times SIBOD) + (0.16 \times SIOD) + (0.15 \times SIAN) + (0.16 \times SISS) + (0.12 \times SipH)$$

Concentrations of thorium and uranium in the water and sediment samples: Water samples were collected directly as they are discharge from the plant or taken from the ponds using a pail. Sediments were scooped from silt trap (at the point of discharge) or from submerged areas of the pond that could be scooped up by hand or pail. Uranium and thorium concentrations in sediment samples were determined by means of direct counting of their gamma emitting progenies. IAEA soil-375 was used as standard reference materials in the comparative technique. Samples were each counted for 12 hours. The determination of uranium and thorium in water samples were based on 2 L of water sampled that was then concentrated to 200 ml. The activity concentrations of both radionuclides were counted using HPGe-PCA (Tennelec-Nucleus) after 30 days secular equilibration.

Results and Discussions

Table 1 shows the pH and Water Quality Indices of water samples measured at different sampling locations in the three different amang processing plants employing one of the three different types of water management systems. pH levels of water recorded at point of discharges from OWS, CWS_n and CWS_{mm} were 5.54 ± 1.02, 2.58 ± 0.02, and 2.86 ± 0.03 respectively. Except for OWS, all other water was very acidic. Acidity of the water is due to the acidity of the amang soil. Earlier studies have shown that amang soil is acidic (pH 2) (Ismail *et al.*, 1996). The large variation of pH levels (18.1% variation from the mean) in OWS is attributed to the different initial acidity of the amang soil. The higher water pH from OWS compared to CWS_{mm} and CWS_n is contributed by a continuous dilution of the acidity of the amang soil by fresh water from the river. On the contrary the lower pH of CWS_{mm} and CWS_n is a consequent of continuous usage of the same water (which was already acidic) to processed new acidic amang soil. It appears that the continuous use of large volume of fresh water has helped to increase the pH of water at the point of discharge before it enters the environment.

Table 2 further explained the percent changes in pH at various locations relative to those measured at the point of discharge for the different water management systems. Data confirmed two important findings. Firstly, a small variation of pH between those measured at the point of discharge and the recycling pond warns the potential of such high acidity having an impact on the neighbouring water bodies if the water were to be introduced into it. Secondly, a continuous supply of fresh water (as used in the OWS) actually helps to reduce the acidity of water from the plant before it is released into the environment.

Further quality of water is described by its WQI. WQI takes into consideration sub-indices of pH, ammoniacal nitrogen, Dissolve Oxygen, Biochemical Oxygen Demand, Chemical Oxygen Demand, and Total Suspended Solids. Grades of WQI (as prescribed by Department of Environment Malaysia) are as follows. Indices 0 – 59, 60-80, and 81-100 indicate contaminated, slightly contaminated, and clean water respectively. Table 1 shows that water samples taken from all the point of discharge, except from the OWS are considered contaminated. The WQI at the point of discharge in an OWS was classified as clean. What is more interesting is that the OWS did not affect the water quality. Water from both recycling ponds was contaminated. Ismail *et al.* (1999) reported similar water quality in a different plant using the CWS_n. Between the two CWS, the water quality of water in the CWS_{mm} is the most contaminated. This was expected because of the volume of the man-made recycling pond was much smaller compared to the natural

Table 1: pH, total suspended solid and water Quality Indices of water samples measured at different sampling locations in amang processing plants employing three different types of water management systems

Water Management Systems	Sampling locations	Parameters pH	WQI
Open Water System	upstream	5.93 ± 0.11	94.25
	Point of discharge	5.54 ± 1.02	86.16
	downstream	4.76 ± 1.26	83.43
Close water system (natural)	Point of discharge	2.54 ± 0.02	39.12
	recycling pond	2.58 ± 0.02	53.09
	adjacent water body (river)	6.84 ± 0.03	64.32
Close water system (man-made)	Point of discharge	2.88 ± 0.03	59.52
	recycling pond	2.86 ± 0.03	31.37
	adjacent water body (pond)	7.14 ± 0.01	25.33

Table 2: Percent difference between different levels of parameters measured relative to values measured at the point of discharge

Water Management Systems	Sampling locations	Parameters pH	WQI
Open Water System	upstream	NSD (7.1%)	(9.4%)
	Downstream	NSD (-14.1%)	(-3.3%)
Close water system (natural)	recycling pond	NSD (1.6%)	(35.7%)
	adjacent water body (river)	SD (169.3%)	(64.4%)
Close water system (man-made)	recycling pond	NSD (-0.7%)	(-27.3%)
	adjacent water body (pond)	SD (149.7%)	(-57.4%)

NSD = not significantly different using t-test
(-ve) and (+ve) values indicate lower or higher than the level measured at the point of discharge.

Table 3: Activity concentrations of thorium and uranium in water and sediment samples

Water Management Systems	Sampling locations	Parameters: Thorium Water ($Bq\ L^{-1}$)	Thorium Sediment ($Bq\ kg^{-1}$)	Uranium Water ($Bq\ L^{-1}$)	Uranium Sediment ($Bq\ kg^{-1}$)
Open Water System	upstream	34.5±1.1	476.6±2.6	35.4±2.1	151.4±2.8
	Point of discharge	26.3±0.8	126.1±1.6	26.8±1.6	136.7±3.1
	Downstream	35.3±1.1	109.3±1.3	33.3± 2.1	90.9±1.9
	point of discharge	34.5± 1.0	118.7±1.1	35.4±0.4	90.3±1.8
Close water system (natural)	recycling pond	32.1±1.0	239.0±2.4	34.4±0.1	198.9±4.0
	adjacent water body (river)	32.1±1.0	15.4±0.6	35.4±0.1	11.4±0.7
	point of discharge	32.1±0.90	1966.6±4.7	29.0±1.4	1110.5±7.3
Close water system (man-made)	recycling pond	36.2±1.0	292.1±1.9	35.4±1.6	516.8±4.4
	adjacent water body (pond)	29.6±0.9	154.4±1.7	29.0±1.4	262.9±3.9

recycling pond. In addition, the source pond for the man-made recycling pond was already contaminated (WQI of pond water body was 57.47% lower than at the point of discharge).

The potential introduction and enhancement of naturally occurring radioactive materials (NORM) into the adjacent water bodies following the processing of amang may be assessed in three ways. The first is to determine the concentrations of NORM, as measured using ^{238}U and ^{232}Th, in sediment and water at the point of discharge. Secondly, is to determine the percent increase of NORM in water and sediment outside the plant, and finally to determine the current and potential risk of radiological environmental impact. Table 3 shows the concentrations of ^{238}U and ^{232}Th in water and sediment samples for all sampling stations. The highest concentrations of ^{238}U and ^{232}Th were recorded in sediment samples from the point of discharge of a plant using the CWS_{mm}. Their concentrations were 1110.5 ± 7.3 and 1966.6 ± 4.7 $Bq\ kg^{-1}$ respectively. The concentrations of ^{238}U and ^{232}Th in water samples ranged from 26.3 – 35.4 $Bq\ L^{-1}$. As comparison valuable minerals such as monazite, xenotime and ilmenite extracted from amang contain 1856.5 ± 9.3 $Bq\ kg^{-1}$ ^{238}U and 10287.1 ± 9.3 $Bq\ kg^{-1}$ 232Th, 6911.1 ± 11.7 $Bq\ kg^{-1}$ 238U and 3733.1 ± 6.0 $Bq\ kg^{-1}$ 232Th, and 318 ± 2.6 $Bq\ kg^{-1}$ 238U and 142.7 ± 1.2 $Bq\ kg^{-1}$ 232 Th respectively (Yasir *et al.*, 2002). With such information and with the fact that such radionuclides are part of the minerals (e.g. Monazite [(Ce, La, Y, Th)] PO_4, Zircon [$ZrSiO_4$]) and are not easily released from the minerals except under harsh conditions (Hart *et al.*, 1993), it may be concluded that radionuclides contamination of sediments are largely due to minerals containing NORM found in sediments and not from free radionuclides dissolve in the water.

For the OWS, the concentration of thorium were highest in upstream's (476 ± 2.6 $Bq\ kg^{-1}$) sediments followed by the point of discharge (126.1 ± 1.6 $Bq\ kg^{-1}$) and downstream's sediments (109.3 ± 1.3 $Bq\ kg^{-1}$). Likewise the pattern was similar for uranium, i.e. 151.4 ± 2.8 $Bq\ kg^{-1}$

in supstream sediment, 136.7 ± 3.1 Bq kg^{-1} in sediment from point of discharge, and 90.9 ± 1.9 Bq kg^{-1} in downstream sediment. The high levels of uranium and thorium in the sediment of the OWS at the upstream sampling station could be accounted to the large stockpiling of unprocessed amang as well as semi-processed minerals near the sampling station. Heavy rain in the area have clearly been seen to have washed down some of these minerals.

Table 3 also shows a marked increase in concentrations of uranium and thorium in sediment at the recycling pond of the CWS_{mm} compared to the CWS_n. This may be contributed by the fact that the recycling pond of the CWS_{mm} is very much smaller in size and the sedimentation would be very much higher (i.e. localized) as compared to the CWS_n where sedimentation were more widely distributed throughout a much larger pond.

Although a high activity concentrations of radionuclides measured at the point of discharge of the plant using the CWS_{mm} was obvious, it was not clear as to why the activity concentrations of similar radionuclides in sediment from the recycling pond was about 15 times lower than at the point of discharge. One possible explanation was that NORM concentration in sediment from the point of discharge was directly dependent on the quality of amang being processed at the time of sampling, which at this particular time was processing amang that could be relatively rich in NORM Depending on the source, amang have been shown to contain different concentrations of NORM. On the other hand the recycling pond contained effluent accumulated over times from mixture of different amang containing NORM that were processed.

Continuous recycling (i.e. using CWS_{mm}) is a source of elevating the concentration of NORM in the man-made pond, with a potential of radiological environmental impact. Steps must be taken to continuously monitor the radioactivity concentration of NORM. Any release of water and sediment containing TENORM into the environment must be controlled by the Atomic Energy Licensing Board.

Radiological environmental risk associated with different water management systems in amang processing was assessed. Radiological environmental risk was assessed based on the pH of water, the Water Quality Index and the uranium and thorium contents in both water and sediments sampled at strategic locations of three different amang processing plants employing three different water management systems. It may be concluded that an open water systems posed a lesser radiological environmental risk to the environment compared to the close water system. Although current practices of recycling the water appears to contain the contaminated water and sediments from impacting the environment, continuous monitoring must be taken to ensure that it remains so.

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