Assessing the potential use of abandoned mining pools as an alternative resource of raw water supply

Faradiella Mohd Kusin, Mohd Syakirin Md Zahar, Siti Nurjaliah Muhammad, Zafira Md Zin and Sharifah Mohd Sharif

ABSTRACT

The water crisis in the state of Selangor has prompted the state water authority to use water from abandoned mining pools as an alternative resource of raw water supply. In this study, the potential use of the mining pool water has been assessed to evaluate its safe use for potable water consumption, which is the source of raw water to be supplied to water treatment plants. Assessments were made between sampling sites that include abandoned mining pools, active sand mining pools, and the receiving streams (two tributaries and the main river, Selangor River) within Bestari Jaya catchment, Selangor River Basin. As anticipated, some concentrations of metals were found in the active mining pool and in its discharge, such as iron, manganese, lead, copper and zinc. However, the trace elements were found at very low concentrations or below detection limits in the abandoned mining pools and in the rivers. It was found that generally the quality of the water in the rivers (upstream of water intake of the water treatment plants) was well below the recommended guideline limits set out by the Malaysia Ministry of Health for untreated raw water, and therefore is safe for potable water use.

Key words | alternative resource, hybrid-off river augmentation system (HORAS), mine water, mining pool, water supply

INTRODUCTION

The recent water crisis of the disruption of water supply in the state of Selangor, Malaysia, has pushed the state government to find alternative resources of raw water supply, including the use of water from abandoned mining pools. This is mainly due to the increasing water demand within the state and the fact that Bestari Jaya (a catchment area within Selangor River Basin) has an abundance of former mining pools. The Bestari Jaya catchment, which was formerly known as Batang Berjuntai, was one of the most progressive sites for tin mining in the country, however, operations ceased in the 1980s. With more than 20 available former mining pools within Bestari Jaya catchment, the approach seems to be a reasonably good option while incorporating natural available water resources. The state water authority has proposed that the water from selected abandoned mining pools be pumped into the main river (Selangor River) as an alternative solution to providing sufficient supply of raw water to water treatment plants within the river basin. These water treatment plants cater for the water demand in the Federal Territory (Kuala Lumpur and Putrajaya) and the state of Selangor, the Klang Valley. The water authority has also proposed that the supply from abandoned mining pools be developed on a larger scale alongside the river water, while also seeking the potential use of groundwater under a so-called hybrid-off river augmentation system (HORAS) project. This is to reduce the large dependency on river water and the fact that the capacity of the existing reservoirs may not be sufficient to meet the demand on extreme occasions, for instance during drought or dry weather periods (Salleh et al. 2011). Approximately 99% of the water supply in Malaysia comes from rivers and streams across the country (Jahi 2001). Despite former tin
mining areas, active sand mining still progressively occurs at some locations within the river basin. Sand mining may on the other hand bring economic benefits to the country. However, the processes of prospecting, extracting, concentrating, refining and transporting minerals have great potential for disrupting the natural environment (Borges et al. 2002). Physical impacts of sand mining such as reduction of water quality and destabilisation of streambed and banks can also result in channel instability and sedimentation problems.

Notwithstanding this, an integrated management approach for the river basin has been brought forward through the implementation of the HORAS project. HORAS is a combination of an off-river storage (ORS) concept and horizontal collector well that incorporates stormwater accumulation from Selangor River and excess water from existing plants, rainwater, and groundwater collection (LUAS 2014). The HORAS concept is essential for reducing the huge reliance on the release of dam water and surface water, and it is also able to meet demand during a drought. Additionally, this will also avoid wastage of rainwater and prevent the risk of flooding for downstream settlements. In the present study, the river water and the abandoned mining pools within Bestari Jaya catchment were investigated for their safe use as potable water resources. This is mainly in response to safety concerns that have recently arisen among the public due to the use of such waters. The environmental consequences of mine-water-related pollution have been described in many studies (Brown et al. 2002; Younger et al. 2002; Younger 2004; Mayes et al. 2010; Kusin 2013). However, the discussion presented here is mainly focused on the assessment of water quality in relation to several guidelines sufficient to answer the questions on its safe use.

Study site

Bestari Jaya is a former tin mining catchment in Selangor River Basin of 2,656.32 hectares and has a total of about 442 ex-mining lakes and ponds of different sizes (Department of Minerals & Geosciences Selangor Malaysia 2002). These lakes and ponds emerge as a result of dredging operations and other methods of tin mining (Tan et al. 1992). In the upper part of the river basin, there are two supplying reservoirs: the Sg. Selangor Dam that drains into the main river (Selangor River) and another reservoir, Sg. Tinggi Dam. The main tributaries draining the middle of the catchment include Sembah River, Kanching River, Kerling River, Rawang River and Tinggi River. Downstream of Bestari Jaya catchment there are several water treatment plants such as Rantau Panjang Water Treatment Plant and Selangor River Water Supply Scheme (SSP1, SSP2 and SSP3), which are the main water distributors to the Klang Valley. These water treatment plants are capable of supplying about 2,670 million litres per day (MLD) of treated water, which is 57% of the total water demand in Klang Valley (LUAS 2012).

The HORAS project is operating in a former mining area of 235 hectares in the vicinity of Sungai Darah Village (Figure 1). The project includes two phases in which the first phase is expected to be capable of supplying 600 to 700 MLD of water, and the second phase will be able to supply 3,000–5,000 MLD by 2020 (LUAS 2014). In terms of its technical aspects, the project also includes the installation of sheet piles 3 kilometres long to prevent river water from seeping into the reservoir and also to protect banks from erosion, construction of a raw water pumping station and access roads. This initiative will reduce the large dependence of water supply on one raw water resource, thus ensuring continuous supply of water to over seven million consumers in the Klang Valley.

MATERIALS AND METHODS

The sampling was carried out to assess the quality of the water as to whether it is safe for water supply consumption. The water sampling was taken at the proposed HORAS project site, Hang Tuah pond and its discharge, existing ex-mining pool (site of former mining), sand mining pool (site of active mining) and in-stream sampling at Streams A and B and the main river, Selangor River (Figure 1). The sampling was performed twice between June and August 2013 and in the same period in 2014, which is associated with the months of lowest flow.

The on-site measurements of pH, electrical conductivity, Eh, total dissolved solids (TDS) and temperature were taken using a calibrated Myron L Ultrameter 6P. Alkalinity was measured in the field by a two-step titration method against sulphuric acid with phenolphthalein and bromocresol
green–methyl red indicators using a HACH alkalinity kit (AL-AP). Turbidity was measured using an Orion Aquafast turbidity meter. Samples for water quality analysis were collected in polypropylene bottles that were pre-washed (soaked overnight in 10% by volume nitric acid (HNO₃)), washed three times with tap-water, then three times with 18.2 Ω MilliQ deionised water). The water samples were collected in 125 mL bottles; acidified with 1% by volume concentrated HNO₃ for total cation and metal analysis, and unacidified samples for anion analysis. All samples were kept cool at 4 °C prior to analysis and analysed within 1 week of sampling. Major cations (Ca, Mg, Na, K) and metals (Fe, Mn, Zn, Cu, Pb and Zn) were analysed using a Varian Vista MPX Inductively Coupled Plasma-Optical Emission Spectrometer (ICP-OES). Anions (Cl) were
analysed using a titration method and SO\textsubscript{4} was determined using a turbidimetric method with a HACH meter. The reliability of sample analyses was tested by charge balance calculations. Electro-neutrality within ±5% was considered to be of suitable accuracy but up to ±10% is acceptable (Appelo & Postma 2005). Sediment sampling and other water quality measurements such as biochemical oxygen demand (BOD), chemical oxygen demand (COD), suspended solids (SS) and ammoniacal nitrogen (for water quality index determination) were also conducted but the discussion is reserved for other publications.

**RESULTS AND DISCUSSION**

**Water quality assessment**

Assessment of water quality on a site-by-site basis is presented in this study based on the sampling at locations S1–S11 in the Bestari Jaya catchment. Detailed hydrogeochemistry of the waters is not presented here and is discussed in other publications. As to response to public concerns on the safe use of such waters, emphasis is given to the content of minerals, especially those that are associated with heavy metal content (Table 1). The mean mineral contents in water at the abandoned mining pools, active mining pools and the rivers are presented in comparison with the standard limits of the World Health Organization (WHO), United States Environmental Protection Agency (USEPA) and Malaysia Ministry of Health (MOH). Generally, the abandoned mining pools have pH in the range of 6.1–6.9, whilst the rivers have pH between 6.1 and 7.1 (circum-neutral range). In contrast, the active sand mining pools show highly acidic water with pH in the range of 3.1–3.7. Apparently, this acidic water is coupled with comparatively higher metal content in the active mining pools compared to other sites.

Of all other metal elements, trace metals like iron and manganese are typically of concern whenever the water is

<table>
<thead>
<tr>
<th>Type of water</th>
<th>SO\textsubscript{4}</th>
<th>Cl</th>
<th>Ca</th>
<th>Mg</th>
<th>Na</th>
<th>K</th>
<th>Cu</th>
<th>Fe</th>
<th>Mn</th>
<th>Pb</th>
<th>Zn</th>
<th>Charge balance (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>aActive (sand) mining pools(^a) S1, S2, S3 (n = 12)</td>
<td>18.33</td>
<td>13.43</td>
<td>8.66</td>
<td>1.04</td>
<td>1.74</td>
<td>3.61</td>
<td>0.01</td>
<td>4.39</td>
<td>0.70</td>
<td>0.03</td>
<td>0.30</td>
<td>6.18</td>
</tr>
<tr>
<td>bEx-mining pools(^a) S4, S9, S11 (n = 12)</td>
<td>19.67</td>
<td>11.50</td>
<td>16.58</td>
<td>2.53</td>
<td>1.78</td>
<td>1.51</td>
<td>&lt;0.001</td>
<td>0.06</td>
<td>0.20</td>
<td>0.02</td>
<td>0.04</td>
<td>9.22</td>
</tr>
<tr>
<td>cIn-stream samples (rivers)(^a) S5, S6, S7, S8, S10 (n = 20)</td>
<td>24.40</td>
<td>10.96</td>
<td>5.92</td>
<td>0.96</td>
<td>0.72</td>
<td>0.02</td>
<td>&lt;0.001</td>
<td>0.09</td>
<td>0.20</td>
<td>0.01</td>
<td>0.04</td>
<td>&lt;9.52</td>
</tr>
<tr>
<td>dTap water (n = 24)</td>
<td>10.22</td>
<td>20.19</td>
<td>6.65</td>
<td>1.10</td>
<td>4.30</td>
<td>3.20</td>
<td>0.01</td>
<td>0.06</td>
<td>0.03</td>
<td>&lt;0.001</td>
<td>0.03</td>
<td>–</td>
</tr>
<tr>
<td>eDrinking water (n = 14)</td>
<td>6.54</td>
<td>19.71</td>
<td>0.36</td>
<td>1.82</td>
<td>2.22</td>
<td>1.01</td>
<td>&lt;0.001</td>
<td>0.03</td>
<td>0.01</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>–</td>
</tr>
<tr>
<td>fMineral water (n = 13)</td>
<td>9.36</td>
<td>34.46</td>
<td>4.46</td>
<td>5.14</td>
<td>10.17</td>
<td>2.91</td>
<td>0.01</td>
<td>0.01</td>
<td>0.03</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>–</td>
</tr>
<tr>
<td>World Health Organization (WHO) (2009) &amp; United States Environmental Protection Agency (USEPA) (2009)</td>
<td>400.00</td>
<td>250.00</td>
<td>–</td>
<td>–</td>
<td>200.00</td>
<td>–</td>
<td>1.00</td>
<td>0.30</td>
<td>0.05</td>
<td>0.05</td>
<td>5.00</td>
<td>–</td>
</tr>
<tr>
<td>MOH (untreated raw water)</td>
<td>400.00</td>
<td>250.00</td>
<td>–</td>
<td>150.00</td>
<td>200.00</td>
<td>–</td>
<td>1.00</td>
<td>1.00</td>
<td>0.20</td>
<td>0.10</td>
<td>5.00</td>
<td>–</td>
</tr>
<tr>
<td>MOH (treated water)</td>
<td>400.00</td>
<td>250.00</td>
<td>–</td>
<td>150.00</td>
<td>200.00</td>
<td>–</td>
<td>1.00</td>
<td>0.30</td>
<td>0.10</td>
<td>0.05</td>
<td>5.00</td>
<td>–</td>
</tr>
</tbody>
</table>

\(^a\)pH range:
Active (sand) mining pools: (3.1–3.7).
Ex-mining pools: (6.1–6.9).
In-stream samples (rivers): (6.1–7.1).
\(^b\)Present study.
\(^c\)Mineral contents in Malaysian tap water monitored by state water authorities (adapted from Azlan et al. 2012).
\(^d\)Mineral contents in Malaysian drinking and mineral water monitored by the Ministry of Health (adapted from Azlan et al. 2012).
intended for water supplies. However, iron and manganese are not health concerns in drinking water (Swistock et al. 2015). The presence of iron and manganese can be associated with the formation of scaling, odour and undesirable taste of the water (Holler 1974). In other words, iron and manganese cause aesthetic problems that make the water undesirable to use in the home and a bitter metallic taste that make the water unpleasant to drink for both humans and animals (Swistock et al. 2015). Therefore, they must not present in water or must present at concentrations very low enough to avoid such nuisances. For these reasons, it is recommended by the Malaysia Ministry of Health that the iron concentration should be less than 0.3 mg/L, and manganese must be lower than 0.1 mg/L in treated water.

As shown in Figure 2(a), the concentrations of iron in the rivers and the abandoned mining pools are well below the recommended acceptable limit (1 mg/L) set out by the MOH for untreated raw water used for potable water supply. However, this is not the case for the active sand mining pools and their discharge (mean iron concentration of 4.39 mg/L). Note that the discharge from these active mining pools does not directly enter the Selangor River (the main river where the intake of the water treatment plant is located). The discharge enters Stream A (a tributary of Selangor River) where the sampled water (S5) indicates an iron concentration of 0.10 mg/L. Sampled water at the confluence of Stream A and Selangor River (S7) shows that iron remains at 0.10 mg/L. In-stream sampling further downstream of Selangor River shows a slight reduction of iron to 0.09 mg/L, indicating the importance of downstream dilution for metal attenuation. Despite this, iron was found at very low concentrations in the abandoned mining pools (0.01–0.09 mg/L). Specifically, the pumped water from one of the abandoned pools (S9) into the main river has an iron concentration around 0.08 mg/L, a level that is far below the acceptable limit for untreated raw water. In fact, all the sampled water in the rivers and the abandoned mining pools have iron content below the MOH, WHO and USEPA recommended guideline limits for treated (potable) water of 0.3 mg/L. This suggests the presence of iron in water at a satisfactory level (sufficiently low concentrations) even prior to treatment at the water treatment plant.

On the other hand, manganese is present at concentrations slightly above the MOH recommended acceptable
limit (0.2 mg/L for untreated raw water) at some locations, which are in the active mining pools and their discharge (∼0.7 mg/L), in the river (S6 and S7 at ∼0.5 mg/L) and at the HORAS pool (S11 at ∼0.4 mg/L) (Figure 2(b)). It is known that generally manganese attenuation in water may not be straightforward in the presence of iron, especially when the oxidation and precipitation of manganese require very high pH and its removal is also subject to adsorption mechanisms (Younger et al. 2002). Note that during the sampling at the HORAS site, progressive excavation work was still taking place at the construction of the reservoir and may have introduced some metal leach-out. Despite this, the level of manganese in the main river that feeds into the water treatment plant satisfies the MOH acceptable limit for raw water (0.2 mg/L). Manganese can exist naturally in water, especially water that has been in contact with rock for a long time. In mining-related water, iron and manganese often occur together in the water but manganese usually occurs at much lower concentration than iron (Kusin et al. 2010, 2012; Swistock et al. 2015).

Other metals such as Zn, Pb and Cu are present at very low concentrations at all locations (Figure 2(c), (d) and (e)) and are well below the MOH, WHO and USEPA recommended guideline limits, also satisfied for potable treated water. Apparently, despite the presence of these metals in the water, they are detected at very low concentrations at the upstream (intake) of the water treatment plants, and therefore should not cause any interference in the operation of the treatment plants and the quality of the treated water. Notably, the pumped water from the abandoned mining pool shows relatively good water quality and would undoubtedly be used as an alternative source of raw water supply for the river basin. Likewise, further development in the use of abandoned mining pools to cater for greater capacity of supply such as the HORAS project would be another good alternative as outlined in the integrated river basin management approach for the river basin. Such an alternative does not pose an undesirable impact in terms of water quality, at least as currently observed during the development of a so-called water reservoir under the HORAS project. Note again that phase one of the HORAS project has started during the monitoring conducted in this study, which includes the operation of water pumping from the Hang Tuah ponds (sampled at S10 and S11).

Implications for raw water supply

The concern with the safety of potable water is generally associated with the mineral content in the water. The content of minerals in the water (monitored in the present study) in comparison with other relevant types of water are presented in Table 1. The mineral contents of Malaysian tap water, drinking water and mineral water were obtained from Azlan et al. (2012). As noted earlier, field monitoring in the Bestari Jaya catchment has been done for the examining pools (including the HORAS site and Hang Tuah ponds), active sand mining pools and in-stream sampling in the rivers (Stream A, Stream B, and the main river, Selangor River). Note that the in-stream sample (river water) data presented here are regarded as the untreated raw water as it will be supplied to the downstream water treatment plants to be further treated. The treated water will then be distributed to the consumers and is therefore comparable to the quality of (treated) tap water supplied to each premises. The tap water is the source of the bottled drinking water (Chan 2004). It is noticeable that the quality of the rivers including Selangor River is almost of the same quality as the tap water in Malaysia generally.

In Malaysia, the overall monitoring of water quality within river basins is the responsibility of the Department of Environment. The state water authorities are responsible for the quality of raw water supplied to respective water treatment plants, although their roles in providing sufficient supply of water are also significant. The Malaysia Ministry of Health monitors the quality and safety of the bottled drinking and mineral water. Notwithstanding this, the quality of water received in most developed countries is clean and safe for consumption and can be consumed directly from the tap without posing any health threat (Rosborg et al. 2006). The quality of drinking water in the United States, Europe and Canada is acceptable according to the criteria set either by their governments or the WHO (Sayre 1988; Rosborg et al. 2006).

The overall water quality of the rivers in terms of their mineral content is in compliance with the MOH acceptable limits for untreated raw water and in fact is well below the guideline limits. However, manganese at some locations exceeds the 0.05 mg/L limit set by the World Health Organisation (WHO) (2009) and United States Environmental
Protection Agency (USEPA) (2009) as discussed earlier. The values of the cations (Ca, Mg, Na and K) and anion Cl in the rivers are notably lower than in the treated tap water. The trace elements are slightly higher but still below the acceptable guideline limits. This suggests that the raw water coming from the rivers within the Bestari Jaya catchment is of treatable quality prior to treatment to meet the recommended acceptable values. Therefore, it should not pose doubtful quality for use despite being sourced partly from the abandoned mining pools.

Generally, the operations of conventional water treatment plants always require close monitoring of the water quality to minimise the risk of plant failure so as to avoid cases of water disruption. Performance monitoring of treatment plants both for water supply and wastewater is mandatory to ensure effluent quality compliance with the specified guidelines and also for prediction of future operation (Rahmat et al. 2014). On a general note, in cases of high content of iron and manganese, several treatment options may be adopted to aid in the removal of these trace metals. These include oxidation and filtration, water softening processes, polyphosphate addition, aeration and ozonation depending on the concentration level of the metals, however, the cost of implementation and maintenance should not be overlooked (Swistock et al. 2015).

CONCLUSION

The assessment of water quality in relation to its safe use for potable water consumption has been undertaken for several locations within the Bestari Jaya catchment, Selangor River Basin. This includes monitoring of the water quality at the newly proposed sites for acquiring an alternative source of raw water in the catchment, the HORAS project alongside other monitored sampling points. In addition to the assessment of water quality at the former mining pools and the rivers, sampling from an active sand mining site was also carried out to evaluate the impact of such activities. As anticipated the sand mining operation does have consequences for the quality of water especially in the vicinity of the site, e.g. highly acidic water and the presence of fairly high metal concentrations. However, the discharge does not directly enter the main river that carries the water to the intake of the water treatment plants. Generally, the overall quality of water in the rivers (two tributaries and the main river) satisfies the MOH recommended acceptable limits for untreated raw water, therefore a better quality would be expected after the treatment. In fact, the water is almost the same quality as the treated water (based on general observation of the quality of tap water monitored by the state water authorities). Notwithstanding the source of the raw water, even though it is sourced partly from the former mining pools, the main concern is the final discharge that will be consumed for potable water use. Apparently, the ex-mining pools have water quality well below the guideline limits for untreated raw water except for some common metals in the water. Based on this study, it was found that the overall quality of the water in the rivers within the Bestari Jaya catchment is of treatable quality and therefore it is safe to be used as a raw water resource for potable water consumption. The idea of using abandoned mining pool water would be a good option at least under current scenarios in the country so as to make use of natural available water resources.

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