Engineering concept for reclamation on land use of abandoned alluvial tin mine as a solution to achieve sustainable post-mining

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Abstract. Hundreds of abandoned tin mines ponds in Bangka Belitung Province are not reclaimed properly during the post-mining activities. Reclamation in the former mining area ideally is a series of ongoing activities with planned post-mining activities. Planning for reclamation of abandoned tin mines or that has been re-mined by the community is a challenge to represent a concrete manifestation of sustainable management in the Indonesian mining sector to fulfill Government Regulation No. 78/2010 and the Minister of Energy and Mineral Resources Decree No. 1827/2018. This study purposes are to formulate the concept of the sustainable reclamation for the alluvial tin mines. Studies that have been conducted are to portrait topographic area by using drone, then followed by hydrology and hydrogeological mapping, infiltration and pumping test, shallow drilling and geohazard study. Air photo using drone can be used for topographic mapping. Ground water flows from the upper part area to central low land area which represents a river with low gradient. Three geohazards are identified such as flood, erosion and minor landslide. Based on the identified geohazards, the detail design of building ditch, sediment trap and reshaping landform are prepared carefully for the alluvial environment.

1. Introduction
Based on the Minerals and Coal Mine Law No 4/2009 reclamation is a progressive activity applying to all stages of mining in order to restore and to improve the environment and the ecosystem quality. Some preparatory works at proposed reclamation area have been conducted in order to achieve sustainable reclamation of abandoned tin mine ponds. Tailing is produced after the valuable mineral is separated, usually it is fine grains [1], then it can be eroded and transported easily by water or wind. The aim of this study is to provide data that can be used for the developing sustainable post-mining programs. To achieve the purposes, the site assessment of the surrounding area with regards to hydrological features and geohazards in order to determine applicable risks such as flooding and erosion. Also, a detailed 3D model of the site is required to plan subsequent reclamation steps. As a basic step, this requires remote mapping of the applicable area, exact measuring of coordinates as well as a ground-based geoelectrical survey. Planning activities for the developing sustainable post-mining programs comprise a community
engagement, remote mapping and an assessment of hydrological features and geohazards, and development of a reclamation, maintenance and monitoring plan.

2. Methods

The total solution must be proposed with minimum time and cost but the aim of study of the developing sustainable post-mining program can be achieved. To know aerial view of the abandon mine, the remote mapping to provide detailed georeferenced data and the immediately surrounding area. Remote mapping shall be done using a multicopter (“drone”) survey and development of a Digital Elevation Model (3D) with a minimum resolution of 0.5 m and associated filmography. Beyond the pilot site and its vicinity, the wider surrounding area shall be assessed by using available spatial and satellite data from public sources such as Google Earth. Thus collected data shall be combined and managed in a Geographic Information System software application. The remote mapping shall extract relevant information from these data such as land use, hydrological information and location of critical infrastructure, villages, as well as land use.

From the remote mapping, a hydrological assessment can be evaluated for the following parameters: Distribution and size of waterbodies in the applicable surrounding area (natural lakes, Man-made lakes, abandoned mine ponds, rivers, springs), Catchment basin analysis, Flow path analysis and surface runoff modelling (Surface and groundwater, Hydrogeological 3D Model), Analysis and interpretation of water quality in surface water bodies on and near the pilot site (in particular, mining ponds).

Water analysis shall include in-situ measurement of basic parameters (such as pH, conductivity and temperature) and laboratory analysis of relevant chemical parameters. The hydrological assessment shall also serve to collect hydrological baseline data on the site that can later be compared to monitoring data.

Following the initial hydrological assessment, the several options shall be developed for management plan of water resources and in immediately surrounding water bodies. This shall include, for example, water treatment and management for recycling or other recommended water usage relevant for reclamation (e.g., drinking water reservoirs, irrigation, fish farming, recreation/tourism etc.), or water disposal in case of significant risks (e.g., contamination, mosquito breeding grounds).

To know a deeper ground information, the geoelectric survey must be employed. The geoelectrical survey shall be implemented in an adequate information in order to obtain information on (1) depth and spatial geometry of the surface between bedrock and overlying unconsolidated material; and (2) groundwater geometry (water table, aquifers).

Applicable geohazards in the area to be evaluated include (1) flooding risks and (2) erosion risks. Based on the previous steps, the information can be used to evaluate and document flooding risks and erosion risks with regard to the pilot site and critical infrastructure in the surrounding area (clarify statistical relevance and annual frequencies for risk assessments). Geohazards shall be documented and illustrated.

3. Results and discussion

3.1. Existing conditions of the study area

From Unmanned aerial vehicle (UAV) surveys, the topographical condition of the study area is generally gently slope (see Figure 1), with a relief ranging from 29 masl in the East to 16 masl in the West. It is surrounded by hills, both of in the northern and the southern part of it. Catchment area of the study area and its corridor is located in a part of a vast catchment area of Sepana River. In common with other areas in the Bangka Region, the study area is subjected to local thunderstorm rainfall events. Typically these events occur during the period between November to January and those months can produce very large run-off events with maximum of 373 mm of rainfall in January. The period between July to September has relatively low rainfall and the lowest is in August with 132 mm of rainfall, although significant run-off events during this time can occur. Surface water run-off to low land is low turbidity, although the runoff turbidity significantly increases during peak periods of flooding. Following a significant event on a high rainfall that soil become saturated in the surface.
The geology detail of the area consists of clay, sandy tailing, phyllite, and limestone. The sandy tailings material is the waste product of tin mining process and mostly occupied the Air Kundur 3 area, which consists of sand and gravel. The material deposition in the river shows weathered material or sedimentation of erosion material underlain by black clay (very fine size). Clay as alteration product occupied at North spot of the river. Phyllite and limestone are found at the Northwest and weathered granite occupies hilly area which is located mainly outside of the study area.

Erosion is one of geohazards that should be considered in this study. It is influenced by the lack of vegetation cover and slope angle. The slope failures in block occurred on the river side in North of proposed reclamation area and several spots area. The slope erosion is mainly influenced by the rainfall and bad landscape condition (loose material and steep slope due to abandoned artisanal mines). The slope height of the abandoned artisanal mines is varies from 1 - 3 meter, slope angle around 80° and the angle of repose varies from 30° – 40°. Tension crack in sandy tailing with 5 cm width occurred at the edge of North Slope. There are no signs of larger stress are identified. The signs of erosion occurred along the path at the South part of the area. The unfinished bridge (incomplete and only constructed halfway) is broken due to bad construction at the North area. The insitu soil pH measurements at the surrounding area are varies from 5.8 to 7. The insitu soil moisture measurements at the surrounding area are varies from 0 to 80%.

There is a river which is connected with some ponds in the study area. Water properties such as temperature, pH, total dissolved solid, and electrical conductivity are measured to obtain insitu quality of surface water. Double-ring infiltrometers are used to measure the infiltration rate of field sites with diameter rings of 30 cm (inner) and 60 cm (outer).

Shallow drilling is conducted by using a hand bore to provide lithological data in the study area. The external diameter is 3 inch and the internal diameter of the PVC well casing is 2 inch with addition slots, i.e. openings in the well-screen which allow groundwater to flow into the well. A total of four boreholes are conducted in proposed reclamation area. The drill cutting reflects the physical lithological data and
supports the sub surface information for geophysical interpretation and engineering analyses. The final construction of boreholes are equipped with the well plug to prevent the water leakage into another aquifer. The groundwater level of each borehole is measured to gain information about the groundwater condition. The measurement is conducted using an electrical dip tape, which produces an electrical signal when the water level is reached.

Pumping test is conducted to obtain data of permeability or hydraulic conductivity (K). It is an essential parameter to understanding the movement of groundwater in the study area and its surrounding. A total of four pumping tests are conducted and insitu water quality test of each borehole is measured to gain the initial water quality. Table 1 shows the findings from pumping test.

### Table 1. Hydraulic conductivity based on pumping test.

| ID  | pH | EC (µS/cm) | TDS (mg/L) | Temperature (°C) | K (m/s)  |
|-----|----|------------|------------|------------------|----------|
|     |    | Air        | Water      |                  |          |
| BH 1| 5.2| 180        | 90         | 32.8             | 9.70E-05 |
| BH 2| 5.5| 110        | 50         | 38.8             | 2.50E-05 |
| BH 3| 4.9| 70         | 30         | 34.1             | 3.50E-06 |
| BH 4| 5.6| 160        | 70         | 35.9             | 5.10E-06 |

3.2. Discussion

The study area occupies relatively wide valley area, low undulating topography and located in the nearly end of the discharged area of the regional catchment. The material along the area is consisted of loose materials, with low density of the cover crop. Shallow water tables are found underneath the area which has a high hydraulic conductivity.

Rocks beyond the area are consisted of in-situ weathered granite, phyllite, tailing material along the disturbed river valley, alluvial sediment in undisturbed river valley and alteration rocks. Its topography is relatively gently slope. Shallow unconfined water table is found in the area. Water table elevation follow the local topography. River water table fluctuation in the northern of the area and along the temporary creeks are very high between two seasons.

The morphology of river which is dominated by a low gradient, relative wide, and consisted of sand-gravel in the river bed with relatively low undulating river bank cause erosion during a heavy rain fall, moreover activities artisanal mining in the area increase occurrence of erosion, flooding and landslide in the area. Due to the environment condition, the reclamation areas, therefore, should be protected from drought or landslide, soil erosion, and excessive run-off water that can sweep away compost, lime, fertilizers, and even the newly planted plant seedlings. Especially for the open area (lacking vegetation cover) that is not yet landscaped and having pits, channels or piles of mine overburden, it is necessary to do soil conservation efforts by terracing the land and grading the soil surface to obtain a stable area. Soil erosion or slope failure pose hazards for not only people and property but also for the landscape feature created as part of reclamation program. Geotechnical failure may occur along structural discontinuities (tension cracks) or along eroded surfaces / gullies. It is important to conduct geotechnical mapping or geological engineering mapping at the proposed area to enable an assessment of surface stability.

The aims of surface water management in order to deal with flooding and erosion risks should be (1) to avoid excessive surface water discharge into the area, (2) to avoid flooding, and (3) to improve surface water management including quality and quantity [2-4]. Surface water management should include installing drainage infrastructure in order to channelize surface water flow from outside of the proposed reclamation project area, to reduce erosion, and to remove the suspended sediment from the surface prior to water discharge into rivers [5]. To reduce erosion and river siltation, and avoid resulting flooding problems, a range of measures can be implemented along rivers and drainage channels to be established in the area:

- Installing a simple sediment trap in small valleys. This sediment trap acts like fence which is constructed from iron and filled with geotextile or other fabric with function as filter.
Non-permanent unlined drainage channels (in areas with low-moderate erosion risk) are used to catch water from the surroundings area and channelize it into the river or ponds in undisturbed areas.

Non-permanent lined drainages are constructed to direct water from the area into the river or ponds in areas with steep gradients and high erosion risks (Figure 2).

Check dams (barriers). This is a non-permanent construction for creeks or channels to reduce erosion due to water flow (formation of erosion gullies). The distance between two check dams (barriers) should be 20-30 m (depending on the slope of the surface) and they are layered with rip rap (Figure 3).

Figure 2. Sediment trap in small valley.  
Figure 3. Check dam.

Escarpment stabilization. After landscaping, the surface may show escarpments due to terracing or morphology changes due to drainage construction. These escarpments should be stabilized in locations of controlled water flow (Figure 4).

Rorak. After landscaping, the surface may show sheet erosion due to the water flow along the surface slope. These sheet erosion should be reduced by directing water flow to rorak (Figure 4).

Figure 4. Design for stabilizing surface escarpments in areas of water flow.  
Figure 5. Design for reducing sheet erosion in areas of water flow.

4. Conclusions
Air photo using drone can support the detail remote mapping in the study and its surrounding areas. Any detail land used and the current activity around the area can be identified. The disturbed material from the previous tin mine activities dominated the upper part of the study area create a high hydraulic conductivity. Three Geohazards have been identified in the area i.e.: flood, erosion and minor landslide.

The flooding can be avoided by building the water gate in several location to pass the excessive water ponds, build ditch and sediment trap for reducing sedimentation in the river. Uncontrolled erosion for
long time could create instability river bank, increasing sedimentation along the low river gradient area lead to the river blocking. To prevent further erosion some structure can be constructed, those are unlined and line drainages, check dams, Escarpment stabilization, and rorak. Potential minor land slide occur as consequence of the abandon pits without any mine closure programs. Reshaping of the landform of the area should be carried out to achieve sustainable reclamation programs.

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