Integrating Historic Mine Hazard Scoring for Comprehensive Assessment of Abandoned Mine Rehabilitation in the Philippines

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Abstract—**Abandoned mines remain a social, environmental, and health-risk problem for the Philippines. These abandoned sites are generally characterized by water-filled pit lakes surrounded with disturbed and exposed soils and sediments containing elevated values of heavy metals and other environmental contaminants. Previous studies with abandoned mines in the Philippines have initiated the use of integrated methods for the assessment of existing abandoned mine site conditions as a tool for decision-making. To further provide a numerical basis for rehabilitation prioritization, this paper aimed to utilize the modified Historic Mine Site Scoring System (HMS-SS) for physical and environmental hazard assessment of the abandoned mercury mine located in Barangay Sta. Lourdes, Puerto Princesa City, Philippines and to produce hazard classification maps based on the generated scores. Results identified the pit lake to be extremely hazardous physically, however, the liquid material (rainfall accumulation in the pit) yielded very low environmental hazard scores with only a few identified points that exceed the regulatory limit. Moreover, the two (2) identified mine tailings sites were found to be physically moderately hazardous but are categorized as extremely hazardous for the environmental aspect. The hazard scoring, coupled with the integrated environmental methods for characterization and development of hazard maps, is recommended as a scientific and quantitative basis for providing decisions in priority of actions to be taken with regards to abandoned mine sites.**

Index Terms—**Abandoned mines, hazard, historic mine site scoring system, Palawan.**

I. Introduction

Abandoned mines remain a social, environmental, and health-risk problem for the Philippines. These abandoned sites are generally characterized by water-filled pit lakes surrounded with disturbed and exposed soils and sediments containing elevated values of heavy metals and other environmental contaminants [1]-[3]. The problems these mines pose can be generally classified as environmental impacts, physical hazards or public health and safety concerns, and socio-economic issues. Unprotected or uncovered mine openings such as pits, adits, shafts, and other mine workings are among the physical hazards of abandoned mines while environmental hazards involve the pollution originating from the abandoned sites [4].

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A. Existing Abandoned Mine Policies in the Philippines

An ‘abandoned mine’ is defined as “a mine covered by a mining lease or any mineral agreements […] which is closed without proper decommissioning or has not been in actual operation for a reasonable period and whose mining contractor cannot be found or for which the mining contractor is unable or unwilling to carry out rehabilitation and/or remediation work” [5]. In the Philippines, there are 27 identified abandoned mine sites (Table I) that require immediate rehabilitation [6] however, only one abandoned mine site is undergoing full rehabilitation [6]. Whilst Executive Order No. 270 series of 2004 [7] accorded the prioritization of remediation and rehabilitation of abandoned mines to address the negative impacts of past mining projects and Executive Order No. 26 series of 2011 [8] listed inactive and abandoned mines sites as priority areas for reforestation activities, only one abandoned mine site in the Philippines is undergoing full rehabilitation as of the writing of this paper [9]. These abandoned mines were still unrehabilitated accordingly due to the lack of legislation in place for closed mines before the Philippine Mining Act of 1995 [9].

As a response to this, Samaniego and Gibaga *et al*. [10] proposed a detailed, graded procedure on the evaluation of environmental conditions of abandoned and inactive mines in the Philippines. Their approach focused on environmental in-situ and laboratory analysis, paired with health risk assessment based on inorganic pollutants. To further aid the prioritization of rehabilitation of the various abandoned mines throughout the country, this paper proposes an integrated methodology incorporating an abandoned mine scoring system that could be adapted for this purpose.

TABLE I: List of Abandoned Mines in the Philippines Adapted from [6]

Abandoned mines	Location	Mineral commodity
Benguet Corporation (formerly Benguet Consolidated, Incorporated)	Balabac Island, Palawan	Iron, *etc.*
Philex Mining Corporation (Sto. Nino Mines formerly Baguio Gold Mining Company)	Tublay, Benguet	Copper, gold
Unidos Mining Corporation	Nabas, Aklan	Silica
Western Minolco Mining Company	Kapangan, Baguio	Copper

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Zambales Base Metals, Incorporated	Upper Baluno, Zamboanga City	Copper
Barlo Mines	Mabini, Pangasinan	Copper
Black Mountain, Incorporated	Tuba, Benguet	Gold
Benguet Exploration, Incorporated	Tuba, Benguet	Gold
Palawan Quicksilver Mines, Incorporated	Puerto Princesa City, Palawan	Mercury
Romblon Marble Mines	Romblon, Romblon	Marble
Silica Sand Mines	Roxas, Palawan	Silica
Acoje Mining Company, Incorporated (AMCI)	Sta. Cruz, Zambales	Metallurgical chromite
Batong Buhay Golds Mines, Incorporated	Pasil, Kalinga	Gold
Benguet Corporation – Antamok Mines (BC-BAGO)	Itogon, Benguet	Gold
Benguet Consolidated Mining Corporation (BCMC)	Itogon, Benguet	Gold
Benguet Corporation –Dizon Copper/Gold Mines (BCD)	San Marcelino, Zambales	Copper
Masinloc Chromite Mines –Benguet Corporation (MCM-BC)	Masinloc, Zambales	Refractory chromite
Filminera Resources Corporation (FRC)	Rosario and Bunawan, Agusan del Sur	Gold
CDCP-Basay Mine	Basay, Negros	Copper
Ino and Capayang Mines (ICM)	Mogpog, Marinduque	Copper
Heritage Mining Corporation Alamag Processing Group	Llorente, Eastern Samar	Chemical chromite
Hixbar Gold Mining	Rapu-Rapu Island, Albay	Gold
Philippine Iron Mines	Jose Panganiban, Camarines Sur	Iron
Philippine Pyrite Corporation	Bagacay, Samar	Pyrite
Surigao Consolidated Mining Corporation, Incorporated	Siana and Mapawa, Surigao del Norte	Gold
United Paragon Mining Corporation	Paracale, Camarines Norte	Gold
Vulcan Mining Corporation	Cordon, Isabela	Gold

B. Abandoned Mercury Mine in Palawan, Philippines

One of the recently most studied abandoned mines in the Philippines is found in Barangay Sta. Lourdes, Puerto Princesa City in the island of Palawan [1]-[3], [10]-[12], and its location is marked in Fig. 1. This site was once operated by the Palawan Quicksilver Mines Inc. (PQMI) from 1953 to 1976 and was left unrehabilitated since then. Several reports of mercury poisoning in the nearby communities arose in 2017 [13], [14] and the claimed cause of these events was pointed to the exposed mine waste and unprocessed ores and the 3-hectare pit lake that was once the open pit mine of PQMI (referred by the locals as *Pulang Lupa Lake*). In 2003, Gray and Greaves *et al*. [15] analyzed the pathway of elevated methylmercury levels in surface and groundwater from the former PQMI site to Honda Bay, a nearby tourist and fishing spot about 3 kilometers away. These results were complemented with the case studies on the effects of mercury and its derivatives on humans, which were conducted by [16]. Their findings showed a statistically significant increase in methylmercury levels in the hair of infants and pregnant women, and also in fish species found in Honda Bay.

This paper introduces the use of the Historic Mine Site Scoring System (HMS-SS) in the Philippines, through a case study in the abandoned mercury (Hg) mine in the Philippines in Puerto Princesa City, Palawan Island (which will be referred to PQMI Study Area for the rest of the paper). This system will not only serve as a ranking tool for rehabilitation prioritization of abandoned mine sites in the country but also a scoring system to ensure the safety of the nearby community and of the environment.

II. Methodology

The ranking approach employed in this study is the modified version of the Historic Mine Site Scoring System (HMS-SS) that was developed initially based on the Abandoned and Inactive Mines Scoring System (AIMSS) for ranking abandoned mines in the state of Montana [17]. This system utilizes the source-pathway-receptor paradigm and numerically weighs each potential feature of interest for both environmental and physical hazards found on the site. This approach is used in conjunction with the proposed comprehensive assessment of abandoned mine site conditions for the Philippines by [4], and it is in this assessment step where the data for scoring will originate.

A. Field Analysis of the Study Area and Identification of Historic Mine Features

In the overall approach of the HMS-SS, the first step is to screen and select the abandoned mine to be classified. This study focused on the abandoned mercury mine located in Barangay Sta. Lourdes, Puerto Princesa City situated in Palawan Island in the Philippines which is referred to locally as the Pulang Lupa pit lake (Fig. 1).

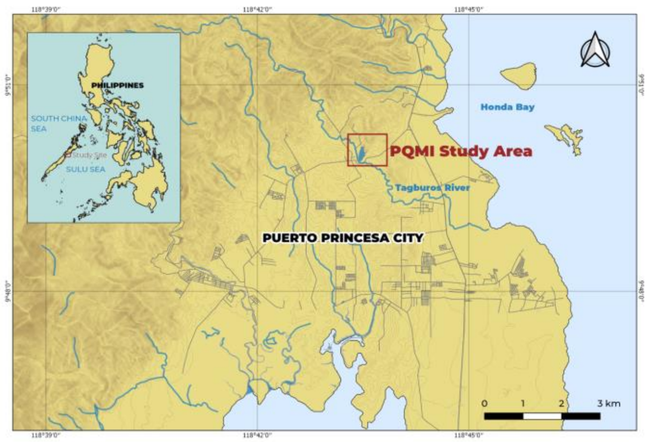

Fig. 1. Geographical locatio n of the PQMI study site.

Following the field methods by [4] as shown in Fig. 2, the team initially conducted a reconnaissance study in the PQMI area back in 2018 to determine the key points of sampling and probable contaminant pathway. Sediment sampling points were chosen in reference to the geologic map from the initial site information and were contained in air-tight zip-lock bags. A sampling of mercury content in the air was conducted using a handheld air pump where adsorbents in small tubes filter the particulates in the air. Due to the tropical climate of the Philippines, surface water and groundwater sampling were conducted in the months of April and July. Site investigations were specifically conducted to acquire information from key informant interviews regarding hazard events related to the PQMI site and to determine the population statistics in the community within 2-kilometers from the *Pulang Lupa Lake* and nearby tailings ponds. Abandoned facilities, current legal matters in the mine area and other pertinent physical structures were recorded and marked on the map using a handheld Global Positioning System (GPS) device. All mine features in the PQMI site that may contain sources of physical and environmental hazards were identified, located in the and assessed during physical traversal in the area. The whole vicinity was also surveyed for the possible pathways of the contaminants from the source, and for the potential victims of the hazards, such as the community, biota and wildlife. The sources, pathway and receptors were documented and the sampling and analysis of groundwater, surface water, stream sediments, tailings and waste piles were performed according to the steps proposed by [10].

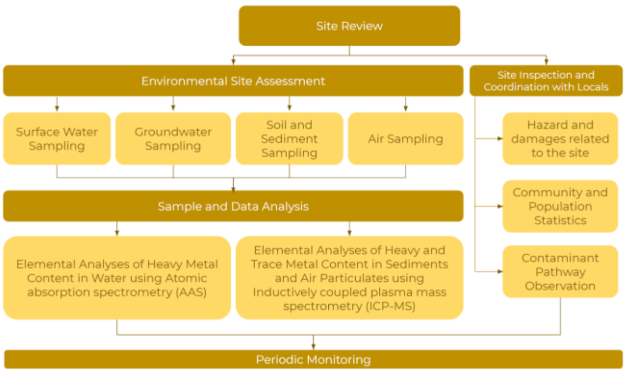

Fig. 2. Flowchart for assessment of abandoned mines employed in this study (modified from [10]).

B. Data Analysis

Water samples collected from the field analyses were placed in 1000-mL polyethylene bottles and were preserved via acidification. All samples were analyzed using Inductively Coupled Plasma – Optical Emission Spectroscopy (ICP-OES) (Agilent Technologies, California, USA) for As, Ba, Cd, Cr, Cu, Fe, Pb, Mn, Ni, and Zn. A cold vapor atomic absorption spectrophotometer (Teledyne Hydra IIAA, Ohio, USA) was used to determine Hg. APHA-AWWA Standard Method for the Examination of Water and Wastewater (1998) [18] was used as a reference in conducting the analyses.

All sediment samples were dried in ambient air, crushed, powdered, and sieved to less than 63 µm grain size. Elemental analyses for Hg and heavy metals were done on the mud-sized portions using Hg and other heavy metals using Direct Mercury Analyzer (DMA) (Milestone, Bergamo, Italy) and Inductively Coupled Plasma – Mass Spectroscopy (ICP-MS) (Agilent Technologies, California, USA), respectively.

C. Hazards Scoring

The identified physical and environmental sources were listed in Table II. Mine features chosen for physical hazards refer to the areas with potential harm or damage to the proximal community while those environmental hazards were considered for the events of chemical release, bioaccumulation, and inhalation by the human body and for the overall health risk. For the PQMI Study Area, three features were selected for scoring: the Pulang Lupa Pit Lake itself (Mine Pit) and two nearby tailings and mine waste ponds as shown in Fig. 2, which is hereby referred to as the Mine Tailings I and Mine Tailings II. For each site, physical and environmental scores were calculated based on each of the solid, liquid, and stream sediment sources present, and their related pathways and receptor trends.

TABLE II: LIST OF IDENTIFIED PHYSICAL AND ENVIRONMENTAL SOURCES ON THE THREE SITES IN THE PQMI STUDY AREA

Mine Features	Physical Scoring		Environmental Scoring	
	Source Features	Potential Risk Types	Source Features	Potential Risk Types
Mine Pit	Water Body	Falling from high walls Falling from unstable walls Drowning Objects within the dump material	Solid Liquid Stream Sediments	Human Ingestion and Inhalation Livestock Freshwater aquatic environment Marine water aquatic environment
Mine Tailings I	Tailings/Mine Waste			
Mine Tailings II	Tailings/Mine Waste			

Physical scoring system follows the modified version of HMS-SS designed by [4]. Based on the extensive evaluation of the potential origin of physical harm for each of the three mine features, scores of 8 to 10 were given for highly dangerous areas, 6 to 8 for moderate, and 0 to 6 for less, each accounting for the source, pathway (exposure) and receptor. This scoring was based on the weights provided by [4] which have been incorporated in a series of literature [4], [16], [19], [20], for the abandoned mine scoring in parts of South Africa. In this paper, the scoring for the source was based on the percentage of the selected area where the hazard was present on the field description, while the exposure scores were evaluated based on the distance of the nearby community from the source. Lastly, the receptor score was weighted on the frequency of the reported victims of physical harm from the source. The amalgamation of the physical hazard scores (*PSc*) is calculated as shown in (1) while total mine physical hazard score (*TPSc*) was taken as the average of all hazardous features present in each site (2), where *n* is the number of identified potential risk types, *P* is the physical hazard score per risk type, *A* is the amalgamation of source, pathway and receptor score and *m* is the number of identified features per site. The factor 1000 was used to reduce the magnitude of scores.

$$PSc = \frac{\sum_{i=1}^{n} P_i A_i}{1000.00} \quad (1)$$

$$TPSc = \frac{\sum PSc}{m} \quad (2)$$

On the other hand, the environmental hazard scoring was mainly established on the results of three potential sources, the solid, liquid, and stream sediment elemental composition from the comprehensive abandoned mine assessment procedures of [10]. The original HMS-SS recommends the use of wave dispersive x-ray fluorescence (WD-XRF) analysis for soil and solid samples [17]; however, this paper recommends the use of the more accurate inductively coupled plasma mass spectroscopy (ICP-MS) technique. All of the weights assigned on respective factors hereunder are detailed in [17] and have been utilized for most of the abandoned mines in Ireland, which public access are available on the Environmental Protection Agency (EPA) website [21].

The results of experimental analyses of concerning heavy metal contaminants were weighted based on the relative toxicity values for different environments and habitats. Each pathway (groundwater, surface water, air, direct contact) and the corresponding receptors per source were accounted for physico-chemical characteristics found on-site. All these properties were summarized to calculate for the environmental hazard score (*ESc*) as shown in (3), where *AV* is the average value for each element, *RT* is the relevant toxicity, which encompasses toxicity in human, environment, and biota due to one or more factors: ingestion, inhalation, liquid wastes and livestock, and *Q* is the total score for the receptor of hazard. Similarly, the factor 10000 was used to reduce the magnitude of scores.

$$ESc = \frac{\sum_{i=1}^{n} (AV_i * RT_i) Q}{10000.00} \quad (3)$$

$$TSc = TPSc + ESc \quad (4)$$

The final mine site score is the summation of all physical and environmental scores (4) and it is then used to classify the whole abandoned mine based on the classification found in the HMS-SS. Depending on the class, the recommended response for the mine site varies, and this can be utilized for numerical ranking of other abandoned mine sites.

D. Rating of Hazards

In order to visualize the scoring system, separate physical and environmental hazard maps were generated for each mine feature using the QGIS version 3.14. Each site was ranked based on their respective total scores as shown in Table III.

TABLE III: INDIVIDUAL PHYSICAL AND ENVIRONMENTAL HAZARD RANKING AND CLASSIFICATION FOR THE HAZARD MAPS

Score	Description of hazard	Hazard Map Legend (color)
>90	Extremely hazardous zones	Red
61-90	Moderately hazardous zones	Orange
31-60	Less hazardous zones	Yellow
<30	Negligible	None

TABLE IV: ABANDONED MINE SITE CLASSIFICATION BASED ON TOTAL MINE SCORE (MODIFIED FROM [17])

Class	Total Mine Score	Summarized Description	Summarized Response
I	>2000	Large complex sites with large number of issues, elevated volumes of metal-rich waste with high potential harm to environment and to human and animal health	Requires full risk assessment and regular monitoring
II	1000-2000	A district with several sites of high amounts of contaminants regularly visited by public; also, relatively high potential harm to environment and to human and animal health	Requires general monitoring of most or all hazard sources on annual basis
III	300-1000	A district with fewer and small sites of high amounts of contaminants regularly visited by public; also, relatively high potential of harm to environment and to human and animal health	Requires general monitoring of most or all hazard sources on biennial basis
IV	100-300	Sites with low to moderate concentration of contaminants regularly visited by public; with moderate potential of harm to environment and to human and animal health	Requires general monitoring of most or all hazard sources every five years
V	<100	Sites which pose little threat to environment and to human and animal health	Do not require monitoring except on specific areas, if applicable

The hazard maps display the areas that are extremely hazardous with red hash marks, the moderately hazardous using orange color and yellow for least hazards. Areas with no known risk were not colored. The total physical and environmental scores generated were used to classify the overall PQMI Study Area based on the original HMS-SS classification shown on Table IV.

III. Results and Discussion

For both the physical and environmental hazards, a total of three mine features were considered: the Mine Pit, Mine Tailings I and Mine Tailings II, as highlighted in Figs. 3-5. Mine Pit corresponds to the abandoned open pit which was later filled with rainwater. The Mine Tailings I refers to the adjacent mine waste stockpile found northeast of the Mine Pit, for which they share a common boundary. Lastly, Mine Tailings II refers to the area far northeast of the pit area and is proximal to the municipal landfill.

A. *Classification of Physical Hazards*

From a physical hazard standpoint, both tailings areas were considered moderately hazardous while the mine pit itself is ranked to be an extremely hazardous zone (Table V, Fig. 4). Major risks from the PQMI mine pit came from the high and unstable walls lining the shore of the pit lake itself, where communities are currently built-in place (Fig. 3a). At the time of inspection, the local government had set-up barbed wires and metal fences on these walls; however, the greater risk came from the potential drowning and health risks that may come from ingestion of water in the pit lake. Site caretaker and locals reported incidents of children swimming and instances of fishing activities in the area. There are also sporadic fruit-bearing and edible plants harvested on the shore of the pit lake but there were no current studies on the bioaccumulation of metals in the biota. The heavy metal concentrations observed in the pit lake for Mn and Ni, Fe, and Mn also exceeded the regulatory limit [22], attributed to the natural concentration in the rocks from the local geology.

TABLE V: PQMI Study Area Physical Hazard Classification for Each Site

Mine Feature	Physical Hazard Total Score	Risk Identified	Classification
Mine Pit	90.55	4	Extremely hazardous
Mine Tailings I	76.87	4	Moderately hazardous
Mine Tailings II	61.10	4	Moderately hazardous

PQMI Tailings I presented hazards mainly from the steep slopes and unconsolidated waste stockpiles, as observed during field survey. The bench features in this site pose risks of falling off due to instability of the ground. The dust generated from the mine wastes are also easily inhaled by the nearby communities. From the air monitoring study conducted on these regions, elevated values were recorded [2], contributing highly on the potential health problem criterion.

Fig. 3. (a). Unstable and steep slopes lining the NE portion of PQMI Pit Lake; (b). Solid wastes found within the PQMI Tailings II area.

Lastly, PQMI Tailings II was found adjacent to the local community landfill of Puerto Princesa City. Large risks in the site were a mixture of objects (mainly garbage; Fig. 3b) found lying in the tailings due to proximity from the landfill. Similarly, dust and leachate provide higher scores for the potential health problems. Other identified hazards were also the steep slopes and unstable walls, which do not have guard rails or fences built at the time of inspection.

Based on the field description and scores calculated, a hazard map showing the classifications for each mine feature were depicted (Fig. 4). The map displays the classification of each zone and the proximity of each site from the community areas (gray color) and a nearby water body (the Tagburos River).

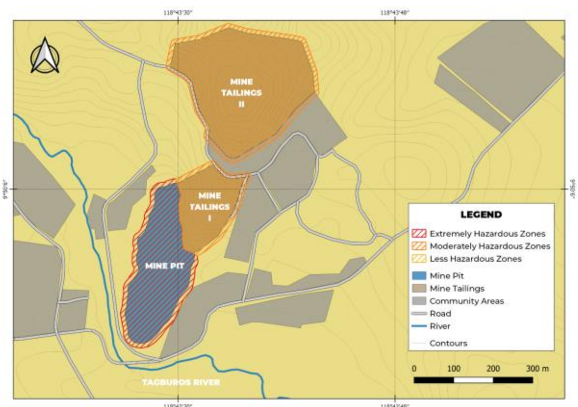

Fig. 4. Physical hazard map of PQMI mine.

B. *Classification of Environmental Hazards*

While classification of physical hazard relies mainly on field survey, reported accounts, and maps, environmental hazards combine both field observations and laboratory analyses of samples collected from each mine feature. At each mine feature, pollution sources were identified and then considered for potential pathways and receptors, as described in Table 6. References for the laboratory results used for this study were from the same authors ([23] for water analyses; [3] for sediment analyses), which were used as input for the scoring.

TABLE VI: PQMI STUDY AREA ENVIRONMENTAL HAZARD CLASSIFICATION FOR EACH FEATURE

Mine Feature	Sources Identified	Pathways & Receptors Identified	Environmental Hazard Total Score	Classification
Mine Pit	(mainly) Liquid	Groundwater, Surface water	4.25	Less hazardous
Mine Tailings I	Solid	Groundwater, Surface water, Air, Direct Contact	94.39	Extremely hazardous
Mine Tailings II	Solid	Groundwater, Surface water, Air, Direct Contact	94.39	Extremely hazardous
Tagburos River	Stream Sediments	Direct Contact	100.25	Extremely hazardous

The liquid accumulation (lakewater) at the abandoned open pit area (Mine Pit) was considered as a liquid source. Heavy metal concentrations of water samples, collected from the surface and at depths of at most 10 meters, were measured as weight for hazard scores for both groundwater and surface water pathway. The groundwater pathway considered the 25 known and dug wells within 1-km of the mine pit area and the respective communal usage. Moderate vulnerability to groundwater adjustment was also determined from the underlying ultramafic lithology of the area. The surface water pathway was evaluated from the distance to the nearest water body where the liquid can be released (>30m from Tagburos River) and the status or observed uses of water (reports of fishing activity). From these parameters, the scoring system classified the mine pit as less hazardous however other ecological parameters could further attest this classification. Furthermore, water samples displayed heavy metal concentrations that were within regulatory limits except for elements that were inherent to the local geology.

Both mine tailings I and II were scored for solid sources. Sediments, soil and rock samples were collected from both areas and then subjected to geochemical analyses. The main contributor for the hazard score came from the elements with highest contamination factor, mercury, chromium, nickel and antimony [3], which were likewise found in elevated values. For solid sources, air and direct contact pathways were considered. During the site inspection, there was an observed release of dust, and it was classified to be low dust potential (75%-95% cover). In addition, the 153 people living within 1-km from the area, and the distance of 12 meters from the nearest residence were used as weights for air receptor score.

For potential direct contact with the waste pile, the instance of physical barriers such as fences or barb wires and the working areas of the family breadwinners (mainly outside the house) were also accounted for. Due to proximity of population from the waste piles and from the chemical analyses, both tailing areas were classified as extremely hazardous.

Lastly, the stream sediments collected from the bed of Tagburos River were classified to be extremely hazardous due to anomalous Hg, Fe, Ni and Cr concentrations and nearness from the community. Only direct contact to the sediments was considered for scoring, particularly, with the presence of livestock and farmlands upstream and downstream the river.

All environmental classifications detailed above were mapped in their relative positions on the PQMI Study Area as shown in Fig. 5.

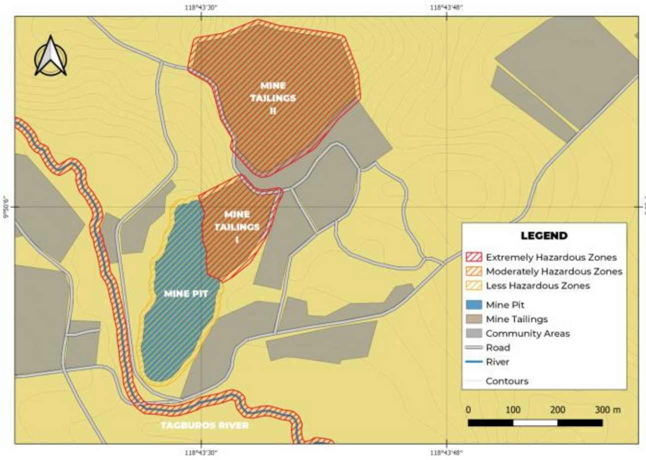

Fig. 5. Environmental hazard map of PQMI mine.

C. Overall Mine Classification

Comparing the two generated hazard maps, the PQMI mine pit has extreme physical hazards associated with unstable slopes and potential for drowning. However, the same site was calculated to have a low environmental hazard score since there was negligible contamination from the heavy metals of the liquid source. On the other hand, the mine tailings were moderately hazardous on a physical scale but generated high environmental hazard scores from the elevated heavy metal values found on the waste piles. The same observation was found for the stream sediments of Tagburos River, rendering all solid sources as extremely hazardous.

In order to rank the PQMI site against other abandoned mine sites also scored using the HMS-SS, all scores per mine feature were summed using equation (4) and resulted in a score of 427.41. From Table 4, the total PQMI abandoned mine site classification is Class III. The observation above summarizes the description for Class III historic mine site - few and small sites of high amounts of contaminants, which were the waste piles in Mine Tailings I and II, where there is a nearby local community. The level of leftover Hg in the waste piles has a high potential of hazard for the environment and biota. The HMS-SS therefore recommends that there should be regular monitoring in the area once every two years, in order to mitigate the potential health and physical damage problems concerning the mine site.

D. Proposed Abandoned Mine Comprehensive Assessment Framework

In order to provide a numerical outlay for the prioritization decisions of the remaining abandoned mines in the Philippines that need rehabilitation, this study proposes the methodology illustrated in Fig. 6 combining the comprehensive environmental assessment processes by [10] and this modified historic hazard mine scoring. Significant part of methodology involves the field procedures that includes environmental analyses of soils, sediments, surface water, groundwater and air as detailed in [10]. In addition to those steps, site inspection of pertinent features in the abandoned mine site area should be conducted. These features include abandoned facilities, physical barriers, waste containment and dimensions and site terrain. During site visit, interviews with key persons are organized in order to determine population, demography, relevant hazard or damages with the abandoned mine site and the legal usage of the site, if any. All of these should be recorded both spatially and temporally as some of the parameters change with time. The parameters are used during both physical and environmental hazard scoring processes, each parameter with their own designated weights. The total score of the mine, as exemplified in the case study, is used for the site classification and response recommendation. The score would also be the numerical basis for each abandoned mine for rehabilitation prioritization.

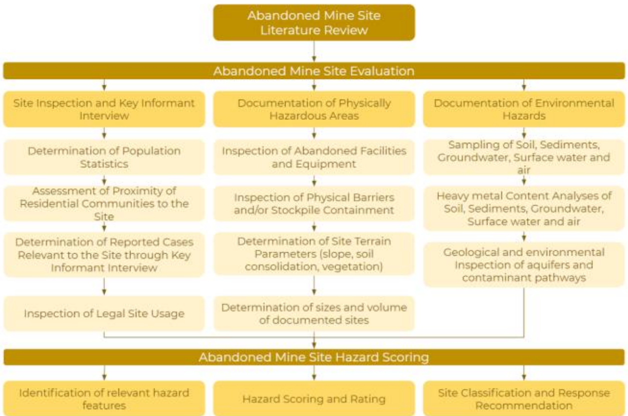

Fig. 6. Proposed flowchart integrating [10] and this study.

IV. Conclusions

Physical hazard scoring identified the Mine Pit to be extremely hazardous while its liquid material (rainfall accumulation in the pit) yielded very low environmental hazard scores with only few identified points that exceed the regulatory limit. The two identified mine tailings features were found to be physically moderately hazardous and are categorized as extremely hazardous for the environmental aspect. Overall, the abandoned mercury mine in Puerto Princesa, Palawan is classified as Class III and, according to HMS-SS, requires a regular monitoring of hazard sources every two years. It has features with high concentrations of contaminants that are commonly frequented by the public and pose a moderate risk of harm to the environment and to human and animal health.

The hazard scoring, coupled with the integrated environmental methods for characterization and development of hazard maps, is recommended as scientific and quantitative basis for providing decisions in priority of actions to be taken with regards to abandoned mine sites.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

All authors are involved in sampling, analysis, and site inspection. All authors wrote the manuscript and read and approved the final version of the manuscript.

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