POTENTIAL TECHNOLOGIES FOR MONITORING THE FATE OF HEAVY METALS IN THE PHILIPPINES: A REVIEW

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ABSTRACT: The Philippines is abundantly endowed with vast and abundant water resources. One of the water quality indicators that has to be importantly monitored is the amount of heavy metals which can be detrimental to the environment and human health when present at exceeding levels in water bodies classified as a potable source of water. As of 2013, a total of 688 water bodies have been classified according to their intended beneficial use by the Environmental Management Bureau (EMB) but only 199 out of the 688 water bodies (approximately 29%) are regularly monitored by EMB. In the 2014 National Water Quality Status Report of EMB, water bodies monitored for toxic chemicals such as cyanide and heavy metals (mercury, lead, and cadmium) are limited and focused only on those water bodies with remarkably known sources of these pollutants. This study therefore aims to identify the underlying challenges in monitoring heavy metals in the Philippines and review the prospective tools and their integration in the assessment, management and rehabilitation of heavy metals that are most appropriate in the Philippine settings. To carry out this study, we first evaluate the institutional policies and its transition through time as against its implementation, then assess the quantitative and qualitative state of the water resources in the country, and finally review emerging technologies and tools to evaluate its applicability in the Philippine contexts.

1. INTRODUCTION

Water pollution includes any detrimental alteration of surface waters, underground waters or the marine environment with a thermal or material pollution. One aspect of water pollution occurs primarily from discharge of liquid substances containing poisonous chemicals including heavy metals (mercury, lead, etc.), also products like arsenic, zinc, copper nickel, cadmium, etc. (Akella, Saini, & Sharma, 2009). In the Philippines, heavy metal contamination is attributed to improper waste disposal, mine tailing spills, and chemical run-offs (GREENPEACE, 2007). Early studies results showed significant levels of mercury contamination caused by mining and high levels of copper and Mo in Davao region’s stream waters and mountain front were detected (Breward, 1996). While the recent Environmental Management Bureau (EMB) water quality monitoring from 2008 to 2013 showed that Class A classified rivers like Agno River, Panique River, and Tubay River exceeded the criterion for mercury levels which could be detrimental to the use of these waters as a source for potable water. In another study conducted by Blacksmith Institute (2014) in the Marilao-Meycauyan-Obando River System, high levels of toxic heavy metals such as copper, manganese, lead, and zinc were found in all three rivers during their extensive water testing conducted last March and October 2008.

Environmental degradation in third world countries like the Philippines has not been quantified and monitored extensively or at a national scale, even with the active operations of mining and other industrial sectors that might harm the country’s vast and abundant resources. The Philippine archipelago is endowed with 18 major river basins covering an approximate area of 108,678 square kilometers, 421 principal rivers with a total length of 3,172 kilometers, and a long coastlines reach of 36,289 kilometers. The country also has 79 lakes that are mostly used for fish production (Environmental Management Bureau, 2014). As of 2013, a total of 688 water bodies have been classified according to their intended beneficial use by the Environmental Management Bureau (EMB). However, from year 2006 to 2013, the EMB of Department of Environment and Natural Resources (DENR) reported that only 199 out of 688 water bodies (approximately 29%) are regularly monitored. It is also observed that the water quality monitoring program of the Philippine government is limited to its resources that may be insufficient on either laboratory facility and equipment or technical manpower and expertise.

Implementing the national mining laws and local ordinances in the context of protecting the environment is another problem. Since the start of the mining industry, there has been a fragmented approach among government agencies bringing about overlaps and conflicts in enforcing the laws. Two bureaus under the DENR, the MGB and EMB, are the main regulatory bodies that administer the principal environmental laws that are applicable to the mining industry. The DENR is mandated to issue administrative orders containing detailed provisions on environmental protections under principal laws like the Mining Act, the Clean Air Act of 1999, the Clean Water Act of 2004, and the Toxic Substance and Hazardous and Nuclear Waste Control Act of 1990. In the effect of regulating mining operations to protect the environment, series of issuances were provided by the DENR. Among these are the DENR Order No. 21-10 which contains detailed provisions on environmental protection; the DENR Order No. 34-1990 which defined water quality criteria and effluent standards; and the DENR Order No. 03-2015 containing the revisions in the implementing rules and regulations of People's Small-Scale Mining Act of 1991 in pursuant to the EO 79.Thus, the current situation in implementing laws and ordinances is studied and the changes made in these policies that challenges the implementation of water quality monitoring efficiently. The next part is to quantitatively and qualitatively evaluate the mining operations in the country and the state of the Philippine rivers.

On the other hand, private and government agencies mostly employs the tedious, costly, time consuming and traditional detection methods of monitoring heavy metals which include ground surveys, in which they usually adopts manual sampling and laboratory analysis method. Heavy metals monitoring is also seldom conducted since the detection devices and methods existing in the market are usually expensive (Ke Lin, 2014). But technology breakthroughs in remote sensing, renewable energy, and wireless sensor networks has already opened up various research opportunities in heavy metals monitoring in aquatic area that promises a more convenient and cost-effective method. This study will therefore evaluate the possible applications and integration of this technologies in assessing the fate of heavy metals that are appropriate in the Philippine contexts. The review further aims to seize the advantages in using these technologies and how they can be implemented in an integrated approach in order to identify practical and low-cost solutions for heavy metals monitoring in water bodies.

2. THE PHILIPPINES' SETTING

2.1 The Environmental Aspects of Mining Laws

Issues on environmental degradations have always been a source of conflict of the mining industries, the government, and private sectors. Adherence to national laws and to international mining best practices and standards is one of the key measures in evaluating a country's determination to protect the environment. Among the best international mining practices requires that mining licenses should not be issued in conflict zones and bans on submarine and riverine tailings disposal and marine mining. No further mining licenses should also be issued until adequate enforceable legislation and controls are put in place to protect the environment and the economic, social, cultural, civil and political human rights of the indigenous peoples and mining impacted communities (Doyle, Wicks , & Nally, 2007).

Starting 1984, a plethora of laws and administrative orders have been created to control small-scale mining through the promulgation of Presidential Decree (PD) 1899. Then in 1991, as part of a broader decentralization effort, Republic Act 7076 (RA7076) was formalized that the Provincial/City Mining Regulatory Boards is authorized to assigned SSM area and award 2 years renewable contract to SSM-cooperatives. Overall, the terms and conditions set to qualify for formalization under RA 7076 are much more stringent than those under PD 1899 (Verbrugge, 2014). Then in 1995, the Mining Act or Republic Act 7942 was enacted to boost the mining industry and at the same time adhere to sustainable development measures. The Mining Act's environmental aspects provided area limitations and the maximum years of operations for mining companies. The assignment of mining rights must be administered by one of the bureaus under the DENR, the MGB. Also, the law provides that mining companies must secure environment clearance certificate (ECC) to ensure compliance to safety and sanitary of mining operations. Section 69 of the Mining Law further requires every contractor to implement environmental protection and enhancement programs covering the period of their mineral agreement or permit as one of the pre-requisites in granting the mineral agreement or permit. The Mining Act also institutionalized an incentive mechanism for mining companies who are utilizing engineered and well-maintained mine waste and tailings disposal systems with zero-discharge of materials/effluents and/or with wastewater treatments plants.

To improve small-scale mining activities in the country, the mining policy as imposed by the Executive Order 79 series of 2012 pointed the following measures to be undertaken: (1) the SSM shall comply with the RA 7076 known as "The People's Small-Scale Mining Act of 1991" the Environmental Impact Statement System requirements under PD 1586; (2) SSM shall only use the declared people's Small-Scaled Mining Areas pursuant to RA 7076; (3) Pursuant to Section 24 of RA 7076, the Provincial/City Mining Regulatory Board in the provinces and cities where they have not been constituted shall be operationalized within three months from the effectivity of EO 79; (4) SSM shall not be applicable for metallic minerals except gold, silver, and chromite, as provided for in RA 7076 and the use of mercury is highly prohibited, and (5) the government agencies shall conduct training and capacity building in the form of technical assistance for SSM cooperatives and associations.

The issuance of EO 79 also expanded the limitations on areas closed for mining tenement applications. Restricted areas added were the Protected areas categorized and established under the National Integrated Protected Areas System ("NIPAS") under Republic Act No. 7586; prime agricultural lands, in addition to lands covered by Republic Act 6657, including plantations and areas devoted to valuable crops, and strategic agriculture and fisheries development zones and fish refuge and sanctuaries declared by the Secretary of the Department of Agriculture; tourism development areas, as identified in the National Tourism Development Plan; and other critical areas, island ecosystems, and impact areas of mining that the DENR may identify pursuant to existing laws, rules, and regulations and the terms and conditions of the grant. Also, through EO 79, LGUs were already empowered and included multi-stakeholders to ensure environmental compliance of the mining companies. The ECC is now coordinated with the LGUs for them to impose local ordinances and limitations that are within the bounds of national laws and regulations on mining activities conducted within their respective territorial jurisdictions.

2.2 The Challenges in Implementing the Laws

Problems associated with an absence of clear responsibilities, with the overlapping of institutional boundaries, duplication of work and a lack of coordination between involved institutions, are common obstacles to effective water pollution control in many countries (WHO/UNEP, 1997) including the Philippines. The enactment of the Philippine Clean Water Act (CWA) in 2004 is recognized as the dramatic shift in water quality management in the Philippines (JICA/DENR-EMB, 2010), however the enforcement of the law through the water quality monitoring guidelines and even the implementation of most of the law's environmental regulation aspects is still at the developing stage. This is due mainly to the government agencies' lack of budget, experience and expertise on national polices and its requirements and provisions like the CWA (JICA/DENR-EMB, 2010), Mining Act, law on requiring the Free and Prior Informed Consent (FPIC) to deal with the complex matters (Raymundo , 2014). While the bureaucratic red tape in the approval of permits by local and national government posed another problem as it is slowing the rehabilitation of existing mines and the development of new ones (Raymundo, 2014; Chase and Lugue, 2006).

According to the Mining Act, the contract and the permits of large scale mining are issued under the national level while the responsibility for environmental protection and conservation is delegated to local government under the Local Government Code. The source of conflict in the policy comes in because the agreement between the local government and the communities was disregarded. A good example to this is the experience of small scale mining in Mt. Diwalwal, Compostela Valley which is off-centered due to the absence of clear policy wherein the miners are placed in hazardous position because their tools and practices are no long congruent to the modern technology so then they are unable to carry their trade under the umbrellas of either large-scale or small-scale regulations (La Vina, De Leon, & Bueta, 2012).

Another challenge is the establishment of a complete, accurate and up-to-date data, which is the basis for the analysis and for assessment of the mining industries that includes not only the technical information wherein the quantity and the quality of the mineral resources are present but most importantly the effect of the environmental, economic and social impact on the mining operations (La Vina, De Leon, & Bueta, 2012). The completeness of data, which should include a comprehensive environmental status report where a mining company would like to operate, is a good basis for the government's decision to whether or not allow them to operate. La Vina, De Leon, & Bueta (2012) further noted that all data must be accessible to the public to guarantee transparency, accountability and full participation by stakeholders. Moreover, La Vina, De Leon, & Bueta (2012) stressed that the violation of the human, socio-cultural, economic and environmental right of local communities by the mining companies is a repeated phenomenon which is actually a problem in law enforcement rather than absence or lack of law.

With regards to implementing the Clean Water Act (CWA), the EMB has 16 regional offices (ROs) nationwide but not all regions are fully equipped to carry out the complete water quality monitoring procedures. Their monitoring programs collect monthly data on physico-chemical and biological analysis from either water samples or using portable on-site monitoring equipment. However, depending on available laboratory facility, instruments, transport and human resources, all monitoring programs are restricted in some way and may collect data primarily by direct sampling or in limited water quality parameters. Also, not all ROs with active mining operations and other related industrial sector have the capability to monitor regularly the levels of heavy metals in the water bodies. This problem was initially addressed through a technical cooperation project between JICA and EMB that was implemented from 2006-2011 with the capacity building of EMB in their mandates under CWA implementing rules and guidelines as one of the main goals. The technical cooperation project aims to provide EMB an adequate understanding of the WQM procedures in conformity with CWA requirements. Three pilot ROs were intensively trained and the capacity of non-pilot ROs were strengthened through participation in the learning process, in activities such as orientation/workshop (JICA/DENR-EMB, 2010).

In the 2013 Fraser Institute's mining policy attractiveness survey, the Philippines ranked third among the least attractive jurisdiction for investment based on the Policy Potential Index (PPI). The PPI serves as a report card to governments on how attractive their policies are from the point of view of an exploration manager (McMahon & Cervantes, 2011). The Philippines ranking crawled up to the second worst jurisdiction with a PPI of 5.2, in the 2014 Fraser Institute survey. Belonging to the bottom list of this survey means the country is poor in terms of administration of current regulations, environmental regulations, regulatory duplication, the legal system and taxation regime, uncertainty concerning protected areas and disputed land claims, infrastructure, socio economic and community development conditions, trade barriers, political stability, labor regulations, quality of the geological database, security, and labor and skills availability (Jackson & Green, 2016).

But starting year 2006, various efforts were observed from the DENR in reinforcing the implementation of CWA, most of which are significant outputs from a technical cooperation project between Philippines and Japan. This cooperation project of JICA and DENR resulted to various milestones in the efforts of the Philippines on water quality management which include the recent issuance of DENR Order No. 2016-08 which provide a new and more stringent water quality guidelines and general effluent standards; DENR Order No. 2013-08 which is the adoption of the integrated water quality management framework; and the increase of approved water quality management areas (WQMAs) to be placed under close monitoring from only 5 in year 2010 to 31 as of June 2016. These accomplishments of the DENR may took the credits as the Philippines was already displaced from the bottom 10 of the 2015 Fraser Institute's mining policy attractiveness survey.

2.3 The Mining Tenements and Mining Practices

Under the Mining Act, mining operations in mineral reservations shall be undertaken by the DENR or through a qualified person under any of the following mode, namely: the Exploration Permit (EP) grants the holder the right to explore (subject to valid, prior and existing rights of any party or parties within the subject area); a mineral agreement, which may be in the form of (a) a mineral production-sharing agreement (MPSA) where the government grants to the contractor the exclusive right to conduct mining operations within a contract area and shares in the gross output. The contractor provides the financing, technology, management and personnel necessary for the implementation of the agreement; (b) co-production agreement, which is an agreement between the government and the contractor wherein the government provides inputs to the mining operations other than the mineral resource; or (c) a joint venture agreement where a joint-venture company is organized by the government and the contractor with both parties having equity shares. Aside from earnings in equity, the government is entitled to a share in the gross output; and (d) a financial or technical assistance agreement (FTAA), which is an agreement for the large-scale exploration, development and utilization of mineral resources.

As of July 31, 2016, the MGB reports that the Philippines has the following approved permits: a total of forty-one (41) issued EPs covering an area of 99,029.6519 hectares, three hundred nineteen (319) MPSAs in 595,234.798 total land area, two (2) Mining Lease Contract (MLC) for a total of 2,486.5797 hectares of land, and a total of forty-four (44) Mining Processing Permits (MPPs) granted to individual/companies.

The economic advantage of mining has always been overtaken by the negative impacts of the mining operations to the environment. Some of the diseases attributed to mining operations are skin rashes as a result of washing with water or working in the rice field (Doyle, C. Wicks, C. and Nally, F., 2007). The usual method in commercial mining is the use of cyanide separation to extract gold from ore. The mining process can also lead to toxic metals being released from the ore in which when it gets into the food chain, they can seriously damage health.

River panning is the basic procedure which relies on the use of a simple pan or sluice box and gravity to capture gold nuggets and is the most used methods in the country. Another method of some of the SSM is self -financed tunneling operation and some of which avail of the credit lent by the owner or local store-owner while others form a team that will gather their own resources. The third method defines the feature of a small-scale mining, the capitalization will depend on the tunneling operation in which the basic tools, equipment, food and shelter for the labor force were given a consideration in the mining operation.

SSM using river panning in Davao provinces were prevalent during 1989 where there are also persistent reports of mercury poisoning in the gold rush areas. During this period, SSM operations were accompanied by the widespread use of mercury as an amalgamation agent for gold recovery from high-grade ores. More recent groups formed themselves into mining cooperatives and employed a more fairly standard modern method of gold extraction using the carbon-in-pulp (CIP) systems (Breward, 1996). The MGB then conducted a survey to determine the mercury disposal pattern in the gold and panning areas. Their findings showed that about 28.6% of the total mercury disposed came from mining companies and 71.4% came from SSM processors (Breward, 1996). Then, in a collaboration project with the British Geological Survey (BGS) and the MGB, an assessment of mercury contamination associated with artisanal gold mining in the Agusan River catchment in eastern Mindanao was conducted in 1996. The study aimed to determine the mercury contents within the Agusan catchment especially in those areas which have been subject to very rapid and largely unregulated growth in small-scale artisanal gold mining, a decade after the discovery of rich gold deposits in the area. Their study results showed that high levels of mercury were found near some of the mining sites, and the dispersion patterns suggest that although dissolved mercury is fairly rapidly lost from solution, a 'reservoir' of mercury may build up in the stream sediments causing a potential long-term pollution problem. It was further noted that much of the severe contamination is localized and the main Agusan river is relatively affected which can be attributed to the growth of more highly-organized SSM using cyanidation rather than amalgamation (Breward, 1996).

On the other hand, modern mining in the Philippines typically consists of open-pit mining of low-grade ores for copper and gold, and strip-mining for nickel. This involves flattening mountaintops, creating huge craters and producing vast amounts of waste in the form of tailings. Large-scale gold mining is particularly destructive because it involves the processing of huge volumes of ground rock, using cyanide to separate gold from the ore. This process also releases other potentially harmful toxic metals, the monitoring of which has been described as inadequate in certain mining operations in the Philippines. In the case of a corporate mining in Benguet, surface mining as well as underground tunneling, blocking caving and open pit mining are the practices in the mining operation. Open-pit and underground bulk mining by Philex in Tuba and Lepanto in Mankayan generate ore and tailings at a rate of up to 2,500 metric tons per mine per day, toxic mine tailings are usually impounded in tailings dams, however, when pressure in the tailings dams builds up, especially during times of heavy rainfall, the mining companies drain their tailings dams of water or face the risk of having the dams burst or collapse, in either case, the tailings eventually find their way out, polluting the water and silting up the rivers and adjacent lands (Cordillera People Alliance , 2007).

2.4 The Philippine River Networks and its State

Under the CWA, the DENR Order No. 1990-34 presented a guideline in the classification of surface and coastal water according to its beneficial use and sets of criteria were provisionally applied with a total of 33 parameters to define the desired water quality per water body classification. Of the 688 classified water bodies by the EMB, this constitutes 313 principal rivers, 301 minor rivers, 16 lakes, and 58 coastal and marine waters. Out of the 688 classified water bodies, 167 have multiple classifications along their stretches or reaches, thus leading to a total of 874 classifications.

Of 874 classified water bodies, five are Class AA and 234 are Class A, which are both intended for public water supply. Majority of the water bodies are classified as Class C, which are intended for fishery, recreation, and supply for manufacturing processes after treatment. A large number of water bodies are also classified as Class B, which are intended for recreational activities involving primary contact such as bathing, swimming, and skin diving. Of the 58 classified coastal and marine waters, only five are Class SA, which are designated as protected marine habitat. Majority are Classes SB and SC, which are intended for contact recreation and aquaculture production, respectively (Environmental Management Bureau. 2014). And as of June 2016, there are 16 WQMAs located in Luzon, 5 in Visayas and 10 in Mindanao. Under the WQMA, the DENR and the stakeholders shall address the water quality problems, sources of pollution, and beneficial uses of the receiving water body. They shall also determine what control measures to institute to effectively achieve water quality objectives or improvements (DENR, 2016).

According to the National Water Quality Status Report of EMB, water bodies monitored for toxic chemicals such as cyanide and heavy metals (mercury, lead, and cadmium) are limited and focused only on those water bodies with remarkably known sources of these pollutants. Further, the EMB monitoring results showed that half of the eight water bodies monitored for cyanide achieved 100 percent compliance rating. This can be equally noted as half of the eight water bodies monitored for cyanide failed to meet the criterion. Also, fourteen out of eighteen or about 78% of the monitored rivers for total mercury exhibited 100 percent compliance to the maximum limit of 2 micrograms per liter (µg/L). In contrast, Agno (98%) and Panique (93%) Rivers both exceeded the criterion in only one sampling event out of the total number conducted, reaching an average mercury concentration of 4.3 µg/L and 430 µg/L, respectively. Likewise, Tubay River (96%) did not meet the criterion in two sampling events out of the 56 conducted, with an average concentration of 2.5 µg/L in both instances. Moreover, Malaguit River (91%) failed to meet the criterion in six out of the 70 sampling events conducted, with average concentrations from as low as 3 µg/L to as high as 9 µg/L. Agno and Tubay Rivers are classified as Class A, but with the noted exceedance of mercury in these rivers, their use as source of potable water could be detrimental. While for Cadmium, of the 18 water body classifications monitored, ten surface waters showed deviations to the criterion. These exceedances ranged from as low as 0.011 mg/L to as high as 0.108 mg/L, with a median value of 0.014 mg/L. The Class A rivers, Chico, Balili, and Agno Rivers, had lowest compliance ratings for Cadmium. Balili River, which is a priority river, showed only nine percent compliance to the criterion, whereas Agno River and the upper reach of Chico River had compliance ratings of 48 percent and 46 percent, respectively (Environmental Management Bureau. 2014). In the same report, results for monitoring Lead in 18 water classifications showed that 11 surface waters showed exceedances to the criterion. Asin-Galiano River did not meet the criterion in one (0.18 mg/L) out of the 34 samplings conducted, hence receiving the highest compliance rating of 97 percent. This is closely followed by the Lower Reach of Davao River with 96 percent and Mogpog River with 93 percent. On the other hand, Budacao River and the Upper Reach of Davao River met the respective lead criterion with compliance ratings above 80 percent (Environmental Management Bureau. 2014).

3. APPLICATION OF ADVANCED TOOLS FOR ENVIRONMENTAL MONITORING

3.1 Remote Sensing Techniques

Remote sensing technologies have long been used effectively as the key tool in environmental monitoring studies, either as input data or as an analytical tool. There are various remote sensing techniques that were employed in many studies like the application of aerial photography, multispectral and hyperspectral image processing and interpretation, and spectrometry. Remote sensing data like satellite images can be an alternative measurement tool for environmental monitoring for the following parameters but not limited to chlorophyll-a (Dlamini, Nhapi, Gumindoga, Nhiwatiwa, & Dube, 2016; Nazeer & Nichol, 2016; Yunus, Dou, & Sravanthi, 2015), total suspended matters (Dekker, Vos, & Peters, 2001), soil nutrient like phosphorus (Grunwald, Vasques, & Rivero, 2014), radiant temperatures (Wilson, Clay, Martin, Stuckey, & Vedder-Risch, 2003), and heavy metals (Shi, Chen, Liu, & Wu 2014; Schwartz, Eshel, & Ben-Dor 2011). In particular, most of the studies related to oceanography and water quality monitoring are utilizing freely available remote sensing datasets from Sea-viewing Wide Field-of-view Sensor (SeaWiFS), Moderate Resolution Imaging Spectroradiometer sensors (MODIS), Ocean Color Monitor: OceanSAT, and Landsat series.

Land use information is important in many applications, i.e., tax assessment, urban planning, and environmental management (M. Park & M. Stenstrom, 2008). Kibena, Nhapi, & Gumindoga (2014), for example, investigated land use changes derived from analyzing satellite images to assess its impact to the water quality of a river that drains to a rural and urbanized part of the catchment. The works of Dlamini, Nhapi, Gumindoga, Nhiwatiwa, & Dube (2016) also proved the use of satellite images to investigate the effect of land use changes within a catchment to identify pollution sources. Their works further identified cheap and readily available datasets and models that can accurately predict key water quality parameter like chlorophyll-a that provides a critical knowledge for understanding lake water quality deterioration levels. While Hartnett & Nash (2015) particularly employed an aircraft remote sensing method to provide data for estuarine water quality models like spatial and temporal imageries of the shoreline for land use mapping and change detection and chlorophyll-a levels for validating prediction models using their own developed sensors mounted in the aircraft to collect water surface chlorophyll-a levels.

In the literature, spectroscopy and analysis is often applied on vegetation (Clevers, Kooistra, & Salas, 2004) and soil mediums (Gannouni, Rebai, & Abdeljaoued, 2012); (Shamsoddini, Raval, & Taplin, 2014); (Eunyoung Choe, et al., 2008). More recently, an extensive review on the potential of integrated field spectrometry and spatial analysis was made by Horta, Malone, Stockmann, Minasny, & Bishop, (2015) which pointed out that the popularity of Vis-NIR spectrometers in soil science are due to its portable format, easy and ready to use in the field, and require minimal or even no sample preparation. Their works further added that with proper calibration, spectrometers can be used to estimate many soil properties. Gannouni, Rebai, & Abdeljaoued (2012) applied laboratory reflectance spectroscopy in detecting Fe-related and clay minerals as well as the quantitative characterization of pollutants from mine waste. Their results indicated that direct quantitative relationship between pollutants and spectral parameters shows that Pb-Zn-Mn are best correlated with a ratio of 610/500 nm range while Ni-Cr have a best correlation with a slope around 980 nm. Outputs from Partial Least Square Regression (PLSR) confirmed these relationships and also indicated that spectral parameters and reflectance values within 400 - 2500 nm range can better predict the contamination for Mn, Pb and Zn. Choe, et al. (2008) also employed band ratios and continuum-removal and band-depth (CR-BD) analysis to investigate correlation between onsite spectral data and heavy metals concentration which they found that in using the DR-BD analysis, Lead and Zinc are highly correlated with depth of the absorption at 500 nm while the band ratio of 610/500 nm can significantly model Copper, Lead and Zinc on soils. While Shamsoddini & Raval (2014) findings indicate that the models derived from the first derivative of the reflectance data estimate heavy metals significantly more accurately than model derived from the original reflectance. Their statistical analysis results indicate that estimates were of greater accuracy for arsenic and lead compared to other heavy metals. This result confirms the works of Clevers, Kooistra, & Salas (2004) where a significant negative correlation between the spectral parameter (Red Edge Position) and heavy metals (Lead, Cadmium, Copper, Zinc and Nickel) concentration was found using the maximum first derivative method.

3.2 GIS Mapping, Modelling and Analysis

Geographic Information Systems (GIS) has long been widely used for various environmental monitoring studies. GIS is both a database system with specific capabilities for spatially referenced data, as well as a set of operations for working with data. GIS are used for the storage, management, analysis and display of geographically referenced data, being valuable tools for assisting planning and decision making in multiple contexts in which geo-referenced information plays a relevant role (Juan M. Sánchez-Lozano, 2014). The most basic use of GIS is its visualization and mapping function. Through GIS, geographic locations of sampling points taken from handheld GPS is easily mapped and viewed in its interface. But GIS can be optimized by applying geospatial analysis to generate spatial distribution maps. Mapping the spatial distribution of contaminants is important in clarifying pollution history (Zhou, Guo, & Hao, 2007) and a good basis of pollution evaluation and risk control (Xie, et al., 2011). Asmaryan, Sh. G., Muradyan V.S., Sahakyan, L.V., & Saghatelyan, A.K. (2013) employed GIS to model the distribution of heavy metals, using models derived from correlating spectral data from spectrophotometer and satellite images, to visually assess the extent of contamination within their study area. But, more than visualization, Mitsios, Golia, & Floras (2003) pointed out that a GIS-based thematic mapping of heavy metals are expected to constitute an important tool because they give the opportunity of continuing renewal of database and verification or even correction of estimation of heavy metals pollution.

GIS also becomes a unique tool for geostatistical analysis and spatial interpolation utilizing measured samples with known values to estimate unknown values so as to visualize the pollution spatial patterns (Yan, et al., 2015). By employing interpolation techniques in GIS, contamination data and other attributes of a point vector layer can be converted into a continuous surface to generate distribution maps of a certain contaminant. Some of the interpolation tools widely used for this purpose are Inverse Distance Weighting (Elbana et al., 2013; Matejicek, Engst, & Janour, 2006) and Ordinary Kriging (Yan, et al., 2015; Matejicek, Engst, & Janour, 2006). Xie, et al. (2011) presented a comparative study on various interpolation techniques where they pointed out that all interpolation methods provided a high prediction accuracy of the mean concentration of soil heavy metals but the spatial uncertainty of polluted areas was mainly located in three types of interpolated region: (a) the local maxima concentration region surrounded by low concentration (clean) sites, (b) the local minima concentration region surrounded with highly polluted samples; and (c) the boundaries of the contaminated areas.

Furthermore, many GIS application have been developed for site selection problems in various research areas such as natural resources management, environmental pollution and hazard control, regional planning, urban development, and utilities and management (Aydin , Kentel , & Sebnem Duzgun , 2013).

3.3 Wireless Sensor Networks for Environmental Monitoring

With the advancement of technology like electronics, components, instruments, and methods are becoming more advanced and sophisticated that even a small amount (in ppg) of substance present in the remotest location are detected and can be transmitted in near real time and converted into useful information. Wireless Sensor Network (WSN) was developed due to the progress of wireless communication and embedded micro-sensing MEMS technologies wherein numbers of autonomous sensors are working collaboratively to monitor parameters of interest (Yick, Biswanath Mukherjee, & Dipak Gho, 2008). Monitoring using WSN is becoming the new norm in environmental monitoring endeavors (Zhuiykov, 2012). It is one of the fastest ways to monitor marine environmental changes (Xu , Shen, & Wang, 2014) in hard- to-reach areas with lesser resources to be utilized. It has the ability to sense, detect and monitor the parameters of interest and transmit the collected data to a central location using wireless communication technologies (Baunach, Kolla, & Mühlberger, 2007). Nowadays, environment monitoring is one of the fields where WSN application gains its momentum, due to the increasing need for sensors that has capability to monitor physicochemical parameters in real time and on-site (Lawlor, Torres, O'Flynn, Wallace, & Regan, 2012). Its best suited area of deployment is on hard-to-reach marine areas (Amundson & Koutsoukos, 2009) where monitoring on site is expensive, tedious and risky.

Marine environmental monitoring has a wide area of applications including heavy metals and on water quality monitoring (Zhuiykov, 2012) which is one of the research areas gaining much attention. Its application also covers marine product contamination monitoring (Ma, Ding, Li, & Zhao, 2010), marine habitat monitoring (Szewczyk, et al., 2004) and others related topics. Study on WSN-based heavy metals monitoring is increasingly popular but was confronted with the problem of the need of highly sensitive sensors (Zhuiykov, 2012) that can be used to monitor presence of very small amount of heavy metals. The focus of water quality monitoring is to have a real time in-situ water quality data like pH, DO, temperature, turbidity, and conductivity (Yue & Ying , 2012) and water conditions like color, wind speed and direction. Mostly it covers rivers, bays, lakes, seashore and other aqueous places (Jiang , Xia, He, & Wang, 2009). With this wide area of coverage, environmental monitoring using WSN has its own requirements for modalities, technologies like sensing (Girod, Estrin, Pottie, & Srivastava, 2001), communication (Rasin & Abdullah, 2009), and floatation (Albaladejo, et al., 2010); and its architectures (Karl & Willig, 2007). However, it is also important to note that yunus are still several challenges in using WSN like resource constraints which includes limited energy supplies, limited memory and computational capacities; dynamic and extreme environment conditions; data redundancy; unreliable wireless communication; no global identification (ID) for sensor nodes; prone to node failure and large scale deployment (Rawat, Singh, Chaouchi, & Bonnin, 2013).

3.4 Renewable Energy Technologies

Renewable energy (RE) technologies are considered the primary, domestic and clean or inexhaustible energy resources (Ocak, Ocak, Bilgen, & Kaygusuz, 2004)where solar energy is one of the most abundant and is available in both direct and indirect forms (Panwar, Kaushik, & Kothari, 2011). The utilization of solar energy was already extended in assisting sensors and platforms that are used for environmental monitoring. This is due to the emerging challenge for sensors to operate at a much longer duration (like years or even decades) after they are deployed. Examples include in-situ environmental/habitat monitoring and structural health monitoring of critical infrastructures and buildings, where batteries are hard (or impossible) to replace/recharge (Winston K.G, 2009). In a WSN-based environment monitoring system, its main purpose is commonly for data collection from the environment where regular access is not possible or impractical (Ferdous, Reza, & Siddiqui, 2016) or very costly. Since sensors are powered by batteries, issues on its limited lifespan (Nallusamy & Duraiswamy, 2011) and the need to replace them periodically is a challenge and where solar photovoltaic systems can offer solutions.

Utilizing solar power in WSN in establishing the topology where node can receive and transmit pocket without consuming the limited battery resource becomes a consideration (Nallusamy & Duraiswamy, 2011). Voigt, Ritter, & Schiller (2003) presented that the solar cell can be used to power up sensor and to charge the batteries during the idle period of nodes, the stored battery energy can be used to power the nodes during the absence of sunlight which the solar- rich nodes can take over the responsibility relaying data to the base station, moreover, this research prove that the solar power method results in energy saving, sustained the lifetime network and a better performance. Polastre, Szewczyk, & Culler (2005) works demonstrated a longer duration solar power subsystem for mote-Telos which is a WSN system. One example is the solar powered autonomous surface vessel (SPASV) which is capable of navigating throughout the inland water and measure a range of water quality properties and greenhouse gas emission. The 16 foot long solar powered vessel collects various water quality information, as well as measuring the spatial-temporal release of various greenhouse gas emissions through the water column while moving, the unique feature of this SPASV is its integration into storage scale floating sensor network to allow mission upload, data downloading and adaptive sampling strategies (Dunbabin, Grinham, & Udy, 2009).

On the other hand, successful applications of remote sensing and GIS have been well-documented in various fields of research such as natural resource management, forest assessment, biodiversity mapping, land use land cover mapping, natural hazard mapping, pollution monitoring. These popular technologies are specifically applied in assessing the status of renewable energy resources and also for planning its cost effective exploitation where a satellite image serves as an input data for such analysis and high resolution satellite image is expected to increase the preciseness of the estimation (Hiloidhari & Baruah, 2014). Using the GIS, two factors of distinct nature, the restriction and criteria for selection, can be represented in layers and used for spatial analysis to identify best location for solar farm. Restriction layers are identified areas which eliminate those areas that photovoltaic solar farms cannot be implemented while layers representing the criteria may take into account the weather, environmental, location, and terrain evaluation aspects (Juan M. Sánchez-Lozano, 2014).

4. INSIGHTS

The environmental laws and policies applicable to mining are the aspiration for the protection of the environment while promoting mining exploitation and development. The existing laws has many strengths but the government’s capability to implement them to resolve regulatory duplications and to harmonize conflicting or overlapping laws are integral part in evaluating its performance in protecting the environment, particularly in water quality monitoring programs. The biggest challenge here is in gauging how to put a balance in boosting the growth of the mining industry and the efficiency of the government to enforce countermeasures to ensure sustainable and healthy environment. Efforts from the government to improve its policy implementation were already observed and the outcomes of the improvements made is hoped to be observed through the all-inclusive national water quality report and the national audit reports of mining companies. These can be achieved if the government agencies will have sufficient and technically-able human resource who will efficiently enforce laws and policies, sufficient budget for inspection in the mining site, and sufficient budget for adequate laboratory facility and water quality monitoring program.

On the positive side, insufficient resources for water monitoring can be addressed if the government will be serious in looking for good alternative methods and put more efforts in embracing established technologies in the fields of environmental monitoring. Remotely sensed data that are freely available can be used as an alternative source of water quality data and various techniques were established on how remote sensing and GIS can aid in estimating contamination and in identifying causal effects of anthropogenic activities. GIS can also address the need for a comprehensive database for water quality and environmental impacts of mining where making these GIS maps accessible by agencies and the public can offer a new wave of evaluating the situation and promote transparency. The use of wireless sensor networks is another alternative and new technology for environmental monitoring that the country should consider and maximize its known advantages like easy deployment of sensors, real-time monitoring, automatic and low cost operation. Although it has some limitations like energy sources for long term deployment but being geographically located near the equator gives the country an opportunity to explore the advantages of renewable energy technologies in which its utilization ranges from powering up sensor nodes to supplying adequate energy for base stations. But it is important to note that even if how effective and promising these technologies are, its strength can still be pulled down by the limited technical expertise, financial resources, and accessibility and availability of a complete database for water quality monitoring.

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