ENVIRONMENTAL IMPACT ASSESSMENT FOR MALYASIAN BAUXITE MINING INDUSTRY

Nagendran Periaiah
Graduate School of Management
International Islamic University Malaysia
Jalan Gombak, 53100 Kuala Laumpur
Malaysia
nagen@envichem.com.my

Rafikul Islam
Department of Business Administration
International Islamic University Malaysia
Jalan Gombak, 53100 Kuala Lumpur
Malaysia
rislam@iium.edu.my

Muhammad Faris Abdullah
Department of Urban and Regional Planning
International Islamic University Malaysia
Jalan Gombak, 53100 Kuala Lumpur
mfaris@iium.edu.my

ABSTRACT

The mining industry plays an important role in the economic development of Malaysia. However, uncontrolled mining activities have caused serious environmental impacts. Recently, bauxite mining in Kuantan, in the state of Pahang, stained fifteen kilometers of Pahang's coastline with red arsenic particles and heavy metal pollution washed from open-pit bauxite mines into the nearby sea. This has caused potentially catastrophic damages to the ecosystem off the coast of Pahang. This triggered the Government of Malaysia to issue a temporary ban on bauxite mining while the state government engaged in expensive clean-up. Mining activities require an Environmental Impact Assessment (EIA). Environmental decisions are complex and multidisciplinary including knowledge bases which incorporate natural, physical, and social sciences, politics, and ethics. This research proposes a decision support framework that uses the Analytic Network Process (ANP) to help decision makers in EIA pertaining to the bauxite mining industry.

Keywords: Bauxite mining; environmental pollution; Environmental Impact Assessment; decision making; Analytic Network Process

1. Introduction

The mining industry plays a significant role in the development of a country. It assures an adequate and continuous supply of raw materials for the construction and manufacturing sectors. Over 33 different types of minerals comprising metallic, non-metallic, and energy minerals are available in Malaysia (MCOM, 2017). The metallic mineral mining subsector commonly produces minerals such as tin, gold, bauxite, and iron ore. Additionally, by-products such as zircon, monazite, rutile, struvite, and silver are also produced from tin and gold mining. The non-metallic or commonly known as industrial mineral subsector produces limestone, clay, kaolin, silica, feldspar, and mica.

In 2017, Malaysia's economy accelerated with 5.9% growth in the gross domestic product (GDP), at a current value of $329.85 billion. Mining and quarrying alone contributed $30.05 billion, which made up 9.11% of the country's GDP (MCOM, 2017). Overall, the total production value of major minerals in Malaysia increased by 55%, from $1 billion in 2010 to $1.5 billion in 2015 (MCOM, 2017). The increasing demand for minerals, especially from China and India, has opened up the path for companies to explore various types of deposits from iron ore to gold. In the 1980s, the collapse of the tin market caused a decline in the Malaysian mining industry. However, that incident did not dissuade experts from believing that there were still untapped deposits of minerals worth roughly $81.9 billion that could transform landowners into billionaires (TMR, 2017). Since 2008, Chinese companies have reportedly invested nearly half a billion dollars in the extraction of iron ore from Malaysia (TMR, 2017). According to the Minerals and Geoscience Department, in 2016, a total of 34 iron ore mines, 32 tin mines, and eight gold mines operated in peninsular Malaysia (JMG, 2018).

Before 1980, Malaysia's metallic mining industries were mainly dominated by tin, iron, and gold mines. Much research including that of Sarupria et al. (2019), Lodhia (2018), Bond and Morrison (2018), Louw (2018), Carvalho (2017), Skuta et al. (2017), Lee et al. (2017), Jain et al. (2016), Garcia et al. (2016)**,** Faradiella et al. (2016), Venkateswarlu et al. (2016), and Jamal et al. (2015) revealed mineral mining as one of the major causes of heavy metal contamination in the environment. Residue containing heavy metals from tin mines and metallurgical operation sites is often further dispersed into the environment by wind and/or water.

Lately, the demand for bauxite mining has increased due to intensifying progress in the industrial sector. Bauxite is usually regarded as the best material for making aluminum. Bauxite is also widely used in the production of paper, water purification, petroleum refining, the electric power industry, the aircraft industry, machinery, and the civil tool-making industry. Due to its broad applications, bauxite mining activities have been escalating. In 2015, Malaysia was the world's top producer of bauxite (CMO, 2016).

The advancement of Malaysia from a minor bauxite producer to the world's top producer has resulted in consequences in the form of increasing detrimental environmental impacts. Figure 1 shows the impact of bauxite mining on surrounding areas in Pahang state, Malaysia.

ISSN 1936-6744
https://doi.org/10.13033/ijahp.v13i1.851

Figure 1 Impact of bauxite mining on the surrounding areas in Pahang
(Source: CMO, 2016)

Clean Malaysia Organization (CMO), an independent online news site reported that the introduction of bauxite mining has transformed the port town of Kuantan from quiet byways to heavy traffic of ore-hauling trucks (CMO, 2016). The surrounding environment, vehicles, homes, and trees have accumulated a thick layer of red dust due to emissions released from the movements of bauxite loading and unloading trucks. Locals have also complained that bauxite emissions have caused skin irritation (Abdullah et al., 2016). Environmental experts have warned that ingestion of bauxite emissions increase the risk of developing cancer.

Many fruit orchards and small-scale oil palm planters abandoned their agriculture businesses and leased their land to mining contractors for short-term cash benefits. Due to uncontrolled licensing and the presence of illegal mining contractors, the areas surrounding Kuantan port have become heavily contaminated, turning it into a red colored zone. During rainy seasons, the surface washout from these contaminated areas flows into the nearby river and turns the water red (Malaysiakini, 2019). Environmental experts have also warned about the occurrence of arsenic and heavy metal in water bodies washed down from the open-pit bauxite mines (USGS, 2016).

Mining activities damage the environment and ecosystem. Many environmental experts hope for an indefinite extension of the ban imposed by the government (Daim, 2019). The state government has carried out vigorous clean-up efforts. Meanwhile, experts from various government agencies and consultants are working together to develop more environmentally friendly bauxite mining standard operating procedures (Povera, 2019).

Environmental and socio-economic protection from mining operations depends entirely on EIA and its enforcement (Solbar & Keskitalo, 2017). However, an EIA is an intrinsically complex multi-dimensional procedure. Due to its complexity, EIA implementation is often not entirely satisfactory (Bond & Morrison, 2018). An EIA often deals with attributes that are difficult to define and components that may involve both quantitative and qualitative factors (Hamida et al., 2021; Kaya & Kahraman, 2011).

During EIA projects, decision makers often receive four general types of technical inputs including the results of modeling and monitoring studies, risk assessment, cost or cost-benefit analysis, and stakeholder preferences (Mahmud, 2016). While choosing to present modeling and monitoring results as quantitative estimates, the project team can incorporate a higher degree of qualitative judgments for risk assessment and cost-benefit analysis (Bond & Morrison, 2018). Structured information about stakeholder preferences may not be presented to the decision maker and conducted in an ad hoc or subjective manner that intensifies the difficulty of defending the decision process as reliable and unbiased (Asadabadi et al., 2019). Moreover, the application of structured approaches often relates to the lack of flexibility in adapting to local concerns or an inaccurate representation of marginal views. The development of a systematic methodology to rank projects based on combined qualitative and quantitative inputs from scientific and engineering studies of risks, costs, and benefits together with the views and values of stakeholders has not yet been achieved (Aminu et al., 2017). This makes it difficult for decision makers to identify all plausible alternatives and make full use of all available and necessary information when choosing between available project alternatives (Beltran et al., 2017).

Multi-criteria Decision Analysis (MCDA) methods have been found to be useful in dealing with complex and ill-defined environmental decision-making problems (Toth & Vacik, 2018; Saffari et al., 2017; Harun & Samat, 2016; Dell'Anna et al., 2020). Further, there is a need to develop systematic MCDA tools to support the decision-making process pertaining to EIA, especially in the context of Malaysia. Beltran et al. (2017) stressed that innovative methods might be required to achieve progress in the EIA process. The Analytic Network Process (ANP) has been found to be a useful MCDA tool for systematically analyzing the views of several groups of experts belonging to diverse fields in an EIA study (Kadoic et al., 2019). Beltran et al. (2017) also proposed the use of the ANP to address the needs of multiple criteria and multiple stakeholders in EIA. In order to simultaneously consider subjective issues and inter-influence among the criteria, this study develops a decision support framework that uses the ANP to help decision makers with EIA pertaining to the bauxite mining industry in Malaysia.

2. Literature review

Developing countries have yielded billions of tons of bauxite and aluminum, but malpractice by the industry has resulted in environmental damage and social unrest. Thorpe and Watve (2015) stressed that bauxite mining and processing had varied and robust impacts on the environment because they not only modify the landscape, but also generate severe pollution by discharging wastes into the biosphere (soil, atmosphere, and water). Bauxite mining is a major open cast mining activity that has a significant negative impact on the local environment (Skuta et al., 2017). The major threats from this activity are dust pollution, vegetation loss, forest fragmentation and

ISSN 1936-6744
https://doi.org/10.13033/ijahp.v13i1.851

biodiversity loss, negative impact on water resources, generation of wastelands, and social impact (Rohan & Samant, 2012). Leena et al. (2017) reported the socio-economic and environmental impacts of mining in Northern Europe which include land degradation, damage to water quality, pollution, harm to livestock and wildlife biodiversity.

Huang et al. (2011) pointed out that the application of conventional EIA tools is becoming increasingly difficult for three reasons. First, there are many emerging risks like climate change and nanotechnology for which information is not available, and decision-making often deals with significant uncertainty. Second, for many traditional stressors and situations, multiple lines of evidence regarding the same measure (e.g., risk) are available, but they may point to different management alternatives. Finally, stakeholders, who may have a vested interest in specific courses of action are gaining increased access to all the available information and given the data uncertainty, can often justify opposing courses of actions.

Bauxite mining is not new in Malaysia. The Malaysian Minerals and Geoscience Department (JMG) reported that bauxite mining has taken place in the state of Johor since early 2000 (JMG, 2018). Bauxite mining operations in Teluk Ramunia, Johor have been operating for more than 17 years without any controversy (Abdullah et al., 2016).

The gross output of bauxite from Johor was valued at $20.02 million in 2015 with seven establishments. In contrast, Pahang’s gross output of bauxite was valued at $613.17 million in 2015 with 88 establishments (DOSM, 2017). These statistics show that the magnitude of bauxite mining in Pahang is almost 30 times more than in Johor. The number of establishments conducting bauxite mining in Johor is also less when compared to Pahang. Therefore, bauxite mining in Johor is under control and does not pose serious environmental impacts to the surrounding areas.

Meanwhile, the recent bauxite mining activities in Kuantan have created different circumstances within a short period of time. Bauxite mining activities in Kuantan offer some exciting economic opportunities for various parties including individual land-owners. However, extensive and aggressive mining activities including transporting and stockpiling of bauxite in huge quantities have taken place. This has ultimately caused environmental problems leading to community outrage (Abdullah et al., 2016).

Malaysia incorporates the Environmental Impact Assessment into a mandatory requirement within the planning-permission process (Mahmud, 2016). The EIA procedure is built into the integrated project-planning concept and conducted in tandem with a pre-feasibility study. In Malaysia, an EIA is obligatory under Section 34A, Environmental Quality Act 1974. Section 34A empowers the Minister of Natural Resources and the Environment to prescribe any activity which may have significant environmental impacts as a Prescribed Activity. The legislation empowers the Director General of the Department of Environment (DOE) to: “…protect and enhance the quality of the environment through licensing, setting of standards, coordination of research, and dissemination of information to the public” (Mahmud, 2016). Section 34A (Amendment 2012) further requires the project proponent of a Prescribed Activity to appoint a qualified person to submit an EIA report to the Director General of DOE for approval. The EIA report must be in accordance with the guidelines issued by the DOE and contain an assessment of the Prescribed

ISSN 1936-6744
https://doi.org/10.13033/ijahp.v13i1.851

Activities' impact on the environment, and details on the proposed measures to be executed (DOE, 2016).

Activities subject to an EIA are prescribed under the Environmental Quality (Prescribed Activities) (Environmental Impact Assessment) Order, 2015. In terms of implementation, two types of EIA reports that are comprised of a First Schedule and Second Schedule are implemented. The activities specified in the First Schedule do not require a public display and public comment, while activities under the Second Schedule require a public display and public comments. A total of 21 categories of projects are listed as Prescribed Activities under the First Schedule and a total of 17 categories of projects are listed as Prescribed Activities under the Second Schedule. Generally, the requirement for the Second Schedule is more stringent and the size or significance of the project is larger compared to the First Schedule.

The Analytic Hierarchy Process (AHP) has been broadly utilized in the area of EIA. The AHP method widely functions to support the complex system related to decision-making from several alternatives, or for weight estimation in many fields (Saaty, 2005). In fact, the AHP helps establish the logical analysis of the problem by dividing it into its component parts. The analysis then aids the decision makers who, by means of several pairwise comparisons, can appreciate the influence of the considered elements in a hierarchical structure (Saaty, 2005). However, for many problems a hierarchy cannot be formed because of dependencies (inner/outer) and influences between and within clusters (criteria, alternatives).

One of the most advanced and complex multi-criteria decision-making methods is the Analytic Network Process (ANP) (Kadoic et al., 2019). The ANP is a generalization of the Analytic Hierarchy Process (Saaty, 2005). The basic structure in the ANP is an influence network of clusters. This method supports modeling dependencies and feedback between elements in the network. For this reason, the ANP is one of the most appropriate methods for making decisions in the fields characterized by dependencies among decision making elements such as in the area of environmental science (Kadoic et al., 2019).

The availability of literature concerning the application of MCDA in EIA specific to bauxite mining operations is still minimal. To date, MCDA tools have been applied in the areas of environmental management (Kheybari et al., 2020), EIA for mining (Ataei et al., 2016), sustainable tourism (Hadiwijaya et al., 2018; Aminu et al., 2017), waste management (Abba et al., 2013; Samah et al., 2010), project management (Beltran et al., 2017), a wind power project (Tian et al., 2013), urban industrial planning (Kaya & Kahraman, 2011), and construction (Liu & Lai, 2009).

An EIA is a possible conflict resolution tool available for use in environmentally sensitive projects such as bauxite mining. The literature has emphasized the need for an EIA to manage various environmental impacts such as dust pollution, water pollution, ecology, land use impact, socio-economic impact, and health impact which have arisen due to mining activities. Although Malaysia has a comprehensive EIA procedure (DOE, 2016) specific for mining industries, there are some weaknesses in the guidelines provided in the EIA handbook, which have resulted in criticism because of its vulnerability to abuse through the submission of multiple mini-projects (Mahmud, 2016).

For those mining projects that were prescribed and subjected to an EIA, the decision-making process faced the risk of high subjectivity. This subjectivity arises from the determination of relevant criteria, evaluation of the criteria, and the incorporation of the decision makers' opinions/judgments (Sarupria et al., 2019). The literature reveals that this problem appears to be under-researched. Although Mahmud (2016) observed that the government and the public understood the EIA process in Malaysia, there were also noticeable deficiencies. Moreover, only a limited number of studies have been conducted in Malaysia pertaining to EIA and mining industries. Motivated by these observations, this research aims to identify the criteria relevant to mining industries, as well as design an EIA decision-making model using the ANP, with special reference to the bauxite mining projects in Kuantan, Malaysia.

3. Research methodology

In the present research, the ANP framework consists of three clusters (environmental, economy and ecological) that serve as a foundation for the development of the decision-making framework. The ANP demonstrated a compound of two essential parts. The first consisted of a control hierarchy or network of criteria that controlled the interactions in the system. The second component of the ANP was the network of influences among the criteria and clusters. The network depended on the criteria, as the network of influence was different for each criterion. Thus, a supermatrix of limiting influence was computed for each control criterion. Then, each of these supermatrices was weighed by the priority of its control criteria, and the results were synthesized through the addition of all the control criteria (Aminu et al., 2017). This study also adopted and modified the decision-making framework for EIA from Ataei et al. (2016), Liu and Lai (2009), Samah et al. (2010), Kaya and Kahraman (2011), Tian et al. (2013), Abba et al. (2013), and Younes et al. (2015).

In the first stage of the research, an exploratory study was conducted to identify and understand the criteria and the influence network. The second stage involved the use of questionnaires to perform the pairwise comparisons. During the third stage, the collected data were synthesized using the ANP SuperDecisions software. Finally, the synthesized results from the ANP SuperDecisions software were used to develop the decision support framework. The research process is shown in Figure 2.

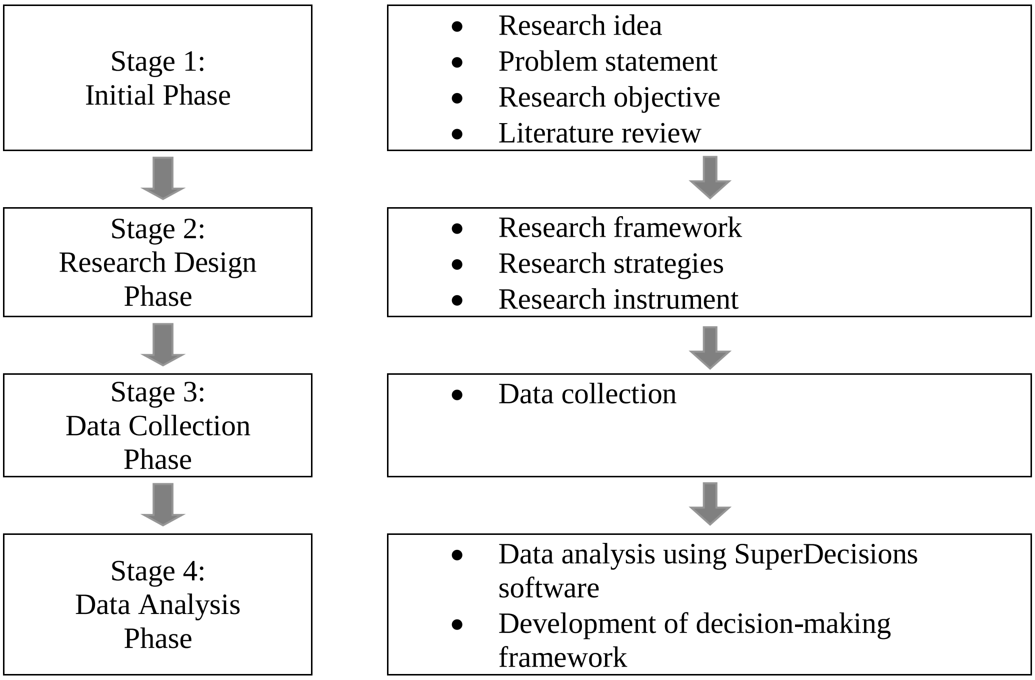

Figure 2 Research process of the study

Several methods often applied during the exploratory stage are interviews with experts in the area (Sarupria et al., 2019; Spiegel, 2017) and a review of secondary sources (Louw, 2018; Leonard, 2017). The exploratory stage in this study involved several semi-structured interviews with people who have knowledge and insight about EIA in mining industries. The main purpose of this exploratory stage was to determine relevant criteria for the EIA in bauxite mining industries.

Quantitative data collection activities commenced after the survey instrument was finalized. Research data were collected through the distribution of the survey instrument to the regulators in the Department of Environment (DOE), Malaysia. The selected regulators were those who oversee EIA approvals and subject experts, known as DOE registered EIA consultants in Malaysia. Several academicians and the public were also included in this study to analyze different opinions on criteria weightage and ranking. Respondents in this research were chosen by considering their understanding of EIA for mining industries.

The EIA consultants selected to identify the clusters of the ANP influence network were from the fields of general environment, ecology, and socio-economic affairs. As for the regulators, the position of Director or Assistant Director for the EIA department in DOE Putrajaya headquarters and DOE Pahang State were selected for the interviews and questionnaire survey. Table 1 provides a summary of the EIA experts from relevant subject areas, regulators, academicians and the public who were selected as respondents.

Table 1
List of respondents for the study

Category	Subject Area/ Location	Number of respondents
Expert – EIA Consultants	General environment (air, noise, and water)	5
	Socio-economic affairs	3
	Ecology	3
Academics	Environment, socioeconomic and ecology	3
Public	Local MP representative, business owner and the village head	3
Regulator – DOE Officer	DOE Putrajaya and Pahang	5
Total respondents		22

As shown in Table 1, a total of 22 respondents participated in this study to make pairwise comparisons among the clusters and their constituent elements. The research questionnaire dealt with ten criteria divided into three clusters as shown in Figure 3. These ten criteria were selected based on the interviews conducted and also based on the literature review.

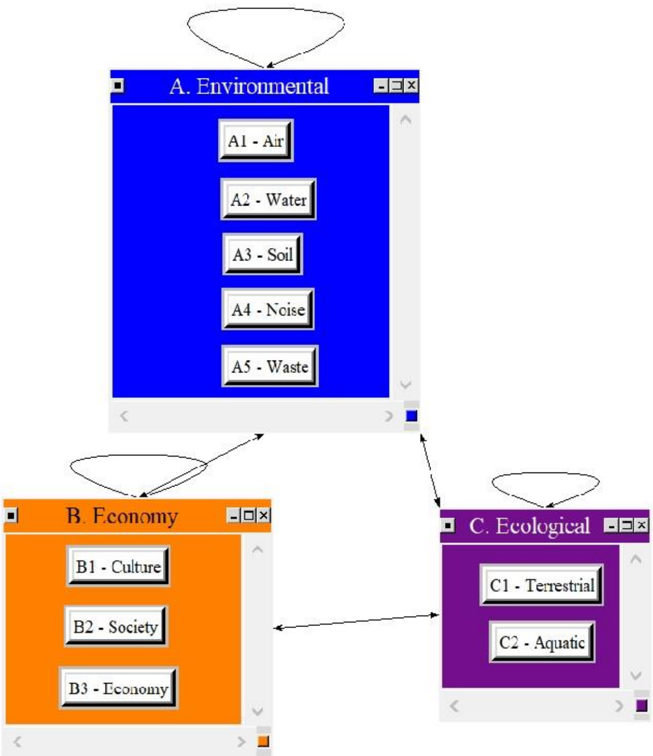

Figure 3 Research conceptual model – Influence network

ISSN 1936-6744
https://doi.org/10.13033/ijahp.v13i1.851

For each criterion, the components were compared according to their relative impact or absence of impact on each component at the top of the supermatrix. This enabled the development of priorities to weigh the block matrices of eigenvector columns under that component in the supermatrix. Weighing the components of the unweighted supermatrix resulted in a stochastic matrix called the weighted supermatrix. Saaty (2005) emphasized that the supermatrix needs to be stochastic to obtain significant limiting priorities.

The supermatrix was reduced to a matrix before taking the limit, whereby each of its columns sums to unity, thus, resulting in a matrix called a column stochastic matrix. Each column in the supermatrix sums to the number of its non-zero eigenvectors. That is why clusters were compared before conversion into a stochastic matrix. The clusters were compared according to their impact on each other with respect to the general control criterion previously considered. In the case of several control criteria, the process was repeated several times for a decision problem, for each control criterion. For each control criterion, several comparison matrices were needed. Each matrix was used to compare the influence of all the clusters on a given cluster to which they were connected. This resulted in an eigenvector that influenced all the clusters. A vector had zero components when there was no influence. The priority of a component was used to weigh all the elements in the block of the supermatrix that corresponded to the elements of both the influencing and the influenced cluster. The outcome was a stochastic supermatrix.

Once the priority weight for each criterion was determined using a pairwise comparison matrix, the priority results were used to develop a decision-making framework. This framework assisted the authorities in their decision-making process pertaining to the bauxite mining project. The determination of priorities is a one-time process, but once established, it may be generalized and used for all subsequent bauxite mining evaluations. The next step is to develop a simplified assessment form for decision makers to evaluate the alternatives.

As this research focused on EIA for the bauxite mining industry, the goal of this research is an EIA report approval. The decision is whether to reject, approve or approve with a condition. Baseline monitoring data and assessment results from EIA consultants can be incorporated into the model. An absolute measurement technique was used to rate each criterion. Each criterion was evaluated by measuring the significance of the criteria intensities. Finally, the overall acceptability of the bauxite mining project was calculated.

4. Results and discussion

4.1 Demographic profile of the respondents

As mentioned in the previous section, the present study involved 22 respondents belonging to six demographic categories including EIA consultants specializing in the general environment, EIA consultants specializing in the socio-economic sector, EIA consultants specializing in ecology, DOE enforcement officers, academicians, and members of the public residing close to the bauxite mining sites. After continuous follow-up for six months, only 22 respondents, or 44% of the 50 e-mails sent out responded by returning the survey questionnaires. Many declined on account of their tight schedule, traveling program or refinery turn-around. Table 2 provides detailed information on the respondents' demographic profile. Twelve of the respondents had more than 10 years of work experience, while the rest had six to 10 years of work

ISSN 1936-6744
https://doi.org/10.13033/ijahp.v13i1.851

experience. As for the respondents' qualifications, 10 individuals were subject specialists with Doctorate degrees (PhD), eight respondents held a Master's degree, and the remaining four held Bachelor's degrees.

Table 2
Detailed information on respondents' profiles

Demographic Profile	No. of respondents	Percentage
Category of respondents:		
DOE officer	5	22.7
EIA Consultant – Environment	5	22.7
EIA Consultant – Socioeconomic	3	13.6
EIA Consultant - Ecology	3	13.6
Academic	3	13.6
Public	3	13.6
Education Level:		
Bachelors	4	18.2
Masters	8	36.4
PhD	10	45.5
Position:		
General Manager & Above	11	50.0
Senior Manager	5	22.7
Manager	4	18.2
Others	2	9.1
Type of Employment:		
Public Sector	5	22.7
Private Sector	11	50.0
Self – Employment	3	13.6
Others	3	13.6
Work Experience:		
6 to 10 years	10	45.5
More than 10 years	12	54.5
Total	22	100

4.2 Model construction

Ten criteria were identified and grouped into three clusters according to their common properties. The definitions of these ten criteria are provided in Table 3 and the three clusters are environmental, economic, and ecological. Through the identification of dependencies among all the components, the inter-relationships structure appears as an influential network. Figure 4 depicts the ANP influence network.

ISSN 1936-6744
https://doi.org/10.13033/ijahp.v13i1.851

Table 3
Definition of the ten criteria

Criteria	Definition
Air	Air quality in Malaysia is reported as the API (Air Pollutant Index). Four of the index's pollutant components are carbon monoxide, ozone, nitrogen dioxide, and sulphur dioxide.
Water	Water quality in Malaysia is reported as the WQI (Water Quality Index). It is calculated based on six of the index's pollutant components, namely Dissolve oxygen (DO), Biological Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Ammoniacal Nitrogen (NH3-N), Suspended Solid (SS), and pH.
Soil	Chemical residue
Noise	Decibel of noise
Waste	Rubbish and construction waste
Culture	Cultural heritage destruction and landscape demolition
Society	Public facility/transportation inaccessibility and community disconnection
Economy	Economic activity disturbance
Terrestrial	Threat to animals, plants, and endangered species
Aquatic	Threat to animals living in water

ISSN 1936-6744
https://doi.org/10.13033/ijahp.v13i1.851

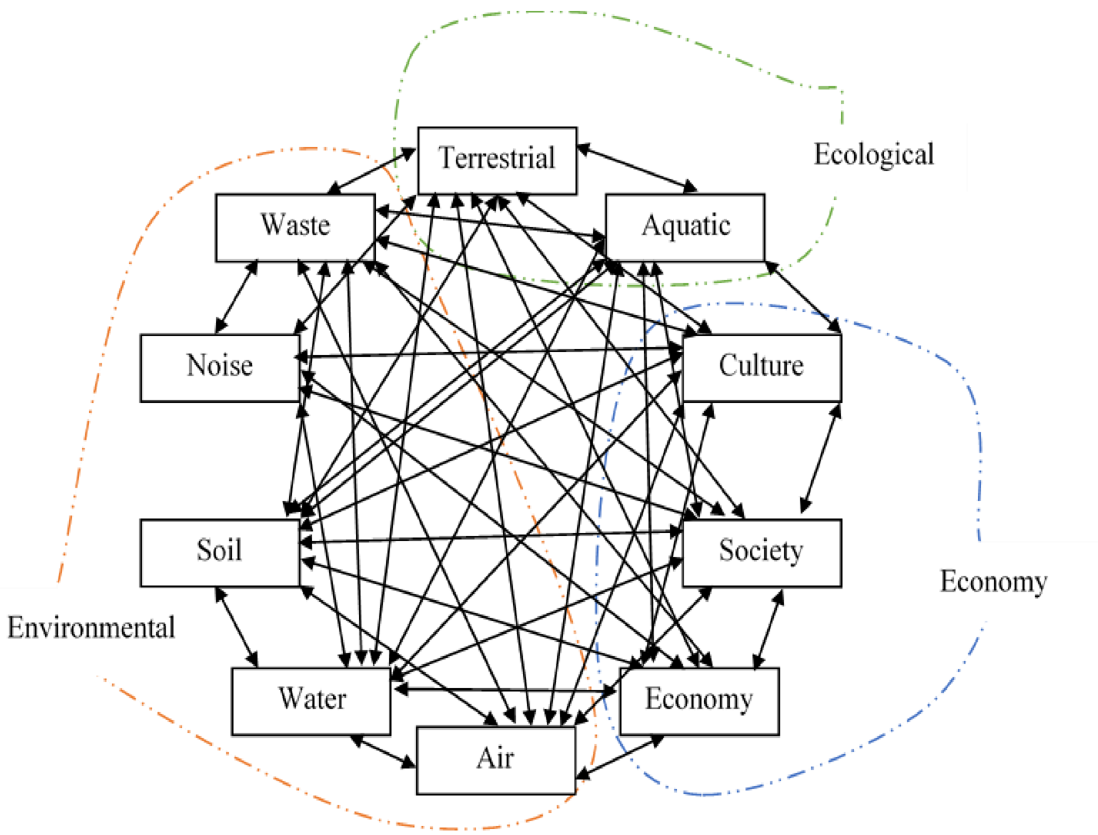

Figure 4 ANP influence network

In Figure 4, the arrow that points from water to soil denotes that soil pollution is influenced by water pollution. This is true especially during heavy rainfall and the monsoon season. Surface water runoff often carries many pollutants and dirt across the soil which causes soil pollution. Meanwhile, the presence of a double-headed arrow between water and soil further shows a two-way influence between soil and water. This indicates that soil pollution may also influence water pollution. Soil from mining sites may enter the water and cause water pollution. Note that no arrow appears between soil and noise. This shows that soil pollution does not influence noise pollution, and vice versa. All the remaining arrows in the network were established following the same procedure. Experts' opinions were sought to determine and confirm the dependence relationships among the criteria.

4.3 Determination of criteria weights

The next stage of the ANP process is to form pairwise comparison matrices for the clusters and criteria. A pairwise comparison matrix was constructed for each cluster and all the respective items it influenced. Each criterion was compared with another criterion as per its relative influence on the main criterion. The relative importance was then arranged into a matrix, and the respondents were asked to choose the relative influence among the criteria, with respect to the chosen criterion. Next, respondents judged the relative importance with respect to the prioritized key criteria, such as air, water, soil, noise, waste, culture, society, economic, terrestrial, and aquatic. In pairwise comparison matrices, Saaty's 1-9 scale was used to express the extent to which one element is dominant over another according to the criterion/property to which they were compared (Saaty, 2005).

Once the comparison of clusters was completed, each criterion that interlinked was further compared with respect to the selected key criteria. Table 4 presents a summary of 10 completed pairwise comparison matrices for all the key criteria by 22 respondents (geometric mean value of 22 respondents). Each matrix represents one of the ten key criteria in this study. Some rows and columns were left blank as there is no relationship between the criteria.

In the air pollution matrix (top left of Table 4), the first comparison between water pollution and soil pollution showed water pollution as little more than equally important as soil pollution, with an intensity of importance of 1.43. This was followed by water and waste at 2.19, and soil and waste at 2.00. The air pollution matrix is a combination of results from three clusters (environment, economy, and ecology).

The next key criterion, water pollution (top right corner of Table 4), has a geometric mean influence with respect to water pollution of 1.64 for air over soil, 2.46 for air over waste, 1.52 for soil over waste, 2.13 for economy over culture, and 1.00 for terrestrial over aquatic. All the remaining eight pairwise comparison matrices in Table 4 were established following the same procedure. All pairwise comparison matrices in Table 4 showed a CR value of less than 0.1, thus, confirming that the pairwise comparisons or judgements given by all the respondents were consistent and acceptable (Asadabadi et al., 2019). After formation of pairwise comparison matrices, the priority values and ranks of the bauxite mining impacts were established using the SuperDecisions software.

The determination of the overall priority values or weightages of the criteria is not straight forward in the ANP as some criteria have more than two dependencies or interlink effects. Therefore, in this ANP application, two more matrices were established, namely a limit matrix (Table 5) and the weighted supermatrix (Table 6). Cells that show a mean value of 0.0 denote the absence of a relationship or dependences among the criteria.

Table 4
Pairwise comparison matrices for the ten criteria

AIR	WTR	SOL	WST	CLT	ECM	TRL	AQU
WTR	1	1.43	2.19				
SOL		1	2.00				
WST			1				
CLT				1	0.69		
ECM					1		
TRL						1	0.54
AQU							1

WTR	AIR	SOL	WST	ECM	CLT	TRL	AQU
AIR	1	1.64	2.46				
SOL		1	1.52				
WST			1				
ECM				1	2.13		
CLT					1		
TRL						1	1.00
AQU							1

SOL	AIR	WTR	WST	CLT	ECM	TRL	AQU
AIR	1	1.57	2.89				
WTR		1	2.03				
WST			1				
CLT				1	0.61		
ECM					1		
TRL						1	1.33
AQU							1

WST	AIR	WTR	SOL	CLT	ECM	TRL	AQU
AIR	1	1.06	0.71				
WTR		1	0.59				
SOL			1				
CLT				1	0.40		
ECM					1		
TRL						1	1.29
AQU							1

CLT	AIR	WTR	SOL	NOS	WST	SCY	ECM	TRL	AQU
AIR	1	0.69	1.08	1.43	1.04				
WTR		1	1.67	1.84	1.38				
SOL			1	1.29	0.88				
NOS				1	0.81				
WST					1				
SCY						1	0.83		
ECM							1		
TRL								1	1.29
AQU									1

SCY	AIR	WTR	SOL	NOS	WST	CLT	ECM	TRL	AQU
AIR	1	0.96	1.87	2.12	1				
WTR		1	1.87	2.52	1.01				
SOL			1	1.14	0.60				
NOS				1	0.59				
WST					1				
CLT						1	0.45		
ECM							1		
TRL								1	1.76
AQU									1

ECM	AIR	WTR	SOL	NOS	WST	CLT	SCY	TRL	AQU
AIR	1	0.96	1.41	2.12	1.41				
WTR		1	1.26	1.93	1.33				
SOL			1	1.85	1.38				
NOS				1	0.74				
WST					1				
CLT						1	0.64		
SCY							1		
TRL								1	2.95
AQU									1

TRL	AIR	WTR	SOL	NOS	WST	SCY	CLT	ECM
AIR	1	1.20	1.20	2.52	1.24			
WTR		1	1.44	2.56	1.30			
SOL			1	2.82	1.27			
NOS				1	0.75			
WST					1			
SCY						1		1.05
CLT						1	1	0.85
ECM								1

AQU	AIR	WTR	SOL	NOS	WST	CLT	SCY	ECM
AIR	1	0.90	1.44	2.41	0.99			
WTR		1	2.04	2.97	1.43			
SOL			1	2.61	1.17			
NOS				1	0.73			
WST					1			
CLT						1	0.80	0.99
SCY							1	1.40
ECM								1

NOS	ECM	CLT
ECM	1	1.01
CLT		1

Legend: *AIR* = Air, *WTR* = Water, *SOL* = Soil, *NOS* = Noise, *WST* = Waste, *CLT* = Culture, *SCY* = Society, *ECM* = Economic, *TRL* = Terrestrial and *AQU* = Aquatic

Table 5
Limit matrix for the clusters and criteria

	Air	Water	Soil	Noise	Waste	Culture	Society	Economic	Terrestrial	Aquatic
Air	0.10313	0.10313	0.10313	0.10313	0.10313	0.10313	0.10313	0.10313	0.10313	0.10313
Water	0.12064	0.12064	0.12064	0.12064	0.12064	0.12064	0.12064	0.12064	0.12064	0.12064
Soil	0.11515	0.11515	0.11515	0.11515	0.11515	0.11515	0.11515	0.11515	0.11515	0.11515
Noise	0.03499	0.03499	0.03499	0.03499	0.03499	0.03499	0.03499	0.03499	0.03499	0.03499
Waste	0.11963	0.11963	0.11963	0.11963	0.11963	0.11963	0.11963	0.11963	0.11963	0.11963
Culture	0.05868	0.05868	0.05868	0.05868	0.05868	0.05868	0.05868	0.05868	0.05868	0.05868
Society	0.02292	0.02292	0.02292	0.02292	0.02292	0.02292	0.02292	0.02292	0.02292	0.02292
Economic	0.03877	0.03877	0.03877	0.03877	0.03877	0.03877	0.03877	0.03877	0.03877	0.03877
Terrestrial	0.18304	0.18304	0.18304	0.18304	0.18304	0.18304	0.18304	0.18304	0.18304	0.18304
Aquatic	0.20304	0.20304	0.20304	0.20304	0.20304	0.20304	0.20304	0.20304	0.20304	0.20304

Table 6
Weighted supermatrix for the clusters and criteria

	Air	Water	Soil	Noise	Waste	Culture	Society	Economic	Terrestrial	Aquatic
Air	0.00000	0.06735	0.05971	0.00000	0.09513	0.06355	0.07006	0.10379	0.18641	0.16389
Water	0.16069	0.00000	0.14719	0.00000	0.20123	0.17970	0.12037	0.10251	0.11310	0.12346
Soil	0.15843	0.26541	0.00000	0.00000	0.18582	0.08550	0.07929	0.13283	0.08711	0.08193
Noise	0.00000	0.00000	0.00000	0.00000	0.00000	0.06742	0.08669	0.08628	0.06219	0.07055
Waste	0.16305	0.14941	0.27526	0.80380	0.00000	0.08627	0.12602	0.05703	0.03363	0.04261
Culture	0.06270	0.06562	0.06562	0.10939	0.07225	0.00000	0.05601	0.05727	0.04739	0.05958
Society	0.00000	0.00000	0.00000	0.00000	0.00000	0.08726	0.00000	0.06028	0.04739	0.03343
Economic	0.05500	0.05208	0.05208	0.08681	0.04544	0.03030	0.06155	0.00000	0.02278	0.02454
Terrestrial	0.15465	0.18616	0.20007	0.00000	0.14198	0.14194	0.20001	0.27014	0.00000	0.40001
Aquatic	0.24548	0.21398	0.20007	0.00000	0.25815	0.25807	0.20001	0.12987	0.40001	0.00000

4.4 Ranking based on all the respondents

This section presents the priorities and corresponding ranks of the ten criteria in the EIA for the bauxite mining industry (Table 7). To generate the priorities, all the respondents were considered together using the geometric means of the individual judgements provided by them. Air pollution ranked first with a normalized priority value of 0.1659 or 16.6%, followed by water pollution at 15.5%, and soil pollution at 14.0%. In combination, these three criteria accounted for 46.1%, and easily outranked the economic potential which was prioritized at only 12.0%. This finding was similar to Ataei et al. (2016) where the researcher used the matrix method for an EIA for coal mining in Iran. The findings of Ataei et al. (2016) also show that the environmental criteria have a high impact at 49.1 %.

Table 7
Priorities and ranks of the ten criteria

Criteria	Priority Value	Rank
Air	0.1659	1
Water	0.1549	2
Soil	0.1397	3
Economic	0.1197	4
Waste	0.1157	5
Terrestrial	0.0882	6
Culture	0.0766	7
Aquatic	0.0719	8
Society	0.0394	9
Noise	0.0279	10

4.5 Development of decision-making framework

A decision-making framework was developed using the priority weights determined by the ANP. Three respondents completed the environmental impact assessment form for the Kuantan bauxite mining project and the geometric means were used to obtain the intensity of impact/pollution. Table 8 summarizes the results for the intensity of impact/pollution for each criterion as rated by the respondents. The intensities of impact/pollution were rated as very low, low, medium, high, and very high. Each of these ratings corresponds to a score of 50%, 26.2%, 13.3%, 6.7%, and 3.6%, respectively. The higher the intensity of impact/pollution, the lower the corresponding score. If one gives the best rating of very low impact/pollution for all the criteria, then the highest total score for the project would be 50 points.

The respondents rated air pollution as very high significance and water pollution as high significance. Soil pollution and negative economic impact were rated as medium significance, while waste generation, aquatic impact, and noise pollution were rated as low significance. Finally, the impact on terrestrial, culture, and society categories was rated as very low significance. The results showed that the overall bauxite mining project at Kuantan scored 21.48 points out of the highest possible 50 points. Hence, this score represents an overall project score of 41.92%.

ISSN 1936-6744
https://doi.org/10.13033/ijahp.v13i1.851

Table 8
Framework of intensity of impact/pollution for each criterion

Criteria	Priority	Impact/ Pollution Level					Score (point)	Overall Project Score (%)	Individual Criteria Score (%)
		Very low	Low	Medium	Slightly High	High			
		0.501	0.262	0.133	0.067	0.036			
Air	0.1659					√	0.60	1.19	7.2
Water	0.1549				√		1.04	2.08	13.4
Soil	0.1397			√			1.86	3.72	26.5
Economic	0.1197			√			1.59	3.18	26.5
Waste	0.1157		√				3.03	6.06	52.3
Terrestrial	0.0882	√					4.42	8.84	100.0
Culture	0.0766	√					3.84	7.68	100.0
Aquatic	0.0719		√				1.88	3.77	52.3
Society	0.0394	√					1.97	3.95	100.0
Noise	0.0279		√				0.73	1.46	52.3
Score	1.00						20.96/ 50	41.92	

5. Limitations and recommendations for future research

The study would have been more reliable if higher level government officials such as the Director of the Department of Environment, Director of Minerals and Geoscience Department Malaysia, and Minister of Water, Land and Natural Resources of Malaysia were involved. Efforts were made to interview these high-ranking officials; however, due to their tight schedules, the interview sessions were conducted with their juniors. This study would have provided a more balanced and complete view on bauxite mining if only high level officials had been interviewed. Their opinions and feedback would have been more relevant as they are the actual decision makers for bauxite mining issues.

The ANP can be used as a final decision-making model by including some alternatives using baseline data or the estimated value for each criterion. The decision-making problem in EIA is whether to approve or reject the proposed project. Since bauxite mining has huge economic potential, one will choose to approve the project. Therefore, most approvals are given together with special requirements to manage issues concerning significant criteria such as air, water, and soil pollution. However, baseline data are not available for bauxite mining in Malaysia as no EIA had been done for bauxite mining. Hence, this study was unable to include alternatives and baseline data.

After receiving the responses from the respondents, it is evident that pollution is a major problem even though actions have been taken to alleviate it. This research only contributes to the prioritization of the significant environmental criteria specific to bauxite mining. As for future research, attention should be directed towards the development of Environmental Management Plans and Standard Operating Procedures (SOP) to reduce the identified significant environmental impact of bauxite mining activities. With air, water, and soil pollution being major concerns, a mechanism to reduce the impacts of these factors should be studied and documented. The enforcement agency such as DOE officers should be more active in managing the impacts.

Future research should also focus on the qualitative part of the research, whereby, high-ranking government officials who oversee decision-making pertaining to EIA should be interviewed to better understand government policy and planning. Further, the ANP analysis should be expanded to include sub-criteria relevant to the environmental and socio-economic criteria. Final decisions such as to approve, reject, or approve with conditions should be incorporated as alternatives in the ANP model. Scientific data such as actual air, water, and soil monitoring results should also be included in the ANP analysis.

6. Conclusion

This study highlighted the repercussions of bauxite mining on the environment through the impacts of the environment, ecology, and economy. Ten relevant criteria belonging to three clusters were identified through the literature survey and further confirmations were obtained from subject experts. The environmental cluster consisted of the following five criteria: air, water, soil, noise, and waste. The economic cluster contained three criteria which are the economy, society, and culture. Meanwhile, the ecological cluster was made up of the terrestrial and aquatic criteria.

The priorities of these criteria are important for decision-making in EIA. The ANP analysis ranked air pollution as the first priority at 16.6%, followed by water pollution at 15.5%, soil pollution at 14.0%, economic impact at 12.0%, waste generation at 11.6%, terrestrial impact at 8.8%, cultural impact at 7.7%, aquatic impact at 7.2%, society at 3.9 %, and finally noise at 2.8%. Indirectly, these values show the amount of effort needed to manage each component to meet the economic benefit of the bauxite mining project. Air, water, and soil pollution are the three highest ranking criteria that require standard operating procedures or a management plan to control and manage the possible detrimental effects that may result from bauxite mining activities.

The priority values for the ten significant criteria derived from the ANP were used to develop a framework that is suitable to support the overall decision-making process concerning the EIA of the bauxite mining industry. The framework supports both the qualitative and quantitative data. Thus, it allows decision-makers to approve, reject, or approve with conditions different bauxite mining projects. Based on the testing done for decision-making framework developed in this study, the bauxite mining projects in Kuantan only scored 41.92%. This result suggests that the decision on bauxite mining in Kuantan should be rejected. However, considering the positive economic benefit to the Pahang state government and the residents, the decision maker may choose to approve the project with conditions.

Finally, this study pioneers the use of the ANP to rank the weightage of the environmental impacts caused by bauxite mining in Malaysia. The primary contribution of this study is the development of a network model that prioritizes bauxite mining impacts, criteria, and clusters using the ANP. This study sets a benchmark for prioritizing the significance of environmental impacts in bauxite mining operations.

ISSN 1936-6744
https://doi.org/10.13033/ijahp.v13i1.851

REFERENCES

Abba, A. H., Noor, Z. Z., Yusuf, R. O., Din, M. F. M. D., & Hassan, M. A. A. (2013). Assessing environmental impacts of municipal solid waste of Johor by analytical hierarchy process. *Resources, Conservation and Recycling*, *73*(April), 188 - 196. Doi: https://doi.org/10.1016/j.resconrec.2013.01.003

Abdullah, N. H., Mohamed, N., Sulaiman, L. H., Zakaria, T. A., & Rahim, D. A. (2016). Potential health impacts of bauxite mining in Kuantan. *Malays Journal of Medical Science*, *23*(3), 1-8.

Aminu, M., Matori, A. N., Yusof, K. W., Malakahmad, A., & Zainol, R. B. (2017). Analytic network process (ANP)-based spatial decision support system (SDSS) for sustainable tourism planning in Cameron Highlands, Malaysia. *Arab Journal of Geoscience*, *10*(286), 1-20. Doi: https://doi.org/10.1007/s12517-017-3067-0

Asadabadi, M. R., Chang, E., & Saberi, M. (2019). Are MCDM methods useful? A critical review of Analytic Hierarchy Process (AHP) and Analytic Network Process (ANP). *Cogent Engineering*, *6*(1), 1-11. Doi: https://doi.org/10.1080/23311916.2019.1623153

Ataei, M., Asr, E. T., Khalokakaie, R., Ghanbari, K., & Mohammadi, M. R. T. (2016). Semi-quantitative environmental impact assessment and sustainability level determination of coal mining using a mathematical model. *Journal of Mining & Environment*, *7*(2), 185-193.

Beltran, P. A., Melon, M. G., & Valera, J. M. (2017). How to assess stakeholders' influence in project management? A proposal based on the Analytic Network Process *International Journal of Project Management*, *35*(3), 451-462. Doi: https://doi.org/10.1016/j.ijproman.2017.01.001

Bond, A., & Morrison, A. S. (2018). *Environmental impact assessment and the quest for sustainable mining* (Vol. Part 2). New York: Routledge.

Carvalho, F. P. (2017). Mining industry and sustainable development: time for change. *Food and Energy Security*, *6*(2), 61-77.

CMO. (2016). Bauxite in Malaysia: Will the ban bring relief? by Clean Malaysia Organization (CMO). Retrieved on: December 11, 2020, from http://cleanmalaysia.com/2016/01/26

Daim, N. (2019). 6-month trial period for new Bauxite mining SOP. *New Straits Times*. Retrieved on: January 17, 2021, from https://www.nst.com.my/news/nation/2019/11/535940/6-month-trial-period-new-bauxite-mining-sop

Dell'Anna, F., Bottero, M., Becchio, C., Corgnati, S.P., & Mondini, G. (2020). Designing a decision support system to evaluate the environmental and extra-economic performances of a nearly zero-energy building. *Smart and Sustainable Built Environment*, 9(4), 413-442. Doi: https://doi.org/10.1108/sasbe-09-2019-0121

DOE. (2016). EIA Order 2015 by Department of Environment (DOE) Malaysia. Retrieved on: August 26, 2020, from https://www.doe.gov.my/portalv1/en

DOSM. (2017). Department of Statistics Malaysia (DOSM). Retrieved on: April 5, 2020, from http://*www.dosm.gov.my*

Faradiella, M. K., Rahman, M. S. A., Madzin, Z., Jusop, S., Yusuff, F. M., & Ariffin, M. (2016). The occurrence and potential ecological risk assessment of bauxite mine-impacted water and sediments in Kuantan, Pahang, Malaysia. *Environmental Science Pollution Research, 24*(1), 1-16. Doi: https://doi.org/10.1007/s11356-016-7814-7

Garcia, L. C., Ribeiro, D. B., Roque, F. D. O., & Quintero, J. M. O. (2016). Brazil's worst mining disaster: corporations must be compelled to pay the actual environmental costs. *Ecological Applications, 27*(1), 5-9. Doi: https://doi.org/10.1002/eap.1461

Hadiwijaya, N. A., Hamdani, H., Syafrianto, A., & Tanjung, Z. (2018). The decision model for selection of tourism site using analytic network process method. *International Journal of Intelligent Systems and Applications, 9*(September), 23-31. Doi: https://doi.org/10.5815/ijisa.2018.09.03

Hamida, A., Alsudairi, A., Alshaibani, K., & Alshamrani, O. (2020). Environmental impacts cost assessment model of residential building using an artificial neural network. *Engineering, Construction and Architectural Management*, Vol. ahead-of-print No. Doi: https://doi.org/10.1108/ECAM-06-2020-0450

Harun, N., & Samat, N. (2016). GIS-based multicriteria evaluation approach in planning tourism development sites in environmentally sensitive areas. *SHS Web of Conferences, 23*(02001), 1-16. Doi: https://doi.org/10.1051/shsconf/20162302001
Huang, I. B., Keisler, J., & Linkov, I. (2011). Multi-criteria decision analysis in environmental sciences: Ten years of applications and trends. *Science of the Total Environment, 409*(1), 3578–3594. Doi: https://doi.org/10.1016/j.scitotenv.2011.06.022

Jain, R. K., Cui, Z. C., & Domen, J. K. (2016). *Environmental impact of mining and mineral processing*. Oxford, UK Butterworth-Heinemann.

Jamal, A., Yadav, H. L., & Pandey, S. S. (2015). Heavy metals from acid mine drainage in coal mines-a case study. *European Journal of Advances in Engineering and Technology, 2*(8), 16-20.

JMG. (2018). Malaysian Minerals Production for 2016 by Minerals and Geoscience Department (JMG) Malaysia. Retrieved on: October 22, 2019, from http://www.data.gov.my/data/ms_MY/dataset/malaysia-minerals-production Doi: https://doi.org/10.7186/bgsm51200501

Kadoic, N., Divjak, B., & Redep, N. B. (2019). Integrating the DEMATEL with the analytic network process for effective decision-making. *Central European Journal of Operations Research, 27*(3), 653–678. Doi: https://doi.org/10.1007/s10100-018-0601-4

Kaya, T., & Kahraman, C. (2011). An integrated fuzzy AHP–ELECTRE methodology for environmental impact assessment. *Expert Systems with Applications, 38*(7), 8553-8562. Doi: https://doi.org/10.1016/j.eswa.2011.01.057

Kheybari, S., Rezaie, F. M., & Farazmand, H. (2020). Analytic network process: An overview of applications. *Applied Mathematics and Computation, 367*(February), 124780. Doi: https://doi.org/10.1016/j.amc.2019.124780

Lee, K. Y., Ho, L. Y., Tan, K. H., Tham, Y. Y., Ling, S. P., Qureshi, A. M., . . . Nordin, R. (2017). Environmental and occupational health impact of bauxite mining in Malaysia: a review. *International Medical Journal Malaysia, 16*(2), 137-150.
Leena, S., Thomas, E., Elena, K., Korchak, E., Vigdis, N., & Gregory, A. P. (2017). Social impacts of the "glocal" mining business: case studies from Northern Europe. *Mineral Economics*, *30*(1), 31-39. Doi: https://doi.org/10.1007/s13563-016-0092-5

Leonard, L. (2017). Examining environmental impact assessments and participation: the case of mining development in Dullstroom, Mpumalanga, South Africa. *Journal of Environmental Assessment Policy and Management, 19*(1), 1750002(1-25). Doi: https://doi.org/10.1142/s1464333217500028

Liu, K. F. R., & Lai, J.-H. (2009). Decision-support for environmental impact assessment: A hybrid approach using fuzzy logic and fuzzy analytic network process. *Expert Systems with Applications, 36*(3), 5119-5136. Doi: https://doi.org/10.1016/j.eswa.2008.06.045

Lodhia, S. K. (Ed.) (2018). *Mining and sustainable development*. New York: Routledge.

Louw, L. (2018). *Addressing critical water and waste issues in Environmental Impact Assessment (EIA): the case of coal mining in South Africa.* (Masters in Environmental Management). North-West University, Potchefstroom Campus. (22142762).

Mahmud, A. R. (2016). *Guideline on Environmental Impact Assessment in Malaysia*. Kuala Lumpur: Department of Environment (DOE), Malaysia

Malaysiakini. (2019). Kuantan MP wants ministry to disclose SOP on Bauxite mining. *Malaysiakini*. Retrieved On: January 2020, from https://www.malaysiakini.com/news/464783

MCOM. (2017). Malaysian Chamber of Mines (MCOM). Retrieved on: April 5, 2018 from http://malaysianminerals.com

Povera, A. (2019). Bauxite SOP finalised, enforcement starts today. *New Straits Times*. Retrieved on: January 17, 2020, from https://www.nst.com.my/news/nation/2019/09/518862/bauxite-sop-finalised-enforcement-starts-today-nsttv

Rohan, J. L., & Samant, J. S. (2012). *Studies on the impact of bauxite mining activities on environment in Kolhapur district.* Paper presented at the Proceeding of International Conference SWRDM-2012, Department of Environmental Science, Shivaji University, Kolhapur. Doi: https://doi.org/10.26634/jfet.14.4.16069

Saaty, T. L. (2005). *Theory and applications of the analytic network process: decision making with benefits, opportunities, costs, and risks*. Pittsburgh: RWS Publications.

Saffari, A., Ataei, M., Sereshki, F., & Naderi, M. (2019). Environmental impact assessment (EIA) by using the Fuzzy Delphi Folchi (FDF) method (case study: Shahrood cement plant, Iran). *Environment, Development and Sustainability*, *21*(2), 817-860. Doi: https://doi.org/10.1007/s10668-017-0063-1

Samah, M. A. A., Manaf, L. A., & Zukki, N. l. M. (2010). Application of AHP model for evaluation of solid waste treatment technology. *International Journal of Engineering Techsci, 1*(1), 35-40.

Sarupria, M., Manjare, S. D., & Girap, M. (2019). Environmental impact assessment studies for mining area in Goa, India, using the new approach. *Environmental Monitoring and Assessment, 191*(1), 1-17. Doi: https://doi.org/10.1007/s10661-018-7135-z

Skuta, R., Kucerova, R., Pavelek, Z., & Dirner, V. (2017). Assessment of mining activities with respect to the environmental protection. *Acta Montanistica Slovaca, 22*(1), 79-93.

Solbar, L., & Keskitalo, E. C. H. (2017). A role for authority supervision in impact assessment? Examples from Finnish EIA reviews. *Arctic Review on Law and Politics, 8*(1), 52-72. Doi: https://doi.org/10.23865/arctic.v8.661

Spiegel, S. J. (2017). EIAs, power and political ecology: Situating resource struggles and the techno-politics of small-scale mining. *Geoforum, 87*(December), 95-107. Doi: https://doi.org/10.1016/j.geoforum.2017.10.010

Thorpe, C. (2015). Lateritic plateaus in the Northern Western Ghats, India; a review of bauxite mining restoration practices. *Journal of the Ecological Society, Special Section: Rocky Plateaus*, 25-44.

Tian, W., Bai, J., Sun, H., & Zhao, Y. (2013). Application of the analytic hierarchy process to a sustainability assessment of coastal beach exploitation: a case study of the wind power projects on the coastal beaches of Yancheng, China. *Journal of Environmental Management, 115*(1), 251-256. Doi: https://doi.org/10.1016/j.jenvman.2012.11.015

TMR. (2017). Mining sector could see silver lining ahead. *The Malaysian Reserve (TMR)*. Retrieved on: January 17, 2020, from https://themalaysianreserve.com/2017/03/31/mining-sector-could-see-silver-lining-ahead/ Doi: https://doi.org/10.1108/oxan-db251218

Toth, W., & Vacik, H. (2018). A comprehensive uncertainty analysis of the analytic hierarchy process methodology applied in the context of environmental decision making. *Journal of Multi-Criteria Decision Analysis, 25*(6), 142-161. Doi: https://doi.org/10.1002/mcda.1648

USGS. (2016). World alumina refinery and bauxite mine production and bauxite reserves by United States Geological Survey (USGS). Retrieved on: April 5, 2018, from https://www.usgs.gov/ Doi: https://doi.org/10.4135/9781412939591.n1177

Venkateswarlu, K., Nirola, R., Kuppusamy, S., Thavamani, P., Naidu, R., & Megharaj, M. (2016). Abandoned metalliferous mines: ecological impacts and potential approaches for reclamation. *Reviews in Environmental Science and Bio Technology*, *15*(2), 327–354. Doi: https://doi.org/10.1007/s11157-016-9398-6

Younes, M. K., Basri, N. E. A., Nopiah, Z. M., Basri, H., & Abushammala, M. F. M. (2015). Use of a combination of MRSS-ANP for making an innovative landfill siting decision model. *Mathematical Problems in Engineering*, 501, 381926 (Online). Doi: https://doi.org/10.1155/2015/381926