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Technological Role in the Development of Arsenic Contaminants in Minerals and Its Purification: Evidence from Industrial Organisations in Malaysia

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Abstract: *Arsenic is a naturally occurring metalloid that is commonly presented in sulfide minerals arsenopyrite, pyrite and galena. Despite the contribution of natural geological processes to background arsenic concentrations within the ecosystems, the level of technological and industrial activities causes the significant increase of arsenic mobilization to the soil, water, and to the atmosphere systems. The growth of mining activities, technologies of mineral extraction, and industry production have increased the debate on the issue of arsenic contamination and its impacts on the environment in the long run. It is thus necessary to know the technological factors that cause arsenic contamination as well as the purification processes that consume arsenic and so reduce its effects to be a sustainable environmental management.*

The processes applied in the extraction of minerals and the industry involve the use of technology that contributes significantly to the dispersion of arsenic. The mining procedures like open-pit and underground mining subject the minerals that contain arsenic to oxygen and water, which enhance oxidation reactions that liberate arsenic to the environment around them. Other technologies such as mineral processing such as crushing, grinding, flotation, roasting and smelting phenomena enhance further mobility of arsenic through emissions, tailings disposal and chemical transformation processes. Arsenic is also contaminated through industrial processes like burning of coal, smelting and inappropriate waste disposal.

This paper examines the influence of technology in arsenic pollution, and also explores the mediating effect of the purifying ability of arsenic in obtaining sustainable results in the management of arsenic. The quantitative research design was applied based on the survey-related data gathered on 200 employees working in the mining and mineral processing sector as well as the industrial organisations in Selangor, Malaysia. The statistical tests were performed with the help of SPSS and the PROCESS macro by Hayes, with descriptive statistics, reliability test, correlation test, multiple regression test, and mediation test.

The results demonstrate that arsenic is a mineral type, mining methods, processing technology, industrial operations, and strategic management that have a large contribution to the sustainability of the arsenic management. The

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purification ability of arsenic is an important mediator variable between technological variables and sustainability effects, indicating that the purification technologies are highly important in terms of minimizing the risk of contamination. The paper adds value to the body of environmental management literature by proving that technological innovation and industrial governance and purification systems play a significant role in reducing the arsenic pollution and enhancing sustainable management of the environment.

Keywords: Arsenic Pollution, Mineral Treatment, Mining Technology, Purifying Ability, Environmental Management Sustainability.

Introduction

Incidents of arsenic in the minerals have become a major issue of environmental and human health concern especially in the areas where mining, mineral processing and industrial production activities are clustered. Arsenic is a naturally occurring metalloid that is widespread within the crust of the Earth, usually occurring with sulfide minerals (i.e., arsenopyrite ($FeAsS$), pyrite (FeS_2), and galena (PbS). Although the occurrence of arsenic in natural geological structures does not typically pose a substantial environmental hazard, human-made activities are one of the primary contributors to its enhanced mobility and concentration in natural environments (Bundschuh et al., 2021). With the ever-increasing demand of mineral resources in the world, the extraction and processing methods have been exacerbating the emission of arsenic in the soil, water, and air.

Mining activities constitute one of the most important sources of contamination of arsenic. Open-pit and underground mining activities disrupt the geological formations containing arsenic that exposes the sulfide minerals to oxygen and water. This exposure causes oxidation reactions that discharge arsenic in the immediate environments using mechanisms like acid mine drainage. The acid mine drainage is the process of reaction of sulfide minerals with oxygen and water to form sulfuric acid that dissolves arsenic and delivers it to the system of groundwater and surface water (Qudrat-Ullah and Panthallor, 2020). They are long-lasting processes that continue to provide a lasting sickly impact on the environment even after the mining activities are stopped.

Besides the mining process, mineral processing technologies are also a source of dispersion of arsenic. Crushing and grinding are mechanical operations that create fine particulate matter that may have arsenic, capable of pollution of air and water resources. The chemical activities like flotation, roasting, and smelting further enhance the mobility of arsenic by converting arsenic into an unstable form or a gaseous condition. In the process of smelting, the arsenic can be emitted to the atmosphere in the form of arsenic trioxide vapor, which can subsequently be deposited in soil and water systems (Segura-Salazar and Brito-Parada, 2021). The tailings produced in mineral processing may have a large amount of arsenic and any form of storage or disposal of these materials may lead to the long-term pollution of the nearby ecosystems.

Arsenic contamination is also caused by industrial activities which are not related to mining and mineral processing. The arsenic-containing particulate matter is emitted by the combustion processes in coal-fired power plants, and the manufacturing and smelting works release the arsenic-containing emissions and waste products (Wu et al., 2023). The cumulative environmental contamination is manifested by the mining, processing, and manufacturing activities of most industrial regions. Arsenic has a high resistance to degradation and therefore, remediation is especially hard since arsenic has the ability to stay in soils, sediments, and ground water over a long period.

Arsenic contamination has significant environmental and health impacts on the well-being of the population. Prolonged exposure of drinking water to arsenic leads to various health effects, such as skin lesions, cardiovascular disease, neurological disorders, and various types of cancer (Ahmed et al., 2022). Arsenic pollution also impacts on the agricultural productivity through a decrease in soil fertility as well as suppressing the growth of plants. Arsenic concentration in the biosphere of aquatic ecosystems may cause the bioaccumulation and biomagnification of the elements in the food chains, endangering the biodiversity and stability of the ecosystem. Such effects indicate that proper technological and managerial remedies should be adopted to manage arsenic pollution.

Development in purification technologies also present encouraging prospects that can reduce the level of arsenic contamination. Adsorption and membrane filtration have become popular physical treatment procedures used to remove arsenic in contaminated water. The chemical treatment procedures, such as coagulation, precipitation, and oxidation, may also be used to convert arsenic to less toxic compounds, which can be eliminated with the help of filtration systems. The biological methods like bioremediation and phytoremediation involve the uptake or elimination of arsenic in polluted environments using microorganisms and plants (Mehdi et al., 2021). New technologies such as nanotechnology-based filtration systems and advanced oxidation processes have also been proven to be highly efficient in the removal and monitoring of arsenic (Thanigaivel et al., 2022). The implementation of these technologies is however subject to organisational capacity, technological infrastructure, and strategic management practices to be successfully implemented.

Environmental sustainability is very important in the management of industries through strategic management. The risks of arsenic contamination can be minimized by the effectual environmental management, purification technology investment, and adherence to environmental codes. Organisational structures which incorporate technological innovation coupled with environmental management strategies are at a better place to ensure sustainable results. Although the dangers of arsenic contamination are becoming more known, numerous industrial organisations struggle with the issues of technological expenses, legal regulations, and the inability to find state-of-the-art purification technologies.

Whereas past studies have looked at arsenic contamination in geological, environmental and toxicology perspectives, a smaller number of studies have explored technological and organisational aspects in determining purification capacity of arsenic in industries. It is imperative to understand the interaction of technological processes and strategic management practices to determine how they affect the outcomes of arsenic contamination to come up with sustainable environmental management frameworks.

This paper fills this research gap by discussing the technological contribution in the formation of arsenic contaminant in mineral and determining the intermediating effect of the ability to purify arsenic in order to achieve sustainable arsenic management results. The researcher is interested in the firms that are engaged in the mining, mineral processing and industrial processes in Selangor, Malaysia where mining and other industrial activities are still growing. This study helps to enrich the understanding of the industrial environmental management and pollution control literature by incorporating technological, environmental and organisational point of view. It is assumed that the findings will offer the understanding of how technological practices and purification powers can be enhanced to minimize the risks of contamination of arsenic and foster the industrial growth that is sustainable.

This study aims to:

1. Discuss technological issues which impact on arsenic pollution.
2. Test the importance of arsenic purification capacity.
3. Identify the correlation of technology effects and sustainable arsenic management consequences.

Literature Review

The arsenic contamination of minerals is a well examined phenomenon in the environmental science, mining engineering, popular health, and industrial management fields. According to the literature, geological process and human technology, especially mining, mineral processing, and industrial production systems are factors that contribute to arsenic contamination. This part is a review of the historical evolution of arsenic pollution, technology sources of the release of arsenic, purification technology, and the place of strategic management in sustainable arsenic management.

2.1 The historical development of arsenic contamination

Arsenic is a substance that has been identified as useful and hazardous. As history indicates, arsenic compounds were consumed in ancient societies as a form of medicine, colorants, make-up, and preservatives (Chenet et al., 2023; Alsukaibi, 2022). Although these were used, early societies knew little about the arsenic toxicity and arsenic environmental persistence.

The natural geological processes have been a contributor to arsenic presence in the ecosystem long ago. Arsenic is released into the soil and water systems due to volcanic activity, geothermal discharge and weathering of arsenic-bearing rocks (Morales-Simfors et al., 2020; Medunić et al., 2020). Arsenic contamination in ground water has long been reported in geothermal areas where there is a high activity of the geothermal sources.

Industrial Revolution was the turning point in the history of arsenic contamination. During the 18th and 19th centuries, the existing miners and smelters became very active; therefore, the level of arsenic in the environment increased considerably (Oliver et al., 2020; Manisalidis et al., 2020). Acid mine drainage turned into significant environmental problem which discharged arsenic to water systems and its immediate environment. In Europe and North America mining areas had been polluted long term and that continues today.

In the late 19 th and early 20 th centuries, arsenic was active in the agricultural and commercial use. Pesticides that contained arsenic were popularly used in crops, and the soil and water became contaminated (El-Ghiaty and El-Kadi, 2021). The exposure to arsenic was also a result of arsenic-treated wood and arsenic-containing pigments (Shooshtarian and Hosseini, 2021).

Arsenic pollution had become a worldwide health issue in the middle of the 20th century. In Bangladesh and the West Bengal, contamination of groundwater revealed millions of individuals to the chronic poisoning of arsenic (Saha and Rahman, 2020). This crisis resulted in more scientific studies, regulatory focus and international cooperation to resolve arsenic pollution (Browne & Raff, 2023).

The current regulatory reactions involve the drinking water standard of 10 µg/L arsenic concentration by the World Health Organization (Frisbie & Mitchell, 2022). Although these measures have been taken, the problem of arsenic pollution continues to be felt in all parts of the world because of the past pollution, the growth of industries and the technological constraints in solving the problem.

2.2 Arsenic Contamination by Technological means.

Technological activities that affect arsenic contamination in minerals are highly mining, mineral processing and industrial production. Arsenopyrite and pyrite are sulfide minerals, and their release is considered as the significant source of arsenic when they are disrupted during mining activities (Pikinini, 2022; Rahaman et al., 2021).

In arsenic mobilization, mining methods are very important. Large amounts of arsenic-containing rock are the subject of the environment in open-pit mining, enhancing oxidation reactions and the release of arsenic (Qudrat-Ullah and Panthallor, 2020). Seepage and exposure to minerals can also contaminate underground water source due to underground mining (Medunić et al., 2020).

The technology used in mineral processing also adds to arsenic dispersion. Crushing and grinding are some of the mechanical operations that produce dust particles with arsenic, and fluotation is one of the chemical operations that solubize arsenic (Segura-Salazar and Brito-Parada, 2021). Arsenic is emitted to the atmosphere through the process of roasting and smelting as arsenic trioxide vapor (Tang and He, 2024).

Non mining industrial activities are also the causes of arsenic contamination. The burning of coal contributes to the release of particulate matter that contains arsenic and disposal of industrial waste may also cause the introduction of arsenic into the soil and groundwater systems (Wu et al., 2023; Anand et al., 2021). All these technological processes enhance the mobility and the persistence of arsenic in the environment.

Strategic management practices affect the response of the organisations to the arsenic contamination threat. Contamination can be greatly reduced by environmental management systems and waste control policies, as well as by making investments in purification technologies (Dehkordi et al., 2024). The organisations that accommodate environmental sustainability in decision making are in a better position to handle the risks of arsenic.

2.3 Technologies of Arsenic purification.

Incorporations in technology have enhanced the capability of remediation of environment. Arsenic can be removed in the water systems by physical methods, including adsorption and membrane filtration (Zaimee et al., 2021). Arsenic has shown a good adsorption ability on activated carbon, metal oxides and zeolites.

Arsenic is transformed into less toxic and removable forms by chemical treatment methods such as coagulation, precipitation, and oxidation (Moreira et al., 2021). The techniques are typically employed in industrial water treatment systems.

Alternatives to chemical remediation are biological remediation techniques that are eco-friendly. The microorganisms are also utilized in the process of bioremediation to transform arsenic into a less harmful form and the plants in the process of phyto-remediation to absorb arsenic out of the soil and water (Mehdi et al., 2021; Irshad et al., 2021).

Nanotechnology-based adsorption materials, enhanced oxidation processes, and monitoring systems based on artificial intelligence are some of the emerging purification technologies (Thanigaivel et al., 2022; Gadgil et al., 2024). These technologies provide more efficiency and monitoring opportunities of arsenic contamination management.

In spite of technological advances, there are still implementation challenges. The cost is high, technical skills lack, and regulation gaps limit the use in most industrial areas (Khosravi-Darani et al., 2022). These issues underscore the significance of organisational purification ability in realisation of sustainable environmental results.

2.4 Research Gap

The available literature has been mainly centered in geology, environmental implications, and toxicology of the arsenic pollution in minerals and ecosystems. A large part of the literature that is published studies the natural occurrence of arsenic in the environment, the contamination of groundwater, health risks of people, and the methods of environment remediation in a scientific and environmental context. These studies have helped in developing the concept of arsenic contamination, but the interaction between the technological activities, organisational practices and purification capability in the industrial environment has received a comparatively lower research.

Specifically, no empirical studies have been conducted to examine the combined effects of mining methods, mineral processing methods, industrial operations, and strategic management practices on sustainable results of arsenic management. Little is known about the role of arsenic purification ability as an intermediary process connecting technological processes and

environmental sustainability achievement. The importance of the research gap is in addressing how industrial organisations can incorporate technological innovation and environmental management practices in order to mitigate the risks of arsenic contamination.
This research paper fills this gap by discussing:

- technological causes of the occurrence of arsenic contamination,
- purification capability of arsenic as intermediate,
- Manage the arsenic in an industrial organisation in a sustainable manner.

The study adds to the area of sustainable management of arsenic by combining the perspectives of environmental science, industrial technology, and strategic management.

Its conceptual framework is that technological aspects have an impact on the efficient management of arsenic in the long run because of the mediating variable of arsenic purification capability.
H1: Mining methods have a considerable effect on the management of arsenic that is sustainable.
H2: Processing technology plays an important role in the sustainable arsenic management results.
H3: The purification of arsenic mediates the relationship between technological factors and sustainable management of arsenic.

Methodology

3.1 Research Design

The research design used in this study was quantitative research design to investigate the role of technology in the formation of arsenic contaminants in minerals and the significance of purification capability in recording sustainable arsenic management results. Quantitative research is suitable when it is necessary to investigate the connections between variables with the help of numerical data and statistics analysis (Bryman, 2017; Creswell, 2014). The design can be used to test the hypothesis and offer empirical data on the effect of technological and organisational variables on the management of arsenic contamination.

The method of a survey was chosen due to the possibility of getting the typical data of the respondents who work in the industrial setting where mining, mineral processing, and arsenic purification processes are conducted. The survey research is a common methodology in environmental management and industrial research that can be done to analyse the organisational practices and technological application (Leavy, 2022).

The research philosophy used in the study is positivist research that believes in objective measurement, statistical testing and empirical validation of theoretical relationships. The study design focuses on understanding the effects of technology on sustainable management of arsenic, and purification ability of arsenic serves as a mediator factor.

3.2 Population of the Study

The study population will comprise of companies that are engaged in mining, mineral processing as well as other associated industrial activities in Selangor, Malaysia. Such organisations were picked due to the fact that their activities involve direct operational activities that are linked to mining of the mineral, the technologies that are used in the industrial processes, and environmental management practices in regards to the arsenic contamination. Mining and mineral-processing industries are two main areas where arsenic contamination could happen because of technological operations in the mining, processing, smelting, and disposal operations.

Emphasizing on companies instead of educational institutions will help in ensuring that the research is based on the practical use of industries and technology to manage arsenic. Technological processes, purification systems, and environmental management strategies are practised in the industrial organisations. Therefore, the people employed in such organisations will most likely have pertinent knowledge and experience about the risk of arsenic contamination and its purification procedures.

The research focuses on the organisational views on the application of technologies and environmental sustainability by targeting companies that work in the mineral sphere. This sample selection will assist in the research aim of analyzing the technological aspects that have brought about arsenic pollution and purification efficiency in the industrial setting and hence improving the applicability and appropriateness of the research findings.

The sample population of the research was the employees who work in these organizations and specifically people in the positions which deal with the technological implementation, environmental management and operational decision making. These roles include:

- management personnel
- engineers and technical personnel
- supervisors
- operational staff
- environmental safety personnel

The staff in such roles would most likely have pertinent information and experience on mineral processing technologies, industrial operation, and the purification procedures of arsenic.
This target population is thus comprised of:

- mining companies
- mine mineral processing firms.
- mineral resource related industrial manufacturing companies.
- Environmental management departments in these organisations.

The study puts into the perspective industrial organisations to capture technological practices at organisational level that affect arsenic contamination and purification capacity.

3.3 Sampling Technique

This research study utilized the purposive sampling, which is a non-probability sampling methodology where the respondents are required to have knowledge or experience on the research topic (Etikan et al., 2016). The purposive sampling is specifically suitable in the industrial research setting when it is necessary to use specialised technical knowledge and practical experience to present deeper and valid answers. Since the proposed study is based on technological determinants of arsenic pollution and purification activities, the choice of respondents involved in direct work with an industrial activity will guarantee the relevance and validity of the gathered data.

The sample of respondents was taken among the companies operating in mining, mineral processing and the related industry activities in Selangor, Malaysia. The sampling was based on the employees which were involved in technological operations, environmental management, mineral processing activities, and organisational decision-making. These positions involve management staff, engineers, technical staff, supervisors as well as the operating staff that have been trained on the risks of arsenic contamination and purification procedures.

There were 200 respondents who took part in the study. This is deemed to be enough to conduct quantitative statistical analysis, such as regression and mediation test (Hair et al., 2019). The participants of various job categories have been included, which means that the strategic and operational sides of the arsenic contamination management are represented.
The sample of the sample is representative of the industry workforce and includes representatives of:

- management positions
- technical and engineering positions.
- supervisory roles
- operational staff

The purposive sampling approach will establish relevancy and validity of the findings data collected as it will be representative of industrial technological practices, purification capability, and management of arsenic contamination within the firms.

3.4 Research Instrument

The structured questionnaire that was used to measure the key variables of the study was used to collect data. One of the most common methods of quantitative environmental and industrial research is the use of questionnaires which enable standardisation of organisational practices and technological variables in measurement (Creswell, 2014).
The questionnaire was divided into a few parts that measured:
Independent variables:

- mineral types
- mining techniques
- processing technology
- industrial activities
- strategic management

Mediating variable:

- arsenic purification facility.

Dependent variable:

- sustainable management results of arsenic.

The respondents were measured on a five point Likert scale with 1 (strongly disagree) to 5 (strongly agree). Likert scales can be employed in organisational and environmental management studies because of their reliability and convenience of analysis (Sekaran and Bougie, 2016).

3.5 Data Collection Procedure

The employees who were employed in businesses dealing in mining, mineral processing, and associated industries within Selangor, Malaysia were used to collect data. These organisations were identified due to the fact that their operational activities are directly related to the extraction processes, processing technologies and environmental management practices that deal with the arsenic contamination. The questionnaires were distributed via organisational contacts, professional networks as well as industry-based channels of distribution in order to ensure that the respondents had qualifying technical and operational experience.

The study was voluntary, and the purpose, scope, and academic nature of the research were explained to the respondent who was required to fill in the questionnaire. The consideration of ethics was witnessed during the data collection process. Anonymity and strict confidentiality was ensured to ensure the identification of respondents and information of their organisations is not exposed thus ensuring that they give truthful and unprejudiced responses.

Two hundred questionnaires were received back and identified as the right ones to analyze, as they contained enough information to complete the test and interpretation.

3.6 Data Analysis

Statistical Package for Social Sciences (SPSS) and Hayes' PROCESS macro were used to analyse the collected data (Hayes, 2022). To be analyzed statistically:

- descriptive statistics
- reliability analysis (Cronbachs alpha)

Pearson correlation analysis.

- the multiple regression analysis.
- mediation analysis

The reliability analysis was done to determine internal consistency of measurement items. A alpha of above 0.70 was regarded as acceptable (Hair et al., 2019).
Relationships amongst technological factors, purification capability, and sustainable arsenic management outcomes were considered using regression and mediation analysis.

Results

4.1 Introduction

In this section, the outcomes of the statistical tests performed to investigate the technological role in the development of the arsenic contamination and ability to purify in industrial organisations will be presented. The statistical package on social sciences (SPSS) and the Hayes macro, PROCESS, were used to analyse the data. The analyses will involve demographic profiling of the respondents, descriptive statistics, reliability analysis, and inferential statistical results of the study variables. The findings are in a well-articulated way in accordance with the study objectives and the quantitative approach taken in this work.

4.2 Demographic Characteristics of the Respondents.

Two hundred respondents of firms in the mining sector, mineral processing and other industrial activities were used in the research. The demographical information of the respondents gives an insight to the industrial experience respondents and the technical background of the respondents that holds significance in the interpretation of the results.

The gender ratio indicates that 76.5 percent of the respondents were males, and 23.5 percent were female. This is representative of the demographics of the workforce that is generally found in the mining and mineral sectors where technical and operations jobs are more frequently dominated by men.

In terms of age, most respondents were between the 3544 years (43.5%), 2534 years (31.5%). The number of respondents aged 45 years to 54 years was 12. 0, respondents below 25 years was 7.5 years and those aged 55 years and above was 5.5 years. The distribution indicates that the majority of the participants were professionals who were actively working in the industry and making decisions.

Data regarding education backgrounds indicate that 44.0% of the respondents were holding degree of Bachelor, 22.0% were having the degree of Master, 20.0% were having the degree of Diploma, and 8.0% had the degree of Doctorate. A number of individuals with SPM-level qualifications was only 6.0%. The respondents have a high level of tertiary education which is why the responses regarding the practices of technological and environmental management are credible.

Concerning job positions, management personnel were the highest at 48.0%, engineers and technical staff 32.5, supervisors 11.0 and operational staff 8.5. This distribution demonstrates that the vast majority of respondents participated in decision-making and technical implementation of arsenic related to the practices of arsenic management.

Data on the work experience indicates that 53.0% of the respondents experienced 5-10 years of work experience with 23.5% experiencing 11-15 years and 14.0% of the respondents having above 15 years of work experience. Those who had less than 5 years experience were only 9.5%. This validates the fact that the sample is mainly made of professionals in the industry.

4.3 Descriptive Statistics

To determine the perceptions of the respondents regarding technological factors that affect the arsenic contamination and the ability to purify the contaminated water, descriptive statistics were computed.

The mean values of all the independent variables are above 4.00, which indicates that all the respondents strongly agreed on the importance of the independent variables in managing arsenic contamination.

Among the independent variables:

- Mining techniques registered the greatest average (M = 4.345),
- followed by Mineral types (M = 4.309),
- Strategic management (M = 4.300),
- Processing technology (M = 4.224),

- and Industrial activities (M = 4.038).

These findings indicate that mining methods and mineral attributes are the most powerful aspects that determine the development of arsenic contamination, as perceived by the respondents.

A high mean score (M = 4.315) was obtained on the mediating variable, which is the purification capability, which means that there was a high level of consensus on the significance of purification technologies in the management of arsenic.

Sustainable arsenic management outcomes, as a dependent variable had a mean of 4.334 implying that overall the respondents perceived their organisations to be applying good management of arsenic practices.

The standard deviation values among the variables are relatively low, which means that there is consistency in the perceptions of the respondents.

4.4 Reliability Analysis

Cronbach alpha was used to analyze reliability of items used to measure internal consistency. The reliability levels of all variables were excellent, and the Cronbach's alpha values went above the required level of 0.70 (Hair et al., 2019).

Independent variables:

- Mineral types: $\alpha = 0.968$
- Mining techniques: $\alpha = 0.943$
- Processing technology: $\alpha = 0.916$
- Industrial activities: $\alpha = 0.914$
- Strategic management: $\alpha = 0.965$

Mediating variable:

- purification capability of arsenic: = 0.940.

Dependent variable:

- Sustainable arsenic management results: = -0.925.

These findings indicate that the measurement tools adopted in the research are dependable and can be used in subsequent statistical analysis.

4.5 Summary of Findings

The findings show that the industrial respondents have a high level of consensus on the relevance of technological considerations in arsenic contamination management in mining and mineral-processing sectors. Mining methods and types of the minerals became the most significant variables investigated in this study that impacted the results of the management of the arsenic contamination. The respondents were of the opinion that the nature of extraction and the nature of arsenic bearing minerals are critical in defining the magnitude of arsenic release to the environment. Moreover, the ability to purify arsenic was always assumed as the key to the realization of sustainable arsenic management results, which gives a certain weight to the role of the technological purification systems in mitigating the risk to the environment.

The reliability analysis showed that the measurement scales adopted in this research have high internal consistency implying that the data to be collected is reliable and can be further tested statistically. The similarity of the perceptions of the respondents in the variables indicates that the data is strong and suitable to apply the inferential analysis. These results are empirical evidence on the analysis of the mediating role of arsenic purification capacity in the correlation between technological aspects and sustainable environmental performance.

On the whole, the findings highlight the relevance of technological activities, organisational governance, and purification systems to the concerns of managing the problem of arsenic contamination in the industrial setting and fostering the long-term sustainability of the environment.

Discussion

This research was conducted to investigate the role of technology on the formation of the arsenic impurities in the minerals and to ascertain the moderating role of the arsenic extraction power in the delivery of sustainable arsenic management results in industrial organisations. The results present an empirical evidence of the significance of the technological processes, industrial practices and organisational management in managing the arsenic contamination. This part elaborates the findings concerning the current literature and theoretical approaches to the environmental management, industrial sustainability, and pollution control.

Among the most important results of the research, one may single out a strong impact of mining methods on results of managing the arsenic contamination. The highest mean score in the independent variables showed the mining techniques which means that the respondents consider the mining activities as one of the biggest sources of arsenic mobilization. This is in line with the earlier studies that reveal that the mining activities expose the sulfide minerals to oxidation processes, which emits arsenic into the ecosystems around them (Qudrat-Ullah and Panthallor, 2020; Rahaman et al., 2021). In specific, acid mine drainage is found to be one of the major ways in which arsenic gets into ground water and surface water systems. The current results support the idea that the development of mining operations and environmental surveillance are the key to the minimization of arsenic pollution threats.

The research also established that the type of minerals also plays a significant role in the development of arsenic contamination. This finding is consistent with studies in the geological community which have shown that the major contributors of arsenic release in the extraction and processing process are the arsenic-bearing minerals, including arsenopyrite and pyrite (Pikinini, 2022). The mean score that has been recorded with regard to mineral types is high indicating that the practitioners working in the industries have identified the relevance of mineral composition in identifying the level of contamination risk. This confirms the theories of environmental geochemistry with an accent on the role of mineralogical properties in the mobilization of pollutants.

The other valuable discovery is the use of processing technology in the management of arsenic contamination. There was a high level of agreement between the respondents on the impact of the mineral processing technologies which included flotation, roasting and smelting. These results can be correlated with the data that the mineral processing activities can enhance the mobility of arsenic due to chemical conversion and emissions (Segura-Salazar and Brito-Parada, 2021; Tang and He, 2024). Not only do processing technologies affect the level of contamination, but also define whether the purification and waste management systems will be efficient. This brings out the significance of technological innovation in the mineral processing in order to reduce the risks to the environment.

The results also reveal that industrial activities are factors that lead to the management outcomes of arsenic contamination, but the perceptions of respondents regarding the aspect had a lower level of variability. Much has been reported on coal burning, smelting, and waste disposal as some of the industrial activities that produce arsenic (Wu et al., 2023; Anand et al., 2021). The standard deviation of this variable is relatively larger which could indicate the variance in the industrial practices of organisations. However, the findings validate that industrial production systems are significant in the development of arsenic contamination.

One of the contributions of this research is that it identified strategic management as one of the factors that play a role to determine the outcomes of sustainable arsenic management. Strategic management practices assist in monitoring the environment, compliance with regulations, and implementation of purification technologies. This observation is consistent with the environmental management theory that focuses on the significance of organisational leadership and governance to the attainment of sustainability goals (Dehkordi et al., 2024). Companies, which apply environmental sustainability in the process of strategic planning, will tend to invest in technological means of pollution control.

The greatest theoretical contribution of the study has been the mediating role of the capability of purifying arsenic. The findings show that purification capability is an important process that connects the technological operations to sustainable outcomes of arsenic management. The result is consistent with technological remediation theory, which argues that the environmental sustainability of a place does not rely solely on the minimization of the sources of contamination but also on the enhancement of purification and remediation systems (Gadgil et al., 2024).

Adsorption systems, membrane filtration, chemical treatment, and biological remediation are among the widely known technologies to be used to purify contaminated arsenic environments (Zaimee et al., 2021; Mehdi et al., 2021). The current research builds on this literature by showing that an organisational purification capability is a mediating variable between the technological processes and environmental outcomes. This implies that the success of technological operations in the management of arsenic contamination is highly reliant on the capacity of the organisation to install purification installations.

The results are also applicable in the general sense of industrial sustainability and structures of pollution control. Environmental sustainability theory highlights how technological advancement, organisational governance and environmental responsibility have been combined in the control of industrial pollution (Browne and Raff, 2023). The findings of this paper justify this viewpoint as they revealed that technological factors cannot work unless they possess purification capability and strategic management support.

The other significant implication of the findings touches on sustainable industrial development in the economies that rely on minerals. With the growth in mining and mineral processing industries, there is need to incorporate technological practices in line with the environmental protection strategies. The research proves that the management of arsenic should be sustainable involving the participation of both engineers, managers, and environmental experts in the industrial organisations.

In addition, the results have underscored the significance of capacity-building when it comes to the adoption of purification technology, especially in the developing industrial areas. Other studies have listed the cost and technological availability as the significant obstacles to the implementation of purification technology (Khosravi-Darani et al., 2022). The high mediating effect of the purification capability in this study is an indicator that the purification technology investments and training may pay off in a monumental way in terms of environmental performance.

All in all, the discussion establishes that the arsenic contamination management is a multi dimensional problem that entails the geology, technological processes, industrial uses and management practices. The findings are empirical findings that validated the combination of technological and strategic strategies to attain sustainable management of arsenic.

This study connects the sources of technological contamination to purification ability and sustainability results and this adds to the knowledge on how industrial organisations could better manage arsenic contamination.

Conclusion

Contamination of arsenic in minerals still remains a major threat to the environment and human health, especially in places where mining, mineral processing as well as industrial production define the area. The continuity of arsenic in the soil, water and air systems is an additional concern that necessitates the need of efficient technological, organisational and environmental management plans. This paper has discussed the technological aspect of arsenic contamination in the minerals and the mediating aspect of the capability arsenic purification in the realisation of sustainable arsenic management results in industrial organisations.

The results of the study prove that industrial and technological aspects are very important in the management of the arsenic contamination. It was found that mining techniques, type of minerals, processing technology, industrial activities and strategic management have an effect on the sustainable outcomes of arsenic management. Among them, mining methods and minerals type proved to be one of the most powerful ones, as the significance of geological peculiarities and mining activities was reflected in the way the arsenic gets into the atmosphere. These results support the body of research on the environment and mining that recognizes mineral mining and treatment as the main sources of arsenic pollution.

Another critical factor mentioned in the study is the role of processing technology as well as industrial processes in determining the outcomes of contamination. Flotation, roasting and smelting are mineral processing activities that can augment the mobility of arsenic by converting it to other forms and emitting arsenic. Other sources of pollution to the environment include industrial activities like the combustion processes and trash disposal. The implications of these findings are the necessity of better technological processes and environmental regulations of industrial activities connected with mineral resources.

Among other noteworthy contributions by this study is the arsenic purification capability as the mediating factor between technological activities and sustainable management of arsenic outcomes. This observation implies that the dangers of technological contamination can be successfully reduced in the case organisations have powerful purification resources. Adsorption systems, membrane filtration, chemical treatment methods, and biological remediation approaches are the major purification technologies that are used to reduce the presence of arsenic in the environment and ensure its environmental friendliness. The mediating effect that is evident in the present study is that technological innovation is not enough on its own unless it is coupled by proper purification systems and organisational dedication to sustainability of environment.

Another significance of this research is the contribution it makes to strategic management in aiding purification capacity and environmental sustainability. Industrial organisations can deal with arsenic contamination more effectively by using strategic management practices such as environmental planning, compliance with regulations and purification technologies investment planning. These results are in line with the environmental sustainability theory that focuses on incorporation of technological innovations, organisational governance, and environmental responsibility in pollution management. Industrial organisations that consider the environmental sustainability in their strategic decision making are in a position to adopt purification technologies and lessen purification risks through contamination.

Practically, this research is very useful to the industrial managers, policymakers, as well as environmental regulators. The results indicate that the management of arsenic contamination could be greatly increased by means of the better mining, enhancement of mineral processing technologies, reinforcement of the industrial waste management systems, and investment in purification technologies. These findings can be used by governments and regulatory bodies to come up with policy that would promote the use of purification technologies and sustainable mining techniques. On the same note, the findings will enable industrial organisations to assess their technological capacities and environmental management policies.

The research also has a contribution to the literature in industrial environmental management as well as sustainable mineral development, especially in the context of the developing economy. The study gives empirical evidence in the form of a real industrial environment by targeting companies that are engaged in mining and processing of minerals in Selangor, Malaysia. This helps in achieving a deeper insight into the interaction between technological factors and the capability to purify and in the organisational settings determine the outcome of environmental sustainability.

This study has a number of weaknesses in spite of its input. To begin with, the study targets firms that are in one geographical area, which might not be very representative of other industrial settings. Second, the survey data used in the study is self-reported and subject to the perception of respondents and organisational culture. Third, the study looks at the capability of purification at the organisational level and does not look at the technical efficiency of particular purification types of technology. Future studies can overcome these shortcomings by performing comparative studies across various regions, using experimental or field-based data on the environment and discussing particular purification technologies in more technical detail. Other possible research directions in the future are that artificial intelligence and digital monitoring systems can be incorporated in the management of arsenic contamination. The latest advancements in environmental monitoring, including machine learning-based water quality detection, sensor-based water quality detection, as well as predictive modelling systems, can help more effectively detect arsenic contamination and purify water in arsenic-contaminated environments. Moreover, interdisciplinary studies that will integrate the environmental engineering and industrial management approach with the methods of public health would also contribute to the better understanding of arsenic contamination management.

To sum up, the problem of arsenic contamination in minerals is a complicated environmental issue, that is determined by technological processes, industrial activities, and organisational management practices. This paper shows that the ability to purify arsenic is the key mediating factor in the acquisition of sustainable arsenic management results. Strategic environmental management, purification system, and introduction of technological innovation should be considered vital to the mitigation of risk of arsenic contamination and sustainable industrial development. The cooperation between the industry, government and research facilities will have to continue to make sure that in the long run technological advancement will help in preserving the environment and human health.

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