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ORIGINAL ARTICLE

Climate variability and mining sustainability: exploring operations' perspectives on local effects and the willingness to adapt in Ghana

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Abstract

The mining industry is susceptible to the effects of local climatic changes just as the surrounding socioecological systems are exposed to both mining and changing climate impacts. Adaptation deficit in mining is a worldwide problem but given the double exposure of surrounding systems, which has emergent outcomes on the industry, operations must adapt to coexist with surrounding rural communities. To understand this susceptibility, the study employed mixed methods to assess the implications of local climatic changes on mining sustainability as perceived among Ghanaian operations through the lens of the corporate adaptation process framework. The results indicate that operational workers are aware of increasing variability in the climatic patterns across southwestern Ghana, citing changes in the start/end of the rain season, torrential rain, prolonged dry season, and a general increase in temperature. The effects of these changing patterns, which affect mining activities, are diverse, including mine water management, safety, and occupational health issues as well as production planning opportunities. Workers ranked high the need to involve stakeholders such as the state-appointed regulators and Ghana Chamber of Mines as key strategies to enjoin adaptation to changing climate at operational sites. In addition, workers perceived the impact on regulatory and economic sustainability performances as major factors determining the industry's perception and willingness to adapt. The study highlights pertinent issues useful for informed policy decision-making in the strive towards attaining sustainable development goals, especially Goal 13, which calls for active collaboration between business and society.

Keywords Climate adaptation · Corporate sustainability · Double exposure · Extractives

Extended author information available on the last page of the article

Introduction

Climate–mining interactions and double exposures in rural West Africa

As a natural resource management activity, a mine, its infrastructure, and its employees are exposed to the dynamics in local climatic conditions. For instance, accurate historic hydrometeorological data is essential for designing mining infrastructure such as pits, tailings storage facilities, and other impoundments, whereas daily meteorological information is essential for planning and scheduling operational routines. In addition, local variability in rainfall directly affects slope stability, environmental quality, and water availability within operational sites.

Extant literature asserts the potential impact of changing climate on mining through reviews (Hodgkinson and Smith 2018; Odell et al. 2018; Phillips 2016) and empirical studies (Gonzalez et al. 2019; Hodgkinson et al. 2014; Liu and Song 2019; Mavrommatis and Damigos 2020; Pearce et al. 2012, 2010). For instance, Phillips (2016) reviewed the climate implications of physical mining activities and environmental quality management within an operational site whereas Gonzalez et al (2019) empirically analyzed such implications by identifying mining regions that are vulnerable to future extreme rainfall events in Peru.

Similarly, countries within the West African region including Ghana have begun experiencing significant changes in climatic conditions (IPCC 2014; Sani and Chalchisa 2016; Sylla et al. 2016). Increasing climatic variability across the tropical forest zones of Ghana is indisputable (Abbam et al. 2018; Atiah et al. 2019; Fosu-Mensah et al. 2012; Nkrumah et al. 2014, 2019). Apart from the detrimental effects on rural livelihoods, mining firms that dominate the forest zones of West Africa (IUCN 2012) are exposed to climate risk as established elsewhere. Climate studies in Ghana have focused on key sectors such as human health, land management, agriculture, fisheries, and water resources (Antwi-Agyei et al. 2012; EPA 2000, 2008; Limantol et al. 2016), with little information on the mining sector irrespective of the socioeconomic significance. Indeed, it has been established that there is a chronic lack of information on the interrelationships between mining and climate change in most developing countries, which on the contrary are climate hotspots (Odell et al. 2018).

Mining is a key pillar to the economies of most West African countries owing to the endowment of mineral resources within the West African Craton (André-Mayer et al. 2015). The region supplies 9% of the world's bauxite and 8% of gold (World Bank 2014). Ghana falls within the West African Craton's mineral province (Markwitz et al. 2016; Williams et al. 2015; World Bank 2014) with over millennia of gold mining as an example (Boso et al. 2017; Hilson 2002). The mining industry contributes immensely to the national economy and the socio-economic development of mining-fringe communities (World Bank 2020) particularly through their corporate social responsibility initiatives (Browne et al. 2011).

As already established, mining activities affect the resilience of surrounding social-ecological systems including rural communities and their dependent biodiversity and ecosystem services (Antwi et al. 2017; Butt et al. 2013; Sonter et al. 2018). For instance, most operational sites in southwestern Ghana are located within or at the fringes of forest reserves and off-reserve forests as well as agricultural lands heavily depended on by surrounding communities. The environmental aspect of mining including land fragmentation and degradation, dust generation, streamflow diversion, and contamination affect the capacity of the forest ecosystem to provide the essential functions and services needed by surrounding communities. Apart from the impact of mining on the surrounding system's resilience, increasing climatic variability and changes can aggravate the situation as established among Australian and Canadian mining-fringe communities (Loechel et al. 2013; Pearce et al. 2012). Studies on mining and climate change impacts on other resources within the same geographic location are mostly considered in isolation such as the impact of mining on ecosystem services (Sonter et al. 2018) or the impact of climate change on ecosystem services (Boon and Ahenkan 2012). However, within the geographic region of mining operations, impacts from physical mining activities and changes in the local climate can affect other resources and the local people simultaneously. According to O'Brien and Leichenko (2000, p.227), such simultaneous and overlapping impacts of changing climate and globally mediated economic system such as mining on other resources is termed 'double exposure' (Leichenko and O'Brien 2008; O'Brien and Leichenko 2000).

Mostly, mining-fringe communities and their dependent ecosystems within the West African region risk double exposure due to the close interaction between mining and rural livelihood systems (see Photo 1) coupled with the changing local climate. Extant literature already hint at the double exposure impacts in mining landscapes and expounds on the need for appropriate institutions to govern such exposures (Bebbington et al. 2015; Birch 2016; Tannor et al. 2022). Given the dynamic interactions between mining and surrounding socio-ecological systems, the success of any mine's adaptation strategies would depend to a large extent on how mining-climate exposures are addressed within the entire mining landscape. Thus making operational level adaptation to the local effects of changing climate an imperative for the industry's sustainability.

Photo 1 Socio-ecological systems dynamics in miningscapes, (source: taken by author)

Will mine operations' adapt to reduce double exposure risk in West Africa?

Generally, adaptation to climate changes within an organisation introduces new costs and might require changes in existing operational practices (Busch 2019; Linnenluecke et al. 2013, 2015). Therefore, these factors could influence the willingness of an organisation to adopt and implement adaptation strategies. Corporate adaptation is well established in management and organisation studies (Lewin et al. 2004) since organisations such as mining companies must constantly respond and adapt to pressures from both internal and external pressures. However, the focus on corporate adaptation to climate change has come strongly in recent times (Averchenkova et al. 2016; Busch 2019; Chester 2020; Goldstein et al. 2019; Hoffmann et al. 2009; Linnenluecke et al. 2013, 2015).

For example, the intergovernmental panel on climate change (IPCC 2014) has admonished industrial sectors such as mining to mitigate and adapt to the impacts of changing climate. Other institutions such as United Nation's Global Compact (Frey et al. 2015), International Council for Mining and Metals (ICMM 2013), Adelphi (Rüttinger and Sharma 2016) and Task Force on Climate-related Financial Disclosures (TCFD 2017) strongly argue a case for mining industries to adapt to the effects of global changes due to the susceptible nature of the industry to climatic variability. Adapting to the impacts of variability in local climate is thus imperative for mining operations, and can serve as a pragmatic tool to address concomitant impacts of mining and climate on surrounding systems although hardly investigated in the West African region.

Adopting the corporate adaptation processes framework (Arnell and Delaney 2006), this study aims to understand the local effects of changing climate on mining operations' performances and the determinants of the industry's perception and willingness to adapt. By gathering empirical perspectives among workers scattered within southwestern Ghana, the specific objectives are to (1) examine the perceived changing climatic variables within the forest belt and the effects on workers' activities. (2) Examine workers perceived strategies to enhance resilience building within operational sites. (3) Deduce the determinants of the industry's willingness to adapt to climate changes. The ensuing section briefly discusses the main components of the corporate adaptation framework, followed by the methodology and results of the empirical perspectives together with general discussion and conclusions.

Conceptual framework

Corporate adaptation process model

The corporate adaptation process framework adopted for the study was originally developed by Berkhout et al. (2006) as cited in Arnell and Delaney (2006, p.229). The framework has been applied within the built environment and water supply companies in the UK (Arnell and Delaney 2006; Berkhout et al. 2006). The modified version of the framework by Arnell and Delaney (2006), consists of four elements namely; awareness of and concern about the potential impacts of climate change, the idea of an adaptation strategy, the concept of adaptation spaces and the notion of adaptation determinants.

According to Arnell and Delaney (2006), without awareness, there would be no concern, and without concern, there will be no adaptation except in extreme of forced adaptation imposed from higher authority. The adaptation strategy refers to what the organisation seeks to achieve by adaptation and how it intends to achieve it whilst adaptation space refers to the set of options potentially available and feasible to the organisation to deal with the impact of climate and other changes. In addition, the notion of adaptation determinants refers to factors that influence an organisation's perception and selection of adaptation options. These are the organisation's susceptibility to change, the resources and capabilities of the organisation, the regulatory and market context.

The organisation's susceptibility to change is defined by how the organisation's activities interact with climatic conditions and other external factors, the resources and capabilities of the organisation determine how the organisation responds to the changes including access to information and knowledge, management culture and external relationship with other stakeholders. Finally, the regulatory and market context can act as the source of pressure for change to occur (Arnell and Delaney 2006, p. 230).

Corporate sustainability performance as determinants of operations' adaptation

Corporate sustainability as a management strategy (Dočekalová and Kocmanová, 2015) is expected to translate into an improved condition for all stakeholders. Besides, the increasing demand for cleaner production and the drive for a green economy is compelling corporate businesses including the extractives to constantly appraise their business values and strive to align towards sustainable patterns.

The development path of corporate sustainability concepts such as corporate environmental management, corporate social responsibility as well as occupational health and safety management have been traced as a reactive response by companies to address increasing risk and hazards associated with their operations as well as national regulations (Schneider et al. 2018). In fact, the battle for businesses to take responsibility for their effects on the environment and society in the long term birthed the concept of sustainability (Kidd 1992). Thus corporate sustainability ascribes the need for businesses to integrate sustainable development concepts into investment, management and operational strategies (Artiach et al. 2010; Bansal 2005; Dyllick and Hockerts 2002; Hahn et al. 2015) following the Bruntland Commission report of 1987. The commission enjoined sustainability to environmental integrity, social equity and economic prosperity on both short and long-term basis, hence linking the sustainability of businesses directly with that of the surrounding social-ecological systems.

Apart from sustainable development underpinning corporate sustainability, corporate sustainability is equated with corporate social responsibility (Aguinis and Glavas 2012; Baumgartner 2014; Marrewijk 2003), which focuses on stakeholder theory, volunteerism and philanthropies (Carroll 2000; European Commission

2011). Others argue that corporate sustainability has evolved from the combination of sustainable development, corporate social responsibility and corporate accountability theory (Wilson 2003). Thus, corporate sustainability involves the integration of sustainable approaches into all aspects of a business that ensures the generation of continuous benefit to all stakeholders both in the short and long term.

Accordingly, some authors (Atkinson 2000; Quaddus and Siddiqque 2011; Schaltegger et al. 2010) assert that assessing corporate sustainability performance should be based on eco-efficiency, that is, referring to environmental sustainability. Others indicate that corporate sustainability performance must be based on the triple bottom (Dyllick and Hockerts 2002) which incorporates economic, natural and social capitals. Similarly, Artiach et al. (2010) argue that corporate environmental management and corporate social responsibility are the main determinants of corporate sustainability from which key performance metrics can be measured. Others include corporate governance factors in addition to the triple bottom (Dočekalová and Kocmanová, 2015; Serafeim 2018) which has gained wide recognition in practice. For instance, Dočekalová and Kocmanová empirically tested a set of performance indicators for assessing corporate sustainability within the manufacturing industries, which are based on widely accepted corporate performance indicators already in use by non-financial performance assessment institutions such as the Global Reporting Initiative, the International Integrated Reporting Frame Council and Guidance on Corporate Responsibility Indicators in Annual Report among others.

Similarly, the metrics or aspects for assessing corporate sustainability performances in mining exist in literature (Azapagic 2004; GRI 2015; Lodhia and Martin 2014). To identify the determinants of climate adaptation within the mining industry, the implication of changing climate on the sustainability performances as measured at operations including economic, social and environmental performances were examined. The sustainability performance aspects used in this study as summarised in Table 1 are excerpts from the fourth edition of the Global Reporting Initiative, G4 (GRI 2015). The G4 enable reporting companies to provide valuable information about the organisation's most critical sustainability-related issues as well as focuses on materiality that is critical to achieve the organisations' goals and manage its impact on society (GRI 2015, p.3).

Thus examining the consequences of local changes on corporate sustainability metrics provide a foresight information on climate adaptation in mining within operations' perspectives. To mimic the everyday language of operational workers, a proxy in terminology was generated by the first author based on her decade of professional experience within the industry.

Research setting/profile

Ghana (Fig. 1) is located along the Gulf of Guinea in the West African region on latitude 4.50 N to 11.50 N and longitude 2.50 W to 0.50 E, covering an area of about 240,000 km^s (Owusu et al. 2013). To the eastern border of the country is Togo, to the West is Ivory Coast and to the north is Burkina Faso. Ghana's climate is generally

Table 1 Aspects of corporate sustainability performance in mining operations

Excerpts from GRI (G4) sustainability performance disclosures	Corporate sustainability performance proxy in mining operations
Economic:	Economic and governance:
Economic performance, indirect economic impact, procurement practices	Production, cost, energy, water Safety performance, occupational health, regulatory compliance
Environmental:	Environmental:
Materials, Emission, Biodiversity, Effluent and Waste, emissions, Environmental grievance mechanism, supplier environmental Assessment, Compliance	Environmental Performance Reporting (environmental quality monitoring activities, material use and waste generation, emissions, wildlife and fish protection, land reclamation and rehabilitation)
Social:	Social:
Labour practices and decent work, human rights, society, product responsibility	Corporate social responsibility reporting (community engagement and development, grievance mechanism, welfare/philanthropies), employee and family wellbeing, security and ethics

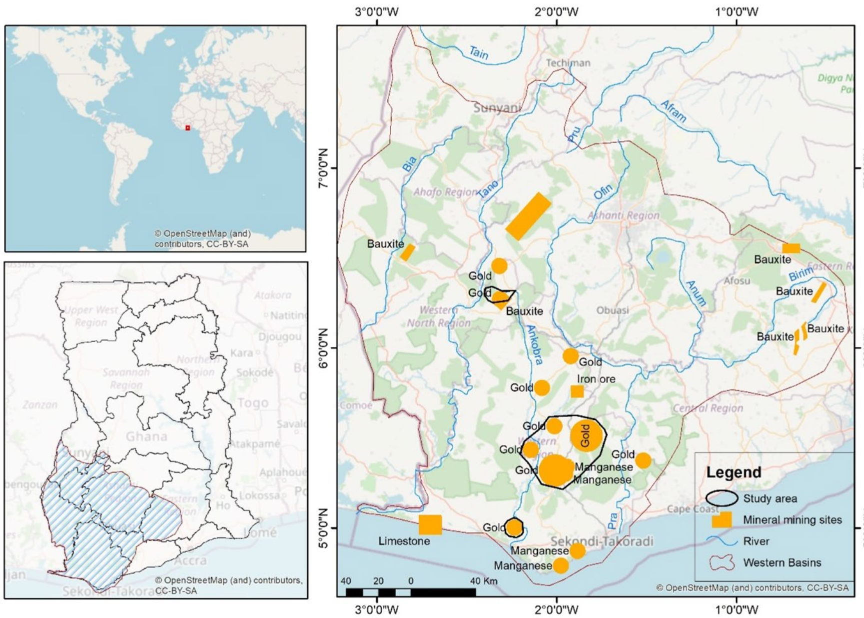


Fig. 1 Map of selected mining landscapes in southwestern Ghana

characterised by the tropical monsoonal climate system with a bimodal rainfall season to the south and a unimodal season to the north (Manzanas et al. 2014). Based on the climate and soil characteristics, the country is divided into the Sudan Savannah and Guinea Savannah agro-ecological zones in the north, Transitional and

Coastal Savannah in the central and southeastern, as well as Deciduous and Rainforest (moist and wet evergreen) to the southwestern (Asravor et al. 2019; FAO 2005).

The country is a low-middle income country based on the World Bank per capita gross domestic product (GDP) threshold, with a projected population of 30.3 million as of 2019 and GDP estimated at US$66,984 million including oil with a per capita GDP of US$ 2212 (GSS/EPA 2020). As a natural resource base economy, mining and logging contribute to 14% of the nation's economy as of 2019 (MESTI 2020). Ghana falls within the southern domain of the Paleoproterozoic Birimian Baoulé-Mossi domain of the West African Craton, from which some of the world's finest gold and other mineral resources are extracted (Markwitz et al. 2016). Apart from gold, which Ghana is only behind South Africa in Africa, the country also exports bauxite, diamond, and manganese (Boso et al. 2017). Particularly the southwestern part of the country is proliferated with large-scale multinational mining operations following the IMF-World bank-led structural adjustment (Hilson 2004), which created investor-friendly environment as well as artisanal and small-scale mining firms.

The 1992 Constitution of Ghana set the basic regulatory framework for natural resource exploitation and for managing the related environmental and socio-economic impacts of such industry. For instance, under the economic policy objectives of the Constitution (Chapter six), the State is enjoined to promote the development of industries Clause 3), whilst taking appropriate measures to protect the environment for posterity (Clause 9), safeguard the health, safety and welfare of employees (Clause 10) as well as encourage workers to participate in the workplace decision-making processes (Clause 11).

The Minerals Commission is the main body established by Act of Parliament (Minerals Commission Act 1993 ACT 450 1993) to implement the constitutional mandate of regulating and managing the utilisation of minerals (metals and industrial ore) and provide for related matters. The Commission operates under the Ministry of Lands and Natural Resources, which administers lands, forestry and mining in Ghana. Mining was hardly permitted within the forest reserves in Ghana until the IMF-led restructuring in the 1990s, which led to a surge in mineral exploration activities (Tienhaara 2006). To curb the menace of deforestation, the Ministry banned mineral operations within forest reserves (Tienhaara 2006, p. 16). Through negotiations spearheaded by the Chamber of Mines of Ghana, permits were retained for selected companies that had advanced in their exploratory activities but for only 2% of production forest reserves at any one time. Those companies with less than the 2% concession could therefore apply for Forest Entry Permit and are expected to comply with the "*Environmental Guidelines for Mining in Production Forest Reserves*" (Republic of Ghana 2001). Thus, mining is ongoing within some forest reserves including some operations that participated in the current study.

Apart from the legislative instruments promulgated by the Minerals Commission and the Geological Survey Authority, other natural resource and environmental laws of Ghana regulate mining activities. These include the Environmental Protection Agency Act, 1994 (Act 490), the Forestry Commission Act, 1999 (Act 571), the Water Resources Commission Act, 1996 (Act 562), the Nuclear Regulatory Authority Act, 2015 (Act 895), the Local Governance Act, 2016 (Act 936) and the Land Use and Spatial Planning Act, 2016 (Act, 925) among others. The Environmental

Protection Agency (EPA) administered under the Ministry of Science, Environment, Technology and Innovation (MESTI) is the main public agency responsible for environmental management in Ghana. The climate change department of the Agency is the focal point of UNFCC in Ghana and spearheads the development of Ghana's Nationally Determined Contributions (NDCs). Similarly, the mining department of the EPA is responsible for issuing environmental certificate to mining companies in compliance with the Environmental Assessment Regulation (L.I. 1652).

Administratively, the case study area is located within the Western and Western North regions. The areas cover parts of the Rainforest (Moist and Wet evergreen) and the Deciduous forests that make up the forest agro-ecological zone of Ghana hence characterised by numerous forest reserves and watersheds within which the mining operations are scattered. The landscape falls within the southwestern river basin system, which covers about 22% of the country's land area consisting of Bia, Tano, Ankobra and Pra river basins (Ghana National Water Policy 2007). The river basins exposed to mining include the Tano, Ankobra and Pra basins. Hydrometeorological studies confirm the increasing climatic variability in the forest zones of Ghana. For instance, Atiah et al (2019, p.1) indicated an increasing trend in rainfall extreme indices such as consecutive wet days, number of heavy rainfall days and annual wet days. Abbam et al (2018) confirmed increasing temperature and declining rainfall within the forest zone (Abbam et al. 2018, p.130) just as previously indicated by Owusu and Waylen (2009). The trend analyses in Fig. 2a and b confirm the varying trend in extreme rainfall intensity and frequency as well temperature across the landscapes. Sefwi Bekwai and Axim synoptic weather stations are the main meteorological stations within the selected mining landscapes respectively.

Research design

The study adopted a pragmatic paradigm by employing both qualitative and quantitative approaches which enable one to recognise the interconnectedness among experiences, knowledge and actions (Creswell and Creswell 2018). In addition, the mining system was holistically structured on the three levels of corporate management of the St. Gallen Management Model (SGMM) (Baumgartner 2014; Schwaninger 2016). These are normative, strategic and operational management levels. The normative, refers to the company's management philosophy, basic attitudes, values, and vision and policy. The strategic management level determines the long-term goals of the company in line with its vision and policy guidelines. The operation management level refers to the routine activities towards achieving the strategic goals involving resource allocation, human resource management, coaching and controlling among others.

The perspectives of adaptation to climate change in mining at normative and strategic corporate management levels were evaluated by reviewing annual reports and strategic policies of participating companies as well as the Ghana Chamber of Mines. In addition, executive managers stationed at operations were interviewed. Whilst operations management level perspectives were examined via field observation, small group discussion and survey instruments across operational sites.

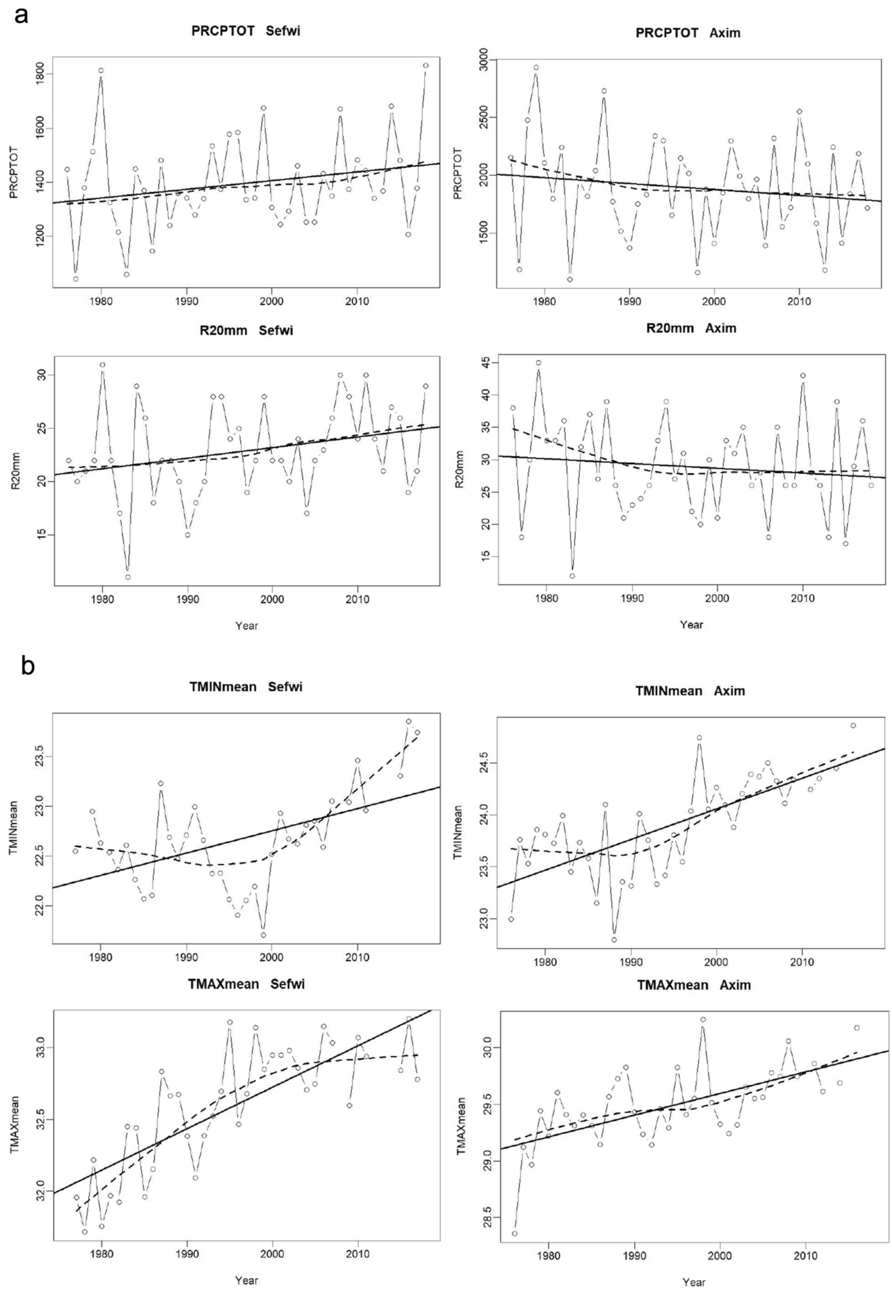


Fig. 2 **a** Rainfall variability across southwestern Ghana (1976–2018); PCRPTOT, Annual total wet day rainfall (mm); R20mm, number of very heavy rainfall days (day). (Source: analysed by author). **b** Temperature variability across southwestern Ghana (1976–2018): TMINmean, mean monthly maximum value of daily minimum temperature (°C); TMAXmean, mean monthly minimum value of daily minimum temperature (°C). (Source: analysed by author)

Data collection strategies, instrument design and data analysis

The study targeted large-scale multinational companies within the Western Regions, which cover parts of the three forest agroecological zones of Ghana where local climatic variability is empirically known to be increasing. The criteria for company participation was based on the willingness of the company to participate. Thus, fifteen mining companies and their contractor services that accepted to participate were enrolled as presented in Appendix 1. Every department within the mine was targeted hence the participating workers were random. Coupled with the pandemic restrictions, the electronic survey administration became the major administering domain.

The primary data were collected using interviews, purposive observation, and quantitative survey instruments. Prior ethical clearance was obtained from the Center for Development Research (ZEF), University of Bonn, Germany. The fieldwork period lasted for seven months consisting of 3 months in 2018 and another four months in 2020. The qualitative data collection was conducted from July to September 2018 within three of the mining operations each selected from one of the forest agro-ecological zones located in the upper, middle and lower study area. The upper study area operates both surface and underground mining, whilst the middle and lower study areas operate only surface mining. These multinational companies belong to Canada, South Africa and UK-Ghana respectively and are members of the Ghana Chamber of Mines.

The survey instrument consisted of three sections with twenty questions. The first section covered the profile of respondent's experience within the mining industry including gender, job position, years of experience, mine location and their respective departments. The second section included the respondent's perspectives on the increasing climate variability within their localities, the interacting effects on their routine operational activities and the adaptation measures pertinent to enhance resilience within operations and the entire mining landscapes. The final section required respondents to rank the implications of changing local climatic conditions on the corporate sustainability performance metrics as monthly reported by their respective departments. The survey instrument was pretested from May to June and conducted from July to October 2020 via paper-based direct survey and electronic survey via emails with assistance from the participating companies. Purposive observations were conducted on field operators and technicians in both underground and surface mining operations as they carried out routine activities. At opportune times, informal discussions and interviews were held with functional managers and executives to clarify field observations.

The survey data was uploaded and cleaned up via Excel for subsequent analysis using SPSS and STATA. Basic descriptive statistics were used to analyse respondents' characteristics whilst cross tabulation was used to analyse different perspectives and graphically presented. Kendall's coefficient of concordance was used to determine the mean rank of the responses. Content analysis was used to analyse the qualitative fieldwork data. The Departments of respondents were recoded into functional sections for ease of analysis as indicated in Appendix 2.

Profile of respondents

Table 2 provides a summary description of the respondents who participated in the survey. Ninety-nine employees working in fifteen mining and mining contractor companies participated in the quantitative study. Out of the total respondents, 82.8% work in 7 mining companies and 17.2% in contractor companies, the latter provide mining-related services for the seven mining companies. 77.8% of respondents identified as males and 22.2% identified females, thus reflecting the male dominance nature of the mining profession. Of the respondents, 33.3% work in production,

Table 2 Respondents' characteristics (Source: survey data)

Variable	N (Percentage)
Company type	
Gold mining companies	75 (75.8)
Manganese mining company	5 (5.1)
Mining Services Contractors	19 (19.2)
Company present location (forest zone)	
Wassa Damang (Rainforest)	16 (16.2)
Nzema (Rainforest)	5 (5.1)
Sefwi Chirano (Deciduous Forest)	54 (54.5)
Tarkwa (Rainforest	14 (14.1))
Wassa Akyempim (Rainforest)	10 (10.1)
Functional departments	
Support services (non-mining)	39 (39.4)
Technical services (civil & maintenance engineering)	25 (25.3)
Production (geology, mining & processing)	35 (35.4)
Positions	
Managers	10 (10)
Supervisors	58 (58.6)
Operator/Technician	17 (17.2)
Assistant/Trainees	14 (14.1)
Years of work experience	
0–5	31 (31.3)
6–10	33 (33.3)
11–15	24 (24.2)
Above 16	11 (11.1)
Gender	
Female	22 (22.2)
Male	77 (77.8)
Age	Age Range (Years)
Mean	35
Max	55
Min	26

33.4% in technical services and 31.3% in support services sections respectively. In terms of positions, 10.1% of the respondents occupied management positions, 58.6% professional and management staff positions (supervisors), and 17.2% field technician/operator positions, while 14.1% were assistants and graduate trainees.

Awareness of climate-mining interactions in southwestern Ghana

Respondents were asked to answer *yes* or *no* to changes observed in the local climatic conditions in the past decade. As shown in Table 3, about ninety-five percent of respondents confirmed having observed changing climatic patterns across the entire forest belt irrespective of their department and the location of the mine. Chi test results indicated no significant changes in perception among respondents located within the Rainforest forest ($p = 0.51$), but some differences in perspectives were observed for workers within the Deciduous forest ($p = 0.01$).

Similarly, Appendix 2 presents the Likert-scale result of respondents' perceived extent of the observed changes in relation to their routine activities. About half of the respondents located within the Rainforest zone perceived a low extent of change ($n = 24$). On the contrary, more than half of the respondents located within the Deciduous forest zone perceived a very high extent of changing climatic pattern ($n = 34$). Moreover, the Chi test result showed no significant changes in perception among respondents irrespective of their functional departments and location ($p = 0.23$).

Table 3 Perception of changing climatic conditions within the forest zones of Ghana

Agro-ecological zone	Have you observed changes in local climate?		
	Yes	No	Total
Deciduous forest			
Production	16	0	16
Support services	20	0	20
Technical services	15	4	19
	51	4	55
Rainforest			
Production	19	0	19
Support services	18	1	19
Technical services	6	0	6
	43	1	44
Total			
Production	35	0	35
Support services	38	1	39
Technical services	21	4	25
	94	5	99

Finally, respondents identified and ranked the changing climatic pattern observed most depending on how their activities were interrupted as summarised in Fig. 3. For instance, local variability such as changes in the start/end of rain season referred to as seasonality received the highest ranking (7) and percentage-wise among respondents from all the departments. Unpredictable rainfall patterns and torrential rains were ranked 7 and 6 mostly among production and support services compared to technical services departments. Notably, respondents from the technical services ranked increased temperature as the highest (7) compared to respondents from production (geology, mining and processing/metallurgy) and support service (non-mining services). This could be attributed to the fact that the activities of technical services section such as boiler-makers and other maintenance engineers involve the use of hot substances, heating sources and related temperature-relevant equipment where the risk of exposure to heat as a routine hazard might be compounding. In addition, ambient temperature is critical in controlling air quality within confined areas, particularly within underground pits, which are maintained by the technical services in charge of ventilation thus accounting for the difference in perspectives.

These results affirm the dynamic interactions between mining and local climatic variability particularly within the forest belt of Ghana for which adapting to the effects of the changes is imperative.

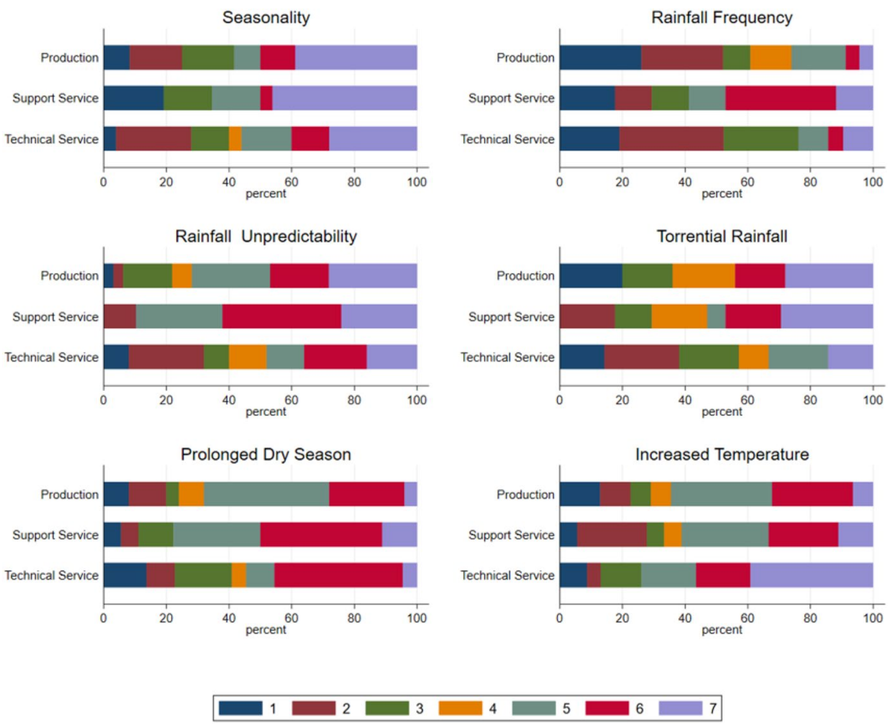


Fig. 3 Climate variabilities in the southwestern forest belt of Ghana (source: survey data). NB: 1–7 is a range of observed variability in local climate ranked from lowest (1) to highest (7)

Susceptibility of mining operations to impact of local changing climate

Table 4 summarises workers' response to the question "*which changing climate effects can or have impact on the company you work with most*". These effect indicators are the results of the thematic analysis of the qualitative fieldwork conducted from July to September 2018. For instance, workers expect changing climate effects such as flooding and inundation (mean score = 9.17), excessive dust generation (mean score = 8.63), water shortage (mean score = 7.36) and fire outbreaks/incidents (mean score = 7.03) to affect the activities of their company most. Secondly, several occupational health and safety-related effects were also ranked high including heat fatigue (mean score = 7.96), risk of workplace incidents (mean score = 7.06), respiratory and cardiovascular diseases burden (mean score = 6.82) among others. Accordingly, the related-samples Kendall's coefficient of concordance was statistically significant ($W^a = 0.05$).

Interestingly, the changing local climatic conditions were viewed to provide both opportunities and challenges. Surface mining professionals particularly noted the high sensitivity of the surface mining activities to rainfall whilst underground mining professionals perceived susceptibility to both rainfall and increased temperature. For example, within the three operations where qualitative fieldwork was conducted, it was observed that surface mining activities (load and haul) were directly halted anytime it rained. Other cost implications associated with rainfall variability were increased equipment maintenance costs due to "wear and tear", haul road maintenance, underground/surface pit dewatering and energy costs due to frequent fluctuation of power from the national grid. Excerpts from interviews are summarised as follows:

"Compared to some previous seasons this season commenced late in June and ended over a short period. Dust generation was high and water allocation had to

Table 4 Effects of increasing climatic variability on mining operations (source: survey data)

Effects of local climatic variability on mineral extractives activities	*N*	Mean rank
Flooding and Inundation	81	9.17
Unreliable weather forecasting	76	6.42
Heat fatigue	71	7.96
Dehydration	73	6.58
Excessive dust/air pollution	86	8.63
Fire outbreaks/incident	70	7.03
Vector-bone and water-related disease burden	57	5.67
Higher burden of respiratory and cardiovascular diseases	66	6.82
Increased case of allergy and allergic diseases	57	5.77
Shortage of water resources	69	7.36
Increased community unrest due climate-related crisis	72	6.72
Traffic-related accident	61	6.69
Increased workplace Incidents	65	7.06

be adjusted to make up for the deficit. The shortened rainy season also provided more dry days for production activities" (Surface Mining Manager August 2020).

"We record high sick leave cases mostly in the dry season that affect mine production.... that is because these days the harmattan (windy conditions in the dry season between November and March) is severe and this triggers respiratory sicknesses asthmatic attacks and other air-bone infections" (Occupational Hygiene Manager, September 2018).

Corporate-level climate-related risk was associated with a license to operate, social conflicts, supply chain, physical mining and infrastructure according to the corporate annual reports (2018–2019) of participating companies. Corroboratively, a management representative indicated in an interview response "*some key risk of climate to the industry is the effect on regulation based on emission targets, social license, water and energy which require strategic attention in every mine"* (Executive Manager September 2020).

Adaptation strategies and spaces within mining operations in Ghana

The results from the survey as shown in Table 5 present operational workers' perspectives on the adaptation strategy and spaces pertinent to enhance resilience building within mining landscapes. Generally, workers perceive collaborative efforts toward integrating climate adaptation through the governing institutions in the industry as prominent. For instance, respondents ranked high the need for state-appointed regulators such as the Mineral Commission and Environmental Protection Agency (mean score = 7.78) to include climate risk-related assessments in mining regulation.

Secondly, workers expect the management of their firms to integrate climate change and related issues at all management levels including the strategic and operations. For instance, the need to include climate change and related policies in corporate strategies had the second highest ranking (mean score = 7.27). Similarly, the need for awareness training and capacity building at operations and in surrounding communities such as mine-wide and community outreaches (mean score = 7.05) and modifying standard operating procedures (SOPs), which are used at the mine to conform to site specific climate related hazards (7.04). Similarly, expectations are for the Ghana Chamber of Mines to sensitise adaptation to impacts of changing climate among members. The Kendall's coefficient of concordance indicated less degree of unanimity, (Wa = 0.06).

Reviewed corporate reports mainly highlighted emission reduction initiatives such as actions to reduce the carbon footprint in mining operations through energy efficiency as noted with empirical evidence in the most recent annual corporate reports (2019) of five out of the seven multinational mining companies. Compared to climate adaptation, two of the mining companies reported their plan to follow the recommendations of the TCFD that included climate risk assessment and adaptations at the operational level. In addition, two sister operations already issue annual

Table 5 Adaptation options towards building resilient miningscapes n = 99 (source: survey data)

Climate adaptation options	Mining operational level adaptation priorities	Mean Rank
Awareness and capacity building	Discuss climate hazards at daily Toolbox meetings	6.90
	Update existing SOPs to include climate related hazards controls	7.04
	Include climate change awareness into Induction presentations and community outreaches	7.05
Integrate climate-related risk into existing risk portfolio	Identify and include climate hazards into the existing Risk Aspect Register	6.98
	Include climate-related cost into budget planning	6.25
	Include climate extreme scenarios in Emergency Response and Preparedness Procedure	5.39
	Consider climate hazards in PPE usage protocols	5.47
	Redesign production facilities to withstand climate-related extremes	5.36
	Factor climate-related challenge in mine closure planning	5.79
Climate adaptation governance mainstreaming into the minerals sector	Include climate change and related policies into corporate strategies	7.27
	Minerals Commission and Environmental Protection Agency must include climate hazard assessment into existing regulations	7.78
	Chamber of Mines to promote climate-related information sharing among its members	6.72

Fig. 4 **a** Implication of climate variability on economic sustainability performance (source: survey data) ▶ NB: 1 = very low 2 = low 3 = high 4 = very high. **b** Implication of climate variability on social and environmental sustainability performance. (source: survey data) NB: 1 = very low 2 = low 3 = high 4 = very high

report on climate change since 2018 based on their corporate strategic policy on climate change.

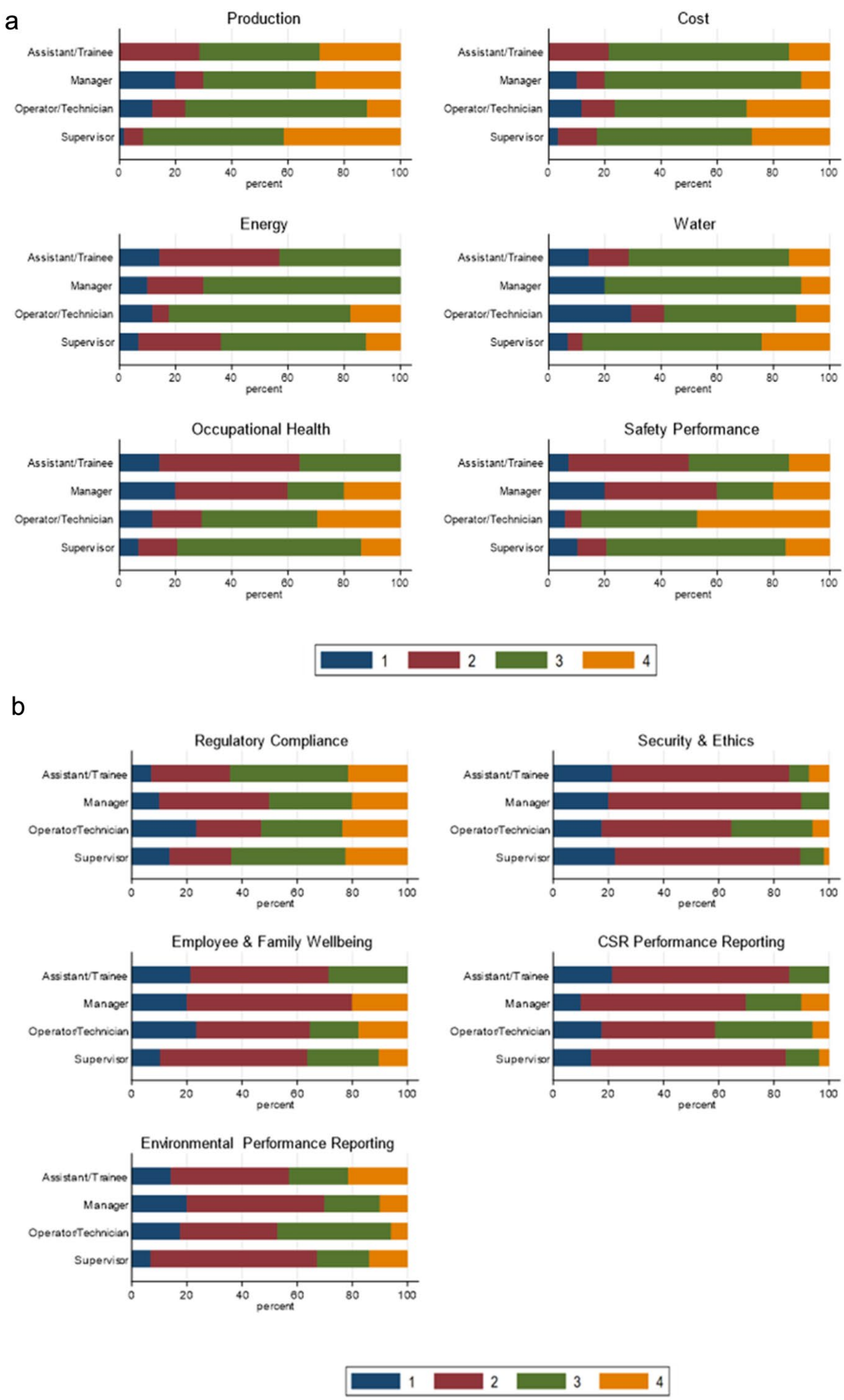
Determinants of climate change perception and willingness to adapt in mining

Finally, workers ranked the consequences of changing climate on corporate sustainability performance metrics in mining to infer the factors that can influence the industry's willingness to adapt. The results are presented in Fig. 4a and b. Irrespective of their positions, workers ranked high consequences of economic performance metrics such as production, cost, energy and water followed by governance performance metrics including occupational health and safety performances as well as regulatory compliance. Secondly, environmental sustainability performance metrics were perceived to have high consequences for changing climate compared to the metrics of social sustainability performances. It is noteworthy that operational workers ranked low the consequences on social metrics such as corporate social responsibility activities (CSR performance reporting) contrary to the corporate reports where *'licence to operate'* which is assured mostly through CSR is listed as a key climate risk to the industry. These reveal the divide between operations' perceptions vis-a-vis corporate reporting.

Discussion

From the empirical evidence, the increasing climatic variability in the forest zone of Ghana as perceived by employees corroborates the findings of previous hydro-climatic studies (Abbam et al. 2018; Atiah et al. 2019; Owusu and Waylen 2009). In addition, studies on indigenous perception of changing climate and the impact on the forest region affirmed similar results of perceived increasing climatic variability across the forest zone of Ghana (Boon and Ahenkan 2012; Fosu-Mensah et al. 2012; Nkrumah et al. 2019; Tannor et al. 2022). For instance, Boon and Ahenkan (2012) focused on climate impact and ecosystem services and livelihoods, whilst Fosu-Mensah et al. (2012) looked at changing climate impact and adaptation among rural agricultural communities. Similarly, Nunfam et al., (2019) examined the perceived heat-related stresses and exposure among mineworkers due to increasing temperature.

Mine water management is a major issue for both underground and surface operations, probably accounting for the high ranking of flooding and water shortages effects. Similarly, the discomfort and hazards associated with working within open-air metallurgical plants, tailing storage facilities, working in confined areas, underground and surface pits and with hot substances correlate with


a
Production
Cost
Energy
Water
Occupational Health
Safety Performance
Assistant/Trainee
Manager
Operator/Technician
Supervisor
0 20 40 60 80 100
percent
1 2 3 4
b
Regulatory Compliance
Security & Ethics
Employee & Family Wellbeing
CSR Performance Reporting
Environmental Performance Reporting
Assistant/Trainee
Manager
Operator/Technician
Supervisor
0 20 40 60 80 100
percent
1 2 3 4

changing climatic pattern. These can result in unplanned situations leading to injuries and equipment damage. The probability of increased road safety hazards associated with workers commuting back and forth, use of moving equipment for routine activities within operational sites and transportation of dangerous goods via the urban and feeder roads within mining region account for respondents' perspectives on the industries' susceptibility to local effects. These perspectives also echo the need for further studies into safety, occupational health and climate implications in mining sites.

Furthermore, the perceived effect of local changes on the operational activities as identified by respondents coupled with the increasing interest of TCFD member mining companies to integrate climate related-risk reflect the susceptibility of the industry to climate change impact. Literature from other regions including China (Sun et al. 2020), Peru (Gonzalez et al. 2019), Chile (Odell et al. 2018), Canada (Ford et al. 2010, 2011; Pearce et al. 2010) and Australia (Hodgkinson et al. 2010, 2014) corroborate these findings from the Ghanaian context. Hence, mining operations in southwestern Ghana need to adapt to the impact of changing local climatic conditions to coexist.

Employees identified practical adaptation strategies and spaces or options but acknowledged the helplessness of the operations management to act without external forces by prioritising regulatory and corporate-level intervention. Hence, the lack of action or slow pace of mining operations to adapt to changing climate might be due to a lack of strong external forces such as national regulations.

Consequently, respondents prioritised the implication of changing climate effect on economic and governance factors, which again infers the relevance of regulation to influence the industry's willingness to adapt to the impact of climate change. This may be so since a loss-making mine operation risk closure for which aspects such as production, cost, water and energy demand are prioritised. Equally, poor performances in regulatory requirements such as safety and occupational health performances, as well as breaching of environmental regulations, can lead to the suspension of a mine or even closure such as specified in Ghana's Minerals and Mining's Health, Safety and Technical Regulation 2012 (L.I 2182).

According to Arnell and Delaney (2006), an organisation's perception and willingness to adapt to climate change depend on the organisation's susceptibility to the changes, internal characteristics such as resources and capabilities as well as the regulatory and market context. From the empirical evidence, it can be deduced that regulatory and market context are most important determining factors of climate adaptation for the mining industry within the Ghanaian context. This may be so because; first, mining operations are generally aware of the susceptible nature of the physical mining activities to the impact of local climatic changes. Secondly, the industry has the financial resources and capabilities as multinational companies to implement such strategies at the operational level but is often slow to adapt. Hence external forces such as national regulation and other stakeholders such as the Ghana Chamber of Mines which once spearheaded the development of *the" Environmental Guidelines for Mining in Forest Reserves"* might be required to enjoin operations level adaptation, which has the potential to enhance resilience beyond the mines. Corroboratively, Bebbington et al. (2015) has discussed the need for appropriate governance mechanisms to combat double exposure of mining and climate change risk within the Latin American mining landscapes.

The primary data collection focused large-scale mining operations although there are an ample number of artisanal and small-scale mining activities ongoing in the region. The sample size was constrained by logistics and time hence generalising the outcome of the study should be done with caution. Irrespective of these limitations, this study contributes to the literature on climate adaptation processes within the mining industry by providing empirical perspectives from the West African region.

Conclusions

The perspectives of mining workers were examined to ascertain the implications of local climatic variability on mining operations performances within southwestern Ghana and to identify the industry's climate adaptation determinants using the corporate adaptation process framework proposed by Arnell and Delaney (2006).

Respondents were generally aware of and are concerned about the impact of changing local climatic conditions such as rainfall variability (seasonality, unpredictability, torrential rain) and increasing temperature on their routine activities. The Respondents perceived that such interactions present both opportunities and challenges to the operations and the surrounding socio-ecological systems. Particularly, mine water management issues (flooding, water shortage, excessive dust), as well as occupational health and safety issues (heat fatigue, work-related incident, disease burden), were ranked as high effects of the changing climatic pattern affecting their operations. Thus, affirming the susceptibility of the industry to the impact of changing climate. Moreover, workers identified institutional collaboration among the industries' governing bodies as a key adaptation strategy pertinent to enhance resilience within the mining system. In addition, they inferred regulatory and economic factors to determine the industries' perception and willingness to adapt to the impact of changing climate.

The empirical perspectives of workers as key stakeholders in the industry reveal the crucial role of institutional collaboration to encourage and drive pragmatic changes within the extractive resource industries, which will benefit local communities and the wider society. The call to combat climate change impact through resilience building and awareness-raising as well as human/institutional capacity on climate change adaptation according to Targets 1 and 3 of SDG 13 require the active involvement of the business society whose activities can potentially worsen the plight of vulnerable groups.

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Data availability statement All data collected from participation institution are available but restricted due to a contractual agreement signed at mine operations to maintain confidentiality.

Declarations

Competing interest On behalf of all authors, the corresponding author declares that there is no conflict of interest.

Ethical approval The study did not involve individual human participant or their data but rather focused on the operations level activities. Irrespective, ethical approval was obtained from the Ethical Committee of the Center for Development Research, University of Bonn. In addition, consent letters were signed at each mine operation before research work began.

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