Climate-Mining interactions and the effects on rural resilience

Perspectives from southwestern Ghana

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Dedication

This work is dedicated to the memory of my grandma Entwiwaa and Uncle James. Their support and presence shaped my worldview and inspirations for this work.

The work is also dedicated to my two kids Jeremy and Christabel for their sacrifice and endurance.

Abstract

Exploitation of natural resources including minerals contribute immensely toward development at different scales across West Africa. Mining is a prominent land-use practice within the region owing to the deposition of diverse mineral resources within the West African Craton though accompanied by huge socio-environmental footprints. The region has also been identified as a climate hotspot with its accompanying local effects. While mining operations are susceptible to the effects of changing climate, the surrounding socio-ecological systems are double exposed to the impacts of mining and changing climate for which vulnerable communities cannot adapt without external interventions such as corporate social responsibility initiatives. Worse of all, the actions of double exposed communities coupled with local climatic effects are detrimental to sustainable mining but climate change adaptation is hardly considered within the industry. What will make the mining industry willing to adapt at operations and enhance climate-resilient development within rural mining landscapes? The research examines this call for the industry to “adapt to coexist” through the lens of industrial ecology and climate change adaptation.

Employing an interdisciplinary approach, the industry is conceptualized as an eco-sociotechnical system in which the dynamically interactive sub-components self-organize and generate diverse outcomes that affect resilience within the entire system. Empirically the local effects of changing climate and the adaptation processes within the mining system in southwestern Ghana are examined. First, spatio-temporal trend in extreme rainfall and temperature variability across southwestern Ghana are analyzed using methods from hydrometeorology. The results confirm intensifying trend in extreme climatic indices such as decreasing number of normal wet years compared to extreme wet and dry years as well as increased warm nights across the forest zones. Secondly, indigenous perspectives confirmed the changing trend in terms of seasonality, prolonged dry season, torrential rains, general increase in temperature and onset of windstorms. The effects of these changes are perceived to affect the sustainability performances of mining operations and livelihood systems of surrounding communities according to workers and household heads respectively. Guided by the corporate climate adaptation model, it was observed that operational workers are aware and have concern that the mining industry is susceptible to the effects of changing local climatic conditions. Workers advocated for collaborative efforts from state-appointed regulators and the industries’ governing bodies to engender climate change adaptation into minerals development and governance. Workers also inferred regulation and economic performance implications to determine the industry’s willingness to adapt. Corroborative perspectives from households within resource-fringe communities affected by different extractive types (mining, forestry, petroleum) and non-extractive communities confirmed a general awareness that increasing local climatic variability affects rural livelihood resources just as extractivism. However, the extent of these perceptions was differentiated by contextual factors of household heads for which livelihood interventions must be tactfully targeted. Household heads also identified various adaptation strategies to enhance resilience within rural miningscapes such as policies to improve farm management and technologies, diversify income sources, enhance climate risk awareness and management and improve rural infrastructure.

The study explored holistic perspectives on local effects of changing climate in rural Ghana to underscore the need for collaborative efforts principally toward tackling climate and extractivism exposures in mining landscapes where adaptation policies are hardly considered. Thus, illuminating the double exposure of socioecological systems in mining landscapes and the discourse on climate change and mining in West Africa. As academic contribution, the study provides interdisciplinary research conceptualization, design and methodologies as well as policy-relevant empirical perspectives in ecology and development.

Zusammenfassung

Wechselwirkungen zwischen Klima und Bergbau und Auswirkungen auf die Widerstandsfähigkeit des ländlichen Raums: Perspektiven aus dem Südwesten Ghanas.

Abstrakt

Die Ausbeutung natürlicher Ressourcen, einschließlich Mineralien, trägt immens zur Entwicklung auf verschiedenen Ebenen in ganz Westafrika bei. Aufgrund der Ablagerung vielfältiger Bodenschätze im westafrikanischen Kraton stellt der Bergbau in der Region eine bedeutende Landnutzungspraxis dar, die jedoch mit enormen sozialen und ökologischen Fußabdrücken einhergeht. Die Region wird auch als Klima-Hotspot mit begleitenden lokalen Auswirkungen bezeichnet. Während Bergbaubetriebe anfällig für die Auswirkungen des Klimawandels sind, sind die umliegenden sozioökologischen Systeme den Auswirkungen des Bergbaus und des Klimawandels doppelt ausgesetzt. Ohne externe Interventionen wie sozialen Verantwortung von Unternehmen können sich anfällige Gemeinschaften nicht anpassen. Schlimmer noch, die Handlungen der doppelt exponierten Gemeinschaften in Verbindung mit lokalen Klimaauswirkungen schaden dem nachhaltigen Bergbau, trotzdem berücksichtigt die Branche Anpassung an den Klimawandel kaum. Was könnte die Bergbauindustrie dazu bringen, sich in ländlichen Bergbaugebieten anzupassen und eine klimafreundliche Entwicklung zu fördern? Diese Studie untersucht die Notwendigkeit der Industrie, sich „adapt to coexist“, unter dem Gesichtspunkt der Industrieökologie und der Anpassung an den Klimawandel.

Mit einem interdisziplinären Ansatz wird die Industrie als öko-soziotechnisches System konzipiert, in dem sich die dynamisch interagierenden Teilkomponenten selbst organisieren und unterschiedliche Ergebnisse generieren, die die Resilienz des Gesamtsystems beeinflussen. Empirisch werden die lokalen Auswirkungen des Klimawandels und die Anpassungsprozesse innerhalb des Bergbausystems im Südwesten Ghanas untersucht. Zunächst werden räumlich-zeitliche Trends bei extremen Niederschlägen und Temperaturschwankungen im Südwesten Ghanas mit Methoden der Hydrometeorologie analysiert. Die Ergebnisse bestätigen einen sich verstärkenden Trend bei extremen Klimaindizien, wie z. B. einer abnehmenden Anzahl normaler Regenjahre im Vergleich zu extrem nassen und trockenen Jahren sowie einer Zunahme warmer Nächte in den Waldgebieten. Auch belegen indigene Ansichten den sich ändernden Trend in Bezug auf Saisonalität, verlängerte Trockenzeit, sintflutartige Regenfälle, allgemeinen Temperaturanstieg und Auftreten von Stürmen. Die Auswirkungen dieser Veränderungen wirken sich auf die Widerstandsfähigkeit der vorherrschenden Wirtschaftssysteme im ländlichen Bergbaulandschaft aus, wie von Arbeitern und Haushaltsvorständen dargelegt. Basierend auf der Corporate Klimaanpassungsmodell wird beobachtet, dass sich die Betriebsmitarbeiter darüber im Klaren sind und Besorgnis haben, dass die Bergbauindustrie anfällig für die Auswirkungen sich ändernder örtlicher klimatischer Bedingungen ist. Die Arbeitnehmer haben auch die Auswirkungen der Regulierungen auf die Wirtschaftsleistung berücksichtigt, um die Bereitschaft der Industrie zur Anpassung zu bestimmen. Bestätigende Perspektiven von Haushalten in Gemeinden am Rande der Ressourcen sind untersucht worden. Die Fallstudiengemeinschaften, die von verschiedenen Arten der Rohstoffgewinnung (Bergbau, Forstwirtschaft, Erdöl) betroffen sind, und die Gemeinschaften, die nicht von der Rohstoffgewinnung betroffen sind, bestätigten

ein allgemeines Bewusstsein dafür, dass die zunehmende lokale Klimavariabilität die ländlichen Existenzgrundlagen ebenso beeinträchtigt wie die Rohstoffgewinnung. Das Ausmaß dieser Wahrnehmungen ist allerdings durch kontextuelle Faktoren der Haushaltsvorstände unterschieden worden, auf die Maßnahmen zur Sicherung der Existenzgrundlage taktvoll ausgerichtet werden müssen. Die Haushalte haben auch verschiedene Anpassungsstrategien genannt, um die Widerstandsfähigkeit der ländlichen Bergbaulandschaft zu erhöhen, wie z. B. Maßnahmen zur Verbesserung des landwirtschaftlichen Managements und der Technologien, zur Diversifizierung der Einkommensquellen, zur Stärkung des Bewusstseins für Klimarisiken und des Risikomanagements sowie zur Verbesserung der ländlichen Infrastruktur.

Die Studie untersucht ganzheitliche Perspektiven auf die Auswirkungen des lokalen Klimawandels in ländlichen Gebieten Ghanas, um die Notwendigkeit gemeinsamer Anstrengungen hervorzuheben, insbesondere im Hinblick auf Klimarisiken und Extraktivismusrisiken in Bergbaulandschaften die in der Politik zur Anpassung an den Klimawandel selten berücksichtigt werden. Auf diese Weise werden die doppelten Belastungen sozio-ökologischer Systeme im Bergbaulandschaften hervorgehoben und zum Diskurs über Klimawandel und Bergbau in Westafrika aufgefordert. Als wissenschaftlicher Beitrag liefert die Studie interdisziplinäre Forschungskonzepte, -entwürfe und -methoden sowie empirische Perspektiven mit Relevanz für die Umwelt- und Entwicklungspolitik.

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List of abbreviation

AEL	*African Explosives Limited*
CCC	*Community Consultative Committee*
CDD	*Consecutive dry days*
CGML	*Chirano Gold Mines Limited*
CHP	*Community based health planning*
CSR	*Corporate social responsibility*
CWD	*Consecutive wet days*
DTR	*Diurnal temperature*
EMS	*Environmental management system*
EPA	*Environmental Protection Agency*
ESTS	*Eco-sociotechnical system*
ETCCDI	*Expert team on climate change detection indices*
FAO	*Food and Agriculture Organization of the United Nations*
G4	*Fourth edition guidelines*
GDP	*Gross domestic product*
GEC	*Global environmental change*
GPCC	*Global Precipitation Climatology Centre*
GRI	*Global Reporting Initiative*
GSS	*Ghana Statistical Services*
HSSE	*Health, safety, security and environment*
IAHR	*International Association of Hydro-Environment Engineering and Research*
H_0	*Null hypothesis*
H_1	*Alternative hypothesis*
ICMM	*International Council on Mining and Metals*
ICT	*Information and communication technologies*
IDW	*Inverse distance weighting*
IMF	*International Monetary Fund*
IPCC	*Intergovernmental panel on climate change*
ISO	*International organization for standardization*
IUCN	*International Union for Conservation of Nature*
KAAD	*Catholic Academic Exchange Service*
MESTI	*Ministry of environment, science technology and innovation*
mm	*Millimeters*
NDCs	*Nationally determined contributions*
NTFPs	*Non-timber forest products*
NMHSs	*National Meteorological and Hydrological Services*
PRCP	*Precipitation*
PRCPTOT	*Annual total wet day precipitation*
R20	*Number of very heavy rainfall days*
R99p	*Extremely wet days*
RAI	*Rainfall anomaly index*
RQ	*Research Question*
SDG	*Sustainable development goal*
SDII	*Simple daily intensity index*

SES	*Social-ecological system*
SOP	*Standard operating procedures*
SPI	*Standardized precipitation index*
TCFD	*Task force on climate related financial disclosure*
Tmax	*Mean monthly maximum temperature*
Tmin	*Mean monthly minimum temperature*
TNmean	*Monthly average value of daily minimum temperature*
TSF	*Tailings storage facility*
TXmean	*Monthly average value of daily maximum temperature*
UK	*United Kingdom*
UNECA	*United Nations Economic Commission for Africa*
UNFCCC	*United Nations Framework Convention on Climate Change*
USD	*United States dollar*
WAC	*West African Craton*
WASH	*Water, sanitation and hygiene*
WMO	*World Meteorological Organization*
WRC	*Water Resources Commission*
ZEF	*Center for Development Research*

Chapter one

1 Introduction

1.1 Problem Statement and Justification

Synergy exists within the goals and targets of various development policies aimed at improving human wellbeing and conserving nature amidst the effects of global environmental change (GEC) by advocating for resilience building as a mainstream for achieving sustainability. For instance, target 1 of the 13th Sustainable Development Goal (SDG) (Actions to combat climate*), "advocates for members to strengthen resilience and adaptive capacity to climate-related hazards and natural disasters"*. Similarly, Article 7 of the Paris agreement campaigns for *"increased ability for Parties to adapt to the adverse impacts of climate change, and to foster climate resilience and low greenhouse gas emissions development"* (UNFCCC, 2015b). Of particular interest in section 2 of the Paris 7th Article is the need to contribute to the long-term global response to protect people, livelihoods and ecosystems of developing country Parties. Thus, the different actors of society including national governments, rural communities, business society and academia have roles to play in ensuring that both natural and human systems are able to adapt to the local effects of GEC.

GEC refers to "*a set of changes to the earth system that are expected to have major effects on human society and ecosystem services"* (Leichenko & O'Brien, 2008). GEC includes systemic and cumulative natural changes (Dirzo et al., 2014; Pyhälä et al., 2016). Systemic changes directly influence the functioning of the earth system such as global warming and climate variability driven by increasing atmospheric concentration of greenhouse gases. The cumulative local changes refer to changes that influence the global environment through the magnitude and distribution of their effects at different scales such as land-use change and loss of biodiversity (Pyhälä et al., 2016). GEC is largely driven by human activities (IPCC, 2007; Karl & Trenberth, 2003; Zalasiewicz et al., 2011) through resource extraction, energy consumption, urbanization, politics, technological change, among others (Zalasiewicz, 2011, p. 838). The effects of GEC in turn affect human societies through impacts on human lives, values, infrastructure and natural resource systems (Folke, 2016; RockStröm et al., 2009; Steffen et al., 2004; Zalasiewicz et al., 2011).

To understand the local dimension of the effects GEC at rural landscape level, an interdisciplinary approach is needed to examine local effects on human and natural systems in order to identify innovative and transformative approaches pertinent to enhance resilience (K. O'Brien, 2012). Resilience within rural landscapes is measured by the synchronous achievement of economic, cultural and ecological balance (Heijman et al., 2019). Hence, pathways to enhance resilience within rural miningscapes must focus on measures to ensure sustainability of the multiple land-use systems such as mining, agriculture and natural heritage systems amidst the local effects of changing climatic conditions. The term 'Miningscapes' refers to the landscapes dominated by mining territories mainly owned by multinational operations (M´endez et al., 2020) and are characterized by conditions whereby socio-environmental footprints from the multiple-land-use practices threaten rural resilience. Rural resilience is opined as a modernized version of rural development whereby rural areas have the capacity to adapt to surrounding changing conditions in such a way, that a satisfactory standard of living is maintained (Heijman et al., 2019, p.383). Moreover, resilience according to Folke (2016) "is *about cultivating the capacity to sustain development in the face of expected and surprising change and the diverse pathways of development and potential thresholds between them"*.

The West African region is particularly vulnerable to the impacts of changing climatic conditions due to its high dependency on rain-fed agriculture and the inherent deficits in developmental and infrastructural systems necessary for conceiving and implementing adaptation measures (IPCC, 2022; K. Sanogo et al., 2017; Yaro & Hesselberg, 2016). Accordingly, the latest report of the Intergovernmental Panel on Climate Change (IPCC) (2022, p. 12-14) emphasizes with high confidence the vulnerability of humans and ecosystems in locations with poverty, governance challenges, limited access to basic amenities and climate-sensitive livelihood resources such as rural West Africa. The region depends mainly on natural resource extraction for development at both national and rural level (André-Mayer et al., 2015; Masurel et al., 2021). Being rich in mineral resources, countries within the southern part of the West African Craton (WAC) are prolific in mineral extraction including Liberia, Ivory Coast, Ghana, Burkina Faso, Mali and Guinea (Markwitz et al., 2016; Williams et al., 2015; World Bank, 2014). Ironically, most of the mineral depositions are located within the Tropical Guinean forest zones (IUCN, 2012) which is globally recognized as one of the most important biodiversity hotspots with several ecoregions (IUCN, 2012, p. 30). Hence, the likelihood of national and rural development as well as conservation trajectories crisscrossing within West African rural landscapes is high. Apart from combating climate-led vulnerabilities, enhancing livelihood resilience within these landscapes is a prerequisite to safeguard the natural and cultural heritage systems, since rural landscapes embody the natural and historic heritage of its nations (Agnoletti, 2014).

The sparse nature of networks systems for monitoring hydroclimatic dynamics in the region leads to a limited availability of hydro-meteorological data within the region. This impede the capacity to monitor trends in variability, including extreme events which is necessary to enable informed decision-making on climate risk awareness and preparedness. Irrespective of the proliferation of satellite based and reanalysis of climatic data mostly adopted as quasi-observational data for the region, caution is given on the accuracy of such data in estimating variability in climate extremes (Manzanas et al., 2014). Hence, available observed data remain relevant to understand the trends in extreme rainfall and temperature variability in the region. Extreme climate indices are particularly useful pointers to understand water resources systems, which are directly affected in quality and quantity by multiple-land-use activities within miningscapes. Particularly, land-use systems such as mining, farming, potable water production, nature conservation and settlements development dynamically interact with the local climatic regimes such as rainfall and temperature variabilities. Hence, changing trends in climatic variability, be they naturally induced or anthropogenic, have implications on the sustainability of human and natural systems for which hydrometeorological hazard studies in such landscapes are incomplete without examining the human perspectives on the local effects of such changes. This makes indigenous knowledge a crucial information source to understand the local effects of changing climate as well as strategizing the adaptation mechanisms within rural landscapes.

The southwestern part of Ghana is dominant for mining and agricultural production owing to the favorable bimodal rainfall regime in southern Ghana. Southwestern Ghana also hosts the country's portion of the Tropical Guinea forest, hence characterized by several protected forestlands. Most of these forestlands protect headwaters of major rivers within the southwestern basin system, which are the Bia, Tano, Ankobra and Pra rivers. The Bia and Tano river basins are transboundary; both rise within Ghana and enter the Gulf of Guinea via the Aby

Lagoon in Ivory Coast. The Tano, Ankobra and Pra basins are particularly known for minerals extraction, timber, cocoa, palm oil and rubber plantations (WRC, 2012a).

Mineral extraction in particular has wide socio-environmental footprints within southwestern Ghana (Armah et al., 2012; Kumah, 2006; Schueler et al., 2011), which can be escalated by the local effects of a changing climate. The simultaneous impacts of mining and changing climate affects the resilience of surrounding fringe communities and their dependent ecosystems. Such impacts can aggravate into discords within and beyond the country if not managed appropriately. On the other hand, the local effects of changing climate directly influence physical mining activities and can affect the sustainability of the industry, thus posing a high risk to the national economy to which mining is a key contributor. Therefore, mining and climate impacts can concurrently burden sustainable development in Ghana if climate change adaptation is not mainstream within rural miningscapes.

Given the challenges above, involving operational workers and rural households to understand the local effects of GEC and adaptation strategies within miningscapes becomes imperative although hardly investigated within the West African region (Odell et al., 2018). There is a general perception that resource-fringe communities, such as those affected by minerals and petroleum extraction, are socio-economically resilient owing to the benefits accrued from corporate responsibility initiatives although no empirical evidence exists to prove such claims. Rather, the local effects of GEC, such as the dynamic processes of mining as a land-use system and changing local climatic conditions can double burden resource-fringing communities and their dependent ecosystems. The need for appropriate governance mechanisms to address mining and climate exposures within resource-fringe communities has been identified within Latin American miningscapes (Bebbington et al., 2015). Since extractive resources remain a key development pillar in Ghana at both national and local scales, the need to examine the dynamics of local change processes confronting sustainable development trajectories within miningscapes cannot be overemphasized.

Thus, this research seeks to advance the need for collaborative approaches towards adaptation to climate change impact in rural miningscapes by first characterizing mining as an industry operating as a sociotechnical system embedded in the natural system. Within this complex system, the local effects of GEC affect the resilience of various components including the mining operations, surrounding rural communities as well as their dependent ecosystems. Consequently, emergent outcomes from surrounding systems will reciprocally affect mining sustainability for which operation's level adaptation is insufficient without involving the surrounding systems. Empirically, the situation of rural miningscapes within southwestern Ghana are examined to provide ground truthing for this conceptual call by this study that mining industries ought to "*adapt to coexist*" within rural miningscapes.

1.2 Research Objective and Questions

This dissertation aims to contribute to enhancing the knowledge and insight on ecology and development by examining the local effects of GEC on sustainable resource development within rural landscapes of southwestern Ghana. The study develops an interdisciplinary framework that conceptualizes the interactions of climate, the extractives and their surrounding socioecological system. Guided by the framework, the following research questions (RQ) are empirically investigated to understand the case of rural mining landscapes across southwestern Ghana:

RQ1. Is there cause for alarm for resource managers regarding trends in rainfall/temperature variability across the forest miningscapes in southwestern Ghana?

I. What is the trend in extreme rainfall events across southwestern Ghana over the past 40 years?
II. Have there been significant changes in extreme rainfall variability across southwestern Ghana?
III. Have there been significant changes in extreme temperature variability across the miningscapes?
IV. Are there performance implications for natural resource management within the southwestern miningscapes?

RQ2. How resilient is the mining industry in Ghana amidst the local effects of changing climate as perceived at operations?

I. Are operational workers aware of, and have concern for the local effects of changing conditions on mining activities?

II. Which adaptation strategies are perceived to enhance resilience building within the miningscape?

III. Which of the corporate sustainability performance metrics influences the industry's perception and willingness to adapt?

RQ3. What have been the experiences of households on the effects of changing climate, ongoing extractivism and livelihood resilience within the miningscapes?

i. Do households perceive climate variability effects on their livelihoods similarly as extractivism?

ii. What are the contextual factors influencing households' perception of climate variability and extractivism exposures on livelihood resources?

iii. Which response strategies can enhance households' capacity to adapt to such double burden?

1.3 Conceptual Framework and Research Approach

1.3.1"Adapting to Coexist": Conceptualizing the Adaptation Processes in Miningscapes

Given the complex nature of climate-mining interactions and the effects on resilience in landscapes in rural West Africa, a conceptual framework was developed to nuance the research problem as well as exemplify the case of Ghanaian rural miningscapes. The framework can serve as an interdisciplinary framework to examine climate adaptation process within landscapes that are exposed to the impacts of extractivsm and changing climate.

Within the context of industrial ecology and system thinking, this research postulates the nature of the mining industry operating within rural landscapes to be systemic and interact dynamically with different entities within the landscape. Secondly, the local effects of GEC perturb the resilience of systems within the entire landscape. Thus, some form of adaptation is needed to enhance resilience within the landscape. Given the systemic nature of the industry, on-site adaptation to local effects of changing climate is inadequate at operations level unless targeted as corporate strategy, which will extend resilience building within the entire landscape.

A key strategy of the international council for mining and metals (ICMM) is to empower the industry to collaborate to enhance sustainable development driven by the improved performance in social, environment and governance issues (ICMM, 2022). ICMM thus reiterates the strong interrelatedness of corporate adaptation to climate change impact and rural resilience within miningscapes. Particularly, embracing climate change adaptation as a corporate responsibility will empower surrounding socio-ecological systems (SES) to adapt to the double exposure impacts of mining and climate change, thus contributing directly to the achievement of sustainable development.

Socio-ecological system (SES) refers to the intertwined and non-decomposable nature of human systems (cultural, social, political, economic) and ecological systems such that their interactions shape the systems' dynamics (Berkes et al., 2003; Gallopin, 2006; Gallopin et al., 2001). SES is considered as the natural unit of analysis for sustainable development research (Gallopin et al., 2001, p.224), hence within the rural miningscapes, resource-fringe communities and their dependent ecological system can be considered as the unit of analysis to understand the double exposure effects of mining and local climatic changes. Pragmatic measures to enhance resilience within such surrounding SES is imperative for mining operations since the emergent outcome of the double exposed systems reciprocally jeopardize sustainable mining.

Furthermore, the willingness of the industry to adapt physical mining activities at operational sites will include improving the capacity of surrounding fringe communities to enhance their wellbeing. This is feasible since mining sustainability performance metrics include socio-environmental performances by which the industry is assessed. One of such corporate sustainability reporting guidelines is the global reporting initiative (GRI) by which most of the leading multinational mining companies are voluntarily assessed (Azapagic, 2004; Fonseca et al., 2014). These sustainability metrics as assessed on operational sites include corporate responsibility activities earmarked to address the environmental aspects of mining such as community engagement and development, environmental management best practices, occupational health and safety management, human resource management, regulatory compliance etc. However, corporate adaptation to climate change impact must be motivated by definitive factors as currently deliberated within different disciplines. For instance, management science, climate change and industrial ecology literature confirm corporate adaptation to climate change impacts as an evolving paradigm (Busch, 2019; Gasbarro & Pinkse, 2016; Hoffmann et al., 2009; M. K. Linnenluecke et al., 2015; Pinkse & Gasbarro, 2019) although organizational adaptation as a subject already exists in the literature (Lewin et al., 2004).

Industrial ecology as a systemic approach (Allenby, 2009; Duchin & Levine, 2018) to manage natural resources seeks to optimize resource management by developing interactions between various stakeholders occupying a common geographic location (Cerceau et al., 2018, p.29). These stakeholders include the biotic and abiotic factors occupying the common geographic location. Industrial ecology enables resource managers to characterize industrial systems not in isolation from the surrounding systems but in tandem with them (Lifset & Graedel, 2002, p.4).

Frameworks of industrial ecology posit the relationship between an industry and its environment as being complex and adaptive (Dijkema & Basson, 2009; Kay, 2002). Complex adaptive systems are known to exhibit multidimensional and emergent behaviors (Berkes et al., 2003) as well as other characteristics as such as interrelatedness, self-organization, feedback, non-linearity and adaptability as abridged by Aritua et al. (2007; p.5) in the context of managing construction projects (Aritua et al., 2009). Others contextualize industries as a subsystem of the natural system (Chertow & Portlock, 2002; Duchin & Levine, 2014; Lifset & Graedel, 2002). For example, Duchin and Levine (2014, p.353) illustrate the built environment as being part of the biophysical structure of the SES, which is subject to the laws of nature in an interactive process.

Progressively, concepts and tools of industrial ecology, such as life cycle assessment and industrial metabolism, have been applied to assess impacts of industrial activities on surrounding systems from an inside-out perspective (Busch, 2019; Chester, 2020). For instance, literature establishes the usefulness of industrial ecology tools to implement corporate responsibility strategies within the mining and building construction industries (Kay, 2003; McKinley, 2008) in a bid to manage the social and environmental problems of the industries.

In relation to climate change adaptation, Busch (2019) reviewed the state-of-the-art tools and concepts of industrial ecology and climate adaptation. He concluded that those tools were less useful to address climate change adaptation within organizations since their designs have been based on inside-out perspectives (Busch, 2019, p.1). However, as a systemic approach, diagnosing the impact of changes from surrounding natural systems on the industry from an outside-in perspective is conceivable since whole systems mutually interact. In addition, being a natural resource system, the industrial system exhibits complexity and is shaped by the unpredictable internal and external dynamics (Aritua et al., 2009; Rammel et al., 2007). Such perspective is in congruence with Chertow and Portlock's (2002, p.9) conceptual framework of industrial ecology where the industrial system is characterized to be embedded in the natural system.

In addition, the dynamic interactions of the system's components generate sustainability outcomes as the emergent properties (Ehrenfeld, 2007, p.77) of the system. This aptly illustrates Allenby's (2006, p.33) definition of industrial ecology "*as a system-based, multidisciplinary discourse seeking to understand emergent behavior of complex integrated human/natural systems*". In this case, the local effects of GEC can be viewed as an emergent outcome, which affects resilience within the entire mining system for which adaptation strategies must not only address issues within the industry, but also include adaptation measures within the surrounding SES. Moreover, the tools of industrial ecology then become relevant to address local effects of GEC within rural miningscapes.

The point of departure from Chertow and others' concept is that the mining industry is characterized as a sociotechnical system operating within the natural system. Actually, sociotechnical system thinking evolved from studies within coal mining operations (Bauer & Herder, 2009) and emphasizes the close intertwines of the social (institutions and actors) and the technical (technology, best practices, infrastructure) subsystems (Fuenfschilling & Truffer, 2016). Thus, the mining industry can be typified as an eco-sociotechnical system whose components (natural, social and technical) interact dynamically to generate emergent properties as the system's sustainability outcomes (figure 1-1).

This complex system is composed of natural systems which include the biotic and abiotic components of the ecosystem such as mineral rich lands, soil, air, faunal and flora diversity and dependent livelihood resources as well as the local climatic system (A) within which all other subsystems are embedded. The social subsystem consists of the socio-political institutions and actors including the organization management, employees and local stakeholders, financial institutions and investors, national government, investors, state-appointed and international regulatory bodies among others which influence the activities of the industry (B). The technical subsystem consists of the industry's technology, infrastructure and operations best practices (C).

The components of the mining eco-sociotechnical system interact dynamically and generate outputs (blue line) which are the extracted minerals. In addition, emergent outcomes such as the environmental aspects emanate from physical mining activities (redlines) which determine the overall performance or sustainability of the operation as well as impact the surrounding systems. The ISO 14001 environmental management system (EMS) defines environmental aspects as the various elements of an organization's activities, product or services that interact or can interact with the environment. The environment in this definition refers to the surroundings in which the organization operates, including air, water, land, natural resources, flora, fauna, humans and their interrelationships. At operations level, environmental aspects are to be managed appropriately to enhance the non-financial or sustainability performances (D) via departments such as human resources, corporate social responsibility, safety, occupational health and environmental management although their efforts can be daunted by the local effects of increasing climatic variability.

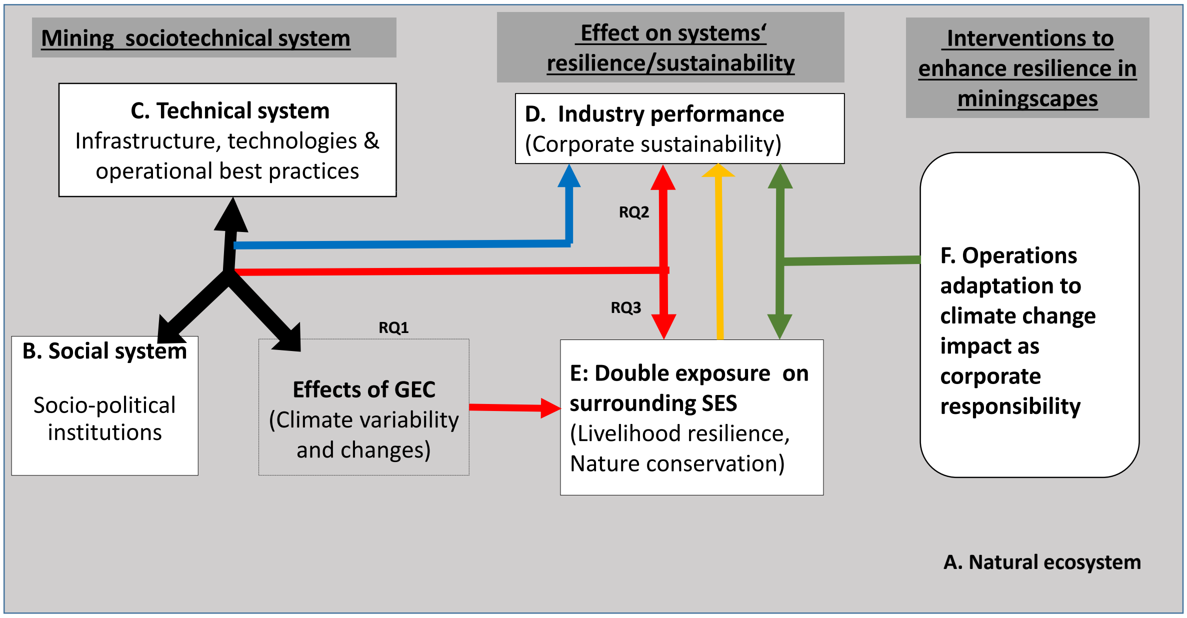

Figure 1-1: "Adapt to coexist": conceptualizing the local effects of GEC on resilience in mining ESTS. (Source: developed by author inspired by Chertow & Portlock, 2002; Ehrenfeld, 2007; Linnenleucke and Griffiths, 2010; O'Brien and Leichenko, 2000). *NB: ESTS = eco-sociotechnical system, GEC = Global environmental change, SES = Socio-ecological systems.*

Simultaneously, these environmental aspects of mining combine with the local effects of changing climatic conditions to double burden the surrounding SES (E). Invariably, the emergent outcomes of double exposed SES (orange line) reciprocally affect operations' resilience if not managed appropriately. For instance, in an operation where effluents are poorly managed, excessive rainfall can facilitate the transport of the contaminant into nearby community water-bodies. This can result in a communal insurgence detrimental to the operation's activities within the landscape, apart from the financial and reputational implications for the corporation.

Thus, it is imperative for the mining industry to perceive and be willing to adapt to the impacts of changing climate through various interventions (green lines) in order to enhance operational resilience and empower surrounding households and their dependent ecosystems to adapt (F). Therefore, corporate adaptation to the impacts of changing climate in miningscapes is key to ensure harmonious coexistence between the industrial system and the surrounding society.

To empirically understand the local perspectives on the impact of changing climate and the adaptation processes within the miningscapes of southwestern Ghana, the three research objectives were identified guided by the components of the framework as summarized below:

The first objective, (RQ1) analyzes climate variability as a natural phenomenon (A) that is changing and its interactions with the mining eco-sociotechnical system. The second objective, (RQ2) examines the self-organized outcomes of climate-mining interactions and the effects on mining operations' performance (D) as well as the adaptation processes. Finally, third objective (RQ3) investigates the double exposure outcome of climate-mining interactions on the resilience of surrounding SESs (E).

1.3.2 Approaches Used to Assess Climate Change Impacts and Adaptation in Miningscapes

Extant literature establishes that physical mining activities are susceptible to the local effects of increasing climatic variability and changes (Deloitte & Touche, 2008; Ford et al., 2010, 2011; Hodgkinson et al., 2010; Odell et al., 2018; Rüttinger & Sharma, 2016) similarly as their surrounding SES (Boon & Ahenkan, 2012; Loechel et al., 2013). More critically, rural communities and their dependent ecosystems fringing mining operations are exposed to the impacts of mining and changing climate simultaneously (Bebbington et al., 2015; Sonter et al., 2018). This concept of double exposure, whereby impacts of economic globalization and GEC affects other resources or human systems, is well established in the literature (Leichenko & O'Brien, 2008; McKune & Silva, 2013; Nolan et al., 2022; K. L. O'Brien & Leichenko, 2000).

Hence, to enhance resilience in miningscapes is not only to ensure that operational performances are not perturbed by the local effect of GEC or at best, operations are able to adapt to the local effects. At the same time, surrounding resource-fringe communities and ecosystems must also have the capacity to adapt to the simultaneous impacts of mining and changing climate. That is, both the mining industry and the surrounding SES must be able to persist or evolve and continue to grow by adapting to the ever changing environment (Preiser et al., 2018; Walker et al., 2004).

The IPCC (2001) defines climate adaptation *"as the adjustment in ecological, social or economic systems in response to actual or expected climatic stimuli and their effects or impacts. This includes changes in processes, practices or structures to moderate or offset potential damages or take advantage of opportunities associated with changes in climate. It involves adjustments to reduce the vulnerability of communities, regions or activities to climatic change and variability"*. Climate adaptation thus involves continuous processes and actions required by a system apart from the system's benchmark activities to develop and evaluate response options to reduce the negative effects of climate changes (Füssel, 2007). Climate adaptation provides an option to analyze factors of socio-environmental injustice (Pelling, 2011) which are prominent in miningscapes. Adaptation processes include changing the system's behavior (Brooks, 2003) by identifying the exposures and sensitivity variables or the aspect of the system's adaptive capacity (Rothman et al., 2014).

Corporate climate adaptation is a formidable option for businesses to capitalize on opportunities and reduce harm from the effects of increasing variability and changes (Berkes & Jolly, 2001; IPCC, 2014). Particularly, corporate adaptation to climate change has the potential to improve the capacity of resource-fringe communities to adapt when considered as corporate responsibility as similarly observed for the agricultural industries (Bianco, 2020). Corporate responsibility refers to the diverse ways by which industries or organizations are responsible to society as a whole and to the segment of society within which the organization interacts (Carroll et al., 2012). The ISO 26000 definition of corporate responsibility challenges organizations to contribute to sustainable development, account for the expectations of stakeholders, comply with applicable laws and be consistent with international norms of behavior. Thus, corporate responsibility strategies might be motivated by both philanthropic and regulatory criteria aimed at integrating sustainable development into mining.

Climate adaptation options and sustainable development targets such as poverty reduction and environmental justice are expected to be complementary (Eriksen & Brown, 2011; IPCC, 2014) although poorly aligned within the mineral extractives. Adaptation analysis is implicit in diverse fields of study such as water management, risk management, community development, livelihood security, food security, among others (IPCC, 2014). These aspects of development geography are pertinent in corporate responsibility and sustainability objectives in mining through which climate change adaptation can be streamlined. For instance, a key task in mine water management is to manage extreme situations (drought and floods) which are a feature of the hydrological system but now aggravated by the impacts of climate and land-use changes. Hence, conceiving adaptation to climate change impacts on water resources within miningscapes can build on the knowledge, tools and infrastructure which are already available, but now have to be overhauled.

On-site adaptation is among the numerous climate responses relevant to prevent the effects of a changing climate on mining system's resilience (Sharma & Franks, 2013). Hence, understanding the impact of climate change and adaptation processes at operations level via identifying the susceptibilities, impacts and the aspect of the system's adaptive capacity as found in previous models developed by Ford and Smit (2004, p.395), Smit and Wandel (2006, p.288) and Garnaut (2008, p.125) are relevant. Ford and Smit's approach was initially used as an analytical tool to assess the impact of climate change on mining-fringe communities in the Canadian Arctic region (Ford & Smit, 2004). To analyze the impact of climate change on mining in Canada, Pearce et al. (2010, p.3) combined two approaches (Ford & Smit, 2004; Smit & Wandel, 2006). Similarly, Garnaut's (2008) model, originally used to assess climate change impact and vulnerability in Australia, was adopted to examine climate adaptation within Australian mining and exploration industries (J. Hodgkinson et al., 2010).

These frameworks had no reference to the consequential outcomes of the mining-climate interactions as identified in an analytical framework used to review current literature on mining and climate change (Odell et al., 2018). The framework from Odell and colleagues identified intersecting impacts on other resources, synonymous to the double exposure concept, as well as the relevance of perception and responses of key stakeholders in shaping public policy and industry practices (Odell et al., 2018, p.5). Thus, including the perspectives of key stakeholders within miningscapes is critical towards strategizing effective adaptation approaches. For instance, the perspectives of key actors such as operational workers and households are critical to understand mining-climate interactions apart from the climate risk analysis, which characterize most of the mining-climate studies (Damigos, 2012; Gonzalez et al., 2019; Liu & Song, 2019).

Other frameworks developed to analyze adaptation to climate change impacts within industrial organizations include the organizational adaptation to climate impact model by Berkhout et al. (2003) as cited in Arnell and Delaney (2006). These authors attribute adaptation to the impacts of climate within an industry as a learning behavior (Berkhout et al., 2006), thus positioning workers as key players in the adaptation process. Arnell and Delaney (2006) modified the model to include the idea of three groups of adaptation determinants, which influence an industry's perception of climate change impacts and willingness to adapt (Arnell and Delaney, 2006, p.2). This modified framework has been applied to examine the climate adaptation processes within water supply companies in England and Wales (Arnell & Delaney, 2006).

Apart from the spatiotemporal analysis of climate variability across the miningscapes, this research adopted the double exposure framework (Leichenko & O'Brien, 2008; Odell et al., 2018) and Arnell and Delany's (2006) model for corporate adaptation to climate change impacts to contextualize the household and operations perspectives, respectively.

1.3.3 Research Design

The general methodological approach employed in the empirical research is presented in figure 1-2 below. A qualitative approach was adopted during the reconnaissance visit to examine the implications of changing local climate on corporate responsibility, which is envisaged as a key development tool in rural miningscapes.

The study then analyzed trends in climatic variability across southwestern Ghana in time and space. Although previous hydrometeorological studies asserted increasing variability in the forest zone of Ghana, the focus of the analysis here was to estimate indices on extremes that have relevant implications for mining as multiple land-use practice.

Subsequently, the effects of mining-climate interactions on resilience from the perspectives of operational workers and rural households were examined. These were achieved by investigating the factors that influence the mining industry's perception and willingness to adapt to the impacts of changing climatic conditions at operations as well as the determinants of surrounding household's view on double pressure of climate variability and extractivism effects on rural livelihoods.

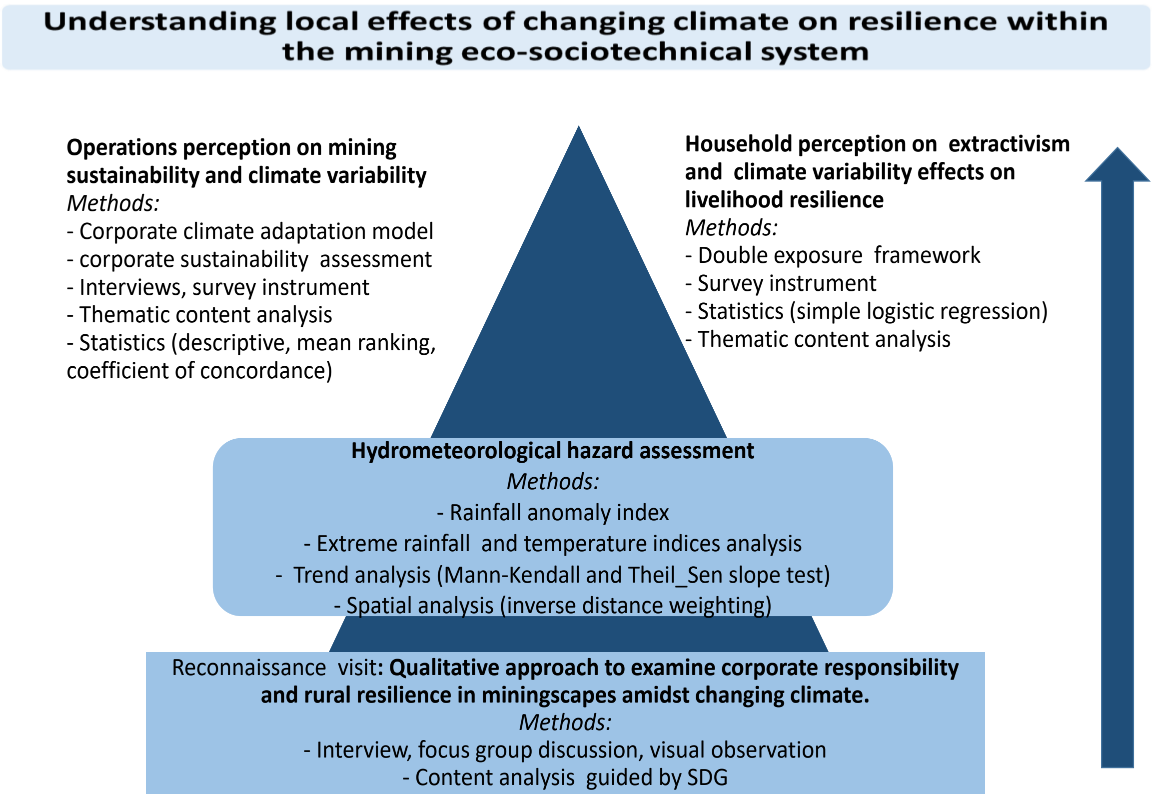

Figure 1-2: General approach of the study

1.4 Thesis Structure

The thesis is organized in six chapters. The forgoing and next chapters present the general background of the study and an overview of the study setting. The rest of the sections are organized into three chapters intended as stand-alone but related manuscripts submitted for publication, followed by the final chapter, which provide general discussion and conclusions.

Chapter 1 states the research problem and justification of the studies, general objectives and research questions as well as the conceptual framework of study.

Chapter 2 expounds on the research background, including the general setting of the empirical studies as well as the results of the qualitative perspectives on corporate responsibility and development within rural miningscapes.

Chapter 3 provides trends in local climatic variability across the miningscapes. Extreme rainfall/temperature trends within southwestern miningscapes are analyzed and spatially represented. In addition, this chapter discusses the implication of increasing climate variability on natural resources management within miningscapes.

Chapter 4 presents the operational workers perception on mining-climate interactions and the effects on corporate sustainability performances that can influence operational level adaptation in Ghana. Through the lens of the corporate adaptation framework, the susceptibility of the industry to local effects of changing climate, the adaptation strategies and spaces pertinent for operation's level adaptation are examined. In addition, the corporate sustainability performance metrics in mining as proxy to determine the industry's willingness to adapt are investigated.

Chapter 5 focuses on the mining-climate-livelihood perspectives at household level and the drivers of these perceptions. The chapter also identifies adaptation measures employed by households to address the double exposure impact of climate variability and extractivism.

Chapter 6 shed light on the main findings, research limitations and develops an outlook for future research.

1.5 Research Output

Outputs from this research have been presented at two scientific conferences (Chapters 3 and 5) via personal and online presentations (University of Freiburg and University of Lomé) and two international colloquia (World Food Day Colloquium 2021 hosted by University of Hohenheim and 2nd meeting of Forestry Research Network for sub-Saharan Africa hosted by the Forestry Research Institute, Ghana).

The research produced three main scientific articles (Chapters 3, 4 and 5) envisaged to be published in peer-reviewed scientific journals. Two articles (Chapters 4 and 5) have been published (*https://doi.org/10.1007/s43546-023-00515-3* and *https://doi.org/10.1016/j.exis.2022.101164*) and the third is under review (Chapter 3). A poster presentation of chapter 3 entitled “Extreme Rainfall/Temperature trend across Ghanaian miningscapes: toward a business case for basin-level climate action “ was orally delivered during the 3rd International Association for Hydro-Environment Engineering and Research (IAHR) Young Professionals Congress on hydro-environment and climate change in 2022 (*https://www.iahr.org/video/clip?id=1466*).

Chapter two

2. Research Background

2.1 Empirical Research Setting

Ghana is located in West Africa along the Gulf of Guinea. Two major mining domains can be identified based on the mineral geology of Ghana. These are the southwestern where large-scale mining activities are dominant (Essah, 2021) and northwestern where the large-scale industry is emerging (Moomen, 2017). The empirical research was conducted within miningscapes located in the southwestern domain as shown in figure 2-1.

The southwestern mining domain is located below latitude 8^0N and scattered within the southwestern river basins system, which covers an area of 52.997 km^2 and forms 22% of the total landmark of Ghana (Ghana National Water Policy, 2007; Opoku-Ankomah & Forson, 1998). Between 2005 and 2014, the southwestern basin system had the lowest water quality index (State of the Environment report, 2016, as cited in EPA/ESA, 2019). In addition, from 2001 to 2010 majority of deforestation in Ghana occurred within the southwestern and central forest zones (World Bank, 2020).

Administratively, the domain covers parts of the Ahafo, Ashanti, Central, Eastern, Western and Western North regions within which at least one large-scale multinational mining operation can be located, coupled with several artisanal and small-scale mining sites.

Rainfall/temperature variability analysis was conducted using observational data from the eight synoptic weather stations scattered within the entire southwestern domain. Further details on the hydroclimatic description of southwestern Ghana are provided in the subsequent chapter where the results of the variability analysis are presented.

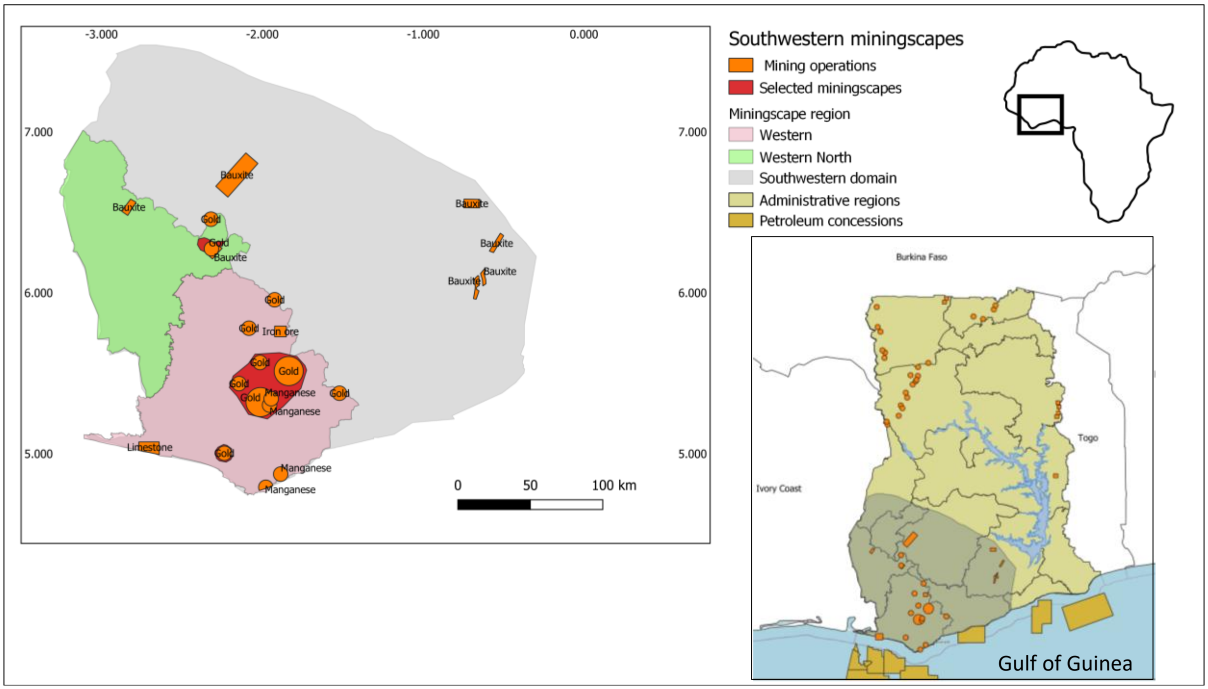

Figure 2-1: Southwestern mining domain and selected miningscapes within the Western regions of Ghana.

The studies on operations and household perception were conducted within selected miningscapes located in the Western and Western north regions. These regions host part of each of the forest agro-ecological zones namely, Rainforest (wet and moist evergreen) and Deciduous forest (FAO, 2005) where previous studies confirm an increasing trend in local climate variability (Abbam et al., 2018; Atiah et al., 2019; Owusu & Waylen, 2009). The two regions also host the two other transboundary river basins of Ghana (Bia and Tano) which drain into the Aby lagoon in Ivory Coast.

The two regions together formed the then Western region until the region was divided in February 2019 via Constitutional Instrument (CI) 117. The two regions host the largest forestlands in Ghana (GSS/EPA, 2020). In addition, the Wet evergreen forest exhibits the highest level of endemism and species numbers in terms of floral diversity, with some listed on the IUCN Red Data List (GSS/EPA, 2020).

The regions are of high economic significance to the country's economic development owing to the vast endowment of other natural resources apart from forest resources. These include mineral resources, and petroleum and the regions are the longest producers of cash crops (cocoa, rubber, oil-palm, coconut) as well as food crops (Amisigo et al., 2015; MoFa, 2011).

The average rainfall/temperature climatology of the two regions are presented in figure 2-2 using high resolution gridded data that was downloaded from the World Bank Climate Knowledge portal (Harris et al., 2020). Apart from Ghana as a country being prone to climate extreme risks such as flooding with its vast implications (Almoradie et al., 2020), the two regions are known to experience high economic losses to climate extreme events and disasters such as flooding and windstorms (GSS/EPA, 2020). These affect major occupations within the region including farming and fishing (Donkor & Agyemang, 2015; J. Mensah et al., 2015). Similarly, climate extremes risk affects mining operations and their related supply chain (Phillips, 2016; Rüttinger et al., 2020; Rüttinger & Sharma, 2016) as well as their surrounding communities although hardly studied within the Ghanaian context. Apart from the economic implications of floods, insufficient management of these events within operational areas may lead to increased incidence and fatalities within the sites. For instance, an informant interviewed indicated that in 2014, an operation located in the upper part of southwestern Ghana recorded a flood-led fatality due to the drowning of a four-wheel vehicle that was stacked in a low-lying access road.

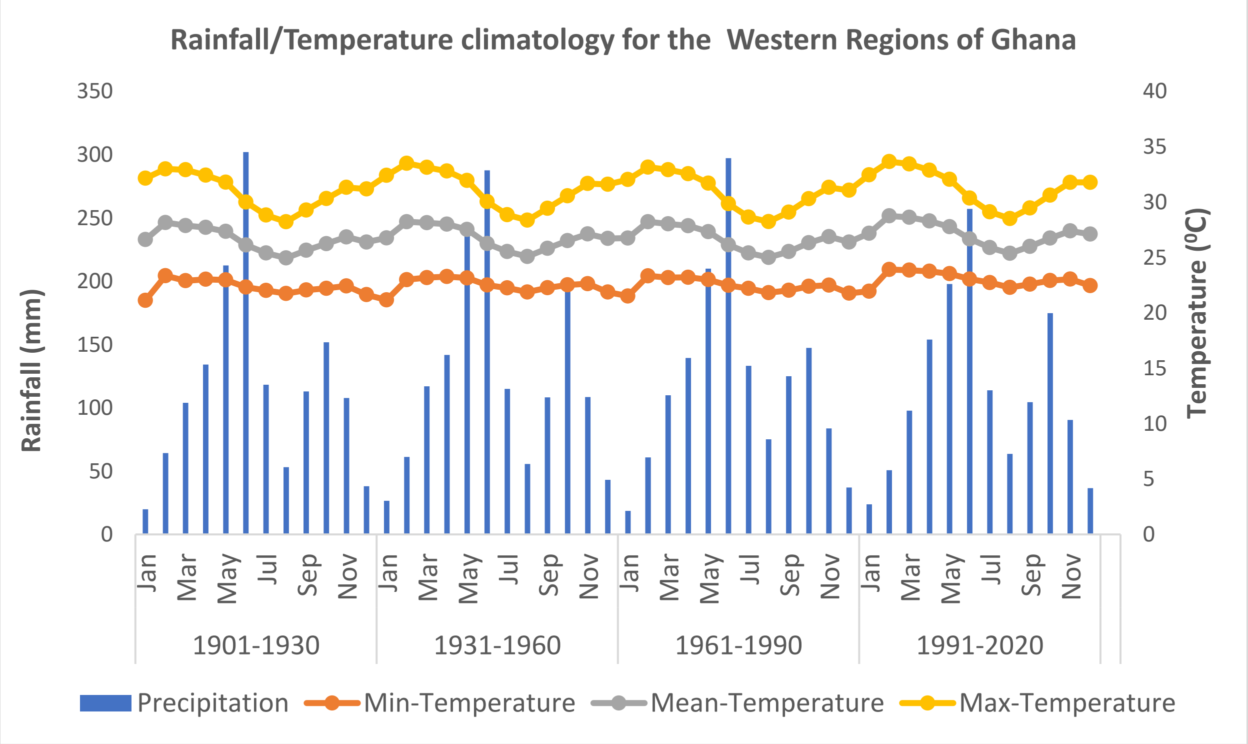

Figure 2-2: Monthly climatology of mean-rainfall and mean-temperature for Western regions of Ghana. (Source: graph plotted by author, gridded data downloaded from World Bank Climate Knowledge portal).

2.1.1 Selection of Miningscapes

Primarily, miningscapes were selected from each of the forest agro-ecological zones dubbed the upper, middle and lower miningscapes as shown in figure 2-3. Most of the mining activities are located very close or within protected forest reserves such as the Tano Suraw Extension forest reserve in the upper miningscape, the Neung North and South forest reserves, as well as the Bonsa River forest reserves in the middle miningscape and the Amanzule wetland in the lower miningscape.

Gold and bauxite are the main resources extracted within the upper miningscape via both surface and underground mining operations. Similarly, gold mining dominates the middle and lower miningscapes although manganese is extracted as well. The lower and upper miningscapes have similar characteristics in terms of size and the rural nature of the landscapes but have differences in agro-ecological characteristics based on the soil and climatic pattern as discussed in detail in chapter four. The lower miningscape includes the estuary of the Ankobra River and is a part of the greater Amanzule wetland where both minerals and petroleum extractive activities affect surrounding communities' livelihoods (Mensah et al., 2015) .

Four groups of resource-fringe communities were identified within the miningscapes. These are the mining affected, petroleum affected, mining and forestry affected as well as non-extractive communities. These surrounding communities are categorized as resource-fringe by virtue of their land ownership, or probably being considered by the mine to be affected directly by the impact of their activities. Therefore, both resource-fringe and non-extractive communities are in reality exposed to the impact of extractivism but to a different extent. Communities were selected along transects laid from the nearby public road to the participating mining operation. Communities were then categorized based on the above-mentioned four groups.

The reconnaissance study was conducted within the three miningscapes by contacting four groups of stakeholders who are considered to have various interests and influence in the industry. The qualitative research sought to underscore the role of corporate responsibility in sustainable development within the rural miningscapes and the implications of local effects of changing climate on the industry's sustainability that may affect corporate responsibility. The results of the study on corporate responsibility and sustainable development in rural miningscapes are presented in the subsequent section whereas the perceived effects of local changes on mining sustainability informed the design of the survey instrument as presented in chapter four. Most interviewees acknowledged the positive impact and bottlenecks of corporate responsibility strategies, including corporate social responsibility and corporate environmental management practices.

In addition, the quantitative studies within mining operations were conducted across all the three miningscapes, whereas the household level was restricted to communities located within the upper and lower miningscapes dubbed *Chirano* and *Nzema*, respectively. The Chirano miningscape is located in the Deciduous forest, whereas the Nzema miningscape is located in Rainforest agro-ecological zones.

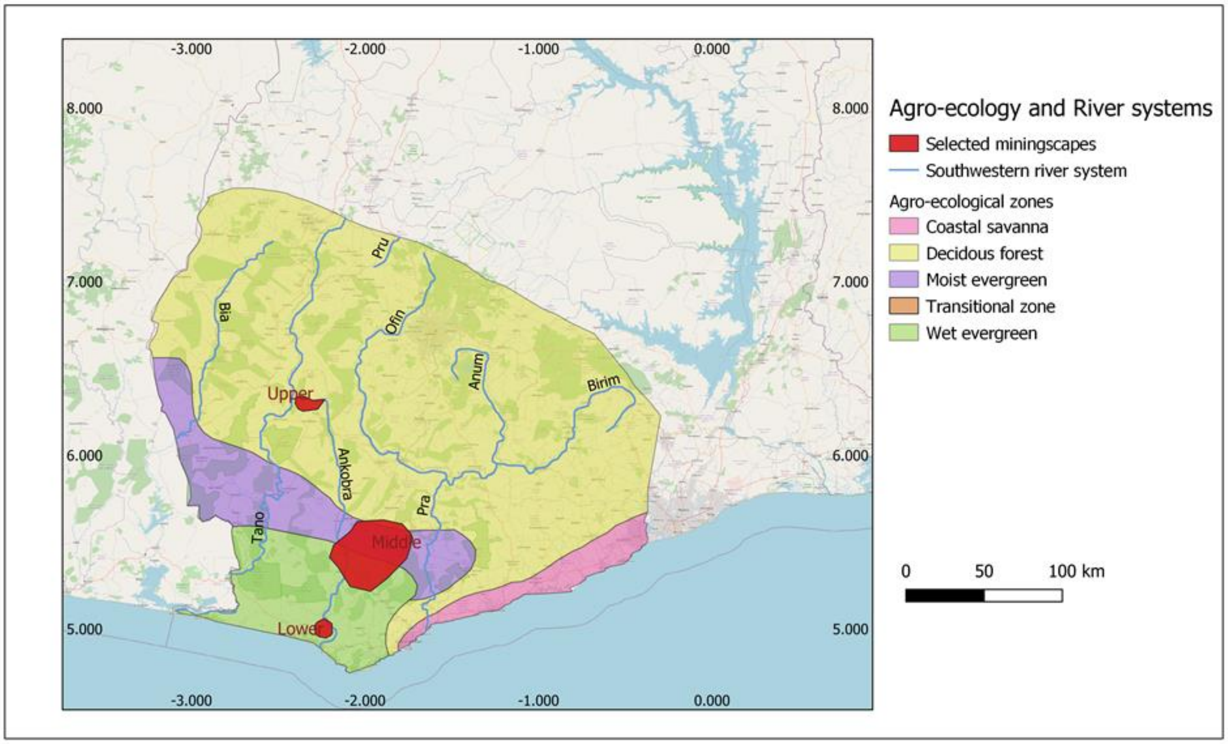

Figure 2-3: Agro-ecology and river systems within the southwestern miningscapes of Ghana.

2.2 Corporate Responsibility and Rural Resilience across southwestern Miningscapes

During the reconnaissance stage of the thesis, qualitative research provided the context of the research background which further shaped the focus of the study. In addition to collecting hydrometeorological data, interviews and small focus group discussions were conducted with four groups of stakeholders identified within the miningscapes. In addition, the direct field observation of company labeled infrastructural systems within the resource-fringe communities demonstrated the direct relationship between corporate responsibility and rural resilience within miningscapes, which can be affected by local effects of a changing climate.

2.2.1 Expert Interviews and Focused Group Discussions

The aim of the interview and focus group discussion was to ascertain the contributions of the corporate responsibility initiatives within the southwestern miningscapes (minerals and petroleum) towards sustainable rural development and whether the effects of local climate on the mining industry have consequences on such contributions.

Interviews were conducted with four groups of stakeholders, involving a total of 50 representatives. The interviewees included the state-appointed regulators represented by the Mining, Climate and Operations departments of the Environmental Protection Agency (EPA), the Inspectorate division of the Minerals Commission, the Health, Safety, Security and Environment (HSSE) division of the Petroleum Commission, the Ankobra Basin secretariat of the Water Resource Commission and the Bibiani office of Forestry Commission. The EPA is the main regulatory body responsible for environmental management in Ghana, whilst the Minerals Commission and Petroleum Commission are responsible for minerals and upstream petroleum development, respectively. The second group of stakeholders is local government represented by the planning officers within the three municipalities and districts where the resource-fringe communities are located. These are the Bibiani Anhwiaso Bekwai (upper miningscape), Prestea-Huni Valley (middle miningscape) and Ellembelle (lower miningscape). The third group consists of non-governmental organizations advocating for sustainable development including Hen Mpoano (lower) and the Sefwi health and education initiative (upper miningscape). The fourth group is the sustainability professionals working within the three large-scale mining companies, one from each miningscapes, as well as representatives from the fringing communities along the transect laid toward the mine site. The sustainability experts are working in departments such as community relations and public affairs, environment, health and safety, wellbeing and occupational hygiene.

In addition, one focus group discussion was conducted for 15 community heads within the lower miningscapes and two small groups of four were conducted within the upper miningscape (figure 2-4). The collected field data were analyzed using thematic content tool via ATLAS.ti.

Figure 2-4: Sessions of focused group discussions held with community heads and workers (Source: photos taken by author during fieldwork)

2.3 Results

2.3.1 Contribution of Corporate Responsibility towards Rural Resilience

Guided by the goals of the Agenda 2030, the thematic analysis revealed various aspects of development to which the identified corporate responsibility initiatives could be associated. The thematic outcomes were therefore categorized in association with the closest SDG as summarized below:

- ***Improved human health*** *(SDG 3, Good health and wellbeing):* Provision of health facilities, community health screening, and health official's honorarium.
- ***Improved education*** *(SDG 4, Quality education):* Provision of school infrastructure, teacher motivation schemes, extra classes support to increase contact hours, increased pupil enrolment, scholarships for second cycle and tertiary education.
- ***Potable water, sanitation and hygiene*** *(SDG 6, Clean water and sanitation):* Interviewees confirmed the provision of water and sanitation facilities from both mining and petroleum companies fringing their communities. To ensure community members take responsibility for their facilities, water and sanitation committees are formed and empowered to

manage the facilities provided although major maintenance works have to be conducted by the company.

- ***Livelihood empowerment*** *(SDG 8, Decent work and economic growth):* Provision of market centers, employment quota, alternative livelihood programs, local content participation programs were mentioned as key areas of mining contribution towards their livelihood resilience.
- ***Social capital*** *(SDG 10, Reduced inequalities):* Engagement with the local stakeholders, including resource-fringe communities, begins at the permitting phase with the statutory public hearing of the environmental and social impact assessment of the project, and provides an avenue for building a strong social networking structure involving the different groups of the communities such as youth and women. According to the expert at the mining department of the EPA, companies are especially motivated by the need to obtain a social license to operate. Thus, companies deliberately provide diverse ways to bring on board the vulnerable in the society through formation of clubs and associations.

  Employees interviewed disclosed the existence of both internal and external communication mechanisms, as well as grievance mechanisms, by which local stakeholders, including fringing communities, are engaged. For instance, there are community consultative committees (CCC) which include representation of all local stakeholders including local government, state-appointed agencies, traditional authorities, youth, and women groups, among others, serving as the liaison by which companies engage to determine development priorities for the fringing communities. In addition, initiatives by expatriate employees and their spouses within certain communities were perceived to enhance social networking. For instance, the Sefwi Health and Education Initiative in the upper miningscape, the Goldfields Credit Union, and Youth in organic farming in the middle miningscape were expressed as avenues for women and youth empowerment.
- ***Mobility*** *(SDG 11, Sustainable cities and communities):* Rehabilitation of inaccessible roads, improved transport system connecting countryside with major towns and cities.
- ***Pollution prevention, land management, biodiversity and heritage conservation*** *(SDG 14 and 15, life below water and on land):* Commitment to prevent pollution was persistent

on the environmental policies of the participating companies. The environmental policy was accompanied by a management system whereby routine monitoring, checking and review of practices vis-à-vis environmental management plans were conducted. The current research did not assess the functionality of the environmental management system but at least the evidence of routine internal and external audits as well as regulatory inspection systems can suffice the efforts toward pollution prevention.

Similarly, land and soil management practices including erosion control mechanisms, topsoil stockpile are conducted on site to concomitantly reclaim degraded lands at operational phase. Some of the mine-degraded lands, such as the waste rock dump sites and tailings storage facilities, had been rehabilitated at different stages (figure 2-5). According to an employee, concomitant rehabilitation is also driven by the need for companies to reduce their reclamation security bond, which is mainly determined by the total areas of disturbed versus reclaimed lands. In addition, companies had operational procedures to protect wildlife and fish, enforced via a stringent permitting scheme to control land disturbance and vegetation clearance within the operational areas although no direct assessment was conducted to ascertain the functionality.

Figure 2-5: Rehabilitation activities at operational sites. a = nursery site to host seedlings; b = direct planting on decommissioned tailings storage facility; c = rehabilitated embankment of active tailings dam located just above the nearby community; d = rehabilitated exploration area (Source: photos taken by author during fieldwork).

According to community representatives, culturally significant landmarks esteemed as deities such as certain hills, trees and streams as well as cemeteries and sacred grooves within the concession are conserved through a collective agreement between the company and the communities. In addition, companies make financial provision to the traditional authorities for cultural activities aimed at preserving the various cultural monuments, which provide a safe place for both faunal and floral communities. Excerpts of the interview on contribution of corporate responsibility towards nature conservation are summarized below:

"We have adopted the progressive rehab method as to when an area is abandoned, we go there and rehabilitate. Currently, the TSF2 which has been closed is undergoing rehabilitation. We do this to stabilize the dams. We try to reduce disturbance so there is an internal permit system before the area is cleared for rehab. Some of these areas fall within forest reserve and it requires a permit from the Forestry Commission. Sometimes it is hard time acquiring and this put people off in doing the disturbance. Likewise, in felling a tree you need a permit. Also, when it comes to clearing you need to clear to specific a dimension and pile the top soil to 18 to 20% topsoil stock piles labeled map. So anytime there is a bare area we have to rehabilitate we have top soil stock piles for it. For example, the waste rock dam by law, we have to sheath it to 2.5m both in oxide and top soil together. So, we juggle around 2.3 of oxide and 2.2 % of topsoil. When we do that, we have to take care of erosion so we plant a cover crop like cowpea which takes 3 months to grow.

Also, *we do not harm nor kill wildlife and we have left certain areas for them as habitats by law. Also, when you accidentally kill any you have to report to management. In our rehabilitation we have incorporated final returns where it is not only the trees like the cowpea, there is flower, insects, birds, rodents. In all our rehab sites we leave satellite water ponding to attract mammals"* (Senior Rehabilitation officer, 2018).

"There is a hill within the forest (Tano Suraw Extension) called Mamnao from which three tributaries namely Sariahu, Suraw and Ankobra originate. Sariahu and Suraw join before entering the Tano River. The hill as a deity belongs to the Chirano traditional council who offer sacrifices at esteemed periods. Before the mine began, the traditional authority would afford one sheep but

now the company annually provides a cow, which is a better option. So far no mining activities have been carried out close to the place of sacrifices as the area is not part of the mining concession although the mining activities are very close. The challenges we are currently facing are not from the mines activities but rather the burning of the forestlands which extends towards Kumasi. So, if we can revert, then the Forestry Commission has to ensure reforestation" (Traditional leader, 2018).

Visual observations during the community visits, corroborated opinions of interviewees and group discussants on the corporate responsibility contribution toward infrastructural development in miningscapes. For instance, mechanized boreholes providing potable water and sanitation facilities were rampantly sighted in all resource-fringe communities visited, in sharp contrast to dilapidated potable water and sanitation facilities within the non-extractive communities although located along the same transect as shown in figure 2-6. Similarly, footage of developmental projects contributed by the different companies for their affected communities were observed as shown in figure 2-7 such as community health based planning (CHP) compound, ICT and library center, fish smoking center, among others. A native from one of the communities who has benefited from community initiatives to study and is subsequently offered employment summarized the benefit of the corporate responsibility initiatives as quoted below:

"Illiteracy rate was very high at Chirano but now most of the youth have further their education to high institutions. CGML has a policy called education assistant program where after the normal class hour teachers are given extra hours to teach kids in order for the teachers to go further in explaining and the kids also capture what they could not. CGML has built schools in various communities. Under health, CGML has built clinics in various communities as well as conducted health education in these communities. W*ater, sanitation and waste management in partnership with Zoomlion, donation, other public supports etc. we also have community sensitization on the importance of cleanliness and other aspects".* (Note: CGMA = Chirano Gold Mine Limited, Zoomlion is the private waste management company in Ghana).

Figure 2-6: WASH facilities located in communities along the same transect. a & c are found in resource-fringe communities, b & d are found in non-extractive communities (Source: photos taken by author during fieldwork) (*WASH = water, sanitation and hygiene*).

Figure 2-7: Footage of corporate responsibility contributions within resource-fringe communities (source: photos taken by author during fieldwork).

2.3.2 Bottlenecks of the Corporate Responsibility contributions in Miningscapes

Key issues identified as drawbacks on the contributions of corporate responsibility initiatives from the analysis are as follows:

- ***Up-down approaches to corporate responsibility initiatives*****:** Interviewees complained of situations whereby developmental projects were not accepted by the intended beneficiary communities and therefore did not yield the envisaged benefits. Such abandoned facilities, including market centers, community centers, and toilets, were observed within the upper miningscapes. Accordingly, community leaders and state-appointed regulators pointed to the poor level of engagement between some companies and their affected communities to prioritize community needs as the cause for project failure.
- ***Construe of impact mitigation with corporate responsibility*****:** Representatives from the regulatory bodies such as EPA, Minerals Commission and Petroleum Commission consistently alluded to the voluntary nature of corporate social responsibility in Ghana, hence depending on the industries' discretion. However, some opined that the requirement for mitigating the impact of extractive activities is legally binding as stipulated in the proponent's environmental impact statement such as the requirement to provide alternative livelihood. Nonetheless, most of these alternative livelihood initiatives are show-cased as corporate responsibility initiatives.
- ***Vulnerability of forest reserves to encroachment when given out as mine lease*****:** Enforcement of forest protection laws is weakened when a mineral concession Lease falls within or very close to forest reserves. Land clearance opens up the forest, thus changing the local microclimate, which affects both floral and faunal biodiversity. Also, fringing communities who originally had no access into forest reserves, now enter forests through poaching and farming activities when the forest reserve is leased for mining. Instances were observed in the Tano Suraw Extension forest reserve, located within the upper miningscape. According to one traditional authority, there had even been forest fires due to community invasion in the above-mentioned forest reserves as similarly reported for the Beni and Bonsar forest reserves in the middle miningscape.

2.3.3 Motivating and financing of corporate responsibility initiatives within miningscapes

From the study, four main categories of financial sources by which corporate responsibility initiatives are funded by the different mining companies were identified. The four categories are summarized below:

1. ***Trust fund*****:** US$1 is accrued for every ounce of gold processed.
2. ***Community budget*****:** Funds allocated by the company specifically for community projects.
3. ***Special royalty*****:** Companies operating within forest reserves are required to deposit 0.06% of annual profit, which is managed by the national liaison spearheaded by the EPA.
4. ***Foundation*****:** USD$1 for each ounce of gold produced, 1% of pre-tax profit and 10% annual profit known as legacy account.

In addition, some respondents commented on the financial implication of corporate responsibility, noting budget constraints and social license as key motivation for financing community initiatives in contrast to environmental management activities such as pollution prevention and rehabilitation which are motivated by regulatory and other requirements. Excerpts from interview on financing and motivating for infrastructural and other projects are summarized below:

"As long as the company is here and there is the Foundation, there cannot be any case where there will be a drop in sustainability. For the maintenance of facilities and other things like clinic, water, sanitation and others, the company will continue to support the community unless Goldfields folds up and the government or the community tends to take it up or the community decides to maintain themselves. In the case of motivation, social license is a factor. People pay taxes and expect the government to develop the communities but since the company is exploring the land it has to give back to these communities for them to benefit from these explorations" (Community Affairs Manager, 2018).

"Depending on the production level and cost leverage indicators, cost control specifically doesn't affect us as a department but if there is cut down in community project cost this takes effect in all departments. The communities, they have been asking for more but we have a limited budget

so at the end of the day, we are not able to meet all their needs. Also, the attitude of some contractors in terms of duration" (Community Relations officer, 2018).

Chapter Three

Rainfall/Temperature Variability in Southwestern Ghana: Towards a case for watershed approach to climate action in miningscapes

Abstract

The use of reanalysis data as pseudo observational data to analyze extreme climate events is cautioned for inconsistencies for which complimenting climate hazard analysis using observed data is imperative especially in rural West Africa where the impact is severe. Using the available observational hydroclimatic data, the study employs rainfall anomaly index and other extreme indices to examine the temporal and spatial trend in climate extremes and the implications on natural resources management within miningscapes of southwestern Ghana.

The results confirm a decreasing trend in the number of near normal wet years compared to extreme wet and dry years as well as significant changes in extreme frequency and intensity trend across southwestern Ghana. Similarly, estimated extreme temperature indices show significant upward trend in the entire southwestern Ghana. These changing trends correspond closely to the forest ecosystem types of Ghana thus affirming the increasing variability in the forest zone of Ghana. Particularly, stations located within prominent miningscapes such as Sefwi Bekwai and Akim Oda (Moist semideciduous) and Axim (Evergreen) had the highest number of dry rainfall years and the lowest number of wet rainfall years.

The implications for sustainable mining can be severe including operational aspects such as infrastructural and energy production systems, occupational health, safety and environmental best practices coupled with regulatory consequences. In addition, rural livelihood resources and biodiversity are double exposed to the effects of changing climate and extractive activities just as the hydrologic regime of river basins within southwestern Ghana, which provide portable water within several regions.

The study illustrate the need for watershed approach that involve strong private-public collaboration to address the local effects of changing climate within southwestern Ghana owing to the socio-economic significance as well as the transboundary nature of the rivers systems.

Keywords: *Climate Adaptation, Forest Ecosystem, Hydrometeorology, Mining, West Africa Craton*

3.1 Introduction

Variability in rainfall affects economic systems at different scales, be it global, regional or local, and is expected to be worsened by increasing human induced climate changes (Kalkuhl & Wenz, 2020). In fact the reports of the Intergovernmental Panel on Climate Change (IPCC) affirm with high confidence the detrimental effect of changing climate on natural resources sectors such as fisheries, agriculture, water resources, forestry and mining (IPCC, 2014, 2022). This will be severe in West Africa where most of the national economies are driven by export of climate-sensitive raw materials such as cash crops, timber, crude oil and mineral resources. Moreover, the 2022 report (IPCC, 2022, p. 6) emphasizes the coupled nature of human systems such as rural infrastructure and industries with the natural ecosystem for which the impact of climate change within one system inevitably affects the resilience of other systems. Hence, the need for climate resilient actions involving active participation of government, civil society and private sectors are strongly advocated (IPCC, 2022).

Mineral resources are particularly crucial to advance the technologically driven economies around the globe (Arrobas et al., 2017). Nonetheless, climate variability and changes control the sustainability of mineral resources' exploitation and development (Liu & Song, 2019; Odell et al., 2018; Rüttinger & Sharma, 2016). Changing climatic conditions exert direct and indirect impacts on the infrastructural systems, the operational activities as well as mine designing and construction (Ford et al., 2011; J. . Hodgkinson et al., 2014; E. Mavrommatis & Damigos, 2020; T. D. Pearce et al., 2010). In addition, communities fringing mining concessions are not spared by the impact of changing local climatic conditions as observed as among Australian mining Communities (Loechel et al., 2013) and the Latin American Communities (Bebbington et al., 2015). Mining-fringe communities actually risk simultaneous impacts from mining activities and changing local climates (Tannor et al., 2022) which can be detrimental among rural dwellers within the West African region.

The West African Craton (WAC) as one of the Precambrian basement rock of Africa is known for its superlative mineral resource deposits including gold, diamond, manganese, iron ore, bauxite, phosphate among others (Markwitz et al., 2015; Williams et al., 2015; World Bank, 2014) in countries such as Ghana, Ivory Coast, Liberia, Sierra Leone, Guinea, Burkina Faso and Mali. Thus, irrespective of the negative socio-environmental footprints of the sector, mineral resources remain as critical commodity for economic development and human wellbeing in the region for which sustainable exploitation is imperative (Ayee et al., 2011; Hodgkinson & Smith, 2018; Signé & Johnson, 2021; United Nations Economic Commission for Africa (UNECA) & African Union, 2011; World Bank, 2018). Coincidentally, most of these mineral deposits in the region are located in the tropical rainforest where rainfall magnitude and pattern are important determinants of faunal/floral species distribution (Guisan & Zimmermann. 2000; Poulter, 2011). Thus, forest product extraction and cash crop farming such as Cacao and Oil palm are key commodities in most miningscapes of the region (Henderson & Osborne, 2000; Wessel & Quist-wessel, 2015).

Ghana for instance is endowed with the largest deposit of gold within the Baule-Mossi domain of the WAC, stretching from the southwestern towards the northwestern regions of the country (Amponsah et al., 2015; Fougerouse et al., 2017; Markwitz et al., 2016; Parra-Avila et al., 2015). Agro-ecologically, the southwestern miningscapes stretches over both the Rainforest and Deciduous forest zones (FAO, 2005; Hall & Swaine, 1981), hence hosting more than two thirds of Ghana's conservation parks and resource reserves protecting biodiversity (WRC, 2009, 2012b). Southwestern Ghana is also considered as an agriculturally productive area characterized by cultivation of a variety of food and cash crops as well as fisheries (Amisigo et al., 2015; Koomson et al., 2020; Owusu & Waylen, 2009). The southwestern miningscape in particular is densely populated due to the high economic prospects (Nyame et al., 2009), thus of high significance to the nation in terms of tax accruals. For instance, between 2018 and 2019, the share of the mining and quarry sector in total direct domestic receipts (including corporate tax, income tax and royalties and land rent benefits) improved from 14.2% to 18.3% (Ghana Chamber of Mines, 2019).

As a tropical country, the rainfall regime in Ghana is strongly influenced by the West African Monsoon, producing a bimodal rainfall regime toward the south and a unimodal rainfall regime towards the north (Manzanas et al., 2014; World Bank, 2011). Natural rainfall variability in the country is thought to be influenced by the vegetation, geographic location, the movement of the Inter-Tropical Discontinuity which modulates the West African Monsoon as well as changes in the Atlantic Sea Surface Temperatures (Amekudzi et al., 2015; Baidu et al., 2017; Quenum et al., 2021; Weldeab et al., 2007). According to the World Bank (2011), the mean annual temperature has increased by 1^0C at an average rate of 0.21^0C per decade, whilst annual rainfall is highly variable on inter-annual timescales since 1960 to 1990 (World Bank, 2011). The IPCC define climate variability as the *"variations in the mean state and other statistics such as extreme occurrences of the climate in all spatial and temporal scales beyond that of the individual weather events be it internal (natural internal processes within the climate system) or external (variations in natural or anthropogenic external forcing*" (IPCC, 2014). Climate variability in terms of trend in number of wet and dry years as well as other extreme indices are relevant climate variables that provide insight into water resources availability, flood risk analysis and drought incidence that can affect both socio-economic and ecological systems (Klutse et al., 2016; Logah et al., 2021; Zaveri et al., 2020). The tendency for intensified climate extremes has been emphasized in the fifth assessment report of the IPCC (IPCC, 2014). Trend in extreme events are also an important juxtaposition to understand current variabilities that form the baseline for comparing future projections. Such information is also necessary to pre-empt climate change adaptation within miningscapes where multiple land-use practices directly affect rural resilience.

Studies points to changing trend in rainfall and increasing temperature as well as changes in extreme events in the northern and southwestern part of Ghana (Abbam et al., 2018; Amekudzi et al., 2015; Atiah et al., 2019; Baidu et al., 2017; Kabo-bah et al., 2016; Larbi et al., 2018; Manzanas et al., 2014; Nkrumah et al., 2014; Owusu & Waylen, 2009). Most of the above-mentioned variability studies in Ghana used reanalysed rainfall data and satellite-based rainfall data due to unavailability or inadequacy of gauge-based data. For instance, Baidu et al., (2017) used reanalysis Global Precipitation Climatology Centre (GPCC) data (1901-2016) to examine variability and found a decreasing trend in annual rainfall over most of the climatic zones including the forest zone, which forms the southwestern part of Ghana. Similarly, Abbam et al. (2018) used University of Delaware's gridded rainfall and temperature (1900-2014) to identify climate stressed locations and the potential effect on agriculture in Ghana. The authors confirmed drier trends with potential drought conditions especially in districts located in the northern and western regions of Ghana. The Western regions form the major portion of the southwestern miningscapes. Previously, Manzanas et al. (2014) compared the use of observational and reanalysis rainfall data for variability and trend analysis in Ghana. The authors warned the use of reanalysis as pseudo observations in Ghana based on the inconsistencies in trend of extreme indicators. Thus, efforts to use observational data for climate variability are imperative to enhance informed-decision making. This is especially pertinent in miningscapes where dominant land-use actors such as mining companies, commercial farmers, timber companies are competing for climate-sensitive resources in tandem with rural livelihoods. Particularly, long-term gauge-based daily time-series data remain critical, as analysis of these data sets provide a retrospective insight into the pattern in rainfall/temperature variations in the locality needed for infrastructural designs and operations. In addition, understanding past trends provide empirical evidence to corroborate the local perspectives of increasing climate variability effects on rural livelihoods, thus prompting appropriate adaptation programs.

The aim of this study is therefore to understand climate variability across miningscapes in southwestern Ghana by analyzing the trend in extreme rainfall events and temperature over time and space. The specific objectives are to; a) Use rainfall anomaly index to analyze the variability in the interannual wet/dry years; b) estimate rainfall and temperature extremes using excerpt from the expert team on climate change detection and indices (ETCCDI); c.) Determine spatio-temporal trend in rainfall/temperature extremes across the miningscapes d) discuss the implication of changing trend for natural resource management within the rural miningscapes.

3.2 Study Area

Ghana (figure 3-1) is located in West Africa and bordered by Ivory Coast to the west, east by Togo, north by Burkina Faso and in the south by the Gulf of Guinea. The country is located on latitude 4.5^0N to 11.5^0N and longitude 2.5^0W to 0.5^0E covering about 240,000km^2 land surface (Owusu et al., 2013). The southwestern miningscapes are located below latitude 8^0N and scattered within the southwestern river basins system which covers an area of 52.997km^2 and forms 22% of the total landmark of Ghana (Ghana National Water Policy, 2007; Opoku-Ankomah & Forson, 1998). Administratively, the miningscapes cover parts of the Ahafo, Ashanti, Central, Eastern, Western and Western North regions within which at least one large scale multinational operational mining site is located, coupled with several artisanal and small scale mining sites. Scattered within the miningscape are rural communities whose livelihoods mainly depend on rain-fed farming and non-timber forest products.

Majority of the southwestern miningscapes fall within the Forest climatic zone based on Meteorological Agency of Ghana classification (Bessah et al., 2022; Owusu & Waylen, 2009) and are part of the Guinea Coast region of West Africa (Nkrumah et al., 2019; S. Sanogo et al., 2015). Rainfall starts from March to July as the major season and September to November as the minor (Asare-nuamah & Botchway, 2019; FAO, 2005). The Forest climatic zone has long term (1976-2018) seasonal rainfall ranges of 1500-2200mm, relative humidity of 30-84% and average temperature range of 28-34^{0}C (Bessah et al., 2022; GSS/EPA, 2020).

According to the Food and Agriculture Organization (FAO) classification of agro-ecological zones for Ghana, northern Ghana is characterized by the Savanna (Guinea and Sudan) zones while the central and southeastern regions fall within the Transition and Coastal Savannah zones respectively. Southwestern Ghana generally falls within the Rainforest (wet and moist evergreen) and Deciduous forest zones (FAO, 2005). The southwestern regions are also characterized to host the Closed-canopy Evergreen forests (wet, upland and moist) as well as the Deciduous (Moist and Dry semidecidous) forest vegetation types based on rainfall gradients and soil conditions (Hall & Swaine, 1981, 1976). The Evergreen forest soils, namely forest Oxisols are highly acidic while the Deciduous forest soils are Ochrosols (Opoku-Ankomah & Forson, 1998) which support agriculture including cocoa production. A common phenomenon exists in the fact that the majority of mineral operations are in close proximity to or within forest reserves, thus making multiple land-use related conflicts a major issue of concern within the miningscape (King & Veit, 2013).

The geology of Ghana falls within the southern Precambrian Leo-Man Shield of the WAC and is divided into four lithotectonic complexes, namely the Paleoproterozoic and intrusive rocks, the Neoproterozoic to Early Cambrian (Voltain group), the Pan african Dahomeyide orogenic belt and the Isolated spatially restricted coastal sedimentary basin (GSS/EPA, 2020). The southwestern miningscape falls within the Paleoproterozoic Birimian Baoulé-Mossi domain of the WAC and is popularly referred as the gold province (André-Mayer et al., 2015; Masurel et al., 2021) although other minerals resources such as diamonds, manganese and bauxite are also mined within the landscape (Markwitz et al., 2016). Geological mineralization in southwestern Ghana is classified into the paleoplacer Sefwi group, orogenic gold-lode deposit (Kumasi group), and the Tarkwa group (Amponsah et al., 2015; Parra-Avila et al., 2015).

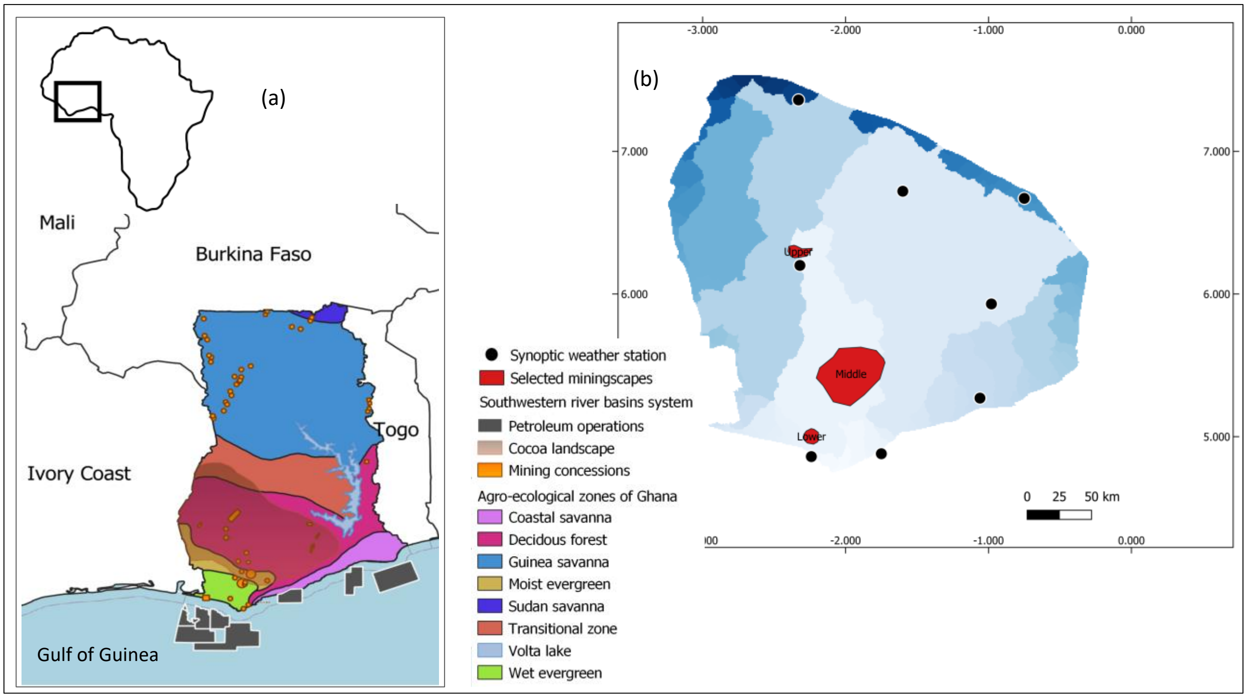

Figure 3-1: Multiple-land-use practices within southwestern Ghana. (a) Cocoa production, mining and mining operations ongoing in southwestern Ghana (b) Available synoptic weather stations within southwestern basin systems.

3.3 Data and Methods

Figure 3-2 summarizes the approach employed in the study. Rainfall anomaly index (Rooy 1956) was computed using observational data from the synoptic weather stations across the miningscape to ascertain the variation in wet and dry years over the past forty years (1976-2018). In addition, excerpts of climate extreme indices were selected from the core indices of the Expert Team on Climate Change Detection and Indices (ETCCDI). The ETCCDI was established in 1999 to coordinate climate detection and indices for the climate research community and World Meteorological Organization's National Meteorological and Hydrological Services (NMHSs). As a support team of the IPCC Technical Assessment Reports until 2018, the joint team of experts currently operate under the World Climate Research Program (WCRP) with the mandate to address objective measurement and characterization of climate variability and change (WRCP, 2022).

In addition, the Mann-Kendall rank correlation test was used to detect trends whilst the Theil-Sen slope estimator was employed to determine the rate of change. The results of the trend analysis were spatially interpolated using the Inverse distance weighting (IDW) method to generate the spatial trend maps for the miningscapes. All the above computation was carried out via R statistical package, while the spatial analysis was conducted via QGIS version 3.1.

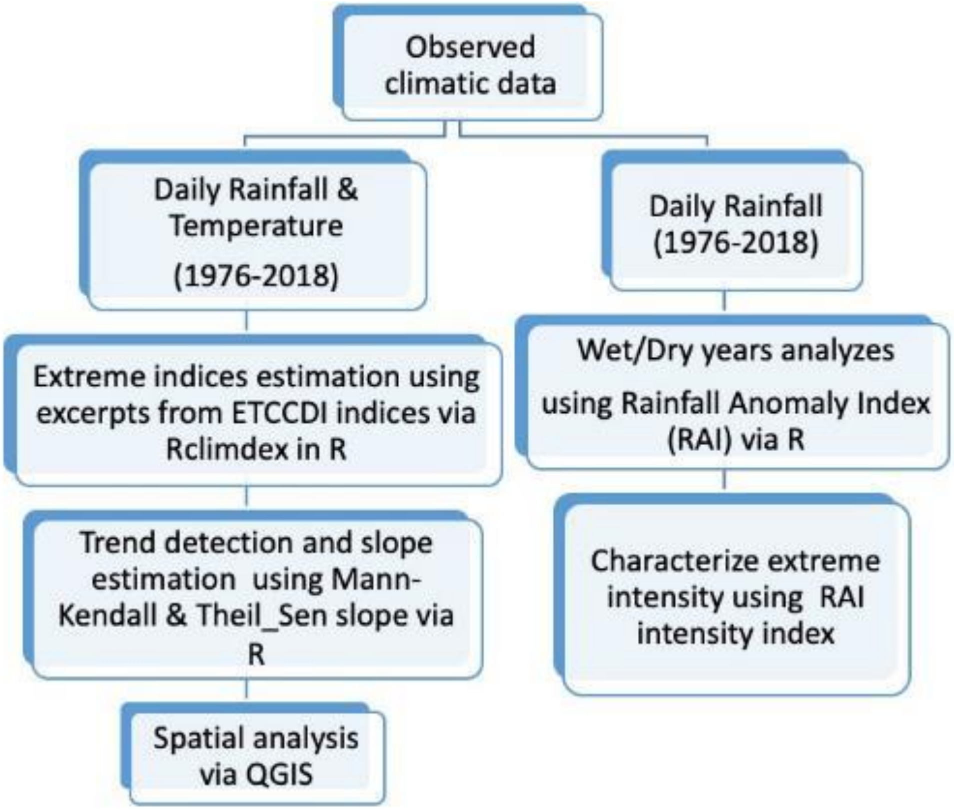

Figure 3-2: Flow chart of study approach

3.3.1 Observed climatic data obtained for study

Daily time series of rainfall and temperature from eight synoptic meteorological stations scattered within the southwestern miningscape were acquired from the Meteorological Agency of Ghana (GMA) for the period 1976-2018. The data form part of countrywide climate data recently homogenized and used to reclassify the climatic zones of Ghana (Bessah et al., 2022).

Figure 3-3 shows the mean monthly rainfall across the miningscape over the period under study (1976-2018). A cursory observation confirms the bimodal nature of rainfall across the miningscape. Similarly, figure 3- 4 shows the mean monthly maximum temperature (Tmax), mean monthly minimum temperature (Tmin) and diurnal temperature range (Dtr) across southwestern Ghana.

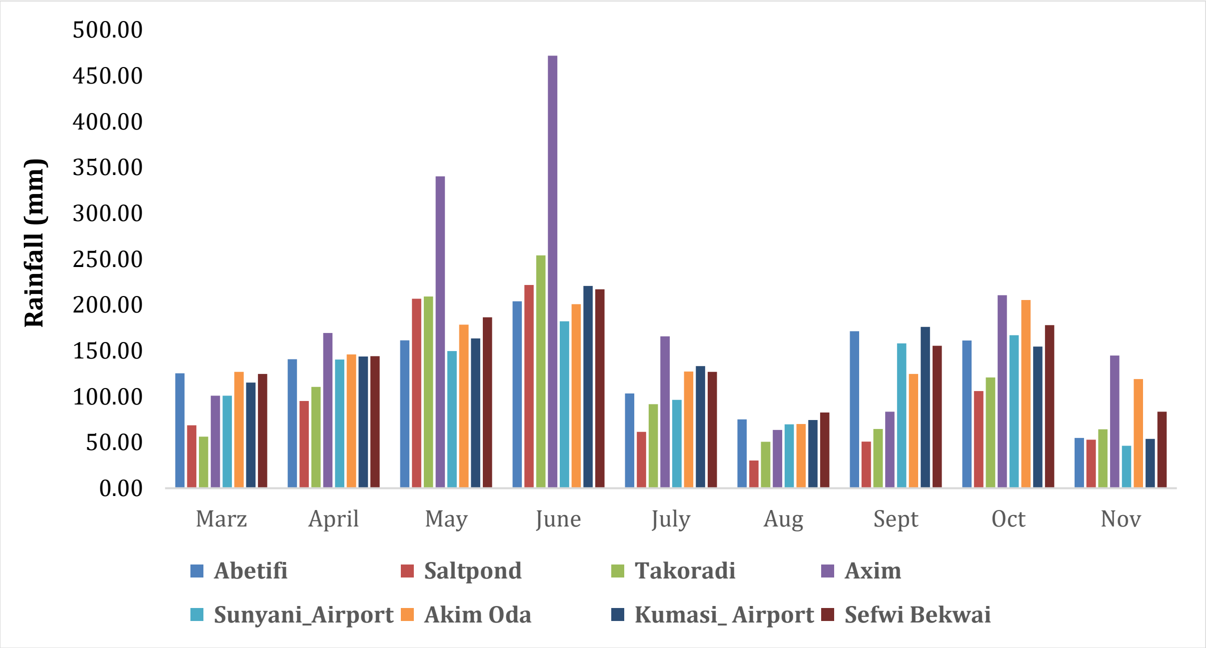

Figure 3-3: Monthly rainfall climatology across southwestern Ghana (1976-2018)

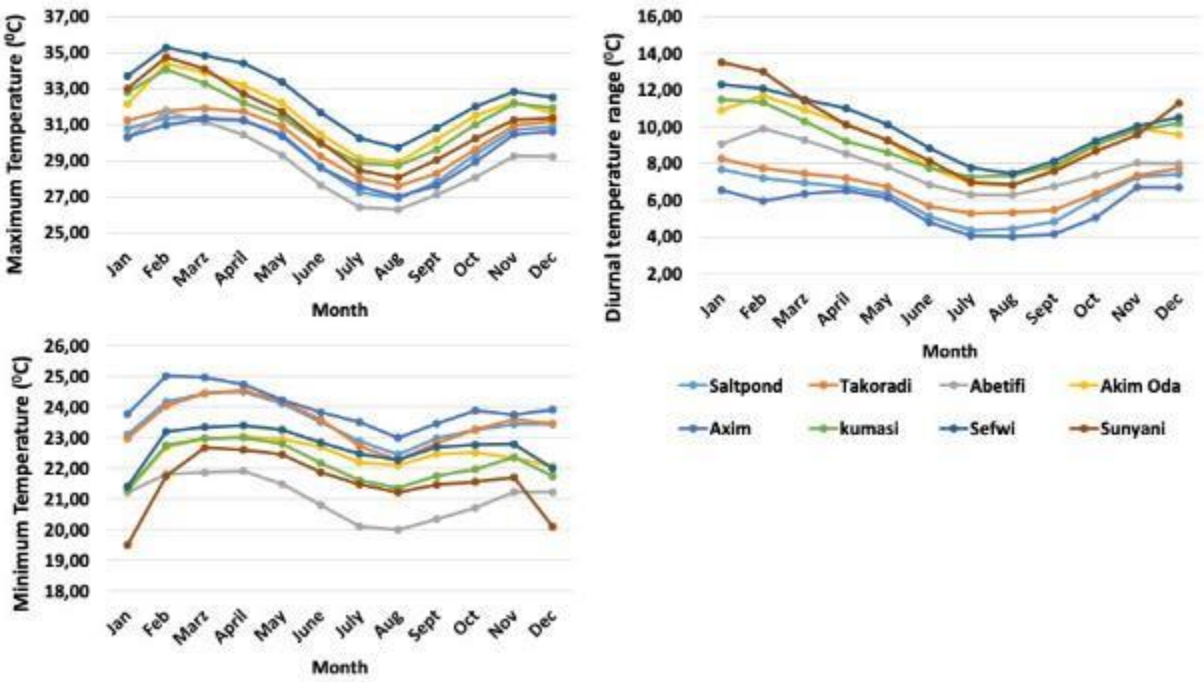

Figure 3-4: Monthly mean variations in temperature across southwestern Ghana (1976-2018)

3.3.2 Analysis of Variability in Wet/Dry Years

The rainfall anomaly index (RAI) was used to compute the interannual variability in rainfall within the landscape. RAI was developed by Rooy (1965) mainly to detect deviation of annual rainfall from long-term averages (Costa & Rodrigues, 2017). Although the World Meteorology Organization (WMO) has prescribed the standardized precipitation index (SPI) to evaluate extreme rainfall characteristics, recent studies detected little difference in performance when compared with the RAI (Hänsel et al., 2016; Raziei, 2021). In addition, studies corroborate the simplicity in use of the RAI as well as the capacity of the index to improve performance in humid climates (Keyantash & Dracup, 2002; Loukas & Vasiliades, 2004; Oladipo, 1985).

RAI is computed as a rank-based drought index which integrates a ranking procedure to assign proportions to positive and negative rainfall anomalies (Raziei, 2021). The RAI is calculated as below (see also Raziei [2021] for a more detailed description of the formula):

$$RAI = \pm 3 \frac{(Pi - \overline{P})}{(\overline{E} - \overline{P})} \qquad (1)$$

Where Pi is the measured rainfall, $\overline{P}$ is the average rainfall, $\overline{E}$ is the average of 10 extrema and ± 3 is the prefix used to limit the lower and upper bounds of the anomalies.

In addition, Rooy (1965) provided nine sets of extreme classifications to define the severity of drought as summarized in table 3-1 below.

Table 3-1: Classification of RAI intensity by Rooy (1965) (adapted from Raziei [2021])

Rainfall Anomaly Index	**Class Description**
≥3	Extremely wet
2 to 2.99	Very wet
1 to 1.99	Moderately wet
0.5 to 0.99	Slightly wet
-0.49 to 0.49	Near normal
-0.99 to -0.5	Slightly dry
-1.99 to -1	Moderately dry
-2.99 to -2	Very dry
≥-3	Extremely dry

3.3.3 Extreme Rainfall/Temperature Indices Computation and Change Detection

Twelve indices of extreme events were selected from the core climate extreme indices approved by ETCCDI as summarized in table 3-2. These indices were computed via RclimDex (Zhang and

Yang, 2004). The selected indices have been used in other climate variability studies in the West African region (Atiah et al., 2019; Logah et al., 2021; Obada et al., 2021). Particularly, the selected indices are relevant pointers to the potential impact of climate change on socio-economic activities at different scales such as mining operations (Gonzalez et al., 2019) and rural livelihoods (Atiah et al., 2019). Table 3-2 provides potential risk and impact of climate variability on mining sustainability that can be inferred from the selected ETCCDI indices as indicated in literature. The base period for extreme indices computation was 1986-2015.

The non-parametric Mann-Kendall (MK) was used to detect trends at each station as used in previous studies (Baidu et al., 2017; da Silva et al., 2015; Kabo-bah et al., 2016; Larbi et al., 2022). The test assumes a null hypothesis (H_0) of no trend, which is tested against the alternative hypothesis (H_1) of the presence of trend according (Önöz and Bayazit, 2003 as referenced in Larbi et al. (2022). In addition, the Theil-Sen slope test, estimates the rate of change in the extreme indices. The Theil-Sen slope is described in detail by Okafor et al. (2017) as an unbiased median based slope estimator previously developed by Sen (1968) to estimate the rate of change in trend analysis (Okafor et al., 2017). Both computations were via the Precinton plug-in of the R statistical package.

Table 3-2: Description of extreme indices and their relevant indications in mining operations

Indicator name, ID (Unit)	**Definition**	***Extremes indicator*: Aspect of mining operations at risk**
TMAXmean, TXmean (ºC)	Monthly average value of daily maximum temperature	a. *Heat spell/stress:* 1.Occupational health and safety incidences (Applebaum et al., 2016; Bi et al., 2011; Kjellstrom et al., 2014; Nunfam et al., 2019; P. A. Schulte et al., 2016) 2. Equipment safety and cooling systems demand (Elgstrand et al., 2017).
TMINmean, TNmean (ºC)	Monthly average value of daily minimum temperature	
Cool nights, TN10p (%)	Percentage of days when TN<10th percentile	b. *Changes in dry and wet bulb temperature:* 1. Ventilation and temperature compliance issues for underground mining operations including increased energy demand (Nelson et al., 2011) 2. Demand for change management in risk and hazard controls such as personal protective equipment (PPEs), hydration issues (Damigos, 2012)
Cool days, TX10p (%)	Percentage of days when TX<10th percentile	
Warm nights, TN90p (%)	Percentage of days when TN>90th percentile	
Warm days, TX90p (%)	Percentage of days when TX>90th percentile	
Simple daily intensity index, SDII (mm/day)	Annual total rainfall divided by the number of wet days (defined as PRCP>=1mm) in the year	c. *Flood and drought risks:* 1. Mine water balance budgeting and management (Rüttinger & Sharma, 2016) 2. Supply chain, transportation and other mine infrastructural facilities safety including tailings (Sharma & Franks, 2013) 3. Rehabilitation and closure management and compliance (Ford et al., 2010)
Annual total wet-day precipitation, PRCPTOT (mm)	Annual total rainfall in wet days (RR>=1mm)	
Extremely wet days, R99p (mm)	Annual total rainfall when RR>99th percentile	*d. Prolonged dry/wet days:* 1. Mine planning and production designs (Gonzalez et al., 2019). 2. Community issues (Loechel et al., 2013) including insurgence and spread of vector-borne infections 3. Environmental quality monitoring compliance issues, e.g., acid mine drainage (Phillips, 2016)
Consecutive wet days, CWD (days)	Maximum number of consecutive days with RR>=1mm	

Consecutive dry days, CDD (days)	Maximum number of consecutive days with RR<1mm	4. Exploration activities (J. Hodgkinson et al., 2010).
Number of very heavy precipitation days, R20 (days)	Annual count of days when rainfall>=20mm	

3.3.4 Spatial Analysis of Trend in Climate Variability

To understand the spatial distribution of the extremes across southwestern Ghana, the inverse distance weighting (IDW) interpolation method was used to interpolate the results of the MK and Theil-Sen slope tests.

IDW interpolation method was preferred for this study due its improved capacity to better reflect local details in climate trend within small scale landscape compared to the kriging method (Shi et al., 2007; Yang et al., 2015; Zarco-Perello & Simões, 2017). In addition, the small size of the study area as well flat nature of the topography warranted the use of simple statistical interpolation rather than the use of sophisticated approaches such as Isoline and Hypsometric methods.

The IDW method, as detailed in (Babak & Deutsch, 2009; Ouabo et al., 2020), weighs a combined set of sample points to determine the cell value (Yang et al., 2015). The IDW as a spatial tool in QGIS 3.16 was utilized with moderate weighting value (2) to control the significance of known points upon the interpolated values (Yang et al., 2015).

3.4 Results and Discussion

3.4.1 Variability in Rainfall Years across Southwestern Ghana

The rainfall anomaly index (RAI) results computed for the 8 stations scattered across southwestern Ghana are presented in figure 3-5a and b, table 3-3 and appendix 3-1. Positive values represent wet years whilst the negative values depict dry years within the study period of 1976 to 2018. The average maximum and minimum wet year intensity for the study area were 5.53 and 0.22 respectively. These correspond to extremely wet and near normal intensities. Similarly, the average maximum and minimum dry year intensity were -5.71 and -0.14 respectively, which corresponds to extremely dry and near normal intensities.

There was an increased number of dry years (-) within all the stations, corroborating previous observations of decreasing annual rainfall from the 1980s onwards which still persist across the entire country (Kabo-bah et al., 2016; Manzanas et al., 2014; Owusu & Waylen, 2009). For instance, with 23 wet years, the Kumasi, Saltpond and Takoradi stations experienced the highest number of wet years whereas Sefwi Bekwai experienced the least number (17). Conversely, the Sefwi Bekwai station experienced the highest number (26) of dry years while Kumasi, Saltpond and Takoradi experienced the lowest number (20) of dry years. The results match closely with the temporal trend in previous studies accounting for drying trend in the forest climatic zone such as found in Sefwi Bekwai, Akim Oda and Abetifi stations compared to the coastal zone such as found in Takoradi and Saltpond stations (Abbam et al., 2018; Atiah et al., 2019; Baidu et al., 2017; Bessah et al., 2022).

Figures 3-6a and b illustrates the frequencies in the intensity of wet and dry years across the landscape based on the RAI intensity categorization. Following the new climatic zonation of Ghana (Bessah et al., 2022); Saltpond, Takoradi and Axim stations are classified to fall within the coastal climatic zone whereas the remaining stations falls within the forest climatic zone. The averages across the two zones were therefore computed as shown in figure 3-6a. Over the last 40 years, southwestern Ghana has experienced 7 and 10 near normal rainfall years across the forest and coastal climatic zones respectively. The rest of the period modulated between extremes of both wet and dry years.

In addition, it was observed that changes in rainfall years corresponded keenly with the forest ecological zones in Ghana as classified by Hall and Swaine (1976, 1981) and shown in appendix 3-3. For instance, Sunyani, Abetifi and Takoradi are located within the Dry semideciduous forest types whilst Saltpond is located within the Marginal forest type. Kumasi, Sefwi Bekwai, Akim Oda are located within the Moist semideciduous forest types whereas Axim station is located within the Evergreen forest zones. Hence, from figure 3-6b, it can be observed that the Dry semideciduous forest as well as the Southern Marginal forest zone have experienced higher numbers of near normal rainfall years compared to the Moist semideciduous and Evergreen forest zones.

These results confirm the increasing rainfall variability in the forest zone of Ghana both in time and space as indicated in previous studies. Yet Manzanas et al. (2014) cautioned the attribution of anthropogenic activities as leading cause to climate variability in Ghana since natural variability plays a key role.

To further expound on the extent of increasing variability, other extreme indices were analyzed for the stations and the results presented in the ensuing section.

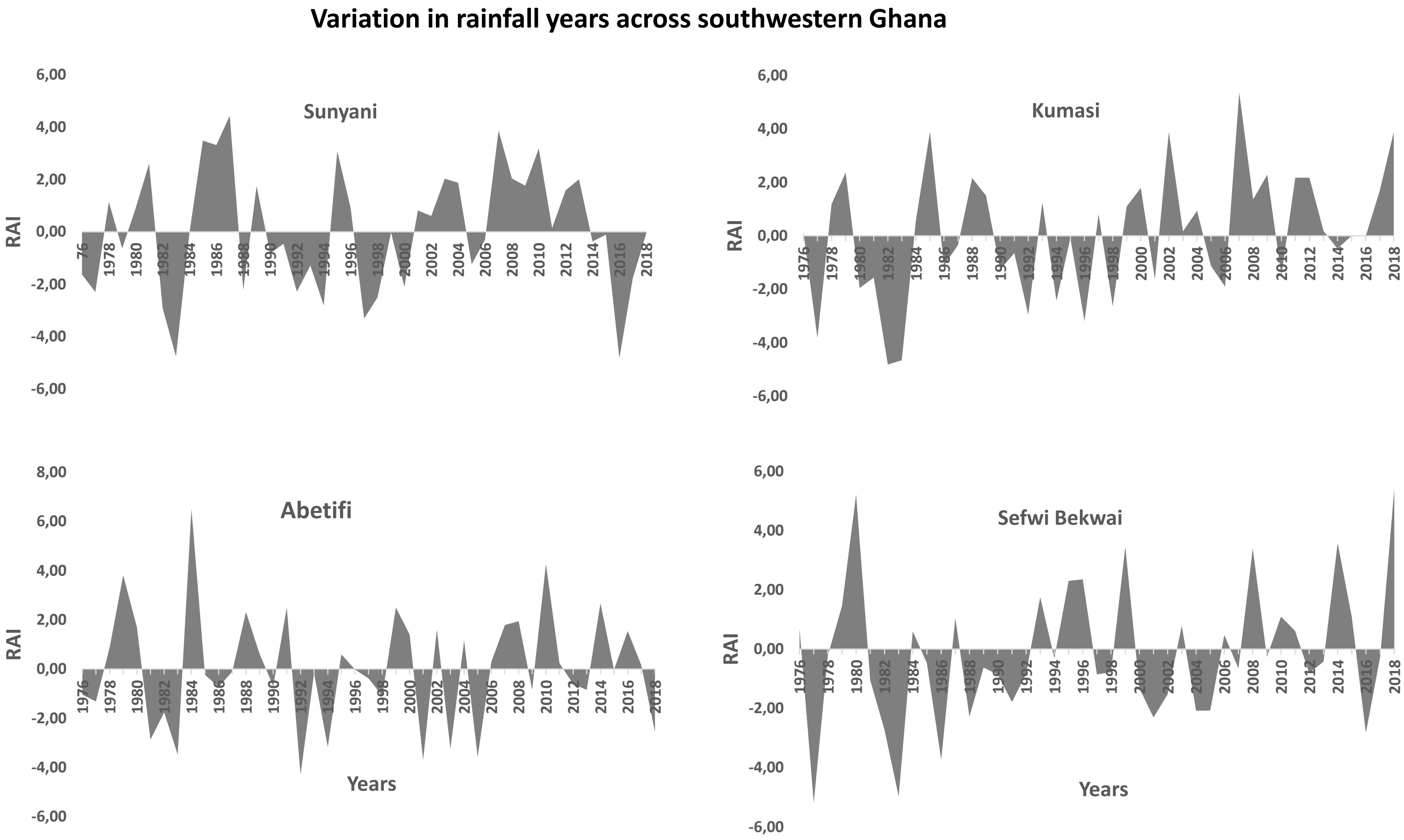

Figure 3-5a: Variability in extreme rainfall intensities across southwestern Ghana (1976-2018). NB: RAI= Rainfall Anomaly Index

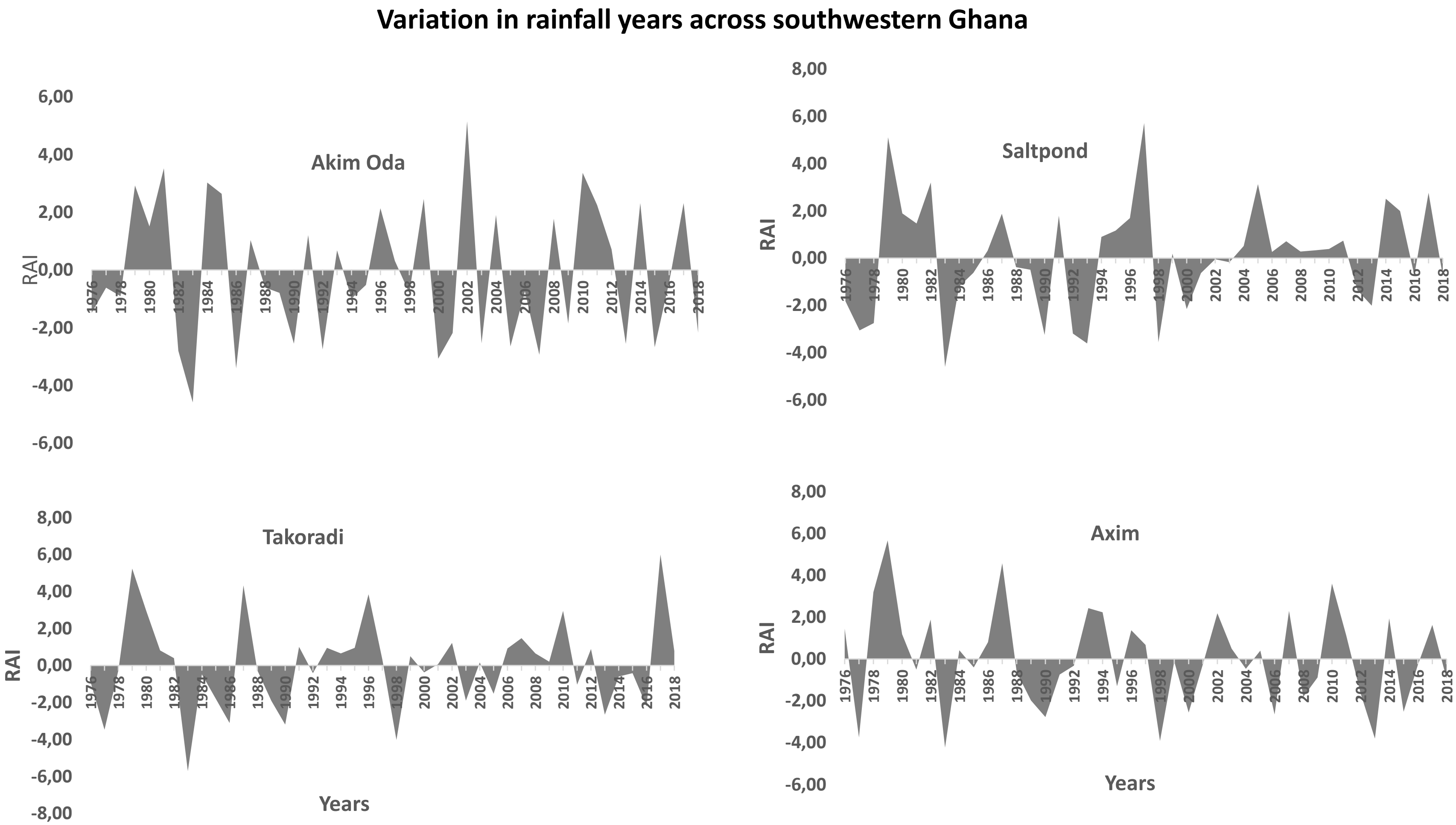

Figure 3-5b: Variability in extreme rainfall intensities across southwestern Ghana (1976-2018)

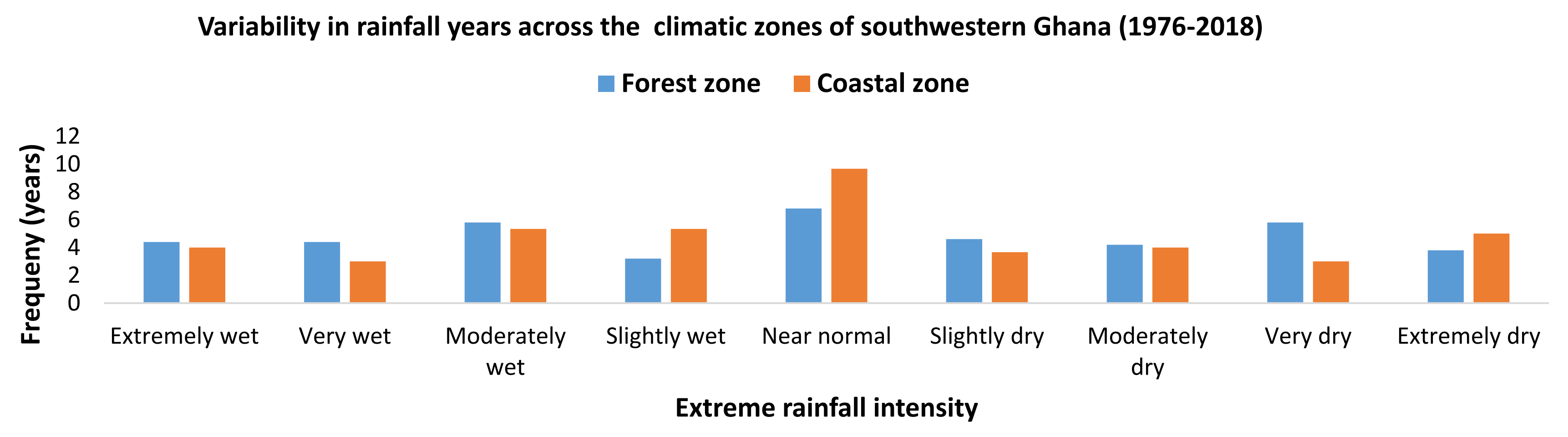

Figure 3-6a: Frequency of wet and dry years across the climatic zones southwestern Ghana

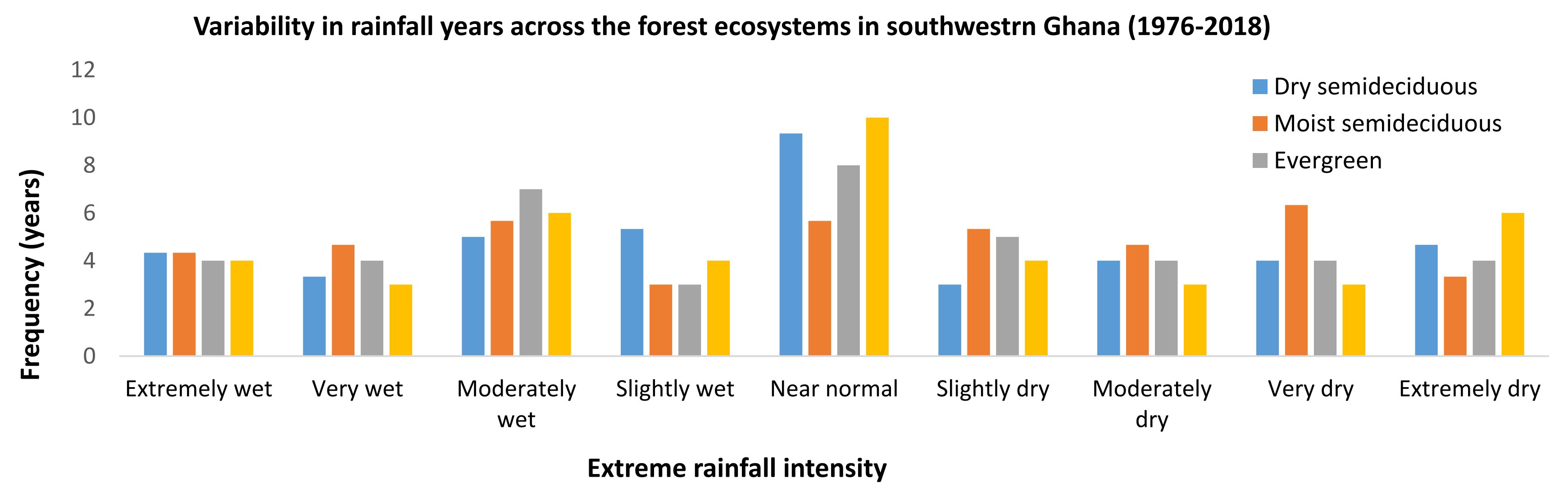

Figure 3-6b: Frequency of wet and dry years across the forest ecological zones in southwestern Ghana

3.4.2 Trend in Extreme Rainfall Indices across Southwestern Ghana

Selected extreme rainfall frequency and intensity indices, namely very heavy rainfall days (R20), simple daily intensity index (SDII), annual total wet day rainfall (PRCPTOT), consecutive wet days (CWD), consecutive dry days (CDD) and extremely wet days (R99P) were computed for all the synoptic weather stations within southwestern Ghana. After estimating the indices, Mann-Kendall (MK) test and Theil_Sen slope were conducted to detect the trend and the magnitude of change respectively.

The results of the MK test and Theil_Sen slope estimation for extreme climate indices across southwestern Ghana are presented in table 3-4. The MK test results indicate the trend be it increasing (+) or decreasing (-), whereas the Theil-Sen Slope estimates the rate of change be it increasing (+) or decreasing (-). Both tests revealed a gradual variation in extreme rainfall intensity indices (SDII, PRCPTOT and R99p) and frequency indices (R20, CWD and CDD) across southwestern Ghana. Based on the MK test for instance, an increasing trend in simple daily intensity index (SDII) can be observed across the entire southwestern Ghana except for the Axim station that exhibited a decreasing trend. In addition, a significant increasing trend was observed for the Kumasi, Sefwi Bekwai and Saltpond stations. Similar trend was observed for the annual total wet day rainfall (PRCPTOT) except for a decreasing trend at Takoradi and Axim stations. With respect to extremely wet days (R99p), an increasing trend was observed for all the stations except for the Sefwi Bekwai, Takoradi and Axim stations, which exhibited negative trends. The Theil_Sen slope estimated similar trends in the rate of change for all the stations as MK except for the extremely wet days (R99p) where no change was detected except for the Sefwi Bekwai station, which exhibited a decreasing rate of change.

For indices estimating extreme rainfall frequency, a positive trend for very heavy rainfall days (R20) was observed for all the stations across southwestern Ghana with significant levels at Kumasi and Sefwi Bekwai stations whereas the Takoradi and Axim stations showed negative trend. Similarly, trend in consecutive dry days (CDD) is decreasing throughout southwestern Ghana except for the Sunyani and Kumasi stations. Consecutive wet days (CWD) trends are decreasing with significant levels at the Saltpond, Takoradi and Axim stations whereas an increasing trend was detected for Abetifi, Sefwi Bekwai, and Akim Oda stations.

Table 3-3: Trend in extreme rainfall intensity and frequency for southwestern Ghana

Extreme climate indices	**Rain gauge**	**lon**	**lat**	**Elevation**	**Mann-Kendall test**		**Theil_Sen Slope**
					Trend	**p-value**	
SDII (mm/day)	Sunyani	-2,33	7,36	308,3	0,05	0,660	0,01
	Kumasi	-1,6	6,72	286,3	0,33***	0,002	0,07
	Abetifi	-0,75	6,67	594,7	0,09	0,396	0,01
	Sefwi Bekwai	-2,32	6,2	170,8	0,20*	0,059	0,03
	Akim Oda	-0,98	5,93	139,4	0,09	0,396	0,01
	Saltpond	-1,06	5,27	439	0,23**	0,029	0,07
	Takoradi	-1,75	4,88	4,6	0,09	0,408	0,02
	Axim	-2,24	4,86	37,8	-0,13	0,229	-0,04
PRCPTOT (mm)	Sunyani				0,07	0,490	1,47
	Kumasi				0,22**	0,040	5,74
	Abetifi				0,06	0,572	1,12
	Sefwi Bekwai				0,15	0,174	2,85
	Akim Oda				0,06	0,572	1,12
	Saltpond				0,09	0,402	2,97
	Takoradi				-0,03	0,761	-0,49
	Axim				-0,10	0,346	-6,03
R99p (mm)	Sunyani				0,05	0,685	0
	Kumasi				0,08	0,449	0
	Abetifi				0,10	0,388	0
	Sefwi Bekwai				-0,14	0,193	-0,29
	Akim Oda				0,10	0,388	0
	Saltpond				0,05	0,693	0
	Takoradi				-0,11	0,343	0
	Axim				-0,02	0,899	0

R20 (day)	Sunyani	0,04	0,705	0
	Kumasi	0,31***	0,004	0,15
	Abetifi	0,13	0,231	0,07
	Sefwi Bekwai	0,20*	0,071	0,1
	Akim Oda	0,13	0,231	0,07
	Saltpond	0,16	0,147	0,08
	Takoradi	-0,05	0,629	-0,03
	Axim	-0,10	0,344	-0,1
CDD (day)	Sunyani	0,04	0,738	0,1
	Kumasi	0,07	0,543	0,12
	Abetifi	-0,12	0,267	-0,24
	Sefwi Bekwai	-0,10	0,341	-0,3
	Akim Oda	-0,12	0,267	-0,24
	Saltpond	-0,14	0,201	-0,3
	Takoradi	-0,14	0,209	-0,24
	Axim	-0,05	0,615	-0,09
CWD (day)	Sunyani	-0,02	0,897	0
	Kumasi	-0,07	0,561	0
	Abetifi	0,05	0,695	0
	Sefwi Bekwai	0,06	0,580	0
	Akim Oda	0,05	0,695	0
	Saltpond	-0,34***	0,003	-0,07
	Takoradi	-0,26**	0,018	-0,07
	Axim	-0,26**	0,021	-0,07

*(NB: ***,**&* denote significant @ 1%,5%,10% probability level)*, *R20=Number of very heavy precipitation days, CDD=*Consecutive dry days, CWD=Consecutive *wet days, SDII= Simple daily intensity index, PRCPTOT= Annual total wet-day precipitation, R99p= Extremely wet days*

The spatial pattern of the MK and Theil_Sen slope estimates are shown in figures 3-7 and 3-8, which align closely with types of forest ecosystems in Ghana. A visual observation of the spatial maps in figure 3-7 shows an increasing trend in most of the extreme rainfall intensity indices (SDII, PRCPTOT, R99p) within the Moist and Dry semideciduous as well as the Marginal forest zones compared to a decreasing trend within the Evergreen forest zone based on MK test. Similar rate of change was estimated except for the very wet days (R99p) where the Theil_Slope estimate no rate of change within the entire study area except for a decreasing rate at Sefwi Bekwai, which falls within the Moist semideciduous forest zone (figure 3-8).

These results are consistent with the findings in previous studies (Abbam et al., 2018; Atiah et al., 2019; Logah et al., 2021). Atiah et al. (2018) analyzed similar indices for the four agroecological zones in Ghana and found an increasing trend in CWD, PRCPTOT and R20 for the entire forest zone. Similarly, Logah et al. (2021) detected an increasing trend for PRCPTOT and SDII for the Volta basin of Ghana. Finally, Abbam et al. (2018) noted increasing temperatures and declining rainfall across the western regions of Ghana, which form a major part of the southwestern miningscapes.

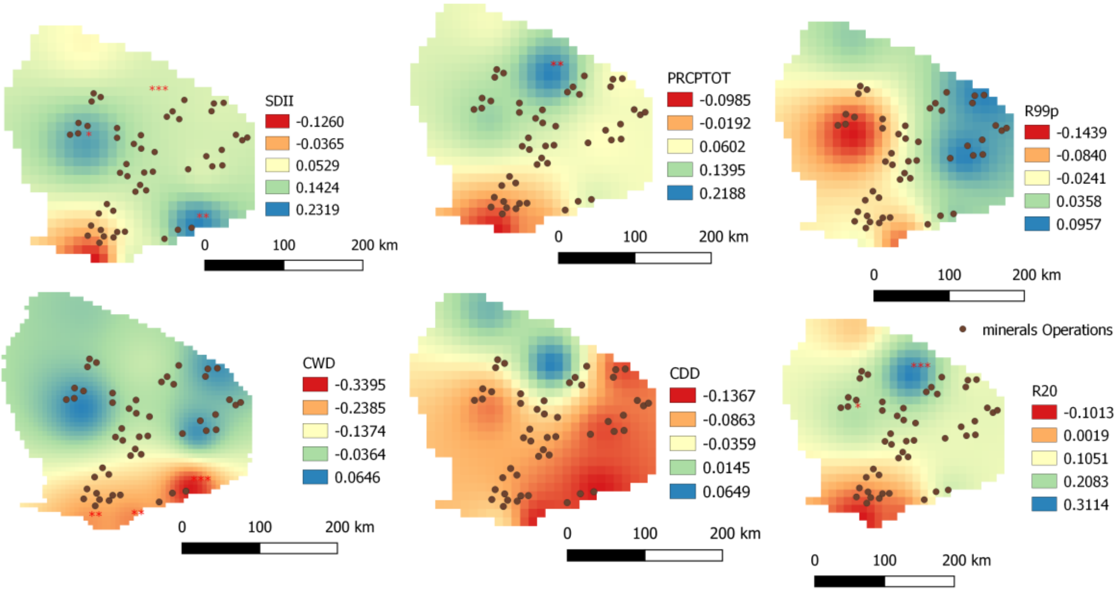

Figure 3-7: Trend in extreme rainfall frequency and intensity across southwestern Ghana using Mann Kendall test.

(NB: ***,**&* denote significant @ 1%,5%,10% probability level), R20=Number of very heavy precipitation days, CDD=Consecutive dry days, CWD=Consecutive wet days, SDII= Simple daily intensity index, PRCPTOT= Annual total wet-day precipitation, R99p= Extremely wet days

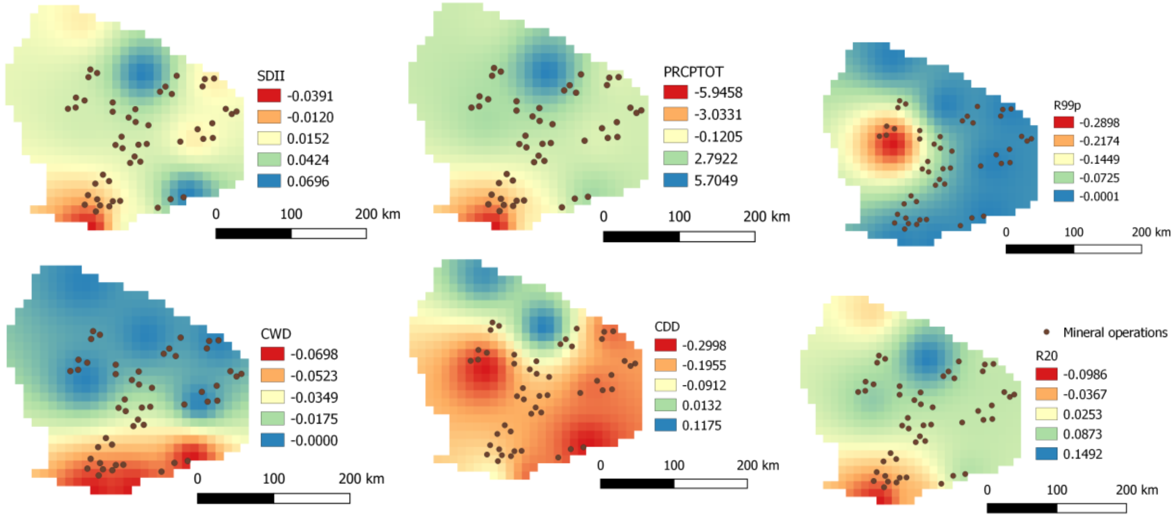

Figure 3-8: Rate of change in extreme rainfall events across southwestern Ghana using Theil-Sen slope.

3.4.3 Trends in Extreme Temperature Indices across Southwestern Ghana

The results of MK trend test and Theil_Sen slope estimated for extreme temperature indices, including mean monthly daily maximum (TMAXmean) and minimum (TMINmean) temperature, cool days, cool nights, warm days and warm nights are shown in table 3-5 and spatially presented in figures 3-8 and 3-9. Generally, significant upward trends in increasing TMAXmean and TMINmean were observed across the stations except for the Abetifi station. The uniqueness in temperature trend at Abetifi station has been attributed to the presence of the Kwahu plateau and the close proximity of the upland evergreen forest zone (Bessah et al., 2022; Ohmura, 2012).

Both statistical procedures reflected a positive trend in TMAXmean, TMINmean and percentage warm days compared to a negative trend in percentage cool nights across the entire landscape (figure 3-9). However, the Theil_Sen slope estimated increasing warm nights over the entire landscape whilst the Mann-Kendall test results showed an increasing trend only within the middle domain. Similarly, based on the MK a significantly increased trend in percentage of warm days and warm nights was observed across the entire southwestern Ghana except for the Takoradi station. However, Theil_Sen slope estimated a negative trend in rate of change in percentage warm days for Abetifi and Takoradi stations. Based on the Mann-Kendall test and the Theil_Sen slope, the percentage cool days and cool nights are significantly decreasing across the entire southwestern Ghana.

Table 3-4: MK and Theil_Sen slope of extreme temperature indices for southwestern Ghana

Extreme climate indices	**Rain gauge**	**lon**	**lat**	**Elevation**	**Mann-Kendall test**		**Theil_Sen Slope**
					Trend	**p-value**	
	Sunyani	-2.33	7.36	308.3	0.215**	0.044	0.01
TXmean	Kumasi	-1.6	6.72	286.3	0.428***	0.000	0.03
(TMAXmean)	Abetifi	-0.75	6.67	594.7	-0.111	0.304	-0.02
	Sefwi Bekwai	-2.32	6.2	170.8	0.309***	0.004	0.02
	Akim Oda	-0.98	5.93	139.4	0.311***	0.004	0.03
	Saltpond	-1.06	5.27	439	0.383***	0.000	0.02
	Takoradi	-1.75	4.88	4.6	0.006	0.966	0
	Axim	-2.24	4.86	37.8	0.232**	0.030	0.01
TNmean	Sunyani				-0.070	0.516	0
(TMINmean)	Kumasi				0.318***	0.003	0.02
	Abetifi				0.146	0.173	0.01
	Sefwi Bekwai				0.127	0.240	0.01
	Akim Oda				0.320***	0.003	0.02
	Saltpond				0.371***	0.001	0.02
	Takoradi				0.048	0.666	0
	Axim				0.232**	0.030	0.02
TN10p	Sunyani				-0.128	0.232	-0.09
(Cool nights)	Kumasi				-0.479***	0.000	-0.48
	Abetifi				-0.428***	0.000	-0.29
	Sefwi Bekwai				-0.305***	0.004	-0.28
	Akim Oda				-0.625***	0.000	-0.51
	Saltpond				-0.486***	0.000	-0.39
	Takoradi				-0.566***	0.000	-0.49
	Axim				-0.597***	0.000	-0.49

TN90p (warm nights)	Sunyani	0.006	0.970	-0.1
	Kumasi	0.340***	0.001	0.26
	Abetifi	0.181*	0.103	0.09
	Sefwi Bekwai	0.328***	0.005	0.15
	Akim Oda	0.366***	0.001	0.33
	Saltpond	0.360***	0.003	0.33
	Takoradi	0.181*	0.103	0
	Axim	0.514***	0.000	0.19
TX10p (Cool days)	Sunyani	-0.466***	0.000	-0.44
	Kumasi	-0.290**	0.006	-0.26
	Abetifi	-0.212*	0.067	-0.35
	Sefwi Bekwai	0.573***	0.000	-0.44
	Akim Oda	-0.618***	0.000	-0.61
	Saltpond	-0.336***	0.003	-0.39
	Takoradi	-0.458***	0.000	-0.67
	Axim	-0.238**	0.037	-0.35
TX90p (Warm days)	Sunyani	0.158	0.140	0.09
	Kumasi	0.560***	0.000	0.4
	Abetifi	0.125	0.283	-0.61
	Sefwi Bekwai	0.556***	0.000	0.25
	Akim Oda	0.544***	0.000	0.2
	Saltpond	0.577***	0.000	0.3
	Takoradi	-0.150	0.165	-0.19
	Axim	0.493***	0.000	0.13

_NB:_

***,**&* denote significant @ 1%,5%,10% probability level)

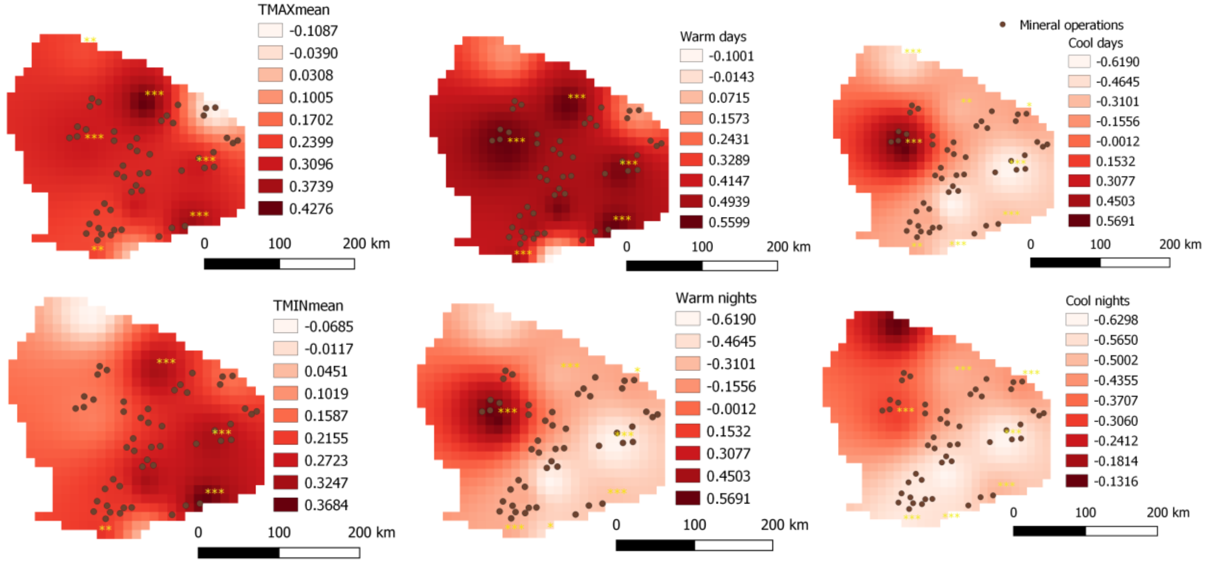

Figure 3-9: Trend in extreme temperature indices within southwestern Ghana using Mann-Kendall test. NB: ***,**&* denote significant @ 1%,5%,10% probability level)

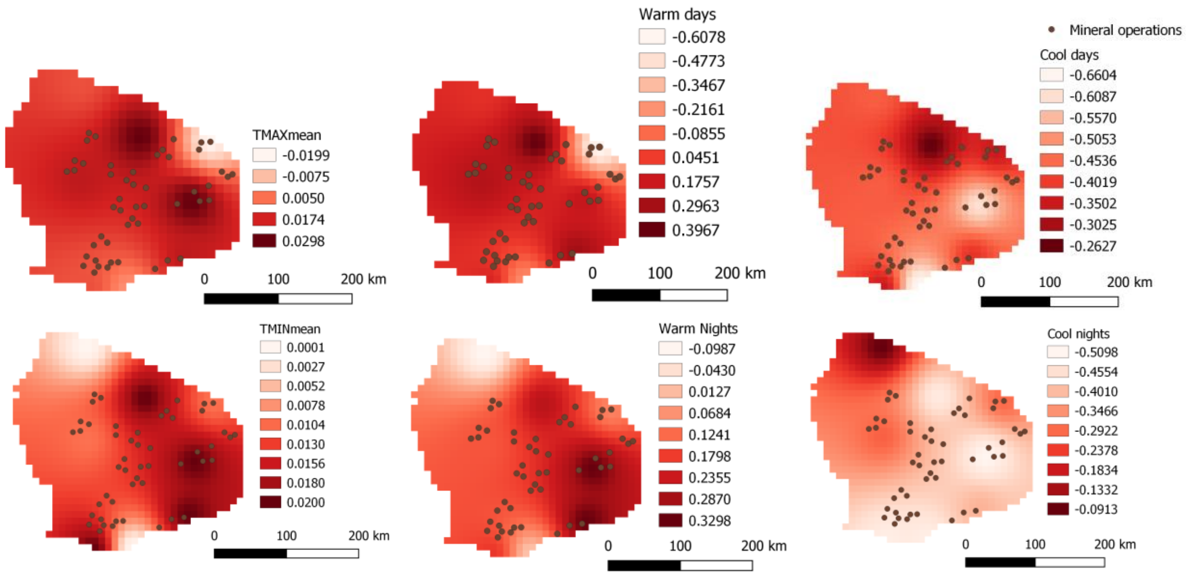

Figure 3-10: Rate of Change in extreme temperature indices within southwestern Ghana using Theil-Sen slope

3.4.4 Implications of local effects on resource systems development

Variability in Ghana's climatic system is increasing and is expected to escalate just as projected for the entire West African region (Sylla et al., 2016). The study shows that extreme rainfall and temperature trends are changing throughout the forest zone as estimated by Atiah et al., (2019) based on the gridded data. Similarly, near normal intensity rainfall years have declined to make way for extreme intensity rainfall years. Invariably, increasing trend in extreme temperature indices such as warm days and warm nights as well as decreasing trend in cool days and cool nights have been observed with significant levels throughout the different forest zones.

These changing trends present opportunities and threats for natural resources development and management within southwestern Ghana. Apart from the impacts on climate-sensitive subsistence activities such as artisanal fishing, collection of non-timber forest products and rain-fed agriculture that dominate rural landscapes, natural resource extraction activities within southwestern Ghana have to be adapted to the local effects of the changing climate. Resource extraction within southwestern miningscapes has high relevance to the nation Ghana as well as the wellbeing of its local inhabitants. For instance, minerals extraction, petroleum, cash crop production (cocoa, rubber, oil palm, coconut) as well as food crops contributes immensely to the economic growth of the country (Amisigo et al., 2015; Ayee et al., 2011; Kumah, 2006; MoFa, 2011). Hence, adapting to the local effects of changing climatic patterns is necessary. The current discussion centers on the implications on the mining industry and the hydrologic regime of basins within southwestern Ghana where the industry dominates although the effects of increasing variability in local climate equally affects other natural resource sectors.

Each phase of the minerals extraction process has some form of connection with the prevailing climatic condition within the mining territory. The operational phase is mainly the commercial phase whereby minerals are produced in commercial quantity and is perceived to be the phase most susceptible to climate extremes (Gonzalez et al., 2019). However, literature affirms the impact of changing climate on each phase of the mining cycle be it feasibility, exploration, development, operation or mine closure (Hodgkinson et al., 2014; Pearce et al., 2010; Rüttinger et al., 2020; Rüttinger & Sharma, 2016) including long-term effects on the soil and aquifers.

Odell et al., (2018) has illustrated the double exposure of water resources to mining and climate change effects whereas Philips (2016) reviewed the linkages between surface mining and water resources amidst the impact of changing climate. However, both surface and underground mining operational activities navigate such that the profiles of the host basins' hydrology and hydrogeology within a mining concession are modified. Key sources of these modifications include the direct effects on effective rainfall and base flow contributions due to rapid land-use changes to make way for mining infrastructure and settlement developments, diversion of streams and rivers away from operational areas, surface and underground pit dewatering, tailings and impoundments facilities among others. Some of these modifications have led to increased risk of rainstorm and flooding within surrounding communities with detrimental effects that are aggravated by transports of contaminants from the mining areas. Flood-led incidence and disasters within miningscapes would be intensified by increasing extreme events within southwestern Ghana. Unfortunately, the rural households within miningscapes are most susceptible to such rainstorm and flood risk (Osei et al., 2021) such as the inundation of their farmlands and human settlements.

Water management activities within the mining sites including raw water abstraction, stormwater and sediment control, water discharges and impoundments, acid mine drainages, water quality control among others can be affected by the changing trend in climate variability. For instance, rainfall has been identified as the main formation factor of acid mine drainage, hence increasing rainfall will increase the cost of treatment (Rochyani, 2017) as well as increased risk of contaminating surrounding water resources. Particularly, managing acid mine drainage becomes a greater challenge when there are rainstorms, which may wash down contaminants into the environment. Acid mine drainage issue is known to be a persisting challenge for most mines within southwestern Ghana (Asamoah et al., 2007) and can be compounded by increasing climatic variability. The consequences can be dire for sustainable mining as well as management of small and medium size river basins around mining sites. Thus, the development and allocation of water resources within the southwestern basin system where water resources are already stressed in quality (Armah et al., 2012) and quantity by competing users (WRC, 2009, 2012b, 2012a) can be endangered by local effects of changing climate.

Another aspect of mining likely to be affected by the increasing variability in southwestern Ghana includes occupational health, safety and environmental incidences. Frameworks advancing climate change impacts on occupational health and safety incidents have been highlighted in literature (Applebaum et al., 2016; Bi et al., 2011; Kjellstrom et al., 2014; P. A. Schulte et al., 2016; Paul A. Schulte & Chun, 2009) and the situation of miningscapes within southwestern Ghana would not be an exception. Recent empirical studies on mining workers located within the middle miningscapes (Evergreen forest zone) of southwestern Ghana confirmed increasing incidence in heat stress and related discomforts among mineworkers (Nunfam et al., 2019). In addition, an informant interviewed within the Sefwi miningscapes indicated the fatality of a colleague driver whose vehicle drowned during the peak of the unexpectedly prolonged rain season in 2014. The Community and Public Affairs department confirmed the incidence. Secondly, the rate of incidence risk on equipment safety is likely to be ascending with increasing temperature extremes including wear and tear, increased water demand for cooling systems including fuel storage and power generation systems. Prolonged dry seasons increase pollen agents in the atmosphere which couple with the excessive dust generation within mining sites to affect workers. These have consequences on workers productivity owing to increased rates of absenteeism. Similarly, flooding and inundation pose safety risks for mobile equipment as well as tailings storage facilities and water storage impoundments. For instance, the risk of dam failure and toppling effects become high with extreme rainfall as slope stability of the engineered berms are compromised (Chioti & Lavender, 2008). In addition, the design of emergency spillway that are based on static flood probability criteria needs to be revisited and adapted to changing situations such as the shift in the flood magnitude. Thus, the function and capacity of the emergency spillway together with related infrastructure needs to be closely monitored and maintained. Similarly, environmental management best practices such as environmental quality monitoring (water quality, air quality, blast vibration and noise), erosion and sediment transport control, land reclamation and post closure activities will not be spared by the effects of increasing climatic variability.

Be it surface or underground mining, infrastructural systems within operational sites are susceptible to intensified climate events within southwestern Ghana. Underground mines can be overwhelmed by increasing recharge rate, thus rendering water discharge practices ineffective.

Similarly, extreme temperature can render underground operations unsafe places to operate especially in situations whereby underground ventilation systems are inadequate. Surface mining operations are equally susceptible to extreme rainfall and temperature frequencies and intensities. The load and haul activities as well as the general transportation and logistics activities of the mine can be curtailed by extreme rainfall given the dilapidated nature of road networks within rural landscapes of Ghana.

On one hand, prolonged dry periods can provide a lean way for surface operational activities, which are mostly disrupted by increased rainfall frequency. On the other hand, mines with negative mine water balance may experience water scarcity. Apart from the potential of a mine operating with a negative water balance due prolonged dry periods, higher temperature and excessive dust generation on the mine, have numerous effects as identified by Damigos (2012) and Gonzalez et al. (2021). These consequences can undermine the capacity of the mine to comply with the safety, health and environment regulations of the industry as well as other requirements such as the global advocacy for renewable energy transition. Whilst energy demand of the industry will increase from the effects of increasing rainfall or otherwise, the use of genset and other non-renewable energy sources as commonly practiced within southwestern miningscapes is becoming unpopular. Energy regulation requirements are likely to be stringent within international markets for mining firms (Nelson et al., 2011) even if energy regulation is porous within the Ghanaian context.

In addition, the double exposure of the hydrologic regime of river basins within southwestern Ghana to impacts of mining activities and increasing climatic variability will enhance water resources competition with the basins system, which provide portable water within several regions. For example, the Pra basin hosts nine constructed water supply reservoirs in the country coupled with the construction of a small hydroelectric dam. The Ankobra basin, though considered as a fully mine-take basin (Obodai et al., 2019) still provides portable water for several municipalities and districts (WRC, 2009) just as the transboundary Tano-Bia basin (WRC, 2012b). Hence, the need for collaborative efforts toward adaptation to climate change impacts within miningscapes in particular cannot be overemphasized.

Highly critical are the two transboundary rivers within southwestern miningscapes, namely the Tano and Bia Rivers which drain into the Aby lagoon in Ivory Coast. Little attention has been given to understand the effects of mining land-use and changing climate on the hydrologic regime of the transboundary basin which is of high socio-economic and ecological significance in the West African region. Various adaptation strategies within the transboundary basin system would have to be amalgamated to address the local effects of changing climate on resource systems within the rural landscapes. Principally, a watershed approach to climate change adaptation that involve public-private partnership would be most appropriate for the transboundary basin. Such an approach would enable both the dominant economic systems and the rural dwellers to adapt to the impacts of mining and local climatic changes within miningscape.

3.5 Conclusions

The study retrospectively examined the variability in local climates of southwestern Ghana, which refers to the variations in long term averages of rainfall and temperature variables. The study analyzed the trend in extreme frequency and intensity of rainfall and temperature indices based on the rainfall anomaly index (RAI) intensity class (van Rooy, 1965) and other indices selected from the ETCCDI extreme indices. The study utilized 40 year daily time series observational rainfall and temperature data from 8 synoptic stations scattered within southwestern Ghana.

The RAI examined the intensity of dry and wet years which confirmed a modulated trend of both increasing number of dry years since the 1980’s and an intensification of extreme rainfall intensity across southwestern Ghana. Particularly, the Sefwi Bekwai, Akim Oda and Axim stations are experiencing increasing dry years and decreased near normal intensities whereas the Sunyani, Abetifi, Saltpond and Takoradi have increasing wet years and near normal intensities.

In addition, 12 extreme indices were selected and estimated for each station within using the R-RclimDex via the R statistical package. The extreme temperature indices were the monthly average value of daily maximum and minimum temperature (TXmean and TNmean in ^{0}C), percentage of days when TN<10th percentile (cool nights in %), percentage of days with TX<10th percentile (cool days in %), percentage of days when TN>90th percentile (warm nights in %) and the percentage of days when TX >90th percentile (warm days in %). The extreme rainfall indices were simple daily intensity index (SDII in mm/day), annual total wet day precipitation (PCRPTOT in mm), extremely wet days (R99p in mm), consecutive wet days (CWD in days), consecutive dry days (CDD in days) and number of very heavy precipitation days (R20 in days). Two statistical procedures (Mann-Kendall test and Theil-Sen slope) were then used to detect the trend and the magnitude of changes in the extreme rainfall and temperature indices across southwestern Ghana.

The results indicated an intensifying trend in the extreme climate indices especially within the Moist semideciduous (Sefwi Bekwai, Kumasi and Akim Oda) and Evergreen (Axim) forest ecosystems where natural resources extraction dominate. These observations corroborate earlier findings for the forest zones of Ghana (Atiah et al., 2019). Similarly, other climatic studies across the southern region of West Africa also revealed an intensified trend in extreme rainfall events along the Guinean coast to which southwestern Ghana belongs (Nkrumah et al., 2019; S. Sanogo et al., 2015; Ta et al., 2016).

The corresponding agro-ecological zones experiencing intensified variability are the Deciduous forest and Rainforest zone which are important for cocoa, oil palm, rubber, coconut and food crop productions and timber resources extractions apart from mining and petroleum activities thus necessitating immediate attention. Since rural livelihood resources grapple within resource extractivism, diverse efforts must be combined to address impacts of changing climate within miningscapes.

Given the transboundary nature and socio-economic significance of the rivers within southwestern Ghana, a watershed approach involving strong private-public collaboration necessary to address the local effects of changing climate. This is necessary to ensure that Agenda 2030 of targets *"of strengthening resilience and adaptive capacity to climate related hazards and natural disasters"* (SDG 13.1) can be achieved within rural West Africa.

Appendices 3

Table 3-1A: Variability in rainfall years across southwestern Ghana based on rainfall anomaly index (RAI)

Rainfall year	RAI_Sunyani	RAI_Kumasi	RAI_Abetifi	RAI_Sefwi Bekwai	RAI_Akim Oda	RAI_Saltpond	RAI_Takoradi	RAI_Axim
1976	-1.62	0.14	-1.04	0.69	-1.48	-1.82	-0.90	1.45
1977	-2.30	-3.83	-1.32	-5.19	-0.62	-3.05	-3.48	-3.75
1978	1.14	1.18	0.87	-0.21	-0.91	-2.75	-0.27	3.19
1979	-0.63	2.37	3.81	1.46	2.93	5.11	5.24	5.66
1980	0.91	-1.95	1.70	5.21	1.51	1.89	2.95	1.18
1981	2.59	-1.56	-2.87	-1.05	3.52	1.47	0.81	-0.51
1982	-2.91	-4.82	-1.77	-2.73	-2.80	3.20	0.40	1.88
1983	-4.75	-4.66	-3.48	-4.98	-4.59	-4.60	-5.71	-4.24
1984	-0.03	0.57	6.50	0.60	3.03	-1.20	-0.48	0.42
1985	3.48	3.90	-0.24	-0.48	2.64	-0.63	-1.80	-0.40
1986	3.31	-1.11	-0.73	-3.74	-3.41	0.31	-3.11	0.81
1987	4.43	-0.34	-0.10	1.05	1.04	1.87	4.33	4.57
1988	-2.21	2.16	2.32	-2.28	-0.61	-0.38	-0.26	-0.63
1989	1.74	1.50	0.63	-0.63	-0.79	-0.49	-1.91	-1.98
1990	-0.82	-1.26	-0.70	-0.86	-2.56	-3.25	-3.19	-2.77
1991	-0.46	-0.64	2.50	-1.79	1.21	1.80	1.01	-0.74
1992	-2.28	-2.95	-4.30	-0.84	-2.75	-3.19	-0.41	-0.32
1993	-1.29	1.25	-0.16	1.75	0.68	-3.61	0.96	2.43
1994	-2.81	-2.43	-3.17	-0.31	-0.99	0.90	0.65	2.23
1995	3.08	-0.08	0.60	2.30	-0.52	1.16	0.96	-1.30
1996	0.92	-3.20	-0.02	2.35	2.14	1.70	3.85	1.38
1997	-3.31	0.80	-0.38	-0.86	0.32	5.72	0.32	0.67
1998	-2.50	-2.64	-1.10	-0.78	-0.80	-3.56	-4.02	-3.92
1999	-0.02	1.10	2.50	3.45	2.46	0.19	0.50	-0.12
2000	-2.10	1.79	1.41	-1.33	-3.07	-2.15	-0.37	-2.56
2001	0.81	-1.62	-3.70	-2.31	-2.18	-0.63	0.07	-0.24

2002	0.61	3.89	1.60	-1.52	5.15	-0.04	1.22	2.19
2003	2.03	0.17	-3.25	0.78	-2.54	-0.17	-1.90	0.50
2004	1.87	0.94	1.16	-2.08	1.91	0.52	0.17	-0.47
2005	-1.24	-1.13	-3.58	-2.08	-2.65	3.13	-1.53	0.39
2006	-0.30	-1.90	0.30	0.48	-0.74	0.27	0.93	-2.65
2007	3.86	5.36	1.79	-0.65	-2.94	0.71	1.48	2.30
2008	2.04	1.37	1.94	3.39	1.78	0.28	0.65	-1.81
2009	1.76	2.28	-0.85	-0.27	-1.85	0.33	0.20	-0.89
2010	3.18	-1.49	4.26	1.10	3.37	0.39	2.95	3.60
2011	0.15	2.18	0.23	0.61	2.25	0.74	-1.03	1.13
2012	1.58	2.17	-0.61	-0.81	0.71	-1.36	0.89	-1.65
2013	2.00	0.18	-0.85	-0.42	-2.56	-2.01	-2.66	-3.80
2014	-0.37	-0.48	2.67	3.58	2.32	2.51	-0.59	1.94
2015	-0.11	0.00	-0.03	1.09	-2.68	2.00	-0.41	-2.52
2016	-4.82	-0.02	1.54	-2.83	-0.42	-0.72	-2.21	-0.28
2017	-1.77	1.70	0.16	-0.26	2.32	2.77	6.00	1.63
2018	-0.07	3.89	-2.57	5.41	-2.17	-0.76	0.78	-0.94

Table 3-2A: Descriptive statistics of wet and dry years across southwestern Ghana (1976-2018)

	Sunyani	**Kumasi**	**Abetifi**	**Sefwi Bekwai**	**Akim Oda**	**Saltpond**	**Takoradi**	**Axim**	**Averages across stations (1976-2018)**
Number of wet years (+)	20	22	20	17	19	23	23	20.00	20.5
Max wet years	1987	2007	1984	2018	2002	1997	2017	1979	
Max wet years intensity	4.43	5.36	6.50	5.41	5.15	5.72	6.00	5.66	5.53
Min wet years	2011	2015	2017	2006	1997	1999	2001	2005	
Min wet years intensity	0.15	0.00	0.16	0.48	0.32	0.19	0.07	0.39	0.22
Number of dry years (-)	23.00	21	23	26	24	20	20	23	22.50
Max dry years	2016	1982	1992	1977	1983	1983	1983	1983	
Max dry years intensity	-4.82	-4.82	-4.30	-5.19	-4.59	-4.60	-5.71	-4.24	-5.71
Min dry years	1999	2016	1996	1978	2016	2002	1988	1999	
Min dry years intensity	-0.02	-0.02	-0.02	-0.21	-0.42	-0.04	-0.26	-0.12	-0.14

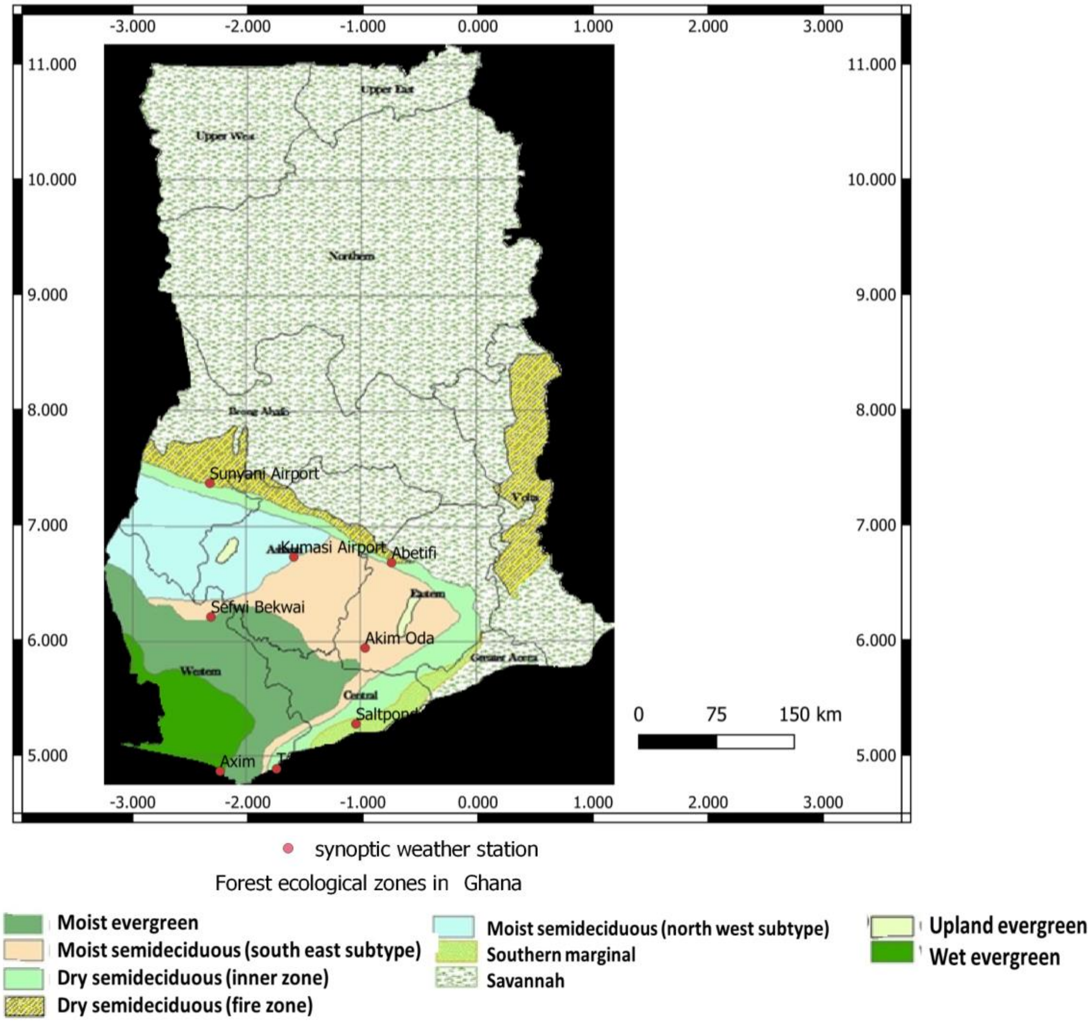

Figure 3-1A: Forest vegetation types in Ghana (source: Hall and Swaine, 1981)

Chapter four

Climate Variability and Mining Sustainability: Exploring operations’ perspectives on local effects and the willingness to adapt in Ghana

Abstract

The mining industry is susceptible to the effects of local climatic changes just as the surrounding socio-ecological systems that are exposed to both impacts of mining and changing climate spontaneously. Adaptation deficit in the mining sector is considered to be a worldwide problem, but given the double exposure on surrounding systems, which has emergent outcomes on the industry, operations must adapt in order to coexist with surrounding rural communities. To understand this susceptibility, the study employed mixed methods to assess the implications of local climate 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 uncertainty in the start /end of the rainfall season, torrential rain, prolonged dry season and the 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 a key component of 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 toward attaining the sustainable development goals, especially Goal 13, which calls for active collaboration between business and society.

Key Words: *Climate adaptation, Corporate sustainability, Double Exposure, Extractives*

4.1 Introduction

4.1.1 Climate-Mining Interactions and Double Exposures in Rural West Africa

As a natural resource management activity, a mine, its infrastructure and 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 & Smith, 2018; Odell et al., 2018; Phillips, 2016) and empirical studies (Gonzalez et al., 2019; J. . Hodgkinson et al., 2014; Liu & Song, 2019; E. Mavrommatis & Damigos, 2020; T. Pearce et al., 2012; T. D. Pearce et al., 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 local climate. Particularly increasing variability in extreme events across the tropical forest zones such as established in chapter three of this research are indisputable. 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; G. 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 (E. K. 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 on which surrounding communities are heavily depending. 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 locations 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 & 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 Leichenko and O'Brien (2000,p.227), such simultaneous and overlapping impacts of changing climate and globally mediated economic systems such as mining on other resources is termed 'double exposure' (Leichenko & O'Brien, 2008; K. L. O'Brien & 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 figure 4-1) coupled with the changing local climate. Extant literature already hints at the double exposure impacts in mining landscapes and expounds 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.

Figure 4-1: Socio-ecological systems dynamics in miningscapes (source: taken by author)

4.1.2 Will Mine Operations’ Adapt to Reduce Double Exposure Risk in West Africa?

Generally, adaptation to climate changes within an organization introduces additional 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 organization to adopt and implement adaptation strategies. Corporate adaptation is well established in management and organization studies (Lewin et al., 2004) since organizations such as mining companies must constantly respond and adapt to pressures from both internal and external proccesses. 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 Nations Global Compact (Frey et al., 2015), International Council for Mining and Metals (ICMM, 2013), Adelphi (Rüttinger & 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 & 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 (i) examine the perceived changing climatic variables within the forest belt and the effects on workers activities. (ii) explore workers' perceived strategies to enhance resilience building within operational sites (iii) 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 conclusion.

4.2 Conceptual Framework

4.2.1 Corporate Adaptation Process Model

The corporate adaptation process framework adopted for the study was originally developed by Berkhout et al., (2003) 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 & 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 organization 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 organization to deal with impact of climate and other changes. In addition, the notion of adaptation determinants refers to factors that influence an organization's perception and selection of adaptation options. These are the organization's susceptibility to change, the resources and capabilities of the organization, the regulatory and market context.

The organization's susceptibility to change is defined by how the organization's activities interact with climatic conditions and other external factors, the resources and capabilities of the organisation determine how the organization 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 sources of pressure for change to occur (Arnell and Delaney, 2006, p. 230).

4.2.2 Corporate Sustainability Performance as Determinants of Operations' Adaptation

Corporate sustainability as a management strategy (Dočekalová & 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 enhanced the consideration of the concept of sustainability in and by companies (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 & Hockerts, 2002; Hahn et al., 2015) following the Brundtland 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 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 (H Aguinis & 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 (M. 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 & 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 & Hockerts, 2002) which incorporate 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 & Kocmanová, 2015; Serafeim, 2018) which has gained wide recognition in practice. For instance, Dočekalová and Kocsmanová empirically tested a set of performance indicators for assessing corporate sustainability within the manufacturing industries, which are based on widely accepted corporate performance indicators. These indicators are already in use by non-financial performance assessment institutions such as the Global Reporting Initiative, the International Integrated Reporting Framework and the Guidance on Corporate Responsibility Indicators in Annual Reports among others.

Similarly, the metrics or aspects for assessing corporate sustainability performances in mining exist in literature (Azapagic, 2004; GRI, 2015; Lodhia & 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 summarized in table 4-1 are excerpts from the fourth edition of the Global

Reporting Initiative, G4 (GRI, 2015). The G4 enables reporting companies to provide valuable information about the organization’s most critical sustainability-related issues as well as focuses on materiality that is critical in order to achieve the organizations’ 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 of climate adaptation in mining within operations’ perspectives. To mimic the everyday language of operational workers, a proxy in terminology was generated by the author based on her decade of professional experience within the industry.

Table 4-1: 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:**
Labor 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

4.3 Methodology

4.3.1 Research Setting/Profile

Ghana is a low-middle income country based on the World Bank per capita gross domestic product (GDP) threshold, with projected population of 30.3 million as of 2019 and GDP estimated at US$66,984 million including oil with a per capita GDP of US$ 2,212 (GSS/EPA, 2020).

As a natural resource based economy, mining and logging contribute to 14% of the nation's economy as of 2019 (MESTI/EPA, 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, manganese (Boso et al., 2017). Particularly the southwestern part of the country (figure 4-1) where the study was conducted is proliferated with large-scale multinational mining operations following the IMF-World bank led structural adjustment (G. M. Hilson, 2004), which created an investor friendly environment as well as artisanal and small-scale mining firms

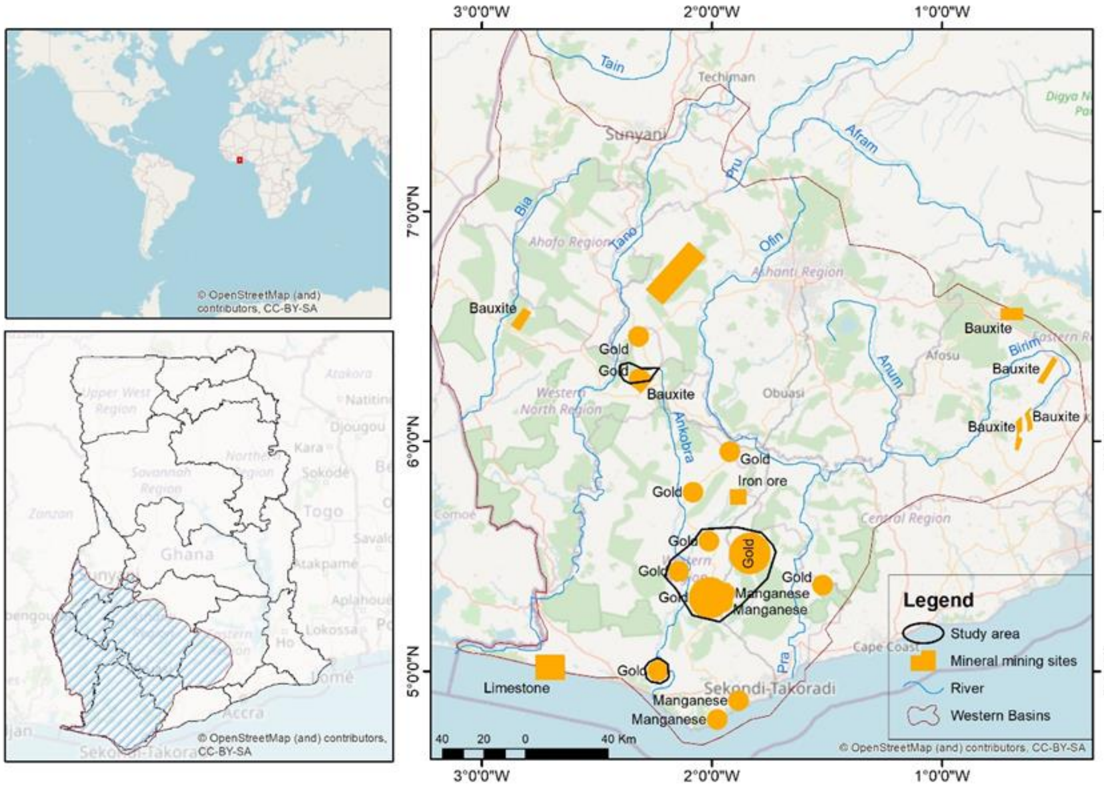

Figure 4-2: Map of selected mining landscapes in southwestern Ghana

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 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 utilization 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 of mineral exploration activities (Tienhaara, 2006). To curb the menace of deforestation, the Ministry banned mineral operations within forest reserves (Tienhaara, 2001, 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. Companies with less than the 2% concession can 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 UNFCCC in Ghana and spearheads the development of the country'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 area covers parts of the Rainforest (Moist and Wet evergreen) and the Deciduous forests that make up the forest agro-ecological zone of Ghana hence characterized 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). Hydrometeorological studies confirm the increasing climatic variability in the forest zones of Ghana as established in the previous chapter. For instance, Atiah et al., (2019, p.1) indicated the 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, 2018, p.130) just as previously indicated by Owusu and Waylen (2009). The trend analyzes in figure 4-2a 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.

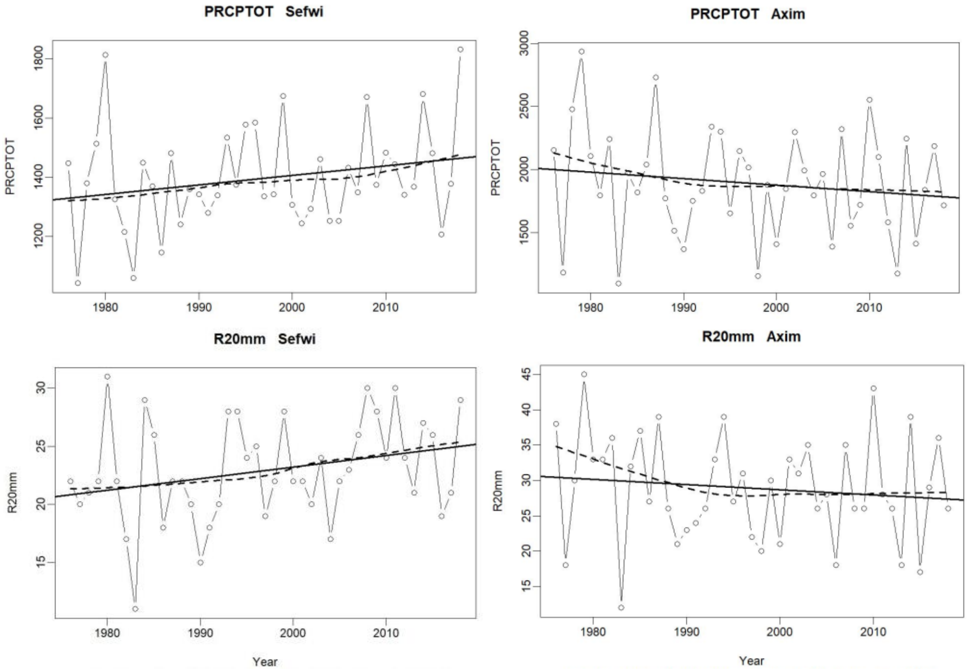

Figure 4-3a: Rainfall variability across southwestern Ghana (1976-2018). PCRPTOT= Annual total wet day rainfall (mm), R20mm= number of very heavy rainfall days (day). (Source: analysed by author)

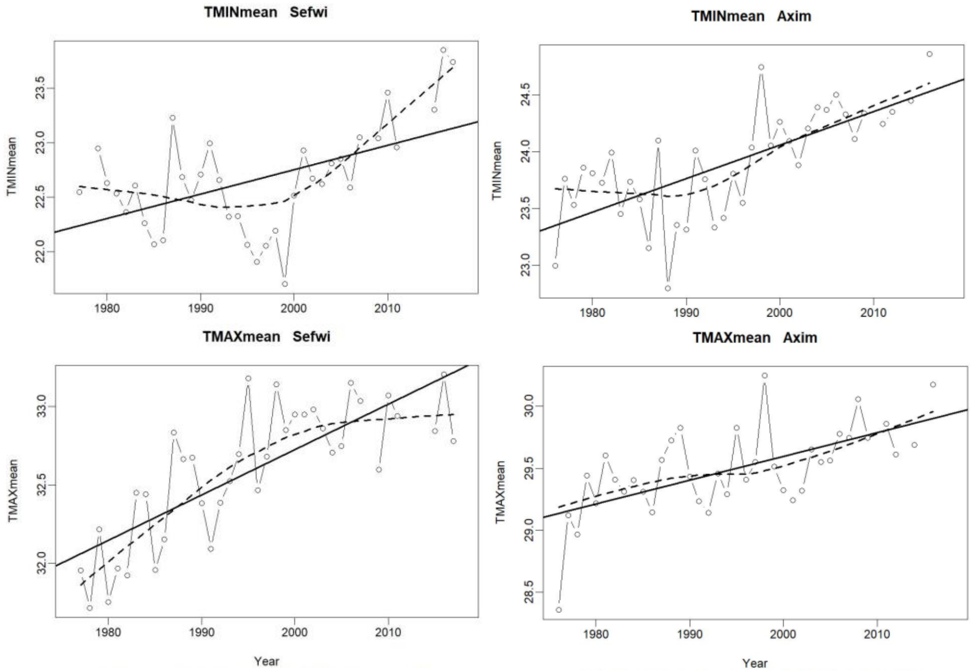

Figure 4-3b: Temperature variability across southwestern Ghana (1976-2018): TMINmean= Mean monthly maximum value of daily minimum temperature (0C), TMAXmean= Mean monthly minimum value of daily minimum temperature (0C).

4.3.2 Research Design

The study adopted a pragmatic paradigm by employing both qualitative and quantitative approaches which enable one to recognize the interconnectedness among experiences, knowledge and actions (Creswell & Creswell, 2018). In addition, the mining system was holistically structured on the three levels of corporate management according to the St. Gallen Management Model (SGMM) (Baumgartner, 2014; Schwaninger, 2016). These are normative, strategic and operation 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 posted at operations were interviewed. Whilst operations management level perspectives were examined via field observation, small group discussion and survey instruments across operational sites.

4.3.3 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 agroe-cological zones of Ghana where local climatic variability is empirically known to be increasing. The criteria for company participation was based on willingness of the company to participate. Thus, fifteen mining companies and their contractor services that accepted to participate were enrolled as presented in appendix 4-1. 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 three 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 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 analyze respondents' characteristics whilst cross tabulation was applied to analyze different perspectives and graphically presented. Kendall's coefficient of concordance was used to determine the mean rank of the responses. Content analysis was employed to analyze the qualitative fieldwork data. The Departments of respondents were re-coded into functional sections for ease of analysis as indicated in appendix 4-2.

4.3.4 Profile of Respondents

Table 4-2 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 seven mining companies and 17.2% in contractor companies, the latter providing mining related services for the seven mining companies. 77.8% of respondents identified as males and 22.2% as females, thus reflecting the male dominant nature of the mining profession. Of the respondents, 33.3% work in the production, 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.

Table 4-2: Respondents characteristics (Source: survey data)

Company Type	N (Percentage)	**Age**	Age range (Years)
Gold mining companies	75 (75.8)	Mean	35
Manganese mining company	5 (5.1)	Max	55
Mining Services Contractors	19 (19.2	Min	26
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	39 (39.4)		
Technical services	25 (25.3)		
Production	35 (35.4)		
Functional Departments			
Support services	39 (39.4)		
Technical services	25 (25.3)		
Production	35 (35.4)		
Positions			
Managers	10 (10)		
Supervisors	58 (58.6)		
Operator/Technician	17 (17.2)		
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)		

4.4 Results

4.4.1 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 4-3, 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 differences in perception among respondents located within the Rainforest forest (*p*=0.51), but some difference in perspectives were observed for workers within the Deciduous forest (*p*=0.01).

Similarly, appendix 4-3 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 low extent of changes (n=24). On the contrary, more than half of the respondents located within the Deciduous forest zone perceived very high extent of changing climatic patterns (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 4-3: Perception of changing climatic conditions within the forest zones of Ghana

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

Finally, respondents identified and ranked the changing climatic pattern observed most depending on how their activities were interrupted as summarized in figure 4-3. For instance, local variability such as changes in start/end of rain season referred to as seasonality received 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 highest (7) compared to respondents from production (geology, mining and processing/metallurgy) and support service (non-mining services).

These could be attributed to the fact that the activities of technical services sections such as boiler-makers and other maintenance engineers involve the use of hot substances, heating sources and related temperature relevant equipment where 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.

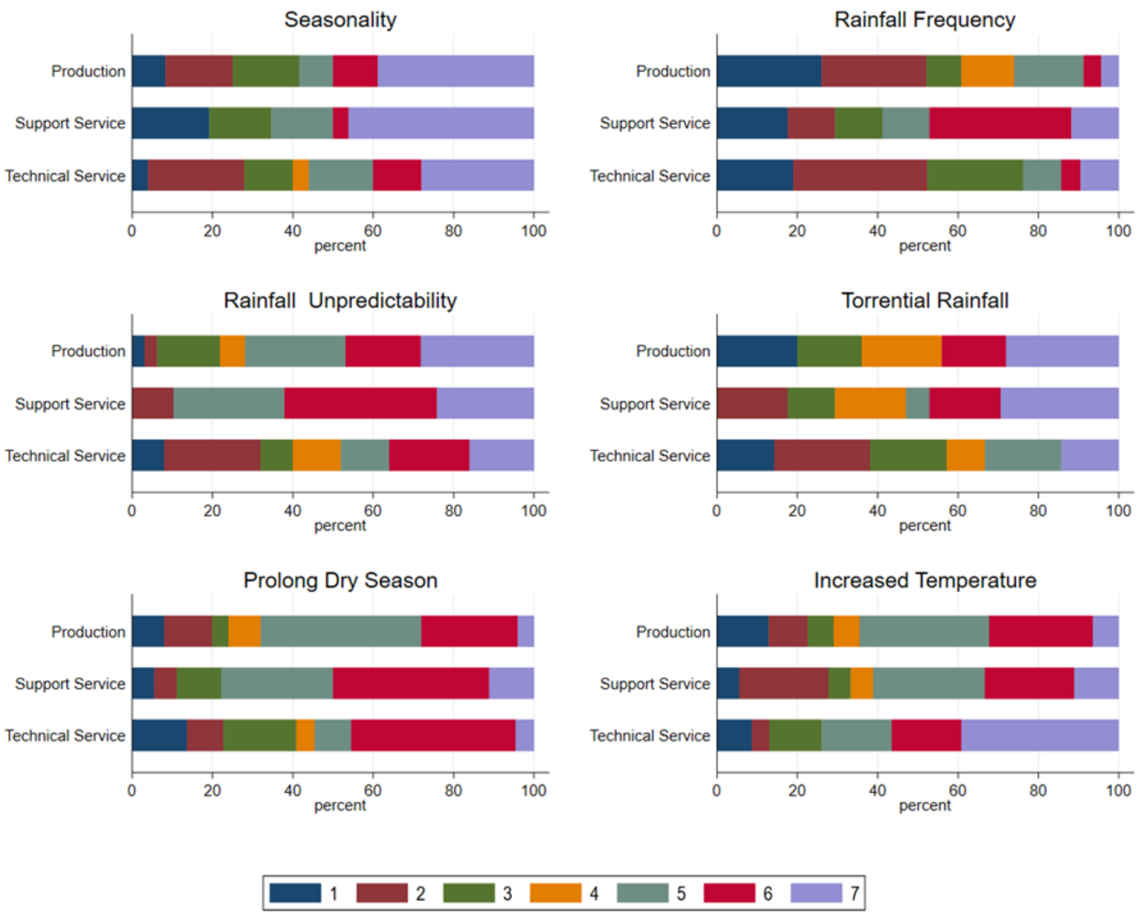

Figure 4-4: Ranking of climate variabilities by mining employees in the southwestern Ghana. NB: 1-7 is a range of observed variability in local climate ranked from lowest (1) to highest (7)

4.4.2 Susceptibility of Mining Operations to Impact of Local Changing Climate

Table 4-4 summarizes workers' response to the question on "*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).

Table 4-4: 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-borne 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**

Interestingly, the changing local climatic conditions were viewed to provide both opportunities and challenges. Surface mining professionals particularly noted 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) directly halted anytime it rained.

Other cost implications associated with rainfall variability were increased equipment maintenance cost 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 summarized 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 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 illnesses, asthmatic attacks and other air-borne infections" (Occupational Hygiene Manager, September 2018).

Corporate level climate related risk was associated with 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 that *"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).

4.4.3 Adaptation Strategies and Spaces within Mining Operations in Ghana

The results from the survey as shown in table 4-5 present operational workers perspectives on the adaptation strategy and spaces pertinent to enhance resilience building within mining landscapes. Generally, workers perceive collaborative effort towards 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 into mining regulation.

Secondly, workers expect 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 into 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 on the Ghana Chamber of Mines to sensitize adaptation to impacts of changing climate among members. The Kendall's coefficient of concordance indicated less degree of unanimity, (W^a= 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 all 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 have already issued annual reports on climate change since 2018 based on their corporate strategic policy on climate change.

Table 4-5: Adaptation options towards building resilient mining landscapes 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

4.4.4 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 figures 4-4a 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 to 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 *'license to operate'* which is assured mostly CSR is listed as key climate risk to the industry. These reveal the divide between operations' perceptions vis-a-vis corporate reporting.

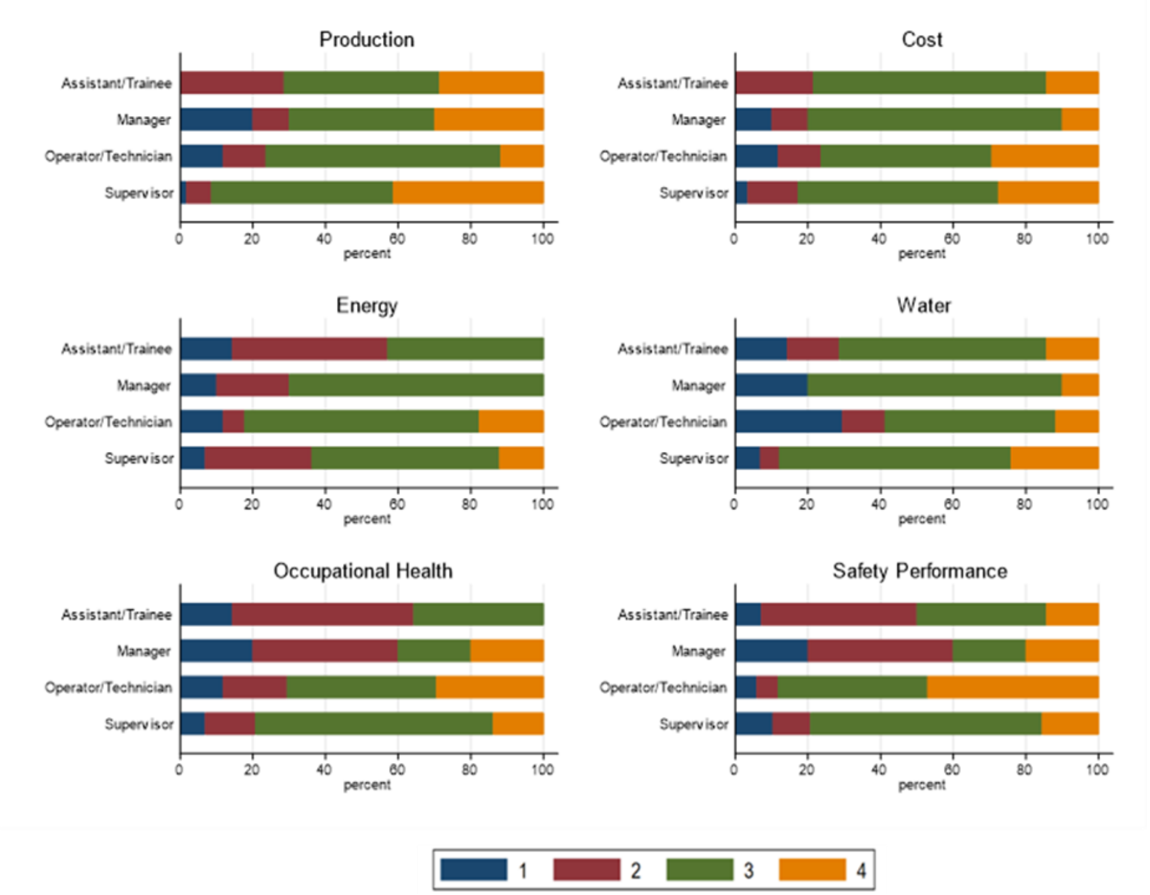

Figure 4-5a: Implication of climate variability on economic sustainability performance

(source: survey data) NB:1=very low 2=low 3= high 4= very high

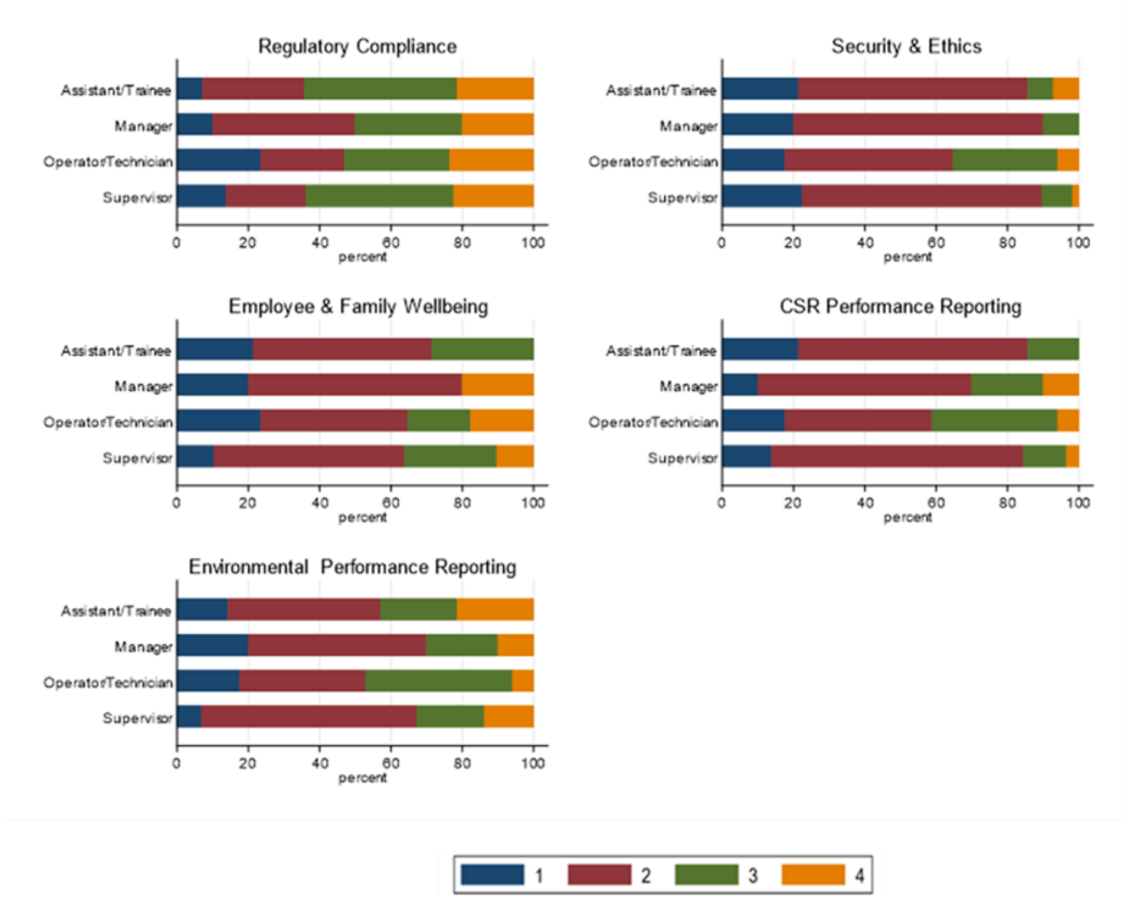

Figure 4-5b: Implication of climate variability on social and environmental sustainability performance. (Source: survey data) NB: 1=very low 2=low 3= high 4= very high

4.5 Discussion

From the empirical evidence, the increasing climatic variability in the forest zone of Ghana as perceived by employees corroborates the findings of previous hydroclimatic 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 in 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; Nunfam 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 (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 shortage 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 changing climatic patterns. These can result in unplanned situations leading to injuries and equipment damages. 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 regions 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; Hodgkinson et al., 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 in order 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 prioritizing 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 lack of strong external forces such as the German law on Supply chains ("Lieferkettengesetz") and other national regulations. Consequently, respondents prioritized 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 risks closure for which aspects such as production, cost, water and energy demand are prioritized. 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 organization's perception and willingness to adapt to climate change depend on the organization'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 are 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 (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 on large-scale mining operations although there are ample number of artisanal and small-scale mining activities ongoing in the region. The sample size was constrained by logistics and time hence generalizing outcome of 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.

4.6 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 have concern for 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 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 reveals 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 impacts through resilience building and awareness-raising as well as human/institutional capacity on climate change adaptation according to Target 1 and 3 of SDG 13 requires the active involvement of the business society whose activities can potentially worsen the plight of vulnerable groups.

Appendices 4

Table 4-1A: List of participating mining operations and contractor companies

Comp_ code	Operations/company name, location	Country of Origin	Type of Company	Type of Operation
1	Kinross Gold Mine, Chirano	Canada	Gold mining company	Surface and Underground mining
2	Gold Fields Ghana, Tarkwa	South Africa	Gold mining company	Surface mining
3	Golden Star Resources Wassa, Akyempim	Canada	Gold mining company	Surface and Underground mining
4	Gold Fields Ghana, Damang	South Africa	Gold mining company	Surface mining
5	Westfield Engineering Services, Chirano	Ghana	Mining Services Contractor	Exploration and Production drilling
6	RedpathThonket Mining Services, Chirano	South Africa & Ghana	Mining Services Contractor/Raiseboring	Raiseboring at Chirano
7	Pamicor limited, Chirano	Ghana	Mining Services Contractor/drilling	Production drilling at Chirano
8	PDSA Company Limited/ Technical Sales and Support, Tarkwa	Ghana	Mining Services Contractor/Technical services	Survey instrumentation at Tarkwa and Damang
9	AngloGold-Ashanti Iduapriem, Tarkwa	South Africa & Ghana	Gold mining company	Surface mining
10	Ghana Manganese company, Nsuta	Australia	Manganese mining company	Surface mining
11	Engineers & Planners Co. Ltd, Tarkwa	Ghana	Mining Services Contractor/Technical services	Load and haul at Goldfields Tarkwa and Damang
12	Adamus Resources Limited, Nzema	UK & Ghana	Gold mining company	Surface mining
13	African Explosives limited (AEL) mining services, Tarkwa	South Africa	Mining Services Contractor/explosives	Charging and blasting at Goldfields Tarkwa, Damang and Wassa
14	Henmpoano, Nzema	Ghana	Social Services Contractor (NGO)	Community engagement at Adamus
15	Maxam Ghana, Chirano	Spain	Mining Services Contractor/explosives	Charging and blasting at Chirano and Iduapriem

Table 4-2A: Recoded mining departments into functional sections

Production	**Technical Services**	**Support Services**
Strategic Mine Planning	Surveying	Environment
Pit Design and Scheduling	Geotechnical	Occupational Health & Safety
Drill and Blast	Maintenance Engineering	ICT
Load and Haul	Underground Ventilation	Human Resources
Geology	Surface & Underground	Security
Crushing Unit	Dewatering	Finance and Administration
Tailings Facility Management		Supply Chain and Logistics
Processing		Training and Development
		Hospitality and Camp Management
		Community & Public Affairs
		Construction and Civil Works

Table 4-3A: Workers perceived extent of changing local climatic conditions in relation to routine activities

		Extent of Observation			
Agro-ecological zone/ Functional Section		**Low**	**High**	**Very high**	**Total**
Deciduous Forest	Production	0	2	14	16
	Support Services	1	6	12	19
	Technical Services	2	9	8	19
		3	**17**	**34**	54
Rainforest	Production	9	4	4	17
	Support Services	8	5	3	16
	Technical Services	7	4	1	12
		24	13	8	45
Total	Production	9	6	18	33
	Support Services	9	11	15	35
	Technical Services	9	13	9	31
		27	30	**42**	99

Chapter five

Climate Variability and Extractivism Exposures: Understanding household perspectives on livelihood resilience in rural Ghana

Abstract

The resilience of African rural livelihoods is at risk due to over-reliance on rain-fed agriculture, which increasingly suffers from climate variability. Extractive communities are exposed to changes from extractivism and climate conditions. The double exposure framework is employed to contextualize factors influencing households' perspectives on the overlapping impacts of these change processes on livelihoods.

The results affirm a general awareness that both climate variability and extractivism affect rural livelihoods. In addition, contextual factors such as gender, cultural connections, education, type of occupation, agroecological and resource extractivism types significantly influence households' perception of climate variability and extractivism effects on livelihoods. For example, large size households located in the deciduous forest zones are more likely to perceive that their livelihoods are double exposed to climatic variability and extractivism effects. Communities affected by mineral/forestry extractivism are more likely to perceive double exposure of climatic variability and extractivism effects on their livelihood sources. Households expect the national government and extractive companies to provide alternative livelihoods and improve infrastructure to enhance their resilience.

The study shows that differential factors underpin the perceived risk of rural livelihoods exposure to climate change and extractivism, thus supporting the need for policy-makers to include mining landscapes in national adaptation programs.

Keywords: *Climate Variability, Extractivism, Ghana, Livelihood, Resilience*

5.1 Introduction

A key way to alleviate rural poverty is to enhance the pathways of building resilience in the livelihoods of the poor, thus reducing their exposure and vulnerability to climate related risk and other socio-economic as well as environmental shocks (SDG 1.5). Rural livelihoods are affected by global environmental changes such as changing land use systems, declining biodiversity, water resource depletion and pollution as well as climate variability and changes (IPCC, 2014; Sani & Chalchisa, 2016; K. Sanogo et al., 2017; Thakur & Bajagain, 2019; Yaro & Hesselberg, 2016). This is facilitated through global trade relations between countries, technology, infrastructure development, global conservation/development standard strategies and guidelines (Kelboro & Stellmacher, 2019; Oldekop et al., 2020).

The situation of rural communities in West Africa is critical due to high dependence on climate-sensitive livelihoods such as rain-fed agriculture and collection of non-timber forest products (NTFPs) (Ahenkan & Boon, 2011; Appiah et al., 2009; Cobbinah & Anane, 2016; Dumenu & Obeng, 2016; Onyekuru & Marchant, 2014). Certainly, insufficient infrastructural systems in rural communities contribute to their vulnerability to the detrimental effect of climatic variability and changes (Mafusire et al., 2010; Shiferaw et al., 2014). The IPCC (2014) defines climate variability as the deviations in the averages of climate properties such as rainfall and temperatures as well as extremes beyond individual weather events (IPCC, 2014).

Over time, rural communities get accustomed to prevailing climate conditions such as rainfall pattern and seasonality as well as the average temperature ranges. However, with the increasing uncertainties, adapting livelihoods to such seasonal changes and extremes become severe for the inhabitants. Hence, improving rural development remains critical to enhance the adaptive capacity of communities (Pouliotte et al., 2009). Adaptive capacity of a community refers to the inherent properties such as access to resources that enable them to modify their actions in order to maintain or improve their quality of life amidst perceived and actual stresses (Gallopin, 2006; Jakku et al., 2010; Wall & Marzall, 2006). Disparities in socio-economic, human and natural endowments of households shape their livelihood resilience (Speranza et al., 2014). Livelihood here refers to the diverse ways by which households and individuals make a living (Ellis & Freeman, 2004; Scoones, 2009). The livelihood strategies of a community therefore define their adaptive capacity and illustrate the extent to which community members can withstand or co-evolve with changes and shocks (Thulstrup, 2015). Resilient livelihoods are able to withstand stress and shocks, including the means to adapt to future stresses (Tanner et al., 2015) such as the direct and indirect impacts of climate variability coupled with extractivism.

Rural communities affected by extractivism (resources-fringing communities) are not spared from the effect of climate variability and changes, irrespective of the notion that livelihoods in such communities are resilient (Norman & Jamele, 2016). Rather, these communities risk the simultaneous impact of extractivism and increasing local climatic changes. Extractivism involves both the technical process of extracting raw materials for export and the political ecology hovering over the entire process (Acosta, 2013; Ayelazuno, 2014; Ye et al., 2020). Such raw materials include precious minerals and metals, crude oil, timber, fisheries and cash crops.

Extractive activities generate direct and indirect impacts on the livelihoods and general wellbeing of their fringing-communities (Wegenast & Beck, 2020) by providing diverse opportunities and threats (G. Hilson & Haselip, 2004; Kemp, 2009). For instance, an entire farming community settlement and their farmlands can be lost to extractive activities, especially in the minerals sector if the ore body occurs beneath such places. Depending on how a household manages its share of settlement and compensation benefits, the vicious cycle of poverty can be broken or entrenched (Tsuma, 2010; E. Wilson, 2019). It is also not surprising that inadequate provision of alternative livelihood instigates social and environmental conflicts (Bebbington et al., 2015; Cuba et al., 2014; Schueler et al., 2011) between the extractive companies and their affected communities.

Inevitably, the national economies of most nations within the West African region are driven by raw material extractions including minerals, timber, petroleum products and cash crops mainly spearheaded by multinational companies with strong backing of international financial institutions (Signé & Johnson, 2021). For instance, the IMF/World Bank led restructuring program in the late 1980s enhanced the proliferation of multinational mining companies within the region which continues to date (G. M. Hilson, 2004; World Bank, 2020). Such collaborations perpetually paralyze fringing communities to compete for livelihood resources within the same landscapes. The economy of Ghana as an example is driven by export of gold, cocoa, timber and crude oil production although shrouded in negative socio-environmental footprints (Eshun et al., 2010;

Sarfo-Mensah, 2005; World Bank, 2020). Remarkably, the share of rural communities from raw material extraction does not reflect vividly within the landscape. For instance, only 2% of royalties from minerals extractive sector is allocated for community development (Mineral Development Fund Act, 2016 Act 912, 2016) whereas none exist for the royalties from the petroleum, forestry and cash crop sector (Ayine, 2008; Petroleum Revenue Management Act, 2011 (Act 815), 2011). Literature on resource curse explicitly exposes these phenomena whereby resources extracted within a landscape do not benefit the inhabitants who are directly exposed to the impacts (Amundsen, 2017). Hitherto, the increasing demand for sustainable resource exploitation is engendering corporate extractive companies to contribute to rural development through corporate social responsibility although these initiatives are most often voluntary and philanthropic in nature (Andrews, 2016; Boso et al., 2017). Moreover, high expectations are on extractive companies to contribute to the rural development in their surrounding communities even by national governments. Thus, rural development in most mining landscapes is surrendered to the dictates of the industry (Bruckner, 2016; Hansen, 2014; Jenkins & Obara, 2008; Odumosu-Ayanu, 2014).

The variability in local climatic conditions is also relevant to the sustainability of the extractives operations especially the minerals sector (T. D. Pearce et al., 2010; Rüttinger & Sharma, 2016). Worse of all, both processes interactively generate outcomes that can jeopardize the livelihood resources of surrounding communities (Leventon et al., 2015; Odell et al., 2018). Odell and his colleagues dubbed this simultaneous impact of mining and climate interactions on other resources as "*intersecting impact"* and expound on the need for perception and responses assessment to attenuate consequences on actors (Odell et al., 2018).

Rural livelihoods in the southwestern mining landscapes are double exposed to the effect of increasing climatic variability and extractivism (Atiah et al., 2019; MESTI/EPA, 2020; World Bank, 2020) due to the proximity of human settlements and farmlands to mining and forest resource concessions (Moomen, 2017). Forest resources extraction and ongoing oil and gas production activities in the southwestern regions have introduced severe changes for rural dwellers to contend with. In most cases, the impact of these exposures is contingent on the socio-economy, social relations, infrastructural and biophysical endowments at the disposal of households and communities. This study therefore adapts the double exposure framework to illustrate the interacting effects of extractivism and climate variability on rural livelihoods in mining landscapes of southwestern Ghana. The study also examines contextual factors influencing households' perception and identifies response strategies that will enhance households' capacity to adapt to such double burden in mining landscapes.

5.2 Conceptualising Double Exposure of Climate Variability and Extractivism

The double exposure framework refers to the overlapping impact of globalization and global environmental changes, unintended or otherwise, on resilience of other human or resource systems (Leichenko & O'Brien, 2008; K. L. O'Brien & Leichenko, 2000). The framework stresses the relevance of a set of combined conditions (Contextual Environment) of the system under exposure (Exposure Unit) such as economic, social, cultural, technological, institutional and biophysical characteristics, among others, to determine the exposure and adaptive capacity of the exposed system. The exposure unit refers to the spatial and temporal dimension of the unit of analysis, which can be a global, regional, community or a system, while exposure refers to the subjection of the system to an effect or influence of stresses or shocks from global change processes. In addition, the framework indicates that anticipatory process and actions (Anticipatory Response strategies), taken timely to influence the contextual environment, are imperative to determine the exposure and Outcome pathways. The Outcomes refer to the tangible and measurable effects, including vulnerabilities and capacities, generated from the interactions of the change processes, which affect the choices that exposed actors can follow (Bebbington et al., 2015). Outcomes consecutively affect the change processes as well as the environmental context and vice versa.

Empirical evidence illustrates the usefulness of the framework to analyze the resilience of resource systems double exposed to global changes and globalization at different spatial and temporal scales. These include the double exposure of pastoralists to economic and environmental changes in Niger (McKune & Silva, 2013) as well as the double exposure of Indian rural livelihoods to climate and trade liberalisation (K. L. O'Brien & Leichenko, 2000), which reflect the rural livelihoods situations. In addition, the double exposure of climate change and the 2008/09 global financial crisis in California (Leichenko et al., 2010) as well as the double exposure of the Ghanaian fisheries sector to climate change and capitalist expansion (Nolan et al., 2022) also reflect national scale situations. In this study, the framework enables a comprehensible analysis of the contextual factors that influence the household level view on double exposure of climate variability and extractivism effects on livelihood resilience in mining landscapes. In addition, the response strategies necessary to enhance adaptive capacity within the mining landscape are examined.

Figure 5-1 depicts rural mining landscapes in southwestern Ghana as a simplified unit of analysis (Exposure unit). Livelihood resources in the landscape are double exposed to the effect of two global change processes. These change processes are extractivism (minerals, timber and petroleum extractions) that are economic tools of globalization, and climate change (local climate variability) manifesting as an effect of global environmental change. Dynamic interactions of the two change processes simultaneously and concurrently (Leichenko et al., 2010) affect the capacity of households to make a living (Household level Outcome). The exposure and outcome pathways of the double exposed livelihoods, however, depend on the contextual environment of the households and the community in general (socio-economy, culture, demography, agro-ecological zones etc.). In addition, availability of adaptive strategies of households, such as means for income diversification and support from government such as availability of social amenities (anticipatory response strategies) within the landscape, are critical to determine the outcome pathways. Similarly, anticipatory response strategies from the extractive companies are critical since outcome feedbacks interact backwardly with extractivism and global changes. For instance, poor crop yields due to seasonal shifts increase resource competition leading to forest encroachment in quest to expand farmlands, which contribute to biodiversity loss as an environmental change effect. Moreover, the competition for land resources within the landscape can generate social upheavals and conflicts, which can jeopardize the extractives industries' '*licence*' to operate.

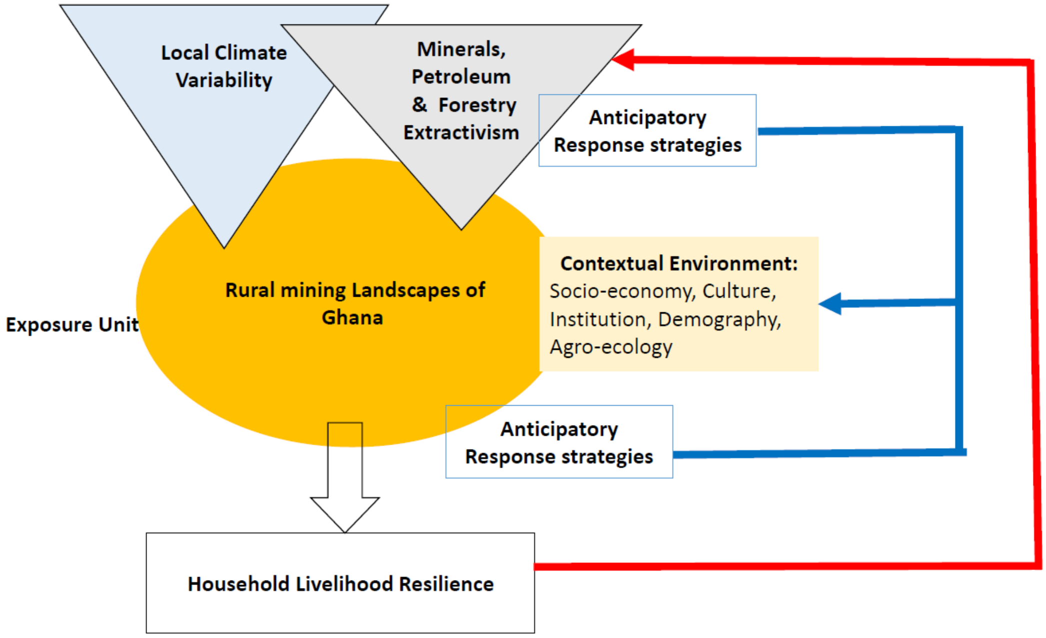

Figure 5-1: The Double Exposure Framework (source: adapted from Leichenko and O'Brien, 2008). The blue lines depict the response strategies anticipated to influence the contextual environment of the exposed system towards positive resilience, red lines depict negative outcome pathways that are counterproductive to extractivism and global environmental changes.

5.3 Methodology

5.3.1 Case Study Location

Ghana is located within the West African region covering an area of 238,500km^{2} within latitude $4^{0}45^{1}$N and 11^{0}N, and longitude $1^{0}15^{1}$E and $3^{0}15^{1}$W (Bempong et al., 2019). The country's southwestern mining landscape where the primary data were collected (Figure 5-2) forms the southwestern basin system covering 22% of the total land area of Ghana (Ghana National Water Policy, 2007). Hydrologically, the basin system is composed of the Bia, Tano, Ankobra and the Pra rivers. Bia and Tano are transboundary rivers which drain into the Gulf Guinea westward in Ivory Coast, while Ankobra and Pra rivers are inland and drains directly into the Gulf of Guinea southward of the country. Southwestern Ghana is known for its long-term mineral and forest resources extractive activities (G. Hilson, 2002), hence of high socio-economic relevance to national development, coupled inevitably with rapid environmental degradation (Junior & Matsui, 2018; A. E. Mensah et al., 2020).

Given that this forest zone is experiencing climate threat (Abbam et al., 2018; Atiah et al., 2019; Fosu-Mensah et al., 2012), which spontaneously affects rural livelihoods, one mining landscape was selected from each of the two forest agro-ecological zones to compare household perspectives. These agro-ecological zones are defined by the climate and soil characteristics (Asravor et al., 2019). The Chirano landscape falls within the Deciduous forest zone, which is relatively productive for agriculture compared to the Nzema landscape located within the Rainforest zone where the soils are highly leached. Apart from mineral and forest resource extractions, cash crop farming such as of cacao, rubber and oil palm plantations are other economic activities in the landscapes. Additionally, the two selected mining landscapes depict extractive operations at the fringes of forest and water resources, which are major livelihood resources in rural communities. Each mining landscape hosts at least one large-scale mining as well as artisanal and small scale mining firms intermingling communities and their livelihood resources. Communities selected include communities whose resources (land, water, farmland, well-being etc) have been affected directly or indirectly by the activities of extractivism. Some are recognized by statute as affected communities if they own part of a concession whilst others are not recognized irrespective of their proximity to the extractive operations.

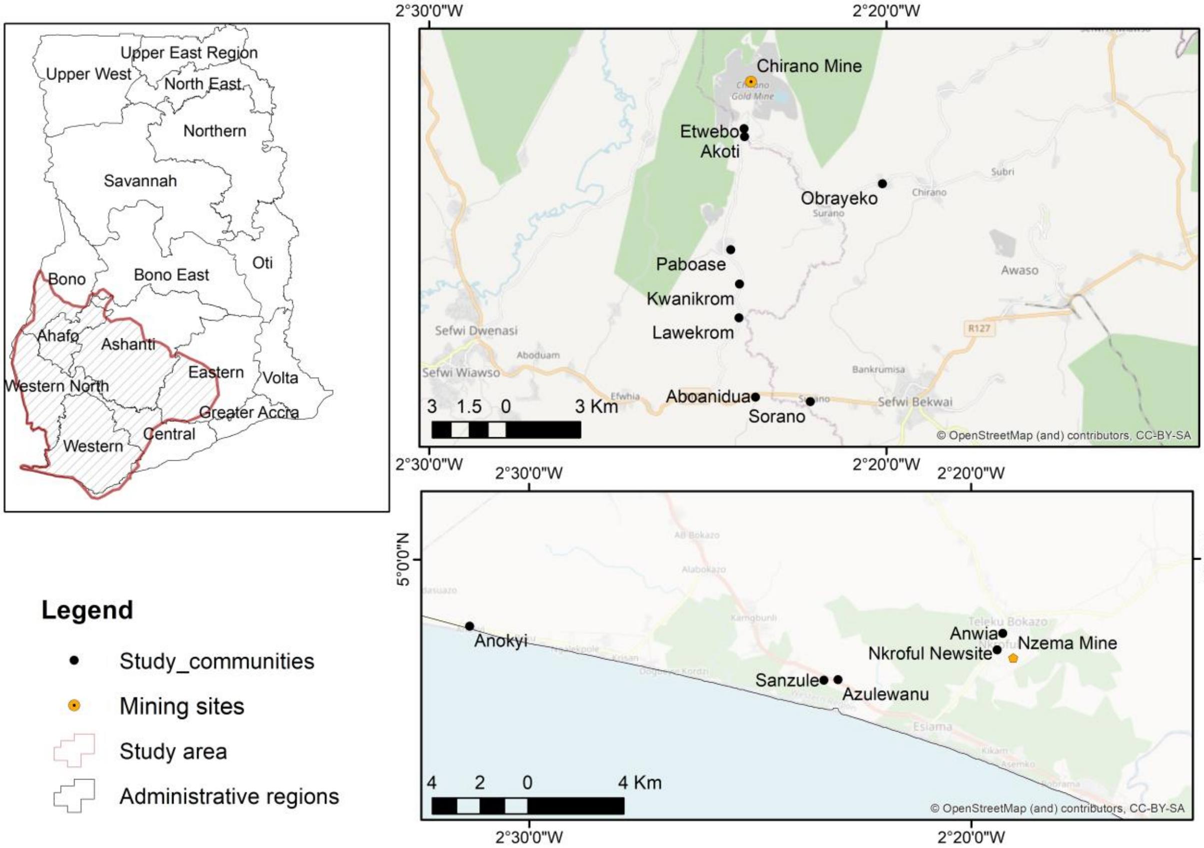

Figure 5-2: Map showing selected communities within southwestern mining landscapes.

Administratively, the landscapes are located in the Western region and the Western North region of Ghana. The latter region was carved out of the former in December 2018. The Chirano mining landscape, falls within the Sefwi Wiawso and Bibiani-Anhwiaso-Bekwai municipalities in the Western-North region. The Nzema mining landscape falls within the Nzema-East municipality and the Ellembelle district in the Western region. Generally, the Nzema and Sefwi people who dominate the Nzema and Chirano landscapes respectively have similar cultural characteristics as they belong to the same Akan ethnic group (E. K. E. Antwi et al., 2020). Rural settlements dominate both landscapes (WRC, 2009). The Nzema landscape is also located within the Greater Amanzule Wetland Conservation Area, whilst the Chirano mining landscape is located within the Tano-Suraw Extension Forest reserve where both minerals and extractivism are actively ongoing. Major livelihood activities in the landscapes consist mainly of petty trading, rain-fed farming, and non-timber forest products (NFTPs) as well as artisanal fishing (Ahenkan &

Boon, 2010, 2011). In addition, the oil and gas production activities along the shores in the Nzema mining landscape generate livelihood dynamics that can affect households.

Across the two landscapes, the rainfall pattern is bimodal, i.e., from the beginning of April to July as the major season and from September to November as the minor season. The dry season, commonly known as the harmattan, begins from December to March, and is characterized by fluctuating day and night ambient temperature with cold, dry and dust-loaded wind (Minka & Ayo, 2014; Sufiyan et al., 2020). The local climatic conditions generally perceived to be changing within the landscapes are shown in Figures 5-3a, b and c. Figure 5-3a depicts the climatic variables mostly perceived to affect crop yield, which are increasing temperature and decreasing rainfall. A recent report on the Ankobra Estuary communities assigned high vulnerability indices to crop yield and fishing (J. Mensah et al., 2015) thus corroborating the household perspectives in figure 5-3a. Analyses of extreme rainfall and temperature indices (figure 5-3b and c) confirm the varying trend in rainfall intensity and frequency as well temperature across the landscapes as indicated in literature (Abbam et al., 2018; Atiah et al., 2019; Bessah et al., 2022). Sefwi Bekwai and Axim synoptic weather stations are the main meteorological stations within the Chirano and Nzema mining landscapes respectively.

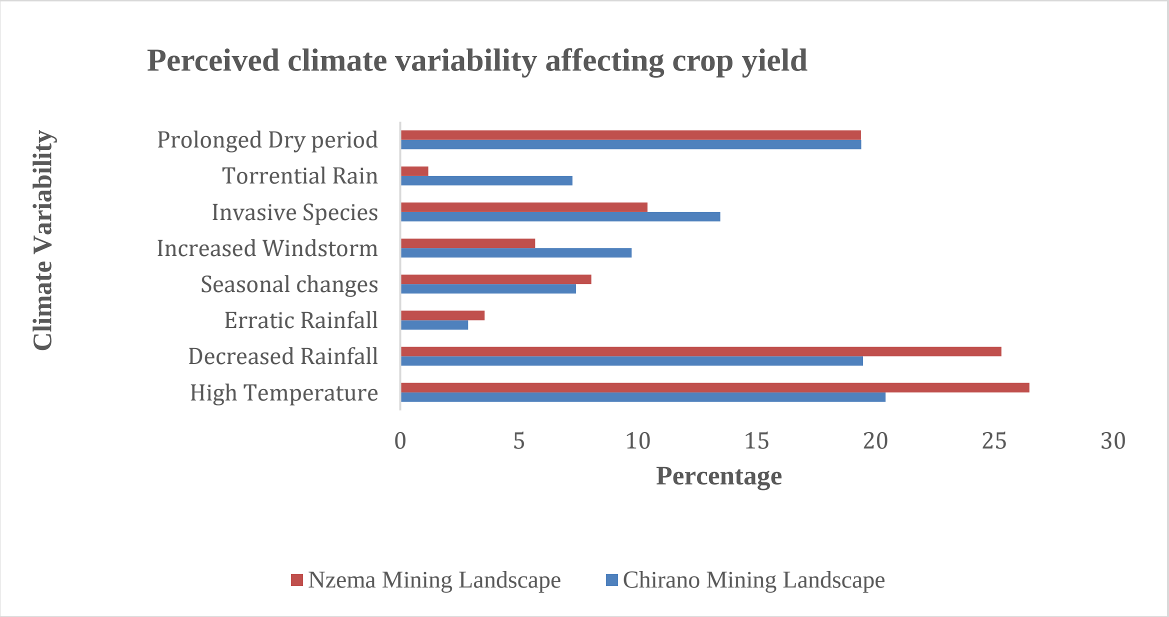

Figure 5-3a: Perceived climate variability among households of southwestern Ghana.

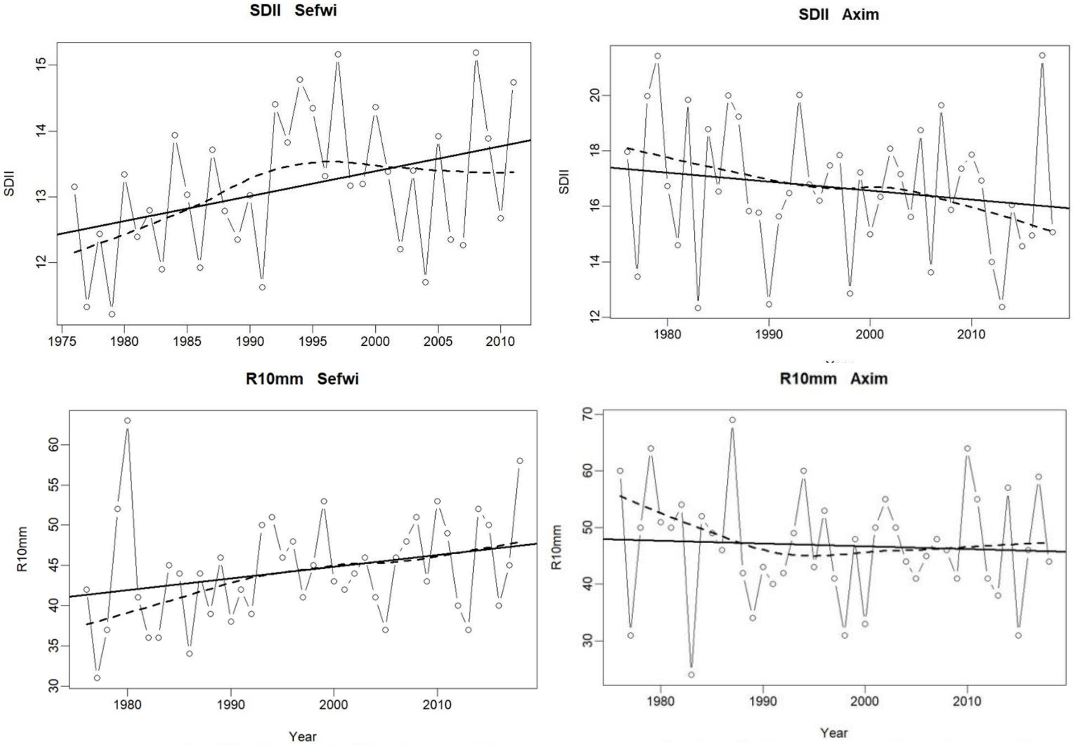

Figure 5-3b: Trend in rainfall variability across Sefwi Bekwai and Axim weather stations (1976-2018); SDII= Simple daily intensity index (mm), R10m=Heavy rainfall days (day). (Source; analyzed by author). NB: Sefwi Bekwai is located within the Chirano miningscape, which is the Deciduous forest agro-ecological zone. Axim is located within Nzema miningscape which is part of the Rainforest Forest agro-ecological zone.

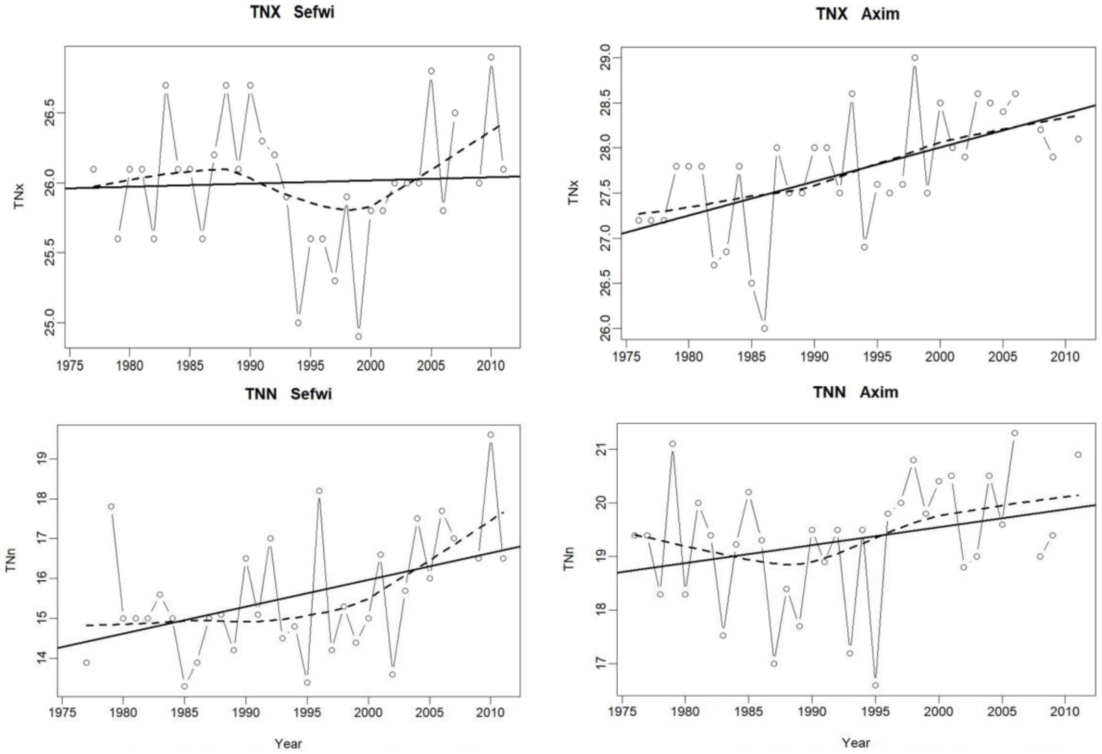

Figure 5-3c: Trend in temperature variability across Sefwi Bekwai and Axim weather stations (1976-2018): TNX=Monthly maximum value of daily minimum temperature (0C), TNN=Monthly minimum value of daily minimum temperature (0C).

5.3.2 Sampling Methodology, Primary Data Collection and Analysis

A stratified random sampling method was employed in conducting the study. First, a transect was laid from the nearest large-scale mining site towards the public road within each landscape.

The communities along the transect were stratified into catchment communities (statutorily recognized traditional landlords of extractives concessions), resettled communities (statutorily recognized landlords of concessions who have been relocated) and satellite communities (not landlords but directly affected by extractive operations such as public infrastructural networks and proximity). Eight communities from the Chirano mining landscape and six communities from the Nzema mining landscape each containing one community strata along the transect were selected. The difference in number is mainly based on the willingness of communities along the transect to participate due to onset of the pandemic. Secondly, a simple random method was then used to survey households within each community strata. Household heads refers to the main breadwinner of the housing unit, which was interviewed.

The survey instrument, structured into three sections, was used to elicit information from the households. The first section collected information on the socio-demographic background of respondents. The second section ascertained their experiences with the effect of increasing variabilities under the local climatic conditions on livelihood sources as well as the effects of extractives' operational activities in proximity to their livelihood sources. The third section qualitatively inquired their perspective on the adaptation measures necessary to enhance resilience in the mining landscape. Community school teachers who later supported as enumerators during the survey translated the survey instrument into the Sefwi and Nzema dialect. The data collection was conducted between April and October 2020.

Data collected were entered and cleaned with Microsoft Excel and imported to STATA (version 16) for further analysis. Descriptive statistics were used to analyze households' perspectives on climatic variability and extractivism effects on their livelihood sources, whereas the Chi square test was used to test for differences in perceptions among households. A logistic regression model was applied to identify the contextual factors that influence respondents' perception of the double exposure climate variability and extractivism effects.

The logit model was adopted due to the dichotomous nature of the decision variables, that is whether respondents perceived climate variability to affect their livelihood or otherwise. The model considers the relationship between a binary dependent variable and a set of independent variables, whether binary or continuous (Peng et al., 2002). The logistic model for 'n' independent variables ($x_1, x_2, x_3 \ldots, x_n$) is given by

$$\text{Logit } P(x) = \alpha + \sum_{i=1}^{n} \beta i x i$$

where Exp (βi) shows the odd ratio for a respondent having characteristics i versus not having, while βi is the regression coefficient, and α is a constant.

5.3.3 Demographic Characteristics of Case Study Households

Table 5-1 provides a summary description of the households who participated in the study. In total, 611 households were surveyed. Based on the agro-ecological zones, 43% of respondents were located in the Rainforest and 57% in the Deciduous forest zones, respectively. Regarding the type of community, 35% of the respondents were located in mineral mining-affected communities, 24% in mineral and forestry mining–affected communities, 15% in petroleum-affected communities and 25% in non-extractive communities.

A substantial number of respondents (83%) who identified themselves as the household heads were natives of their communities. The average household size was five with the majority of household heads having at least basic education, while 29% being illiterate. In terms of gender, 55% were males and 45% were females. The average age was 45 (± 11). In addition, 76% of the respondents were married while the remaining were either divorced, widowed or not married. Almost all household heads (94%) had some form of economic activity in terms of their working status. Farming was the major occupation (60%), while 15% reported to be self-employed for instance as hairdressers, tailors, repairmen etc. Eleven percent (11%) were petty traders, 6% mining employees and 5% were formal employees such as teachers and health workers.

Table 4-1: Summary descriptive of case study households

Variable	Explanation of variables	Mean	Standard deviation
Age	In years	44.86	10.72
Female	Dummy (1=yes,0=otherwise)	0.45	0.50
Education			
No school	Dummy (1=yes,0=otherwise)	0.29	0.45
Primary	Dummy (1=yes,0=otherwise)	0.11	0.32
Junior high school	Dummy (1=yes,0=otherwise)	0.29	0.45
Senior high & vocational school	Dummy (1=yes,0=otherwise)	0.22	0.42
Tertiary	Dummy (1=yes,0=otherwise)	0.08	0.27
Marital status			
Married	Dummy (1=yes,0=otherwise)	0.76	0.43
Divorced	Dummy (1=yes, 0=otherwise)	0.07	0.26
Widow	Dummy (1=yes, 0=otherwise)	0.09	0.28
Single	Dummy (1=yes, 0=otherwise)	0.08	0.28
Working status	Dummy(1=yes,0=otherwise)	0.94	0.27
Primary occupation			
Farming	Dummy (1=yes, 0=otherwise)	0.60	0.49
Mine worker	Dummy (1=yes, 0=otherwise)	0.06	0.24
Self-employed	Dummy (1=yes, 0=otherwise)	0.15	0.36
Petty trader	Dummy (1=yes, 0=otherwise)	0.11	0.31
Formal sector	Dummy (1=yes, 0=otherwise)	0.07	0.25
Type of extractivism fringing communities			
Mineral extractivism	Dummy (1=yes, 0=otherwise)	0.35	0.48
Mineral & forestry extractivism	Dummy (1=yes, 0=otherwise)	0.24	0.43
Petroleum extractivism	Dummy (1=yes, 0=otherwise)	0.15	0.36
Non-extractives	Dummy (1=yes, 0=otherwise)	0.25	0.43
Household size	count	4.80	4.29
Natives of community	Dummy (1=yes, 0=otherwise)	0.83	0.38
Agroecological zone			
Deciduous forest zone	Dummy (1=yes,0=otherwise)	0.57	0.49
Rainforest zone	Dummy (1=yes,0=otherwise)	0.43	0.49
Number of households, valid N=611			

5.4 Results

5.4.1 Double Exposure of Extractivism and Climate Variability on Rural Livelihoods

The general extent to which the effects of the various extractive activities (minerals, petroleum and forestry extractivism) and changing climatic patterns are perceived to affect livelihood sources within the mining landscapes of southwestern Ghana (Table 5-2). Majority of household heads perceive that their livelihood sources are exposed to both extractivism (92%) and climatic variability (92%) effects. Moreover, the majority perceive a high extent of double exposure of their livelihoods, thus corroborating the double exposure of their livelihoods to the two changing forces.

Table 5-2: Perceived effect of extractivism and climate variability on livelihood sources

Variable	Explanation of Variables	Mean	Standard deviation
Extractivism affect livelihood sources	Dummy (1=yes, 0=otherwise)	0.92	0.27
Extent of extractive activities effect on livelihoods	Likert Scale	3.0	0.82
Increasing climate variability affect livelihood sources	Dummy (1=yes, 0=otherwise)	0.92	0.28
Extent of climate variability effect on livelihoods	Likert Scale	3.0	0.32
Number of households, N=611			

NB: Likert Scale with 1 = low, 2 = no effect, and 3 = high

In addition, households' perspectives were compared between the Nzema and Chirano mining landscapes (Figure 5-4). Majority of respondents (93%) from the Nzema mining landscape perceived the high effect of climate variability on their livelihood sources just as extractivism (96%). Within the Chirano mining landscape, 89% of respondents perceived their livelihood sources exposed to climate variability effects just as extractivism effects (71%).

Moreover, the Chi square test result indicates no significant difference in respondents' perception on climate variability effect on livelihood sources (*p=0.124),* whereas significant differences existed on the perceived effect of extractivism on livelihood sources (*p<0.0001)*.

Hence, rural livelihoods in mining landscapes are perceived to be double exposed to the effect of extractivism and changing climatic conditions. However, the difference in perception also underscores the fact that key factors making up the contextual environment are influencing the perspectives of household heads. Thus, contextual factors influencing households' perspectives were determined using a linear logistic regression model.

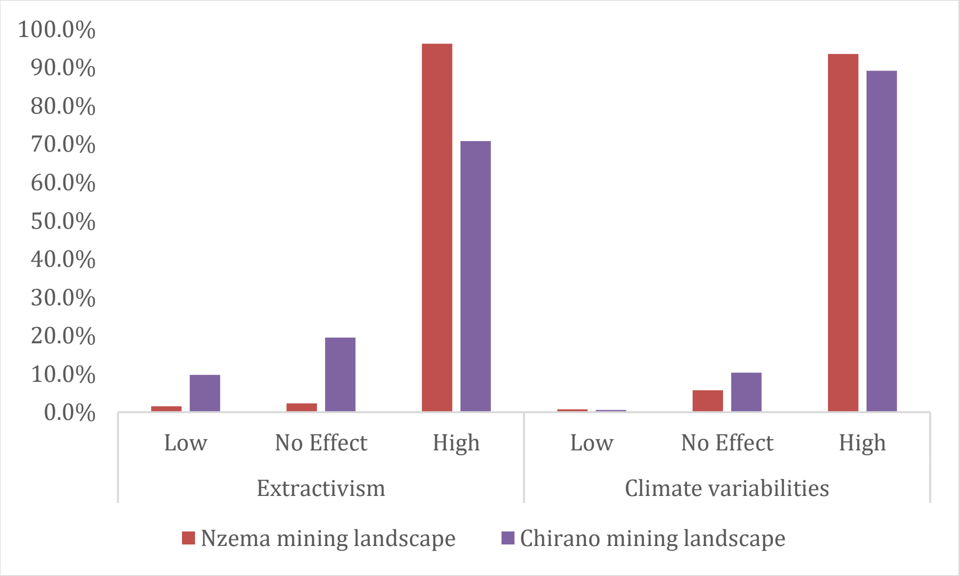

Figure 5-4: Perceived effects of climatic variability and extractivism on livelihood resilience

5.4.2 Contextual Factors Underlining Climate Variability Exposure on Rural Livelihoods

Certain socio-economic, demographic, communal, and agro-ecological types (table 5-3) were significant in determining households' perspectives on the exposure to climate variability effects on their livelihoods.

More specifically, native household heads with large household size were more likely to perceive the effects of climate variability on their livelihoods. In comparison, female household heads were less likely to perceive that climate variability affects their livelihoods. Moreover, the more educated respondents were, the less likely they perceived that climate variability affects their livelihoods. Finally, household heads with primary occupations other than farming were less likely to perceive that their livelihoods were affected by increasing climatic variability. It is, however, noteworthy that the widowed, divorced and unemployed are more likely to perceive that climate variability has influence on their livelihoods although these were not statistically significant.

Respondents living in communities affected by both minerals and forestry extractivism were more likely to perceive that climate variability affects their livelihoods. In contrast, respondents from communities affected by petroleum extractivism were less likely to perceive that climate variability affects their livelihoods. Lastly, respondents located in the Deciduous forest zone were more likely to perceive that climate variability affects their livelihoods. Literature corroborates the significance of NTFPs as livelihood strategies in the deciduous forest within the Chirano mining landscape (Ahenkan & Boon, 2010). Since ecosystem services are susceptible to climate changes (Millar et al., 2007), it is no surprise that households attest the influence of climate variability exposure on their livelihood sources.

Table 5-3: Perceived effect of climate variability on livelihoods in mining landscapes

Variable	**Estimate (Standard error)**	**Odd ratio Estimate (Standard error)**
Household size	0.17(0.06)**	1.18(0.07)**
Age	-0.03(0.02)	0.97(0.020)
Female	-0.91(0.45)*	0.40(0.18)**
Primary Education	0.19(0.73)	1.21(0.88)
Senior High Education	-0.25(0.42)	0.78(0.33)
Tertiary Education	-0.92(0.51)*	0.40(0.22)*
Married	-0.26(0.56)	0.77(0.43)
Divorce	0.30(0.84)	1.35(1.13)
Widow/Widower	0.38(0.89)	1.46(1.31)
Working Status	0.37(0.57)	1.44(0.82)
Mining Worker	-1.48(0.61)**	0.23(0.14)**
Self-Employed	-1.30(0.44)**	0.27(0.12)**
Formal Sector	-1.50(0.50)**	0.22(0.11)**
Native of Community	0.86(0.44)*	2.36(1.05)*
Minerals & Forestry Extractivism	15.88(0.87)***	1.27(1.11)***
Minerals Extractivism	-0.31(0.88)	0.74 (0.65)
Petroleum Extractivism	-1.87(0.79)**	0.16(0.12)**
Deciduous forest	16.21(0.47)***	1.91(5129)***
Constant	3.52(1.65)**	33.67(55.72)**
Number of Observations	611	611
X^2	4034.37***	4034.37***
Pseudo R^2	0.32	0.32

****,**, *Significant at 1, 5 and 10% probability level, respectively. Standard errors in parentheses*

5.4.3 Contextual Factors Underlining Livelihood Exposure to Extractivism

Similarly, seven out of the ten socio-demographic and economic characteristics making up the contextual environment of the households seem to influence the perceived exposure of a household's livelihood sources to the extractivism effect as presented in table 5-4.

Equally, respondents who are natives of their communities with large household sizes were more likely to perceive that extractive activities affect their livelihoods. However, adult respondents were less likely to perceive that extractivism affects their livelihoods. In a similar manner, female respondents were less likely to perceive that extractivism affects their livelihoods compared to males. Respondents with formal employment were also less likely to perceive that extractivism affects their livelihoods, whereas the widowed and divorced respondents were more likely to perceive that extractivism affects their livelihoods although not statistically significant.

On the contrary, respondents from communities affected by mineral extractives were more likely to perceive that extractivism affects their livelihoods whilst communities affected by both minerals and forestry extractives are less likely to perceive that extractivism affects their livelihoods.

Table 5-4: Perceived effect of extractivism on livelihoods in mining landscape

Variable	**Estimate (Standard error)**	**Odd ratio Estimate (Standard error)**
Household size	0.14(0.07)**	1.15(0.08)**
Age	-0.05(0.02)**	0.95(0.02)**
Female	-0.87(0.39)**	0.42(0.17)**
Primary Education	-0.63(0.48)	0.53(0.25)
Senior High Education	-0.39(0.49)	0.67(0.33)
Tertiary Education	-0.12(0.94)	0.89(0.83)
Married	-0.16(0.69)	0.86 (0.59)
Divorce	1.67(1.19)	5.31(6.30)
Widow/Widower	0.07(0.88)	1.08(0.94)
Working Status	-0.16(0.52)	0.85(0.44)
Mining Worker	0.87(1.1)	2.39(2.63)
Self-Employed	-0.67(0.51)	0.51(0.26)
Formal Sector	-2.11(0.76)**	0.12(0.09)**
Native of Community	1.20(0.39)**	3.33(1.29)**
Minerals & Forestry Extractivism	-3.27(1.07)**	0.04(0.04)**
Mineral Extractivism	1.69(0.73)**	5.44(3.97)**
Petroleum Extractivism	-0.03(0.61)	0.97(0.58)
Deciduous Forest	3.53(1.20)**	34.07(40.97)**
Constant	3.52(1.53)**	33.72(51.47)**
Number of Observations	611	611
X^2	75.69***	75.69***
Pseudo R^2	0.27	0.268

****,**,*Significant at 1, 5 and 10% probability level, respectively. Standard errors in parentheses*

5.4.4 Response Strategies to enhance Livelihood Resilience to Double Exposure

The perceived strategies of households' needed to influence the contextual environment of mining landscapes are summarized qualitatively in table 5-5. Households were determined to improve their adaptive capacity to reduce exposure through both individual and communal actions.

For instance, most households being farmers propose to engage in irrigated farming practices by constructing small dams being demanded from national and local governments, while others propose to improve farm management practises such as planting more disease and pest resistant crop varieties, adjust planting seasons and type of crops, practice crop rotation and apply fertilizer, among others. However, it is noteworthy certain strategies such as farming near water bodies reveal in an explicit way the risk of households being vulnerable to double exposure due to insufficient knowledge or lack of support. This may be due to insufficient access to information on sustainable agricultural practices. Some households also plan to diversify their income sources by engaging in other activities such as labor jobs, harvesting crops with other households to get surplus as well as trading. In addition, some households anticipate other Outcome pathways such as flooding and related human security and health implications. As an example, some respondents proposed to build walls around their houses to prevent flood water from entering their houses and to clean gutters. They also indulge the national government and non-governmental organizations to improve social amenities in the respective communities such as the drainage systems and health facilities as well as providing capacity building in terms of extension and awareness creation.

Table 5-5: Adaptation strategies to enhance livelihood resilience in mining landscapes (source: survey data)

Anticipatory Response strategies	**Frequency (strategies repeated)**	**Examples of measures mentioned**
Farm management and technology	672	*I will construct small dams on farms, farming closer to river/stream, irrigation for farming, planting other crops that could withstand the season conditions, application of fertilizers, organic manure and other agrochemicals, crop rotation, adjusting to the start of rain, warehouse construction*
Income diversification	197	*Engage in other activities aside farming, engage in some laborer work for survival, harvesting crops, trading, engaging in other activities that would be suitable, do construction work, drive taxi*
Communal, Government, NGO intervention in rural infrastructure, health care services and risk reduction for the rural population	179	*Will visit health center in our communities for medical assistance, assistance from government and other NGO's, construction of drainage systems, build bridges on farm ways, desilting choked gutters, build walls around my house, plant trees around houses to control flood*
Knowledge management, networks, and governance	99	*I will educate the public on flood and erosion control, I would seek advice from extension officers, I will listen to the weather forecast to plan my farming activities, education on climate change, access to weather forecast*
Migration	90	*Relocating to stay with other family members at where it is safe, relocate to the city*
Barriers to adaptation	289	*No assistance or got no support /not financially equipped/ no idea on any relevant measure to take/ lack of technical knowledge*

5.5 Conclusion

Rural livelihoods in mining landscapes of southwestern Ghana are exposed to the effects of the interacting changes, but the exposure and outcome are dependent on the contextual factors of the household and the communities. The focus of the study was to identify contextual factors at household level that influence their perspectives of the double exposure on livelihood resilience. This is necessary to identify vulnerability indicators such as being a widow, divorced or unemployed to whom policy can be directed to in contrast to the common assumption that livelihoods in mining landscapes are resilient. In addition, the study examined the anticipatory response strategies that can cushion adaptive capacity of households against double exposure of extractivism and climate variability effects.

The study provides an empirical perspective on the simultaneous effects of extractivism and climate variability on livelihoods as perceived by households in mineral/ petroleum/ forestry affected communities, dubbed resource-fringing, and non-extractive communities selected within southwestern Ghana. Both Nzema and Chirano mining landscapes belong to the forest zone of Ghana with almost similar biophysical characteristics, which make similarities in household perception on climate variability effects plausible. This perception is affirmed in other studies on the climate-sensitive nature of rural livelihoods in the forest zone of Ghana (Antwi-Agyei et al., 2014; Boon & Ahenkan, 2012; Dumenu & Obeng, 2016; Fosu-Mensah et al., 2012; Limantol et al., 2016; Sani & Chalchisa, 2016). However, there were differences in perception among households on the effect of extractivism exposure. This may be differentiated by the contextual factors such as socio-economic and household characteristics like household size, gender, age, education, type of primary occupation of household heads and being a native of communities as well as the type of extractivism in a community.

It is particularly noteworthy that female household heads are less likely to perceive that climate variability and extractivism exposures affect their livelihoods. This could be so since rural women have the cultural liberty to engage in petty trading such as direct sales in the market or door-to-door sales in rural communities irrespective of age, thus diversifying their income sources compared to men hence feeling empowered and resilient (Okyireh & Nkansah, 2016). Nevertheless, more detailed gender related anthropological studies would be needed to ascertain these observations. However, being a widow, divorced and unemployed were not statistically significant determinants of respondents' perceptions, but such groups are nonetheless more likely to perceive that climate variability and extractivism affect livelihoods. This observation reveals the existence of vulnerable groups within resource-fringing communities burdened by double exposure, irrespective of the notion of self-reliance in mining landscapes.

In addition, households were free to propose adaptation measures without coaching which enabled them to independently articulate as possible. Some measures such as "*farming near water bodies*" and *"not directly affected"* reveal poor environmental awareness at the community level and lack of information on sustainable agricultural practises like climate-smart agriculture and sustainable intensification programs that are already promoted in the savannah and transitional zones of Ghana (Alare et al., 2018; Zakaria et al., 2020). Hence, it is imperative for policy-makers to consider mining landscapes to contain equally vulnerable groups who need to be sought after on livelihood empowerment and climate adaptation programs.

It is also noteworthy that resource-fringing communities expect the national government and NGOs to support community development by improving infrastructural and health care systems; and to reduce flood risk and health related implications apart from economic resources. For instance, community members are willing to undertake communal activities to improve drainage systems in anticipation of flooding and use insecticides to control pest infestation. Flooding is already anticipated in mining landscapes that are spatially characterized by various impoundments and river diversions constructed in the different mining sites (Osei et al., 2021) thus affirming the relevance of households perceived response strategies. In addition, such communal groups intending to promote community resiliency need to be facilitated as a means to promote community level adaptation.

In summary, this study establishes and confirms the usefulness of the double exposure framework to contextualize the interactive effects of climate variability and extractivism on other resource systems in mining landscapes for which proactive responses are imperative.

Chapter six

Discussion, Summary of Findings and Outlook

6.1 Discussion

The discourse throughout this thesis is to affirm that rural landscapes of West Africa are vulnerable to the impacts of changing climate due to not only local effects of climate but also the inherent vulnerabilities orchestrated by global economic systems such as resource extractions. The changing trend in rainfall and temperature variability observed across the forest zones of southwestern Ghana as presented in chapter 3 and confirmed by similar studies (Abbam et al., 2018; Atiah et al., 2019; Logah et al., 2021; Nkrumah et al., 2019) point to the fact that socio-ecological systems surrounding miningscapes are double exposed to the local effects of changing climate and extractivism. Hence, vulnerable households and communities within rural miningscapes such as established in Chapter 5 may not be capable of adapting to the double burden without external interventions such as corporate social responsibility contributions from the multinational companies. Other sources of vulnerabilities in rural West Africa that compounds local effects include socio-economic and infrastructural deficits (Thakur & Bajagain, 2019; Yaro & Hesselberg, 2016) as well as impacts of global trade relations between countries, technology and global conservation and development policies (Kelboro & Stellmacher, 2019; Oldekop et al., 2020). Actions to enhance climate-resilient development must therefore include for example improving living conditions and infrastructural systems of rural West Africa, which will suffice to address several of the SDGs. In addition, a strong sense of willingness of rural dwellers to participate through diverse efforts to enhance their adaptive capacity can be inferred from the strategies and measure identified by respondents (Chapter 5). So, avenues to enhance participatory and sustainable socio-economic development within the rural West African regions is an imperative as similarly echoed in the progress report on the implementation of Agenda 2063 of the African Union (NEPAD, 2022).

Sustainable industrial development is key to ensure equitable growth and human wellbeing (SDG 9, target 2). Accordingly the extractive industries, including minerals mining, poses huge potential to enhance development across the entire continent as discussed in the preceding chapters and reiterated in the African Mining Vision (United Nations Economic Commission for Africa [UNECA] & African Union, 2011). For instance, the economies of West Africa are characterized by export of mineral resources particularly in countries located within the southern domain of the West African Craton including Ghana (André-Mayer et al., 2015; Markwitz et al., 2016; Williams et al., 2015; World Bank, 2014). Ironically, most of these resources are located within the Tropical Guinea Forest, which leads to huge implications for socio-ecological systems offsetting. In fact, the geological mineralization and the biodiversity conservation priority areas within the forest zone of West Africa overlap (IUCN, 2012). Thus, a dynamic web connects mining industries and their surrounding socio-ecological systems. These networks are characterized by diverse expectations from various interest groups to which the industry must adapt in like manner as any organization adapts to its externalities (Hoffmann et al., 2009; M. Linnenluecke & Griffiths, 2010; M. K. Linnenluecke et al., 2013, 2015). Typifying the mining industry to operate as a complex eco-sociotechnical system within the rural landscapes of West Africa, as attempted in this study, was not out of place given this dynamic relationship between the industry and their surrounding socio-ecological systems. The framework "adapt to co-exist in miningscapes" as discussed in chapter 1.5 proved useful for analzing the local effects of global environmental change on resilience within the complex mining system.

Chapter 2 and 4 projected the diverse efforts taken by multinational mining companies to impose various industry best practices, self-accountability and assessment criteria in forms of corporate responsibility and corporate sustainability performance assessments as means to accounts for their socio-environmental footprints. For instance, efforts of the industry toward integrating biodiversity can be inferred from the corporate environmental policies reviewed as well as the environmental practices observed during the fieldwork thus affirming previous assertions on the industry's commitment toward biodiversity conservation (Boiral & Heras-Saizarbitoria, 2017; Fonseca et al., 2014). In addition, a strong link can be detected between corporate responsibility and sustainable development in mining regions as empirically established in the study area through the lens of SDGs (Chapter 2.3). Hence, corporate participation toward reducing vulnerability of socio-ecological systems to double exposure impacts in miningscapes is intrinsic in corporate responsibility and sustainability. However, such strategies as climate change adaptation lack the normative and regulatory recognition necessary to ensure proactive operational level implementation. Furthermore, climate-positive corporate social responsibility (CSR) for instance has the potential to generate dual benefit of enhancing climate-resilient rural development and improving corporate image as well as creating competitive advantage for the operation in terms of securing social license.

The motivation for the industries' interest in corporate social responsibility (CSR) is attributed to a quest for the industry to take responsibility for their impacts and improve corporate reputation (chapter 2.3.3). These finding thus corroborate CSR determinants within the extractive sector as indicated in literature (Boso et al., 2017; Brammer & Pavelin, 2006; Browne et al., 2011). Similarly, an exposition on the different interpretations attributed to the concept and practices of CSR can be inferred from the current study. For instance, the definition of CSR is explicit on the inclusion of the three triple bottom; People, Profit and Planet (Herman Aguinis & Glavas, 2012; Baumgartner, 2014; European Commission, 2011). However, household respondents interpreted CSR contributions within the context of community engagement and development, philanthropy as well as grievance and conflict management as discussed in chapter 2.3. Furthermore, CSR performance was categorized as one of the social sustainability performance metrics according to the perspectives of operational workers and was used together with other metrics to analyze the determinants of corporate climate adaptation in mining (Chapter 4.1.5). CSR practises within Ghanaian mining context is therefore anthropocentric, that is, it focuses mainly on the social pillar of sustainable development (People) whereas the environmental (Planet) and economic (Profit) are managed by separate functionaries. Thus, CSR initiatives alone are insufficient to enhance overall sustainability performance of the mining system. Such interpretation also seem justifiable due the fact that potential environmental impacts of mining and any other extractive activities are heavily regulated whereas the social impacts are relegated to CSR which is mainly philanthropic and voluntary. Hence, socio-environmental impact assessment criteria in the country have to be realigned to embrace the triple bottom (socio-economic, environment and governance), which can form a formidable legal framework to manage double exposures in rural landscapes.

Consequently, examining the implications of local effects on mining sustainability using the different metrics affirm the need for mining industries to shift their view from corporate responsibility that is about addressing operational impacts toward corporate sustainability, which present a shared value perspective (Almansoori & Nobanee, 2019). Such shift in corporate view provides a compelling argument for the industries' role to enhance climate-resilient rural development in miningscapes. The general dimensions of CSR and corporate sustainability as being two sides of the same coin (Marrewijk, 2003) is corroborated in this study. That is, corporate sustainability is the ultimate goal of an industry whereas CSR is one of the approaches to achieve sustainability as illustrated in figure 6.1 below. Hence, targeting corporate climate adaptation as a corporate responsibility intervention within the extractives as teased out by the framework “adapt to co-exist” is of both academic and practitioner relevance. The framework also has generic usefulness as being the lens through which the double burden of related global economic systems and environmental change effects on another systems’ resilience can be assessed.

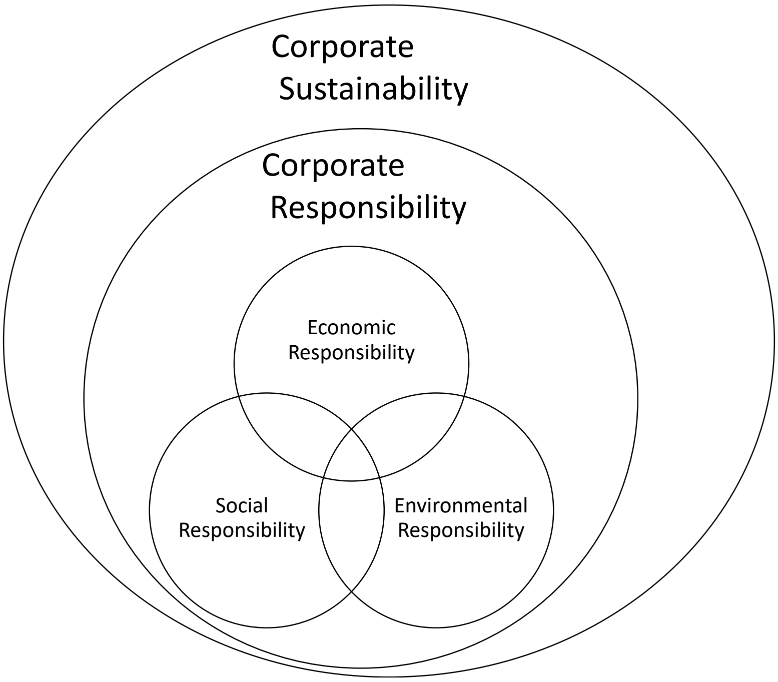

Figure 6-1: General model of CS/CR and its dimensions. Source: van Marrewjik (2003).
NB: CS=Corporate sustainability, CSR=Corporate social responsibility

In the context of Ghana, corporate sustainability in mining has been conceptualized to include sustainability as land reclamation at the base, followed by sustainability as disjointed CSR/social license activities and sustainability as long-term community development at the peak (Essah & Andrews, 2016). Land reclamation activities in mining are regulated by minerals and environmental regulatory requirements in Ghana (Environmental Assessment Regulations, 1999; Minerals and Mining (Health, Safety and Technical) Regulations (L.I.2182), 2012), whereas CSR is voluntary (Andrews, 2016). Sustainability as a long-term community development does not yet exist according to the authors. However from the current studies, glimpses of this type of sustainability can be elucidated across miningscapes where multinational companies have established various development revenue schemes for their affected communities as discussed in chapter 2.3.3. Another aspect of sustainability in mining identified in this study but not included by Essah and Andrews (2016) is sustainability as the assessment of operations' safety, health, environmental and quality management practises.

In chapter 4, annual sustainability reports of participating companies were reviewed in a bid to identify climate change adaptation issues, and the general composition inferred the management practices of corporate sustainability in mining. Sustainability reports were characterized by aggregated reports on various industry best practices such as OHS, environmental management, human resources management, employee affairs, community relations and public affairs that are collated via the GRI or other sustainability assessment criteria. Empirically, the implication of local effects of changing climate on corporate sustainability performance in mining was examined using the GRI-based proxy. These affirm the evolution of corporate sustainability reporting in the Ghanaian mining industry irrespective of the absence of direct sustainability regulation such as us initiated recently in Germany *("Das Lieferkettensorgfaltspflichtengesetz").* Moreover, corporate sustainability in the Ghanaian mining sector align closely with definition by Artiach et al. (2000), which refers to the *"strategies to measure the extent to which the industry embraces economic, environmental, social and governance factors into operations, and the impact they exert on the industry and society"*.

The local effects of a changing climate compounds efforts of the mining industries toward persevering in sustainability management. Particularly, mining activities in Ghana can be daunted by the local effects of increasing variabilities in extreme rainfall events and temperature across southwestern Ghana as established in the study (Chapter 3). Thus, the demand for climate-smart mining as corroborated in extant literature (Hodgkinson & Smith, 2018) is highly anticipated for the case of Ghana. The industry must not only address climate mitigation as mining operations are huge contributors of greenhouse gas emissions (Mzenda & de Jongh, 2014), but adapt to the local impacts of changing climate. Operations' adaptation to climate change is critical for the Ghanaian industry given the complex nature of the industry within the country at different scales.

Just as other mining operations scattered across the globe, operations within southwestern Ghana are susceptible to the local effects of the changing climate (Chapter 4). Global evidences are found in Europe (Damigos, 2012; E. Mavrommatis & Damigos, 2020; Evangelos Mavrommatis et al., 2019), Asia (Sun et al., 2020), Australia (J. . Hodgkinson et al., 2014; J. Hodgkinson et al., 2010; Rüttinger & Sharma, 2016; Sharma & Franks, 2013), North America (Ford et al., 2010, 2011; T. D. Pearce et al., 2010) and Latin America (Gonzalez et al., 2019;

Odell et al., 2018). The empirical cases for Africa is minimal, particularly in the sub-Saharan region, as highlighted also by Odell et al. (2018). Examining sustainable mining in the face of changing climate as presented in chapter 4 therefore provides a useful baseline for further inquiry into climate and extractive systems in West Africa, given the dynamic interrelationships among the industry, national economies and rural resilience. Hence, policies on corporate adaptation to climate change impact within the extractive industries across the West African region ought not to be prerogative decisions of multinational companies but rather merit national and international interest. Besides, the willingness of the industry is mainly dependent on regulation and market context (Chapter 4), hence a polycentric governance approach to climate change mainstreaming within the extractive industry might be instrumental for the region.

The concern for mining operations adaptation may not attract academic interest. However, the dynamic relationship between the industries' operational activities and their surrounding socio-ecological systems, where inequalities, conflicts and resource depletion abound, justifies the call for academic enquiry. Given the fact that mining activities directly affect the definitive factors of rural resilience such as socio-economic, cultural heritage and ecology (Heijman et al., 2019), the local effects of a changing climate will combine to double burden for the vulnerable groups of such communities as well as the natural ecosystem. The various ecosystem services, including functional and provisional, are affected by mining (Sonter et al., 2018) as well as changing climate (Boon & Ahenkan, 2012). Similarly, the vulnerability of mining-fringe communities to the effects of changing climate has been recognized (Bebbington et al., 2015; Ford & Smit, 2004; Loechel et al., 2013). The current study however establishes that, both resource-fringe communities and their dependent ecosystem services (surrounding socio-ecological system) are affected simultaneously by the impacts of mining as globalization tool and global environmental change. Thus, climate change adaptation strategies in mining must necessarily be socio-cultural and nature-sensitive in order to enhance integrative rural resilience in miningscapes.

6.2 Summary of Findings

Specifically, this study examined the effects of changing climatic conditions on the resilience of multiple land-use practices within southwestern Ghana. The mining industry was characterized as a complex socio-technical system embedded within the natural system, whereby the dynamic interactions of the components self-organize and generate outcomes that affect mining operations' performance and resilience of surrounding SES. Hence, the adaptation strategies to enhance resilience building within the entire miningscape is unequivocal.

Within this *adapt to coexist* framework; three research objectives were identified from which the research questions were developed. The first research question investigated the trend in extreme rainfall and temperature variability within southwestern Ghana. Secondly, three miningscapes were selected within the Western regions of southwestern Ghana to examine the local effects of the changing trend from the perspectives of mining operational workers. Finally, the perceived double exposure effects of the changing climate and extractive activities on livelihood resilience at household level were investigated within two of the selected miningscapes.

To implement the research objectives, the research adopted the corporate adaptation process model and the double exposure framework as guide in the design and collection of the empirical data. Hydro-meteorological data consisting of four decades (1976-2018) of daily observational rainfall and temperature for the eight synoptic weather stations located across southwestern Ghana were obtained from the Ghana Meteorological Agency. In addition, field data were collected in 2018 and 2020.

Different methods were employed in addressing the research questions. For instance, a drought index was used together with other climate extreme indices (based on ETCCDI), trend detection tests and spatial analysis test via GIS tools were used to study the historic trend in climatic variability in southwestern Ghana. In addition, mixed methods were used to examine the perspectives of operational workers and households of surrounding communities scattered within the two forest agro-ecological zones.

The findings for each of the research objective are addressed in the preceding chapters (Chapters 3-5). The following section synthesizes the main findings that answered each of the three research questions.

RQ1. Is there cause for alarm for resource managers regarding trend in rainfall and temperature variability across the forest miningscapes in southwestern Ghana?

The spatio-temporal analysis of extreme rainfall/temperature variability within southwestern Ghana was performed using the available 40 years daily time series observational data.

The results confirmed an intensifying trend in the rainfall years and further extreme rainfall indices including simple daily intensity index (SDII in mm/day), annual total wet day precipitation (PCRPTOT in mm), extremely wet days (R99p in mm), consecutive wet days (CWD in days), consecutive dry days (CDD in days) and number of very heavy precipitation days (R20 in days). Similarly, variability in extreme temperature indices, such as the monthly average value of daily maximum and minimum temperature (TXmean and TNmean in 0C), percentage of days when TN<10th percentile (cool nights in %), percentage of days with TX<10th percentile (cool days in %), percentage of days when TN>90th percentile (warm nights in %) and the percentage of days when TX >90th percentile (warm days in %) were significantly changing across southwestern Ghana.

The rainfall anomaly index (RAI) with its advantage of improved estimation capacity for small-size landscape level was used via R statistical package to analyze the variability in rainfall years for the eight synoptic weather stations across southwestern Ghana. The RAI results were characterized using the extreme intensity classes. In addition, the selected ETCDDI indices were estimated using the accompanying Rclimdex package. To detect the trend in variability, the Mann-Kendall rank correlation test and Theil_Sen slope test were used. Finally, spatial analysis was conducted to generate the spatial pattern in the selected extreme climate indices across the miningscapes of southwestern Ghana.

The RAI analysis indicated changes in the intensities of wet and dry years, with a shift from near normal years towards extremely wet and dry years at the different synoptic weather stations. These stations correspond to the different forest vegetative type and the forest agro-ecological zones of Ghana. Notably, stations located in the inner zone of the Dry semideciduous forest vegetation and the Marginal forest zones are experiencing increased near normal intensity of rainfall years compared to stations located within Moist semideciduous and Evergreen forest vegetation types. Subsequently, the selected ETCDDI extreme rainfall and temperature indices unveiled similar pattern of increasing variability, which corroborate previous studies on rainfall variability within the southern region of West Africa.

These changing trends provide opportunities and challenges for climate-sensitive livelihood resources within the miningscapes where existing commercial land-use systems such as mining, timber extraction, and cash crop production affect the capacity of rural communities to manage their dependent natural resources sustainably. Owing to the significant contributions of natural resource extraction within the southwestern miningscapes into national coffers, adapting to the local effects of changing climate within southwestern miningscapes need to be prioritized. For instance, managing socio-environmental impacts of extractive land-use, be it timber, minerals, or petroleum extractions, would be increasingly challenged whereas food and cash crop production would be complicated by the effects of changing climate conditions. The operational activities of mining in particular are very susceptible to the local effects of changing climate but can be compounded by consequences of poorly managed socio-environmental aspects, thus watershed level adaptation is particularly critical for the industry.

In addition, the effects of increasing trends in extreme climate and mining poses a double impact on the hydrological regime of the river basins' within miningscapes. The dynamics in mining land-use activities modify the drainage profiles of host basins. Hence, water resources development and management within southwestern basin systems will be increasingly challenging. On a whole, the rippling effects of increasing variability in climate conditions within southwestern Ghana can be capitalized as a platform to collaborative adaptation within miningscapes.

Given the significance of water resources within southwestern system, two of which are transboundary (Tano and Bia), further studies will be needed to better understand the double exposure of mining and changing climate impacts on the water quality and the hydrological regime of the river basins within the southwestern miningscapes. Moreover, the protected forest zones of southwestern Ghana are known to host several IUCN listed endemic floral and faunal species, though some of these protected sites are located near to or within miningscapes. Hence, the likelihood of biodiversity exposure to both mining and climate impact is high but needs to be confirmed by further studies.

RQ2. How resilient is the mining industry in Ghana amidst the local effects of changing climate as perceived at operations?

The study investigated the perception of changing climate, the consequences on the mining industry' performance and the factors that will influence the industry to adapt to the impacts. The corporate adaptation process model by Arnell and Delany (2006) was adopted as the theoretical framing by which empirical data was collected. Ninety-nine (99) operational workers from 15 mining and contractor service companies were surveyed. Interviews and focus group discussions were conducted for three companies and their surrounding fringe communities. Each of the three companies is located in the Deciduous, Moist evergreen and Wet evergreen forest agro-ecological zones, respectively. Both statistics and content analysis tools were employed in the data analysis.

Based on the corporate adaptation process model, the results indicate that operational workers are aware of the changing pattern in the climate conditions of southwestern Ghana, including increasing temperature and variability in rainfall pattern. Workers have concern for the effects of these changing patterns that affect performances of their operations including flooding, air pollution, work place incidents and water shortages, which have consequences on the overall sustainability performances at operations level. Moreover, workers perceive the need for adaptation, which can be instigated mostly by the regulatory and economic context of the industry.

Owing to logistic limitation, the study focused on workers within multinational companies although additional inputs from operational workers from small-scale companies would have been an advantage. The interest of workers pleading for climate adaptation mainstreaming into mining development and regulation needs to be further inquired in order to formulate appropriate adaptation policies, which will not only ensure sustainable mining but also enhance resilience in rural miningscapes since mining impacts combine with changing climate to double burden rural communities and their dependent ecosystems.

The current situation of climate change impact and adaptation processes within the different operations affirms that, the mining industry in Ghana is by far not sufficiently resilient to the local effects of changing climatic conditions. Therefore, integrating climate adaptation into mining is critical to ensure sustainable mining. In addition, climate change adaptation can only be operationalized at mining sites when integrated into the firm's corporate and strategic management policies. Furthermore, the key factors that can engender resilience building within miningscapes include regulatory systems governing mining activities in Ghana.

RQ3. What has been the experiences of households on the effects of changing climate, persisting extractivism and livelihood resilience within the rural miningscapes?

Employing the double exposure framework, the objective of the fifth chapter sought to understand the perspectives of households within the miningscapes as to the extent to which the local effects of changing climate and extractive activities affect livelihood resources within the forest miningscapes. Household heads attested to the simultaneous exposure of their livelihoods to impacts of changing climate and extractivism. Factors accounting for these perspectives included the socio-economic characteristics of the households, the type of resource extracted as well as the agro-ecological zone within the communities are located. Households also identified anticipatory responses to enhance resilience within miningscapes.

The research was originally designed to be conducted using participatory approaches but the onset of the Covid 19 pandemic restrictions impeded this approach. Hence, a survey instrument was developed with indebt inputs from community representatives. Notwithstanding, the results revealed the existence of vulnerable groups within resource-fringe communities, which are mainly perceived to be resilient owing to the overhaul of corporate responsibility initiatives.

6.3 Outlook

The study ultimately sought to understand the cumulating impacts of changing climatic conditions and mining on corporate sustainability performance as well as the resilience of surrounding SES. The study exposes the dynamic interactions between the industry and rural resilience across Ghanaian miningscapes, thus providing the impetus for effective interventions such as not only focusing on-site adaptation strategies but also integrating rural adaptation to climate change impact as a corporate responsibility strategy. The aim was to provide empirical cases for collaborative approaches toward adaptation within rural miningscapes where the combined impacts of resources extraction as an economic development tool and local effects of changing climate affects rural resilience.

Empirically, the research collected views of key stakeholders such as mining workers and local communities on adaptation measures, which can be a useful start up for integrating adaptation processes into operations and corporate responsibility strategies. For instance, representatives from communities within the three miningscapes had different attitudes towards the extent to which the communities are engaged and supported in terms of development. Generally, the traditional authorities within the upper and middle miningscapes expressed satisfactory level of engagement with the mining companies, in sharp contrast to a skeptical perspective expressed by representatives within the lower miningscapes. Further studies would be needed to substantiate the divergent perspectives on community engagement and development across the miningscapes, which is a key driver of rural development across the miningscapes.

The thesis lays foundation for an inter/trans disciplinary approach to examine climate change impacts and adaptation processes within landscapes characterized by multiple land-use practices. An immediate need for attention would be to understand the occupational health and safety implications of the current and projected climatic changes in mining not from a single mine perspective but rather via a watershed approach, probably facilitated by the Ghana Chamber of Mines. Outcomes of such a study can be useful even for the non-member contractor companies as well as the small-scale and artisan mines. In addition, a key task in mine water management is to manage extreme situations (drought and floods) which are a feature of the hydrological system but now aggravated by rapid dynamics in land-use and local climate. So, conceiving adaptation to climate change in mining via a watershed approach can build on knowledge, tools, infrastructure which are already available within the various mining sites. Moreover, there is mutual benefit generated for mining operations and their surrounding communities should watershed approach be adopted for climate change impact, vulnerability and adaptation assessment. That is, such approach to mine water management will consider the watershed as the spatial unit rather than the operations' concessional area to coordinate interventions such as managing extreme situations and water balancing.

Similarly, mining as a land-use system plays a major role in the capacity of the country to achieve SDG goal 15 *"life on land"* since the various environmental aspects of mining interacts with the quality of life on land within miningscapes. Hence studies to understand the double exposure of mining and climate change impacts on the forest ecosystems within miningscapes are crucial to ensure that key policy instruments such as biodiversity conservation are effectively integrated into mining in Ghana.

Particularly the Tano-Aby transboundary river basin, in which the study area is located, has not received much research attention in terms of the effect of land-use and changing climate on the hydrological regime including water quantity (eg. flood and drought situations and their management) and quality (eg. water pollution and its effect on drinking water provision). Given that the miningscapes are located at the upstream of the basin on which hydro-electric dams have been constructed for diverse purposes in the neighboring country

(Ivory Coast), research is urgently needed to generate knowledge and data crucial for informed-decision making.

Another peculiarity of extractive activities across West Africa is the land right and management dynamics, which justify the conceptual call of the industry "*to adapt to coexist within rural miningscapes*". In Ghana for example, the minerals resources of the country are vested in the President on behalf of the people (Afeku & Debrah, 2003). Thus, mineral concessional lands cannot be purchased but rather leased out although individuals holding properties on the land, such as farmlands and settlements, are to be compensated or resettled accordingly (Minerals and Mining Compensation and Resettlemlent Regulations, 2012). This again nurses a close relationship between multinational companies and their surrounding communities, thus requiring the companies to acquire social license to operate. These dynamics in the land rights and compensation schemes may have strong associations with the livelihood dynamics of the surrounding communities. Hence, livelihood systems that are more likely to be doubled exposed to the impacts of extractivism and local climate effects (chapter 5) can be further influenced by the land right and management systems within rural miningscapes. Further studies are advocated into land right and management within miningscapes to underscore their contributions to the inherent vulnerability of rural West Africa.

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