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Research Article

Balancing Mineral Resource Development and Food Security in Northwest Ghana

Abdul-Wadood Moomen[1]*, Michela Bertolotto[2] and Pierre Lacroix[3,4]

[1]School of Mines and Built Environment, University of Energy and Natural Resources, Sunyani, Ghana
[2]School of Computer Science, University College Dublin (UCD), Bellfield, Dublin 4, Ireland
[3]GRID-Geneva, Institute for Environmental Sciences, University of Geneva, Bd Carl-Vogt 66, CH-1211 Geneva, Switzerland
[4]EnviroSPACE Lab., Institute for Environmental Sciences, University of Geneva, Bd Carl-Vogt 66, CH-1211 Geneva, Switzerland

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***Corresponding author:** Abdul-Wadood Moomen, School of Mines and Built Environment, University of Energy and Natural Resources, Sunyani, Ghana, E-mail: abdul-wadood.moomen@uenr.edu.gh

ORCiD: https://orcid.org/0000-0002-6842-5078

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Abstract

Food security remains a pressing global challenge, particularly in emerging mining regions where the competition between agriculture and mining intensifies. Thus, the main objective of this study is to understand the potential spatial balances between mineral resource development and the food security situation in Northwest Ghana. Despite its agricultural dependence, the region faces declining soil fertility, erratic rainfall patterns, and land degradation, exacerbating food insecurity. The mining sector, while offering economic potential, poses threats to agricultural land, water resources, and rural livelihoods. First, the case study examines existing food security conditions in the area based on reported data. Secondly, the study assesses the proxies using 1990, 2000 2010, and 2020 Landsat 7 ETM, ETM+, and Landsat 8 OLI image classifications. The study then compares the results to derive knowledge on existing and potential food security issues and looming mining activities in the region. The study finds that earlier studies reported food security challenges in Districts that are now earmarked to host mining. However, based on primary data, the analysis indicates little food security in the region with a minimum per capita consumption above the global average of 2,640 kca/cap/day in the observed years. Using Earth Observation data, the minimum food availability in a year is still above the reported average for Sub-Saharan Africa. The study finds that areas that host mining concessions and exploration leases show no food security hotspots but are highly degraded with flooding hotspots pronounced in the East and bare lands, devoid of vegetation, common in the West. These findings would help both local and national decision-makers to prioritize responses to Agenda 2030 SDGs in the study.

Abbreviations

ETM: Enhanced Thematic Mapper; ETM+: Enhanced Thematic Mapper Plus; OLI: Operational Land Imager; SDGs: Sustainable Development Goals; UN: United Nations; NGOs: Non-Governmental Organisations; UNEP: United Nations Environment Programme; WHO: World Health Organization; SSA: Sub-Saharan Africa; DFID: Department for International Development; AU: African Union; UWR: Upper West Region; GSS: Ghana Statistical Service; UTM: Universal Transverse Mercator; MoFA: Minister of Food and Agriculture; FAO: Food and Agriculture Organization; PL: Prospecting License; GIS: Geographic Information Systems

Introduction

In this 21st century, the challenges of food security remain a top global developmental concern. Hence, food security has remained a priority in food security as a priority, it is now a priority Goal 2 in the UN Agenda 2030 Sustainable Development Goals (SDGs) [1]. While achieving Zero Hunger and food security is desirable (SDG 2), the question is: *is it feasible in emerging mining regions?* It is particularly a developmental issue and comes with two complex options: 1) bread or stone and 2) bread from stone, especially in mineral resource-rich countries in Sub-Saharan Africa. This has led to the emergence of two schools of thought; one that proposes the choice of substituting food production for mining or vice versa, and one that believes that raw mineral production in a place could drive industrialization, economic diversification, and food security with a reinvestment of mineral revenues and returns [2]. Today, the challenges facing mineral resource-rich developing countries with growing populations range from

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loss of biodiversity on land, to food security, water and poverty. To address these problems whilst meeting the Sustainable Development Goals (SDGs), agriculture and mining, which are the most viable activities in these countries, need to work together, in collaboration with state governments, Non-Governmental Organizations (NGOs), and scientists, to develop meaningful strategies that would meet the needs of rural communities around mining sites.

The ever-evolving sophisticated human lifestyle threatens the attainment of global food security by the year 2030 [3]. In this complex epoch characterized globally by high demand for education, entertainment, recreation, transport, clothing, and shelter, there is also an associated growing demand for energy, automobile vehicles, and the use of electronics at homes, workplaces, schools and during recreational activities. This thirst is associated with mineral products and increasing demand for raw mineral material production, which is land-based and comes often in direct competition with food production. The growing demand for raw minerals production is not always associated with scientific analysis of the carrying capacity (total per capita resource consumption rate of a particular population in a given period and a given location) of source environments, resulting in higher food security concerns in these locations [4,5]. Rather, attention has been largely focused on agricultural intensification as a mechanism for producing more food and livestock, even though food insecurity in many places is largely assumptive. Meanwhile, the global demand for mineral raw materials is projected to increase in the coming years [6]. Much of these raw material supplies are expected to come from developing countries where food security issues, increasing human populations, and drastic environmental degradation are markedly ubiquitous [7,8].

For instance, while a WHO-UNEP joint study finds that land degradation and associated effects on food security are prevalent in Africa [9], the African press newspaper indicates that a UN report in 2019 reveals that there is a consistent rise in hunger in Africa [10]. , Meanwhile, the mining industry is expanding its activities into many African countries that are already experiencing land degradation and shrinking cultivable space. The biggest challenge, therefore, is whether to take the choice of bread or stone, or bread from stone [11]. This requires robust scientific analysis of the carrying capacity of natural systems on which both food production and mining activities occur. Whilst most scientific studies have focused on the negative impacts of mining on farmlands [12,13], few studies have addressed the question of bread or stone and bread from stone for vulnerable rural African countries [11,14,15]. Meanwhile, sustainable mining and social license-to-operate concepts encourage such studies before mine commissioning so that local communities and decision makers can be adequately informed [16,17]. Thus, the unanswered question is: in an emerging area, to what extent do exploration and mining impact on current food security situation?

In recent times, there has been an unprecedented level of growing demand for primary commodities from land-based production activities such as agriculture and mining. These include butter, bread, meat, accommodation, and minerals for transport, communication, fashion, adventure, etc. This demand translates into unprecedented consistent price hikes and associated high profits of food and mineral commodities, which attract further investment interests and development objectives on land [18,19]. Consequently, a new form of competition and displacement should be envisaged in places where rising stakes in mineral resource exploration looms. Both land-based extractive sectors often share areas of interest, and their activities interpenetrate, leading to displacement of the weak objective. In many jurisdictions, regulatory and legal frameworks predetermine agriculture as the weak among the two land-based production objectives. For instance, the constitution of Ghana vests minerals, as national property irrespective of where they are found, in the President of the Republic on behalf of, and in trust for the people. This provision, therefore, instigates compulsory acquisition of mineral-bearing lands, including agriculture lands. This raises issues of food security whenever and wherever mineral extraction interest is expressed in Ghana. Although the two sectors interlink through the input-output cycle, such as the provision of agricultural implements, nutrients, food and energy, globally, mining often displaces agriculture with these primary input needs: productive land, irrigation water, labor, and environmental impacts.

Early studies characterize the emerging Northwest mining region of Ghana with incidences of food insecurity due to poor soil fertility and land degradation [20,21]. Given that mining and agricultural activities typically occur in rural and remote subsistence farming communities, both sectors, together, have a strong opportunity to drive inclusive growth for smallholder farmers; reduce poverty, generate income, and uphold sustainable development. This is possible if synergies, in the use of space, could be harmonized between them to avoid loss of agrarian potential to mine-based direct employment, community displacement and resettlement. However, there are growing perceptions in society that direct mining, and its associated urban growth also introduces competition for local space, ultimately displacing smallholder farmers. Comparatively, mining uses less land than agriculture, in general. However, both agriculture and mining require large tracts of land for production processes. It is, therefore, necessary that the knowledge gaps around the spatial symbiosis between mining and agriculture be addressed.

Hence, this paper seeks to build better awareness of the realities and to engage with affected communities in a new area of the mining industry activities in Ghana. No existing study is found on this perspective in the Northwest of Ghana. , this paper aims to first provide a brief overview of the theoretical framework on land-based primary production, carrying capacity and associated implications for food security. Next, the paper conducts a case study in the emerging Northwest mining areas of Ghana. Specifically, the paper assesses the existing state of food security in the region and validates the findings with satellite data. In this regard, the paper compares the expressed mining interests through exploration concessions with the existing state of food security in the study area. It undertakes such comparison for three reasons; 1) studies in the

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area largely focus on soil fertility, and climate change and their impacts on agriculture. Thus, this paper focuses on how the mining sector could contribute to this unaddressed challenge; 2) this may help to better understand the range of contexts in which mining may instigate food insecurity; 3) appraise the interdependencies, if any, between the agricultural and mining sectors in the theories of agriculture production, urbanization, and carrying capacity, the implication for the national economy and rural communities [22,23].

Theoretical framework and related work

Mineral resource production, economics and agricultural land availability

Approximately 24% of the world's agricultural land (crop cultivation and pasture for livestock) is in Africa [24,25]. Its rich natural endowment is not only agriculture, but it also includes about 40% of the world's mineral resources in stock [26-28]. Yet, poverty and hunger are on the rise amidst rising exploration and mining concessions in many African countries with high mineral stocks. According to Rees [29], stock resources are substances that have taken millions of years to form and are fixed in supply. Stock resources are further classified into consumed by use and, recyclable [30]. Minerals are examples of the former, and soil fertility, water, and pasturelands are examples of the latter [31]. While stock resources that are consumed by use are relatively non-renewable, recyclable stock resources are relatively renewable [32,33].

We neither know when we exceed the limits nor how fast will the resource be recycled if its natural limit is reached. Exploitation without limit to the quantity that can be used eventually leads to resource scarcity. Resource scarcity is an economic theory that explains the price relationship between dynamic supply and demand. According to the scarcity principle, the price of a good, which has low supply and high demand, rises to meet the expected demand [34,35]. The price for a scarce good should rise until an equilibrium is reached between supply and demand [36,37]. However, this would result in the restricted exclusion of the goods only to those who can afford it. If the scarce resource happens to be grain, for instance, individuals will not be able to attain their basic dietary and nutritional needs. This would go against SDGs 1, 2, and 3 on poverty elimination, food security, and well-being for all.

For example, if the market price for wheat goes down, farmers will be less inclined to maintain the equilibrium supply of wheat to the market (since the price may be too low to cover their marginal costs of production). In this case, farmers will supply less wheat to consumers, causing the quantity supplied to fall below the quantity demanded. In a free market, it can be expected that the price will increase to the equilibrium price, as the scarcity of the good forces the price to go up [38]. For instance, anytime gold prices fall, gold-producing companies hoard production, coercing high demand [39]. Once demand increases, prices increase and there is the propensity of suppliers to produce more stock resources, leading to risks of resource exhaustion and consequent scarcity [40]. Thus, because of free markets, whenever there is a consistent rise in mineral commodity prices, many actors enter into mineral production [41]. Such trends lead to rising demand for endowed lands, which largely coincide with prime agricultural lands, particularly, in developing countries [42]. Many land title holders are, therefore, motivated to withdraw fertile lands from agricultural production into mineral resource development. Examples include the conversion of cocoa farms and pasturelands into illicit mining in some cocoa farming communities in Ghana, Tanzania, and Cote D'Ivoire [43]. Hence, a new scarcity of land for agriculture production has emerged in many Sub-Saharan (SSA) countries that are global hotspots for mineral exploration and mining.

Global statistics indicate a steady rise in human population in SSA countries, raising questions about land availability for food production and housing, vis-a-vis the carrying capacity [44,45]. The limited availability of land for agricultural production due to urbanization is the basis for Thomas Robert Malthus (1798) theory on food production constraints. Malthus published this theory in his 1798 writings, *An Essay on the Principle of Population*, which is an economic theory that sees fluctuations in the human population as reasons for fluctuations in prices. Thus, according to Malthus, when population growth is higher than agricultural production, famine or war, and resulting poverty is imminent. Generally, resource extraction, such as mining activities, attracts population growth, pulls new settlers to the locality, and increases demands for farmlands for the provision of infrastructure and housing needs. However, Ester Boserup [46], for instance, expostulates that population growth induces advancements in technology through modification of labor and capital, enabling the use of substitutes instead of land grabs, and also the introduction of division of labor, specialization, and economies of scale. These are the characteristics of a modern mine, which is highly capital-intensive, and complex in terms of skills, expertise, and technology requirements [47,48].

Cyclical cause-effect of resource production

Nevertheless, such a claim fails to consider that mineral resource development, agriculture, and population dynamics are influenced by, and, in turn, influence health, transportation, environment, war, and administration [49]. These elements are captured under respective targets of the global Agenda 2030 Sustainable Development Goals (SDGs). In most developing countries, like Ghana, the form of agriculture practiced by a larger part of the country is rural subsistence farming. In most of these rural areas, there is a higher carrying capacity, accompanied by a lower level of agriculture output per unit of labor under prevailing environmental conditions. According to the postulations made by Boserup [46], under these conditions, population growth becomes a necessity with the potential for the adoption of new and productive technologies. Mineral resource development brings with it such innovative population growth, royalties, infrastructure, and provision of health services [50]. This ideal phenomenon results in a rate of savings that could be enough to provide the requisite capital for local investment and economic growth necessary to accommodate the increasing population. An s.

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In respect of these ideals, mining induced urbanization, as often assumed, does not directly instigate food crises due to population pressure on agricultural land [51,52].

This demystifies Malthus's obsession that while advanced technology and agricultural techniques would improve rates of food production and well-being, this may as well population growth rate cycle may also be triggered with implications on food security [53]. While Malthus' ideas underestimate the role of technology in addressing food security, over the past century, food production has dramatically increased. Thus, Garrett Hardin [54] states that increasing food production to suffice population growth rates is an elusive ideology if technology does not offset exponential population growth rates and associated urbanization, particularly, in developing countries. It is noteworthy that people reproduce faster than cycles of food production, which does not necessarily lead to food crisis. Ance, Hardin [55] draws an imaginary scenario that in a village of 15 households, a household is allowed to graze only a cow on the communal pasture. In the year, the pasture is sufficient to feed only 15 cattle on average. In the same period, if one household head decides to feed two cattle in the same pasture, the pasture will support 16 at a lesser weight for each. Thus, natural resource extraction within the principles of sustainable development, does no harm to existing food security.

Beyond this principle, most mineral resource-rich countries, including Ghana, grapple with the tragedy of the commons. This is the situation where every industry produces and reproduces at higher rates without consolidating gains for the health of the growing population and food security. To contextualize, the prisoners' dilemma is used to characterize the tragedy of the commons in resource development. In this analogy, two people (mining and population) are accused of a crime (food insecurity). When they are interrogated separately, each could choose either to rat on the other ('defect' or 'confess') or say nothing ('not confess'). Any choice of response comes with an implication; mining displaces farmlands, pasture, and soil contamination – withdraws with all the new technologies, skills, and capital opportunities to expand local economies; population brings land grabbing for urbanization, diseases, and alien culture – withdraws with skilled labor, technologies, and capital investments in the local economies. But, to conclude, it is critical to consider a most argued factor: resource consumption, footprint, and carrying capacity complex. A footprint is a measure of the number of hectares needed to support current consumption patterns [56]. In other words, it is taking resource consumption and representing it as an equivalent amount of land used. To this end: what is the per capita footprint in every mineral resource-rich area in Ghana? Thus, do we know the number of hectares of resources used by the average person in an emerging mining economy in Ghana, to determine the trade-offs or levels of synergy between mining and agriculture? Such data and knowledge are generally dearth.

Creativity versus anxiety for land resource scarcity

If we get the existing phenomenon right, the looming food security, as generally perceived to be exacerbated by mineral resource development may not be logically accurate. The total population growth rates, coupled with the existing per capita resource consumption rates in a locality could already have made such a locality vulnerable to food security [57]. Thus, in mining regions, food insecurity may not emanate only due to excavation or contamination rates or a decline in cultivable and pastureland availability, but also due to existing high consumption rates, sociocultural, and economic factors. Moreover, schools of thought, such as Verhulst [58], and Donella, et al. [59] in the reports of the Club of Rome, argue that the shortage of resources could be a check on high population growth rates in a limited environment. On the contrary, several other schools of thought, including, the works of Hobfoll [60], De Gregori [61], Ahuja and Katila [62], Solow [63]; and Halbesleben, et al. [64], posit that in every generation or locality, people strive to retain, protect, and build resources (substitutes) to meet their needs and demands at any given time. Following the theory of Erich Zimmermann [65], that "Resources are not; they become", environmental resources are neither limited nor consumed by use. However, the needs and demands of a society dictate what becomes a resource and what are the stocks. Human society possesses the cognitive capacity and technology to convert existing physical materials into new resources to meet the demands of the times [66,67].

Albeit, in any industrial age, the primary inputs for production in material terms are physical resources. If land, soil, and associated mineral resources are materials for production, then these are fixed and consumed by use. Meanwhile, these materials existed before they were later recognized as resources and transformed or extracted to meet the needs and demands of society [65]. Thus, Ayres [67] argues that there is nothing like "new material", but there are "new resources". Science and technology, facilitated by populations' creativity introduces new uses of existing materials of the physical environment and devices to form new devices or materials or both for societal needs and demands. This is the total of human capital from the growing populations and environmental endowment in their supposedly "fixed state" [38,67]. These arguments have demonstrated that in this age, high population growth rates provide several opportunities for innovation and economic transformation. Case in point is the People's Republic of China, and India, which have transformed significantly from being overpopulous countries to being global technology and resource giants [68-70]. These examples notwithstanding, Verhulst [58] explains that when the demand of the existing population on the available resources (i.e., the population size times the basic per capita resource consumption rate required for maintaining life in a man period, say daily, monthly or annually), such as agricultural lands for meat and grain, is equal to the rate of resource supply, the population will reach its saturation level.

Carrying capacity and land resources

The saturation level is determined by both the resource supply and the per capita resource consumption rate in a given period. In simple terms, this is referred to as the carrying capacity of the environment for the local population [71,72].

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Although the literature on the growth of the world population as against agriculture production rates and food security has become prevalent, few studies have reported on the carrying capacity assessment of essential land resource extraction, in the same context. Since the projections of Malthus and that of the Club of Rome, and considering the agricultural carrying capacity of the Earth, the actual world population has increased from one estimate to the next. Yet no study has come up with the corresponding shorter remaining period within which the world's population would reach its saturation level. Rather, recent studies typically generate high figures for the earth's potential agricultural carrying capacity, which are largely attributed to improvements in agricultural technology led to higher yields per acre [73-75]. As a matter of course, there have always been improvements in agricultural technology, much less farmland extensification, that have often increased Earth's agricultural carrying capacity [76-78].

Accordingly, there are two forms of carrying capacity: human carrying capacity (biophysical and social carrying capacity), and ecological carrying capacity [56,79]. Human carrying capacity describes the number of human beings that can be supported on a sustainable basis in a given area within natural resource limits in a given period and by human choices concerning social, cultural, and economic conditions within the same period [80]. Particularly, whereas biophysical carrying capacity entails the maximum population that can be supported by the existing environmental stock resources of a given area at a given level of technology, social carrying capacity involves the sustainable biophysical carrying capacity at the disposal of a given society [80]. On the other hand, ecological carrying capacity is a measure of the amount of renewable resources in the environment in units of the number of organisms these resources can support, which is a function of the per capita consumption rate of a given population of surviving organisms [56,81].

In ecological terms, the carrying capacity of an ecosystem is the size of the population that can be supported indefinitely with the available resources and services of that ecosystem [82]. Thus, analysis of the carrying capacity of an ecosystem depends on three factors: 1) the number of resources available in the ecosystem, 2) the size of the existing population, and 3) the number of resources each individual is consuming [83]. In terms of nutrition intake, carrying capacity has been defined as *the accessible and utilizable energy in the habitat divided by per capita energy consumption* [72]. Rees [56] defines carrying capacity as the number of individuals of a given species that a given habitat can support without being permanently damaged. It is, therefore, rudimentary that if the population of a given species exceeds the carrying capacity of its habitat, then either such species will either deplete its resources, or its wastes will build up and poison its members, or both possible incidences may occur, and the population will crash [72,84,85]. Conversely, such a presumption may work perfectly for non-human species that may be confined to the limits of growth, lack of technology, and creativity. In popular human culture, science and technology allay obsessions and resistances to growing populations ingenuity, and creativity to provide and live within their means [86]. Yet, in terms of space for resource extraction and optimization, carrying capacity can only be affected by a particular social group behavior, and habitat suitability.

Under such circumstances, carrying capacity can be defined as the total surface of agricultural land available (cropland, pastureland, irrigable) divided by the estimated land area required by individual farmers for a given production period [87,88]. It is related to subsistence, tolerance, security, maximum harvest, and minimum impact densities in livestock and wildlife management [79]. In the case of efficient agriculture, the carrying capacity is only determined by the ratio of the total productive area and the nonagricultural used area (per person) [89,90]. This could then be transposed over an optimal mineral resource extraction surface area within the same locality, recognizing that carrying capacity is not static, but is affected by the abundance and distribution of limited resources, such as land, and by how individuals compete for these limited resources [71,91,92]. Meanwhile, emerging trends of population across SSA countries are growing, implying a net decline in land availability for agricultural production. As the human population continues to expand, associated demand for both agriculture products and mineral raw materials production for technological advancements is expected accordingly. To sustain humanity, its needs for food and mineral commodity lead modern life systems, carrying capacity assessment is critical for emerging mining regions and resource optimization [93,94].

Mineral resource production for food security

In recent times, many intervention schemes and scientific proposals mostly focus on agricultural intensification to address food security [95]. It is, however, critical to postulate that food insecurity is largely a heuristic problem in many places with declining land productivity, climate change, and soil nutrient depletion [96-98]. Both agriculture and mining rely on similar inputs, outputs, and externalities. Thus, food insecurity may also result from food stress due to soil and water contaminations by heavy metals in ore processing in mining regions, leading to poor quality of nutritional value of food produced [43,99]. Yet, agriculture needs mined products, such as potash, for soil improvement. Mining uses less land; it leads to less degradation of water and land than agriculture does. The works of Barbier [100], Matson, et al. [101], Spaling and Smit [102], Stavi and Lal [103], Terminski [104], Tilman [105], Skinner, et al. [106], Clark and Tilman [107], Yang, et al. [108] and Padhiary and Kumar [109] present case studies in this regard. Apart from soil and water contaminations by agriculture and mining, both activities often compete over the same inputs (water and soil), and jointly or differentially displace rural communities [92].

Despite the "input-output" relationships between the two industries, the negative impacts of the mining sector are generally perceived, notably, the reduction of productivity of adjacent agricultural lands. However, some analysts suggest that each cycle of boom in the mining sector replicates a simultaneous equivalent boom in the agriculture sector.

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Some reasons attributed to this relationship can be found in the reports of Carter, et al. [110] and De Gorter, et al. [111]. Moreover, recent investment streams have demonstrated the benefits of joint inclusion in certain financial vehicles through the generation of capital from one for reinvestment in the other [27,112-115]. For instance, a 2005 DFID study that initiated the establishment of the defunct Savannah Accelerated Development Authority in Ghana concluded that the economic development of the Northern Savannah Regions of Ghana could only be achieved through evocative investment in agriculture, which is heavy capital demanding [14]. The requisite capital can only be obtained through returns from the extraction of the area's rich mineral resource endowments [14,116].

It is apparent from the foregoing discussions that there are knowledge gaps in the mineral resource development sector in Africa, and its catalytic approach to engender sustainable and integrated rural development, through agriculture, enhanced food security, and poverty alleviation. Through tailored and strategic research, there is an opportunity to build knowledge and improve awareness of the realities for informed policy decision-making, and stakeholder engagements in Africa. In stock estimates, Africa holds about 40% of the world's mineral resources [117]. Yet, many countries in Africa, that hold significant mineral reserves, consistently score lower on the human development and sustainability index [27,118]. For instance, from 1996 to 2015, food imports to SSA nations increased radically, showing low food production and insecurity [119,120]. Evidently, in reported cases, about 239 million people in SSA cannot afford 3 square meals a day amidst the growing prospect of mineral resource extraction [121-124]. Meanwhile, SSA governments find a need to exploit mineral resources to support agricultural production and food security issues.

To this end, Frankenberger and Goldstein [125] define food security as the condition where "the viability of the household as a productive and reproductive unit is (not) threatened by food shortage". Food security always refers to the availability or supply of food more than the per capita consumption rate in a given region or locality. It is commonly defined as "access by all people at all times to enough food for an active, healthy life" (World Bank, 1986: 2). According to Darfour and A Rosentrater [126], about 1.2 million people, representing 3.5% of the population of Ghana, are facing food security challenges, another 2 million people are prone to food insecurity risks. These risks are associated with potential natural or man-made shocks such as the late rains experienced in 2024 or extensive soil contamination by illegal mining across most farming communities. The potential influence of increasing population rates at 2.5% per annum and declining yields in areas that are not prone to illegal mining cannot be underestimated. Nevertheless, there has not been any deliberate scientific study that assesses the combined effects of these factors to establish the trends of food security in the mining areas of Ghana. Besides, the limited scientific studies on this subject find that food security challenges in Ghana are pronounced in rural areas of the Northern Savannah Regions [95,127]. These Regions include the Northern, Northeast, Savannah, Upper East and Upper West regions, respectively.

In terms of regional distribution, the Upper East region has the worst insecurity status (28%) followed by the Upper West region (16%) [20,128,129]. Food security challenges in the Upper West Region are attributed to high incidences of endemic poverty, poor soil fertility, outmoded farming practices, and lack of capital investments in agriculture [20,21,130]. Considering historical data, the past and future of many African countries, including Ghana, are largely dependent on both mining and farming. There is, therefore, an urgent need for a more nuanced understanding of the dynamics that could optimize opportunities between the people, mining, and farming. These efforts require adequate evidence for determining appropriate actions. Notable among such evidence-based actions would interrogate food security in mining areas with two principal objectives: assessment of existing food security, and mapping of food insecurity. The limited studies have often failed to apply a clearly defined metric of food security based on which food-secure and food-insecure areas can be identified in mineral resource development. Perhaps, its necessity has not yet been fully apprehended in the mining literature.

Materials and methods

Study area

A case study is conducted in the emerging northwest mining region of Ghana, situated in the Upper West Region (UWR). In the African mineral resource development context, Ghana is a significant player with a diverse rich mineral resource endowment. In its Medium Term Development Policy Framework, Ghana seeks to transform its economy by modernizing the agriculture and mining sectors [131,132]. Previously, mineral resource development was concentrated in the Ashanti, Eastern, Central, and Western Regions. In recent times, viable quantities of mineral deposits have been discovered in the Savannah, Upper East, and Upper West Regions. Commercial production of gold has commenced in the Upper East Region. Exploration and site construction for gold and graphite production have advanced in UWR. The study area of our research is the UWR (Figure 1), which consists of 11 Districts. However, our study focuses, largely, on the seven Districts that have exploration and mining leases.

Traditionally, the economy of the regions of Northern Ghana is primarily agriculture, employing over 90% of rural populations in these areas. However, due to unfavorable climate change impacts, growing urbanization, and dwindling farm yields, rural communities in the area are building resilience and adopting off-farm and non-agricultural livelihood activities [133]. These include petty trading, wood carving, gardening, illicit mining and shea butter processing. A study by DFID [134] finds that to achieve economic growth in the Northern regions, including Upper West, agro-based industries and tourism must be improved, and that the amount of capital required to support these industries can only be generated through reinvestment of proceeds from extraction of its rich mineral resource endowment.

Data collection and preparation

There are 10 weather stations currently active across the

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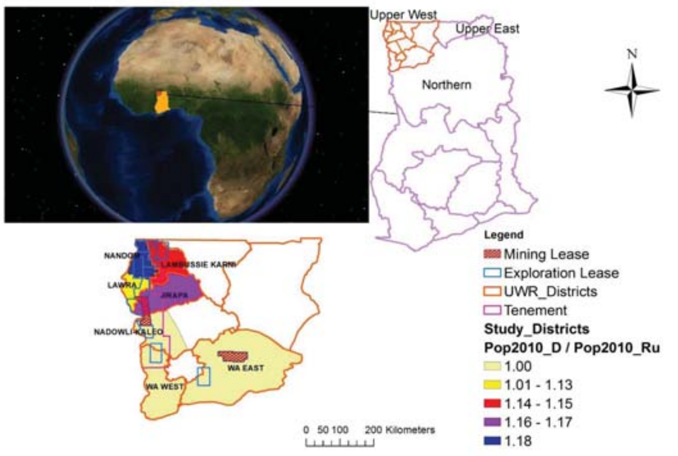

Figure 1: Study Area.

11 Districts of the Upper West Region. The stations are: Funsi (Wa East), Jirapa (Jirapa District), Kundungu (Wa East), Lawra (Lawra District), Nandom (Nandom District), Nadowli (Nadowli Kaleo District), Tumu (Sissala East), Wechiawu (Wa West District), Wa (Wa Metropolis), and Babile (Lawra District). To establish baselines, and assess the potential influence of rainfall patterns on agriculture performance and the existing trends in the region, in situ rainfall data were obtained from these stations. Two field visits were done between December 2018 to February 2019. The objective of the fieldwork was to map the spatial extents of land use activities across Districts. A digital map, containing shapefiles of all Districts in the study area was obtained from the Ghana Statistical Service (GSS). The tenement map for exploration and mining activities was downloaded from the companies' website. The map is in the Universal Transverse Mercator (UTM) projection system. The exploration leases together with drill holes in the tenement map were uploaded onto ArcMap and digitized. The coordinates of training samples were taken using a hand-held GPS with 5 meters positional accuracy. The 2021 population and economic activity data were also obtained from the GSS to be analyzed for addressing the ecological footprint and food availability in the study area. Data on crop yield were obtained from the Ministry of Food and Agriculture (MoFA). These data cover 1992 to 2022. Cloud-free Landsat 7 ETM and ETM$^+$, and Landsat 8 Operational Land Imager (OLI) were obtained for land use and land cover analysis of the study area. These span years 1990, 2000, 2010, and 2020.

Analysis

The rainfall data were used to cast the average annual rainfall patterns across the study area. The patterns would explain the impacts of rainfall on per capita food availability. The land use extent maps of the villages were overlaid with the prospecting and exploration leases (PL) in ArcMap to identify areas of food insecurity and high ecological footprint. However, there is no standard model to proceed with this kind of map overlay analysis, considering the mining sector activities and potential cropland displacement. The per capita daily calorie intake and the available energy consumption were adopted from the Food and Agriculture Organisation (FAO) of the United Nations 2022 database. The per capita food consumption rate was estimated using the average daily food consumption figures from the data obtained from MoFA and FAO. To calculate food availability to the populations across the study area, the method introduced by Frelat, et al. [135] was adopted and modified. In this method, the food energy potentially available to a person is divided by the energy requirements of the person (http://faostat.fao.org/site/354/default.aspx). The existing statistics on areas of crop production, associated farm yields, and average daily food consumption were further analyzed to derive knowledge on the existing food security status of the area.

The study examined the existing environmental conditions of the area based on Landsat ETM and OLI data classifications. Five land use and land cover classes were created: waterbodies, barren land, built-up, vegetation, and croplands. Vegetation comprised of tree and grass cover, and the cropland comprised of all cereals cultivated in the study area. These include maize, millet, groundnuts, rice, and beans. The reported croplands and food production values were combined in a Geographic Information System (GIS) to analyze the carrying capacity of cropland with cognizance of potential food security issues and looming mining activities in the region. The carrying capacity assessments were done by first estimating the available areas of cropland, which was derived from the MoFA data. Croplands in PLs were derived from the 1990, 2000, 2010, and 2020 classified images in ArcMap. The size of each within a PL was then calculated. These were then used to calculate both ecological footprint and biocapacity. The following formula adopted from Yue, et al. [136] and Yu, et al. [137] was adapted to the local needs of this study:

$$EF = \sum_i^n \left(\frac{P}{YN} * YF * EQF \right) \quad (1)$$

Where:

EF = Ecological footprint.

P = Total amount of cereal production per year.

YN = District average yield for cereal crops.

YF = Yield Factor; and

EQF = Equivalence Factor for the country and land.

$$BC = \sum_i^n \left(A_i * Y_i * E_i \right) \quad (2)$$

Where:

BC = Biocapacity; Ai = biologically productive area of land use or land cover class i;

Yi = yield factor of land use or land cover class i. This is calculated using the annual ratio of the district-level yield of a generic product to the Regional average yield of the same product. The yield factor converts local biologically productive land into units of regional average productivity and thus facilitates comparisons across Districts;

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Ei = equivalence factor of land cover class i. This is a scaling factor used to convert specific land use types into a universal unit of biologically productive area (gha). The equivalence factor is calculated each year as the ratio of the district-level average productivity of a specific land use or land cover type to the average productivity of all biologically productive lands and waterbodies in the country.

Results

Figure 2 shows the annual average rainfall patterns over the period considered (1990 – 2022) in the study area. Whilst Kundungu in Wa East District recorded the highest annual average rainfall of 220 and 310 mm in 2008 and 2012, respectively, all other stations recorded below 200 mm. The minimum rainfall within the period was 55 mm in 1994, which was recorded in Babile in the Lawra District. Between 2020 and 2022, except Babile which recorded below 100 mm in 2018, all the Districts recorded above 100 mm of rainfall.

Figure 3 shows the food availability per person per District. In the year 2000, the Nandom and Lawra Districts recorded the highest per capita food availability up to 27,000 and 26,000 kca/cap/day. The Sissala East and Sissala West Districts recorded the lowest food availability on the same date. In 2010, the Jirapa District observed the highest food availability per person at the rate of 8,000 kca/cap/day. The current date, 2020, within which prospecting and exploration activities have already advanced in the region, observed a rise in food available to persons in the area. In particular, it is observed that Lawra District recorded a hike of 10,000 kca/cap/day. Yet, Daffiama-Bussei-Issa District recorded the lowest of 2,500 kca/cap/day. Using the total population from the year 2000 to 2020 and the reported average crop yield per District, Figure 3 shows the existing per capita consumption in each District (food availability per person per day per District). Lawra and Nandom have the highest per capita consumption rates in the year 2000 (25000 Kca/cap/day). All other Districts record below 10000 Kca/cap/day. From 2010 onwards, the per capita consumption is observed to have taken a downward trend, going to the lowest of 1000 Kca/cap/day in the Daffiama-Bussei-Issa District. This District, however, does not have any PL to anticipate displacements.

Comparing the food availability across the Districts and within the mineral prospecting and exploration concessions, Figure 4 shows that while Nadowli-Kaleo District had 21,000 kca/cap/day in the year 2000, Jirapa and Lawra Districts recorded 3,500 kca/cap/day and 1,900 kca/cap/day. The cultivated areas were extracted from 2000, 2010, and 2020 classified Landsat data. Meanwhile whilst Lawra District experiences the lowest, Nadowli Kaleo, Jirapa and Wa East Districts record the highest PL per capita food consumption potential displacement. At the time-intense exploration started in the area in the year 2000, Nadowli-Kaleo recorded the highest per capita food consumption rate in PL, followed by Wa East, and Wa West Districts. In 2020, almost all the Districts had a high per capita food consumption, reaching a peak of 18000 kcal/cap/day and 17000 kcal/cap/day in the Jirapa and Wa East Districts, respectively.

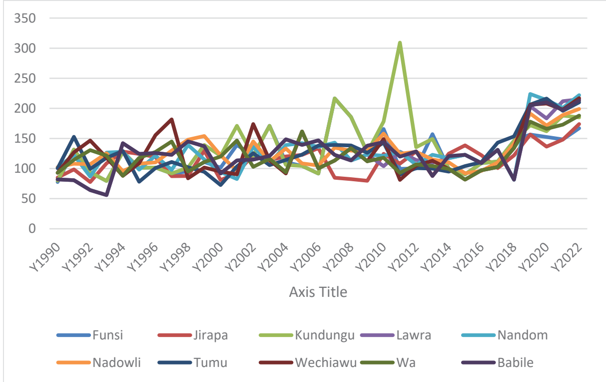

Figure 2: Annual average rainfall patterns in the study area.

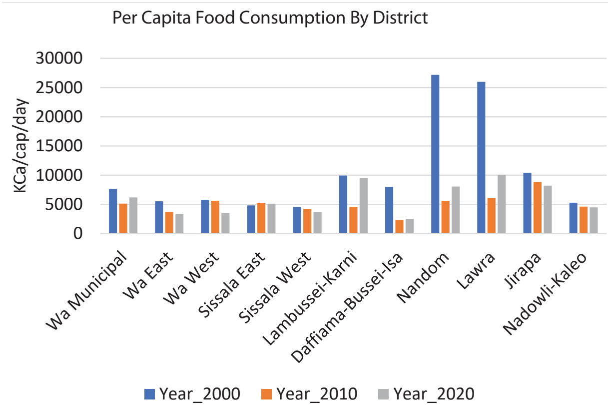

Figure 3: Food availability by Districts.

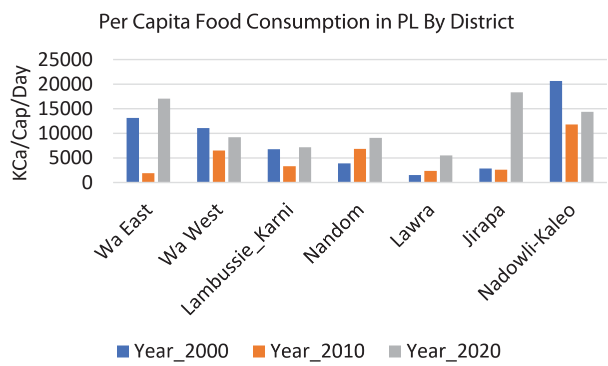

Figure 4: Food availability within PL and satellite data validation.

From an overlay of classified satellite images, Figure 5 shows the surface of cultivated areas within the mining and exploration concessions (PL) in the study area. This analysis starts from the year 2000 when mineral prospecting and exploration became intense, until 2020. From the overlay of classified images, Nandom District consistently has the highest cultivable lands (9368 ha in 2000 to 14144 ha in 2020) within prospecting and exploration concessions. Wa West District records the lowest (1855 ha in 2000 and 2864 ha in 2020). The amount of cultivated land area that falls within PLs translates to a displacement of 2600 Hg/Ha of food crops at 3000 Ha in 2000 in Wa East, and a lowest of 6500 Hg/Ha at 9500 Ha in the Nandom District (Figure 6). For the year 2020, Nadowli-

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Kaleo District records 39000 Hg/Ha of food crops at 5466 Ha within prospecting and exploration concessions and records the lowest of 22000 Hg/Ha at 4504 Ha. Figure 7 shows the results of the biocapacity of the study area. Data from 1990 to 1993 were missing from the data received.

Thus, the results range from 1994 to 2020. From 1994 to 2004, Sissala East District has the highest biocapacity above 1,000 Hg/Ha. From 2005 and 2014, Wa Municipality records the highest biocapacity, well above 1,000 Hg/Ha. From 2016 onwards, Nadowli-Kaleo District experienced a high above 1,300 Hg/Ha and only dropped to 1,000 Hg/Ha in 2020. However, within the areas that contain mineral prospecting and exploration, Figure 8 shows that Lambussie-Karni and Nandom Districts recorded the highest biocapacity of 750 Hg/Ha and 1,800 Hg/Ha, respectively, in the year 2020. In the year 2000, both Lambussie-Karni and Nandom again recorded the highest. The general ecological footprint within the Districts is presented in Figure 9. The highest footprints were noted in 1994 at Sissala West and Sissala East. These are 0.29 and 0.24 Hg/Ha, respectively. In 2002 and 2003, Wa Municipal, Wa West, Wa East, Sissala West, and Nadowli Kaleo recorded a high above 0.2 but below 0.25, respectively.

Discussion

In many places, including SSA countries, rainfall remains a key variable influencing agricultural performance and food availability potential. Precipitation levels, particularly rainfall, play a central role in determining annual food production outcomes. Beyond agriculture, rainfall also impacts mining operations, influencing activities such as daily extraction, flooding control, liquid tailings dam management, and ecological restoration. These interconnected factors contribute to the ecological footprint of mineral resource development projects. Several earlier studies, such as Lal [98], Alhassan [128], Kusakari, et al. [138]; and Dekongmen, et al. [139] have reported on the impacts of rainfall-induced flooding on farm yield and production in the Upper East and West Regions of Ghana. These effects include loss of cropland, destruction of crops, and weed proliferation, all of which disrupt agricultural productivity. Meanwhile, other studies attribute threats to food security in the study area to irregular and dwindling quantities of rainfall. For example, the study of Atitsogbey, et al. [140], Quaye [141], Abbam, et al. [142] Mwinkom, et al. [143] and Osman [144] find that local farmers in the Upper East and Upper West Regions attribute the declination of farm yields to drought and erratic rains. Despite the risks posed by climate variability, the findings of this research show that rainfall patterns between 1990 and 2022 have been relatively stable and sufficient to support agricultural production.

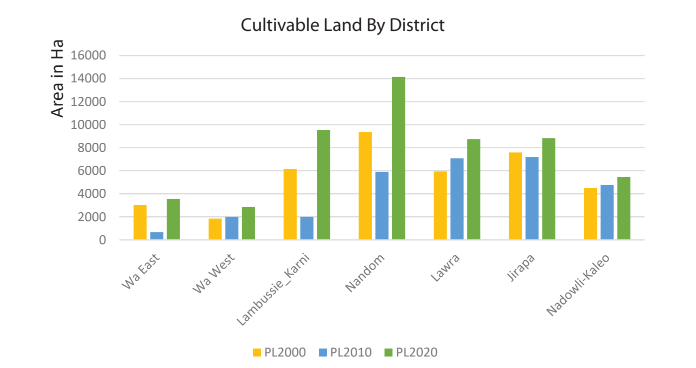

Figure 5: Cultivable lands within prospecting and exploration concessions.

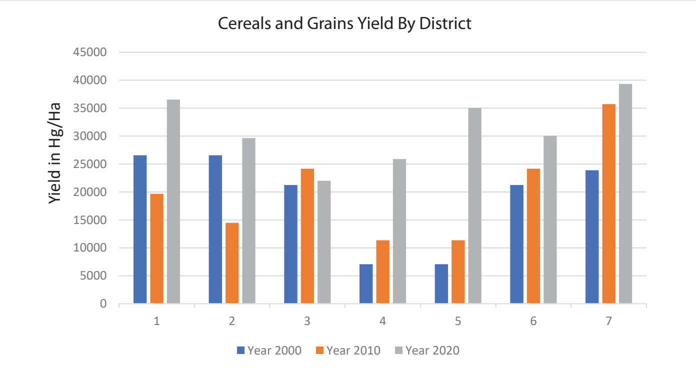

Figure 6: Crop yield potentially affected per District within a concession.

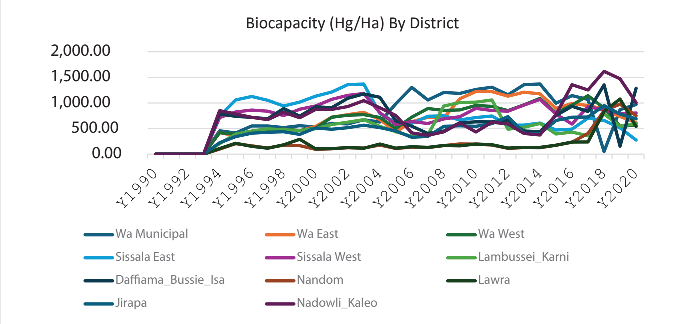

Figure 7: Biocapacity assessment by District.

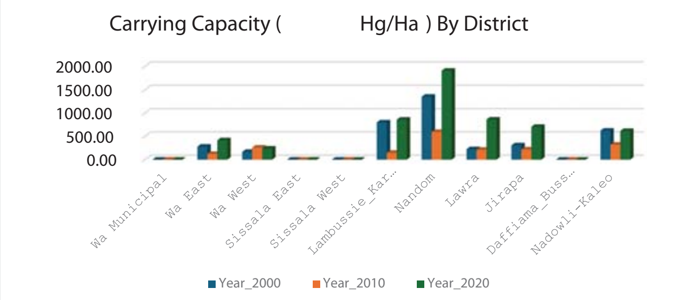

Figure 8: Carrying capacity assessment within PL by District.

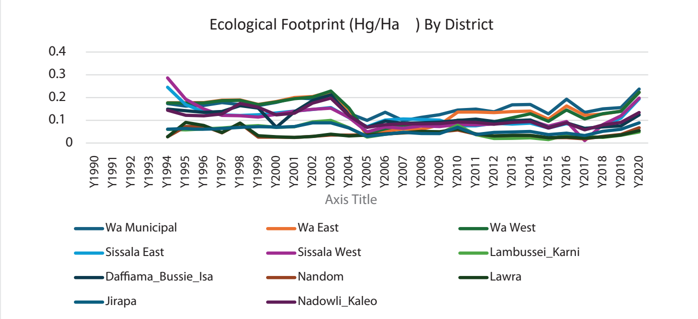

Figure 9: Existing Ecological footprint by District.

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Within the study period, the lowest rain records were in Babile, which was a little below 50 mm in 1993. Historically, the rainfall ranges in the Upper West Region are between 800 and 1,300 mm per annum [129,145,146]. These rainfall levels provide a strong foundation for sustained food production. While the population across the Districts was observed to grow consistently over the years, the results also show a consistent increase in cereal production from 1994 to 2020. The classified satellite data show that within the same period, more land has been invested to increase food production across all Districts over the years. It, therefore, suggests that growing populations increase the demand for cereals in the region. These findings contradict the Pro-Malthusian theories that suggest population growth reduces land availability for food production due to urbanization and industrial expansion.

The results on food availability indicate that while the population and urbanization are growing simultaneously, there is relatively enough food for everyone to feed daily. These findings are consistent with the study of Darfour and A Rosentrater [126], who reported a consistent increase in the population size, the number of farmlands, and the total food production in the Upper West Region. The results show that the median value for the lowest level of food crop consumption across all Districts is roughly 1,500 kcal/cap/day, and the median value of food availability is about 4,000 kcal/cap/day. Districts that host exploration and mining concessions have even higher dynamics than the other Districts. Based on these values, it suffices to conclude that the study area is “sufficient food available” [135]. Acheampong, et al. [147] observed that over 90% of rural households in Ghana remain close to the global borderline for food security. While most households in the Upper West Region meet or exceed daily caloric requirements, some outliers still struggle to achieve food sufficiency. These disparities underscore the need for targeted interventions to address food insecurity among the most vulnerable populations.

To understand the potential influence of mineral resource development on food security in the Districts, the prospecting and exploration concessions were analyzed. The results provide sufficient grounds to proffer that the looming conversion of some existing farmlands to mining, the Districts will not turn into a hotchpotch of food security. A higher value than one in food availability analysis means that there is enough food across space and in the locality [135,148]. From the results presented, all Districts record hundreds of folds, and the yield factor has been consistent across the study period. Even, within the prospecting and exploration concessions, the yield factors have shown resilience, indicative that mining will not have an alarming impact on food supply in the coming years. Despite these optimistic results, some challenges require attention. Nyantakyi-Frimpong and Bezner Kerr [149] contend that incipient land use activities are reducing the land availability to subsistence farmers in the Northern Part of Ghana, including the Upper West Region. This causes inequalities, such as landlessness, among rural farmers in all the Districts. Consequently, Atuoye, et al. [20] observed a falling agricultural productivity in Upper West Region due to increasing population over the years. While other studies, such as Mason-D’Croz, et al. [3], Ecker [95], Dzanku [121], and Haggblade, et al. [150] cite several other factors causing a decline in agricultural production, a combination of these factors increases the pressure on available land, which may lead to higher ecological footprint and biocapacity deterioration [151], if not managed effectively.

The existing ecological footprint of the study area was measured to understand the extent of land required to sustain food availability, and per capita food consumption rate without mining, given all other forms of disturbances. This considers the amount of cultivable land available within the concessions that could be used for food production. In any measurement, when the ecological footprint is greater than the biocapacity, it means that even the current agriculture consumption and production levels are unsustainable [56,152,153]. The introduction of exploration and mining may further stress cultivable lands. However, from the results, it is observed that the ecological footprint is far lower than the biocapacity levels of all Districts assessed. The special focus on Districts currently under exploration and mining concessions shows a wider difference between the potential ecological footprint and the biocapacity of the concessions. The results prove that there is more cultivable land available to produce more food to feed the increasing population with mining [154]. The biocapacity levels within the prospecting and mining concessions are greater than the ecological footprint of the Districts. Although existing literature reports on the impacts of climate change and land degradation in the study area [21,155,156], the results show that agriculture remains the sustainable form of food supply to growing demand, including -mine-associated urbanization. Although mineral exploration and mining imply a further decline in land available for agricultural production in the region, the current trends demonstrate the potential sustainable means. However, proactive measures are necessary to mitigate the long-term effects of environmental degradation. This includes investing in climate-resilient farming techniques, enhancing soil fertility, and promoting sustainable land management practices.

Conclusion

This study analyzed the existing conditions of agricultural production, food security, carrying capacity, and a potential implication for mineral resource development in the Upper West Region of Ghana. Assessing patterns of rainfall from 1990 to 2020, the study sought to initially establish a relationship between factors that have a direct impact on food security. It emerged that rainfall patterns, over the period, have been consistent and, thus, have little impact on food security. With the observed patterns of rain, food production rates versus yield and population growth have seen a counterbalance. Assessing the food availability rates, it is found that the per capita food consumption in the area is far above the FAO-determined minimum threshold of 2420 kcal/cap/day. Within places where mining is to take place, the food availability rate is higher and the ecological footprint indicators are permissible. Thus, all Districts have the lowest global hectares of ecological footprint

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per hectare. Carrying capacity assessment shows that the area has a higher index to contain multiple resource development opportunities. The study finds that areas that host mining concessions and exploration leases show no food security hotspots. It is, however, crucial to conduct a full biocapacity and carrying capacity assessment of individual communities within the mining enclaves. This would enhance mining and exploration projects' optimism for addressing the SDGs in the study area.

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