Assessing the Effects of Mining Projects on Maternal, New-born and Child Health in sub-Saharan Africa

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Abbreviations

ADB	Asian Development Bank
AIDS	Acquired Immunodeficiency Syndrome
aOR	Adjusted Odds Ratio
As	Arsenic
ASGM	Artisanal And Small-Scale Gold Mining
ASM	Artisanal And Small-Scale Mining
CDC	Center For Disease Control And Prevention
CDI	Chronic Daily Intake
CHMP	Community Health Management Plan
CI	Confidence Interval
CISM	Manhica Health Research Center
COREQ	Consolidated Criteria For Reporting Qualitative Research
COVID-19	Coronavirus Disease 2019
CR	Cancer Risk
CSR	Corporate Social Responsibility
DALYs	Disability Adjusted Life Years
DANN	Deoxyribonucleic Acid
DHS	Demographic And Health Survey
DID	Difference-In-Difference
EIA	Environmental Impact Assessment
EKNZ	Ethikkommission Nordwest- Und Zentralschweiz
ESHIA	Environmental, Social And Health Impact Assessment
ESIA	Environmental and Social Impact Assessment
FGD	Focus Group Discussion
GPS	Global Positioning System
HAZ	Height-For-Age
Hg	Mercury
HI	Hazard Index
HIA	Health Impact Assessment
HIA4SD	Health Impact Assessment For Sustainable Development
HIV	Human Immunodeficiency Virus
HQ	Hazard Quotient
HRI	Health Risk Index
IELCR	Incremental Excess Lifetime Cancer Risk
IFC	International Finance Corporation
IHI	Ifakara Health Institute
ILCR	Incremental Lifetime Cancer Risk
IQR	Interquartile Range
IRSS	Research Institute Of Health Sciences

km	Kilometres
LHDI	Low Human Development Index
LMIC	Low- and Middle-Income Country
MCH	Maternal and Child Health
MDG	Millennium Development Goal
MMR	Maternal Mortality Rate
MNCH	Maternal, New-Born And Child Health
MSD	Musculoskeletal Disorders
NADEL	Center for Development And Corporation
NREPS	Natural Resource Extraction Projects
OR	Odds Ratio
Pb	Lead
PEL	Permissible Exposure Limit
r4d	Swiss Programme For Research On Global Issues For Development
RR	Risk Rating
S&P	Standard & Poor
SD	Standard Deviation
SDC	Swiss Agency For Development And Cooperation
SDG	Sustainable Development Goal
SIA	Social Impact Assessment
SNSF	Swiss National Science Foundation
SSA	Sub-Saharan Africa
SSI	Semi-Structured Interview
STI	Sexually Transmitted Infection
Swiss TPH	Swiss Tropical and Public Health Institute
T-HQ	Targeted Hazard Quotient
U5MR	Under 5 Mortality Rate
UHAS	University f Health And Allied Sciences
UN	United Nations
WASH	Water, Hygiene And Sanitation
WAZ	Weight-For-Age
WB	World Bank
WHO	World Health Organization
WHZ	Weight-For-Height

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Summary

Background: Over the past two decades, natural resource extraction has drastically increased in many world regions due to increasing demand for various commodities that the earth can provide, such as metals, minerals, gemstones, coal, oil and gas. For instance, metals and minerals are extracted for electronic devices, including batteries, with an exponentially increasing need, also because of the pressing transition to a low-carbon future. Sub-Saharan African (SSA) countries are among the most important producers of natural resources, currently hosting more than 2,000 mining projects, and many more are being planned. The implementation of industrial mining can come with significant local, regional and national economic growth. For instance, the construction stage of mining projects represents an opportunity for local communities to gain employment with a comparatively high salary. With increased socioeconomic status, communities can invest in other livelihood activities such as agriculture, fishery and trade. Income from mining employment can also allow people to access better health care and services for disease prevention.

However, in the scientific literature, many shortcomings of mining projects in mitigating their negative impacts on local communities and the environment have been described. This includes loss of agricultural land and resettlement of households, which can cause socioeconomic disruption with potentially profound consequences for the well-being and health of affected communities. Furthermore, rural communities may be transformed into small towns characterized by high population density and overcrowded housing conditions driven by job seekers in migrants. Job-seekers' arrival often leads to changing lifestyles, including altered dietary practices and commercial sex work, which pose new risks to public health in general, particularly to women and children living in mining areas.

Objectives: The overarching goal of this thesis was to assess the effect of mining projects on maternal, newborn and child health in SSA. The activities to work towards this goal pursued three specific objectives: (a) to provide a global overview of human health-related studies that have been carried out in ASM contexts, placing particular emphasis on those directly engaged in ASM activities, as well as those living within mining areas and surrounding populations; (b) to assess the effects of mining projects on child health in SSA and (c) to explore women and health professional´s perception on how mine have changed the occurrence and patterns of health conditions affecting women and child aged under-five years in communities hosting mine projects in Mozambique.

Research partnerships: The research is embedded in the “Health impact assessment for sustainable development” (HIA4SD) project. In the frame of this project, six PhD students researched different aspects of health in the context of natural resource extraction projects in different parts of SSA. The resulting evidence is then used to facilitate a policy dialogue that aims to strengthen the inclusion of health in impact assessment in the four project countries, namely Mozambique, Tanzania, Burkina Faso and Ghana.

Methods: Each specific objective applied a different methodological approach. Firstly, a systematic scoping review was conducted to map ever-investigated health aspects worldwide in artisanal and small-scale mining (ASM) contexts. This included a rigorous and systematic search in the readily available databases PubMed, Scopus and Web of Science. After systematic screening and selection of papers, 176 papers were included for final analysis. Secondly, for assessing the causal effect of the activation industrial mining project on child health indicators in SSA, we apply a quasi-experimental difference-in-difference design for analysing a combination of household and child data from the Demographic and Health Survey (DHS) dataset and historical mining data from SSA. Regression models were used for data analysis using STATA software. Thirdly, a descriptive qualitative research approach was pursued to understand how mining operations have changed the occurrence and patterns of health conditions affecting MCH. The data collected in four industrial mining areas in Mozambique was then coded using Nvivo for subsequent data analysis and interpretation.

Results: The screening of 176 health studies from 38 countries conducted in ASM communities showed that most health studies (n=155) were focused on health in ASM extracting gold. While different methods for investigating exposure and related health outcomes were revealed, studies focused primarily on collecting environmental and human samples (n=154). Of those, only a few (n=30) investigated infectious diseases such as malaria, Sexually Transmitted Infections (STIs) and HIV, and most importantly, vulnerable groups, such as women of reproductive age and children, deserved less attention. The merging of DHS data with data on industrial mines yielded 90,951 children entries from 81 mine sites launched in 23 SSA countries. Analysis showed that the launch of a new mining project lowers the likelihood of neonatal mortality by 45%, while declines in the risk for childhood diarrhoea (by 30%) were seen four years prior to extraction and increased odds for cough episodes (by almost 100%) was seen five years after the extraction onset. We found no evidence of mine openings and operations on child anthropometrics. Finally, based on the voices of 207 women and 15 MCH nurses living in close proximity to industrial mining in Mozambique, an array of maternal and child health conditions, including STIs and HIV/AIDS, gastrointestinal disorders, neurophysiologic, respiratory and cardiovascular, were perceived as resulting from mine exposure. The underlining factors were, overall, explained through various complex and interconnected mechanisms, including changes in individual, community, structural and environmental determinants of health. Mine-induced in-migration and changes in socioeconomic conditions were revealed to have a considerable role in the perceived impacts.

Conclusions and recommendations: Our findings reveal that, while there is limited evidence on the impact of ASM on maternal and child health, quantitative findings point to a positive impact on selected child health indicators; our analysis shows that the effect varies with the life stages of a mining project, with negative impacts arising in the later stage of mine operation. Economic gain during the first stage of mine operation may explain positive effects, but the accumulation of air pollution due to mine operation (e.g., through extraction and processing) can set off early benefits. Women and health professionals revealed an array of health conditions similar to those investigated around ASM communities.

Even though further research is warranted for a better understanding of the dynamics underlying mechanisms of impacts and to identify policies that can foster long-term positive health effects of mining activities, management of environmental degradation combined with strategic interventions targeting maternal and child health and specific needs of the affected communities are recommended. Further, the inclusion of MCH in the frame of Health Impact Assessments of large infrastructure developments (and other large economic developments) seems to be a critical path to follow for engaging mining projects to work jointly with the public sector towards the achievement of the Sustainable Development Goals (SDGs) of the 2030 Agenda of the United Nations.

Resumo

Contextualização: Nas últimas duas décadas, a extração de recursos naturais aumentou de forma drástica em muitos países do mundo, devido ao aumento da demanda por vários recursos que a terra pode fornecer como: metais, minerais, pedras preciosas, carvão, petróleo e gás.Por exemplo, metais e minérios são extraídos para dispositivos eletrônicos, incluindo baterias, com uma necessidade de uso crescente também por causa da urgente transição para um futuro de uso de baixo carbono. Os países da África Subsaariana (SSA) estão entre os mais importantes na produção de recursos naturais, actualmente contendo mais de 2.000 projectos de mineração e muitos outros em planeamento para o futuro.

A implementação de projectos de extração mineral pode ser acompanhado por um crescimento econômico importante ao nível local, regional e nacional. Por exemplo, a fase de construção do projecto de mineração representa uma oportunidade para as comunidades locais obterem empregos com um salário considerado alto comparando a outras àreas. Com o aumento do *status* socioeconómico, as comunidades podem investir em outras actividades de subsistência, como agricultura, pesca e comércio. A renda de empregos nos projectos de mineração também pode permitir que as pessoas tenham acesso a melhores cuidados de saúde e serviços para prevenção de doenças.

No entanto, a literatura científica evidenciou muitas dificuldades dos projectos de mineração na mitigação de seus impactos negativos nas comunidades locais e no meio ambiente. Isso inclui a perda de terras agrícolas e o reassentamento de famílias, podendo causar impactos socioeconómicos no bem-estar e a saúde das comunidades afetadas. Além disso, as comunidades rurais podem ser transformadas em pequenas cidades caracterizadas por uma alta densidade populacional e condições de habitação saturadas impulsionadas pela migração interna de pessoas à procura de emprego. A chegada de individuos a procura de emprego muitas vezes leva a mudanças no estilo de vida, incluindo práticas alimentares alteradas e prostituição, no qual representam novos riscos para a saúde pública em geral e, para mulheres e crianças que vivem em áreas de mineração em particular.

Objetivos: O objetivo geral desta tese foi de avaliar o impacto dos projetos de mineração na saúde materna e infantil em paises da ASS. As actividades desenvolvidas para o alcance deste objetivo, foram guiadas por três objectivos específicos: (a) fornecer uma visão geral dos estudos relacionados à saúde que foram realizados em contextos da mineração em pequena escala (ASM), colocando ênfase particular naqueles directamente envolvidos em actividades de ASM, bem como comunidades que vivem em áreas de mineração e em àreas vizinhas; (b) avaliar os efeitos dos projectos de mineração na saúde infantil na ASS e (c) explorar a percepção das mulheres e dos profissionais de saúde sobre mudanças nos padrões de

condições de saúde que afectam mulheres e crianças menores de cinco anos em comunidades que hospedam projetos de minas em Moçambique.

Parcerias de pesquisa: A pesquisa está incorporada no ambito projecto “Avaliação do impacto na saúde para o desenvolvimento sustentável” (HIA4SD). O projeto inclui seis alunos de doutoramento que realizaram pesquisas sobre diferentes aspectos em torno do tema saúde no contexto de projetos de extração de recursos naturais em paises da ASS. As evidências trasidas serão usadas para facilitar um diálogo político para fortalecer a inclusão da saúde na avaliação de impacto nos quatro países que fazem parte do projeto, nomeadamente Moçambique, Tanzânia, Burkina Faso e Gana.

Métodos: Cada objectivo específico conteve uma abordagem metodológica diferente. Em primeiro lugar, para mapear estudos que investigaram aspectos de saúde no contexto da mineração artesanal e de pequena escala (ASM) em todo o mundo, foi realizada uma revisão sistemática de literatura. Isso incluiu uma pesquisa rigorosa nas bases de dados prontamente disponíveis PubMed, Scopus e Web of Science. Após triagem sistemática e seleção de artigos, 176 artigos foram seleconados para análise final. Em segundo lugar, para avaliar os efeitos do projecto de mineração industrial de ativação nos indicadores de saúde infantil em SSA, aplicamos um projecto de diferença em diferença quase experimental para analisar uma combinação de dados dos agregados familiares e crianças colhidos na Pesquisa Demográfica e de Saúde e mineração histórica dados do SSA. Modelos de regressão foram usados para análise de dados usando o software STATA. Em terceiro lugar, para obter uma compreensão aprofundada de como as operações de mineração mudaram a ocorrência e os padrões de condições de saúde que afetam o MCH, foi realizada uma abordagem de pesquisa qualitativa descritiva. Os dados colhidos em quatro áreas de mineração em Moçambique foram então codificados usando o Nvivo para posterior análise e interpretação dos dados.

Resultados: A selecção de 176 estudos de saúde de 38 países realizados em comunidades ASM mostrou que a maioria dos estudos de saúde (n = 155) enfocou a saúde na extração de ouro da ASM. Embora diferentes métodos para investigar a exposição e os resultados de saúde relacionados tenham sido revelados, os estudos se concentraram principalmente na reclha de amostras ambientais e humanas (n = 154). Destes, apenas alguns (n = 30) investigaram doenças infecciosas como malária, infecções sexualmente transmissíveis e HIV e, o mais importante, grupos vulneráveis, como mulheres em idade reprodutiva e crianças, mereciam menos atenção. A fusão dos dados do DHS com as informações sobre as minas gerou dados de 90.951 crianças de 81 locais de minas lançados em 23 países da ASS. A análise mostrou que o lançamento de um novo projeto de mineração reduz a probabilidade de mortalidade neonatal em 45%, enquanto os declínios no risco de diarreia infantil (em 30%) foram observados 4 anos antes da extração e aumentaram as chances de episódios de tosse (em quase 100%) foi observada 5 anos após o início da extração. Não foram encontradas evidências de aberturas de minas e operação na antropometria infantil. Finalmente, com base nas vozes de 207 mulheres e 15 enfermeiras MCH que vivem nas proximidades da mineração industrial em Moçambique, uma série de condições de saúde materna e infantil, incluindo DST e HIV / AIDS, distúrbios gastrointestinais, neurofisiológicos, respiratórios e cardiovasculares, foram percebidos como resultado da exposição à mina. Os factores subjacentes foram, em geral, explicados por meio de vários mecanismos complexos e interligados, incluindo mudanças nos determinantes individuais, comunitários, estruturais e ambientais da saúde. A migração interna induzida por minas e as mudanças nas condições socioeconômicas revelaram ter um papel considerável nos impactos percebidos.

Conclusões e recomendações: Os resultados revelam que embora haja evidências limitadas sobre o impacto da ASM na saúde materno-infantil. Embora as descobertas quantitativas apontem para um impacto positivo nos indicadores de saúde infantil selecionados, nossa análise mostra que o efeito varia de acordo com as fases de vida de um projecto de mineração, com impactos negativos surgindo na fase posterior da operação da mina. O ganho econômico durante a primeira fase da operação da mina pode explicar os efeitos positivos, mas o acúmulo de poluição do ar devido à operação da mina (por exemplo, extração e processamento) pode preujudicar os benefícios iniciais. Uma série de condições de saúde foi revelada por mulheres e profissionais de saúde, que são semelhantes às investigadas em comunidades ASM.

Embora mais pesquisas sejam necessárias para melhor compreender a dinâmica subjacente aos mecanismos de impactos e identificação de políticas que podem promover o efeito positivo de longo prazo das actividades de mineração na saúde, gestão da degradação do meio ambiente combinado com intervenções estratégicas voltadas para a saúde materna e infantil e necessidades específicas das comunidades afetadas são recomendadas. Além disso, a inclusão de MCH no quadro de avaliações de impacto na saúde de grandes desenvolvimentos de infraestrutura parece um caminho importante a seguir para engajar projetos de mineração para trabalhar em conjunto com o sector público para o alcance dos Objetivos de Desenvolvimento Sustentável da Agenda 2030 das Nações Unidas.

Résumé

Contexte: Au cours des deux dernières décennies, l'extraction des ressources naturelles a considérablement augmenté dans de nombreuses régions du monde en raison de la demande croissante de divers produits que la terre peut fournir, tels que les métaux, les minéraux, les pierres précieuses, le charbon, le pétrole et le gaz. Par exemple, les métaux et les minéraux sont extraits pour les appareils électroniques, y compris les batteries, dont les besoins augmentent de façon exponentielle, également en raison de la transition urgente vers un avenir à faible émission de carbone. Les pays d'Afrique subsaharienne comptent parmi les plus importants producteurs de ressources naturelles, accueillant actuellement plus de 2 000 projets miniers, et de nombreux autres sont en cours de planification. La mise en œuvre de l'exploitation minière industrielle peut s'accompagner d'une croissance économique locale, régionale et nationale significative. Par exemple, la phase de construction des projets miniers représente une opportunité pour les communautés locales de trouver un emploi avec un salaire relativement élevé. Avec un statut socio-économique amélioré, les communautés peuvent investir dans d'autres activités de subsistance telles que l'agriculture, la pêche et le commerce. Les revenus tirés de l'emploi dans le secteur minier peuvent également permettre aux populations d'accéder à de meilleurs soins de santé et à des services de prévention des maladies.

Cependant, la littérature scientifique décrit de nombreuses lacunes dans l'atténuation des effets négatifs des projets miniers sur les communautés locales et l'environnement. Il s'agit notamment de la perte de terres agricoles et de la réinstallation de ménages, qui peuvent entraîner des perturbations socio-économiques susceptibles d'avoir des conséquences profondes sur le bien-être et la santé des communautés touchées. En outre, les communautés rurales peuvent se transformer en petites villes caractérisées par une forte densité de population et des conditions de logement surpeuplées en raison de la présence de migrants à la recherche d'un emploi. L'arrivée des demandeurs d'emploi entraîne souvent des changements de mode de vie, notamment une modification des habitudes alimentaires et le commerce du sexe, ce qui pose de nouveaux risques pour la santé publique en général, et en particulier pour les femmes et les enfants vivant dans les zones minières.

Objectifs: L'objectif principal de cette thèse était d'évaluer l'effet des projets miniers sur la santé maternelle, néonatale et infantile en Afrique subsaharienne. Les activités visant à atteindre ce but poursuivaient trois objectifs spécifiques : (a) fournir une vue d'ensemble des études liées à la santé humaine qui ont été menées dans des contextes d'ASM, en mettant particulièrement l'accent sur les personnes directement engagées dans les activités d'ASM, ainsi que sur celles qui vivent dans les zones minières et les populations environnantes ; (b)

évaluer les effets des projets miniers sur la santé des enfants en Afrique subsaharienne et (c) explorer la perception des femmes et des professionnels de la santé sur la façon dont les mines ont changé l'occurrence et les schémas des conditions de santé affectant les femmes et les enfants âgés de moins de cinq ans dans les communautés accueillant des projets miniers au Mozambique.

Partenariats de recherche: La recherche est intégrée au projet "Évaluation de l'impact sur la santé pour le développement durable" (HIA4SD). Dans le cadre de ce projet, six doctorants ont étudié différents aspects de la santé dans le contexte de projets d'extraction de ressources naturelles dans différentes parties de l'Afrique subsaharienne. Les résultats sont ensuite utilisés pour faciliter un dialogue politique visant à renforcer la prise en compte de la santé dans l'évaluation d'impact dans les quatre pays du projet, à savoir le Mozambique, la Tanzanie, le Burkina Faso et le Ghana.

Méthodes: Chaque objectif spécifique a fait l'objet d'une approche méthodologique différente. Tout d'abord, une étude systématique a été menée pour recenser les aspects sanitaires jamais étudiés dans le monde entier dans les contextes de l'exploitation minière artisanale et à petite échelle (ASM). Pour ce faire, une recherche rigoureuse et systématique a été effectuée dans les bases de données facilement accessibles PubMed, Scopus et Web of Science. Après une sélection systématique des articles, 176 articles ont été retenus pour l'analyse finale. Deuxièmement, pour évaluer l'effet causal du projet d'activation de l'exploitation minière industrielle sur les indicateurs de santé des enfants en Afrique subsaharienne, nous appliquons un modèle quasi-expérimental de différence dans la différence pour analyser une combinaison de données sur les ménages et les enfants provenant de l'enquête démographique et de santé (EDS) et de données historiques sur l'exploitation minière en Afrique subsaharienne. Des modèles de régression ont été utilisés pour l'analyse des données à l'aide du logiciel STATA. Troisièmement, une approche de recherche qualitative descriptive a été adoptée pour comprendre comment les opérations minières ont modifié l'occurrence et les schémas des conditions de santé affectant la santé maternelle et infantile. Les données recueillies dans quatre zones minières industrielles du Mozambique ont ensuite été codées à l'aide de Nvivo pour l'analyse et l'interprétation ultérieures des données.

Résultats: L'examen de 176 études sanitaires de 38 pays menées dans les communautés d'ASM a montré que la plupart des études sanitaires (n=155) étaient axées sur la santé des ASM qui extraient de l'or. Bien que différentes méthodes d'étude de l'exposition et des résultats sanitaires connexes aient été révélées, les études se sont principalement concentrées sur la collecte d'échantillons environnementaux et humains (n=154). Parmi ces études, seules quelques-unes (n=30) ont porté sur les maladies infectieuses telles que le paludisme, les infections sexuellement transmissibles (IST) et le VIH, et surtout, les groupes vulnérables, tels que les femmes en âge de procréer et les enfants, ont reçu moins d'attention. La fusion des données de l'enquête démographique et sanitaire et des données sur les mines industrielles a permis d'obtenir 90 951 entrées d'enfants provenant de 81 sites miniers lancés dans 23 pays d'Afrique subsaharienne. L'analyse a montré que le lancement d'un nouveau projet minier réduit de 45 % la probabilité de mortalité néonatale, tandis que le risque de diarrhée infantile diminue (de 30 %) quatre ans avant l'extraction et que le risque d'épisodes de toux augmente (de près de 100 %) cinq ans après le début de l'extraction. Nous n'avons trouvé aucune preuve de l'influence des ouvertures de mines et des opérations sur l'anthropométrie des enfants. Enfin, d'après les témoignages de 207 femmes et de 15 infirmières en santé maternelle et infantile vivant à proximité d'une mine industrielle au Mozambique, toute une série de problèmes de santé maternelle et infantile, y compris les IST et le VIH/SIDA, les troubles gastro-intestinaux, neurophysiologiques, respiratoires et cardiovasculaires, ont été perçus comme résultant de l'exposition à la mine. Dans l'ensemble, les facteurs sous-jacents ont été expliqués par divers mécanismes complexes et interconnectés, y compris des changements dans les déterminants individuels, communautaires, structurels et environnementaux de la santé. L'émigration induite par les mines et les changements dans les conditions socio-économiques se sont révélés jouer un rôle considérable dans les impacts perçus.

Conclusions et recommandations: Nos résultats révèlent que, bien qu'il y ait peu de preuves de l'impact de l'ASM sur la santé maternelle et infantile, les résultats quantitatifs indiquent un impact positif sur certains indicateurs de santé infantile ; notre analyse montre que l'effet varie en fonction des étapes de la vie d'un projet minier, les impacts négatifs apparaissant dans les dernières étapes de l'exploitation de la mine. Les gains économiques réalisés au cours de la première phase d'exploitation de la mine peuvent expliquer les effets positifs, mais l'accumulation de la pollution atmosphérique due à l'exploitation de la mine (par exemple, au cours de l'extraction et du traitement) peut annuler les premiers avantages. Les femmes et les professionnels de la santé ont révélé un éventail de problèmes de santé similaires à ceux étudiés dans les communautés d'ASM.

Même si des recherches supplémentaires sont nécessaires pour mieux comprendre la dynamique qui sous-tend les mécanismes d'impact et pour identifier les politiques susceptibles de favoriser les effets positifs à long terme des activités minières sur la santé, il est recommandé de gérer la dégradation de l'environnement et de mettre en place des interventions stratégiques ciblant la santé maternelle et infantile et les besoins spécifiques des communautés touchées. En outre, l'inclusion de la santé maternelle et infantile dans le cadre des évaluations d'impact sur la santé des grands développements d'infrastructures (et d'autres grands développements économiques) semble être une voie critique à suivre pour inciter les projets miniers à travailler conjointement avec le secteur public en vue de la réalisation des objectifs de développement durable (ODD) de l'Agenda 2030 des Nations unies.

1 Introduction

This PhD thesis seeks to provide a general understanding of “how natural resource extraction projects (NAtural Resource Extraction Projects) affects maternal, new-born and child health” in resource extraction settings. This project was framed and pursued as part of a large ongoing, mixed-methods research project entitled “Health Impact Assessment for Engaging Natural Resource Extraction Projects in Sustainable Development in Producer Regions” (henceforth referred to as HIA4SD project) (Winkler et al., 2020a). The generated evidence will promote policy dialogue on strengthening Health Impact Assessment (HIA) in Mozambique, Tanzania, Burkina Faso, and Ghana and, in a later stage, in sub-Saharan Africa (SSA) and contribute to the conception of tools to foster the achievement of health-related targets of the SDG 2030 agenda. Based on this project research, also the health of women and children will be an essential aspect of the policy dialogue promoted under the second phase of the HIA4SD project, in addition to making an important contribution to the scientific literature on the associations between natural resource extraction activities and the health of specific population groups.

1.1 Natural resource extraction in sub-Saharan Africa

1.1.1 Historic remarks

Human history has always been closely linked to controlling, extracting, and using natural resources such as metals, stones, coal, minerals, gas, oil, water, and timber (Behrens et al., 2007). Since the beginning of recorded history, natural resource extraction (e.g., ancient gold mining) in southern and eastern Africa was undertaken through artisanal mining and associated with East Coast trade (Huffman, 1974). During colonization, mining reached an industrial scale and provided employment for local people (Huffman, 1974; Dondeyne et al., 2009). Today, natural resource extraction activities are performed through both artisanal and small-scale mining (ASM) and by large-scale extractive industries (henceforth referred to as industrial mining projects), and the resources extraction methods range from the mining of minerals and metals over oil drilling to logging (Frickel & Freudenburg, 1996).

Technological advancements and the need to meet the rapidly growing demands for food, fresh water, fibre, minerals and fuel at the local and international level have led to the discovery of new deposits of a range of resources over the past five decades (Jim, 2007). Consequently, the natural resources extraction sector has been booming, particularly in SSA countries, changing the ecosystems more rapidly and extensively than in any comparable period in human history. Today, SSA endows more than 2,000 industrial mining projects, and many more are planned, also because the demand for specific metals is projected to increase under the scenario of a low carbon future (Arrobas et al., 2017; Projects IQ, 2019; Standard & Poor's Global, 2020). **Figure 1** illustrates the type and location of industrial mining projects across SSA countries. In addition to industrial mining, other Natural Resource Extraction Projects, such as oil and gas projects, are being developed and operated.

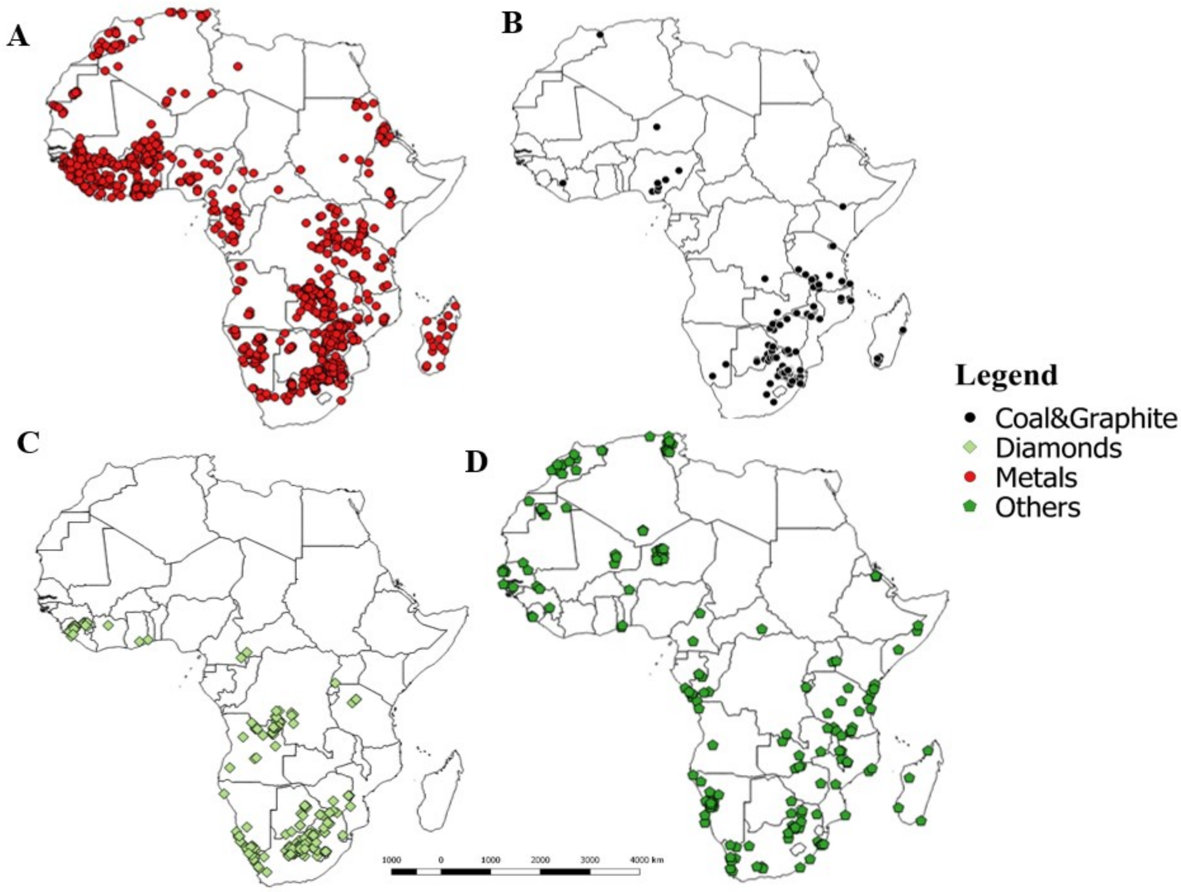

Figure 1. Location of ongoing large industrial mining projects in SSA countries by type of primary extracted resources. Panel A, Minerals; Panel B, Coal and Graphite; Pane C, Gemstones and Panel D, Other Commodities.

1.1.2 Resource extraction, economic growth, and public health

Most residents and leaders of rural regions in SSA in low- and middle-income countries (LMICs) believe that extracting natural resources can be an antidote to regional poverty (Frickel & Freudenburg, 1996). This belief is based on the fact that the extractive sector has excellent potential to contribute to national economic development (Aragón et al., 2015; Chuhan-Pole et al., 2017). Indeed, ASM is recognized to be more beneficial for the “poorest sections” of society (Dondeyne et al., 2009; Hilson & Maconachie, 2020; Hirons, 2020). This recognition is based on the fact that the livelihoods of an estimated 80-150 million people over the world are somehow dependent on ASM, of which more than 40 million people are artisanal miners, a ten-fold employment rate when compared to industrial mining projects (Buxton, 2013; Levin-Nally, 2014; Artisanalmining.org, 2018). Therefore, ASM was found to reduce poverty in many settings, primarily across SSA countries (Fisher et al., 2009; Hilson, 2009; Siegel & Veiga, 2009).

Beyond the potential benefits of ASM activities, a large body of scientific literature points to local and regional economic growth driven by the implementation of industrial mining projects (McMahon & Moreira, 2014; Aragón et al., 2015; Chuhan-Pole et al., 2017). Indeed, it has been found that women living in close proximity to industrial mining projects tend to be more empowered; i.e., women have better jobs opportunities and good salaries and are less likely to accept domestic violence (Tolonen, 2014; Kotsadam & Tolonen, 2016). This economic gain can be translated into higher food security, better nutrition, improved housing, education, and access to health care, particularly for women of reproductive age and young children (Kotsadam & Tolonen, 2016; Chuhan-Pole et al., 2017; Dietler et al., 2021b). In addition, mining-related interventions such as corporate social responsibility (CSR) have often contributed to local development by, for example, increasing access to drinking water and sanitation for local communities with better and modern infrastructures (Kemp et al., 2010; Admiraal et al., 2017; Dietler et al., 2021a).

However, the evidence on translating economic benefits into health gains is controversial. On the one hand, it was shown that local economic growth and development could decrease the incidence of malnutrition (Romero & Saavedra, 2016; von der Goltz & Barnwal, 2019), diarrhoeal and respiratory diseases (Fewtrell et al., 2005; Chuhan-Pole et al., 2017) and other environment-related health conditions, particularly in young children (Dietler et al., 2021b). Further, women tend to have better education and more access to health care and, thus, a lower fertility rate, which may contribute to increased child survival (Grytten et al., 2014; Chuhan-Pole et al., 2017; Benshaul-Tolonen, 2018). On the other hand, natural resource-rich countries in Africa tend to have a lower average life expectancy and higher maternal and child morbidity and mortality rates than non-natural resource-rich countries with equivalent incomes (African Development Bank (AfDB) & Bill & Melinda Gates Foundation (BMGF), 2015b, 2015a). Many factors potentially contribute to these adverse effects of industrial mining: (i) ASM is expanding rapidly and in an uncontrolled way, employing large numbers of women and children in an environment with no security and health precaution measures (Organization, 1999; Dondeyne et al., 2009; Hilson, 2009; Levin-Nally, 2014); (ii) adverse environmental impacts such as air, water, and land pollution are often abundant (Dondeyne et al., 2009; Hilson, 2009; Buxton, 2013) leading to the loss of biodiversity (Bridge, 2004; Ostfeld, 2017; Mabey et al., 2020) in such way that (iii) mine workers as well the surrounding communities are often exposed to hazardous emissions and vector- and non-vector related diseases (Behrens et al., 2007; Stuckler et al., 2011; Ostfeld, 2017). Furthermore, job-seeking-related in-migration and rapid urbanisation are known characteristics of communities impacted by resource extraction activities, overburdening public services[1] and triggering inception of (overcrowded) informal settlements (Marais et al., 2018; Pelders & Nelson, 2018). This dynamic can increase the incidence of respiratory and sexually transmitted diseases, including HIV/AIDS (Goldenberg et al., 2008; Stuckler et al., 2011; Smith-Greenaway & Madhavan, 2015; Westwood & Orenstein, 2016). This situation can also threaten the health and wellbeing of indigenous communities due to competition for insufficient local resources or even the surge of (armed) conflicts (Berman et al., 2017; Mabey et al., 2020).

1.2 Maternal and child health (MCH) – Definitions

According to the World Health Organization (WHO) definition, women of reproductive age include those aged between 15 and 49 years (World Health Organization, 2015). Further, the United Nations (UN) Inter-Agency Group for Child Mortality Estimation (UN IGME) (2020) use the term “child” to refer to a person aged less than 15 years (i.e., 0-14 years) (United Nations Inter-agency Group for Child Mortality Estimation, 2020). However, in the present thesis, the term “maternal, newborn, and child health” will refer to the health of mothers and children under five years, including those in the neonatal period.

The scientific literature offers different definitions of Maternal and child health (MCH), each with specific perspectives. Usually, maternal health refers to the wellbeing of pregnant women, including health care for the woman and child during the prenatal, childbirth, and post-partum[2] period (Nhatave, 2006; World Health Organization, 2018a). A broader concept of child health embraces three main aspects: developing potential, capacities, and need satisfactions to allow them to ‘interact successfully with their biological, physical and social environments’ (Council & Medicine, 2004). According to Belsey (2010), `maternal and child health (MCH) includes the broad meaning of health promotion and preventive, curative and rehabilitative health care for mothers and children (Belsey, 2010).

The WHO (2018) notes that ‘while motherhood is often a positive and fulfilling experience, for too many women it is associated with suffering, ill-health, and even death’; hence, it is a crucial period for the health of women and children worldwide (World Health Organization, 2018a). The WHO Expert Committee on Maternal and Child Health (WHO-ECMCH) states that the status of MCH is assessed through measurements of morbidity, mortality, growth, and development (World Health Organization, 1976). Thus, maternal morbidity includes a broad range of illnesses, disabilities, or poor health conditions in consequence of, or aggravated by, pregnancy and/or childbirth with a negative effect on the health outcomes of mothers (Filippi

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[1] Including health care facilities, water and sanitation infrastructures.

[2] Up to 42 days after delivery World Health Organization. (2018a, 2021). *Maternal Health - Overview*. World Health Organization (WHO). Retrieved 18 February 2018 from http://www.who.int/maternal-health/en/

et al., 2016). Maternal mortality is specified as the "death of a woman during pregnancy, childbirth or within 42 days of the end of pregnancy, regardless of the duration and site of the pregnancy, from any cause related to or aggravated by the pregnancy or its management, but not from accidental or incidental causes" (World Health Organization, 2012; Filippi et al., 2016).

1.3 Maternal and child health: trends, causes and risk factors

Over the past two decades, the world has witnessed a dramatic improvement in maternal and child health (World Health Organization, 2021a). For instance, between 2000 and 2017, maternal and under-five mortality rates dropped by more than 38% and 55%, respectively (World Health Organization, 2021a). This progress, however, is unequally distributed across regions and countries, with LMICs lagging behind (Liu et al., 2016; Sharrow et al., 2020; World Health Organization, 2021a). In 2017, more than half of global under-five and 94% of maternal deaths occurred in SSA, where curable diseases such as diarrhoea and respiratory disorders remain the major killers of young children (Liu et al., 2016; Chuhan-Pole et al., 2017; World Health Organization, 2021a).

1.3.1 Causes and ricks for poor maternal health in SSA

Generally, it is argued that most women die due to complications during and following pregnancy and childbirth (World Health Organization, 2016b, 2016a).Causes of maternal deaths are classified as direct obstetric deaths[3] and indirect obstetric deaths[4] (World Health Organization, 2012). Indirect and direct causes accounted for 73% and 27.1% of all maternal deaths between 2003 and 2009, respectively (Say et al., 2014; Filippi et al., 2016; Akker et al., 2017). Most notable are non-pregnancy-related but curable or treatable infections such as sexually transmitted infections (STIs) and HIV/AIDS, tuberculosis, malaria, adult febrile illness, viral hepatitis and neglected tropical diseases (Menendez et al., 2008; Timofeev et al., 2013; Say et al., 2014; Filippi et al., 2016).

The most common determinants that affect maternal health include individual non-medical factors such as age, parity, unintended pregnancies, marital status, women's education, ethnicity and religion, poverty, household income, obesity, other nutritional factors, and past obstetric history; social and economic factors, including women's empowerment, availability of reproductive health services[5], abortion regulation, and conflict; and physical environment[6] and health systems characteristics such as availability of trained health professionals and

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[3] Deaths resulting from the obstetric complications of pregnancy, interventions, omissions, incorrect treatment, or a chain of events resulting from any of the above

[4] Deaths resulting from a previous existing disease, or disease that developed during pregnancy that was not due to direct obstetric causes but was aggravated by physiological effects of pregnancy

[5] Includes traditional health services

[6] Including transportation network, rapid urbanization, water and sanitation, and quality of care and accountability

health facilities (World Health Organization, 2015; Filippi et al., 2016). Scientific evidence supports the hypothesis that maternal morbidity increases in settings with low antenatal and postnatal care coverage and lack of skilled birth attendance (Alvarez et al., 2009; Girum & Wasie, 2017).

1.3.2 Causes and ricks for poor child health in SSA

Age-specific mortality shows that children are more vulnerable to dying during the first 28 days of life – the neonatal period, particularly during the first week (Sharrow et al., 2020; United Nations Inter-agency Group for Child Mortality Estimation, 2020). The leading causes of child death are infectious diseases (51.8%), including pneumonia, sepsis, meningitis, diarrhoea, malaria, and HIV/AIDS infections (Liu et al., 2016; Institute of Health Metrics and Evaluation (IHME), 2019). These are followed by other medical conditions such as neonatal complications (44%), preterm birth complications (15.4%), intrapartum-related complications (10.5%), injuries (5.5%) and congenital disorders (4.9%) (Li et al., 2015; World Health Organization, 2021a). In addition, malnutrition also plays an essential role in the incidence of diarrhoeal diseases in children aged under-five, thus increasing the mortality rate (Walker et al., 2013; Liu et al., 2016; Chuhan-Pole et al., 2017; World Health Organization, 2021a).

Several studies have found that child health is more likely to be poor in environments with some degree of degradation, including unsafe drinking water, poor sanitation and hygiene, and air pollution (Binka et al., 1995; Sacarlal et al., 2009; Liu et al., 2016). Child health is also liked to the mother's education, place of living, household economic status, and ethnic belonging (Brockerhoff & Hewett, 2000; Rutherford et al., 2010; Niragire et al., 2017). Further, maternal health-seeking behaviour and fertility have a significant role in children´s health. For instance, absence or low uptake of antenatal and postnatal care, delivery out of health facility, and short preceding birth intervals often result in complications during pregnancy and labour (Mavalankar et al., 1991; Brockerhoff & Hewett, 2000; Niragire et al., 2017), mainly when women is malnourished with poor access to adequate health care such as attendance by skilled health professionals (Rutherford et al., 2010).

1.4 Resource extraction, MCH, and the Sustainable Development Goals (SDGs)

Health is a beneficiary of, and contributor to, development and wellbeing (i.e., *material, psychological, social, cultural, educational, work, environmental, political, and personal security*) and hence, central to the three dimensions of sustainable development: (i) the environment, (ii) society and (iii) economy (United Nations, 2015b). The United Nations (UN) developed two key frameworks aiming to promote human wellbeing and sustainable development: the Millennium Development Goals (MDGs) in the year 2000, followed by the Sustainable Development Goals (SDGs) in the year 2015 (United Nations, 2015b).

The MDG targets of "*improve maternal health*" (MDG 5) and to "*reduce child mortality by two-thirds*, between 1990 and 2015" (MDG 4) remain unmet, particularly in African, South-East Asia, and Eastern Mediterranean regions despite significant progress (Boerma, 2015; World Health Organization, 2015). For instance, substantial improvement was achieved worldwide during the MDG era (1990-2015), with the number of maternal deaths per 100 000 live births (i.e., the maternal mortality ratio, MMR) declining by 44% and the number of deaths of children aged below five years per 1000 live births (i.e., under-five mortality rate, U5MR) reducing by 56% (estimates of U5MR are from 1990-2016) (World Health Organization, 2015; United Nations Inter-agency Group for Child Mortality Estimation, 2020).

Although the knowledge and technologies for life-saving interventions are available, the survival of mothers and children remains a matter of urgent concern. Recent estimates indicate that, as of 2020, more than 800 women were dying each day from preventable causes related to pregnancy and childbirth, and 15,000 children under age five die every day (46% in the first month of life), mostly from preventable causes and treatable diseases (United Nations Children's Fund, 2019; United Nations Inter-agency Group for Child Mortality Estimation, 2020). These facts highlight the need for continued focus on MCH in the SDGs and substantial effort during the upcoming decade (United Nations Inter-agency Group for Child Mortality Estimation, 2020).

With 17 goals and 169 targets, health is embodied in one SDG-specific goal (SDG3, "*ensure healthy lives and promote wellbeing for all at all ages"*) comprised of 13 targets for health, of which two are specific for MCH: "*By 2030, reduce the global maternal mortality ratio to less than 70 per 100,000 live births*" (SDG 3.1) and "*By 2030, end preventable deaths of new-borns and children under five years of age, with all countries aiming to reduce neonatal mortality to at least as low as 12 per 1,000 live births and under-5 mortality to at least as low as 25 per 1,000 live births*" (SDG 3.2) (Boerma, 2015; United Nations, 2015b).

As seen in the previous sub-chapter, various determinants of MCH are included in other SDGs' goals. For instance, SDG1 (*no poverty*), SDG2 (*zero hunger*), SDG4 (*quality education*), SDG6 (*clean water and sanitation*), SDG8 (*employment and economic growth*), SDG11 (*sustainable cities and communities*) and SDG16 (*peace, justice and strong institutions*) specifically act on key determinants of health including SDG5 (*gender equity*) and SDG10 (*reduce inequalities*) directly link to universal health equity (United Nations, 2014). Together the SDGs embrace 29 health-related targets and a more significant number of specified measurable indicators (United Nations, 2014).

However, These MCH determinants are still more prevalent in LMICs, including natural resources-rich regions such as SSA countries (von der Goltz & Barnwal, 2019). Thus, it seems still ambitious for African countries to achieve the 2030 Agenda of the Sustainable Development Goal (SDG) related to maternal and child health (United Nations, 2015a).

On the other hand, it is well known that large-scale extraction of natural resources such as metals and minerals plays a fundamental role in the economic growth of LMICs; as a consequence, it represents an unprecedented opportunity window for leveraging Africa, particularly SSA, which holds a third of it, toward better health quality for young children (Frickel & Freudenburg, 1996; Arrobas et al., 2017).

1.5 MCH in the natural resource extraction context

The interlinkage between industrial mining projects (including oil/gas and hydropower) and maternal health is illustrated in **Figure 2**. The figure shows that industrial mining can affect maternal and child health outcomes through distal and proximal channels. This chapter will describe channels by which mining activities affect MCH locally and nationally, emphasising negative and positive impacts.

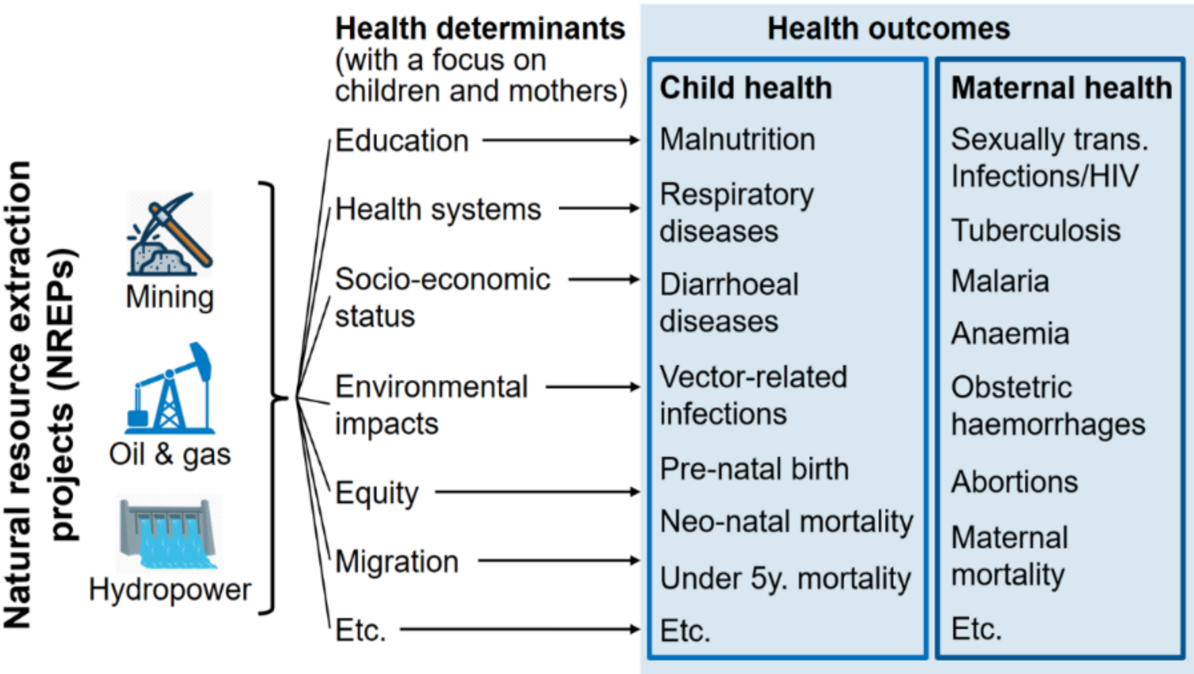

Figure 2. Associations between NAtural Resource Extraction Project, MCH-related determinants and health outcomes.

1.5.1 Positive mine-induced MCH outcomes

Extractive activities have the positive potential to act on maternal and child health and wellbeing positively. At the local level, mines can make women more empowered by reducing gender inequality and discrimination through job creation targeting women (see **Figure 2**), both directly – in the mining sector - and indirectly – by creating economic projects along with technical and financial support (Tolonen, 2014; Andersson et al., 2015; Tolonen, 2018; Kenmare Resources plc (KMR), 2020). With regular income, women can invest in their siblings, including health care access and disease prevention actions, buy a better house and housing conditions, access to clean drinking water and good sanitation and access to education and better and nutritious food (McMahon & Moreira, 2014; Tolonen, 2014; Chichester et al., 2017; Kenmare Resources plc (KMR), 2020). As a consequence, childhood survival can increase due to reduced risk for morbidities such as diarrhoea and respiratory infections and a decrease in childhood malnutrition rate (Benshaul-Tolonen, 2018; von der Goltz & Barnwal, 2019; Dietler et al., 2021a; Dietler et al., 2021b). With more children surviving per woman, mining projects positively impact well-being (United Nations Children's Fund, 2015; Smith-Greenaway et al., 2021).

Empowered women can also make decisions on their own. For example, Tolonen (2014) found that women living in close proximity to active gold mining projects are less likely to state a barrier to health care access for themselves and accept domestic violence (Tolonen, 2014). At the same time, the reduced barriers to health care access can render better obstetric outcomes and, thus, improved health for women (Mushi et al., 2010; Adisasmita et al., 2015; Hanson et al., 2015; Romero & Saavedra, 2016). In addition, public-private partnerships can synergise efforts for disease control and elimination programmes for strengthening local health systems, foster good health by improving access to health care, and ultimately improve maternal and child health indicators such as mortality (Fernandes et al., 2014; African Development Bank (AfDB) & Bill & Melinda Gates Foundation (BMGF), 2015a; Winkler et al., 2019).

At the national level, MCH can be improved through indirect channels. For example, mine-generated revenues[7] for governments are available for public spending such as investment in upgrading or building infrastructure (e.g., roads in remote areas connecting people to the rest of the country), schools for better education, health facilities for better health care and improving access to clean water and sanitation (African Development Bank (AfDB) & Bill & Melinda Gates Foundation (BMGF), 2015b, 2015c). Further, mine projects can also act on social activities (social protection) and economic diversification strategies (African Development Bank (AfDB) & Bill & Melinda Gates Foundation (BMGF), 2015c). It can convert poverty-stricken, marginalised communities and workforce into economically grounded communities and directly address local maternal and child health (Thukral et al., 2010).

1.5.2 Negative mine-induced MCH outcomes

While positive health outcomes for women and young children are thought to be driven by local and national economies resulting from mining investments (Polat et al., 2014; Aragón et

[7] taxes, royalties and profit share

al., 2015; Chuhan-Pole et al., 2017), adverse effects on social and environmental determinants can offset such benefits. The potential impacts of industrial mining projects on MCH-related determinants of health and associated health outcomes are manifold, as illustrated in **Figure 2**. For example, mining-induced environmental changes (air, land and water pollution) and the degradation of capital resource (i.e., loss of biodiversity, forest and minerals), in combination with changing ecosystems, has resulted in altered patterns of vector-related diseases, increased exposure to hazardous emissions and adverse effects on women's mental health and child well-being (International Labour Organization (ILO), 1999; Thukral et al., 2010; Drace et al., 2012; Hebert et al., 2012).

In addition, project-induced in-migration can strain local health systems, sanitation and water systems and food security and, thus, increase the malnutrition rate (International Finance Corporation, 2009b; Thukral et al., 2010; Dietler et al., 2020a). Mining implementation is a disruptive process that interferes with women's economic well-being, social networks, and ultimately poor health-seeking behaviours (Brasier et al., 2011; Smith-Greenaway & Madhavan, 2015). Evidence shows that insufficient stakeholder involvement, poor impact assessment (e.g., limited inclusion of health aspects) and adverse project-related impacts can lead to local (armed) conflict and injustice, increased women and children's vulnerability to exploitation and abuse, and violation of children's rights to education (International Labour Organization (ILO), 1999; Thukral et al., 2010; Berman et al., 2017; Dietler et al., 2020b). In mining settings, the displacement due to land alienation often makes women struggle to access essential services such as education and healthcare, and thus increases the risk for MCH morbidity and mortality, particularly among the poorest and most vulnerable fraction of society (Le Billon, 2001; Macassa et al., 2003; Wigley, 2017; Zvarivadza, 2018b).

1.6 Impact assessments

To overcome the anthropogenic and environmental pressures induced by resource extraction projects and any other large infrastructure projects, almost all countries globally have established a legal requirement that an environmental impact assessment (EIA) must be done prior to the implementation of a large development project in order to minimize adverse consequences on the environment, society, and public health while promoting the development of sustainable infrastructures and resource extraction projects (Burton et al., 1983).

In contrast to EIA, only a few countries have established a legal requirement for other forms of impact assessment, such as social impact assessment (SIA), health impact assessment (HIA), and human rights impact assessment (HRIA), which have – at least partially – arisen through discontent with EIA practice (Harris-Roxas et al., 2012; Krieger et al., 2012; Salcito et al., 2015). A publication by Winker and colleagues (2013) showed that, in the absence of an external project requirement, HIA is missing from the program and policy arena in almost all low-HDI countries (Winkler et al., 2013). **Figure 3** shows that this holds particularly true for Africa, where not a single country actively promotes HIA through a policy, regulation, or another means of endorsement (Winkler et al., 2013; Leuenberger et al., 2019). Furthermore, the EIA of industrial mining projects in Africa is generally driven by the environmental sector, with a poor methodological approach, while the health sector and other sectors are insufficiently involved (Steinemann, 2000; Harris et al., 2009; Harris et al., 2015b; Winkler et al., 2020a).

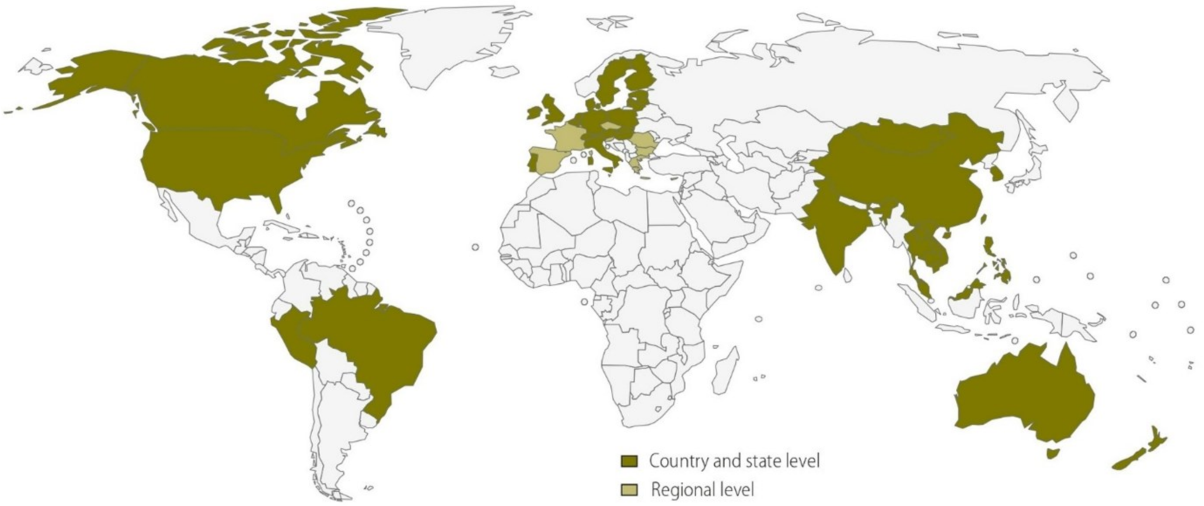

Figure 3. Countries, states, and regions that are actively promoting Health Impact Assessment (HIA) through a policy or regulation. Source: (Winkler et al., 2013).

Beyond environmental impacts, health is a highly dynamic topic in the context of NAtural Resource Extraction Project. If potential negative impacts are not appropriately mitigated, they pose a particular risk to public health (Winkler et al., 2012b). Hence, there is a clear need for a prospective health risk management approach, such as HIA (Singer & de Castro, 2007). Guidelines for conducting HIA of large infrastructure development projects have been developed by the International Finance Cooperation (IFC) (International Finance Corporation, 2009b, 2009a) and other non-governmental bodies, such as the Asian Development Bank (ADB) (Asian Development Bank, 2018), the World Bank (WB) (The World Bank, 2017) and the World Health Organization (WHO) (World Health Organization, 2022).

Although there are several challenges (Harris et al., 2015a), impact assessment can also be conducted as an integrated approach of both EIA and HIA; however, including health, particularly of MCH, into EIA seems more promising in strengthening impact assessment as already established at the country level (Winkler et al., 2013). Evidence shows that MCH is poorly addressed in impact assessment with as few as three related indicators –child immunization, maternal mortality, and child mortality - found to be commonly included in impact assessment reports of industrial mining in SSA countries (Leuenberger et al., 2019; Dietler et al., 2020b).

1.7 Research needs or identified knowledge gaps

There is a substantial body of literature providing insights into opportunities and risks for public health associated with the implementation of resource extraction activities, as well as underlining mitigation strategies to prevent and minimize associated negative effects (Shandro et al., 2009; Drace et al., 2012; Male et al., 2013). Nevertheless, most of the research on resource extraction and health fails to describe specific causes for child mortality and morbidity that are directly and/or indirectly linked with natural resource extraction activities (Moodie et al., 2013; Basu et al., 2015; Long et al., 2015; Brisbois et al., 2019). Based on this background, it is clear that there is a pressing need to understand better how and when industrial mining projects affect maternal and child health. Such shreds of evidence can inform policy and decision-making at the national and regional levels in order to engage mine projects toward the achievement of the SDG 2030 targets.

While other forms of extracting natural resources, such as artisanal and small-scale, are widespread and ensure livelihood for many people across the globe, they are often linked to many adverse environmental and health issues. Thus, scientific opinion on whether ASM can foster the countries achieving the SDG 2030 targets is controversial (Hirons, 2020). Hence, a holistic understanding of what health issues have been investigated in ASM communities is warranted to trigger specific research and identify strategies for transforming the ASM sector into a strong partner for sustainable development is warranted.

The increasing presence of extractive industries in Africa opens windows for many health challenges within the social and environmental health domain (African Development Bank (AfDB) & Bill & Melinda Gates Foundation (BMGF), 2015c) but also presents an opportunity to promote maternal and child health through public-private partnerships. However, little is still known about how the establishment of industrial mining effect MCH. Further, our current understanding of the association between mining projects and maternal and child health comes from quantitative studies that often rely on secondary data analysis, which uses modelling approaches. Hence, research focused on primary, hands-on experienced voices on how mining projects affect the health of the mining-hosting community, particularly for women and children aged under-five years, is warranted. Understanding the underlying factors, the mechanism of action, and the root causes determining health is vital for effective health promotion in settings with unique characteristics, such as mine-affected communities.

1.8 Objectives of the PhD project

This thesis aimed to investigate the associations between natural resource extraction projects and maternal and child health in sub-Saharan Africa. The activities to work towards this goal are divided into three specific objectives:

- *Specific objective 1* – to provide a global overview of human health-related studies that have been carried out in ASM contexts, placing particular emphasis on those directly engaged in ASM activities, as well as those living within mining areas and surrounding populations.
- *Specific objective 2* – to assess the effects of mining projects on child health in sub-Saharan Africa
- Specific objective 3: to explore women's and health professional´s perceptions on how industrial mining has changed the occurrence and patterns of health conditions affecting women and children aged under-five years in communities hosting mine projects in Mozambique

1.9 Methods: general description

This PhD thesis is nested in the framework of the HIA4SD (https://hia4sd.net/), a multi-centric, multi-phase, and multidisciplinary research project funded under the Swiss Program for Research on Global Issues for Development (r4d Programme; www.r4d.ch). Within six years, six partner research institutions, including two coordinating in Switzerland and four implementing in Africa, joined a project consortium and conducted research primarily in large-scale ming project settings to analyze the conditions under which impact assessments are an effective regulatory mechanism to engage natural resources extraction projects in working towards the health-related targets of the SDG 2030 agenda in the four sub-Saharan countries named above (Farnham et al., 2020; Winkler et al., 2020a).

Within each institute, PhD candidates were selected to pursue research under the HIA4SD project: two at the Swiss Tropical and Public Health Institute (SwissTPH), Switzerland, and one in each African institute, namely: Manhica Health Research Center (CISM), Mozambique; University of Health and Allied Sciences (UHAS), Ghana; Research Institute of Health Sciences (IRSS), Burkina Faso; Ifakara Health Institute (IHI), Tanzania. The sixth institution - the Center for Development and Corporation (NADEL), Switzerland, join as a co-coordinating partner. As a result, six complementary thematic areas were developed, composing the primary building block of the first phase of the project – 2017-2020 – aiming to generate scientific evidence about various issues of health in industrial mining settings across SSA countries with a significant focus on the four African countries pertaining each research partner institute. The current work of this thesis addresses maternal and child health in communities hosting mine projects (**Figure 4**). The second phase of the project – 2020-2023 – will mainly consist of a policy dialogue informed by the shreds of evidence generated under the first phase. The dialogue aims to foster the institutionalization of HIA in the project partner countries and the Sub Sahara Africa.

This thesis addresses the first objective by conducting a systematic scoping review, including peer-reviewed literature investigating health issues in Artisanal and Small-scale mining communities worldwide (see Chapter 2).

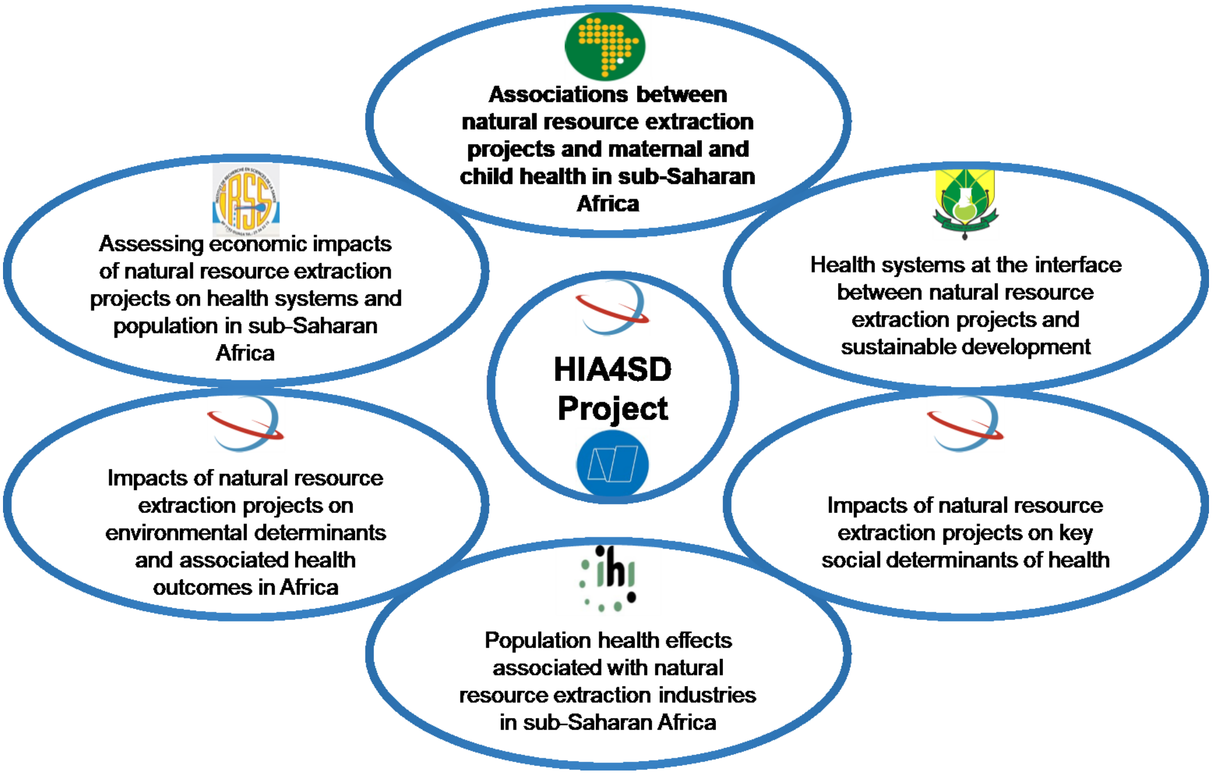

Figure 4. Thematic approaches were building the backbone of the HIA4SD project in the first phase.

A quantitative study was conducted aiming to address the second objective. For this purpose, historical mining data from the Standard & Poor's Global Market Intelligence Mining Database comprising of location, operational status, and other characteristics of the mines in SSA (Standard & Poor's Global, 2020) with Child and household data from the Demographic and Health Survey program (Demographic and Health Survey (DHS), 2021), from which select household and child data located around isolated mines (at least 20 km from each other) where combined. The constructed dataset for this research allowed for conducting an assessment of the impact of industrial mining projects on child health across SSA countries (see Chapter 3).

In order to get more insights into the mechanisms into which industrial mining projects affect maternal and child health, an exploration of women's and health professional´s perception of how mining have changed the occurrence and patterns of health conditions affecting women and child in communities hosting mine projects in Mozambique using qualitative approaches. Participatory Focus Group Discussions (FGDs) and Semi-Structured Interviews (SSIs) were used to collect data in four districts hosting coal, heavy sands, and Ruby mining companies. It is important to stress that besides Mozambique, data was collected in three other African countries involving the six PhD students. To pursue this, the core team of the HIA4SD project jointly developed a data collection manual compromising the different data collection tools pertaining to the different research topics (**Figure 4**). A thematic analysis based on verbatim transcripts of the FGDs and Interviews was conducted to address the third objective (Gale et al., 2013) (see Chapter 4).

Further, the analysis and interpretation of the research findings from this systematic mixed-method approach (i.e., HI4SD project) are possible using the triangulation technique involving findings from all six PhD students. Thus, there are several additional publications to which this PhD project contributed (see **Table 1**), in addition to the three primary papers of this PhD thesis.

Table 1. List of publications for which the PhD candidate has been the leading author or co-author.

Title	Chapter	Journal	Year	Role	Status
Health Studies in The Context of Artisanal and Small-Scale Mining: A Scoping Review	Chapter 1	International Journal of Environmental Research and Public Health [Cossa et al. Int. J. Environ. Res. Public Health **2021**, 18,1555. https://doi.org/10.3390/ijerph18041555]	2021	First author	Published
Assessing the effects of mining projects on child health in sub-Saharan Africa: a multicountry analysis	Chapter 2	Globalization and Health [Cossa et al. Globalization and Health (**2022**) 18:7 https://doi.org/10.1186/s12992-022-00797-6]	2021	First author	Submitted, under review
Perceived impacts of large-scale mining activities on maternal and child health conditions in Mozambique: A qualitative study	Chapter 3	Plos One (Under Review)	2021	First author	Submitted, under review
Health impact assessment and health equity in sub-Saharan Africa: a scoping review	General Discussion	Environmental Impact Assessment Review [Leuenberger et al (**2019)** *Environmental Impact Assessment Review*, *79*, 106288. https://doi.org/10.1016/j.eiar.2019.106288]	2019	Co-author	Published
Investigating Health Impacts of Natural Resource Extraction Projects in Burkina Faso, Ghana, Mozambique, and Tanzania: Protocol for a Mixed Methods Study	General Discussion	JMIR Research Protocols [Farnham et al. *JMIR Res Protoc* **2020**, *9*, e17138. https://doi.org/10.2196/17138]	2020	Second Authrou	Published
Health impacts of industrial mining on surrounding communities: local perspectives from three sub-Saharan African countries	General Discussion	PLOS One [Leuenberger et al. (**2021**) *PLoS One, 16*(6), e0252433. https://doi.org/10.1371/journal.pone.0252433]	2020	Co-author	Published
Incorporating community perspectives in health impact assessment: A toolbox.	General Discussion	Environmental Impact Assessment Review [Leuenberger et al. (**2022**). *Environmental Impact Assessment Review, 95*, 106788. https://doi.org/https://doi.org/10.1016/j.eiar.2022.106788]	2022	Co-author	Published
Mozambique policy brief	General Discussion	Health Impact Assessment for Sustainable Development web site [Cossa et al. (**2021**). https://hia4sd.net/wp-content/uploads/2022/02/PolicyBrief_Health-Impacts_Mozambique_r4d.pdf]	2021	First author	Published

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2 Article 1: Health Studies in The Context of Artisanal and Small-Scale Mining: A Scoping Review

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Review

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Abstract: Artisanal and small-scale mining (ASM) is an important livelihood activity in many low- and middle-income countries. It is widely acknowledged that there are a myriad of health risk and opportunities associated with ASM. However, little is known with regard to which aspects of health have been studied in ASM settings. We conducted a scoping review of peer-reviewed publications, using readily available electronic databases (i.e., PubMed, Scopus, and Web of Science) from inception to 14 July 2020. Relevant information was synthesized with an emphasis on human and environmental exposures and health effects in a context of ASM. Our search yielded 2764 records. After systematic screening, 176 health studies from 38 countries were retained for final analysis. Most of the studies (n = 155) focused on health in ASM extracting gold. While many of the studies included the collection of environmental and human samples (n = 154), only few (n = 30) investigated infectious diseases. Little attention was given to vulnerable groups, such as women of reproductive age and children. Our scoping review provides a detailed characterisation of health studies in ASM contexts. Future research in ASM settings should address health more comprehensively, including the potential spread of infectious diseases, and effects on mental health and well-being.

Keywords: artisanal and small-scale mining; health effects; health hazards; low- and middle-income countries; mercury; injuries and fatalities

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1. Introduction

Artisanal and small-scale mining (ASM) is commonly defined as any mining activity of ore deposits that are considered not cost-effective for large-scale industrial extraction [1]. Although cross-country distinctions between artisanal mining and small-scale mining exist, both share a number of common characteristics [2]. For example, both artisanal mining and small-scale mining are activities predominantly pursued by the informal sector, usually involving a few to hundreds of individuals using basic equipment [3]. Consideration of health and safety measures in ASM working processes are low [3–6]. It is currently estimated that ASM activities are practiced by more than 40 million people in over 120 countries [4,7,8]. Most of the activities are concentrated in low- and middle-income countries (LMICs) in Africa, Asia, and the Americas [4,5]. Driven by a number of factors (e.g., demand for minerals, gold price, and poverty), the ASM sector shows a significant diversity in various dimensions: (i) demography (up to 50% of miners are women and 10% are children); (ii) origin of miners (mix of local communities and migrant mine workers);

(iii) seasonality (e.g., rush mining due to discovery of new mineral deposits, resulting in rapid in-migration); (iv) legal status (e.g., 70–80% of ASM are informal in many countries); and (v) targeted commodities (e.g., gold, cobalt, coltan, and diamond) [7–9]. Despite the informal nature of activities, ASM represents a considerable share in global minerals and gemstones extraction. For instance, approximately half of the ASM miners are working in gold mines with a share of 20% of the global gold supply [2,8]. In addition to gold, ASM has a considerable global share in the supply of sapphire (80%), tantalum (26%), tin (25%), and diamonds (20%) [8]. Taken together, ASM is an important economic activity that provides livelihood opportunities for an estimated 80–150 million people [10,11].

Worldwide, ASM activities are on the rise. The activities are associated with both risks and opportunities for the health of miners, their families, surrounding communities, and populations living up- and downstream from ASM sites [2,5,12]. For instance, ASM can induce changes in people's socio-economic status and potentially reduce poverty, and improve their ability to access health care and education [13,14]. Income from ASM employment may reduce food insecurity [15] and improve housing conditions, which may result in reduced transmission of vector-borne diseases, such as malaria [16] and improved respiratory health [17]. Furthermore, it has been suggested that health and environmental benefits may be achieved, should governments and other key players formalise the ASM sector, provide financial assistance, promote improved technologies, educate on environmental protection, and encourage artisanal miners to form associations [18,19].

However, positive effects on health associated with ASM activities are often overshadowed by negative impacts. It is interesting to note that concerns about risks associated with occupational exposures in mining settings have already been raised in the 17th century by Ramazzini [20]. More than two centuries later, the exposure of surrounding communities to diseases related to mining was reaffirmed by Rose [21] and Cole [22]. Today, ASM is still expanding and generally presents as a highly labour-intensive activity with low health and safety standards in place [23], exposing the ASM workforce—often including women of reproductive age and children [6,9,12]—to a range of chemical, physical, biological, biomechanical, and psychosocial hazards [5,12,24], frequently resulting in "rapid development of disease and premature death" [21]. In addition to the occupational environment, ASM-related health hazards also affect surrounding communities, including particularly vulnerable groups (e.g., children, women of reproductive age, and elderly) [2,8,25]. Indeed, health effects related to chemical exposure, such as mercury (Hg), cobalt (Co), arsenic (As), and lead (Pb), including neurological, renal, and autoimmune disorders, have been reported in occupationally and non-occupationally exposed individuals in ASM settings [24,26–32]. Moreover, mining-induced in-migration and changing life styles pose considerable health risks affecting miners and exposed communities [2,8,12,33,34].

Taken together, it is widely acknowledged that ASM activities affect human health in myriad direct and indirect ways. However, little is known about how exactly people's health and well-being are affected by ASM contexts in different parts of the world. To our knowledge, most health-related research on ASM settings have focused on gold extraction (i.e., ASGM) and associated exposures to Hg [23,35–39]. Indeed, a considerable body of evidence is available on environmental and human exposure to Hg in ASGM contexts [24,29,35]. At the same time, many other health hazards and risks are likely to prevail in the context of ASM that received far less attention [40]. Similarly, health risks that are ubiquitous across any type of ASM might have been studied more frequently in ASGM context, as compared to effects that are specific to other minerals being extracted in ASM [23]. For example, few studies pertaining to health effects in ASM contexts have tempted to include exploitation other than gold, such as artisanal fluvial extraction of river sand and informal gasoline trade [40]. An overview of health studies in the context of ASM will not only enhance the understanding of which health aspects have been studied thus far, but will also allow to identify potential research gaps that can guide future research efforts in ASM.

This paper aims to provide a global overview of human health-related studies that have been carried out in ASM contexts, placing particular emphasis on those directly engaged in ASM activities, as well as those living within mining areas and surrounding populations. The research was guided by the following questions: (i) in which countries have ASM activities been conducted and what type of ASM contexts have been studied? (ii) What health effects and ASM-related exposures to health hazards (environmental or biomarkers) were studied? (iii) Which population groups were included in these studies? (iv) What type of environmental and human samples were collected? (v) What type of exposures were measured? (vi) Which signs, symptoms, diseases, injuries, and fatalities were investigated?

2. Materials and Methods

A scoping review was conducted targeting the peer-reviewed literature [41]. The search was oriented towards, but not limited to, epidemiological studies that investigated health issues such as communicable and non-communicable diseases, signs and symptoms, injuries, and fatalities in ASM contexts. Established health indices such as human biomonitoring (HBM), health risk assessment (HRA), and risk analysis (RA) that were applied in ASM settings, were also considered. Studies that were carried out in industrial mining contexts were deliberately not included in the current scoping review, as our focus was on ASM.

2.1. Search Terms and Strategy

Relevant studies were identified through a systematic search guided by the "Preferred Reporting Items for Systematic reviews and Meta-Analyses extension for Scoping Reviews (PRISMA-ScR): Checklist and Explanation" [42]. Two steps were taken to develop the search terminology. First, the search terms were independently developed as an iterative process by two reviewers (H.C. and R.S.). Second, the two draft search terms were compared and consolidated into a final search strategy. Any disagreement was discussed with another two researchers (A.L. and M.S.W.). The final search strategy (in English only) consisted of two search term blocks: (i) ASMs related and (ii) health effects related terms (see Appendix A, Table A1).

2.2. Peer-Reviewed Literature Searches and Screening

We conducted the electronic literature search applying a systematic search strategy in three readily available electronic databases, namely (i) PubMed; (ii) Scopus; and (iii) Web of Science (WoS). No spatial, temporal, or language restriction was applied for the search term administered on 14 July 2020. The records retrieved from the three databases were pooled together and imported into EndNote version X9.2 (Thomson Reuters Corp.; New York City, NY, USA; https://endnote.com). Of note, the search strategy was amended to the specific features of the databases (see Appendix A, Table A1).

In a first step, records were de-duplicated based on authorship, title, and publication year of the articles identified in the different databases. For this purpose, automatic detection and hand curation was done using both EndNote and Microsoft Excel (Microsoft Office Standard 2016, version 16.0.4266.1001; Microsoft Corporation, Redmond, WA, USA). In a second step, all records other than original research papers and reviews were excluded (i.e., conference proceedings, books, book chapters, editorials, opinion pieces, patents, and correspondences) using the reference type field in the EndNote software. In a third step, titles and abstracts of all records were independently screened by four reviewers, including three authors (H.C., P.A., and R.S.) and one collaborator (A.G.) using EndNote and Microsoft Excel for data management. Discrepancies were discussed in pairs (H.C.-R.S., H.C.-A.G., and H.C.-P.A.) until consensus was reached, if need be with input of an additional author (M.S.W.).

The remaining full texts were screened uniquely by H.C. with support, whenever needed, from M.S.W., applying the following set of inclusion criteria for the final selection of the relevant articles: (i) study was carried out in an ASM environment or an environment affected by ASM; (ii) study investigated human health outcomes and/or human health related indicators (environmental samples or human biomarkers); (iii) the articles is open access or accessible with the rights of the University of Basel (Basel, Switzerland). A post hoc approach for inclusion criteria was applied in order to focus on the comparison of quantitative epidemiological studies solely conducted in the context of ASM. Hence, qualitative studies, systematic reviews, and studies focusing on both ASM and other (illegal/informal) activities, such as farming and electronic waste recycling, were excluded for the current scoping review.

2.3. Data Extraction and Analysis

Two authors (H.C. and M.S.W.) developed the data charting form in a Microsoft Excel spreadsheet for data extraction with the following variables: articles' background data (author, year of publication, country, study type, study design, and natural resources extracted); characteristics of study population (age, age group, sex, and population groups); type of health-related samples taken (environmental samples and related pollutants, and human samples and related biomarkers); investigated health issues (signs and symptoms related to chemical exposures; adverse health conditions, and fatalities); and health risk indices (HRI), i.e., health indicators calculated to quantify human health risks associated with the environmental hazards [43,44]. Online electronic supplementary materials of included articles were accessed and screened for additional data extraction whenever necessary. Data extraction based on the full-text analysis was mostly driven by one researcher (H.C.). Microsoft Excel (Microsoft Office Standard 2016, version 16.0.4266.1001, Microsoft Corporation; Redmond, WA, USA) was used for data entry and cleaning, and subsequently imported into STATA (Stata Corporation, version 14.2, LLC; College Station, TX, USA) for data analysis. Drawing on the concept put forth by Levac and colleagues [41], a descriptive thematic approach was used to characterise the included articles. Identified categories were summarised as frequencies and continuous variables as median and interquartile range (IQR). In cases where the characterisation of the articles refers to a sub-group of the total number of articles identified, the nominator (number of articles of interest [x]), denominator (total number of relevant articles [y]), and percentage (%; [x/y]) are specified in the results section. The number of studies per country were compiled using Microsoft Excel and exported into QGIS (version 3.14.0-Pi, Free Software Foundation, Inc.; Boston, MA, USA; https://qgis.org/en/site/) for illustration. In case multiple countries were reported in a single article, countries were counted separately. Similarly, the type of extracted commodities and number of reporting studies were compiled using Microsoft Excel. When more than one commodity was reported, a separate counting was done for each. PowerPoint (Microsoft Office Standard 2016, version 16.0.4266.1001, Microsoft Corporation; Redmond, WA, USA), was used for edition and final illustration of all figures.

3. Results

3.1. Overview of Studies

We identified a total of 2764 records based on PubMed, Scopus, and WoS. After deduplication (1176 removed records), 1588 unique studies remained from which 1412 were excluded based on reference type (n = 289), title and abstract screening (n = 987), and full text screening (n = 136). Hence, 176 articles were deemed eligible for data extraction and analysis, as shown in the PRISMA flow chart (Figure 1). All articles included were in English with the exception of two that were in Spanish.

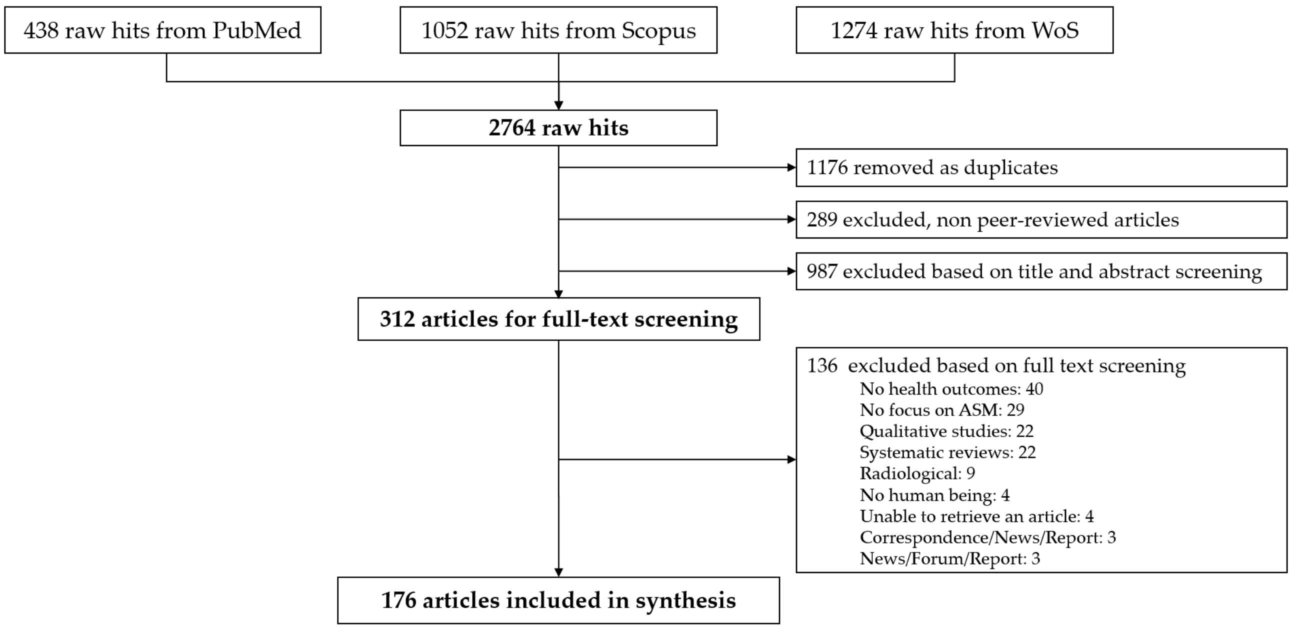


Figure 1. Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) flow chart indicating the number of articles that were searched in PubMed, Scopus, and Web of Science (WoS), screened, and included in the current scoping review (ASM, artisanal and small-scale mining).

3.2. Study Characterization Regarding Country and Year of Publication

Panel A in Figure 2 shows the geographical distribution of the 176 included articles that present primary (*n* = 167) and secondary (*n* = 26) data from 38 countries. Most of the studies were conducted in Africa (*n* = 95; 16 countries), followed by Asia (*n* = 53; 10 countries) and Latin America and the Caribbean (*n* = 50; 11 countries). Only one study involved individuals from a European country [45]. The number of published articles per country ranged from 1 to 32. Ghana is the country with the largest number of published articles (*n* = 32).

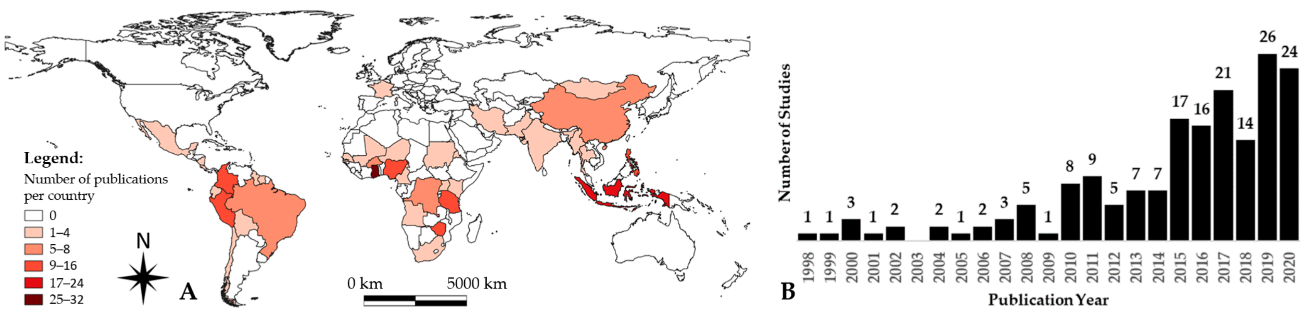


Figure 2. Geographical and temporal distribution of included articles (*n* = 176) per country (**A**) and year of publication (**B**). Source: authors' compilation from extracted data; national administrative boundaries dada ware obtained at Anomaly Hotspots of Agricultural Production (ASAP) (https://mars.jrc.ec.europa.eu/asap/files/gaul0_asap_v04.zip) [46].

While most of the studies focused on a single country (93.8% [165/176]), studies including more than one country (i.e., multi-centric studies) accounted for 6.2% [11/176]. Multi-centric studies involved two to five countries from Africa (*n* = 2), Africa and Asia (*n* = 8), and South America and Europe (*n* = 1).

The oldest paper identified was published in 1998 (Figure 2, Panel B). The median (IQR) of articles per year was 5 (range: 2–13). Two thirds of the articles (67% [118/176]) were published between 2015 and 2020, indicating an increasing trend in peer-reviewed ASM-related published articles in the last 5 years.

3.3. Study Characteristics Regarding Key Topics Covered

Of the 176 included health studies, most were related to HBM (*n* = 32), HRA (*n* = 30), and human health assessment (*n* = 26). Few studies (*n* = 4) presented medical case reports (Figure 3). The remaining studies were related to integrated approaches, comprising HBM and health assessment (HA) (*n* = 68), HA and HRA (*n* = 9), HBM, HRA and HA (*n* = 6) and HRA and HBM (*n* = 1). Of note, three out of four medical case reports were related to both HBM and HA [47–49].

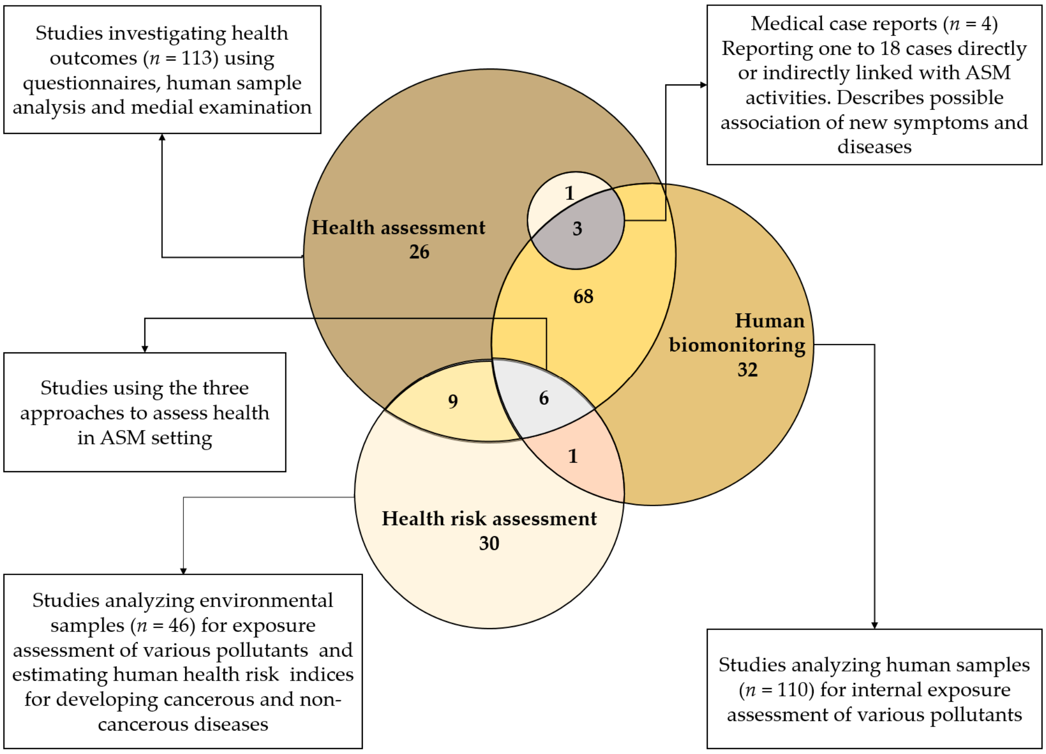


Figure 3. Overview of the characteristics of the 176 included health studies. Three main approaches for studying health were employed, including (i) health assessment (HA); (ii) human biomonitoring (HBM); and (iii) health risk assessment (HRA). Overlaps indicate studies for which more than one approach was used.

A high diversity of types of health studies was observed (Figure 4). Based on the extracted data, we examined how included studies (*n* = 176) assessed health-related exposure and health effects from ASM activities. The following study type clusters were identified: (i) HA (i.e., medical investigation, *n* = 113); (ii) HBM (*n* = 110); (iii) HRA studies (*n* = 46); and (iv) medical case reports (*n* = 4). A large number of articles (*n* = 71) applied integrated environmental monitoring (EM) approaches, applying different combinations of HBM, HA, and HRA.

Exposure assessments were performed through examination of human samples, environmental samples (including biotic and food samples), and self-reported exposure through questionnaires. In all studies, samples were submitted to laboratory examination for chemical and biological hazards exposure assessment. Physical hazards exposure was mainly assessed through questionnaires and field observations. Of note, most of HRA studies (*n* = 45) investigated chemical hazard exposure, including heavy metals, metalloids, and trace elements.

In regards to the strategies applied for investigating health outcomes from ASM exposure, a broad range of approaches were employed (Figure 4). For instance, HBM studies were more focused on the level of internal body exposure to chemical hazards (e.g., Hg). Signs, symptoms, diseases, injuries, and fatalities were reported in the remaining study type clusters, except for HRA studies, which reported health risk indices. The main tools used to investigate health outcomes and other health-related indicators were: (i) laboratory analysis of samples (for pollutants, infections and physiologic parameters); (ii) questionnaires for self-reported health outcomes and health risk indices estimations using HRA tools; and (iii) medical examination.

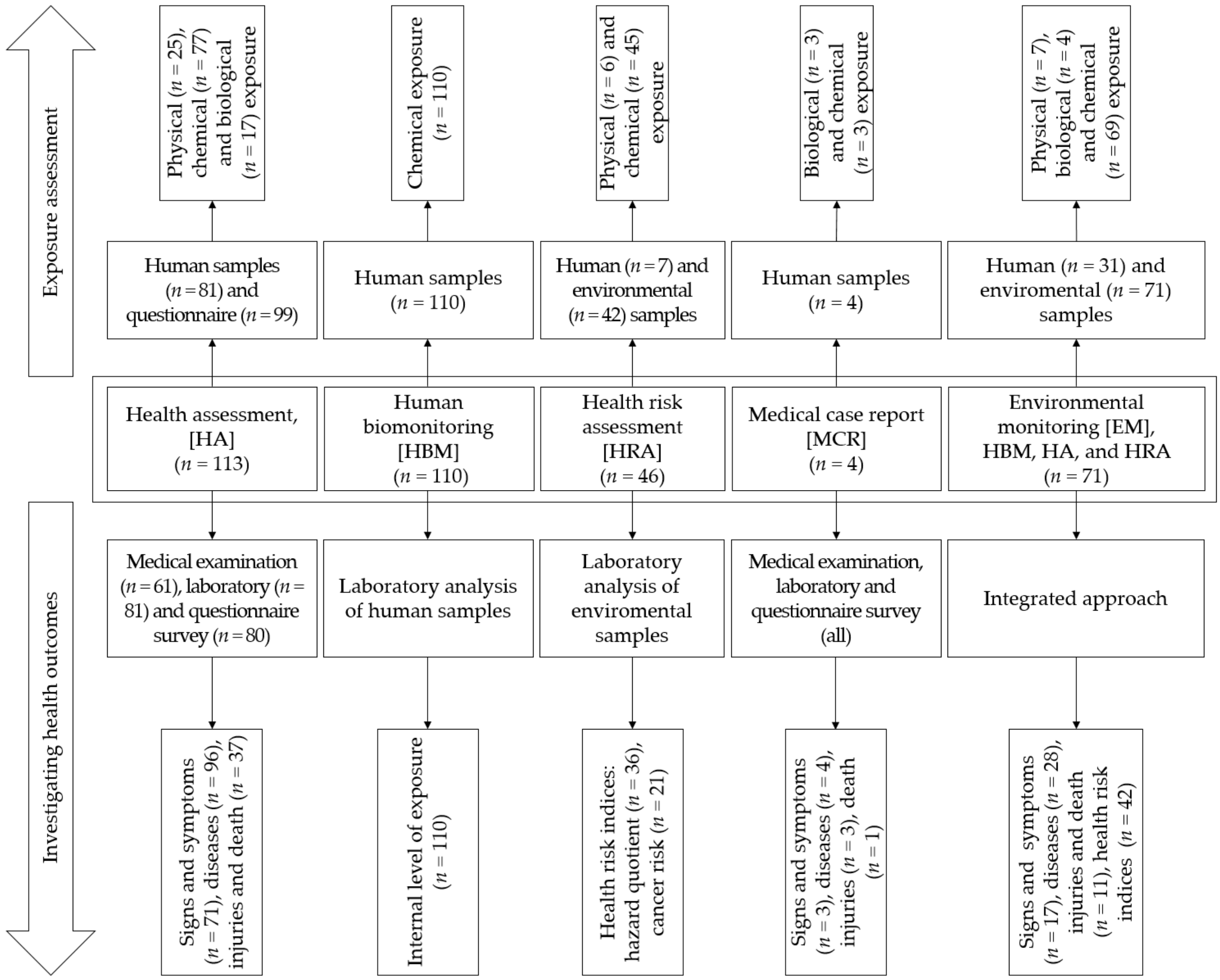


Figure 4. Overview of the main study type clusters, and a conceptual framework of exposure assessment and health outcome investigation strategies. Overlaps exist between different approaches; hence, frequency exceeds the total of 176 included studies.

3.3.1. Type of ASM as Function of Extracted Commodities

Figure 5 shows the type and number of commodities reported to be extracted in the ASM contexts investigated in the included articles. A total of 23 extracted commodities were reported. The large majority of identified studies were carried out in ASGM context (n = 155). Other less reported commodities, such as coltan, aluminium (Al), coal, diamond, lead (Pb), Hg, and tin (Sn) are also shown in Figure 5. Of note, 10 studies were conducted in ASM settings where more than one commodity was extracted, including gold (Au), diamond, and emerald, (n = 2) [50,51]; iron (Fe), Sn, and Al (n = 2) [44,52]; Pb and zinc (Zn) (n = 2) [53,54]; Au, limestone, and Al (n = 1) [55]; Au and copper (Cu) (n = 1) [56]; Au, Sn, cassiterite, coltan, and gemstones (n = 1) [57]; and Au, manganese (Mn), and bauxite (n = 1) [58].

Figure 5. Type of ASM studied as a function of extracted commodities. The numbers indicate the total of reporting studies. Note: Al, aluminium; Bau, bauxite; Cas, cassiterite; Co, cobalt; Cr, chrome; Cu, copper; Ge, gemstones; Lime, limestones; Mn, manganese; Peg, pegmatite; San, sandstones; Sph, sphalerite; and Tnz, tanzanite.

3.3.2. Characteristics of Study Populations

All studies, except one [59], mentioned the gender of the study population (Table 1). Most (87.5% [154/176]) included males and females. Of those, half (50.6%; [75/152]) included individuals of all ages (i.e., from 6 months and above) followed by those including adults only (i.e., 18 years and above) (32.9% [50/152]). More than half of these studies (54.5% [6/11]) investigating health in female subjects only, were focused on specific subgroups, i.e., pregnant women (n = 5) [32,60–63] and women of reproductive age (n = 1) [64].

As shown in Table 1, almost half of the studies (48.3% [85/176]) included both miners and residents. Two-thirds of these studies (67.0% 57/85]) addressed population groups of all ages and a quarter (25.0%; [21/85]) focused on adults (aged ≥18 years) only. Few studies (5.7% [10/176]) investigated children's health. Seven articles (4.0% [7/176]) did not mention the age of study subjects. The maximum reported age was 98 years [65]. Among those investigating health in children, one included children working in ASM [59].

Table 1. Distribution of study populations by age group, gender, and population groups (n = 176).

Population Characteristics	Children (<15 Years)	Adolescents and Adults (≥15 Years)	Adults (≥18 Years)	All Ages (≥6 Months)	Age Group Not Defined	Total
Gender						
Males and females	8	14	50	77	5	154
Female	1	5	2	1	1	10
Male	0	0	9	1	1	11
Gender not defined	1	0	0	0	0	1
Population groups						
Miners and residents	1	5	21	57	1	85
Miners	0	8	32	7	5	52
Residents	9	6	8	15	1	39
Total	10	19	61	79	7	176

3.4. Type of Investigated Samples and Health Effects

Overall, 154 studies were identified that analysed at least one type of environmental or human samples. Human biological samples were collected in 114 studies. Environmental samples of human health relevance were collected in 71 studies. Thirty-one studies comprised both environmental and human sampling. While Hg alone was investigated in 74.4% [131/176] of the studies, physical (e.g., dust, exposition, and landslide) and biological hazards (e.g., human immunodeficiency virus (HIV), malaria, and soil-transmitted helminth infections) were investigated in 27 and 18 studies, respectively.

3.4.1. Environmental Samples and Related Pollutants

In all included studies (*n* = 176), 10 different types of environmental samples were collected and analysed. Soil (*n* = 36), water (*n* = 35), fish (*n* = 22), sediment (*n* = 21), and non-fish food (*n* = 15) were the most frequently collected environmental samples (Figure 6, Panel A).

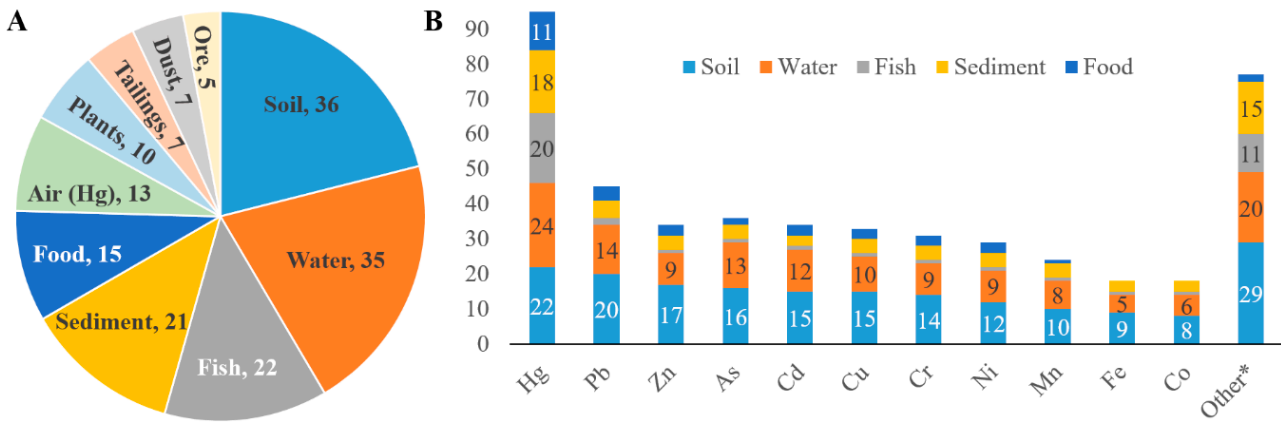


Figure 6. Profile of investigated environmental samples and pollutants. Numbers are frequency of reporting articles. Panel (**A**), type of examined samples and Panel (**B**), type of investigated pollutants. Note: Hg, mercury; Pb, lead; Zn, zinc; As, Arsenic; Cd, cadmium; Cu, copper; Cr, chromium; Ni, nickel; Mn, manganese; Fe, iron; Co, cobalt; and (*) other environmental pollutants reported in few studies (e.g., 1 to 4 studies, each).

Hg and Pb were the most investigated ASM-related pollutants. For instance, in water samples Hg and Pb concentration levels were assessed in 24 and 14 studies, respectively. The same pattern was observed for other environmental samples (Figure 6, Panel B). The highest diversity of assessed environmental pollutants was observed in soil samples (28 pollutants). Air samples were analysed exclusively for Hg concentration using both portable Hg detector devices [49,66] and laboratory air analysis [67]. One study investigating air pollution measured oxygen (O_2) and carbon monoxide (CO) concentrations, and other physical parameters, such as temperature and dust concentration [68]. Other environmental pollutants reported in a few studies investigating soil, water, fish, sediment, and food samples are summarised in Appendix B, Table A2.

As part of Appendix B, Table A3 provides details on environmental pollutants determined in dust and ore samples and Figures A1 and A2 give details on other environmental samples, such as non-eatable plants and tailings, respectively.

3.4.2. Human Samples and Related Biomarkers

Panel A in Figure 7 presents the different types of human samples and biomarkers (internal body exposure) investigated in the included studies. Overall, 11 types of human samples were collected and analysed for both exposure assessments and medical examinations of study participants. The three most investigated types of human samples are hair (*n* = 71), urine (*n* = 54), and blood (*n* = 51).

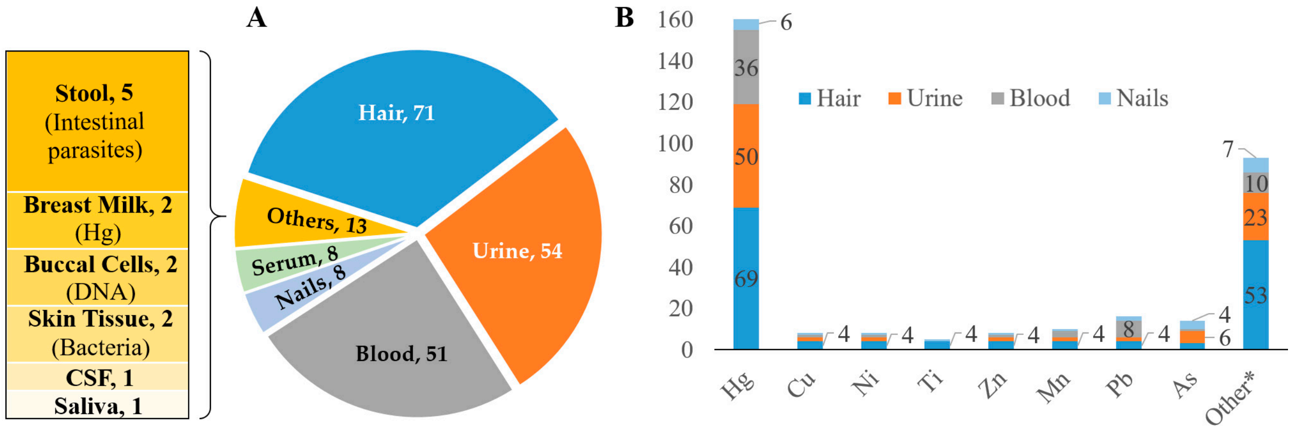


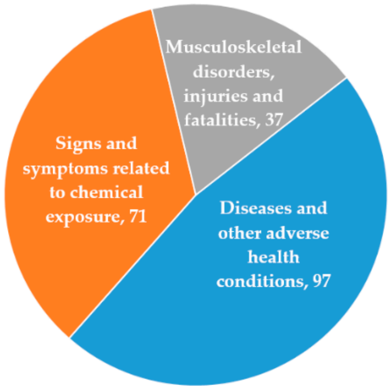
Figure 7. Human samples and biomarker profile. Investigated biomarkers include heavy metals and metalloids. Numbers are frequency of reporting articles. Panel (**A**), type of examined samples and Panel (**B**), type of investigated pollutants. Note: CSF, cerebrospinal fluid; DNA, deoxyribonucleic acid; Hg, mercury; Pb, lead; Zn, zinc; As, arsenic; Cu, copper; Ni, nickel; Mn, manganese; Ti, titanium; and (*) other chemical pollutants reported in few studies (e.g., 1 to 3 studies, each).

The diversity of pollutants assessed in hair (n = 46) was higher than in urine (n = 25) and blood (n = 13) (Figure 7, Panel B). Most biomarkers were reported in less than four articles each. Two studies contributed significantly to the diversity based on the assessment of hair-biomarkers [69,70]. Similarly, the diversity of pollutants revealed through urine biomarkers was mostly related to the study from Nkulu and colleagues [31], measuring the level of 25 different pollutants in urine. Hg levels measured in hair (n = 69), urine (n = 50), and blood (n = 36) were clearly the chemical exposure most assessed in the last two decades. The second most reported pollutant was the level of Pb (measured in blood, n = 8) and arsenic (measured in urine, n = 6). Moreover, breast milk samples were exclusively analysed for Hg concentration levels [71,72]. Other less reported chemicals are given in more detail for hair, urine, blood, and nail biomarkers in Appendix C, Table A4. The list and frequencies of physiological parameter measured in serum is provided in Appendix C, Table A5.

Besides chemical pollutants, blood, and urine samples were also analysed for other physiological parameters, such as blood lactate and cyanide [73,74], haematological parameters, and other blood chemistry [47,75], mitochondrial DNA, and other DNA mutations [48,76–78], immunological response to vaccines, and other immune-related proteins [50,79,80], renal and respiratory parameters [75,81], and infectious diseases, such as malaria [82] and HIV [47,83]. Saliva (cortisol salivary) [84], Buccal cells (DNA damage and mutations) [63,77], and stool samples (soil-transmitted helminths and *Vibrio cholerae*) [85,86] were also reported.

3.5. Adverse Health Conditions and Fatalities

Of the 176 studies included in our analysis, 144 (81.8%) reported at least one of the following three groups of health issues: (i) prevalence or incidence of diseases and other adverse health conditions (n = 97); (ii) signs and symptoms related to chemical exposures (n = 71), with Hg exposure being studied most often (n = 53); and (iii) musculoskeletal disorders, injuries, and fatalities (n = 37) (Figure 8). An integrated approach was applied in more than half of the studies (n = 74). For instance, a combination of two (n = 48) and three (n = 20) types of health issues were identified and six studies incorporated all four types of health issues [87–91] in their reports. Health effects from gold extraction activities alone were investigated in 84% [149/176] of the studies.



Diseases and other adverse health conditions	Frequency	Studies assessing Hg
Nutritional status	38	30
Respiratory disorders	32	22
Renal disorders	31	30
Gastrointestinal	28	23
Poisoning	29	27
Cardio-Vascular	23	15
Malaria	15	11
Anaemia	12	11
Tuberculosis	11	5
Diabetes	8	7
Immune disorders	8	6
Reproductive disorders	8	6
HIV/STI	7	4
DNA-Damage	7	5
Hepatic	5	3
Thyroid function	5	4
Parkinsonism	5	5
Pyramidal syndrome	5	5
Pneumonia	4	2
Cancer	4	4
Abortion	4	4
Adverse birth outcomes	4	3
Others[1] (frequency < 4)	16	-

Signs and symptoms related to chemical exposure	Frequency	Studies assessing Hg
Potential-Signs and symptoms	47	39
Neurological symptoms	44	41
Visual disorders	27	21
Neuro-motor function	21	19
Neuropsychological	20	20
Pain	20	8
Hearing disorder	14	8
Stress	12	7
Cognitive impairment	11	9
Neurodevelopmental	7	7
Intelligence quotient	3	3

MSD, injuries and fatalities	Frequency	Studies assessing Hg
Musculoskeletal disorders	17	7
Death	16	7
Wound	11	4
Burn	11	1
Fracture	9	0
Laceration	8	1
Contusion	7	0
Dislocation	4	0
Amputation	4	0
Facial	4	0
Spinal cord	3	1

Figure 8. Main and sub-categories of adverse health conditions investigated at both population and individual level in ASM settings. Note: DNA, deoxyribonucleic acid; Hg, mercury, HIV, human immunodeficiency virus; MSD, musculoskeletal disorders; and STIs, sexually transmitted infections. Other adverse health outcomes are reported in less than four studies, each.

3.5.1. Signs and Symptoms Related to Chemical Exposure

The use of Hg and its health effects were the major issues in the studies that met our inclusion criteria. We identified 71 studies addressing at least one sign and symptom related to exposure to Hg and other metals. Notably, most of these studies (61.9% [44/71]) had a strong focus on Hg alone, while an additional 12.7% [9/71] focused on concomitant exposure to Hg and other metals, such as Pb and As. Two-thirds of the studies [47/71] investigated potential signs and symptoms of exposure to environmental contaminants. Forty-one out of 44 studies investigating neurological symptoms assessed Hg exposure in the affected population. Likewise, 21 and 19 studies of those investigating visual disorders (n = 27) and neuro-motor function disorders (n = 21) assessed Hg exposure, respectively. All studies reporting neuropsychological symptoms (n = 20) also assessed Hg exposure. Other signs and symptoms included pain, hearing disorders, stress, cognitive impairment, and intelligence quotient (Figure 8). Only three studies investigating signs and symptoms of cyanide exposure were identified [73,74,92].

3.5.2. Adverse Health Conditions

Our study sample revealed 34 subcategories of diseases and other adverse health conditions. As shown in Figure 8, the six most frequently studied subcategories were: (i) nutritional disorders (n = 38); (ii) respiratory disorders (n = 32); (iii) renal diseases (n = 31); (iv) gastrointestinal disorders (n = 29); (v) poisoning (n = 29); and (vi) cardiovascular diseases (n = 23). Thirty studies addressed at least one infectious disease, such as malaria (n = 15), tuberculosis (n = 11), HIV infections and STIs (n = 7), typhoid (n = 5), and pneumonia (n = 4). Details on other types of communicable diseases reported in less than four studies are provided in Table A6, Appendix D.

3.5.3. Musculoskeletal Disorders, Injuries, and Fatalities

Eleven types of musculoskeletal disorders, injuries, and fatalities were reported in 37 studies. Musculoskeletal disorders (n = 17) were most frequently reported, followed by wounds (n = 11) and burns or abrasions (n = 11). Fatalities were reported in 16 studies, of which 12 were conducted in African countries.

3.6. Health Risk Indices

As shown in Figure 9, five HRIs were reported in 46 studies out of 176, namely (i) hazard quotient (HQ); (ii) hazard index (HI); (iii) cancer risk (CR); (iv) permissible exposure limit (PEL); and (v) risk rating (RR). The most frequent health index was the HQ (*n* = 36) of which (88.9% [32/36]) were from studies assessing chemical exposure from environmental samples only. Both total and targeted HQ (T-HQ) were used in some studies. HI is the sum of all computed HQs [93] and was computed in 20 studies. Both HQ and HI are individual health risk estimation for non-carcinogenic endpoint of environmental contaminant exposure [94].

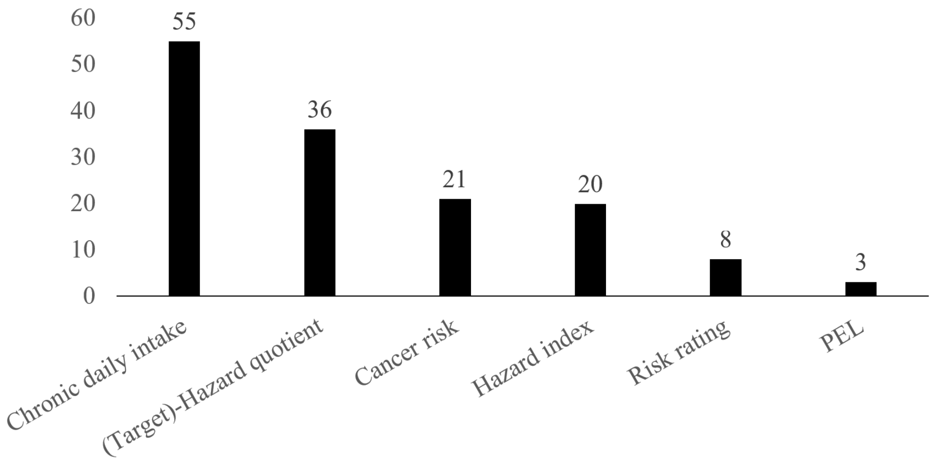


Figure 9. Health risk indices reported 46 out of 176 included studies. Figures represent the number of studies reporting each index. Note: PEL, permissible exposure limit.

The following most estimated HRI was the CR (*n* = 21), which is a term used to characterise lifetime probability of developing any type of cancer disease [52]. Two synonyms are used for this estimate, such as incremental lifetime cancer risk (ILCR) and incremental excess lifetime cancer risk (IELCR) [94,95]. This indicator was exclusively estimated by human health risk assessment studies. RR (*n* = 8) and PEL (*n* = 3) were the less estimated HRI.

Adding to the five previous estimates, the intake rate estimate (i.e., chronic daily intake, CDI) were also considered in about a third of the studies (*n* = 55). Three routes of pollutants intake were reported. Ingestion (*n* = 53) was reported most frequently, followed by inhalation (*n* = 18) and dermal absorption (*n* = 16). Furthermore, 12 studies considered the three intake routes in an integrated manner.

4. Discussion

A total of 176 articles from 38 countries in Africa, Asia, and the Americas were identified in our scoping review and subjected to in-depth analysis. Systematic classification of the studies revealed a heavy focus on health research in the context of ASGM. Consequently, Hg exposure and associated health-related effects in affected populations were by far the most investigated research topics. The transmission of infectious diseases, such as malaria, STIs (mainly HIV), and tuberculosis in ASM contexts has received comparatively little attention. Musculoskeletal disorders, wounds, and burns were the types of injuries mostly investigated. Only a few health studies specifically investigated vulnerable population groups, such as women of reproductive age and children.

4.1. Representativeness of Health Research in ASM

ASM is practiced in 124 countries, primarily in LMICs in Africa (*n* = 49 countries), Asia (*n* = 35 countries), and Latin America and the Caribbean (*n* = 29 countries). In Europe (*n* = 6 countries), Northern America (*n* = 3 countries), and Oceania (*n* = 2 countries), ASM is far less often pursued [4]. However, the 176 health-related research articles included in our scoping review represent only a third of the countries hosting ASM activities (37.9% in Latin America and the Caribbean, 33.7% in Africa, 28.6% in Asia, and 16.7% in Europe). None of the included studies were conducted in Northern America and Oceania. Hence, from two-thirds of the countries with ASM activities, no health-related research has been reported in the peer-reviewed literature. When considering that ASM contexts are hotspots for occupational risks and public health challenges [23,24], this finding clearly points out that health research in ASM is a neglected area of research in many countries hosting ASM activities.

There are several potential underlying reasons why health in the context of ASM lacks pointed research. First, despite the current trend in urban mining, such as gold jewellery manufactures [96], ASM operations are often performed in distant or difficult-to-access settings [2,8]. Hence, data collections at mining sites are challenging in terms of access, while financial and human resources for research are often constrained [35,36]. Second, ASM activities are generally informal and take place in contexts with high cultural sensitivities [8,97,98]. This poses challenges to accessing people involved in ASM, including vulnerable population groups such as women of reproductive age, children, and ethnic minorities. Third, research efforts that aimed to build on secondary data sources from ASM settings have faced challenges with data availability and quality. For instance, it was found that data availability and quality were limited for estimating disease burden and disability-adjusted life years (DALYs) due to Hg use in ASGM in Zimbabwe and elsewhere [35,36]. Despite the many potential challenges faced with the implementation of health studies in ASM settings, the high public health relevance—more than 40 million being directly exposed to ASM [4]; many are vulnerable or marginalised groups [8]; and many potential health issues [8,12]—calls for the definition of a comprehensive global research agenda that promotes health research in ASM contexts. This also aligns with ongoing initiatives such as the Global Mercury Partnership and the agenda of the World Bank, which has already recognised this topic as a "big global data gap" [15].

4.2. Inclusion of Vulnerable Groups

In health studies carried out in ASM contexts, women of reproductive age and children were rarely investigated as stand-alone groups. Among the few studies identified that included vulnerable groups, none focused specifically on the health status of women of reproductive age or children who were directly involved in ASM activities. Hence, health research in ASM contexts largely missed out on the most vulnerable population groups. This is in contrast to existing literature that has long established the vulnerability of women of reproductive age and children in ASM [2,5,12,99]. The limited health data pertaining to these vulnerable groups may be due to fear of ethical issues when conducting research involving vulnerable population groups [100], the informal nature of the sector [12], as well as cultural sensitivities and high gender-based inequities [97], which renders these groups less reachable due to their fear and distrust of participating in research studies [101]. When considering that an estimated 30–50% women and more than one million children are directly involved in ASM activities [15], better targeting, and inclusion of vulnerable groups in health studies carried out in ASM communities is a pressing need [102].

In order to address these challenges, it is essential that ethical boards, national and local health authorities, local organisations working in ASM settings and, most importantly, ASM communities are involved in every phase of the research process [103]. Indeed, early involvement of ethical boards presents an opportunity for overcoming potential uncertainties on how to invite vulnerable individuals to serve as participants in health research in ASM contexts with all the required special justification [100,104]. The integration and support from multi-sectoral and multidisciplinary stakeholders, including collaboration with governmental and non-governmental organisations, indigenous populations, local leaders, and potential participants is a common practice and proven useful [49,105–107]. The value added of such multi-stakeholder engagement enhances trust between participants and scientists when conducting research involving vulnerable groups [100,101,105]. Independent of the context and chosen approach, it is critical to give the community´s voices and decisions equal importance in addressing issues related to limited health data on vulnerable groups [49,106].

4.3. Gaps Identified in Exposure Assessments

The systematic characterisation of the articles identified in our scoping review revealed a high diversity of exposure assessment approaches, comprising the sampling and analysis of 51 different chemical hazards in both environmental and human samples. While the systematic use of multiple biomarkers when assessing the effect of (environmental) pollutants has been suggested previously [108], the observed strong focus on Hg is striking. This finding may, at least partially, be explained by the adoption of the Minamata Convention on Mercury in 2013, which triggered considerable interest in Hg pollution and exposure in ASGM [102,109]. Indeed, three-quarters of the articles identified were published after the adoption of the Minamata Convention in 2013. At the same time, the emphasis on Hg use in ASGM may be overshadowing other important health issues that prevail in ASM communities, such as silicosis and tuberculosis, water- and vector-borne disease and sexual health issues, such as STIs, including HIV [23]. This is confirmed by a global study showing that ASM scholars and practitioners are more concerned with Hg exposure in ASM communities than other health hazards [14]. Indeed, Hg exposure and its toxicological consequences pose considerable health and environmental concerns due to the expansion of ASGM activities into urban and sub-urban communities [96,110]. With only one quarter of the health studies in ASM contexts that addressed other health issues than Hg exposure in ASGM, there might be an important research gap. Future studies should therefore make an effort to comparatively assess the public health relevance of different chemicals, biological, biomechanical, physical, and psychosocial hazards that occur simultaneously in ASM settings [2,5,16], for ultimately developing a research agenda that addresses all major health risks and opportunities in ASM.

4.4. Widening the Focus of Health Conditions Studied

Less than one in five articles identified studied communicable diseases, such as malaria, tuberculosis, and HIV in ASM contexts. When considering that 68.8% of the burden of disease in LMICs, where ASM is mostly practiced, is caused by communicable, maternal, neonatal, and nutritional diseases [111,112], this finding is surprising. Moreover, it is likely that these conditions are more prevalent in ASM settings compared to the countries' average due to the remote environments and potentially weak local health systems [111,113]. Indeed, studies have shown that ASM settings are characterised by high prevalence of air-, water-, blood-, and vector-borne diseases [5,114,115], as well as STIs and HIV [5]. The observed "high polarity" in health-related studies in ASM context may be linked to limited concern on other health hazards beyond Hg among ASM experts worldwide [14]. As a consequence, today, we face a systematic health data gap in the ASM sector at both national and regional levels, and, thus, scarce knowledge about the existing relationship between ASM activities, and the effect of other harmful exposures to the environmental and human health; a situation that may even further deteriorate in the current and future scenario of the coronavirus disease 2019 (COVID-19) pandemic.

4.5. Strengths and Limitations

This scoping review attempted to draw a general picture of research covered, thus far, with regard to health issues in ASM communities worldwide. Given the unrestricting nature of our piece (i.e., all types of ASM were included), we feel that our study makes a meaningful contribution to the literature, providing new insights into health research practice in ASM contexts. This scoping review, however, comes with several limitations. First, we did not include grey literature and peer-reviewed articles for which no titles and abstracts in English were available. Second, radiological studies, systematic reviews, and qualitative studies were, post hoc, excluded from data extraction and analysis due to time and human resources constraints. Third, due to the lack of standard terms for investigated adverse health conditions, such as symptoms of Hg intoxication among included studies [27,63,82,116], misclassification or entry duplication may have occurred during data extraction, which may inflect or deflect our findings. Fourth, we did not characterise the included articles in relation to the location where studies were conducted (e.g., rural vs. urban mining), which might have affected the interpretation of our results [45,49,96,110]. Fifth, we acknowledge that for conclusively judging the inclusion of vulnerable populations groups (e.g., women of reproductive age, children, and ethnic minorities) in health research in ASM contexts, a more holistic review is needed that does not only focus on published peer-reviewed literature.

5. Conclusions

Heath studies in ASM contexts have gained in popularity and diversity over the past two decades. At the same time, when considering the global magnitude of ASM practice, the number of health-related studies in ASM appears to be low and several specific contexts are not adequately represented in the existing body of literature. This also applies to ASM activities other than ASGM. Indeed, 88.1% of the articles identified are representing gold mining contexts, and, thus, other ASM commodities, such as coltan and cobalt, both showing increasing demand worldwide, are largely neglected. Furthermore, there is a dearth of studies that have focused on specific vulnerable population groups that are directly involved in ASM processes. In addition to a biased representation of ASM contexts and affected population groups, health studies in ASM communities show a heavy focus on Hg-related exposures and associated health effects, whilst communicable diseases and other health conditions not associated with Hg use have received relatively little attention. Future research efforts addressing the "global health data gap" in ASM contexts should diversify in terms of commodities and health issues studies, while also paying particular attention to the most vulnerable population groups.

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Appendix A

Table A1. Search terminology for the three electronic databases, PubMed, Web of Science, and Scopus. Number of records as of 14 July 2020.

Database	Search Terminology and Strategy	Number of Records (14 July 2020)
PubMed	((artisanal[TIAB [1]] OR small-scale[TIAB]) AND (mining[TIAB] OR mine[TIAB] OR miner[TIAB] OR mining[Mesh])) AND (health *[TIAB] OR health *[Mesh [2]] OR disease *[TIAB] OR disease *[Mesh] OR injur *[TIAB] OR wound *[TIAB] OR "Wounds and Injuries"[Mesh] OR infect *[TIAB] OR infect *[Mesh] OR inciden *[TIAB] OR incidence[Mesh] OR prevalen *[TIAB] OR prevalence[Mesh] OR death *[TIAB] OR death[Mesh] OR dead *[TIAB] OR die[TIAB] OR died[TIAB] OR dying[TIAB] OR mortal *[Mesh] OR fatal *[TIAB] OR surviv *[TIAB] OR survival[Mesh] OR safety[TIAB] OR "safety management"[Mesh] OR risk[TIAB] OR risk[Mesh] OR hazard[TIAB] OR poisoning[TIAB] OR poisoning[Mesh])	438
Web of Science (all databases)	TS [3] = (((artisanal OR small-scale) AND (mine OR miner OR mining)) AND (health OR disease * OR wound * OR injur * OR infect * OR inciden * OR prevalen * OR death * OR dead * OR die OR died OR dying OR mortal * OR fatal * OR surviv * OR safety OR risk OR hazard OR poison *))	1274
Scopus	title-abs-key [4] (artisanal OR "small-scale" OR "small-scale" OR "small scale") AND title-abs-key (mine OR miner OR mining) AND title-abs-key (health OR disease OR diseases OR wound * OR injur * OR infection * OR inciden * OR prevalen * OR death * OR dead * OR die OR died OR dying OR mortal * OR fatal * OR surviv * OR safety OR risk OR hazard OR poison *)	1052

[1] Specify the search for titles and abstracts; [2] specify medical subject headings (Mesh); [3] specify the search for topic; [4] specify the search for titles and abstracts and keywords.

Appendix B

Table A2. Type of environmental pollutants and frequency of reporting studies in soil, water, sediment, fish, and food samples. Frequencies are given for pollutants reported in up to four studies, each.

Chemical Names and Symbols of Pollutants	Frequency of Reporting Studies per Type of Environmental Samples				
	Soil	Water	Sediment	Fish	Food
Antimony (Sb)	4	2	2	0	0
Selenium (Se)	4	3	1	1	2
Aluminium (Al)	3	2	2	0	0
Barium (Ba)	2	1	0	0	0
Phosphorus (P)	2	0	0	0	0
Tin (Sn)	2	1	0	0	0
Titanium (Ti)	2	2	0	0	0
Calcium (Ca)	1	0	0	0	0
Cerium (Ce)	1	1	0	0	0
Lithium (Li)	1	1	0	0	0
Molybdenum (Mo)	1	2	1	1	0
Neodymium (Nd)	1	1	0	0	0
Silicon (Si)	1	0	0	0	0
Uranium (U)	1	1	0	0	0
Vanadium (V)	1	1	0	0	0
Yttrium (Y)	1	1	0	0	0
Zirconium (Zr)	1	1	0	0	0

Table A3. Type and frequency of reported pollutants in ore and dust samples. Twenty-four environmental pollutants were reported in each sample (ore; *n* = 7 and dust; *n* = 7). In dust samples, most pollutants were reported in one study [31]. Frequencies are given for pollutants reported in up to four studies, each.

Chemical Names and Symbols of Pollutants	Frequency of Reporting Studies per Type of Environmental Samples	
	Dust	Ore
Mercury (Hg)	3	1
Lead (Pb)	2	4
Aluminium (Al)	1	1
Antimony (Sb)	1	1
Arsenic (As)	1	2
Cadmium (Cd)	1	2
Cerium (Ce)	1	1
Chromium (Cr)	1	1
Cobalt (Co)	1	1
Copper (Cu)	1	1
Iron (Fe)	1	1
Lanthanum (La)	1	1
Manganese (Mn)	1	2
Molybdenum (Mo)	1	1
Neodymium (Nd)	1	1
Nickel (Ni)	1	1
Selenium (Se)	1	1
Silicon (Si)	1	0
Tin (Sn)	1	1
Titanium (Ti)	1	1
Uranium (U)	0	1
Vanadium (V)	1	1
Yttrium (Y)	1	1
Zinc (Zn)	1	1
Zirconium (Zr)	1	1

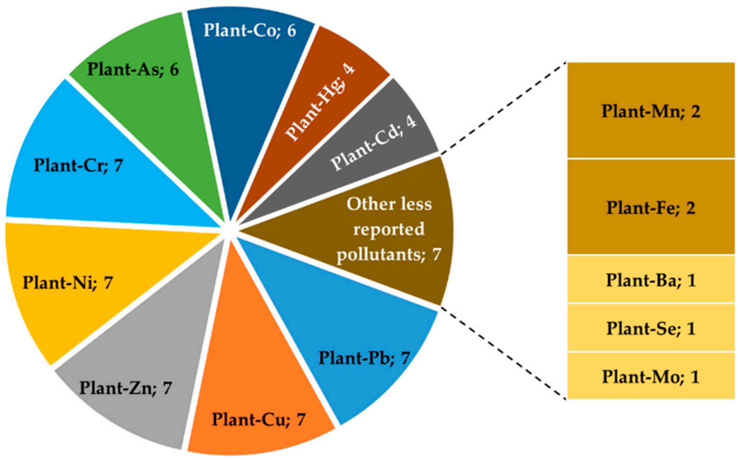

Figure A1. Biomarkers determined in non-edible plants and frequency of reporting articles (*n* = 10). In total, 14 pollutants were reported. Note: As, arsenic; Ba, barium; Cd, cadmium; Co, cobalt; Cr, chromium; Cu, copper; Fe, iron; Hg, mercury; Mn, manganese; Mo, molybdenum; Ni, nickel; Pb, lead; Se, selenium; and Zn, zinc.

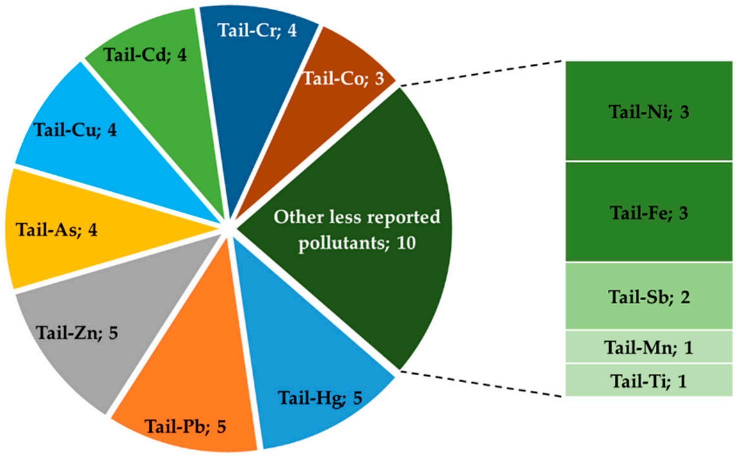

Figure A2. Environmental pollutants measured in mine tailings samples (n = 7). Note: As, arsenic; Cd, cadmium; Co, cobalt; Cr, chromium; Cu, copper; Fe, iron; Hg, mercury; Mn, manganese; Ni, nickel; Pb, plumb; Sb, antimony; Ti, titanium; and Zn, zinc.

Appendix C

Table A4. Type of chemical pollutants and frequency of reporting studies per type of human samples. Frequencies of reporting articles are given for pollutants reported in up to three studies, each.

Symbols of Chemicals	Frequencies				Symbols of Chemicals	Frequencies			
	Hair	Urine	Blood	Nails		Hair	Urine	Blood	Nails
Cd	3	2	3	1	I	1	0	0	0
Co	3	2	2	1	In	1	1	0	0
Cr	3	2	1	1	Mg	1	0	0	0
Al	2	2	0	1	Mo	1	1	0	0
Ca	2	0	0	0	Nb	1	0	0	0
Cl	2	0	0	0	Pd	1	0	1	0
Fe	2	0	0	0	Pt	1	1	0	0
K	2	0	0	0	Rb	1	0	0	0
Na	2	0	0	0	Sb	1	1	0	1
P	2	0	0	0	Se	1	2	0	1
S	2	0	0	0	Sn	1	1	0	0
Si	2	0	0	0	Sr	1	0	0	0
Ag	1	0	0	0	Te	1	1	0	0
Au	1	0	0	1	V	1	1	0	0
Ba	1	1	0	0	W	1	0	0	0
Bi	1	1	0	0	Y	1	0	0	0
Br	1	0	0	0	Zr	1	0	0	0
Ce	1	0	0	0	Be	0	1	0	0
Cs	1	0	0	0	Li	0	1	0	0
Ga	1	0	0	0	Tl	0	1	2	0
Ge	1	0	0	0	U	0	1	1	0

Note: Ga, gallium; Ge, germanium; In, indium; Rb, rubidium; Sr, strontium; Te, tellurium; Tl, thallium.

Table A5. Physiologic parameters assessed in serum samples in eight studies.

Physiological Parameter	Frequency
Micronutrients	7
Autoantibody/IRP	5
Creatinine	4
ALT	3
AST	3
Urea	3
Glucose	2
HIV antibodies	2
T4	2
TSH	2
T3	1

Note: ALT, alanine transaminase; AST, aspartate transaminase; IRP, immune-related proteins; T3, triiodothyronine; T4, thyroxine; and TSH, thyroid-stimulating hormone.

Appendix D

Table A6. Profile of communicable and non-communicable diseases reported in less than four studies, each.

Diseases	Frequency
Hepatitis	3
Typhoid	3
Agnathia–otocephaly	1
Bodily vibration syndrome	1
Buruli ulcer	1
Dengue	1
Dermatophyte infections	1
Hansen	1
Heatstroke	1
Hernia	1
Infertility	1
Sexual violence	1

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3 Article 2: Assessing the Effects of Mining Projects on Child Health in Sub-Saharan Africa: A Multi-Country Analysis

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Assessing the effects of mining projects on child health in sub-Saharan Africa: a multi-country analysis

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Abstract

Background: The African continent hosts many industrial mining projects, and many more are planned due to recent prospecting discoveries and increasing demand for various minerals to promote a low-carbon future. The extraction of natural resources in sub-Saharan Africa (SSA) represents an opportunity for economic development but also poses a threat to population health through rapid urbanisation and environmental degradation. Children could benefit from improved economic growth through various channels such as access to high-quality food, better sanitation, and clean water. However, mining can increase food insecurity and trigger local competition over safe drinking water. Child health can be threatened by exposure to mining-related air, noise, and water pollution. To assess the impact of mines on child health, we analyse socio-demographic, health, and mining data before and after several mining projects were commissioned in SSA.

Results: Data of 90,951 children living around 81 mining sites in 23 countries in SSA were analysed for child mortality indicators, and 79,962 children from 59 mining areas in 18 SSA countries were analysed for diarrhoea, cough, and anthropometric indicators. No effects of the launch of new mining projects on overall under-five mortality were found (adjusted Odds Ratio (aOR): 0.88; 95% Confidence Interval (CI): 0.68–1.14). However, activation of mining projects reduced the mortality risk among neonates (0–30 days) by 45% (aOR: 0.55; 95% CI: 0.37–0.83) and risk for a child to develop diarrhoeal diseases by 32% (aOR: 0.68; 95% CI: 0,51–0.90). The timing analysis of observed changes showed that there is a significant decline in the risk for childhood diarrhoea (aOR: 0.69; 95% CI: 0.49–0.97), and the mean height-for-age z-scores by 28 percentage points, during the prospection and construction phase; i.e., within four years to the initiation of extraction activity. No effects were found for cough and weight-for-height.

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Conclusion: The results presented suggest that the impacts of mining on child health vary throughout the mine's life cycle. Mining development likely contributes positively to the income and livelihoods of the impacted communities in the initial years of mining operations, particularly the prospection and construction phase; these potential benefits are likely to be at least partially offset by food insecurity and environmental pollution during early and later mining stages, respectively. Further research is warranted to better understand these health impacts and to identify policies that can help sustain the positive initial health impacts of mining projects in the long term.

Keywords: Child morbidity, Child mortality, Demographic and health survey, Diarrhoea, Mining, Nutrition, Sub-Saharan Africa

Introduction

The African continent holds one-third of global natural resources [1, 2] and hosts more than 2000 industrial mining projects at different development stages [2, 3]. This number might further increase with the growing demand for various minerals to promote a low-carbon future [1]. While the extraction of natural resources represents an opportunity for countries rich in natural resources in sub-Saharan Africa (SSA), the impact of large-scale mining projects on the health of young children remains unclear.

On the one hand, mining projects can positively influence determinants of health and, thus, improve child health. For example, the development of mining projects has the potential to increase the share of workers with regular incomes – including women of reproductive age [4, 5] – and, thus, improves households' capacity to buy healthier foods, access health care, and send the children to school [5–7]. Furthermore, mining projects can improve housing conditions, including proper sanitation and safe water [8, 9]. In turn, better housing, sanitation, and water conditions can reduce the incidence of environment-related diseases such as respiratory infections, diarrhoeal diseases, malaria, and undernutrition [10–12].

On the other hand, it has been reported that mining activities can have adverse effects on child health and development [13, 14]. For example, mining activities can negatively affect local and regional agricultural production through environmental degradation and changes in land use [15, 16]. Consequently, food insecurity can increase, which is of particular concern for young children and pregnant women [6, 17, 18]. Additionally, mining projects have high energy and water demand, potentially triggering local competition over existing resources, including access to safe drinking water [19–21]. In the contexts where natural resources are extracted, adverse environmental impacts such as air, noise, and water pollution are a significant concern for child health [20, 22, 23]. Studies found that exposure to environmentally poor conditions during the early stages of human life, including in-utero exposure, can result in long-term adverse effects on cognitive abilities, respiratory functions, and nutritional status [14, 17, 24].

Estimated impacts of mining projects on child health outcomes, such as diarrhoea, respiratory infections, and child mortality, have been highly heterogeneous to date [6, 25, 26]. One reason for the high heterogeneity seen in the empirical literature is the often differential focus on early (opening phase) vs. late (extraction phase) of mining [27, 28]. It also seems plausible that the heterogeneity of the currently available results is due to the narrow focus of current studies either on just one country or one mineral (such as gold) or both [6, 7, 14, 29].

This paper aims to understand the impacts of mining activities on child health using data from 81 mining projects launched across the sub-Saharan African region between 2002 and 2019. More specifically, we pursued the following research questions: (i) What is the effect of mine opening on child morbidity and mortality in sub-Saharan African countries? (ii) How many years before or after the launch of extractive activities can health impacts be detected?

Methods

Data sources and management

This study was conducted by combining two different georeferenced data sources, namely: (i) the socio-demographic and health data from Demographic and Health Survey (DHS) and (ii) mining data from the Standard & Poor's Global Market Intelligence (S&P GMI) Mining Database [3]. Both data sets were restricted to SSA.

Socio-demographic and health data

The DHS program conducts nationally and regionally representative household survey data in over 70 low- and middle-income countries. The DHS surveys are conducted following a two-stage cluster random sampling strategy, randomly selecting households within randomly selected enumeration areas. In most countries, DHS surveys are conducted every 4–6 years. The survey datasets are available on request on the website of the DHS program (www.dhsprogram.com). For this study, we use data from all DHS standard surveys from SSA for which geographic coordinates were available as of March 2020 (see Fig. 1, panel A). All household and child datasets were combined with the corresponding geographic data to merge with the mining data. Of note, the DHS program introduced random noise to the cluster coordinates to ensure the privacy of the respondents: in urban settings, clusters' coordinates are shifted up to 2 km (km), and in rural areas, clusters are typically displaced by 5 km.

Mining data

The proprietary mining dataset was accessed through a subscription to the S&P Global Market Intelligence platform (www.spglobal.com) [3]. The mining data comprises four primary indicators: geographic point location (Global positioning system, GPS) coordinates, extracted commodities, and historic mining activities between 1980 and 2019 (e.g., mine opening and closure years). We set the year of mine activation (i.e., initiation of exploration and evaluation activities) at 10 years before the reported extraction onset, i.e., the earliest year of the operation phase with reported extraction or production. We did this, aiming to include the prospection and construction phase of the project. We created a sub-sample of mines that opened within the period during which DHS data were available (i.e. 1986–2019). Finally, mines located closer than 20 km from another mine were excluded to avoid overlapping impact areas (see Fig. 1, panel B). Panel A of Fig. 1 shows the 81 mines analysed by primary commodity extracted (coal ($N = 5$), diamonds ($N = 7$), metals ($N = 59$), and other mines ($N = 10$)).

Merging of datasets by spatial analysis strategy

The GPS coordinates for each DHS survey cluster and the mine point locations were used to match all surveyed households and children to one or several mines. DHS clusters within 50 km of the distance of each mine were selected. Based on previous studies showing that impacts are centralised within 10 km from a mining, project we set the treatment group within this distance range [4, 6–8, 14, 17, 30, 31]. Hence, clusters within 10 km from the mine were classified as "impacted clusters" (or treated), while clusters at 10–50 km distance were classified as "comparison clusters" (or controls). To assess the impact of mine opening events on child health outcomes, we restricted our analysis to mines with DHS records before and after the mine opening year. Figure 1 exemplifies the selection of data around mining projects in Sierra Leone. Figure 2 summarises the overall data set construction process. Data merging was done using ArcGIS Pro (Version 2.2.4, Environmental Systems Research Institute, Redlands, CA, USA).

Study design

This is a quasi-experimental difference-in-difference (DiD) study comparing child health outcomes in areas directly surrounding mines to more distant locations from the same regions before and after mine activation [32, 33]. The primary parameter of interest is the interaction term between the DHS cluster's proximity to a mine and the post, i.e., observations made after the mine was activated. The interaction term estimates the additional change (improvement) in health outcomes seen in areas close to the mines relative to other areas nearby but outside of the direct influence of the mines. The resulting estimates can be given causal interpretation as long as the common trend assumption holds; i.e., as long as the treatment (within 10 km) and control areas (10–50 km from mines) would have experienced the same

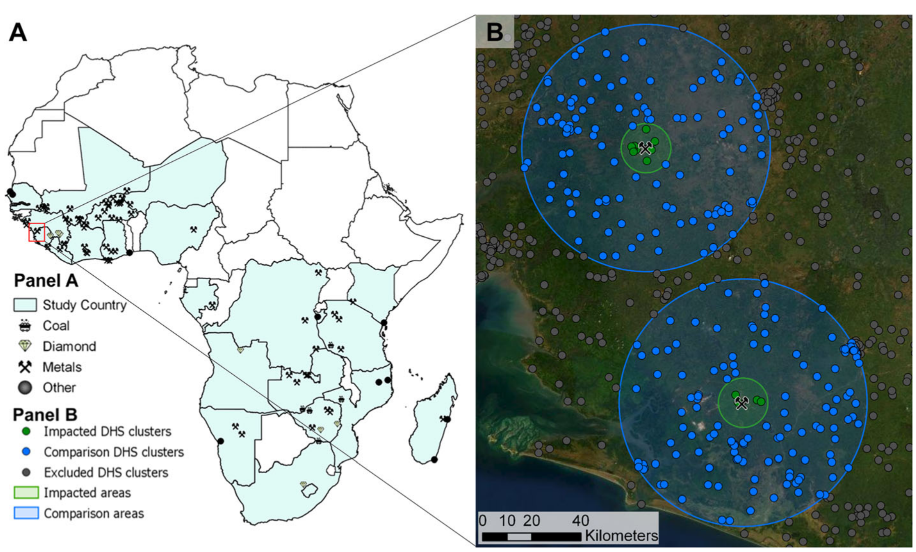

Fig. 1 Spatial distribution of mines (panel A) and visualisation selected DHS clusters (panel B)

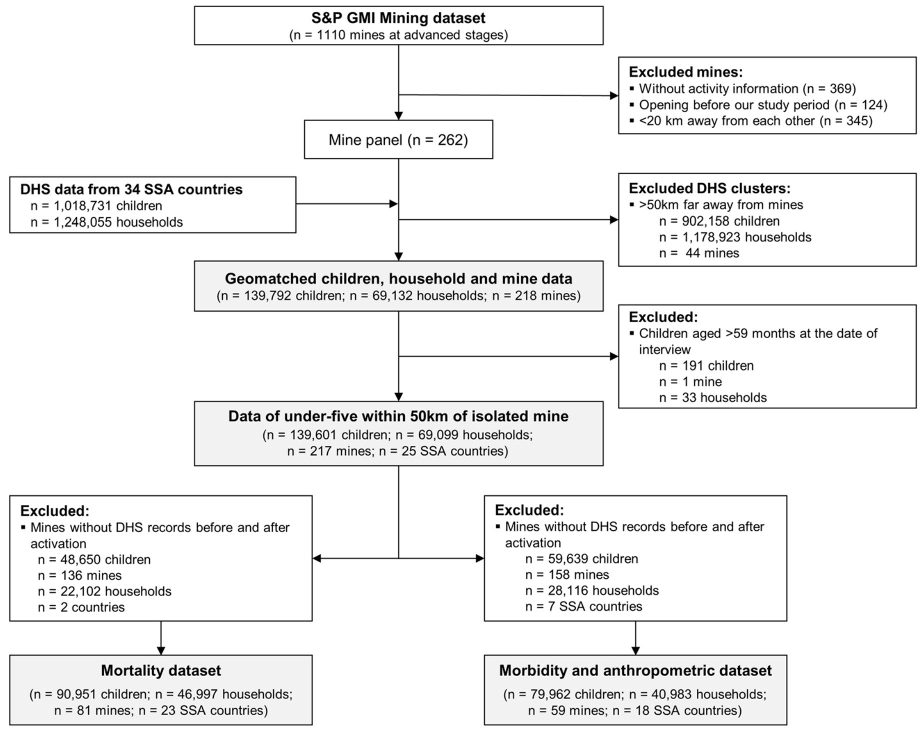

Fig. 2 Dataset merging strategy. Note: children can occur in multiple comparisons. See a description of the matching process below

changes in health outcomes in the absence of the mining project.

Selected variables

Outcome variables

In the present study, our centred attention is three primary child health outcomes. Firstly, we analysed child mortality indicators. All DHS surveys record all children born to the mothers in the last five years and the time point of any child death. Based on the information for age-at-death included in the DHS data, we computed a dummy variable indicating age-specific survival status (i.e. died or alive) for neonates (0–30 days), post-neonates (1–11 months), and children (12–60 months). While we kept the original DHS definition for under-five and child mortality [34], we computed neonatal and post-neonatal mortalities as children who died before reaching the age of 1 and 12 months, respectively. To calculate post-neonatal and child mortality rates, we only included children that had survived the first month or the first year, respectively. Missing data for children's age at death was imputed using a hot deck approach by taking the same age at death as the last child encountered the same birth order in the data file [35].

Secondly, we analysed child morbidity indicators. The DHS datasets include morbidity data for all children under-5 years living at the survey time. We used information on whether a child experienced diarrhoeal or cough episodes in the last two weeks before the survey date. Of note, "don't know" responses were recoded into "missing values".

Thirdly, we analysed child anthropometrics data: to compute the z-scores of height-for-age, weight-for-height, and weight-for-age, DHS surveys collect data on height (in centimetres) and weight (in kilograms) for all living children aged under-five years in the household and the age of the child in months. Height-for-Age (HAZ), Weight-for-Age (WAZ), and Weight-for-Height (WHZ) z-scores were then calculated using standardised reference growth curves [35].

Exposure variables

The primary exposure variable in our analyses was the interaction of the distance to the mine (impacted and comparison clusters) and the mine's activity status at the year of childbirth (for child mortality) and the year of DHS survey (for morbidity and anthropometric indicators). Two variable definitions were used to determine the mine's activity status. For the primary analyses, mine activation (including the planning, exploration, prospection, and construction activities) was assumed to be at 10 years before the launch year (year zero) of mineral extraction (from now on referred to as "extraction onset"). Therefore, children born or surveyed less than 10 years before the extraction onset or later were considered exposed to an active mine, while children born/surveyed before were used as the reference group. The active mining phase was further divided into four phases corresponding to 5-year intervals for secondary analysis. These phases were defined relative to the year of extraction onset, namely: (i) the planning phase – 9 to 5 years before the extraction onset, (ii) prospection and construction phase – 4 years to extraction onset year, (iii) early extraction phase - between 1 to 5 years after the extraction onset and (iv) advanced extraction phase - more than 5 years after the extraction onset. The last phase was summarised in one category due to the low sample size. As for the dichotomous temporal categories, the time before mining activation (i.e., 10 years or more before the extraction onset) was used as the reference group.

Covariates

Many covariates were included in the analysis to adjust for child, maternal, and household characteristics. Child-level covariates included sex, age in completed months, twin birth, and a child's birth order. Child age and birth order variables were recoded into 5 and 6 categories. At the maternal level, the included covariates were the highest education level, maternal age in five year-groups, and the total number of children born to women. We merged the "higher education" with "secondary education" responses and dichotomised the number of children at a cut-off value of five and above. Lastly, the household characteristics included were wealth index quintile and household location (i.e., rural vs urban). Beyond covariates, we included the mine fixed effect term in all models to account for spatial (i.e., mine location) and year fixed effect to account for temporal (i.e., year of the survey and year of childbirth) variability.

Statistical analysis

The descriptive statistics for child health outcomes and covariate variables were double stratified by mine activation status and the distance between the DHS cluster and the mine. Logistic maximum likelihood models for binary outcomes variables (i.e., mortality, diarrhoeal, and cough episodes) and ordinary least-squares linear regression models for continuous outcome variables (i.e., anthropometric z-scores) were estimated. The regressions control for child-, maternal- and household-level factors. In addition, mine and year (childbirth year for mortality outcomes and survey year for morbidity and anthropometric outcomes) are included as fixed effects, respectively.

We assume that there are similar trends in the outcome variables across years in the absence of a causal effect induced by the presence of the mine activation [6, 7, 14, 33] and that the location of the mine projects and their activity status are not systematically correlated with other factors affecting our main outcome variables [33]. We tested this assumption by plotting child health outcomes stratified by DHS cluster's proximity to the mine and mine activity status against the mine life stages periods.

Main specification

In the main analysis, we investigated the child health impact of mine activation using the interaction between the clusters' distance to the mine and the dichotomous mine's activity status at the year of childbirth for mortality analysis and the DHS survey year for morbidity and anthropomentric analysis (i.e., active vs non-active mine). This approach allowed us to compare the change in the prevalence of child health outcomes between the treatment group (interaction term takes the value one) and the control group (interaction term takes the value zero).

Alternative specification

For the secondary analysis, an alternative specification was used to investigate child health impact throughout the mine life stages (time-varying effects of mine exposure). For this purpose, the interaction term between the clusters' distance to the mine and the four-phased mine's activity status (planning, prospection and construction, early extraction, and advanced extraction phases) was used. In this approach, the prevalence of child health outcomes of each treatment group (interaction terms take values between 1 and 4) is compared against a unique control group (interaction term takes the value zero).

Sensitivity analysis

Given that mines may affect populations beyond the predefined 10 km boundary, we explore alternative exposure definitions in our sensitivity analysis. Specifically, we exclude these areas from the analyses by introducing an increasingly large buffer of potentially affected areas (i.e. 10–15 km, 10–20 km, and 10–25 km) around our treatment areas. This should also reduce misclassification concerns related to up to 5 km random noise added to DHS cluster coordinates.

The regression models were estimated using the statistical software STATA version 14.2 (Stata Corporation, LLC, College Station, TX, USA). Statistics are reported as Odds Ratio (OR; logistic regression) and beta coefficients (linear regression) where applicable, with 95% Confidence Intervals (95% CI) clustered at the survey-cluster level. *P*-values lower than 0.05 were considered significant.

Results

Descriptive statistics

Two separate datasets were constructed and used in the study: (i) a data set focusing on child mortality and (ii) a data set containing all available information on childhood morbidity and anthropometric datasets (Fig. 2). Below, the descriptive statistic of the childhood mortality dataset is outlined, while the descriptive statistic of the childhood morbidities and anthropometrics is given in the Additional File 1.

The final child mortality dataset contains a subset of data from 72 cross-sectional DHS datasets from 23 out of 34 SSA countries (67.6% coverage) (see Table 1). Ninety thousand nine hundred fifty-one children from 46,997 households around 81 mining projects were included. The Additional File 2 shows the complete list of included mines, country location, the year of extraction onset, the primary extracted commodities, and the total number of observations before and after mine activation. Some clusters with few observations were included in some countries, such as Gabon and South Africa, most probably located near a mine in a neighbouring country.

The main descriptive statistics for child, mother and household-level characteristics are presented in Table 2. Most children (70.1%; $N = 63,790$) were born after mine activation. Table 2 also shows some differences among comparison and impacted groups in pre and post-mine activation periods. Overall, 3.4% ($N = 3095$) of children were born close to active mines. Child mortality was similar in impacted and comparison areas before mine activation and improved over time (was on average, lower after mines opened).

Child mortality

The time and spatial trends of under-five and age-specific crude mortality rates (deaths/1000 live births) in impacted and comparison groups are illustrated in Fig. 3. Similar mortality rates before mine activation are seen for under-five (panel A) and child mortality (panel D). An overall positive impact of mine activation is observed for all mortality indicators. Indeed, a noteworthy drop in the crude under-five mortality rate is observed during the advanced extraction phase in areas close to active mines (see panel A, Fig. 3). The same effect is observed during the prospection and construction phase and the

Table 1 Dataset composition, including country name, country code, survey years, and total observations per country

Country name and DHS code	Survey years	Observations	Percentage
Angola (AO)	2007, 2016	173	0.19
Burkina Faso (BF)	1993, 1998, 1999, 2003, 2010, 2014, 2017, 2018	17,885	19.66
Burundi (BU)	2010, 2011, 2012, 2013, 2016, 2017	7902	8.69
Congo Democratic Republic (CD)	2007, 2013, 2014	448	0.49
Ivory Coast (CI)	1994, 1998, 1999, 2012	1347	1.48
Gabon (GA)	2012	333	0.37
Ghana (GH)	1993, 1994, 1998, 1999, 2003, 2008, 2014, 2016	5272	5.80
Guinea (GN)	1999, 2005, 2012, 2018	5074	5.58
Kenya (KE)	2003, 2008, 2009, 2014, 2015	2767	3.04
Liberia (LB)	2006, 2007, 2008, 2009, 2011, 2013, 2016	4476	4.92
Lesotho (LS)	2004, 2009, 2014	29	0.03
Madagascar (MD)	1997, 2008, 2009, 2011, 2013, 2016	1150	1.26
Mali (ML)	1995, 1996, 2001, 2006, 2012, 2013, 2015, 2018	14,343	15.77
Mozambique (MZ)	2011, 2015, 2018	905	1.00
Nigeria (NG)	2003, 2008, 2013, 2015, 2018	946	1.04
Niger (NI)	1992, 1998	71	0.08
Namibia (NM)	2000, 2006, 2007, 2013	172	0.19
Sierra Leone (SL)	2008, 2013, 2016	3402	3.74
Senegal (SN)	1993, 1997, 2005, 2008, 2009, 2010, 2011, 2012, 2013, 2014, 2015, 2016	11,918	13.10
Tanzania (TZ)	1999, 2007, 2008, 2010, 2011, 2012, 2015, 2016, 2017	3132	3.44
South Africa (ZA)	2016	5	0.01
Zambia (ZM)	2016, 2016, 2016, 2016	1538	1.69
Zimbabwe (ZW)	1999, 2005, 2006, 2010, 2011, 2015	7663	8.43
Total		90,951	100.00

Table 2 Descriptive statistics for selected maternal and child factors

Variables	Total *n* = 90,951	Birth before mine activation (*n* = 27,161)		Birth after mine activation (n = 63,790)	
		Impacted [0–10 km]	Comparison [10–50 km]	Impacted [0–10 km]	Comparison [10–50 km]
		n = 1073	*n* = 26,088	*n* = 3095	*n* = 60,695
Child mortality indicators					
Child death (0–59 months)	6995 (7.7%)	125 (11.7%)	2848 (10.9%)	166 (5.4%)	3856 (6.4%)
Neonatal death (0–30 days)	2699 (3.0%)	58 (5.4%)	977 (3.8%)	66 (2.1%)	1598 (2.6%)
Post-neonatal death (1–11 months)	2314 (2.6%)	31 (3.1%)	963 (3.8%)	57 (1.9%)	1263 (2.1%)
Child death (12–59 months)	1982 (2.3%)	36 (3.7%)	908 (3.8%)	43 (1.5%)	995 (1.7%)
Child characteristics					
Child is male	46,149 (50.7%)	521 (48.6%)	13,164 (50.5%)	1556 (50.3%)	30,908 (50.9%)
Child is single birth	87,585 (96.3%)	1031 (96.1%)	25,099 (96.2%)	2994 (96.7%)	58,461 (96.3%)
Child age (months): n (mean; sd)[¥]	83,956 (28.2; 17.3)	948 (31.2; 17.9)	23,240 (30.7; 17.4)	2929 (27.4; 17.2)	56,839 (27.2; 17.1)
Birth order of a child: n (mean; sd)	90,951 (3.5; 2.4)	1073 (3.9; 2.5)	26,088 (3.9; 2.6)	3095 (3.3; 2.2)	60,695 (3.4; 2.3)
Maternal characteristics					
Mother's age (years): n (mean; sd)	90,951 (29.0; 7.0)	1073 (29.1; 7.3)	26,088 (29.2; 7.1)	3095 (28.7; 6.8)	60,695 (28.9; 7.0)
Mother no education	52,274 (57.5%)	738 (68.8%)	17,722 (67.9%)	1498 (48.4%)	32,316 (53.3%)
Mother primary education	21,180 (23.3%)	184 (17.2%)	4770 (18.3%)	773 (25.0%)	15,453 (25.5%)
Mother secondary and higher education	17,492 (19.2%)	151 (14.1%)	3596 (13.8%)	824 (26.6%)	12,921 (21.3%)
Mother born less than 5 children	57,898 (63.7%)	653 (60.9%)	15,634 (59.9%)	2135 (69.0%)	39,476 (65.0%)
Household (HH) characteristics					
HH wealth: poorest quintile	17,452 (19.4%)	272 (25.4%)	4643 (18.4%)	529 (17.1%)	12,008 (19.8%)
HH wealth: second poorest quintile	19,600 (21.8%)	224 (20.9%)	5313 (21.1%)	684 (22.1%)	13,379 (22.0%)
HH wealth: third quintile	18,041 (20.0%)	167 (15.6%)	5039 (20.0%)	655 (21.2%)	12,180 (20.1%)
HH wealth: fourth quintile	17,011 (18.9%)	256 (23.9%)	4904 (19.5%)	708 (22.9%)	11,143 (18.4%)
HH wealth: fifth quintile (richest)	17,957 (19.9%)	154 (14.4%)	5299 (21.0%)	519 (16.8%)	11,985 (19.8%)
HH location is rural	62,644 (68.9%)	869 (81.0%)	18,014 (69.1%)	2157 (69.7%)	41,604 (68.6%)

¥ Live children only; sd – standard deviation

Descriptive statistics are stratified by time to mine activation (i.e., ten years before the extraction) and the DHS clusters' distance to the mining sites. Data from 72 Demographic and Health Surveys from 23 SSA countries. The included DHS data was collected between 1992 and 2018 and restricted to clusters within 50 km from isolated mines (i.e., mines separated at a minimum distance of 20 km from each other). All measures represent unweighted sample proportions

advanced extraction phase for crude neonatal mortality (see panel B, Fig. 3). A similar trend is observed for older children (Fig. 3, panels C and D), except for an observed considerable decline during the planning and early extraction phases for child and post-neonatal crude mortality rate, respectively.

Table 3 shows the average impact on child mortality indicators. On average, mine activation is associated with lower odds for neonatal mortality rate (aOR: 0.55, 95% CI: 0.37–0.83; column (2)). No statistically significant changes were observed for under-five (column (1)), post-neonatal (column (3)), and child (column (4)) mortality overall.

Table 4 shows estimated impacts stratified by time relative to the start of mine extraction, i.e., the year of extraction onset. For neonatal mortality, we find largest reductions during the prospection and construction phase (aOR: 0.43, 95% CI: 0.25–0.75), as well as in the advanced extraction phase (aOR: 0.10, 95% CI: 0.02–0.61; column (2)). Post-neonatal and child mortality appear to increase slightly, but the rise is not statistically significant.

Child morbidity

Figure 4 shows the relative change in diarrhoea (panel A) and cough (panel B) prevalence over time (years before and after mine activation) and cluster proximity (0–10 km and 10–50 km) at the year of the DHS survey. Overall, diarrhoea prevalence in impacted areas declined considerably after mine activation compared with diarrhoea cases in comparison areas. Although similar in both areas over mine stages, a decline is also observed for cough prevalence.

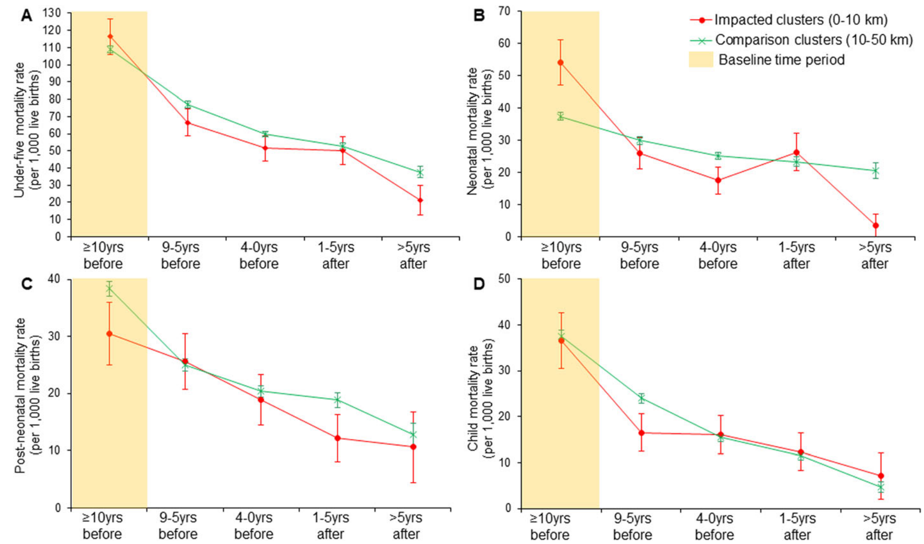

Fig. 3 Time and spatial trend on crude mortality rate. Under-five mortality rate (panel A) and crude age-specific neonatal (panel B), post-neonatal (panel C), and child (panel D) mortality rates. The time corresponds to years relative to extraction onset (x-axis). The yellow shade illustrates the baseline period used in the regression models. Error bars show standard errors clustered at the survey-cluster level

The impacts of the mine activity status on the anthropometrics mean z-scores are shown in panels C-E of Fig. 4. The trend of the mean HAZ is shown in panel C and ranges from − 1.6 and − 0.9 standard deviations (SDs) over the study period. When compared to children in comparison areas (i.e., 10–50 km away), mine activation seems to trigger a rapid decrease in mean HAZ, followed by an increase, but similar trends between the two groups.. The mean WAZ decreases after mine activation among children living nearby (0–10 km) but remains similar to those living far from active mines. Of note, the mean WAZ increases substantially soon after the extraction onset.. Moreover, the mean WAZ is above − 1.2, but below − 0.4 SDs, an indication of a low probability of underweight and overweight children over the study period (Fig. 4, panel D). The anthropometric WHZ seems to be much more positively affected than HAZ and WAZ measures (see Fig. 4, panel E), ranging from − 0.5 to 0.2 SDs over the study period. Again, mine activation seems to trigger an increase in the mean WHZ. It is important to note that the mean WHZ among children living close to an active mine remains higher over the study periods than children in comparison areas, nevertheless similar between the period before mine activation and in the advanced extraction

Table 3 Estimates of association between mine exposure and child mortality indicators using the main specifications

Interaction (proximity*active)$	(1) Under-five mortality (0–59 months)	(2) Neonatal mortality (0–30 days)	(3) Post-neonatal mortality (1–11 months)	(4) Child mortality (12–59 months)
Crude model†	0.78	0.55**	1.11	0.86
	(0.58–1.04)	(0.36–0.83)	(0.69–1.80)	(0.52–1.43)
Observations	90,951	90,951	88,252	85,938
Adjusted model‡	0.88	0.55**	1.22	1.17
	(0.68–1.14)	(0.37–0.83)	(0.81–1.86)	(0.75–1.82)
Observations	90,056	89,812	87,281	82,558

* p < 0.05, ** p < 0.01
$ - interaction term between clusters' proximity (0–10 km) and the mine activity status at childbirth year; † – model including interaction term only; ‡ – model adjusted for gender, twin births, birth order, number of children ever born to mother, maternal age, maternal education, residence, wealth index, mine, and birth year
The treatment group corresponds to children born within 10 km from active mines. The reference group (control) are children born within a distance radius of 10 km before mine activation and those born 10–50 km away regardless of mine activity status
The estimates are relative to the year of childbirth using logistic regression models. The reported estimates are crude and adjusted odds ratio (OR), and the 95% confidence intervals (CIs) are shown in parentheses and are clustered at the survey-cluster level

Table 4 Estimates of association between child mortality indicators and the interaction of mining proximity (0–10 km vs 10–50 km) and the mine life stages using alternative specifications

Interaction (proximity*active)$	(1) Under-five mortality (0–59 months)	(2) Neonatal mortality (0–30 days)	(3) Post-neonatal mortality (1–11 months)	(4) Child mortality (12–59 months)
Close* planning phase (9–5 years before)	0.93	0.62	1.50	0.90
	(0.67–1.27)	(0.36–1.04)	(0.89–2.54)	(0.49–1.65)
Close*prospection and construction phase (4–0 years before)	0.84	0.43**	1.21	1.40
	(0.60–1.19)	(0.25–0.75)	(0.68–2.13)	(0.81–2.41)
Close*early extraction phase (1–5 years after)	1.04	0.81	0.87	1.67
	(0.68–1.58)	(0.46–1.43)	(0.43–1.78)	(0.68–4.12)
Close*advanced extraction phase (> 5 years after)	0.43	0.10*	0.89	1.17
	(0.16–1.18)	(0.02–0.61)	(0.30–2.68)	(0.30–4.51)
Observations	90,056	89,812	87,281	82,558

* $p < 0.05$, ** $p < 0.01$

$ - interaction term between clusters' proximity (0–10 km) and the mine activity status at childbirth year; All models are adjusted for child sex, twin births, maternal age, maternal education, residence, wealth index, birth order, number of children ever born to mother, mine, and birth year

The treatment group corresponds to children born within a distance radius of 10 km from active mines, categorised in four mine life stages. The reference group (control) are children born within 10 km before mine activation plus those born 10–50 km away regardless of mines' activity status

Mine life stages stratify all logistic regression estimations compared against the reference comprised of the interaction between clusters located at 10–50 km and all periods of mine life stages

The reported estimates are crude and adjusted odds ratio (OR), and the 95% confidence intervals (CIs) are shown in parentheses and are clustered at the survey-cluster level

phase. The mean WHZ is notably increased soon after the extraction onset.

Table 5 shows the logistic regression results for diarrhoeal and cough episodes (columns (1) and (2)) and the linear predictions for anthropometrics z-scores (i.e., HAZ, WAZ and WHZ) (columns (3–5)). We found an indication of significant protection for experiencing diarrhoea among children living near active mines. The risk for diarrhoea significantly decreases by 32% soon after mine activation (aOR: 0.68, 95% CI: 0.51–0.90) (column (1)). Although not significant, children living in mining areas seems to experience a decreased percentage points on their mean HAZ (column (3)) but increased WAZ and WHZ z-scores (columns (4 and (5)).

The time-specific variation's results for the interaction term between mine proximity to the survey cluster and the period of mine activity are illustrated in Table 6. We investigate the effect in four periods of 5-years each in the mine life stages. While the risk for diarrhoea decreases over time, the significant effect of the interaction on the risk for a child experiencing diarrhoea episodes is seen during the prospection and construction phase (aOR: 0.69, 95% CI: 0.49–0.97) (see Table 6, column (1)). Conversely, the risk for a child to experience cough episodes among those living close to an active mine is seen to increase over the study period, particularly during the advanced extraction phase, although not statistically significant (aOR: 1.51, 95% CI: 0.80–2.86).

While the effect of the interaction on children's nutritional indicators over time does not show a clear pattern, we found a significant decrease of 28 percentage points on the mean HAZ during the prospection and construction phase, an indication of an increased rate of children shorter for their age in this mining phase across mining areas (Table 6, columns (3)). It is worth noting that the percentage points of the mean z-score of weight-for-age and weight-of-height increase over the study period, although all statistically insignificant (Table 6, columns (4) and (5)).

Sensitivity analysis

Results of the regression model sensitivity analysis are presented in Fig. 5. In all comparisons, the first bar (green diamond) represents the baseline point estimates from Table 3 and Table 5. The remaining bars show results when excluding 10–15 km (red dot), 10–20 km (blue triangle) and 10–25 km (red square) areas. We do not observe significant changes in the estimated impacts on either outcome.

Discussion

This paper assessed the impact of 81 large-scale mining projects launched in 23 SSA countries between 2002 and 2019. We found that mine activation lowered the risk for neonatal mortality by 45% and the risk for childhood diarrhoea by 32% among children born and living within 10 km of an active mine compared to children living further away. However, no immediate impact on cough and nutritional status was seen. Looking more closely at the timing of observed changes in health outcomes, we observed that the risk for neonatal mortality reduced significantly during the early mining phases (by 53% in the

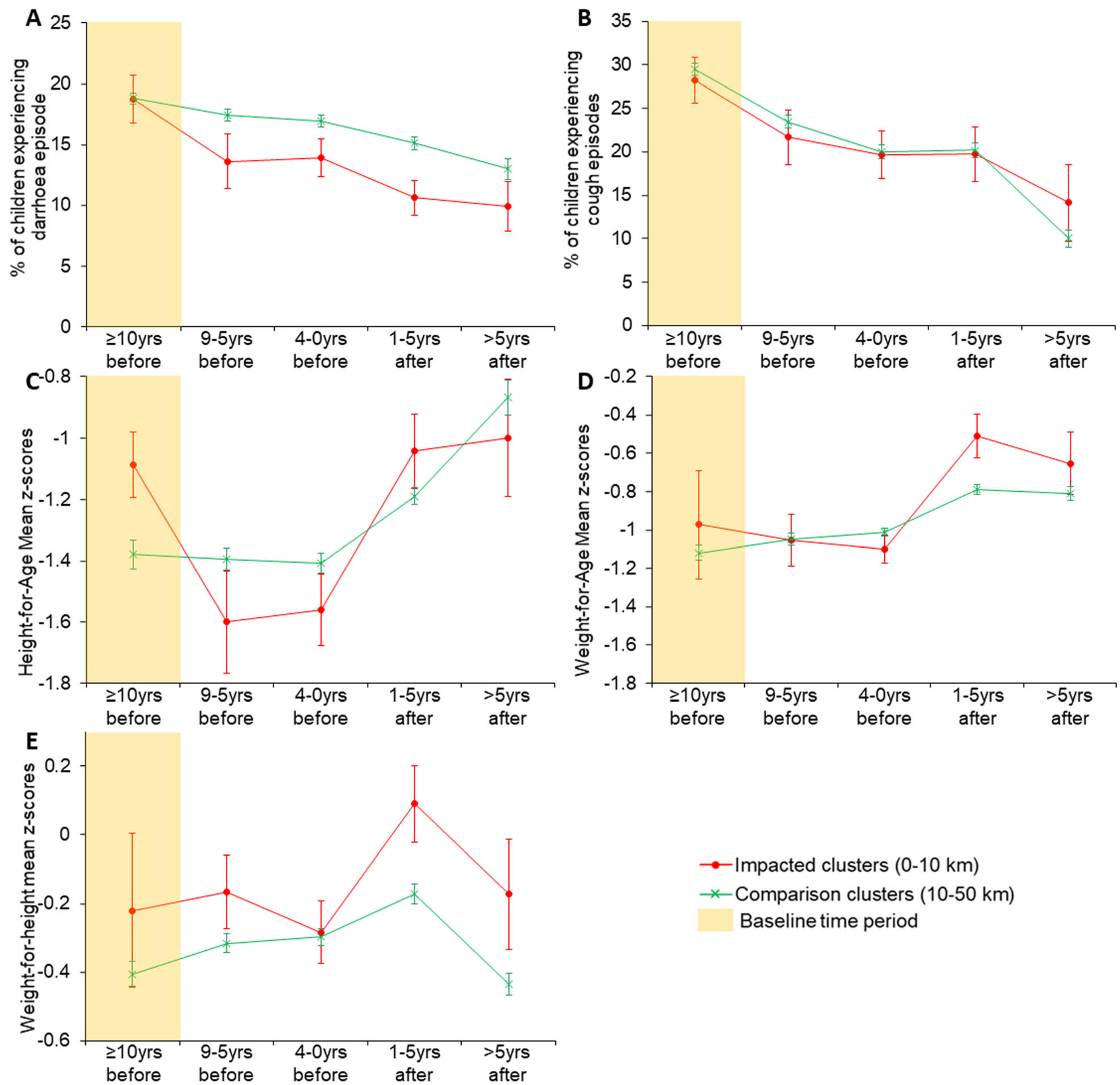

Fig. 4 Morbidity and child anthropometrics trends in impacted and comparison areas. Panel A, diarrhoea; panel B, cough; panel C, height-for-age z-scores; panel D weight-for-age z-scores and panel D, weight-for-age z-scores. Temporal comparison is relative to the mine extraction period (x-axis), and spatial comparison is relative to the cluster's proximity to the mine (impacted, 0–10 km vs comparison, 10–50 km areas). The yellow shade illustrates the baseline period used in the regression models. Error bars show standard errors clustered at the survey-cluster level

prospection and construction and 90% during the advanced extraction phases). The odds for childhood diarrhoea decreased by 31% and the mean height-for-age z-scores reduced by 28 percentage points during the prospection and construction phase.

The reduced neonatal mortality close to mines is in line with other studies using DHS data [4, 7], which have documented similar decreases in infant mortality in the first 6 and 12 months of children's life [4, 7]. The present study showed the primary benefits during the neonatal period, while no impacts on post-neonatal mortality were found. Another study investigating infant mortality around gold mines across SSA reported mixed effects, with impact heterogeneity primarily driven by mine location [6]. Our analysis shows that the lack of effect on post-neonatal mortality may come from the large and almost instant drops in mortality rates experienced by communities far away from mines, while no significant decline in the vicinity of the mines at the time of mine activation is observed. Drops in the risk for neonatal

Table 5 Estimates of association between child health outcomes, anthropometrics, and mining exposure using the main specifications

Interaction (proximity*active)$	(1) Diarrhoeal episodes	(2) Cough episodes	(3) Height-for-Age z-scores	(4) Weight-for-Age z-scores	(5) Weight-for-Height z-scores
Crude model†	0.74	1.01	−0.35*	−0.07	− 0.03
	(0.54–1.01)	(0.73–1.42)	(−0.62 - -0.08)	(− 0.64–0.50)	(−0.50–0.43)
Observations	59,868	58,593	35,027	35,609	34,594
Adjusted model‡	0.68**	1.01	−0.16	0.10	0.10
	(0.51–0.90)	(0.77–1.31)	(−0.40–0.08)	(−0.28–0.48)	(−0.28–0.48)
Observations	59,078	57,799	35,027	35,609	34,594

* $p < 0.05$, ** $p < 0.01$
$ - interaction term between clusters' proximity (0–10 km) and mine activity status at survey year; † – model including interaction term only; **‡** – adjusted for gender, child age, twin births, maternal age, maternal education, residence, wealth index, birth order, number of children ever born to mother
The treatment group corresponds to children located within a distance radius of 10 km from active mines at the DHS survey year. The reference group (control) are children located within a distance radius of 10 km before mine activation and those born 10–50 km away regardless of mines' activity status at the DHS survey year
Logistic regression models are used for estimating the odds ratio for diarrhoeal, and cough episodes (columns (1) and (2)) and linear regression models are used for anthropometric indicators (columns (3), (4), and (5)). The reported estimates for morbidities (i.e., diarrhoea and cough) are crude and adjusted odds ratios (OR), and the child's anthropometrics are crude and adjusted beta coefficients. The 95% confidence intervals (CIs) are shown in parentheses and are clustered at the survey-cluster level

mortality around recently opened mines are often linked with increases in local welfare and women empowerment [4, 7]. Studies have reported that women living close to mines are more likely to have formal education, have better jobs, earn more income and live in wealthier households [17, 31]. These changes could contribute to reducing neonatal mortality in mining areas, as observed in our study.

Our results suggest that the impact on neonatal mortality risk likely differs substantially across the mining life stages. We found mortality reductions mainly during the prospection and construction phase and the advanced extraction phases. The pre-extraction period typically corresponds to the mine investment period, which generates local employment and consequently household economic growth [6, 17, 36]. The post-extraction effects

Table 6 Estimates of association between child health outcomes, anthropometrics, and the interaction of mining proximity (0–10 km vs 10–50 km) and the mine life stages using alternative specifications

Interaction (proximity*mining phase)$	(1) Diarrhoeal episodes	(2) Cough episodes	(3) Height-for-Age z-scores	(4) Weight-for-Age z-scores	(5) Weight-for-Height z-scores
Close* planning phase (9–5 years before)	0.73	1.05	−0.20	0.03	0.03
	(0.48–1.10)	(0.74–1.48)	(− 0.53–0.14)	(−0.39–0.45)	(−0.42–0.47)
Close*prospection and construction phase (4–0 years before)	0.69*	0.96	−0.28*	− 0.00	0.06
	(0.49–0.97)	(0.67–1.39)	(−0.55 - -0.01)	(− 0.39–0.39)	(−0.33–0.46)
Close*early extraction phase (1–5 years after)	0.69	1.06	−0.04	0.22	0.17
	(0.47–1.02)	(0.70–1.61)	(− 0.34–0.26)	(−0.19–0.62)	(−0.23–0.57)
Close*advanced extraction phase (> 5 years after)	0.55	1.51	0.03	0.36	0.25
	(0.26–1.17)	(0.80–2.86)	(− 0.40–0.46)	(−0.09–0.82)	(−0.16–0.66)
Observations	59,078	57,799	35,027	35,609	34,594

* $p < 0.05$, ** $p < 0.01$
$ - interaction term between clusters' proximity (0–10 km) and the mine activity status at survey year
All models are adjusted for child sex, twin births, maternal age, maternal education, residence, wealth index, birth order, number of children born to mother, mine and birth year
The treatment group corresponds to children located within a distance radius of 10 km from active mines at the DHS survey year, categorised in four mine life stages. The reference group (control) are children located within a distance radius of 10 km before mine activation plus those born 10–50 km away regardless of mines' activity status at the DHS survey year
Mine life stages stratify all regression estimations compared against the reference comprised of the interaction between clusters located at 10–50 km and all periods of mine life stages
Logistic regression models are used for estimating the odds ratio for diarrhoeal, and cough episodes (columns (1) and (2)) and linear regression models are used for anthropometric indicators (columns (3), (4), and (5)). The reported estimates for morbidities (i.e., diarrhoea and cough) are crude and adjusted odds ratios (OR), and the child's anthropometrics are crude and adjusted beta coefficients. The 95% confidence intervals (CIs) are shown in parentheses and are clustered at the survey-cluster level

are more surprising, as mine-related pollution from extraction activities might increase over time and offset the positive employment and income effects seen in the initial stages [23]. During the latter stages of the mining projects, improvements can be explained by further economic development or health promotion activities supported by mines. In line with this hypothesis, it is argued that the size of primary exports by mines increases in later stages during the resource extraction phase [36, 37]. Consequently, they may contribute more to local and national economic growth and potentially ramp up corporate social responsibility activities, such as investments in local water and sanitation infrastructures [8, 36, 38, 39]. Overall, these results suggest that the impact of mining projects on local development [6, 40, 41] might be an opportunity for African countries to work towards the ambitious target of the 2030 Agenda for Sustainable Development to curb infant and under-five mortality [42].

Only a few studies examine the effect of mines on child morbidity and malnutrition [8, 14, 17]. Using similar data, Dietler and colleges found no effect of mining activities on diarrhoea prevalence [8]. Our findings suggest that mine activation reduces the risk for a child experiencing diarrhoeal episodes if living within 10 km. In addition, the impact of mining projects on childhood diarrhoea may be more prominent during the prospection and construction phase of the mine. Fluctuations of impacts according to the stage of mine developments have been reported by other studies [27, 28]. In our study, the differential effect size depending on the mining life stages may explain the absence of consistent findings in other studies [6, 43].

Although curable, diarrhoeal diseases remaina common cause of death for young children in SSA countries [6, 41]. Many of these deaths attributed to poor water and sanitation infrastructures [39, 44–47]. The opening of many large-scale mining projects in the last two decades represents an excellent opportunity for lowering both prevalence of and mortality due to diarrhoea [1, 2, 6]. The planning, construction, and early extraction periods are capital and investment-intensive. In addition, intense corporative social responsibility interventions on water and sanitation and job creation characterise these project phases and, thus, are more likely to decrease waterborne diseases such as diarrhoea [8, 38]. Further,

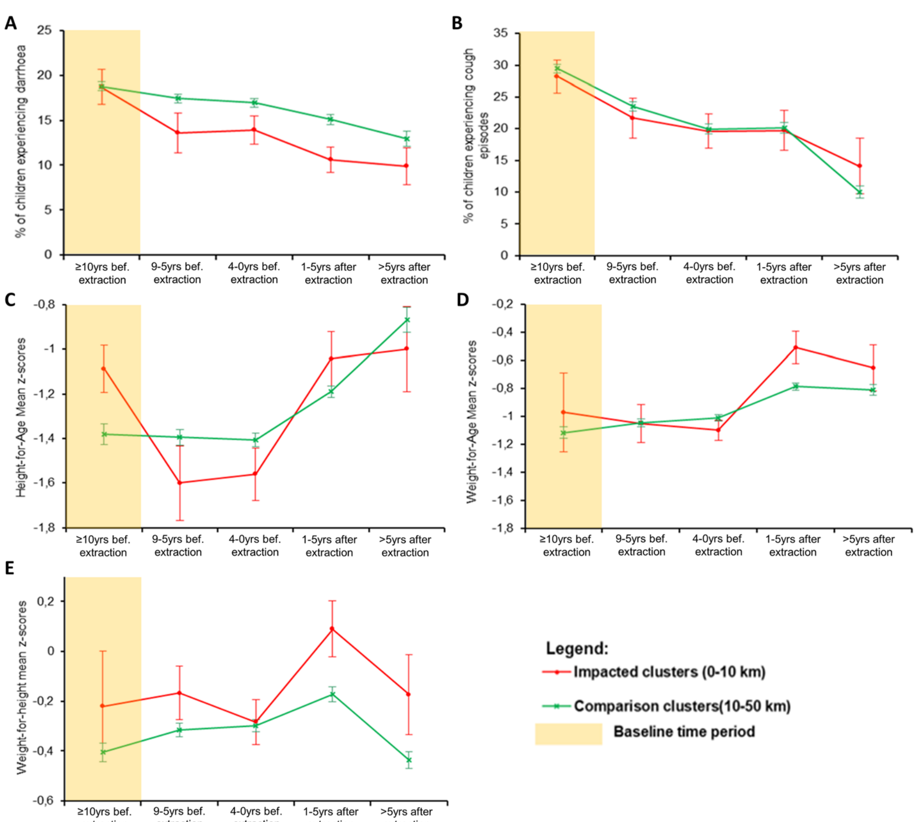

Fig. 5 Sensitivity analysis of all child health indicators using logistic (mortality and morbidities) and linear (anthropometrics) regression models. Estimates are adjusted Odds Ratios of under-five and age-specific mortality rates (panel A) and child morbidities (panel B) and adjusted beta coefficients of child anthropometrics (panel C). The baseline specification model (control group is the entire 10–50 km area) is included for comparison. Error bars show 95% confidence intervals clustered at the survey-cluster level. bef - before; yrs. - years

this economic development is concurrent with women's empowerment, which can facilitate investments in child health and, thus, disease prevention [4, 30, 43]. Further investigation is warranted to illustrate economic growth translation into health gain at the local level in industrial mining areas.

Contrary to diarrhoea, there was a sharp increase in the risk for cough episodes in impacted areas over the study period, particularly later in the advanced extraction phase, although not statistically significant. These results are similar to those of previous studies reporting increased likelihood for respiratory-related diseases in children living in mining communities [48, 49] and may reflect the increased levels of air pollution around active mines found in other studies [50–53]. Additionally, mining-related and other environmental pollution have been associated with poor child health outcomes, including respiratory diseases [23, 54, 55]. Our findings, however, point to a need for further research to better understand the distribution pattern across countries and different types of mines. In addition, managing air pollution around recently active mining projects could help reduce the respiratory-related disease burden among young children.

We found no evidence of the effect of mining on any nutrition indicator when using baseline specifications. However, when exploring the timing of observed changes, children 's growth appears more limited during the prospection and construction phase of the mine. Our findings are in line with those reported in other studies conducted in low and middle-income countries, which found that mining activities were associated with an increased rate of poor nutritional status of children born from mothers living close to large mines [17, 56]. However, these findings do not corroborate with those reported in a similar study conducted in the context of gold mines in Colombia [14]. Romero and Saavedra reported that living near active gold mines did not affect either low birth weight or stunting in newborns [14]. However, contrary to our findings, recent evidence suggests lower stunting and underweight rates in children living in mining communities [9]. Mixed-effects of mine operations on anthropometric indicators have also been reported in three SSA countries [6, 43]. These differences may partially be explained by differences in the empirical approach used across studies. We use a different temporal exposure definition (i.e., only records from less than ten years before the mine extraction phase are considered to be exposed to mine activities). Our strategy may have affected our results in two ways: [1] the selection strategy for the control group led to smaller sample size and reduced overall statistical power, and [2] more positively, by analysing only changes over time and abstracting from cross-sectional relationships between mining locations and general population and health characteristics.

The rapid change in the land use during the prospection and construction phase of mining projects, including land-grabbing by mining companies, environmental degradation, and structural shifts in income-generating activities, can lead to food insecurity and, thus, poor nutrition status, particularly for young children [16, 27, 57]. This land change and its effect is in line with our results showing an increase in the prevalence of stunted children during the prospection and construction phase. This period is usually considered the baseline period by most studies reporting improvement in the nutritional status of children living close to recently opened mining projects [8, 17, 43]. These differences can be explained by the fact that such a definition of temporal exposure can affect the estimated effect by allocating more stunted children to the control group and thus changing the estimated effect's direction and size. Our findings point to a need for further research to assess the temporal variations in childhood nutritional status in mining areas.

This study was guided by a well-known and extensively discussed methodology [4, 6–8, 14, 17, 30] to explore mine-induced changes in child health outcomes. The main contribution to the existing scientific literature is that the modified identification strategy and alternative specifications better investigate causal effects over the mine life stages. Nevertheless, our findings have several limitations. Firstly, our temporal exposure definition reduced the sample size and, thus, the statistical power of most of the performed analyses. Specifically, our strategy resulted in smaller sample size before mine activation, which did not allow us to see trends in the prevalence of health outcomes in the absence of the mining projects.

Similarly, a small sample size was also obtained for five years and later after the onset of extraction activities, limiting our analysis of desegregated observations at this period, i.e., between 5 and 10 years and more than ten years after the onset of extraction activities. At the same time, it allocated more children with 'positive' health outcomes to the treated group, which may have changed the direction and size of the estimates. Secondly, we focus on large-scale mining projects; however, a substantial proportion of the health-related effects may derive from artisanal and small-scale mining activities, which are often found in proximity to industrial mining projects [25, 45]. Thirdly, we did not exclude large cities from our sample, which could introduce some bias. Many factors may play a role in child health, and substantial differences exist between city and non-city settings. We could not adjust for several factors such as population density and urbanisation. Furthermore, self-reported data such as diarrhoea and cough are prone to recall and reporting bias. Lastly, the inaccuracy of mine GPS data and the coordinate reallocation by the DHS could have introduced errors and reduced our statistical power.

Conclusion and recommendations

The results presented in this paper suggest that the impact of mines on child health is complex and likely non-linear over time; i.e., significant effects can be found in some mine life stages but not in others. We find evidence that the launch of industrial mining projects accelerates the improvement of neonatal survival and reduction in the risk for childhood diarrhoeal in SSA countries, with significant contributions during the prospection and construction and in the advanced extraction phases. While the launch of industrial mining projects seems not to have any impact on childhood cough and nutritional status, our evidence points to an increase in stunting rate before the launch of extraction activities and increased rate of respiratory disease symptoms once extraction starts, reflecting an increase of food insecurity and environmental pollution, respectively. Therefore, health management plans with an emphasis on maintaining positive health impacts throughout the mining life stages and addressing the identified risks on respiratory and nutritional health in children are advisable.

On the other hand, the varying effects of industrial mining on child health outcomes throughout the mining life stages may reflect differential mine-related contributions to economic growth and community development over time. Further research aiming to provide more insights into the temporal effects of mine impacts and, thus, a better understanding of these complex dynamics of health impacts are recommended. These future studies should be powered by using longitudinal data to determine whether the association between these health outcomes and mining varies based on the mining setting (e.g., type of resource extracted, country location of the mine, preventative measures taken by the company). The studies should include health monitoring data that should be part of the mine's health mitigation and monitoring plan.

Abbreviations

aOR: Adjusted Odds Ratio; CA: California; CI: Confidence Interval; DHS: Demographic and Health Survey; DiD: Difference-in-Difference; GPS: Global positioning system; HAZ: Height-for-Age z-score; HH: Household; OR: Odds Ratio; S&P GMI: Standard & Poor's Global Market Intelligence; SD: Standard deviations; SSA: Sub-Saharan Africa; UNDP: United Nations Development Programme; USA: United State of America; WAZ: Weight-for-Age z-score; WHZ: Weight-for-Height z-score

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s12992-022-00797-6.

Additional file 1 Table A1. Descriptive statistics of childhood morbidities and anthropometrics**.**

Additional file 2 Table A2. Descriptive statistics of mine projects, including hosting country and primary commodity.

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Authors' contributions

Conceptualisation, H.C., D.D., M.S.W and G.F; methodology H.C., D.D., M.S.W and G.F; formal analysis, H.C., D.D., M.S.W and G.F; writing—original draft preparation, H.C. and D.D.; writing—review and editing, H.C., D.D., E.M., K.M., M.S.W and G.F; visualisation, H.C. and D.D.; supervision, M.S.W and G.F; funding acquisition, M.S.W. All authors have read and agreed to the published version of the manuscript.

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Availability of data and materials

In the present study, secondary data was used. All transformed, generated or analysed data during the study are included in this published article and the Additional Files 1 and 2. The full dataset is also available by request at the Demographic and Health Survey (https://dhsprogram.com/) and Standard & Poor's (S&P) Global Market Intelligence Mining websites (https://www.spglobal.com/).

Declarations

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

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Globalization and Health

CORRECTION

Open Access

Correction: Assessing the effects of mining projects on child health in sub-Saharan Africa: a multi-country analysis

Hermínio Cossa[1,2,3*], Dominik Dietler[1,2], Eusébio Macete[3,4], Khátia Munguambe[3,5], Mirko S. Winkler[1,2] and Günther Fink[1,2]

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Following publication of the original article [1], the authors flagged that the article had published with a duplicate of Fig. 4 in place of Fig. 5.

Figure 5 has now been corrected in the published article and may be found in this erratum.

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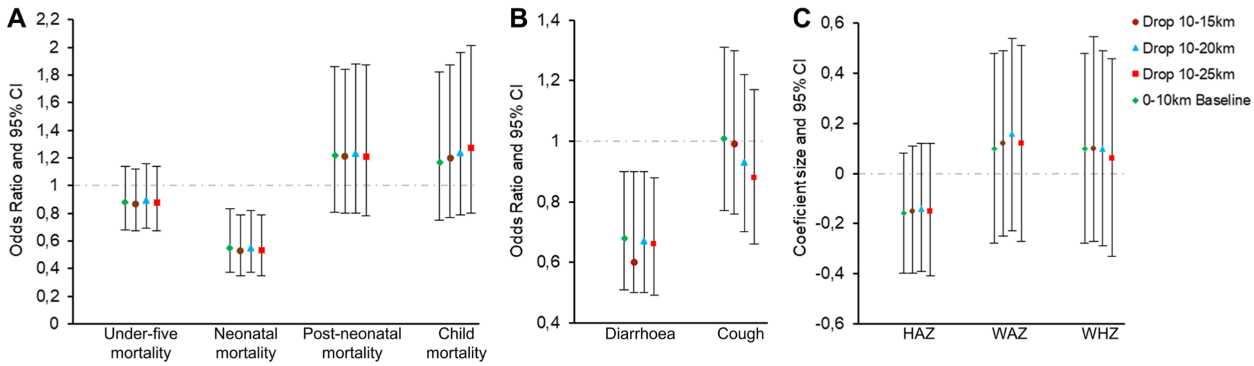

Fig. 5 Sensitivity analysis of all child health indicators using logistic (mortality and morbidities) and linear (anthropometrics) regression models. Estimates are adjusted Odds Ratios of under-five and age-specific mortality rates (**A**) and child morbidities (**B**) and adjusted beta coefficients of child anthropometrics (**C**). The baseline specification model (control group is the entire 10–50 km area) is included for comparison. Error bars show 95% confidence intervals clustered at the survey-cluster level. bef - before; yrs. - years

3.1 Additional file 1: Table A1.

Descriptive statistics for morbidity and the anthropometric dataset

The final child morbidity and the anthropometric dataset contains a subset of data from 63 cross-sectional DHS datasets from 18 out of 34 SSA countries (53%% coverage). A total of 79 962 children from 40 983 households around 59 mining projects were included.

The descriptive statistics for child, mother and household-level characteristics are presented in Table A1. Most children (76%; N=60 753) were recorded after mining activation. Among children recorded after mine activation, 4.4% (N=2 682) lived close to active mines, similar to those recorded before mine activation. Table A1 also shows differences between comparison and impacted groups in pre- and post-mine activation periods.

Data on childhood diarrhoea and cough were missing in 25 and 27 per cent of cases, respectively. For anthropometric measures, data were missing in more than 55% of recorded children. Missing data are due to the inclusion of non-standard DHS survey data in our primary dataset, such as the Malaria Indicators Survey (MIS) and Service Provision Assessment (SPA) surveys that do not record the above outcomes.

Diarrhoea and cough prevalence is lower in children close to active mining projects than in their faraway peers. In all groups, the mean anthropometric measures are above the benchmarks for child malnutrition.

Table A 1. Descriptive statistics for selected maternal and child morbidities and anthropometrics

Variables	Total n = 79 962	Survey before mine activation (n = 19 209)		Survey after mine activation (n = 60 753)	
		Impacted [0-10 km] n = 856	Comparison [10-50 km] n = 18 353	Impacted [0-10 km] n = 2 682	Comparison [10-50 km] n = 58 071
Childhood morbidities					
Child had diarrhoea recently [¥,a]	10 132 (16.9%)	136 (18.7%)	2 958 (18.8%)	226 (12.6%)	6 812 (16.3%)
Child had cough recently [¥,b]	13 321 (22.7%)	191 (28.2%)	4 281 (29.5%)	354 (19.7%)	8 495 (20.4%)
Child anthropometrics					
Height-for-Age z-scores: n (mean; sd) [¥,c]	35 027 (-1.3; 1.7)	243 (-1.1; 1.9)	6 162 (-1.4; 1.8)	1 118 (-1.4; 1.7)	27 504 (-1.3; 1.7)
Weight-for-Age z-scores: n (mean; sd) [¥,d]	35 609 (-1.0; 1.3)	253 (-1.0; 1.7)	6 359 (-1.1; 1.5)	1 110 (-0.9; 1.3)	27 887 (-1.0; 1.3)
Weigh-for-Height z-scores: n (mean; sd) [¥,e]	34 594 (-0.3; 1.4)	233 (-0.2; 1.8)	6 143 (-0.4; 1.5)	1 079 (-0.1; 1.3)	27 139 (-0.3; 1.3)
Child characteristics					
Child is male	40 589 (50.8%)	410 (47.9%)	9 289 (50.6%)	1 354 (50.5%)	29 536 (50.9%)
Child is single birth	77 023 (96.3%)	822 (96.0%)	17 660 (96.2%)	2 595 (96.8%)	55 946 (96.3%)
Child age (months): n (mean; sd) [¥,f]	73 877 (28.2; 17.3)	756 (27.8; 17.3)	16 318 (26.6; 17.1)	2 529 (28.6; 17.6)	54 274 (28.7; 17.2)
Birth order of a child: n (mean; sd)	79 962 (3.5; 2.4)	856 (3.8; 2.5)	18 353 (4.0; 2.6)	2 682 (3.4; 2.3)	58 071 (3.4; 2.3)
Maternal characteristics					
Mother´s age (years): n (mean; sd)	79 962 (29.1; 7.0)	856 (28.7; 7.3)	18 353 (29.0; 7.2)	2 682 (29.1 (6.7)	58 071 (29.1; 7.0)
Mother no education	47 209 (59.0%)	573 (66.9%)	13 279 (72.4%)	1 480 (55.2%)	31 877 (54.9%)
Mother primary education	17 915 (22.4%)	154 (18.0%)	2 994 (16.3%)	626 (23.3%)	14 141 (24.4%)
Mother secondary and higher education	14 833 (18.6%)	129 (15.1%)	2 080 (11.3%)	576 (21.5%)	12 048 (20.8%)
Mother born less than 5 children	51 028 (63.8%)	544 (63.6%)	10 839 (59.1%)	1 790 (66.7%)	37 855 (65.2%)
Household (HH) characteristics					
HH wealth: poorest quintile	14 760 (18.7%)	207 (24.2%)	3 039 (17.4%)	477 (17.8%)	11 037 (19.0%)
HH wealth: second poorest quintile	16 150 (20.4%)	182 (21.3%)	3 552 (20.3%)	541 (20.2%)	11 875 (20.5%)
HH wealth: third quintile	15 698 (19.9%)	129 (15.1%)	3 492 (20.0%)	578 (21.6%)	11 499 (19.8%)
HH wealth: fourth quintile	15 465 (19.6%)	204 (23.8%)	3 485 (20.0%)	609 (22.7%)	11 167 (19.2%)
HH wealth: fifth quintile (richest)	16 999 (21.5%)	134 (15.7%)	3 895 (22.3%)	477 (17.8%)	12 493 (21.5%)

HH location is rural	54 503 (68.2%)	694 (81.1%)	12 569 (68.5%)	2 022 (75.4%)	39 218 (67.5%)

¥ Live children only; sd – standard deviation

[a] missing data is 25.1%.
[b] missing data is 26.7%.
[c] missing data is 56.2%.
[d] missing data is 55.5%.
[e] missing data is 56.7%.

Figures are stratified by time to mine activation (i.e., ten years before the extraction period) and the DHS cluster´s distance to the mining sites. Data from 72 Demographic and Health Surveys from 18 SSA countries. The included DHS data was collected between 1992 and 2018 and restricted to clusters within 50 km from isolated mines (i.e., mines separated at a minimum distance of 20 km from each other). All measures represent unweighted sample proportions.

3.2 Additional file 2: Table A2

Descriptive statistics of mining projects, including hosting country and primary commodity

Table A2 shows the distribution of mining projects across the study area, including the name of each mine, the leading operating company, the opening year (start of production, primary ore extracted and the number of children whose demographic and health data were collected before and after opening.

Eighty-one mines operated by 64 mining companies in 22 sub-Saharan African countries were included in the study. The oldest mine (Homase Gold Mine, Ghana) was opened in 2002 and two mining projects from Mozambique (Chirodzi Coal Mine) and Burkina Faso (Wahgnion Gold Mine) were more recent in 2019. The most sought resources are Gold (43 mines), followed by Diamonds (seven mines), and Copper and Coal (5 mines each).

The number of children whose demographic and health data were collected before and after the start-up year ranges from 40 at the Otjikoto gold mine (Namibia) (0.04% contribution to the total) to 9 391 at the Tienfala iron ore mine (Mali) (10.3% contribution to the total number of children registered).

Table A 2. Descriptive statistics of mine projects, including hosting country and primary commodity.

Mine Name	Operator Name	Open Year	Country	Primary Commodity	Records Before Opening	Records After Opening	Total	Percent
Homase	GoldStone Resources Limited	2002	Ghana	Gold	95	1 321	1 416	1.56
Murowa	RioZim Limited	2004	Zimbabwe	Diamonds	1	421	422	0.46
Samira Hill	Societe de Patrimoine des Mines du Niger SA	2004	Niger	Gold	45	162	207	0.23
Loulo	Barrick Gold Corporation	2005	Mali	Gold	55	558	613	0.67
Ahafo	Newmont Goldcorp Corporation	2006	Ghana	Gold	153	523	676	0.74
Sengwa	Sengwa Colliery (Private) Limited	2007	Zimbabwe	Coal	17	168	185	0.20
Taparko	Nord Gold SE	2007	Burkina Faso	Gold	198	870	1 068	1.17
Bonikro	BDG Capital Limited	2008	Cote d'Ivoire	Gold	144	110	254	0.28
Bouroum	Nord Gold SE	2008	Burkina Faso	Gold	435	777	1 212	1.33
Hwini-Butre	Golden Star Resources Limited	2008	Ghana	Gold	151	445	596	0.66
Kalsaka/Sega	Perseus Mining Limited	2008	Burkina Faso	Gold	713	1 811	2 524	2.78
Plant 11	Trevali Mining Corporation	2008	Sierra Leone	Diamonds	124	1 761	1 885	2.07
QMM	Rio Tinto	2008	Madagascar	Ilmenite	38	510	548	0.60
Yaoure	Perseus Mining Limited	2008	Cote d'Ivoire	Gold	276	239	515	0.57
Youga	Avesoro Resources Inc.	2008	Burkina Faso	Gold	445	1 534	1 979	2.18
Bomboko	BDG Capital Limited	2009	Guinea	Diamonds	138	386	524	0.58
Buzwagi	Acacia Mining plc	2009	Tanzania	Gold	18	603	621	0.68
Inata	Balaji Group of Companies	2009	Burkina Faso	Gold	99	582	681	0.75
Mandala-Bouro	BDG Capital Limited	2009	Guinea	Diamonds	222	268	490	0.54
Douta Alluvial	Bassari Resources Limited	2010	Senegal	Gold	5	752	757	0.83
Essakane	IAMGOLD Corporation	2010	Burkina Faso	Gold	111	591	702	0.77
Old Nic	New Dawn Mining Corp.	2010	Zimbabwe	Gold	416	1 225	1 641	1.80
Tongon	Barrick Gold Corporation	2010	Cote d'Ivoire	Gold	76	100	176	0.19
Anjin Zimbabwe	Zimbabwe Mining Development Corp	2011	Zimbabwe	Diamonds	106	274	380	0.42
Guiro	Komet Resources Inc.	2011	Burkina Faso	Gold	298	726	1 024	1.13
Liberia Mines	ArcelorMittal	2011	Liberia	Iron Ore	288	1 744	2 032	2.23
Monastery	Thabex Ltd.	2011	South Africa	Diamonds	1	33	34	0.04
Nzema	BCM International Limited	2011	Ghana	Gold	141	178	319	0.35
Tienfala	Sahara Mining	2011	Mali	Iron Ore	2 662	6 729	9 391	10.33
Ambatovy	Sherritt International Corporation	2012	Madagascar	Nickel	81	330	411	0.45
Ansongo	Transatlantic Mining Corporation	2012	Mali	Manganese	201	289	490	0.54

Bagoe River	PG Alluvial Mining Plc	2012	Mali	Gold	364	909	1 273	1.40
Forecariah	China International Fund Management Co. Ltd.	2012	Guinea	Iron Ore	146	1 703	1 849	2.03
Kibali	Barrick Gold Corporation	2012	Dem. Rep. Congo	Gold	3	50	53	0.06
Kilimapesa	Goldplat Plc	2012	Kenya	Gold	243	1 645	1 888	2.08
Kodieran	Wassoul' Or SA	2012	Mali	Gold	171	204	375	0.41
Lubambe	EMR Capital Pty. Ltd.	2012	Zambia	Copper	10	456	466	0.51
Luremo	Luminas-Sociedade Mineira de Luremo	2012	Angola	Diamonds	5	168	173	0.19
New Luika	Shanta Gold Limited	2012	Tanzania	Gold	16	161	177	0.19
Trekkopje	Orano SA	2012	Namibia	U3O8	39	17	56	0.06
Vele	MC Mining Limited	2012	South Africa	Coal	75	153	228	0.25
Agbaou	Endeavour Mining Corporation	2013	Cote d'Ivoire	Gold	157	123	280	0.31
Akyem	Newmont Goldcorp Corporation	2013	Ghana	Gold	361	368	729	0.80
Graphmada	Bass Metals Limited	2013	Madagascar	Graphite	28	163	191	0.21
Hahotoe-Kpogame-Kpeme	Komet Resources Inc.	2013	Ghana	Phosphate	197	298	495	0.54
Kasempa	H and S Mining Ltd	2013	Zambia	Copper	7	62	69	0.08
Kwale	Base Resources Limited	2013	Kenya	Ilmenite	335	1 065	1 400	1.54
Perkoa	Trevali Mining Corporation	2013	Burkina Faso	Zinc	1 346	1 078	2 424	2.67
Sega	Perseus Mining Limited	2013	Burkina Faso	Gold	1 181	1 311	2 492	2.74
Arcturus	TN Securities (Pvt) Limited	2014	Zimbabwe	Gold	1 057	1 829	2 886	3.17
Grande Cote	TiZir Limited	2014	Senegal	Ilmenite	876	1 582	2 458	2.70
Maamba Collieries Ltd	ZCCM Investments Holdings Plc	2014	Zambia	Coal	24	299	323	0.36
Mazowe	Metallon Corporation Limited	2014	Zimbabwe	Gold	795	1 066	1 861	2.05
Namoya	Banro Corporation	2014	Dem. Rep. Congo	Gold	34	39	73	0.08
Otjikoto	B2Gold Corporation	2014	Namibia	Gold	9	31	40	0.04
Otjozondu	Rolek Resources Limited	2014	Namibia	Manganese	33	43	76	0.08
Bea Mountain	Avesoro Resources Inc.	2015	Liberia	Gold	437	2 270	2 707	2.98
Buckreef	Tanzanian Gold Corporation	2015	Tanzania	Gold	200	983	1 183	1.30
Kapulo	Mawson West Limited	2015	Dem. Rep. Congo	Copper	38	228	266	0.29
Trident - Sentinel	First Quantum Minerals Limited	2015	Zambia	Copper	45	148	193	0.21
Baobab	Avesoro Resources Inc.	2016	Senegal	Phosphate	3 404	3 687	7 091	7.80
Karma	Endeavour Mining Corporation	2016	Burkina Faso	Gold	898	1 018	1 916	2.11
Kokoya	Avesoro Resources Inc.	2016	Liberia	Gold	353	762	1 115	1.23
Nampala	Robex Resources Inc.	2016	Mali	Gold	663	443	1 106	1.22

Ancuabe	AMG Advanced Metallurgical Group N.V.	2017	Mozambique	Graphite	40	296	336	0.37
Balama	Syrah Resources Limited	2017	Mozambique	Graphite	61	331	392	0.43
Balogo	Avesoro Resources Inc.	2017	Burkina Faso	Gold	392	459	851	0.94
Fekola	B2Gold Corporation	2017	Mali	Gold	242	242	484	0.53
Franceville	Nouvelle Gabon Mining	2017	Gabon	Manganese	43	290	333	0.37
Gakara	Rainbow Rare Earths Limited	2017	Burundi	Lanthanides	1 142	6 940	8 082	8.89
Hounde	Endeavour Mining Corporation	2017	Burkina Faso	Gold	388	377	765	0.84
Yanfolila	Hummingbird Resources Plc	2017	Mali	Gold	409	353	762	0.84
Bel Air	Alufer Mining Limited	2018	Guinea	Bauxite	486	471	957	1.05
Boungou	SEMAFO Inc.	2018	Burkina Faso	Gold	247	181	428	0.47
Dian Dian	United Company RUSAL Plc	2018	Guinea	Bauxite	596	636	1 232	1.35
Imperial	Noble Group Limited	2018	Nigeria	Zinc	340	606	946	1.04
Mako	Resolute Mining Limited	2018	Senegal	Gold	398	922	1 320	1.45
Miniere Musoshi Kinsenda	Jinchuan Group International Resources Co. Ltd	2018	Dem. Rep. Congo	Copper	59	364	423	0.47
Rukwa Coalfield	Edenville Energy Plc	2018	Tanzania	Coal	227	403	630	0.69
Chirodzi	Jindal Steel & Power Limited	2019	Mozambique	Coal	75	102	177	0.19
Wahgnion	Teranga Gold Corporation	2019	Burkina Faso	Gold	713	435	1 148	1.26

4 Article 3: Perceived Impacts of Large-Scale Mining Activities on Maternal and Child Health Conditions in Mozambique: A Qualitative Study

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Currently, this manuscript is under review and has been improved

Abstract

Many countries in sub-Saharan Africa are currently endowing natural resource extraction projects (NREP) investments. While the economic boom resulting from the extractive industry is undeniable, potential adverse effects on maternal and child health (MCH) are a significant concern in affected communities. This study assessed the impacts of industrial mining projects on MCH as perceived by women of reproductive age and MCH nurses in Mozambique.

Following a qualitative research design, the study was conducted in 19 communities from four mining districts in Mozambique (Montepuez, Moma, Larde and Moatize). Data comprised (i) 19 focus group discussions (FGDs) with 207 women who were pregnant or had at least one child under five years of age; and (ii) 15 semi-structured interviews (SSIs) with maternal and child health (MCH) nurses. Qualitative data analysis followed a thematic approach based on coding with Nvivo 12.

Based on participants' voices, industrial mining projects were linked to various MCH conditions clustered in 21 groups. The most commonly reported conditions across study communities are the following groups: Sexually Transmitted Infections (STIs) and HIV/AIDS, gastrointestinal disorders, neurophysiologic, respiratory and cardiovascular. The extractive industry's impact on MCH was explained through various complex and interconnected mechanisms, including changes in individual, community, structural and environmental determinants of health. The perceived factors often involved mine-induced in-migration and socioeconomic and environmental conditions changes.

This paper provides an overview of perceived health conditions affecting MCH in communities close to Mozambique's industrial mining projects. The extractive industry's impact on MCH was explained through various complex and interconnected mechanisms, including changes in individual, community, structural and environmental determinants of health. Further research is warranted to elucidate better the dynamics of the identified mechanisms through which extractive projects affect MCH.

Key Words

Environmental Health, Industrial Mining, Immigration, Maternal and Child Health, Perceptions, Sexual Behaviour

Introduction

Many countries in sub-Saharan Africa have witnessed a boom in the industrial extractive sector over the past two decades (Andersson et al., 2015; Bihale, 2016; Roe, 2018; Extractive Industries Transparency Initiative (ITIE), 2020). The extensive discovery of mineral resources continues to attract foreign investment, considered essential for regional economic development and, thus, critical for improvements in various welfare indicators, including maternal and child health (MCH) (Yakovleva et al., 2017). This assumption aligns with the United Nations Development Programme 2015 report, which argued that private sector investments could improve health and contribute to sustainable development (United Nations Development Programme (UNDP), 2015).

Indeed, it has been shown that, in countries with a low human development index, a partnership between local health systems and industrial mining projects can drive significant improvement in MCH conditions in surrounding communities (i.e., villages, settlements, neighbourhoods or localities) (Foreit et al., 1991; Tarras-Wahlberg et al., 2017; Knoblauch et al., 2020). For example, quantitative econometric studies revealed that the implementation of industrial mining projects is often associated with reduced childhood malnutrition through increasing women´s economic empowerment (e.g., regular income from direct or indirect mining employment), contributing to improved food security (Tolonen, 2014; Kotsadam & Tolonen, 2016; Chuhan-Pole et al., 2017; von der Goltz & Barnwal, 2019). Additionally, studies using the Demographic and Health Survey (DHS) data from Sub-Saharan Africa reported improved housing conditions, better water infrastructures, increased health care coverage and clean cooking fuel use in communities close to mining projects (Dietler et al., 2021). These positive impacts may explain the observed decrease in the incidence of respiratory, vector- and water-borne diseases such as malaria and diarrhoea, and improved childhood survival, particularly in the first year of life, soon after mining opened in the same region {Dietler, 2021 #664;Cossa, 2022 #818;Tolonen, 2014 #657).

However, mining development has often been associated with the concept of resource curse{Aragón, 2015 #672} due to existing evidence of the negative impacts of industrial mining projects on affected communities (Ahern et al., 2011; Bihale, 2016; Cortes-Ramirez et al., 2019). For instance, mining-related land occupation has been found to cause environmental degradation such as water, land and air pollution (Yelpaala & Ali, 2005; Jayachandran, 2009; Ahern et al., 2011; Greenstone & Hanna, 2014), changes in the local ecosystems increasing vector- and water-borne diseases transmission (Yelpaala & Ali, 2005; Stuckler et al., 2011; United Nations Development Programme (UNDP), 2015; Bihale, 2016). In addition, land occupation for mining activities often leads to the displacement of native communities (United

Nations Development Programme (UNDP), 2015; Bihale, 2016), reducing access to better education, food security, quality health care, clean drinking water and appropriate sanitation (Stuckler et al., 2011 ; Watch, 2013; Caxaj et al., 2014; Bihale, 2016). At the same time, industrial mining projects often attract job seekers (mining-induced immigration), increasing the population´s density, which alters the socioeconomic and cultural structures and local lifestyles (Dietler et al., 2020).

These changes in the natural capital often increase the vulnerability of the local population, particularly for women of reproductive age, pregnant women, newborns and children under five (Leuenberger et al., 2021c), to adverse health outcomes such as respiratory diseases, diarrhoea, malaria, and malnutrition (Kemp et al., 2010; von der Goltz & Barnwal, 2019; Knoblauch et al., 2020). Indeed, mining communities across the USA, Europe, and China are at higher risk of mortality and morbidity - with a broad spectrum of diseases - among the exposed population (Cortes-Ramirez et al., 2019). Furthermore, immigration into mining communities is of significant concern to MCH because it often results in an increased burden of STIs, including HIV/AIDS, due to increased drug abuse and unsafe sexual commercial transactions (Clift et al., 2003; Lightfoot et al., 2009; Cronjé et al., 2013; Dietler et al., 2020).

Against this background, it is clear that mining development's real impact is still poorly understood and may vary with many factors, including mining project location and the type of mined commodity. At the same time, the growing body of literature describing the manifold interlinkages between mining and the health status of the affected population is dominated by positive-oriented quantitative studies, primarily focusing on single and specific health outcomes or a particular type of mining project, with limited power to disclose the non-biological mechanisms of impacts (Chuhan-Pole et al., 2017; Karakaya & Nuur, 2018; Mactaggart et al., 2018; Brisbois et al., 2019; Cossa et al., 2021). Hence, interpretivism-oriented qualitative studies, i.e., those investigating the effects of the extractive industry from the community´s perspective, are of extreme importance because perceived health impacts may differ from, or may add context to, those impacts observed through quantitative research approaches (Leuenberger et al., 2021b).

In this paper, we present the findings of a qualitative study investigating the perceived impacts of industrial mining activities on MCH in Mozambique - a country rich in natural resources (e.g., coal, heavy sands, natural gas and rubies) with more than 350 active projects as of 2020 (Extractive Industries Transparency Initiative (ITIE), 2020). Using qualitative data collected in four mining districts, we aimed to assess the perceived impacts of industrial mining projects on MCH in Mozambique. The work presented here is guided by the following overarching question: “How do women of reproductive age and MCH nurses living in mining areas perceive the effect of industrial mining projects on MCH?”

Methods

Study Design

This qualitative study is nested in the health impact assessment for sustainable development (HIA4SD) project, which follows a mixed-methods approach for investigating the health impacts of natural resource extraction projects in Burkina Faso, Ghana, Mozambique, and Tanzania (Farnham et al., 2020; Winkler et al., 2020). We collected qualitative data through focus group discussions (FGDs) and semi-structured interviews (SSIs) in rural communities surrounding industrial mining projects in Mozambique. The FGDs and SSIs gathered information on local perceptions regarding changes in MCH induced by mining projects.

Settings

In Mozambique, data were collected as part of the HIA4SD project in four districts (Montepuez, Moma, Larde and Moatize) located in three provinces from northern and north-western Mozambique (Cabo Delgado, Nampula and Tete) (**Fig 1**). The districts were intentionally selected because they have hosted industrial mining projects in the communities since 2004 (see S1 Table). The three districts accommodate approximately one million people (490.135 men and 511.623 women) (Instituto Nacional de Estatística (INE), 2017). These rural districts have a low urbanisation rate, and the principal occupations are agriculture, forestry, fishery, livestock, trading and handicrafts (Maunze et al., 2019). Local languages include Emakua in Montepuez, Moma and Larde, and CiNyungwe, in Moatize (Maunze et al., 2019). Furthermore, a high facility-based maternal mortality ratio (above 200 deaths per 1.000 deliveries) has been reported elsewhere (Chavane et al., 2017). Across the three districts, fertility (5.1 - 6.9 children per woman) and child mortality (85 – 125.7 deaths per 1000 live births) rates are above the provincial average (Chipembe et al., 2012). With one health facility per 24 to 29 thousand people, the districts have low health services coverage, and the leading causes of morbidity are malaria, HIV/AIDS, STIs and diarrhoeal diseases (Ministério da Administração Estatal (MAE), 2013, 2014a, 2014b).

Over the past two decades, the districts have been characterised by an expanding mining sector (Ministério dos Recursos Minerais e Energia (MIREME), 2020). Two large mines extracting gemstones and heavy sands are located in the northern part of the country (one in Montepuez and another in Larde and Moma Districts, respectively). Five other mining companies are located in the so-called Moatize Coal Region within Moatize District in northwestern Mozambique, extracting coal, construction stones and associated minerals. All these mining operations (open-pit mines placed amidst villages) were established in the early 2000s (construction phase) and are currently owned and operated by international mining companies (S1 Table).

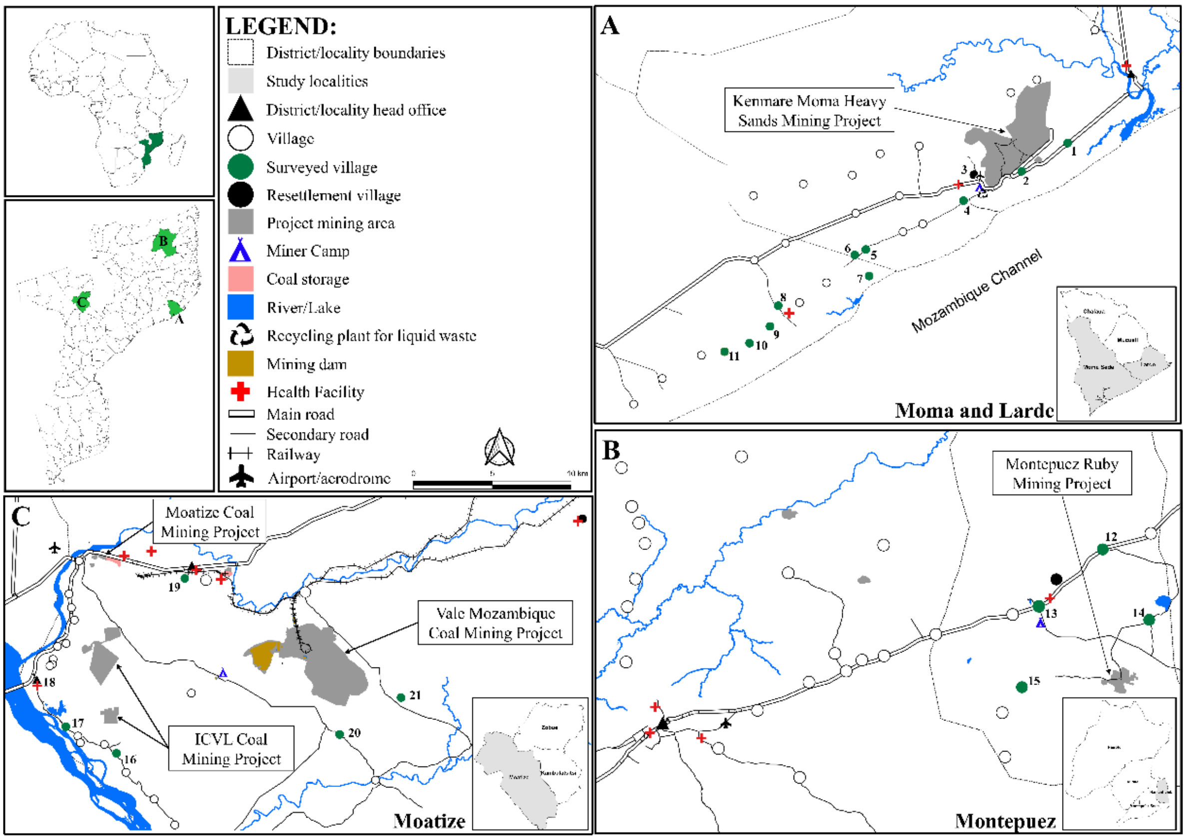

Fig 1. Point location of data collection. (A) Moma and Larde district. (B) Montepuez district and (C) Moatize district. Numbers are for identification only (see S1 Table) and do not indicate the data collection sequence. Note that we included 21 communities, of which 19 indicated green cycle, one locality head office in Benga (black triangle) and one resettlement village in Larde (black cycle).

Community entry, sampling and recruitment

The central- and local-level authorities, including the health sector, were informed about the study before data collection. Several meetings were held with community leaders and other gatekeepers (i.e., community health workers and representatives of local associations) to explain the motivation and conduction of the study. The field team received specific protocols and ethical training to conduct the SSIs and FGDs in local and Portuguese languages.

A two-step approach was applied to identify and recruit potential participants for the FGDs in each study area. First, in collaboration with the gatekeeper, a transect walk was conducted to understand the study area (i.e., the set of communities near industrial mining projects in selected districts) and identify eligible communities (Leuenberger et al., 2022). Second, eligible communities were selected based on the proximity to the mining site. Third, potential participants were identified based on the study's inclusion criteria: adult women aged 18 years or older who were pregnant or had a child under the age of five years at the moment of enrolment, regardless of occupation status. In each study district, we aimed to conduct a minimum of two FGDs (8 FDGs in total), each involving 6 to 10 eligible women.

The identification and selection of MCH nurses for SSIs were made in collaboration with the district chief medical officer, who provided telephone contacts of all potential participants after contacting and informing them about the study. The inclusion criteria for MCH nurses' recruitment were working in the study area before the mine opened (S1 Table) and being knowledgeable about MCH issues at the community and health facility levels. The SSIs were scheduled by phone and conducted face-to-face at a time and place according to the participants' preferences. At least three SSIs were conducted per study district (12 SSIs in total).

Data collection

Data collection was conducted from May 2019 to January 2020. Data were collected through two distinct topic guides to orient the FGDs (S1 Appendix) and SSIs (S2 Appendix), consisting of open-ended and probing questions. FGD and SSI guides were written in English, double-translated into Portuguese by the local researchers involved in the HIA4SD project, and administered in the language of the participant's choice (either in Portuguese, Emakua, or CiNyungwe). All sessions were audio-recorded using digital voice recorders (Olympus WS-852 and WS-853, Olympus Imaging America INC., New York, USA; http://www.olympus.com). In addition, observation notes on interactions and conversational dynamics were taken.

FGDs were performed by two research assistants, one moderator and another observer. The FGDs took place in a location previously suggested by the gatekeeper and lasted approximately one hour. Discussions were structured around two topics, namely: (i) experiences and perceived changes in maternal and child health conditions – both positive and negative – due to the industrial mining activities, and (ii) the mechanisms of impacts on MCH as perceived by participants (S1 Appendix). These topic questions were developed based on the researcher's experience in the conduct of "health impact assessment" of mining projects and research in eco-complex environments (Winkler et al., 2012). In addition, FGD was combined with a participative ranking technique to trigger lively discussion and engage all types of participants alike, including potentially less participative ones, whereby participants could vote for, rank perceived impacts and share the logic behind their choices (Ager et al., 2010).

One research assistant who also took notes during the sessions performed the SSIs. Each SSI lasted approximately 45 minutes and was conducted at the participant's chosen location and language. SSI topics focused on experiences and perceived changes induced by industrial mining activities on MCH at the community level.

All participants' socio-demographic data from FGDs and SSIs were collected and registered using standardised forms. For the FGDs, data included the participant´s age (in years), the highest degree of education, literacy (if the participant could read), the participant´s occupation, employment status (if participants were mine-worker or engaged in a local organisation) and the participant's years living in the community. For the SSIs, socio-demographic data comprised the participants´ age, years living or working in the community, time of working experience (in years) and type/level of health facility.

Data management and analysis

Socio-demographic data were entered into Microsoft Excel (Microsoft Office Standard 2016, v16.0, Microsoft Corporation., Redmond, WA, USA) and imported to STATA version 14.2 (StataCorp LLC, Texas, USA; www.stata.com). We summarised categorical data in frequency tables and continuous data as median (with Interquartile Ranges, IQR) and means (with Standard Deviations, SD).

The audio-recorded materials obtained from FGDs and SSIs were archived in a password-protected digital format and transcribed *verbatim.* Those conducted in local languages were translated into Portuguese during transcription. All SSIs transcripts were quality checked by the first author. One in ten FGDs transcripts was checked for quality control by swapping transcripts among transcribers. Quality control consisted of listening to the audio to confirm the transcription accuracy and amending the identified discrepancies (Poland, 1995). This process was followed by feedback to the transcriber for continuous quality assurance and improvement.

Data analysis combined deductive and inductive coding approaches based on thematic analysis (Fereday & Muir-Cochrane, 2006) using Nvivo Plus (version 12.6, QSR International, 2019; https://www.qsrinternational.com/). We used a pre-existing coding structure developed under the framework of the HIA4SD project (Leuenberger et al., 2021c). The coding structure was refined based on the FGDs and SSIs question guides and further expanded, iteratively, based on the themes emerging from participants' accounts captured in the data analysis process and confronted by discussions among the study team members. The final coding structure consisted of five main groups of nodes: (i) health conditions, (ii) health determinants, (iii) impact direction (positive, neutral, negative), (iv) actor linkage (e.g., mining projects, government, and health sector) and (v) beneficiaries/affected population (e.g., children, mothers, and adolescents). We categorise health conditions based on their similarities and affected body systems, organ or tissue as reported by the participants. Since participants did not distinguish symptoms from diseases, the categories were named based on previous researchers' knowledge and experience on health issues. For example, we grouped terms such as HIV, AIDS, Syphilis and Gonorrhoea into the same category group (i.e., STIs and HIS/AIDS) regardless of the participant's language. Other terms used to describe digestive system disorders, such as belly pain, diarrhoea, dysentery and vomiting, were clustered into the gastrointestinal disorder category (see codebook in S3 Appendix).

The coding was done independently by the first author and two research assistants with a social science background using the same coding structure. Each coder was assigned a unique set of transcripts. Newly identified themes were discussed in weekly-based meetings. Besides reflecting on the findings, new themes were either linked to new nodes that would either branch out from the initial structure or form new broad ideas, which would, in turn, branch out until saturation (Gale et al., 2013; Boene et al., 2020). After coding 20 out of 34 transcripts, saturation was reached since no new emerging themes were identified. All databases were merged with all transcripts incorporated for further data analysis, which the first author conducted.

Data were analysed using coding browsing, frequency of common words or expressions linked to the subject matter, matrix coding, and crosstab queries whenever needed, and summarised in matrixes and charts of response rate and coding frequencies. The analysis of perceived pathways for the mining impacts was conducted based on the survey responses combined with notes from field observations. For this purpose, queries were conducted using matrix coding between nodes of most reported health conditions and different node groups (e.g., actor linkage, health determinants). Pathways of impact were illustrated using in-text citations and a map of concept. The presentation of findings complied with the consolidated criteria for reporting qualitative research (COREQ) guidelines for reporting qualitative research (Tong et al., 2007).

Ethical Considerations

Ethical approval for the study was granted by the Institutional Committee on Bioethics for Health at the Manhiça Health Research Centre, Mozambique (CIBS-CISM/049/2018 date 06 November 2018) and the Ethics committee of North-western and Central Switzerland (Ethikkommission Nordwest- und Zentralschweiz, EKNZ) in Switzerland (No. 2018-00386) (Farnham et al., 2020). Written informed consent in the language of the participant's preference was obtained from all participants before the data collection procedure. The informed consent form explicitly requested permission to record the interviews and discussions. A witnessed consent was obtained for illiterate participants (e.g., those who could not read or write). The field team used a unique identification number or code (letter, number or combination) to guarantee the participants' anonymity during FGDs. After each session of the FGD, participants were offered a meal based on snacks and refreshments. The gatekeepers were reimbursed for transportation and communication costs.

Results

Characteristics of FGDs and SSIs

In total, nineteen FGDs were conducted involving 207 participants from 21 communities located close to three mining sites in Moma and Larde districts (n=11), Montepuez district (n=4) and Moatize (n=6). On average, 11 women participated in each FGDs session with a minimum of 6 and a maximum of 12 participants per session. The median duration of FGDs sessions was 59 minutes, with a maximum of 79 minutes. Fifteen SSIs were conducted with MCH care providers from 10 health facilities (8 health centres, one district hospital and one rural hospital). The SSIs lasted between 24 to 76 minutes (**Table 1**).

Table 1. Overview of the characteristics of FGDs SSIs' sessions, including distribution across study districts, the number of involved communities and health facilities, and their distribution per study district.

	Study Districts				
	Cabo Delegado Montepuez	**Nampula Larde**	**Nampula Moma**	**Tete Moatize**	**Total n [%]**
FOCUS GROUP DISCUSSIONS					
Number of sessions: n [%]	6 [31.6]	4 [21.1]	4 [21.1]	5 [26.3]	19 [100]
Number of communities: n [%]	4 [19.0]	5 [23.8]	6 [28.6]	6 [28.6]	21 [100]
Number of participants					
Total: n [%]	61 [29.5]	46 [22.2]	48 [23.2]	52 [25.1]	207 [100]
Average per FGD [SD]	10.2 [2.2]	11.5 [1.0]	12.0 [0.0]	12.0 [0.9]	10.9 [1.5]
Min - Max	6 - 12	10 - 12	12 - 12	10 - 12	6 - 12
Length of FGD [minutes]					
Median [IQR]	59.8 [54.6 - 62.6]	53.3 [46.6 - 56.0]	57.3 [52.9 - 60.8]	77.2 [73.7 - 77.6]	59.5 [51.7 - 63.4]
Min - Max	36.8 - 63.4	41.5 - 57.0	51.0 - 61.9	43.7 - 78.9	36.8 – 78.9
SEMI-STRUCTURED INTERVIEWS					
Number of sessions: n [%]	4 [26.7]	5 [33.3]	2 [13.3]	4 [26.7]	15 [100]
Number of health facilities: n [%]	2 [22.0]	2 [22.0]	2 [20.0]	4 [40.0]	9 [100]
Length of SSI [minutes]					
Median [IQR]	45.1 [42.7 - 61.8]	38.9 [37.2 - 41.6]	29.4 [24.4 - 34-4]	51.7 [51.3 - 55-8]	43.3 [38.0 - 51-5]
Min - Max	42.3 - 76.4	31.9 - 43.5	24.4 - 34.4	48.0 - 55.9	24.4 - 76.4

Note: IQR – Interquartile Range; n, Absolute frequency; %, Relative frequency; Min, minimum; Max, maximum.

Participants' characteristics

Participants from the focus group discussion

The socio-demographic characteristics of the FGD participants and their distribution across study districts are presented in **Table 2.** FGD participants were aged 18 and 55 years, and some were migrants (41.9%, 85/203) with living time ate the community varying from 1 year up to 55 years. Most FGD participants (84.6%, 173/207) were active in the agriculture sector, living with their partners (73%, 151/207) and were illiterate (86%, 178/207). Only a few participants (n=3) attended up to 10 years of formal education. None of the participants reported working or having worked in the local mining company; however, we did not collect data regarding partners' occupations. However, most participants reported that their partners were frequently involved in various incoming activities, including artisanal and small-scale Ruby mining (in the Montepuez district), traditional fishing (in Moma and Larde) and artisanal and small-scale coal mining and pottery for traditional brick-making (in Moatize district).

Participants from semi-structured interviews

Table 3 presents the main characteristic of participants from SSIs and their distribution across study areas. Fifteen MCH nurses aged between 23 and 53 years were included in the study. The majority (73%, 11/15) lived in the community for no longer than five years at the time of recruitment. The working time of MCH care providers varied between 2 months to 35 years. The Median (Interquartile Range) time of working experience was 8.5 (5.0 - 14.0) years, and only 5 (31.2%) participants had worked more than ten years in the career of Maternal and Child Health.

Table 2. Socio-demographic characteristics of focus group discussion (FGD). The table shows the number of participants and their distribution per study district.

Participants Characteristics	Study Sites				Total
	Cabo Delegado Montepuez	Nampula Larde	Nampula Moma	Tete Moatize	
Number of participants: n [%]	**61**	**46**	**48**	**52**	**207**
Age [years]					
Median [IQR]	30.0 [24.0 - 34.0]	25.5 [20.0 - 30.0]	28.5 [23.5 - 33.5]	25.5 [20.0 - 33.0]	28.0 [22.0 - 33.0]
Min - Max	18 - 46	18 - 55	18 - 49	18 - 40	18 - 55
Living in the community [Years]					
Number of participants: n [%]	60 [98.4]	46 [100]	48 [100]	50 [96.2]	204 [98.6]
Median [IQR]	25.5 [19.5 - 31.0]	19.5 [10.0 - 25.0]	16.5 [4.5 - 28.5]	22.5 [18.0 - 33.0]	21.0 [10.0 - 30.0]
Min - Max	3 - 45	3 - 55	1 - 43	2 - 40	1 - 55
School attendance [Years]					
Median [IQR]	3.0 [0.0 - 6.0]	2.0 [0.0 - 5.0]	0.0 [0.0 - 3.0]	4.5 [2.0 - 7.0]	3.0 [0.0 - 5.0]
Min - Max	0 - 10	0 - 8	0 - 7	0 - 10	0 – 10
Occupation: n [%]					
Farmers	58 [95.1]	42 [91.3]	48 [100]	25 [48.1]	173 [83.6]
Housewife	0 [0.0]	1 [2.2]	0 [0.0]	26 [50.0]	27 [13.0]
Other*	3 [4.9]	5 [10.9]	0 [0.0]	1 [1.9]	9 [4.3]
Literacy: n [%]					
Literate	14 [23.0]	10 [21.7]	5 [10.4]	0 [0.0]	29 [14.0]
Illiterate	47 [77]	36 [78.3]	43 [89.6]	52 [100]	178 [86.0]
Marital status: n [%]					
Living with partner	61 [100]	39 [84.8]	42 [87.5]	9 [17.3]	151 [72.9]
Single	0 [0.0]	7 [15.2]	6 [12.5]	43 [82.7]	56 [27.1]
Migration Status£					
Migrant	21 [24.7]	26 [30.6]	27 [31.8]	11 [12.9]	85 [41.9]
Non-Migrant	39 [33.1]	20 [16.9]	21 [17.8]	38 [32.2]	118 [58.1]

Note: * this category includes footballer, activist, trader and community midwife; IQR – Interquartile Range; n, Absolute frequency; %, Relative frequency; Min, minimum; Max, maximum. £ Our definition of migration status considered the participant's age and the time they reported living in the study community.

Table 3. Socio-demographic characteristics of SSI participants and their distribution per study district.

Participants Characteristics	Study Sites				Total (n=15)
	Cabo Delegado Montepuez (n=4)	Nampula Larde (n=5)	Nampula Moma (n=2)	Tete Moatize (n=4)	
Participants' Age [Years]					
Median [IQR]	39.0 [33.0 - 44.5]	30.0 [25.0 - 30.0]	39.0 [34.0 - 44.0]	39.0 [33.0 - 51.0]	35.0 [30.0 - 42.0]
Min - Max	28.0 – 49.0	23.0 – 36.0	34.0 – 44.0	31.0 – 53.0	23.0 – 53.0
Years living In the Community					
Median [IQR]	7.2 [0.8 - 26.5]	2.0 [2.0 – 2.0]	2.0 [1.0 - 3.0]	32.0 [0.2 - 33.0]	2.0 [0.7 – 22.5]
Min - Max	0.2 – 40.0	0.4 – 5.0	1.0 – 3.0	0.0 – 51.0	0.0 – 51.0
Migration Status£					
Migrant	1 [33.3]	0 [0.0]	0 [0.0]	2 [67.7]	3 [20.0]
Non-Migrant	3 [25.0]	5 [41.7]	2 [16.7]	2 [16.7]	12 [80.0]
Work experience [Years]					
Median [IQR]	14.0 [6.1 – 22.5]	5.0 [5.0 - 9.0]	6.5 [3.0 - 10.0]	10.0 [8.0 - 18.0]	8.5 [5.0 - 14.0]
Min - Max	0.2 – 29.0	2.0 – 9.0	3.0 – 10.0	5.0 – 35.0	0.2 – 35.0
Seniority in MCH* provision: n [%]					
<= 10 Years	1 [9.1]	5 [45.5]	2 [18.2]	3 [27.3]	11 [68.8]
> 10 Years	3 [60.0]	0 [0.0]	0 [0.0]	2 [40.0]	5 [31.2]

Note: IQR – Interquartile Range; n, Absolute frequency; %, Relative frequency; Min, minimum; Max, maximum. £ Our definition of migration status considered the participant's age and the time they reported living in the study community.

Perceived health status of the community

When questioned about the health status of the communities, a wide range of health conditions were mentioned, both during FGDs and SSIs, which could be clustered into 21 categories (S2 Table). Participants from both FGDs and SSIs perceived STIs (e.g., syphilis, gonorrhoea and HIV/AIDS), gastrointestinal disorders (e.g., diarrhoea and belly pain), malaria, neurophysiologic disorders (e.g., headache and back pain) and obstetric disorders as being the primary ill-health conditions affecting the community. HIV/AIDS and gastrointestinal disorders were identified as the most concerning ones among these conditions.

The profile of health conditions reported by the community (women) was similar to those reported by health professionals. However, some differences are worth noting: in any instance, health professionals reported helminthic infections, oedema and hearing disorders as health concerns (S2 Table). In addition, the type of health issues reported by the communities across different types of mining (i.e., extracted commodities) were different, and this may potentially reflect that different mining is related to differences in the exposure and, thus, different health conditions. For example, out of 21 categories (S2 Table), hearing disorders were not mentioned across heavy sand mining projects, while helminthic infections and cancer were not reported across coal and Ruby mining projects.

Communities' health conditions linked to mining development

Sixteen out of 21 categories of health conditions were linked to mining implementation and development in the four districts. The S1 Fig presents the list of health conditions linked with mining activities in all study communities, highlighting differences and similarities in the perspectives of women and health professionals. The profile in the S1 Fig suggests that community members are conscious about their health status and well-being and have a say regarding changes induced by the extractive industry.

Perceived mining impacts on Women and Children´s Health

When asked to what extent the mining project or its activities contributed to maternal and child health, most participants claimed that pregnant women, mothers and children under-five experienced adverse health conditions, particularly soon after project implementation. Differences and similarities in the types of health conditions can be observed between different types of mining and respondents (**Fig 2**).

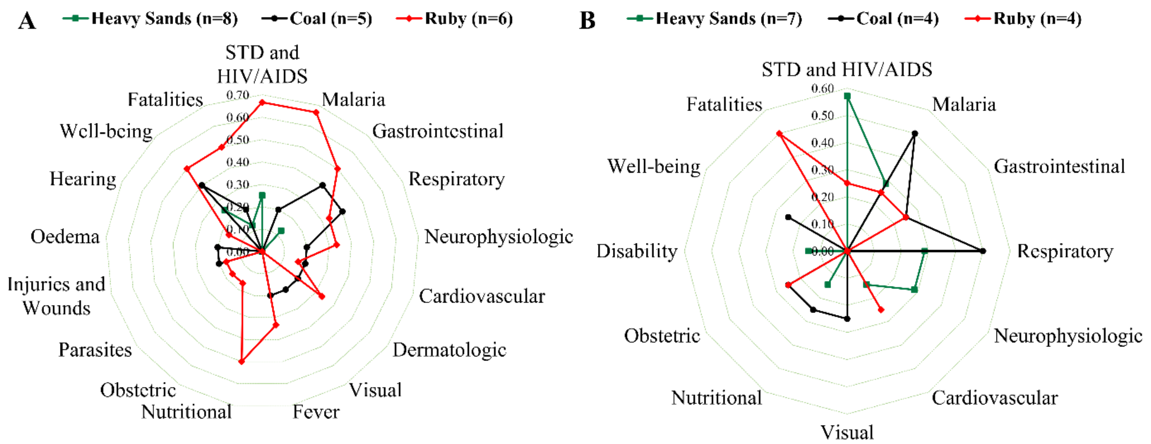

Fig 2. Maternal and child health conditions by type of mining and respondent's perspectives. Only health issues linked to industrial mining projects and related activities are presented. (A) Health issues linked to mining development by pregnant women and mothers of children aged under five years. (B) Health issues linked to mining development by health professionals. Figures indicate response rate (0 not mentioned in any session).

At the same time, when asked about the reason for the changes in their health status, two main perspectives were reported, namely: (i) new health conditions that were introduced in the community (either due to mining, for instance, STIs, including HIV/AIDS and hearing problems, or not due to mining, for instance, cancer, helminthic infections), and (ii) existing health conditions that worsened over time soon after mine implementation. The four resulting categories are illustrated in **Fig 3**. For example, HIV/AIDS was reported as being unknown before the implementation of the mine and was perceived as "*very dangerous to community members, in particular for pregnant women and young children*" - FGD, Moma. In the subsequent chapters, only those perspectives perceived to be linked to the presence of mining projects will be presented.

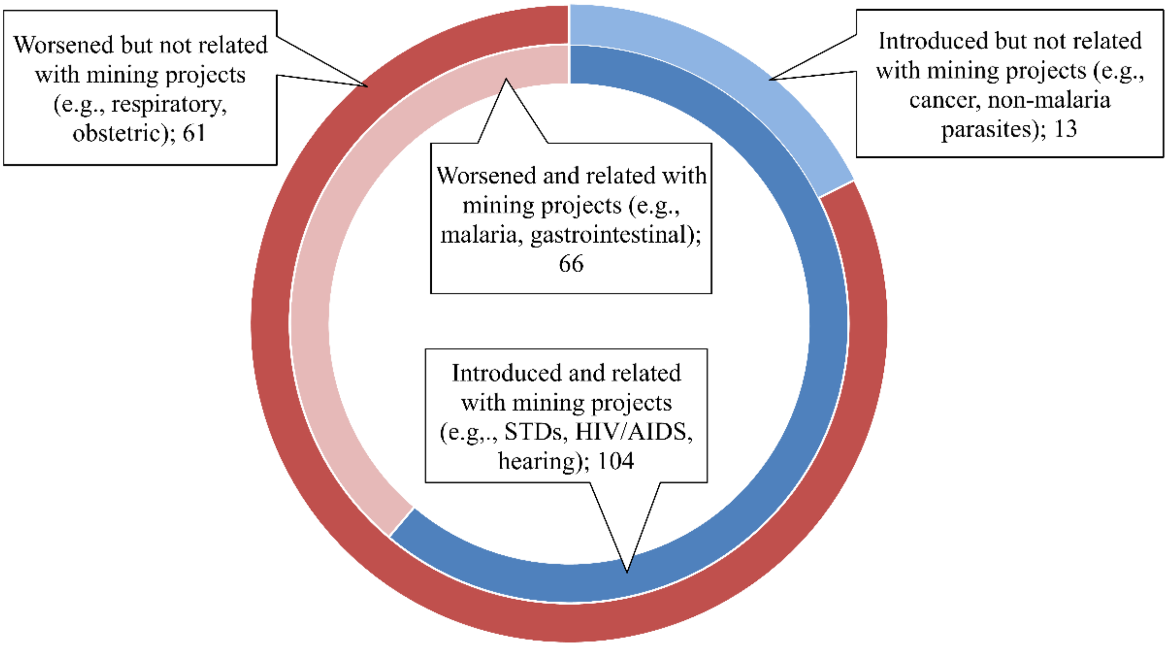

Fig 3. The four categories of perceived mechanisms for the impact of mining on MCH. Figures represent the frequency of coded references for each category. Outer ring: not related to mining projects; inner ring: related to mining projects.

Health conditions introduced by mining projects: underlying mechanisms

Our analysis shows several perceived mechanisms explaining how "*mining projects came with diseases*" (**Fig 4**) at various levels, from individual/family, to community and structural such as health care services provision and employment. In the following chapters, we describe relevant mechanisms as perceived by participants.

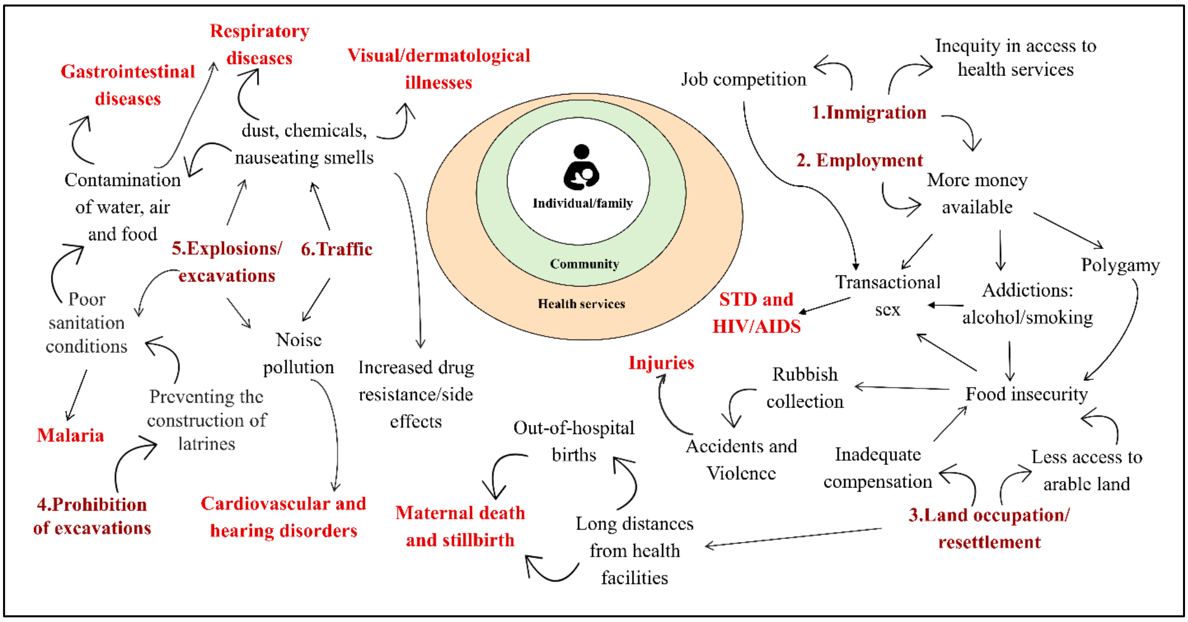

Fig 4. Perceived mechanisms of mining impacts on maternal and child health. Dark oranges are major determinants of health; red are major groups of health conditions.

Immigration, living cost and sexual transactions

Both women and MCH nurses perceived that STIs, HIV infections and AIDS were among the most concerning health issues for mothers and their children that are directly linked to the presence of mining projects. They perceived that mining implementation brought several challenges to the community and the health sector. In all four study areas, participants perceived that mining-induced in-migration was the main driving force for increased living costs, forcing rapid lifestyle changes (e.g., drug and alcohol consumption). In line with their voices, the increased living cost contributed to the introduction of sexual transactions and prostitution, particularly by young women and adolescent girls, to generate an income as a way out of poverty. In addition, the introduction and spread of STIs and HIV/AIDS in the community are thought to be linked with the increased practice of multiple sexual partnerships practised by young and adult (in-migrants and local) miners because they are economically benefited and can pay the bills regularly. Furthermore, women reported that their lack of knowledge about many STIs and HIV/AIDS plays a crucial role in the spread of these diseases in the community.

In FGDs conducted in communities close to Ruby (Montepuez) and heavy sands (Moma) mining projects, participants reported that mining activities have negatively affected the behaviour of community members. This perception was particularly prevalent among adolescent girls and young women. As explained earlier, changes in sexual behaviours are perceived as the primary reason behind high rates of HIV infections among young women. One of the participants renting a room for in-migrants stated that:

"[…] they call the young girls to receive money inside the room … they took advantage and did ugly things to them without their consent … in-migrants stay at home doing ugly things to the girls, and this ends up in a tragedy … as the case of AIDS, and other diseases." - Participant of FGD, Montepuez

MCH nurses also shared the same perceptions and considered that HIV is a serious health concern affecting MCH in mining-affected communities. Besides HIV infection, MCH nurses also stated that unwanted pregnancies were a concerning issue resulting from the earlier mentioned transactions, as in most instances, no condoms are used, particularly when adolescent girls get involved with "rich" in-migrants in exchange for money and other goods such as dressing and food for their families, often encouraged by their parents. In all study areas but one (Moatize), having multiple partners was perceived as the rule rather than the exception due to cultural, religious, and recent economic influences. Multiple partners were also involved in migrants whose health status was unknown and who could transmit diseases.

"We do not know what type of diseases each person [in-migrant] has, that is why we have many diseases such as HIV/AIDS and tuberculosis … because of [the culture of] multiple [sexual] partners with in-migrants we get syphilis, HIV and NORO (STI). – FGD, Montepuez

Changes in environmental factors affecting health outcomes

Many health conditions (e.g., dermatologic problems, hearing disorders, respiratory conditions and cardiovascular diseases) that were related to the presence of mining projects were mostly perceived to be caused by changes in environmental factors. These include air pollution (predominantly from mineral coal dust, traffic dust and nauseating smells), noise pollution (from mine blasting) and water pollution (linked to dust deposition on drinking water reservoirs such as tanks and other water bodies). Of note, air and water pollution were reported in all mining sites, whilst noise pollution was of particular concern among communities living near coal mining projects.

Most participants' discourses from coal mining communities were predominantly focused on the effect on their well-being and mental health, with particular emphasis on noise pollution from explosions and air and water pollution. Participants also reported that maternal and child well-being and mental health were mainly affected by dynamite explosions from coal mining projects, often occurring either unexpectedly or when sleeping, causing panic and shock and, ultimately, cardiovascular disorders.

"When (mining companies) explode dynamites while children are sleeping, they get scared … we have been having problems of hypertension [cardiovascular disorders] when they

explode dynamites, our hearts do not stay in place, we have headache problems, we no longer have peace, we just live here because we have houses here and we have nowhere to live … and we have nowhere to run" - Participant of FGD, Moatize.

Participants also linked the emergence of respiratory, gastrointestinal, malaria, neurophysiologic conditions, deaths due to blasting noise, and air and water pollution. The primary source of air and noise pollution was reported not only to come from the dust and the explosions in coal mines but also from the digging and increased road traffic around the Ruby and heavy sands mining projects, causing respiratory disorders (e.g., colds, coughs and tuberculosis) due to wind-borne contaminated particulates from mine waste to the community. Furthermore, dust and chemicals from mining projects were reported to pollute food, driving gastrointestinal-related conditions such as diarrhoea and abdominal pain, particularly among children aged below five years.

"Our children are suffering from Chimphine (cold) and malaria [due to] river water that comes with chemical products that the mining company throws in the river. When we drink that water, it causes us Mimba (belly pain), diarrhoea and sometimes people die because of chemicals that mine companies throw [in the river] … we did not have such problems before mine opening." – Participant of FGD, Moatize.

According to participants´ voices, the number of mosquito breeding sites increased near heavy sand mine projects, which resulted in an explosion in the mosquito population and, thus, an increase in malaria cases.

Air pollution from dust, as well as the use of dust-contaminated water, was reported to cause eye diseases (e.g., conjunctivitis) and dermatologic disorders (e.g. skin rash). Dynamite blasting was perceived to be the reason for new cases of hearing loss and impairments.

Poor hygiene and sanitation lead to gastrointestinal disorders

In a community close to the Ruby mine concession area (Montepuez), participants reported increased diarrhoea and other gastrointestinal-related conditions, particularly among children under five, due to poor hygiene at the individual and community levels. Participants also explained that the mining company prohibited the construction of any infrastructure requiring digging the soil as a strategy for controlling artisanal mining practices. As a result, the community faced poor waste management and poor sanitation conditions, leading to open defecation, threatening drinking water and crop quality.

Hygiene maintenance was also reported as challenging across coal mining communities due to ubiquitous dust deposition. Besides causing respiratory illness, participants said that people are forced to eat contaminated food due to coal dust, which renders them sick with many gastrointestinal diseases, including abdominal pain and diarrhoea.

Health problems associated with land loss and increased living costs.

The loss of land was perceived to play a central role in many mining-induced health conditions. According to the women, food insecurity and malnutrition are issues that did not exist in their community before the mining projects. Nevertheless, the mining activities (industrial mining and artisanal mining) occupied their agricultural fields with poor or no compensation, resulting in increased cost of living, hunger and poor well-being.

Compensations by the mining companies for land loss were seen as inadequate and a reason for poor behaviours among the beneficiaries, as a participant living in communities near heavy sand mining activities explained:

> *"[…] the received compensation for the land lost to the company does not help because it is little money as such that others spent money on beverages and women, the result is hunger in the family."* - Participant of FGD, Larde

This was further linked to food insecurity and poor nutritional status, particularly for young children. Consequently, children scavenge garbage in the mining dumpsters for food and end up being cut with broken glass or beaten by mine workers, contributing to poor mental health and well-being.

According to participants, this scenario leads young women to get sexually involved with in-migrants and mine workers as an alternative income generation activity. Mine workers, likewise in-migrants, are also perceived as people with many diseases, particularly STIs and HIV/AIDS, hence seen as the primary source of new infections.

Distant health facilities: mismatch with disease severity and adverse outcomes

The increase in the frequency and severity of gastrointestinal diseases such as cholera and "Nhathuzu" (dysentery) affecting pregnant women and young children in the community was perceived to be linked to both mine-induced changes on environmental conditions (e.g., dust), people's behavioural conduct (e.g., poor individual hygiene practices) and food insecurity and malnutrition. In addition, poor health outcomes (e.g., death) due to the severity of these ill-health conditions were blamed on the long distances to the nearest health facilities. Participants from coal and Ruby mining areas reported that it was common for pregnant women to die from dysentery on their way to health facilities. For example, a pregnant woman stated:

"[…] we, women with Phadhupi (pregnancy) are dying because of mineral coal dust, we are suffering a lot from Nhathuzu (dysentery) as the hospital is distant we are dying on our halfway […]" - Participant of FGD, Moatize.

Participants also reported that the long distances to the nearest health facility significantly contributed to increased maternal deaths due to complications during extra-hospital deliveries, often on their way, at home and in agricultural fields.

Medicines no longer have the expected effects.

The reported loss of drug effectiveness in curing diseases such as malaria, common colds and coughs was a concern of particular importance. According to participants, increasing infections result in deaths because pathogens resist previously effective drugs, including traditional medicines. Opinions around this issue converged among participants from Moatize and Montepuez. On the one hand, participants said that medicines no longer affect existing diseases because of the poor quality of available drugs. On the other hand, it was said that continuous exposure to poor environmental and sanitary conditions is behind the loss of curative effectiveness of drugs. Further, inhalation of coal dust was associated with frequent adverse reactions to medicines (both conventional and traditional), such as belly pain, diarrhoea, fever, headache, vomits and dermatologic complaints illnesses (e.g., skin rash), which are common after taking medicines for "*Massapi kuphipa*" (black lung) and other respiratory related diseases (e.g., tuberculosis) and HIV/AIDS).

Perceived contributions from mining projects

Most of the positive changes mentioned by participants are not necessarily linked to improvement in health conditions, nor specific to maternal and child health, but rather too unspecific interventions at the community level implying other transversal sectors, including (i) the health sector *per se*; (ii) education and human development; (iii) transport and communication; and (iv) public work, housing and water resources.

Despite the potential impact of all these interventions on health and that, in general, women recognised the importance of interventions implemented to benefit the community; they did not appreciate them as being a direct contribution to MCH. In addition, they mentioned that interventions were mostly unsatisfactory, misused (in the case of infrastructure) or non-functional.

Support from mining projects to the local health sector

Several interventions in the health sector were mentioned in all study areas. Participants living close to Ruby mining projects mentioned the construction of a health facility as the significant benefit and the sponsoring of a mobile clinic assisting local communities. In heavy sand and coal mining projects, people's also mentioned the construction of health facilities as the main benefit. Additionally, strong collaboration between the mining project and the health sectors was mentioned during interviews with MCH nurses in Larde.

Concerning the contribution to the education sector, the educational sector was pointed out as receiving the most attention from mining companies in all study areas. In all FGDs and interviews, participants discussed constructing and upgrading school infrastructures. In particular, participants reported that heavy sand mining projects provided school supplies for needy people, scholarships for young girls, and for pursuing health-related courses.

Regarding the transportation sector, in a community close to a coal mining project, participants reported that one of the mine companies had provided a “txopela” (three-wheeled motorised vehicle) as the primary means of transportation to shorten the distance between the community and health facilities. However, the company took it back because no one could drive it.

Regarding the public works and water sector, participants agreed that mining companies were highly active in supplying safe drinking water infrastructures. Installations ranged from tap water around Ruby and coal mining projects to water tanks in heavy sand and coal mining project areas. However, participants claimed that the water was either of poor quality (brackish) or polluted with coal dust or chemicals from the mine. In other instances, participants claimed not to have enough money to pay for the water since a symbolic price was established to guarantee infrastructure maintenance.

Discussion

We applied a descriptive qualitative research approach to investigate how the health of pregnant women, mothers and their children is affected by mining projects in selected mining communities in Mozambique. Our qualitative dataset deriving from 19 FGD and 15 SSIs (with MCH nurses) across three large mining communities revealed a large diversity of health conditions perceived to be impacted by the mining activities. While the large diversity of affected health conditions was reported in the FGDs with women, MCH nurses were generally more conservative in attributing them to mining activities. In summary, mining projects were perceived to affect the incidence of STIS, HIV/AIDS, and respiratory and gastrointestinal disorders. The profile of health issues found in our study is in agreement with the district's health reports (Maunze et al., 2019), which puts STIs and HIV/AIDS and diarrhoea at the top of health conditions affecting the communities the most, particularly among children and adolescents. This finding suggests that local communities know their health status, and our exercise captured the most perceived health impacts of local extractive industry activities. Mining projects were also linked to the increase in fatality rate and poor well-being, particularly from the mental health perspective.

Besides the many perceived adverse effects of mining projects on the health of the communities through a wide range of interconnected pathways modifying several determinants of health, many potentially positive inputs from mining projects were reported. However, those were not directly focused on specific health issues nor targeted specifically at maternal and child health. Overall, the dominant perceptions leaned towards the thought that the presence of mining projects mainly results in adverse social and environmental conditions, in turn affecting MCH.

The synergic effect of in-migration, poverty and sexual behaviours on HIV/AIDS and STIs

Our findings show a synergic effect between in-migration, poverty and changing sexual behaviours in increasing the transmission of HIV/AIDS and other STIs. Study participants reported that, soon after mining insertion in the communities, there was a substantial increase in in-migration, the prevalence of HIV/AIDS and other STIs and poverty, particularly affecting the poorest and least educated. Patterns of labour migration to large-scale development projects sites such as mining, oil/gas, agriculture and construction have been widely described in the literature, where young males play a significant role, often long away from "home" communities (Godfrey, 1992; Kaur et al., 2011; Corno & de Walque, 2012; Srivastava & Sutradhar, 2016; Bainton et al., 2017; Maclin et al., 2017). Labour migration is also found to increase drug and alcohol consumption and addition, social tension and crime in the hosting communities (Goldenberg et al., 2008a; Kaur et al., 2011), and these factors are well-known driving poverty (Smyth & Kost, 1998; Mbatia et al., 2009; Valdez et al., 2009) and thus, to health risky sexual behaviour to HIV/AIDS infection such as frequent and unprotected sex, particularly among young, poor adolescents and those far from their usual social context (Prual et al., 1991; Apostolopoulos et al., 2002; le R. Booysen & Summerton, 2002; Madise et al., 2007; Pascoe et al., 2015).

Two main mechanisms of perceived interlinkage between in-migration, poverty, STIs, and HIV/AIDS were revealed during FGDs with women of reproductive age. The first mechanism is linked to the search for alternative income by local young and disadvantaged (i.e., poorer) societal strata. In this mechanism, in-migrants, particularly mineworkers, were perceived as people with poor health and, thus, a source of infections for young women seeking income through commercial sex to alleviate extreme poverty. These young women further intercourse with locals without protection, thus disseminating HIV infections. Our findings align with previous studies that have described the role of in-migrants in transmitting sexually transmitted diseases in mining settings. For instance, several studies found that HIV/AIDS epidemic is one of the top three health outcomes of the 'resource curse' on the migrant mine workforce, particularly among South African Gold miners (Stephens & Ahern, 2001; Lurie et al., 2003; Matangi, 2006; Corno & de Walque; de Soysa & Gizelis, 2013; Baltazar et al., 2020), and HIV prevention programmes focused on the migrant labour force often fails because it does not take account of the psychosocial environment of the labour force (Stephens & Ahern, 2001), which is characterised by high working loads and limited opportunities to access sexual health care (Stephens & Ahern, 2001; Goldenberg et al., 2008b). In addition, migrant mineworkers play an essential role in the transmission of HIV/AIDS because they often spend long periods separated from their families and friend (Goldenberg et al., 2008b).

The second mechanism explains the role of in-migration and poverty in increasing multiple sexual partners after the onset of mine projects. Having multiple sexual partners and sexual transactions between migrant mineworkers and local young women were reported to have increased in the four study communities after the implementation of mining projects. This 'poor' sexual behaviour was perceived to substantially contribute to the increased risk for STIs and HIV/AIDS among young (pregnant) women and newborns. In line with our findings, payment for sex, engagement in extramarital sex and low use of condom is associated with increased risk for STIs and HIV/AIDS infections among female community members living around large-scale gold mines Sub-Saharan Africa (Dietler et al., 2022) and in northern Tanzania (Clift et al., 2003; Corno & de Walque; Baltazar et al., 2020). Further, a study conducted by Brockerhoff and colleagues (2018) found that young males migrating for labour have a higher likelihood of frequent and unprotected engagement with multiple partners (Brockerhoff & Biddlecom, 2018), particularly those engaging in alcohol, drug binges parties or both (Goldenberg et al., 2008a).

In Mozambique, HIV prevalence among high-moving people (i.e., Long Distance Truck Drivers and Mozambican Mine Workers in South Africa) were estimated at 15.4% (Ministry of Health (MISAU) et al., 2012) and 22.3% (Ministry of Health (MISAU) et al., 2013), respectively, which was higher than the national prevalence of 13.2% among the adult population (15.4% among women and 10.1% among men) (Ministério da Saúde (MISAU) et al., 2018). This trend suggests that migration may play a critical role in increasing poor sexual behaviour and HIV transmission in mining hosting communities in Mozambique, making these communities a significant target segment when designing HIV/AIDS and STIs-related interventions.

Taking all together, we hypothesise that the possible mechanism underlying the synergic effect between in-migration, poverty and sexual behaviour is that in-migration often puts competition over existing job opportunities and natural capitals such as water and land, triggering living costs (e.g., by pushing down wages and increasing housing costs) and thus, increases poverty among the most vulnerable population such as young women (Aragón et al., 2015). As a way out, locals seek alternative income by engaging with the most 'benefited' societal strata – represented mainly by (in-migrant) mineworkers – often with alcohol consumption, in unprotected and multi-partnered sexual intercourse and thus, increasing the risk for HIV/AIDS and other STIs such as syphilis and Chlamydia (Steen et al., 2000; Clift et al., 2003; Goldenberg et al., 2008a).

As a consequence, these synergic effects are highly relevant to MCH in mining areas; thus, interventions targeting associated diseases (e.g., voluntary HIV testing and counselling; provision of HIV and STIS treatment) and underlying factors (e.g., health education and promotion of safe sexual practices, particularly in high-risk groups such as sex workers and men in the transportation sector) need to be promoted by mining companies in collaboration with the (local) health sector and other relevant stakeholders (Knoblauch et al., 2017). Beyond safeguarding MCH in mining areas, such interventions will benefit the health of communities and mining workers.

Environmental change and community behaviour – a mutual effect

Expectedly, environmental change due to mining operations was mostly discussed and associated with the surge or increase in the prevalence and incidence of a multiplicity of poor health conditions. Reported domains of environmental change included perceived effects on ambient air quality, water availability and quality, food contamination and noise pollution. Interestingly, the interaction between the presence of mines and community behaviour and local practices seems to play a crucial role in maintaining a healthy environment. Previously, we discussed the impacts of industrial mining development on community health across African Countries in light of various social, physical, economic and environmental determinants (Leuenberger et al., 2021a; Leuenberger et al., 2021c). This chapter will focus on the perceived effect of change in each maternal and child health dimension as perceived by local community members and maternal and child health professionals in the three mining sites.

Air pollution and community practices

Mine-driven changes in ambient air quality (i.e., air pollution) were the perceived high levels of fine and coarse dust particles in the air. In addition, some local practices such as sleeping in the yard overnight, drying cornflour, outdoor cooking and water storing were reported to be substantially affected due to dust deposition occurring even when mining operations are less intense, exacerbating its adverse impact on public health, particularly of young children and pregnant women. Air pollution is the most frequent adverse environmental change reported across (open-cast) mining settings across the globe. Source emissions include (coal) mine exploitation activities (e.g., blasting and diggings), road traffic, gases emitted from the burning of fuel, and wind-borne harmful particulates from mine waste (Ghose, 2002; Chaulya, 2004; Brotons et al., 2010; Mwaanga et al., 2019; Source International, 2019; Irene et al., 2021; Khazini et al., 2022).

Based on the participants' tells, it became clear that there is a strong perception of the interaction between dust emitted from various sources and community practices. This interaction leads to a wide variety of exposure patterns and mechanisms, including inhalation, skin and eye contact, and consumption through contaminated water and food, resulting in exacerbation or surge of a wide range of diseases, including respiratory (e.g., cough, tuberculosis and nasal constipation), dermatological, visual and gastrointestinal problems, mainly affecting young children. Our findings corroborate many epidemiological studies conducted in (open-cast) mining settings. For instance, a study conducted in industrial mining in England found an increased likelihood of children visiting a clinician for respiratory conditions (Pless-Mulloli et al., 2000). Studies assessing the association between respiratory symptoms and ambient levels of industrial pollutants in Estonia and Chile reported that children living near (i.e. within 5 km) industrial projects were more likely to develop respiratory illnesses such as dry cough, rhino conjunctivitis and asthma (Herrera et al., 2016; Idavain et al., 2019). In addition, adults living near coal mining sites were found to have and increased susceptibility to chronic obstructive pulmonary and respiratory diseases compared to those living far away (Hendryx & Luo, 2015). Further, mining dust, inhaled or consumed through contaminated food or water, can cause gastrointestinal diseases such as diarrhoea, a significant contributor to childhood illness and death in rural areas in low-income countries (World Health Organization (WHO), 1993). Poor air quality has been found to influence gastrointestinal microbiome composition (Dujardin et al., 2020), increased risk for gastrointestinal cancers (Pritchett et al., 2022), skin wrinkles and ageing (Krutmann et al., 2014; Li et al., 2015) and neurodermatitis (Ising et al., 2003).

Although our analysis derives from purely qualitative sources, the similarity of our findings (perception of high-level exposure to air dust maters from mining activity) with evidence described in epidemiological studies, which quantifies the risk of health outcomes in populations potentially exposed to mining activity and its by-products (Pless-Mulloli et al., 2000; Hendryx & Luo, 2015; Herrera et al., 2016; Idavain et al., 2019) highlights the importance and reliability of using a qualitative approach in implementing health impact assessment of large-scale infrastructure development such as the extractive industry.

Water Pollution and community hygiene practice

In the present study, water availability and quality were perceived as one of the most relevant environmental determinants negatively affected by mining operations. Data scrutiny revealed that there are different perceived mechanisms of water pollution, namely (i) pollution of water through dust deposition into water bodies and reservoirs and (ii) contamination of underground water by chemicals from mining projects through percolation.

Although the establishment of mining projects has been associated with increased access to modern water and sanitation infrastructures (e.g., piped water, pumps or drilled wells), mainly through corporate social responsibility programs (Admiraal et al., 2017; Dietler et al., 2021; Leuenberger et al., 2021c), communities surrounding mining areas face water scarcity and degradation of water quality due to pollution, with an increase in water-borne diseases such as diarrhoea (Source International, 2019; Leuenberger et al., 2021b). Further, mining operations have been associated with (chemical) water contamination occurring through the release of effluents into water bodies such as streams and rivers (Mwaanga et al., 2019) and poor (mine) waste management, especially in situations where dumps are close to water streams/bodies (Benka-Coker & Bafor, 1999; Adeyemi & Ojekunle, 2021).

Another reported factor contributing to water pollution is open-air faecalism due to poor sanitation. Some communities had no sanitation facilities due to the prohibition of latrine construction imposed by the mining companies. Nevertheless, poor community and individual sanitation practices, such as open-air faecalism, occur in other communities even though some households have sanitation facilities such as traditional latrines. Hence, poor water accessibility and quality were perceived as the root of increased and spread gastrointestinal disorders such as diarrhoea, vomiting, dysentery and belly pains. These findings agree with other studies reporting a correlation between water pollution from various sources and the emergence of related diseases across industrial areas. For instance, Adeyemi and colleagues (2021) reported a high risk of non-cancer health issues, particularly for infants, due to exposure to high-level concentrations of heavy metals through water from hand-dug wells and boreholes across industrial areas in Nigeria (Adeyemi & Ojekunle, 2021). Indeed, access to improved water and sanitation is associated with reduced risk for child mortality (for sanitation only), childhood diarrhoea mild or severe stunting (Fink et al., 2011). Further, a 2005 systematic review conducted by Fewtrell and colleagues revealed that interventions focused on water accessibility and quality (e.g., point-of-use water treatment) were as effective as when combining multiple interventions such as water, sanitation and hygiene measures (Fewtrell et al., 2005).

When considering the high number of people living under poor water, sanitation and hygiene (WASH) conditions across the world (an estimated 1 in 3 people that do not have access to safe drinking water) (Center for Disease Control and Prevention (CDC), 2022; The United Nations Children's Fund (UNICEF), 2023), of which a significant fraction of children lives in mining sites, particularly in sub-Saharan Africa (Cossa et al., 2022), these findings suggest mining development should represent an opportunity for improving and saving lives through water and sanitation interventions (Cairncross & Valdmanis, 2006; Admiraal et al., 2017; Leuenberger et al., 2021b) and thus foster achievement of health-related targets of the 2030 Sustainable Development Goals.

Noise pollution and cardiovascular diseases

Mining operation and increased (mine-related) road traffic were associated with increased noise pollution across all study sites and thus substantially increased cardiovascular disease incidence. Mechanisms such as fright and panic due to mining-related explosions, with consequent increased personal heart rate, were most reported around coal mines. In other Ruby and Heavy Sand mining areas, noise pollution was most associated with increased traffic related to mining operations, but its mechanisms of impact on heart disease were not clearly explained.

It has been established that noise is integral to open-cast and underground (industrial) mining environments resulting from various operational activities and sources (Tripathy & Patnaik, 1994). Indeed, several studies have demonstrated the existing association between industrial mining and other large-scale developments and noise pollution over the world (Sharma et al., 1998; Kisku et al., 2002; Singh et al., 2010; Duarte et al., 2015; Manwar et al., 2016; Lokhande et al., 2018; Biały et al., 2021) with adverse health outcomes including increase risk of developing cardiovascular diseases (Halonen et al., 2015; Tsaloglidou et al., 2015; Jariwala et al., 2017; Sorensen & Pershagen, 2019; Munzel et al., 2021; Baffoe et al., 2022; Maljaee et al., 2022; Moreyra et al., 2022). Further, various mechanisms explaining the development of cardiac diseases due to exposure to noise pollution are described in the literature, and these include emotions such as panic, fright, excessive anger, anxiety, sadness, grief and acute stress (Walters et al., 2008; Edmondson et al., 2013; Ghadri et al., 2016; Wegener, 2022).

We understand that industrial mining development demands a high road and railway transportation system, thus propagating noise pollution beyond mining operation sites, which further increases the number of people exposed to high-level noise doses, particularly at night. However, our findings show that mining operations play a significant role in the increase of heart disease incidence, affecting vulnerable populations and entire communities. Thus, the environmental management plans from the Environmental Impact Assessment should include noise management strategies such as warning before blasting and establishing transport schedules for (large) volumes of material through road or rail, which should be disclosed to the affected communities.

Mining projects as an opportunity for MCH

The four study areas are rural settings transforming (or being transformed) into small towns due to rapid mine-driven population growth, extending beyond the mine vicinity thanks to the development of infrastructures such as roads, bridges, railway lines, and commercial projects, the accompanying the evolution of mines. These communities have a common characteristic of poorer health conditions, partially due to lower socioeconomic status and limited access to clean water and sanitation infrastructures. Indeed, rural communities hosting industrial mining have been described as being remote, with limited access to education and health care services (Yakovleva et al., 2017), relying on natural capital (e.g., water, land and forest) to meet their daily needs (Ansoms & McKay, 2010; Barbier, 2012). This standard of living has continually been transformed with the establishment of large projects such as mining industries (Emuze & Hauptfleisch, 2014; Dietler et al., 2020). This transformation, however, is primarily due to interventions provided as part of mining concession or in the context of corporate social responsibility (CSR) programs, particularly with a focus on resettled communities during the initial stage of mining development (Bihale, 2016; Admiraal et al., 2017; Tarras-Wahlberg et al., 2017; Lange & Wyndham, 2021).

On the one hand, there is a positive direction regarding opportunities for mining companies to contribute to maternal and child health. Local communities recognised that the presence of the mine was a driving force for local socioeconomic development, and thus, the mine positively impacted maternal and child health. For instance, most participants mentioned that mining companies had a significant role in improving water, sanitation and hygiene (WASH) conditions (delivery of clean water supply, better sanitation facilities), on the expansion of the health system (mobile clinic and support to mobile health brigades, upgrading and construction of health facilities), in reducing the distance between the health unit and the community (provision of transportation system), in improving education conditions (upgrading and construction schools, donating education material and providing scholarships for local young girls) and introducing alternative income generating activities (loans for agriculture, livestock and trade) to the community, particularly for (resettled) women. In line with our findings, several quantitative studies have reported positive and sustainable effects of mining development on various determinants of health such as water and sanitation (Admiraal et al., 2017; Yakovleva et al., 2017; Dietler et al., 2021), on the transportation system and access to electricity (Egger et al., 2021), on the health system (Yakovleva et al., 2017; Macuane & Muianga, 2020), education (Yakovleva et al., 2017; Egger et al., 2021) and women empowering (Tolonen, 2014). Further, mine companies in Tanzania and Burkina Faso have introduced alternative farming methods ("*zaï*" in Burkina) (Leuenberger et al., 2021c), a highly productive, well adopted and utilised technology in Ghana and Kenya (Danquah et al., 2019; Danso-Abbeam et al., 2019; Kimaru-Muchai et al., 2020). Our findings suggest that mining companies have several opportunities to improve community health, and its implementation varies with the mining development stage.

On the other hand, mining companies seem to have missed several opportunities for improving community health in Mozambique. Beyond population growth, our fieldwork noted a remarkable transformation of natural ecological services such as rivers, lakes and forests, suggesting that mining operations may have put some pressure on existing natural services (e.g., water and land availability), thus threatening local community health. It has been argued that mining operations can reduce surface water, lower groundwater levels, and contaminate water supplies, thus affecting the availability and quality of existing drinking water(Admiraal et al., 2017; Leuenberger et al., 2021b). In addition, some participants reported that most interventions from mining projects were either unsatisfactory or non-functional, to some extent due to programme discontinuation, lack of maintenance or training of the local communities for correct use and management, shortages of consumables such as medicines and inequality in the distribution of intervention. These findings are in agreement with previous studies reporting that, in most instances, mining interventions do not meet local community needs and are thus seen as useless interventions, perpetuating adverse health effects due to mining and associated activities (Lillywhite et al., 2015; Leuenberger et al., 2021b). Furthermore, it has been reported that gender and socioeconomic inequality is prevalent in mining social investments (Lange & Wyndham, 2021; Leuenberger et al., 2021b), and healthcare services in resettled communities affected by mining projects are precarious, with shortages of essential medicines (Bihale, 2016). These findings show, however, that despite the investment of mining companies in promoting the health of local communities, interventions have been perceived as 'unsustainable', while companies are missing several opportunities to meet the basic needs of local communities, particularly for vulnerable groups such as (pregnant) women and children.

The sustainability of interventions, especially those providing collective goods and social services, such as access to healthcare, high-quality education, transportation and communication, could be achieved through three main approaches: (i) strong adherence to international impact assessment guidelines, including health impact assessment. Many guidelines are now available in this area, including the (International Finance Corporation (IFC), 2009a, 2009b; Asian Development Bank (ADB), 2018; Winkler et al., 2021; World Health Organization (WHO), 2022). The second approach is related to (i) multi-sectoral collaboration between mining companies, non-governmental organisations, governments and host communities. When it comes to health, it is well established that `*health cannot be attained by the health sector, either alone or even primarily*´ (Listorti, 1996). This suggests that the planning and implementation of any mining interventions should be multi-sectoral, with a geographical coverage beyond local communities. It should be settled on mutual transparency, democracy and trust (Listorti, 1996; Aragón et al., 2015). The third approach is linked to (ii) capacity building of communities for better use and management of infrastructures and donated goods. For example, communities hosting mining operations in Mozambique are not trained in the use and management of social infrastructures, and there is poor or no technical assistance for maintaining collective goods such as water pumps functional (Lillywhite et al., 2015; Bihale, 2016; Leuenberger et al., 2021b).

Improved public services – marginal gains in health

Despite the numerous interventions in health and sanitation infrastructures made by the mining projects, perceptions of negative impacts on the health and well-being of women and young children dominated the participants' discourse. These challenges, particularly experienced by pregnant women, are widespread in Mozambique's rural areas, despite mining projects (Munguambe et al., 2016). However, our findings contrast with a recent study from Leuenberger and colleagues (Leuenberger et al., 2021c). Their multi-country qualitative study conducted in mining areas found that mine-related interventions were perceived as beneficial for mothers and linked to a decrease in maternal and child mortality (Leuenberger et al., 2021c). The difference in the methodology can explain this difference in our findings. In their analysis, Leuenberger and colleagues (2021) used data from three African Countries (i.e., Mozambique, Burkina Faso and Tanzania) while we used data from Mozambique only. Another methodological issue is that, in our sample, we include both community members (represented by mothers of children aged under-five and pregnant women) and local health professionals. However, Leuenberger and colleagues (2021) reported findings from community members represented by adult women and men.

This implies that mining companies should not move alone when it comes to safeguarding and promoting public health; instead, mining should move hand-in-hand with the (local) health and other relevant (non)governmental sectors (Bihale, 2016). A recent study on community-based, joint collaborative intervention strategies targeting MCH in rural non-mining areas in Mozambique showed to be most beneficial to pregnant and postpartum women in terms of the timely assessment of healthcare needs linked to obstetric emergencies (Amosse et al., 2021). This reveals that public-private-community collaborative models are advisable to maximise positive outcomes of mining-related interventions.

Thus, our study adds to the body of evidence pointing out the need for community-based intervention strategies and programmes that meet the needs of vulnerable groups in Mozambique while engaging the communities in the co-creation of such interventions (Munguambe et al., 2016; Amosse et al., 2021). This would have triple benefits: better primary health care services linked to the communities and responding to their expectations, improved MCH indicators that are visible to the community, and an essential contribution to sustainable development.

Mining health impacts differ with the type of extracted commodity

Differences in environmental impacts

Although environmental degradation was evident in all study sites, significant differences were observed and reported. For example, perceptions of high levels of polluted air, water and noise were frequently reported in coal mining areas, while water scarcity and lack of sanitation facilities were notably reported in Ruby and Heavy sand mining areas. Mine-related waste management was reported concerning all but heavy sand mining communities. This difference in environmental change induced by mining activity reflects the role of techniques used to extract natural resources. For example, open-cast coal mining often uses explosives for mining, which spread dust into the atmosphere, followed by deposition on water bodies and reservoirs. Mining explosions generate intense noise pollution (Sharma et al., 1998; Ghose, 2002; Chaulya, 2004) and vibrations, resulting in housing degradation and risk for accidents and deaths (Florkowska, 2013; Source International, 2019) perceptions of differences in water availability and lack of sanitation facilities may be influenced by factors such as participant's age, length of residence and education (Shi & He, 2012).

Health issues

We found that the profile of health impacts varies with the type of extracted commodity. For example, visual, obstetric, parasite infections, injuries and hearing disorders were reported in all but one mining site (i.e., heavy sand mining projects) and STIs and HIV/AIDS were not a primary concern in communities around coal mining projects. Further, respiratory and dermatologic issues were of concern around coal and Ruby mining projects (Fig. 2). These perceived differences may be linked to existing differences in gender norms and migration rates (e.g., STIs and HIV/AIDS) (Caxaj et al., 2014; Kotsadam et al., 2017), differences in impacts on environmental determinants of health (Shi & He, 2012; Leuenberger et al., 2021b) and structural differences (e.g., relative differences on distance from home to the health facilities) and level of urbanisation (Campbell & Roberts, 2003; Emuze & Hauptfleisch, 2014).

Study strengths and limitations

The present study provides the first in-depth description of maternal and child health impacts induced by the implementation of mining projects in Mozambique. We describe local perceptions of the mechanisms underlying the introduction and spread of various health conditions affecting women of reproductive age and children under five years. Nevertheless, similar to other qualitative studies, our research comes with a set of limitations. First, our findings are prone to recall and reporting bias as participants may not clearly remember the trend of health issues before the implementation of the mining projects. Second, there might be selection bias as not all participants lived enough time in the selected communities to have fully experienced the situation before the arrival of mining activities. We address this limitation by triangulating the findings from the FGDs with women and the SSIs with MCH nurses and field notes. Third, different field teams – composed of local, knowledgeable research assistants – were assembled for data collection. This may have resulted in minor differences in the quality of collected data, which may affect the comparability of data across study sites. To cope with this issue, interviewers received thorough training on standardised data collection procedures, rigorous data quality control was performed throughout the implementation of the field data collection, and the study coordinator was present in the field in all stages of data collection. Fourth, the diversity and complexity of how local communities named diseases and other health conditions may have influenced misclassifications during coding and data analysis. We addressed this issue by involving a multidisciplinary research team in the weekly discussion meetings during the data analysis and clustered the terms into major categories to facilitate analysis and reporting. Fifth, we acknowledge that this paper reports voices from community members represented by women who themselves experience more hardship than prosperity, that were not miners nor their partners, and the health sector represented by MCH nurses only, and not including the representatives of the mining projects. This may have influenced our findings as no data about partners' occupations were collected; thus, results must be interpreted cautiously. Finally, all questions in our data collection tools were focused on "negative health impacts" only; i.e., we sought to understand "health problems" due to mining implementation or activities, which may have biased participants' responses toward "negative" health impacts; although follow-up questions were made to explore positive health impacts.

Conclusions

This paper provides an overview of perceived health conditions affecting MCH in communities close to Mozambique industrial mine projects. Based on the voices of women and MCH nurses, mining projects were linked to an array of maternal and child health conditions, of which STIs and HIV/AIDS, gastrointestinal disorders, neurophysiologic, respiratory and cardiovascular were considered the most important ones. The perceived impacts of the extractive industry on MCH were explained through various, complex, and interconnected mechanisms, including changes in individual, community, structural and environmental determinants of health. While our findings can be used to inform specific interventions focused on health promotion and social transformation initiatives (such as community transportation and environmental and waste management), tailored explicitly to MCH in settings where introduced elements (such as mining activities) have uniquely affected the communities' health status, further research is warranted to elucidate better the dynamics of the identified mechanisms through which extractive projects affect MCH.

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Data availability

The data used for this paper are qualitative (i.e., verbatim transcript of focus group discussions and semi-structured interviews). Participants shared personal information, which is challenging to anonymise completely. Further, Participants have not provided informed consent for storing their data in a public repository. Given these reasons and to guarantee confidentiality, we would instead not share our data in a public repository. Request to access the datasets should be directed to the data centre of the Manhica Health Research Center through e-mail: sergio.tamele@manhica.net.

Supporting information

Figures

S1 Fig. Community health conditions linked to mine development. The intersection (green area) highlights differences and similarities between the perspectives of pregnant women and mothers of children aged under-five years (left) and health professionals (right)

Tables

S1 Table. Characteristics of study sites. Overview of characteristics of study districts, including information about selected communities and mining projects and data collection time-point.

S2 Table. Qualitative matrix of reported health conditions during FGDs sessions distributed by study districts. The colour indicates the gradient of coding frequency, and the figures indicate coding frequency.

Appendices

S1 Appendix. Focus Group Discussions (FGDs) topic guide

S2 Appendix. Semi-structured Interview (SSIs) topic guide

S3 Appendix. Codebook of developed code structure. Thematic codes for the perceived health impacts on maternal and child health, social, environmental and economic determinants of health. Exemplary quotes extracted from the transcripts are used for illustrative purposes and code descriptions.

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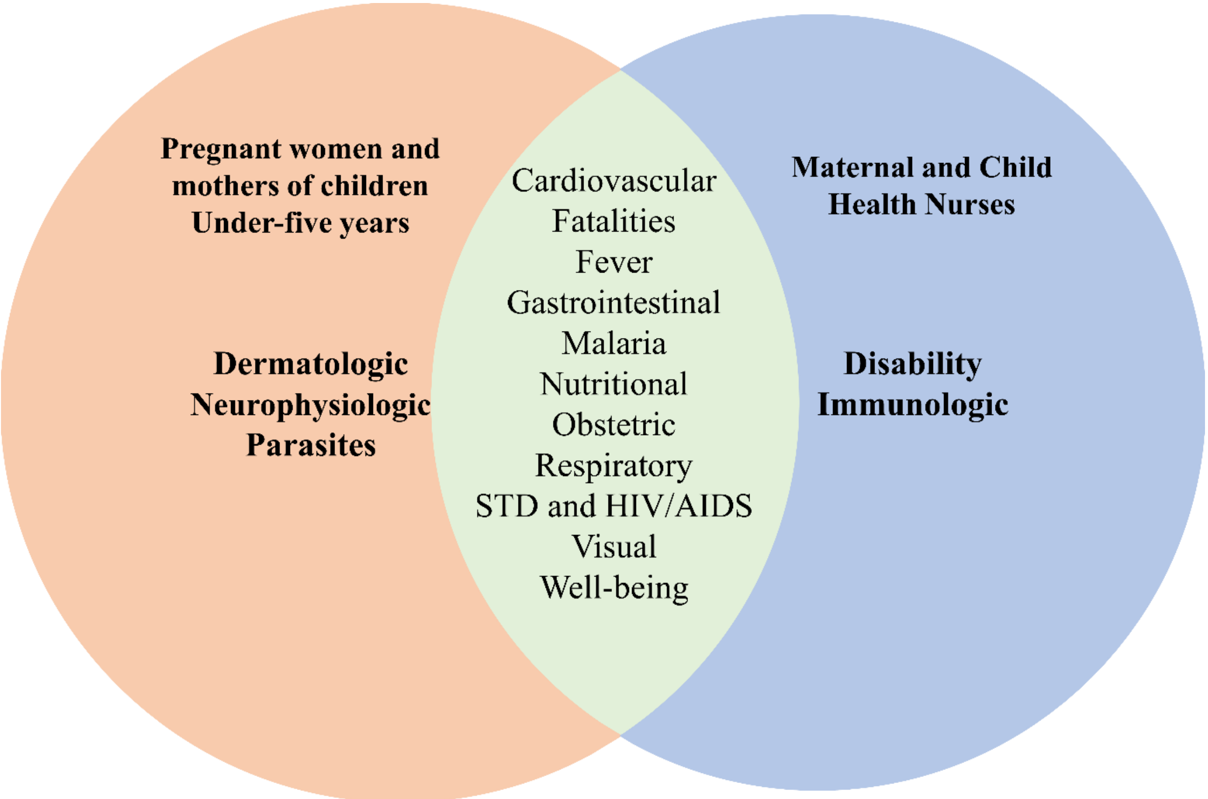
4.1 Article 3 Supporting information

4.1.1 Supporting Figures



Supplementary Fig 1. Community health conditions linked to mine development. The intersection (green area) highlights differences and similarities between the perspectives of pregnant women and mothers of children aged under-five years (left) and health professionals (right)

4.1.2 Supporting Tables

Supplementary Table 1. Characteristics of study sites. Overview of characteristics of study districts, including information about selected communities and mining projects and data collection time-point.

Province (District)	Selected communities	Local languages	Mining project	Company at time-point of data collection[a]	Headquartered (Country)	Resources extracted on site	Year of Construction (start)	Year of Operation (Start)	Type of mine	Time point of data collection	Additional information
Nampula (Larde)	1. Naholoco; 2. Topuito; 3. Mutiticoma*; 4. Tipane, and; 5. Hôri	Emacua; Ekoti, and, Lomué	Kenmare Moma Mine (Moma Titanium Minerals Mine)	Kenmare resources, plc	Ireland	Heavy sands	2004	2007	Open-pit	July 2019	Mine located next to the coast
Nampula (Moma)	6. Namalico; 7. Mualadzi; 8. Pilivili; 9. Epuitini; 10. Muolone, and; 11. Namaize	Emacua; and, Lomué	Kenmare Moma Mine (Moma Titanium Minerals Mine)	Kenmare resources, plc	Ireland	Heavy sands	2004	Extraction expected to start in 2020	Open-pit	July 2019	Community consultations related to the construction of plant C on going during data collection
Cabo Delegado (Montepuez)	12. Nanhupo; 13. Namanhumbir; 14. N´sewe, and; 15. N´thorro	Emacua	Montepuez Ruby Mine	Gemfields LTD	London	Ruby; Água-Marinha; Granadas and, Turmalina	2011	2013	Open-pit	May – June 2019	Region marked by (armed) insurgent activities; Construction of the Resettlement camp ongoing during data collection
Tete (Moatize)	16. Nhambalualo; 17. Khangale; 18. Benga[&]; 19. Nhantchere; 20. N´chenga, and; 21. Mphandue	Nyungwe (CiNyungwe)	Moatize Coal Mine	Vale Moçambique	Brazil	Coal	2005	2011	Open-pit	September (2019) and January (2020)	Mine and communities located next to the Rovubue and Zambeze river; Artisanal coal mining for construction bricks artisanal manufactures; Artisanal extraction of construction stones; Intense trade activities
			Minas de Benga, Lda (MBL)	ICVL[b] Zambeze (Mauritius) Limited and, Riversdale Moçambique Limitada	India	Coal and Associated minerals	2009	2012	Open-pit		
			Minas de Moatize	Beacon Hill Resources	London	Coal and construction stones	2005	2011	Open-pit		
			Minas de Rovubué, Limitada	Talbot Group Investments Pty Ltd	Australia	Coal	2013	Under construction	Open-pit		
			Eta Star Moçambique, SA	Eta Star India Projects Private Limited	India	Coal	2004	Under construction	Open-pit		

[a] If more than one company, the majority shareholder is indicated

[b] International Coal Ventures Private, Limited

* Ressetled village

[&] Locality head office

Sumplementary Table 2. Qualitative matrix of reported health conditions during FGDs sessions distributed by study districts. The colour indicates the gradient of coding frequency, and the figures indicate coding frequency.

	Larde		Moma		Moatize		Montepuez		**Total**		
	Heavy Sands		Heavy Sands		Coal, Minerals and Stones		Gemstones (Ruby)				
	Women	MCH nurses	Women	MCH nurses	Women	MCH nurses	Women	MCH nurses	Women	MCH nurses	All
STD and HIV/AIDS	92	39	110	15	55	36	128	18	385	108	493
Malaria	49	11	111	15	79	11	81	31	320	68	388
Gastrointestinal	64	3	84	8	175	10	43	4	366	25	391
Respiratory	28	13	1	7	81	31	24	0	134	51	185
Neurophysiologic	120	3	109	0	63	0	36	1	328	4	332
Cardiovascular	11	2	17	0	74	7	1	4	103	13	116
Dermatologic	19	0	32	0	13	3	6	0	70	3	73
Visual	8	0	23	0	7	7	8	0	46	7	53
Fever	3	0	3	5	19	1	9	3	34	9	43
Nutritional	11	5	4	1	29	15	15	20	59	41	100
Obstetric	2	7	22	1	88	18	33	15	145	41	186
Parasites	6	0	0	0	0	0	5	0	11	0	11
Injuries and Wounds	7	0	2	0	1	1	3	0	13	1	14
Oedema	3	0	5	0	18	0	2	0	28	0	28
Cancer	2	0	0	0	0	3	0	0	2	3	5
Hearing	0	0	0	0	18	0	2	0	20	0	20
Immunologic (Linfatic)	2	1	0	0	0	4	1	0	3	5	8
Disability	9	1	29	0	2	1	1	0	41	2	43
Well-being and Emotional	66	3	41	0	118	4	66	4	291	11	302
Fatalities	10	4	21	1	26	1	64	20	121	26	147
Others	4	2	1	0	22	1	1	0	28	3	31
Total	516	94	669	53	928	154	547	120	2660	421	3081

Note: Figures are number of codding references; MCH - Maternal and Child Health

4.1.3 Appendices – Data collection Tools

Below, we present two set of tools used for collecting qualitative data in the frame of this research.

The first tools (the S1 Appendix) is the Focus Group Discussion Guide, which was conducted involving mothers of children aged under five years and pregnant women living in mining host communities in Montepuez, Moma, Larde and Moatize (Mozambique). The tool is organized has follow:

1. General information about the study objectives, inclusion and exclusion criteria of the target goup, sampling strategy and recruitment.
2. Participants data and identity protection including confidentiality statement, basic rules for conducting FGD and room for participants to make questions
3. A standard form to collect data about the FGD. This form includes variables such as date and specific place of the FGD, initial and final number of participants, time (start and end), spoken languages and brief (and general) description of the participants.
4. The body of the guide is divided in two blocks. The first was intended trigger a discussion about the primary health problems (big concerns) affecting MNCH, while exploring how mining implementation impacts (positive and negative) the identified issues. In this block participants also ranked the issues they identified and the 3 most important were discussed.
5. The second block explore the 'most important resources and idea for interventions' that can work as a solution for the identified problems.
6. We close the Discussion by summarizing the points discussed and thank participants for their time.

The second tool (the S2 Appendix) is the Semi-structure Interview guide for local maternal and child health professionals. The structure of this guide is the same as of S1 Appendix (FGD) with differences in the main body only.

The topic discussed with MHC professionals were divided into six groups namely (i) ice break, (ii) working conditions and major changes after mining insertion, (iii) perceptions on the status of maternal and child health; (iv) sexual and reproductive health-related programs and the role of mining companies in the provision of (v) MCH and reproductive health programmes and (v) exploration of ideas for solving MNCH-related problems.

cism centro de investigação em saúde de manhiça	***Centro de Investigação em Saúde da Manhiça (CISM)*** **Departamento de Ciências Sociais** ***Health impact assessment for engaging natural resource extraction projects in sustainable development in producer regions*** **(HIA4SD PROJECT)** **FOCUS GROUP DISCUSSION GUIDE** **Mothers and pregnant women** **S1 APPENDIX**	Swiss TPH Swiss Programme for Research on Global Issues for Development

General Information comprising background of project, purpose of interview and informed consent information to be synchronizedfor all interviews

Objective of the discussion

- This interview aim to explore local perception on maternal, neonatal and child's health (MNCH) changes induced by the presence of extractive industry;
- Identification and discussion about the most important challenges (diseases and MCH service provision) among mothers of children under the age of five years and pregnant women;

Target population

The potential respondents must fulfil the following main characteristics:

- Be living in the community where the study is conducted;
- Be a mother of children up to five year old;
- Be a pregnant women or in the reproductive age (18 to 49 years);
- Willing to share her experience in a focus group discussion.

Sampling and recruitment

- The research team is responsible to contact potential participants who are willing to volunteer for a focus group discussion.
- All participants have to be informed about the study and to sign the informed consent sheet before participating in the study. Take your time to explain the informed consent to the study participants carefully, especially if they are illiterate.

The recruitment of the FGD is closely linked to the transect walk, which was conducted at the beginning of the site visit. In order to explore the diversity of impacts, within the study sites, choose the recruitment areas and study participants carefully. Also make sure, that everyone is able to express his or her opinion (and thus, try to avoid too heterogeneous groups). Primarily, participants should be recruited through the gatekeeper (e.g. leader of the community). Please, take time to explain the gatekeeper the objective of the study and the main characteristics of the participants.
In each site, two (02) FGD are conducted, with 6 to 10 mothers and pregnant women from the negatively impacted study site (e.g. a Neighbourhood) regarding your impact map from the transect walk (map 5) Hence, people are recruited form (a) village(s) in the larger project area with red symbols only.

Identified volunteers have to be very knowledgeable about the history of the project and community development. Make sure that all participants for one FGD speak the same language to facilitate the conversation.

Expected Outputs

Each FGD session, should be documented in one word file, including table of participants, verbatim transcript, pictures of the participatory tool and notes (if any). A template is given in Annex X in the data collection manual.

Additionally to the word file, the audio file as back-up should be stored as well.

Final versions should be saved with the proper name ("COUNTRY_SITE_K[number]_2019XXXX_[INITIALS].doc" and COUNTRY_SITE_K[number]_2019XXXX_ [INITIALS]_audio.mp3" respectively) in the respective folder in the SwichtDrive folder (to be created).

Material needed

- Informed consents;
- Pens / ink to sign the informed consent;
- Refreshments and biscuits;
- Mind. 5 Flipcharts/A3 papers (to categorize the impacts);
- Paper card with illustrations of health condition or other health-related issues;
- Objects to represent each major (health or health-related) problems;
- Sticky Notes;
- Markers;
- Cards with numbers (or codes) to identify participants during the FGD
- Pens and paper for taking notes;
- Audio recorder (with enough battery and store capacity);
- Camera (with enough battery and store capacity) to take pictures of the tools at the end of the FGD.

Introduction and negotiation of the GD terms

Welcome and thank you for volunteering to take part in this focus group, you have been asked to participate as your point of view is important. I realize you are busy and I appreciate your time.

Introduction of the facilitator and assistant: My name is (state your name)____from the Manhiça Health Research Center, I would like to welcome you to this interview. I will be the moderator of this group and with me Sr. (state your college's name) also from the Manhiça Health Research Center will take notes and record this discussion with your permission.

Project general information and Objectives

- The overall aim of this project is to promote Health Impact Assessment in Africa. For this reason, we aim to better understand how mines affect health of the local communities.
- In light of this context, focus group discussions are held in districts with at least one company extracting natural resources. The FGD is held with adult community members to explore their perspectives of health impacts of extractive industries among different population groups.
- This FGD is designed to assess your current thoughts and feelings about health impacts of the natural resource extraction project in children below the age of 5 years, their mother and pregnant women, and to explore the maximal diversity of the range of these health impacts.
- The focus group discussion will maximal last about 2 hours

Organization of the Discussion

- The discussion is divided two main blocks: the first will address the perceptions of impact of the industry to maternal, neonatal and child's health and the, second block will explore the community's perception of the key resources available for prevention and response that can help them, or keep them safe, in the circumstances they face.

Confidentiality

We will be recording this focus group (with your permission) to ensure that none of the responses you give get lost. My colleague will also be taking notes during the discussion. However, all information registered will be kept confidential and in any circumstance you will not be identified by your name.

- You don't have to answer if you don't feel like it;
- However, please try to answer and comment as accurately and truthfully as possible.
- In order to promote group cohesion and give everyone equal opportunity to speak, we will follow the rules of the group:

Basic rules

- The most important rule is that only one person speaks at a time. There may be a temptation to jump in when someone is talking but please wait until they have finished;
- Please don't refrain the stories of others outside the our group;
- There are no right or wrong answers.
- When you do have something to say, please do so. There are many of you in the group and it is important that we obtain the different views of each of you.
- All participants will respect each other's point of view;
- Please, raise your hand and state your number (in your card) before speaking.[if participants forget to say the code number, the moderator **MUST** make reference after participant´s intervention saying: we have listen the intervention of Mrs x (say the number of the participant)]

Questions?

- *Ask if anybody has questions and let them time to think*
- *If not, start with the warm-up question*

Note:

The recording of the section MUST be negotiated with participants and the "yes" must be marked in the informed consent sheet inthe appropriate place

- Check if you have all necessary to start.
- Throughout the interview, please ensure active participation and make room for divergent opinions to be expressed.

Introduction of participants

- Please introduce yourself to the group with your name (first name only), age, your profession/occupation (how do you earn money/what is your main occupation), level of education (completed), religion, marital status, household's leaders occupation (e.g. husband), number of people who live with and tell us, how long you have been living in this community. *Please, fill in all information in the table below*.

Form 1. Participant demographic information [Data to be captured in table below]

Nr	Initials	Age	Marital *status*	Education (highest degree)	Can read	Occupation	Employed bythe mining company?	Engagement in civil organization? Specify organization and role if applicable	Time you live in this community
1									
2									
3									
4									
5									
6									
7									
8									
9									
10									

Form 2. General information of the discussion in focal group

Reference Number: **HIA4SD_MZ_FDG_______00|__|___|- |__|___|__|** ***HIA4SD_MZ_FGD_ [000X (FGD nr] [place]***			
Interview date: |_____|____|/|____|____|/|____|____|		Place:	
Initial number of participants:		Final number of participants:	
FDG Start Time:		FDG end time:	
Language (s) spoken during the interview:			
Brief Description of Participants:			
FGD Outcome : |___| Recorded	|___| Not-recorded		
|___| Complete	|___| Incomplete	|___| Impossible to complete	|___| To be completed
Reasons:			
Facilitator |___|__|__|		Editor |___|___|__|	

Conducting the Focus Group Discussion

- Turn recorder on and say the place and date of the FGD.
- Greet the group one more time and say that you will initiate the discussion which will be recorded. Ask the group to respond "**YES**"

BLOCK 1: MATERNAL, NEONATAL AND *CHILD HEALTH – THE BIG CONCERNS*

Topic: Identify and discuss the most important challenges affecting maternal, neonatal and child health due to implementation of natural resource extraction project**.**

ICE BREAKING QUESTIONS

- What is your traditional name?

If you have one, you can share with participants as well!

- What is your favourite food?
- What do you like to do during your free time?

1. The set of the biggest problems are identified by participants

Notes

Discussion begins, make sure to give people time to think before answering the questions and don't move too quickly. Use the probes (see the end of the document) to make sure that all issues are addressed, but move on whenyou feel you are starting to hear repetitive information.

Explains that aim of the group is to understand what are the biggest problemsfacing children below the age of 5 years, their mothers and pregnant women (i.e. maternal and child health) in the community. Make clear that it is the point of the group that is important (not individual).

Encourage the participants to name major **health conditions or health- related problems including health determinants**. Ask clarifying/supplementary questions to clarify the nature of each suggested 'problem'.

The note-taker lists 'problems' in the sequence they are suggested (numbering each clearly in turn). Continue until ten separate problems have been identified, or until there are no additional suggestions.

If participants do not identify a specific concern and you have reason to suspect may be present in this setting (e.g. from transect walk), you may ask "In some communities____(name the concern. **Reefer to theprobe list in the last page**) has been mentioned as a problem; is that a problem here?" Prompts may include both health conditions (diseases) and health service provision or any other health-related issues.

If the participants do not report it to be a problem, it should not be listed by the note-taker. If the participants do see it as a problem it should be added to the list by the note-taker (with a star or asterisk used to mark it as a concern that was only mentioned after prompting).

Great! That was already a very good start! Let us follow with the next step.

2. Representing the identified problems with illustrations/figures in cards in a ground or wall.

If possible use illustration (cards) or other means (objects) to represent each identified problem. Make sure that all participants are engaged in the process.

The moderator and participants then select cards (with illustrations) or objects (e.g. stones, pencils, leaves, cloth etc.) to represent each of the problems identified. The moderator goes through each concern in turn and decides together with the participants what card/object can be used to represent it. Once linked with a concern, the cards/objects are put in a pile on the ground in front of the

moderator. [This step can be completed once a full list of concerns has been identified; however, it is often easier to find a card or object to represent each concern as that concern is identified by participants].	

3. Participative ranking in action	Notes
Asks the group to agree among themselves which are the biggest problems and which are lesser problems by ordering the cards or objects in a line (*ifyou use cards you can do this in a wall; rather if you use objects, please use the ground*): the biggest problem at one end of the line, and the lesser problems at the other. To facilitate the process, draw a scale of **1** to ***n*** (being **n** the number of problems identified). One will represent the biggest and the***n*** the lesser problem. You can help this process, but do not direct it. [One participant may be in charge of moving/positioning the cards/objects while the rest of the group discuss about the better position the card/object MUST be put]. First – the participant in charge of positioning take one card/object and say"this card refer to_[name of the health condition; e.g. diarrheicdiseases]" and ask the rest of the group in which position the card/object belongs. [the group MUST decide and the moderator ask if is there anyone who have different thought; if one report a different position then the moderator ask for the reason for such positioning]. The group interact until they reach a consensus of the "best" position for the card. Explore the reasons –their '**account'** – for the positioning of the three most important health "problems". Prompt by asking the group: a. Why those issues are the most important for them? b. Has these problems been the same or you (participants) have notice changes over time? c. If changes are reported, ask how can they describe such changes? (i.e. get better or worse)? d. What is/was the role of the industry for such changes? *e.* Is there any *specific important aspect on industry activities that caused the effect?* The note-taker records verbatim key statements used in negotiating thepositioning of cards/objects. [Note: "Biggest problem" may be replaced or augmented with "most prevalent problem" or" most serious problem" depending on what information is considered most relevant]. In the end of a cycle, the note-taker take pictures of ranking. When the line is complete, the moderator checks with the group by asking: "So you are saying that X is the biggest problem faced by children, their mothers and pregnant women here, then also Y is a big problem, and then comes Z etc. etc." Prompt the group to make adjustments to the line if their discussion suggeststhey wish to change their ranking. The note-taker then records (verbatim and pictures) the final ranking of problems. This provides a prioritized listing of protection concerns in the next block	

BLOCK 2: THE MOST IMPORTANT RESOURCES - *IDEA FOR INTERVENTIONS*	
4. Exploring the key resources available for prevention and response.	
Explains that aim of this session is to understand what are the key resources available for prevention and response considering the first three biggestproblems already identified in steps 1 to 3. The above process (steps 1 to 3) is then repeated to consider the **key resources available for prevention and response**. Ask participants to identify the things that can help children and their mothersas well as pregnant women, or keep them safe, in the circumstances they face. Similar to before, for each resource/means of coping that participant identify, an appropriate card or object is selected. This process continues as previously until ten different resources (cards/objects) have been identified (or participants **cannot** identify any otherresources). Again, if there are resources that have been mentioned elsewhere **or you suspect** that are not identified by the participants, participants can be askedif they are relevant in this situation. a. Apart from health service provision, ask also for other kind of interventions not directly linked to health such as water provision, construction of infrastructure, education, market, etc. Regarding the **three** most important identified problems? b. What do you do (Self-strategy) to overcome these health conditions? *c.* If they s*uggest they are, they should be added to the list (with their having to be prompted noted by a* ***star or asterisk).***	***Notes***
5. Participative ranking in action	
*Again, ask the gr*oup to agree among themselves which are the most and least important resource/means of coping the problems by ordering the cardsor objects in a line (**remember,** *if you use cards you can do this in a wall; rather if you use objects, please use the ground*): The most important resource/means of coping being at one end, and the least important at the other. As you did before, to facilitate the process, draw a scale of **1** to ***n*** (being n thenumber of problem identified). One will represent the most important and the ***n*** the least important resource/mean. It is important that the participants have opportunity to discuss and revise the positioning of cards/objects on the line. [*Please, use the same strategy for ranking as you did before for "health problems"*]. Prompt for the role of the industry in the implementation of listed resources asking the group: a. Is/was there anything done by the industry and thus to improve the health of the community whit regards to the resources that we listed now? b. If the group report some interventions (by the industry), ask whether how did it address their needs or of the community? i. How did it contribute to improve the health of the entirecommunity? ii. How did the health/health (seeking) behaviour of the communitychange?	

c. In your opinion, what should be the role of the industry inimplementing such interventions? **The note-taker records verbatim justifying the positioning of specific cards or objects. He also takes picture of each cycle of ranking and discussion [i.e. *positioning and repositioning*].** Prompt the group to make adjustments to the line if their discussion suggeststhey wish to change their ranking. The note-taker then records the final ranking of resources. The positioning of the objects should provide opportunity to discuss all the remaining questions as required.	
6. Additional comments	
This was already the last question/activity. But before ending the session, I would like to ask you, if there is something else that you would like to tell us? *Be aware, that now really interesting topics might arise! Don't forget to take notes, if you already switched off the recorder.*	
Closure	
- Now that we have finished the discussion, I will tell the discussion summary to the group, to make sure we didn't missanything. - Is this an accurate summary? Did we miss anything? Do you want to add something else, which we didn't discuss before? - Do you have any questions? If you have questions later on, the number of the research team is on the informed consent sheet, and you can contact us any time.	

Closing and Final comments:

Thank the participants for their time and insights:

We are very grateful that you have agreed to participate in this important discussion. We know that we take up your precious time. Your comments are very important to help us produce solid evidence on the impact that mining companies have on public health as well as inform decision makers to change the impact assessment policies in the mining sector, thus contributing to the well being of the local population.

Thank you for your participation.

Remember applause!

Facilitators' Comments

Board 1. List of Health determinants for probing during Focus Group discussion

Probes for discussion:	
• *Access to the health care facility and maternal and child health services* ○ *Distance to the health facility* ○ *Availability/options of Transportation* ○ *Preference to other health services* ○ *Relationship with healthcare workers* ○ *Quality of delivered services* ○ *Access to prescribed drugs* ○ *Access to post-partum heath care service* ○ *Health care services overloaded due to in-migration* • *Economic opportunities* vs *challenges* ○ *Partner's participant works to, or provide service for the company* ○ *Participant works to, or provide service for the company* ○ *Unemployed due to lack of skills* ○ *High level of competitively due to in-migration* • *Existing reproductive health programs running at community or health facility level* ○ *Clarity of the delivered message through the program*	• *Perceived pollution driven by the company* ○ *Water, lend and air pollution aggravating specific health condition (e.g. diarrhoea, respiratory disease)* ○ *Noise from industry activities (e.g. mental disorders)* ○ *Prostitution (e.g. STI and HIV/AIDS)* • *Standards of living* ○ *Cost of living* ○ *Housing* ○ *Electricity* ○ *Water* ○ *Transportation* • *Health care preference* ○ *Traditional healer rather than health care facility* ○ *Beliefs in well or only traditionally treated diseases.* • *Pregnancy complication* • *Rule of the partner during the pregnancy and child care* ○ *Partner well engaged and contribute to the successfulness of the process* ○ *Partner absent (absenteeism)* ○ *Partner's physical violence*

Board 2. Potential health condition and health provision indicators affected by mining and related activities (May expand list following pre-test if possible)

Potential impacted health conditions	**Potential health provision parameter**
Malaria	Health needs of the community
Tuberculosis	Empowered community- Level of health education
HIV/AIDS	Ability to pay for the care
Malnutrition	Reach of services through outreaches
Worm Infestation	Extended reach of services through mobile clinics
Hypertension	Public infrastructure including road network, electricity and WASH facilities
	Availability of health facilities
	Range of health services available e.g. Surgical
	Availability of emergency services- e.g. ambulance
	Quality of Health Service
	Numbers of health workers in the community
	Retention of health workers
	Availability of health commodities especially drugs
	Availability of transport logistics such as ambulance
	Availability of health information for decision making
	Accountability of the health system to the community
	Opportunities for collaboration

General Information comprising background of project, purpose of interview and informed consent information to be synchronized for all interviews

Objective of the interview

- This interview aim to identifying opportunities and challenges on maternal, neonatal and child health (MNCH) due to extractive industry implementation at district level.

Interview overarching question

- What are the opportunities and challenges for health providers in MNCH care domains raised after NREP implementation?

Target population

The potential respondents must fulfil the following main characteristics

- Be a midwife or a nurse living and or working at the health facility (public or private, but not the health facility in the mine) in the district of interest
- Participant must be in the community before the onset of the NREP or have worked at least 2 years after the industry implementation
- Participant must be someone with deep knowledge about the community of interest.

Sampling and recruitment

- The research team is responsible to contact knowledgeable health workers informants who are willing to volunteer for an individual interview.
- First participants can be identified at the health facility via "health authorities" or during the key informant interview with health sector decision makers on health system component.
- All respondents have to be informed about the study and to sign the informed consent sheet before participating in the study.

Interview organization

- Avoid to guide/facilitate the answers of the respondent
- If necessary, adapt the questions to the local, linguistic and cultural context as well as to the current interview
- Questions are structured as follows:

1. Heading; main objective of this section

Indications for the moderator in italics.

a) Main question

i) Probes to dig deeper and prompts to point out on specific aspects

Introducing the facilitator and negotiating the terms of the Interview

Welcome

And thank you for volunteering to take part in this interview, you have been asked to participate as your point of view is important. I realize you are busy and I appreciate your time.

Introduction of the facilitator(s):

Name & Background (Nationality, Institution, Position) of facilitator(s), role within the project and the up-coming interview.

My name is (state your name)____from the Manhiça Health Research Center, I would like to welcome you to this interview. I will be the moderator of this interview and with me Sr. (*state your college's name*) ____ also from the Manhiça Health Research Center will take notes and record this discussion with your permission.

Project general information

- This research is part of the "HIA4SD" project under the lead of the Swiss Tropical and Public Health Institute (Swiss TPH) which closely collaborates with health research institutes from the four partner countries (Burkina Faso, Ghana, Mozambique and Tanzania).
- The overall aim is to promote Health Impact Assessment in Africa. For this reason, we aim to better understand how mines affect health of the local communities.
- In light of this context, interviews with local knowledgeable maternal and child health care providers are held in districts hosting at least one extractive industry.
- This interview is designed to assess your current thoughts and feelings about health impacts of the natural resource extraction project and to explore the maximal diversity of the range of these health impacts.
- The interview will last about 1.5 hour at maximal.

Confidentiality

- We will be recording this interview with your permission to ensure that none of the responses you give get lost. My colleague will also be taking notes during the interview. All information registered will be kept confidential and will not be identified by your name.
- You don't have to answer if you don't feel like it or feel uncomfortable with any question.
- However, please try to answer and comment as accurately and truthfully as possible

Questions?

- Do you have questions so far?
- *Let enough time to think, address the questions and then, start with the introductory question.*

Note:

The recording of the section MUST be negotiated with participants and the "yes" must be marked in the informed consent sheet inthe appropriate place

- Check if you have all necessary to start.
- Throughout the interview, please ensure active participation and make room for divergent opinions to be expressed.

Introduction of participants

- So, let's start with the introductory question:
- Please introduce yourself with your name, age, your occupation (in which health facility do he/she work?), level of education(completed), and tell us, how long you have been living and working in this community.

Form 3. Participants Demographics

Full name	
Professional background	
Institution	
Current position	
Years of practice in current position*	
Years of practice at current institution	
Date of the interview	
Place of the interview	
Phone number	
e-mail	
Other means of contact	

*Cumulative – not just at current place of work?

Form 4. General information of the interview

<table>
<tr><td colspan="4">Reference Number: **HIA4SD_MZ_KII____00|___|___|- |___|___|___|** *HIA4SD_MZ_KII_ [000X (FGD nr] [place]*</td></tr>
<tr><td colspan="2">Interview date: |______|____|/|____|____|/|____|____|</td><td colspan="2">Place:</td></tr>
<tr><td colspan="2">Interview Start Time:</td><td colspan="2">Interview end time:</td></tr>
<tr><td colspan="4">Language (s) spoken during the interview:</td></tr>
<tr><td colspan="4">Brief Description of the Participant:</td></tr>
<tr><td colspan="4">Interview Outcome :</td></tr>
<tr><td>|___| Recorded</td><td colspan="3">|___| Not-recorded</td></tr>
<tr><td>|___| Complete</td><td>|___| Incomplete</td><td>|___| Impossible to complete</td><td>|___| To be completed</td></tr>
<tr><td colspan="4">Reasons:</td></tr>
<tr><td colspan="2">**Facilitator (Initials)** |__|____|______|</td><td colspan="2">Editor (I n i t i a l s) |______|______|______|</td></tr>
</table>

Conducting the Interview

Turn recorder on and say the place and date of the Interview.

*Greet the participant one more time and say that you will initiate the interview which will be recorded. Ask the participant to respond with an audible "**YES**"*

QUESTIONS FOR PARTICIPANTS

1. Self-report of health status: this section include warm up questions but also seek to explore the local understanding of "to behealthy"

Notes

a. How would you describe your overall health *status*?
   - *i) How do you feel today?*

b. Please tell me briefly how you describe your community's overallhealth status.
   - *i) What does your community consider to be healthy?*
   - *j) What about the health of pregnant women and children belowthe age of five?*

2. Work condition and major changes

a. Please tell me about your work experience in this community.

b. In your work conditions as a nurse of MNCH, what has been themajor changes you experienced due to the mining activities?What about the availability of infrastructure or quality of water, electricity, equipment or medicines, particularly forhealth service related to maternal and child health?

c. According to that we discussed before, what are the major changesthat you have noticed after industry implementation?
   - *a. Does it get better or worse?*

d. Would you tell that the industry implementation is an opportunity or achallenge the provision of maternal and child health service? Why?

3. Perception on maternal and child health

a. How would you describe the health of mothers (with children under-five years) in this community?
   - *i) Would you describe giving some examples?*
   - *j) What about the health of pregnant women at that time?*
   - *k) What about the health of children under-five years old?*
   - *l) Would you link a particular health condition to a specific phenomenon? (If participant don´t report the industry implementation, then prompt for that).*

b. If participants report any link between (specific) health conditions related to MNCH, ask if there are any other health condition that he/she can link to the industry implementation. (Prompt for other health conditions not listed by the participant.)

c. How would you describe the behaviour of women during pregnancy and early after delivery?

Do you see any changes related to consumption of health seeking behaviour, diet, family planning, alcohol, Tobacco and other drug consumption during this period; what about that?

d. In your opinion, is there any relationship between that behaviour and implementation of this industry? Why, why not?
   - *i) Will you please elaborate giving some examples? What would be the impacts that we can observe in the future?*

4. Sexual and reproductive health-related program running at healthfacility level community.	Notes
a. We have hear that here are some programs related to sexual and reproductive health running at health facility. [*Show the list of identified programs to the participants and ask if he/she recognize some*]. *If the respondent report an* ***YES****, proceed with next questionIf the respondent report a* ***NOT*** *jump to point "c"* *i) Would you talk about a specific program that you are familiarwith?* *j) Who implemented/initiated these program/s?* ***Probe for therole of the industry in implementing the programs****!* *k) What about the experience (education or training status) ofpeople delivering it?* b. In your opinion, how these activities/programs have been contributing for maternal and child health? *i) How is the program accepted by mothers and pregnant women?* *j) How are pregnant women and mothers engaged or involved in these activities? What about the level of accomplishment with the program indication? Why?* c. Apart from our list that we showed you before, is there any other MNCH-related program running (here) at the health facility that you would like to share with us? [if participant report any program, pleaseask] *i)* Who initiated such program/s? Probe for the role of theindustry in implementing the programs *j)* How do you think these programs are useful for maternal andchild health in the community? *k)* How is the program accepted by mothers and pregnantwomen? *l)* How are pregnant women and mothers engaged or involved inthese activities? *m)* What would you tell about the level of accomplishment with theprogram indication? Why?	
5. Reproductive health-related program running at the community	
a. We have identified some programs related to sexual and reproductive health running at the community. [*Show the list of identified programsto the participants and ask if he/she recognise some*]. *If the respondent report an* ***YES****, proceed with next questionIf the respondent report a* ***NOT*** *jump to point "c"* *i) Would you talk about a specific program that you are familiarwith?* *j) Who implemented/initiated these program/s* *k) what is the role of the industry when it comes* *l) What about the experience (education or training status) ofpeople delivering it?* b. In your opinion, how these activities/programs have been contributing for maternal and child health? *i) How was the program accepted by mothers and pregnantwomen?* *j) How are pregnant women and mothers engaged or involved inthese activities?* *k) What about the level of accomplishment with the programindication? Why?* c. Apart from our list that we showed you before, is there any other MNCH-related program running (here) at the health facility that you would like to share with us? [if participant report any program, pleaseask] *i) Who initiated such program/s* *j) How do you think these programs are useful for maternal andchild health in the community?* *k) How is the program accepted by mothers and pregnantwomen?*	

l) How are pregnant women and mothers engaged or involved inthese activities? *m) What would you tell about the level of accomplishment with theprogram indication? Why?*	

6. Ideas for coping MNCH-related problems	**Notes**
a. In your opinion, what do you think that can be done to respond or help solving the health problems that children and their mother and pregnantwomen are facing in this community? *i) Prompt for the role of the industry in implementing the strategy for copingMNCH-related "problems" identified by the participant:* *j) In your opinion, what should be the role of the industry inimplementing such interventions?* *k) What are the other actors you suggest to join in such initiatives?*	
7. Additional comments	
Before we go, would you like to give any additional information or comments or any recommendations or solutions in addressing maternal and child health considering extractive industries implementation/operation? *In your opinion what are the impacts than can be observed in future?*	
8. Closure	
➢ Now that we have finished the interview, I will tell a brief summary justto make sure we didn't miss anything. ➢ Is this an accurate summary? Did we miss anything? **Thank you for your participation.**	

Closing and Final comments:

Thank the participant for his/her time and insights:

We are very grateful that you have agreed to participate in this important interview. We know that we take up your precious time. Your comments are very important to help us produce solid evidence on the impact that mining companies have on public health as well as inform decision makers to change the impact assessment policies in the mining sector, thus contributing to the well being of the local population.

Notes on Comments:

____

____

____

____

____

____

5 General Discussion

The main goal of this PhD thesis was to investigate how natural resource extraction affects maternal, newborn, and child health (MNCH) in sub-Saharan African (SSA) countries. The main findings of this thesis research are presented in three manuscripts (Chapters 2-4) that were submitted to the international peer-reviewed literature (two published, submitted and under review). The manuscripts emphasise the mining sector, with the first manuscript presenting a systematic mapping of past health-related research carried out in artisanal and small-scale mining (ASM) contexts worldwide (Chapter 2). Using data from the Demographic and Health Survey (DHS) program and Standard & Poor's Global Market Intelligence Platform, the second manuscript investigates associations between the opening and operation of industrial mining projects and child health across 23 SSA countries (Chapter 3). The third manuscript applied a qualitative research approach to studying how women (including pregnant women and caregivers of under-five years) and health professionals[8] perceive the impacts of three industrial mining projects on MNCH in Mozambique (Chapter 4). The combination of different methodological approaches in the current PhD thesis allowed a comprehensive assessment of how MNCH is affected by natural resource extraction activities in SSA, thus, providing different perspectives as summarized in Section 5.

This chapter starts by first reflecting on the contribution of the different approaches to the three core pillars of the Swiss Tropical and Public Health Institute (Swiss TPH): (i) innovation – by developing new tools and methods; (ii) validation – by testing of the developed tools and methods in real-life; and (iii) application – by validating the tools, methods and emerged concepts. The last step comprises integrating tools, methods and concepts into the health system or the transformation into policies (Section 5). This step is complemented by reflections on the contribution of this PhD thesis to the mission and vision of the Manhiça Health Research Center´s (*Centro de Investigação em Saúde de Manhiça*, CISM):

- Mission: *to foster and carry out biomedical research in priority health areas to promote and safeguard the health of the most vulnerable populations*
- Vision: *to be a center of excellence in biomedical research is to generate evidence to direct public health policies in Mozambique and other regions*

The subsequent sections of the discussion (5.3-5.5) critically reflect the new insights on the effects of natural resource extraction activities on maternal, newborn, and child health. This reflection is done by first summarizing the main lessons (from the developed manuscripts and

[8] Maternal, neonatal and child health care nurses

the literature) on how (factors and mechanisms into which) mine activities affect MNCH (Section 5.3). Secondly, the potential for better inclusion of MNCH in the existing impact assessment practices is examined in Section 5.4. Thirdly, identified opportunities for the mining sector (ASM and industrial mining) to contribute to achieving the 2030 Agenda for Sustainable Development through public-private partnerships are summarised (Section 5.5). Finally, the discussion chapter is closed with an outlook and further research needs (Section 7).

5.1 Main findings

The systematic analysis of health-related studies conducted in context ASM shows that both mine workers and the general community[9], including women of reproductive age and children, are primarily focused on gold extraction (i.e., artisanal and small-scale gold mining, ASGM); hence, exposed to mercury (Hg) and developing associated health effects. The study also found that other ASM activities than ASGM are not adequately represented in the literature, both in number and geographically. Interestingly, communicable diseases, such as sexually transmitted diseases (STDs), HIV/AIDS, tuberculosis, malaria and other health conditions unrelated to Hg exposure, were less investigated when compared to non-communicable diseases. Further, musculoskeletal disorders, wounds, burns, and fractures were the most investigated injuries resulting from poor working conditions of mine workers. A few studies focused specifically on MNCH outcomes, although they represent a majority group in ASM communities and are often directly involved in ASM processes. The dearth of studies focused on MNCH put further challenges to the understanding that these activities affect the health of women and children and may worsen in the era of the “global health data gap” in the ASM sector.

Results obtained from the child health in industrial mining study indicate that the opening and operation of industrial mining projects in SSA countries reduce the risk of a child dying in the first month of life by 45% for children born and living within 10 kilometres (km) mine when compared to those born and living further away from an active. There was no instant effect on childhood diarrhoea, cough, or nutritional status. The study also found that childhood health outcomes change over time: while the likelihood of neonatal survival increases over time soon after mine activation[10], the odds of diarrhoea lower by 30% up to 4 years before the onset of

[9] In the qualitative study, the term “community” is used to refer to different units investigated in the field, terminologies varies with context and includes villages, settlements, neighbourhoods and localities.

[10] In this PhD project, industrial mine activation was set at 10 years before the reported year of extraction onset; i.e., soon after initiation of exploration and evaluation activities.

extraction, and the odds for cough episodes increased by almost 100% five years after extraction onset.

In Mozambique, women and health professionals living in mining areas had the perception that communities living in close proximity to industrial mining projects are affected by many health conditions[11] , which could be clustered into 18 categories. Overall, industrial mining projects were mostly perceived to be linked to the emergence of STIs and HIV/AIDS, gastrointestinal, neurophysiologic, respiratory, and cardiovascular disorders while increasing the number of fatality cases, people with disabilities, and poor well-being. These mechanisms of impact (i.e., introducing new health conditions and exacerbating the existing ones) were linked with the in-migration of young men job-seekers, changing social, economic, cultural, and behavioural structures of native communities, as well as various effects of environmental degradation on health determinants and disease patterns. The latter (i.e., the exacerbation mechanism) also included poor access to health care and the poor effect of medicines on existing and new health conditions.

5.2 Thesis contributions to core Swiss TPH pillars and CISM

Table 2 summarizes the main contributions of this PhD thesis to the core pillars of Swiss TPH and the mission and vision of CISM. While the three core pillars (Innovation, Validation, and Application) govern the activities at Swiss TPH, the CISM's mission and vision represent the institute's commitment to safeguarding vulnerable population groups' health and contributing to fostering national and international policies.

[11] Health conditions are defined as health problems as mentioned by participants and includes infections, signs, symptoms, diseases, well-being status and fatalities.

Table 2. Contribution of developed papers in the framework of this PhD project to the core pillars of Swiss TPH and Manhiça Health Research Center (CISM). FGD, focus group discussion; HIA, health impact assessment

<table>
<tr><th rowspan="2">Chapters in this thesis</th><th colspan="3">Core pillars at Swiss TPH</th><th colspan="2" rowspan="2">Main Mission and Vision at CISM
and
Emerging research field at CISM</th></tr>
<tr><th>Innovation</th><th>Validation</th><th>Application</th></tr>
<tr><td>3 – Scoping review</td><td>A holistic picture of health-related studies in ASM settings worldwide</td><td>Mapping all health and health-related issues ever investigated in the ASM sector worldwide</td><td>Findings will guide further research about the effect of ASM on various infectious diseases and mental health, including the focus on MNCH outcomes.</td><td>Innovative approach for mapping ever investigated health issues in ASM communities in Mozambique and beyond</td><td>Findings can be used to identify country-specific research needs.</td></tr>
<tr><td>4 – Child health in mine projects in SSA</td><td>For the first time, we combine DHS and mining historical data to investigate the timing of the impact of the opening and operation of industrial mining projects on child health in SSA.</td><td>Combination of different datasets for mine impact assessment at the regional and country levels</td><td rowspan="2">Findings will inform and facilitate a policy dialogue to strengthen current regulatory approaches to impact assessment in Africa and ultimately promote sustainable development at the national and international levels.</td><td>Innovated and validated methods for investigating the health impacts of large infrastructure projects at the local and national level</td><td rowspan="2">The methods can be used for future studies in the emerging research fields at CISM.
Findings will inform and facilitate policy dialogue to promote the use of HIA in Mozambique.</td></tr>
<tr><td>5 – Perception of women and health professionals on MNCH impacts in Mozambique</td><td>Participative ranking methodology with women of reproductive age to study perceptions of how implementation and operation of industrial mining projects impact MNCH</td><td>Analyzing MNCH health impacts from both community and health professional perspectives</td><td>The Participative ranking methodology is an additional technique to the existing FGDs tools.
Tools proved to work for assessing health impacts in different mining contexts.</td></tr>
</table>

5.3 Effects of resource extraction activities on MCH: underlying mechanisms

This chapter discusses findings on the mechanism of impacts of ASM and industrial mining projects on maternal and child health based on the factors involved in the underlying mechanisms. It starts by reflecting on how mine-induced changes in social and economic structure have an effect on the health of affected communities, posing emphasis on MCH (Section 5.3.1). The following section (Section 5.3.2) reflects on the main challenges women (along with their young children) face in the working environment. Section 5.3.3 highlights the major impacts of mining activities on the living environments and related health outcomes. Last but not least, section 5.3.4 discusses the distribution of the impacts of mining on the affected population while focusing on mining projects' location, type of extracted commodities and life stage.

5.3.1 Changes in the social and economic structure of affected communities

Despite the current trend of mining activities in urban and peri-urban settings, such as gold jewellery manufactures and coal extraction (Nhlengetwa, 2015; Abbas et al., 2017; Nottebaum et al., 2020), a large body of literature has described both ASM and industrial mining projects as often occurring in rural, remote and hard-to-reach settings (Hentschel et al., 2003; Hilson, 2013; United Nations Development Programme, 2016; Fritz et al., 2018). These concepts imply that in many mining contexts, the indigenous but well-social- and economically established communities[12] are somehow affected (Hilson, 2012a; Hilson, 2012b; Benshaul-Tolonen, 2018; Idavain et al., 2019; Adeyemi & Ojekunle, 2021). However, our findings show that these impacts are often complex and non-linear throughout the life stages of mining project operations (Cossa et al., 2021b); hence, differently perceived (Cossa et al., 2021a) and investigated (Cossa et al., 2021c).

The discovery and initiation of natural resources extraction often transform these settings into "*el dorado*"-like and often attract a significant number of job-seekers, both nationals (in-migrants) and foreigners (immigrants) (Corno & de Walque, 2012; Jackson, 2018). Consequently, rapid in-flux changes local communities' social and economic structure (International Finance Corporation, 2009b). Hence, new lifestyles, behaviours and practices are often introduced into the communities, which are being transformed from rural regions into small towns. Soon life in these regions began to be competitive in all dimensions. In turn, locals adopt these new lifestyles to escape poverty or gain a social status that allows them to

[12] In the absence of an external disrupting factor (e.g., implementation of an industrial mining project), indigenous communities often have hand-on and traditional ownership of the natural capital (land, water and forest) and a resource management and self-governance system that is sustainable and it includes identity, spirituality and culture (https://sustainabledevelopment.un.org/index.php?page=view&type=30022&nr=750&menu=3170)

insert themselves in the new competitive environment equitably and fairly (Brasier et al., 2011).

Interestingly, this is in line with our findings. For example, our findings show that (the presence of) mining projects induced changes in income-generating activities because of the loss of land, reduced agricultural production due to land pollution, and reduced access to land for pastoralism and artisanal and small-scale mining. The resulting changes in livelihood activities often lead to new strategies at the household level for "*putting food on the table",* such as prostitution and sexual transactions, which were perceived to increase the risk for the spread of sexually transmitted infections (STIs), including HIV/AIDS. In addition, our qualitative research reveals that there were many migrants, both national and international, within the investigated communities, primarily young men, that often engaged in unsafe sexual intercourse with young local women. Migrants were also perceived to change sexual partners frequently or have multiple sexual partners simultaneously. These poor sexual behaviours were linked to increasing incidence trends or introducing new diseases in the communities, particularly STIs and HIV/AIDS, gonorrhoea and syphilis. These dynamics and mechanisms were also observed by different studies (Goldenberg et al., 2008; Jackson, 2018) and linked to low and challenges to accessing health care (Rutherford et al., 2010; Munguambe et al., 2016a), with a high rate of alcohol consumption (Lightfoot et al., 2009) and reduced capacity of the local health system in providing essential services promoting health (Konte & Vincent, 2021).

Considering the high vulnerability of (young) women and the high rate of vertical transmission of STIs in low and middle-income countries (LMICs) (Newell, 2000; World Health Organization, 2021b), particularly among non-empowered women (Kotsadam & Tolonen, 2016; Tolonen, 2018), our findings suggest that the burden of STIs and related deaths in resource extraction settings in SSA countries a possibly underestimated and this points at the need for interventions specifically targeting MCH in mining settings to safeguard both the health of women, new-born and children and ultimately the community and future generations. These can include implementing and developing alternative income generation projects, complemented with training and financial support, focused on affected communities targeting the most vulnerable groups. In addition, interventions should include health education and improvements in access to health care, such as testing and treatment of infections for both migrants and local communities.

5.3.2 Occupational health

Even though occupational exposure and related diseases have been a matter of concern for centuries (Cole, 1944; Rose, 1944; Ramazzini, 2001), we still have a long way to go in minimizing the issue at all levels (Donoghue, 2004). For instance, working conditions in industrial mining projects usually meet relatively high standards, often resulting from increasing compliance with national laws and international regulations (International Labour Organization (ILO), 2016; Legislation, 2021). A clear example from our findings is that community members perceive mine workers as people with good living conditions, better salaries, housing, quality food and access to the health care system and preventive programmes. However, mine workers still face severe injuries at the workplace (Aliabadi et al., 2019). Not surprisingly, findings from our research show that a common perception of community members living close to mining projects in Mozambique is that “mine workers are people with poor health”. Explicitly, participants reported that mine workers were sick people with infectious diseases such as tuberculosis. Our results are similar to those reported in a study from South Africa (Stuckler et al., 2011). According to the authors, industrial mining activities are linked with increased odds of acquiring tuberculosis because working conditions, particularly underground mining pits, create high-risk environments favouring tuberculosis transmission among mine workers (Stuckler et al., 2011).

When considering that an increasing number of industrial mine workers are women worldwide (Dyke & Dallmann, 2013; Bihale, 2016; Chichester et al., 2017) and several studies have reported poor women-related health outcomes as a matter of occupational health in mining settings (Jennings, 1999; Burdorf et al., 2006; Coelho et al., 2011) such as increased odds for poor obstetric outcomes (Ahmed & Jaakkola, 2007); it becomes clear that the exposure to hazardous working conditions has a deleterious effect on the human body, particularly for pregnant women, the foetus and new-born (Tirima et al., 2018; von der Goltz & Barnwal, 2019).

In addition, our analysis shows that more than two-thirds of health-related studies conducted in ASM included at least a miner and reported a degree of accumulation of pollutants in their body, often causing various adverse health conditions such as abortion, reproductive disorders and adverse birth outcomes. These findings may be explained by the fact that ASM is, in most cases, an informal sector with poor occupational health conditions (Hilson, 2012a), rendering ASM one of the most hazardous occupational activities globally, threatening not only the health of male artisanal miners but also women, new-born and young children (Ikingura et al., 1997; World Health Organization, 2016a). While we could not directly assess the health of industrial mine workers in Mozambique, we found that 15% of studies investigating health in the ASM context assessed physical hazards such as dust, exposition and landslide in the working place, reporting several related injuries (e.g., hearing loss and burning) and fatalities. Our findings corroborate previous studies reporting physical and chemical occupational health issues in Africa and the Philipines (Lu, 2012; Elenge, 2013).

Studies have found that, in the ASM context, women work longer hours, side-by-side with their siblings, with no social safety net and are exposed to hazards such as noise from pestles and hammers (Rand, 2010; Lu, 2012). Similarly, hearing loss-causing noise in mining industries' working environment is quite common and is a concern for occupational health in African countries (Moroe et al., 2018; Sun & Azman, 2018; Sun et al., 2019).

When considering that an increasing number of women are expected to work in industrial mining projects in the coming decades (Dyke & Dallmann, 2013) and there already about 50% of women and 10% of children working in ASM environment (Lahiri-Dutt, 2008; The International Institute for Sustainable Development (IGF), 2018), occupational health in the mining sector continue to be a serious public health problem despite increase trend in awareness and implementation of health and safety measures at work environments - a policy often enforced by international organizations (International Labour Organization (ILO), 2021) particularly in industrial mining projects. Thus, gender-sensitive strategies for women's occupational health and safety in small-scale mining should be implemented. For long-term development goals, women should be given alternative and more environmentally sustainable forms of employment.

5.3.3 Changes in environmental conditions

Although several improved water sources have been reported to be installed across mining hosting communities, mine-induced environmental degradation leads to hampered water quality and availability in mining settings in Mozambique. Consequently, women living in mining areas face particular challenges in maintaining good hygiene practices to prevent diseases at the household level. This challenge further exacerbated existing waterborne diseases such as diarrhoea. Our findings align with previous studies conducted in similar settings (Adeyemi & Ojekunle, 2021; Leuenberger et al., 2021). For instance, Adeyemi and Ojekunle (2021) found that the levels of heavy metals in groundwater (hand-dug wells and boreholes) in communities living near Industrial areas in Nigeria were above the maximum standard level established by the World Health Organization (World Health Organization, 2004) and the Canadian Drinking Water Quality (Toft et al., 1987), with potential to cause several human health problems such as diarrhoea, lung and kidney damage, vomiting, and stomach irritation and the fragility of bones (Adeyemi & Ojekunle, 2021).

On the contrary, another study found that, in SSA countries, households located in close proximity to active mines have higher odds of access to modern water and sanitation infrastructure (Admiraal et al., 2017; Dietler et al., 2021a). These improvements in water and sanitation infrastructures are often linked with mine-related interventions as part of their mining concession agreements or through Corporate Social Responsibility (CSR) programs (Fewtrell et al., 2005; Admiraal et al., 2017; Frederiksen, 2018). These CSRs related interventions are often provided only once, with no guarantee of maintenance (e.g., in the case of construction of infrastructure), and therefore lose their social, economic and cultural value in the memory of local communities. It is possible, however, that the provided water and sanitation may not be equally distributed among affected communities (Jenkins, 2004), which tend to have access to water with poor quality due to mine-related pollution (Nhantumbo et al., 2020). In addition, mining can also pollute allocated water and water system, which may, in turn, be unsafe for drinking and other uses (Terrascope, 2017; Adeyemi & Ojekunle, 2021).

Similarly, in the context of coal mining, women reported that dust from mining explosions also poses challenges in maintaining household hygiene. Besides, poor housing conditions due to the cracks caused by mine explosions and subsequent vibrations allow for the inside deposition of dust loads worsening hygiene conditions and resulting in several adverse health outcomes (**Figure 5**). Similar findings have been reported by studies investigating health in coal mining sites and linked this issue to an increase in risk for mortality and respiratory diseases (Hendryx & Ahern, 2008; Leuenberger et al., 2019).

Figure 5. Water (panel A), Sanitation (Panel B) and housing (Panel C) in communities around coal mine projects in Mozambique

In addition, poor waste management of industrial mines has raised serious concerns among communities living closer to mine projects (Kuna-Gwoździewicz, 2013). This report was confirmed by our findings, which showed that children are exposed to mine-related waste when playing or collecting rubbish, looking for food and other goods. As a result, they were reported to suffer from diarrhoeal diseases and injuries from cuts by broken bottles. These findings are similar to those reported by Aweng and Fatt (2014). According to these authors, most garbage collectors from Dump Sites in Kelantan, Malaysia, have ever injured by sharp objects (70%), and another suffered from sore throat, cough, fever (60%), respiratory (38%) and skin diseases (28%) (Aweng & Fatt, 2014).

In the context of ASM, we found that several studies have focused on water, hygiene and sanitation (WASH) and related health outcomes. Hence, it is commonly known that ASM communities face serious environmental issues, including difficulties in access to safe water and sanitation (Ralph et al., 2018; Tsang et al., 2019). An ASM community located close to industrial mining in Montepuez (Mozambique) reported that they face serious challenges concerning hygiene, sanitation and access to clean water and, thus, suffer from various adverse health conditions, including diarrhoea. Poor health outcomes from water and air pollution across ASM communities have been reported elsewhere (Fewtrell et al., 2005; Kemp et al., 2010; Nhantumbo et al., 2020).

Overall, our findings suggest that impacts on environmental determinants of health are pretty similar between ASM and industrial mining contexts, often involving air, water and soil pollution threatening the life and health of affected communities, particularly for pregnant women and children. These findings call for an urgent need for interventions promoting environmental health, such as managing air and water pollution and mine-related waste to protect the health of affected communities, particularly vulnerable populations such as women and young children.

5.3.4 Inequity in the distribution of mine impact on MNCH

The impact of industrial mining projects seems uneven, varying with mining location, type of extracted commodity and mine life stage (United Nations Development Programme, 2016; Chuhan-Pole et al., 2017; Dietler et al., 2021a). This observation is partially confirmed by our results showing that coal mine projects in Mozambique tend to have more impacts on respiratory disorders due to intense air pollution from coal dust resulting from mine explosions. However, STIs were reported more in communities close to Ruby mine projects, affecting women and children. Further, our study shows that both respiratory and STIs were reported more by participants living in close proximity to heavy sand mine projects. These differences in industrial mining projects' impacts by location (i.e., countries) have been reported elsewhere (Polat et al., 2014). At the same time, Polat and colleagues (2014) explain the observed differences in household welfare and childhood nutrition through changes in the economic gain of families living in the immediate mining catchment area of a 20km radius. These reports align with most econometric studies showing that gold extraction significantly reduces poverty at local and regional levels across SSA countries (Aragón et al., 2015; Hilson, 2019). However, evidence of translation from economic growth into health gain is scanty. In another study, Dietler et al. (2021) reported that women living in close proximity (i.e., <10km) from an active mine have better housing conditions than those living further away but with similar rates of respiratory diseases (Dietler et al., 2021b). Hence, these findings point to a need for further research to understand better the role of differences in economic gain across mining project sites on the observed differential impact.

Few studies have reported differences concerning the mine life stage (Benshaul-Tolonen, 2018) despite broad knowledge that the impact of a mining project varies according to the phase of development (Brasier et al., 2011; United Nations Development Programme, 2016). Our analysis shows that mining does not readily affect childhood diarrhoea and respiratory problems soon after opening; instead, the risk for diarrhoea is reduced late in the construction phase but before the onset of extraction activities. Further, we observed that the odds of respiratory illness increased five years after extraction commenced, probably reflecting the increase in air pollution (Hendryx & Ahern, 2008). Again, we partially explain this by potential differences in the economic gain throughout different mine life stages (Brasier et al., 2011; Aragón et al., 2015; United Nations Development Programme, 2016), which calls for a pressing better understanding of these associations and how economic gains are translated into health outcomes. Overall, environmental management soon after the initiation of extractive mining activities close to the mining catchment area is needed to protect the health of affeted communities, particularly for children under five years. Environmental management should be specific to the type of mining and mined commodity as well as mining location-based. For example, across coal mining sites where dynamites are used during mining operations, environmental management should include the implementation of an early warning system to allow communities to protect themselves and their belongs (e.g., food and water) to avoid exposure to air pollution, exploding mining dynamites during rainy days so that dust is timely ground deposited. Other mining sites, such as gemstone exploitation (e.g., Ruby) and minerals (e.g., heavy sand), dampening access roads frequently enough to avoid dust due to heavy road traffic and dampening or covering extracted products during transportation to reduce air pollution would be advisable.

5.4 Strengthening the inclusion of MCH in health impact assessment

In this chapter, we reflect on how and at which stage the inclusion of MCH can strengthen Health Impact Assessment (HIA) for large-scale projects, including industrial mining. We start by discussing the current practice of HIA in SSA countries (Section 5.4.1), then outline the main steps of the HIA process in Section 5.4.2. Based on the identified stages and our findings, we reflect on the main stages of the HIA process in which MCH can be integrated, what aspect can be included, and what implication for HIA can be observed.

5.4.1 Health impact assessment – current practice in SSA

It is well established that the implementation and operation of large infrastructure projects should be preceded by a health impact assessment (HIA) to identify and mitigate potential negative impacts on the health (Harris et al., 2015b; Winkler et al., 2021). HIA is a tool whose process is well established to support decision-making processes in the frame of licencing the development of a large initiative and, thus, has the potential to foster Sustainable Development in all contexts (Quigley et al., 2006; Winkler et al., 2021). Although expanded over the world since its establishment two decades ago (Birley, 1995; Scott-Samuel, 1996), HIA is still not actively promoted through policy or regulation across the African continent (Winkler et al., 2013). At the same time, using the HIA as a tool depends on the project financier, who is generally headquartered outside the African continent. It results that HIA is under-practised in most SSA countries while the inclusion of health in other means of impact assessment (i.e., environmental impact assessment, EIA) is still scanty (Leuenberger et al., 2019; Dietler et al., 2020b; Winkler et al., 2020b). For instance, a study scrutinizing several types of impact assessment reports, including HIA, EIA, Social Impact Assessment (SIA), Environmental and Social Impact Assessment (ESIA) and Environmental, Social and Health Impact Assessment (ESHIA) conducted in SSA countries found that among those addressing health, MNCH issues such as child immunization, maternal and child mortality were addressed in less than half of the reports (Dietler et al., 2020b). Such can be partially explained by the fact that only in four out of 34 SSA countries is there at least one HIA practitioner, of which a few have more than five years of experience (Winkler et al., 2020b). This finding is problematic considering the findings of the present PhD thesis, showing that the health of women and children living close to industrial mining projects are diversely and negatively affected. This reflects the importance of including MCH in the impact assessment process in a comprehensive approach, be it in HIA as a stand-alone approach or integrated into other forms of impact assessment (Quigley et al., 2006; Dietler et al., 2020b).

5.4.2 Health impact assessment – the process

HIA has extensively evolved since its introduction by the World Health Organization (WHO) thanks to constant review and adaptation by HIA practitioners worldwide. Currently, HIA process comprises six stages grouped into three main categories (World Health Organization, 1999; Quigley et al., 2006; Winkler et al., 2021). Ultimately, the guidance document provides a set of tools and methods for each of the phases of HIA: (i) screening (preliminary evaluation to determine the necessity of an HIA); (ii) scoping (identifying the range of potential project-related health impacts and defining the terms of reference, based on published literature, local data and broad stakeholder consultation); (iii) risk assessment (qualitative and quantitative appraisal of the potential health impacts concerning defined communities and the project development, including stakeholder participation); (iv) appraisal and mitigation (development of a Community Health Management Plan (CHMP) based on the findings of the risk assessment); (v) implementation and monitoring (realisation of the CHMP including monitoring activities that allow for adaptation); and (vi) evaluation and verification of performance and effectiveness (a pivotal step to analyse the HIA process as a whole) (Winkler et al., 2021).

5.4.3 *Identifying potential health issues affecting women and children*

HIA guidance documents recommend that the team conducting HIA for a proposed project should, beyond the professionals and experts on HIA, be composed of interdisciplinary and intersectoral personnel (Winkler et al., 2021). Our findings from the qualitative suggest that MCH nurses working in mining project areas are knowledgeable about health issues affecting women and children at the community level. Hence, including local, well-trained health professionals in the team performing HIA seems promising because they can quickly identify potential impacts and hence contribute, not only during the scoping stage but also throughout the process of HIA (Quigley et al., 2006; Winkler et al., 2021). In inclusion of health experts on MCH can contribute to the team two folds: (i) During the scoping step, they can identify key MCH indicators such as mortality, endemic and rare health issues (e.g., malária and respiratory infections, malformations) as well as obstétric conditions that can potentially be affected by the development of the project, and (ii) can indicate geographical boundaries where MCH can potentially be affected as they have hands-on knowledge about the health status in the community, their geographical relationship (e.g., challenges to access health care services) and health system dynamics.

According to Winkler and colleagues (2013), the team must do a baseline description of relevant health hazards, health promoters, health determinants and potential health outcomes in the proposed project (Winkler et al., 2021). For this purpose, primary and/or secondary data can be used. Hence, data availability and quality are critical for the success of this process (Steckling et al., 2014). Based on our results showing a large diversity of health outcomes related to MCH resulting from exposure to mining activities, MCH health in settings with unique characteristics, such as those affected by mining projects, are of severe public concern (Sun & Azman, 2018). The inclusion of MNCH indicators to be assessed can strongly contribute to HIA. The use of HIA tools to assess the impact of industrial mining projects has proven to provide valuable shreds of evidence for improving the health of affected communities (Winkler et al., 2012a; Knoblauch et al., 2020). Based on this background, it is clear that including a comprehensive list of MCH indicators, such as mortality, obstetric conditions and infectious diseases, during the scoping step of the HIA process can further provide insight into how the implantation of projects would impact MCH. Besides, HIA-rooted MCH indicators can provide insights on specific mitigation strategies tailored to women and children at the community level to be included in the HIA report and evaluated and monitored in the following stages.

5.4.4 *Gender mainstreaming in decision-making processes and the mining industry*

Women are always at the forefront of child health care from conception, delivery and development, and mining settings are no exception. Women´s burden is often two-fold, including working and responsible care of family, particularly young children (Lu, 2011; Fernes, 2019). While women and children are often seen as vulnerable groups in society and excluded from most mining-related impact assessment processes (Glucker et al., 2013), women´s economic empowerment has the potential to be directly translated into promoting children's health by increasing their resources and capacity to invest in the siblings (Tolonen, 2014; Benshaul-Tolonen, 2018). This can be translated into the sustainability of the impact assessment *per se* as a decision-making orienting tool that would be informed based on evidence ensuring the work toward the achievement of SDGs at all levels (Yakovleva et al., 2017). This implies that the active future workforce needed for industrial mining projects will be ensured to continue their existence and operation would.

It results that impact assessment of large development initiatives based on a gender-sensitive approach would ensure equality and equity if women are included in the early stage of impact assessment (e.g., during the consultation process) as their voices would sound and influence the decision-making process, increasing their odds in entering into the mining industry and thus, women empowerment (Dyke & Dallmann, 2013; Chichester et al., 2017; The International Institute for Sustainable Development (IGF), 2018).

5.4.5 Design and implementation of strategies for specific population groups

Because the actual practice of environmental impact assessment lacks an integrative approach and focuses on health determinants, it often fails to elucidate specific causes for and patterns of maternal and child morbidities and mortality that are directly and/or indirectly linked with natural resource extraction activities (Stephens & Ahern, 2001; Hendryx & Ahern, 2008; Ahern et al., 2011). Consequently, they have limited power to inform specific mitigation strategies and foster mining projects to work toward specific targets of SDG 2030 agenda. Examples can be found in various contexts where the strategies implemented for the resettlement of affected populations have resulted in serious socioeconomic disruption and poor MCH outcomes, including increased malnutrition due to food insecurity and poor obstetric outcomes (Watch, 2013; Bihale, 2016). According to the authors, communities are often resettled in remote places, with an extreme lack of drinking water, limited sanitation infrastructures and far from essential public services such as health facilities (Watch, 2013; Bihale, 2016).

Involving MCH specialists in the current Health Impact Assessment would inform the design and implementation of specific interventions to promote MCH in the short and long term, targeting specific population groups locally. The designed strategies would also target the real needs of those groups and thus maximise positive results – with low resources - while minimizing harmful health effects of mine operations (Winkler et al., 2021). For this purpose, specific maternal and child health aspects must be discerned in the early stages of the HIA process. By doing so, interventions can be carefully specified and tailored to specific vulnerable groups and needs. This implies that a multidisciplinary and multi-sectoral approach – including the health sector - is needed for conducting an impact assessment of large-scale infrastructure with the inclusion of MCH.

Importantly, there is a need for balancing the community expectation and ming project capacity while ensuring sustainability, equity and equality (Winkler et al., 2021). For instance, in one study area, participants reported that a mining project introduced a mobile clinic for communities living in remote areas and far, but not for those living close to the health facilities. This intervention was perceived as not equally distributed of the intervention, and women often felt marginalized. Besides, participants also reported that the mobile clinic was more beneficial because of lack of medicine, a different scenario compared with the beginning of the mining project. This unsustainable nature of interventions could be avoided if specific needs were carefully assessed during the impact assessment process.

5.5 The mining sector as a vital partner for sustainable development

The potential of the mining sector to contribute to sustainable development has been highlighted by many international organizations, as well as independent studies (United Nations Development Programme, 2015);Dubiński, 2013 #109;Yakovleva, 2017 #551}. This is because resource extraction activities, both through ASM and industrial mining projects, are interlinked with almost all SDG 2030 goals through direct and indirect routes and pathways (Lambert, 2001; Haan et al., 2020; Hilson & Maconachie, 2020; Hirons, 2020). For example, by providing employment for the non-skilled and poor population, ASM provides livelihoods for many people worldwide and, thus, is vital for achieving SDG1 (Hilson & Maconachie, 2020). In addition, industrial mining can, in collaboration with the health sector, foster preventive healthcare at the local level (United Nations Development Programme, 2016). In the following chapters, a reflection is pursued on how the extractive sector can be transformed into a strong partner for sustainable development. The first reflection is related to the ASM sector (Section 5.5.1), followed by Section 5.5.2, in which a thorough reflection on the potential of the industrial mining sector is made.

5.5.1 Potentials of ASM sector

A large body of scientific literature gives examples of potential benefits of ASM activities. For instance, ASM provides livelihoods for an estimated 150 million people globally by providing alternative in-coming generating activity for non-skilled and poor personnel (SDG1) (see **Figure 6**) (Haan et al., 2020; Hilson & Maconachie, 2020). Direct and indirect income generated through ASM can be spent on health care and disease prevention strategies such as investing in better housing, clean drinking water and sanitation (SGD3) (Gan et al., 2017;

Dietler et al., 2021b), while potentially also reduce food insecurity by investing in agriculture or buying food of high quality (SDG2) (Hilson, 2012b; Haan et al., 2020; Hilson & Maconachie, 2020). While in our scoping review, we did not seek a particular pathway into which ASM interacts with the SDGs; studies have reported positive impacts of ASM as an alternative economy and livelihood (SDG), (Siegel & Veiga, 2009; The World Bank, 2019) and food security (Zhang et al., 2020). However, it is worth recognizing that there is still a long to go in transforming ASM into a sector that fully leverages sustainable development due to its already-known challenges (Dooyema, 2012; Tirima et al., 2018; World Health Organization, 2018b; Mathee et al., 2019; Haan et al., 2020; Hirons, 2020). This takes us to the question of `whether and how ASM can work hand-to-hand toward the 2030 agenda of the SDGs?´

Figure 6. Artisanal coal mine for burning bricks for construction in Tete province, Mozambique. Panel A, the open pit of ASM; panel B, mined coal and panel C, artisanal bricks for housing ready to be burnt. Source: Authors

Many authors and institutions have suggested the formalization of the ASM sector as a mechanism to transform ASM into a vital partner for Sustainable Development (Florentina-Cristina et al., 2015; United Nations Development Programme, 2015; Hilson & Maconachie, 2020; Hirons, 2020). Formalization is thought to have the potential to reduce, or even eliminate, negative impacts on social structure (SGD 5) and environmental determinants (SDG 6, 13, 14 and 15) of ASM since it may be possible to know *where* and *how* ASM is happening (Hilson et al., 2018; Haan et al., 2020). Besides, it is also thought that formalization can secure the "miners´ right to work" and can facilitate financial and technical support (SDG 8) (Hirons, 2020). Although the formalization of the ASM sector has been successful in some contexts (Hilson et al., 2018), many challenges still need to be overcome if tangible results are to be observed. Many of these challenges, including, but not limited to, government capacity building, stable policies, a peaceful political environment, organisation of miners, techno-scientific knowledge of the ASM sector and the '*large-scale bias*' concept, are discussed in detail elsewhere (Verbrugge & Besmanos, 2016; Marshall & Veiga, 2017; Zvarivadza, 2018a; Hilson, 2019; Hirons, 2020). In light of the above discussion, it is clear that while the ASM offer many challenges, adequate formalization can be the best approach for turning the sector into a more vital partner for sustainable development. However, the success of such achievement is context-dependent, and any approach should count on many factors.

5.5.2 Potentials and shortcomings of industrial mining projects sector

Many countries and governments in SSA are in favour of investments through industrial mining projects when it comes to fostering local and national economic development and, thus, achieving the most, if not all, SDG 2030 targets (Dubiński, 2013; United Nations Development Programme, 2015; Hilson, 2019). Like ASM, industrial mine projects interact positively and negatively with all the SDG 2030 agenda targets to different degrees (United Nations Development Programme (UNDP) & UN Environment (UNE), 2018). Many Studies have reported successful cases of economic development induced by the extractive industry and suggested strong positive effects on health indicators (Aragón & Rud, 2009; Aragon & Rud, 2013; Tolonen, 2014; Andersson et al., 2015; Aragón et al., 2015; Kotsadam & Tolonen, 2016; Tolonen, 2018). Our findings confirm that the opening and operation of industrial mining positively affect infant (neonatal) survival and childhood diarrhoea across 23 SSA countries (SDG 3.2 and 3.3). Other studies have also reported similar findings where evidence of mine impacts are reported acting on a range of SDG indicators, e.g., on SDG 3.2 (Benshaul-Tolonen, 2018), SDG 3, 5 and 8 (Tolonen, 2014), SDG 11 and SDG 3 (Dietler et al., 2021b) SDG 3.3 and SDG 6 (Dietler et al., 2021a). Based on this, it is worth asking, `why such economic growth is not seen at a global, even regional scale?´. The clue is that these effects are, however, often found to be geographically concentrated; i.e., effects are seen in a radius of 10 to 20 kilometres from the mine, and the impact also varies with various phases of the mine's life stage: from exploitation to mine closure (United Nations Development Programme, 2016). For instance, during the construction phase of the projects, positive impacts are often observed as the mine provides countless job positions (SGD 1 and 8) (United Nations Development Programme, 2016).

This implies a pressing need to scale up the positive impacts of industrial mining, but achieving this objective partnership (SDG 17) between the mining sector, the government and other stakeholders is necessary (United Nations, 2015b). With a good partnership, gains can be through two main channels: (i) success stories regarding strategies targeting specific groups of the population for improving health can serve as a learning point for governments and, thus, scale up to another context either with similar characteristics or mine-free contexts experiencing similar health issues. This has been proven true in some contexts in Mozambique, where access to health care is of concern among pregnant women, often leading to poor obstetric outcomes (Munguambe et al., 2016b). The second channel into which gain can be drawn is the accountability on (ii) mining-related Corporate Social Responsibility (CSR), which can be maximized if the operationalization of CSR integrates societal concern and decisions for implementation (including local economic projects) are based on evidence (Jenkins, 2004; Abdelmajid et al., 2021). This can further reduce the economic gap between `haves and have not´ as discussed elsewhere (Brasier et al., 2011; Leuenberger et al., 2021). Our study has an in supports of this as we found that in all study sites in Mozambique, mines have made various interventions focused on structural settings, including upgrading health facility infrastructures and expanding health services to the communities through the mobile clinics (SDG 3), provision of drinking water (SDG 6), job opportunities (SDG 8), building and upgrading on health (SDG 3) and education infrastructures (SDG 4), the introduction of chicken breeding projects and other economic activities (SDG 1, 2 and 8), most of which through their CSR.

While there are several descriptions of relevant indicators through which the extractive sector can act on SDG 2030 (Lambert, 2001; Dubiński, 2013; United Nations Development Programme, 2016; United Nations Development Programme (UNDP) & UN Environment (UNE), 2018), specific actions as still in need. Such actions should be country and local context specific to respond to each challenge depending on the type of mine, country and region of location and phase of mine. Thus, Health Impact Assessment (HIA) is a tool that potentially can fill this gap (Quigley et al., 2006; Leuenberger et al., 2019; Winkler et al., 2021). Generated evidence through HIA, combined with other means of impact assessments, has a solid potential to inform appropriate actions at all stages of mine operations and, thus, minimize or mitigate related health risks and foster health opportunities (Winkler et al., 2021).

6 Conclusion and recommendations

This PhD study is rooted in three main approaches, namely a systematic review, a quantitative study and a qualitative study, for constructing a holistic understanding of how maternal and child health is affected by activities related to the extractive sector (**Figure 7**). Overall, limited studies are addressing specifically maternal and child health in ASM contexts over the world, while a number of health determinants and health outcomes are reported by most of the studies on ASGM. On the other hand, industrial mining opening and operation positively affect child health, which varies throughout the life stages of a mine according to the indicator of interest. In contrast, a myriad of health conditions is perceived to affect maternal and child health across mining settings in Mozambique.

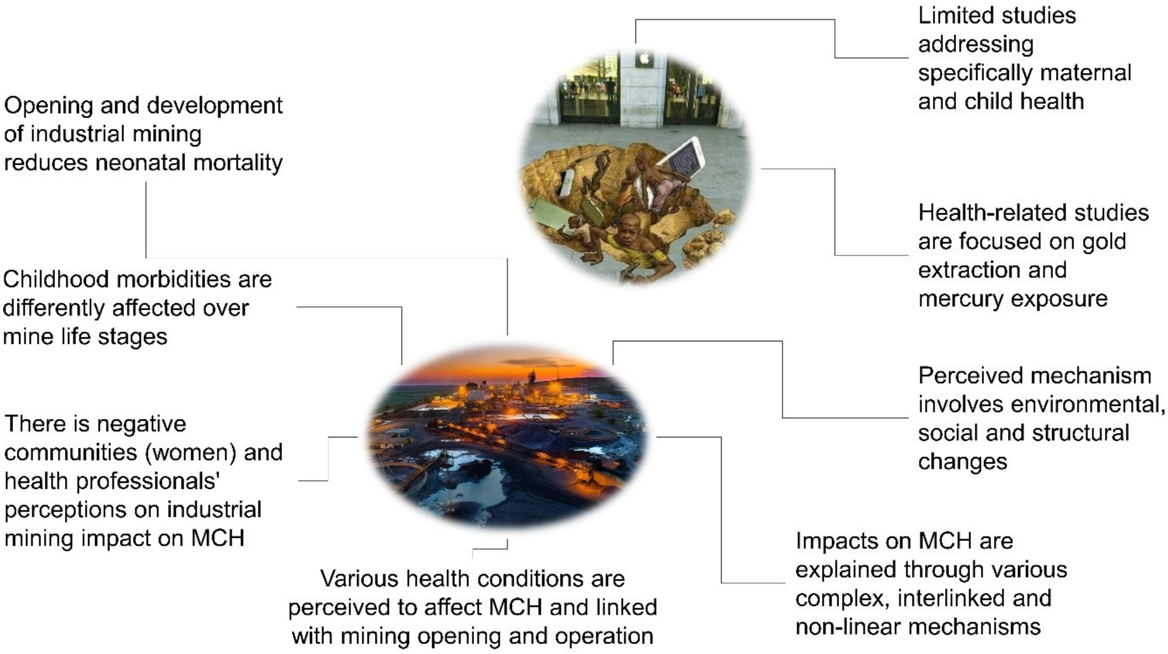


Figure 7. Schematic of concluding remarks

Based on our findings, our current understanding of how industrial mining affects MCH is complex and mixed; however, both ASM and industrial mining share the type of health determinants and mechanisms that impact and, ultimately, health outcomes. Further, including MCH indicators has a strong potential for strengthening the HIA process, while the extractive sector can benefit from it and work toward achieving SDG 2030.

Environmental management, including air pollution and mine-related waste, seems advisable given the increased risk for childhood exposure and subsequent development of respiratory conditions, injuries from cuts from broken bottles and water-borne diseases.

Industrial mining should create gender-sensitive opportunities for alternative economic development in affected communities and, thus, reduce inequalities and vulnerability. In addition, there is a pressing need for health education targeting vulnerable groups and immigrants to prevent disease transmission while providing better quality health care services for improving MCH at the local level.

7 Identified research needs

In the background of the findings of this PhD research, some identified knowledge gaps can be filled by conducting further research in the area of MCH in the mining context. Hence, the following research needs and recommendations are put forth:

- Assess the association between economic growth and the impact on maternal and child health induced by industrial mining projects. For this, the combination of economic and health data from various sources, including Demographic and Health Surveys (The DHS Program, 2018), Household Budget Surveys (HBS) (Instituto Nacional de Estatistica (INE), 2017) and the District Health Information System v2 data (Farnham et al., 2023) can be combined with historical mining data. Stratified analysis can inform which economic strata do better off from industrial mining opening and operation.
- Assess the inequity distribution of mine impact on various maternal and child health indicators, including differences across countries and types of mines. This would provide insights into contexts where specific actions are needed in order to foster mine projects to work toward specific targets of the SDG 2030

Our qualitative study was based on the community's voices which could introduce some bias. Future studies should include the voices of mine projects in order to have a holistic picture of relevant impacts and draw meaningful context-specific strategies to mitigate negative externalities.

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9 Curriculum Vitae

Personal details

Name	Hermínio Fernando Humberto Cossa
Date of Birth	09 July 1981
Nationality	Mozambican
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Bsc, MSc, Dr. phil. designatus

Summary

Herminio Cossa holds a PhD in Environmental Epidemiology with a research focus on Health Impact Assessment (HIA) of large infrastructure development projects from the University of Basel (Switzerland). He holds a Master in Health Sciences and is a Biologist with 15 years of experience in Clinical Laboratory. Dr Cossa is a researcher at the Manhica Health Research Center (Manhica, Maputo, Mozambique), focusing on Health Impact Assessment of large infrastructure projects, natural phenomena, population group behaviours, and community and institutional interventions in public health. His areas of interest are Environmental Health, Maternal and Child Health and Adolescent Sexual and Reproductive Health. The area of interest expands to the application and use of secondary data routinely collected by various sectors (*big data*) - public and private - in research on the impacts of anthropogenic environmental and climate change on public health on a national and global scale.

He is experienced in designing quantitative, qualitative and mixed epidemiological studies, focusing on socio-behavioural and perception research on the impacts of community and institutional interventions in public health. In addition, he is a post-doctoral fellow in Maternal and Child Health Impact Assessment of the Extractive Industries and other large-scale developments, focusing on applying data from the health information system for monitoring and evaluation as research tools in the context of the extractive industry in Mozambique. He is also experienced in data collection using qualitative (e.g. conducting surveys) and qualitative techniques such as non-participant observations, interviews and focus group discussions, as well as analysis and interpretation of qualitative data using the qualitative data analysis program Nvivo (version 12.6). Dr Cossa has been offering training on Health Impact Assessment, using qualitative techniques in research, including qualitative data collection (including techniques mentioned above), coding, analysis and interpretation of qualitative data since 2021.

Education

11/2017-07/2021	***University of Basel and Swiss Tropical and Public Health Institute***
	PhD in Environmental Epidemiology, Major in Health Impact Assessment of Large Infrastructure (Maternal, new-born and child health)
	Thesis in collaboration with:

PD Dr. Mirko S. Winkler (Swiss Tropical and Public Health Institute)
Prof. Dr. Günther Fink (Swiss Tropical and Public Health Institute)
Dr. Khátia Munguambe (Manhiça Health Research Center)
Dr. Eusébio Macete (Manhiça Health Research Center)

7/2014 – 7/2017	**Fundação Osvaldo Cruz, Instituto Osvaldo Cruz (FIOCRUZ/IOC)**
	Master of Science, Major in Parasitic Biology (Genetic and Biochemistry) Dissertation in collaboration with: Prof. Dr. Nilsa Razão de Deus (INS/MISAU, Mozambique) and Prof. Dr. Alda Maria da Cruz (FIOCRUZ/IOC, RJ)
9/2009 – 1/2013	**Universidade Eduardo Mondlane, Maputo-Moçambique**
	Bachelor of Science in Biology, Major in Biology and health

Trainings

03-2023	***Clinical Research (PTY) LTD*** *Service & Quality Beyond Complience*
	ToT GCLP, train-the-treiner *Good Clinical and Laboratory Practice Course*
03-2023	***Clinical Research (PTY) LTD*** *Service & Quality Beyond Complience*
	ToT GCP, train-the-treiner *Good Clinical Practice*
07 – 08/2020	***Department of Geography, School of Earth Sciences, Central University of Karnataka,* India** ***State Institute of Urban Development, Karnataka,* India**
	Online GIS Training Program using QGIS
01 – 02/2019	***ETH Zürich***
	Health Impact Assessment: Concepts and Case Studies
01/2019 – 11/2020	***Swiss Tropical and Public Health Institute***
	Qualitative and mixed methods: theory and practice *Current Ecological and Health Issues in Africa*: Workshop *Statistical modelling: practice* Environmental Epidemiology: Workshop
April 2017	***Center for Disease Control and Prevention***
	Application of Laboratory Medicine Best Practices Initiative (LMBP™) A-6 Methods for Laboratory Practitioners (*Web-based*)
July 2014	**Center for Disease Control and Prevention**
	Microbiology (Basic Curriculum) (*Web-based*)

Working experience

06/2021 – atá hoje	**Manhica Health Reseach Center**
	Researcher and study coordinator Trainer in Health Impact Assessment of Major Infrastructure Projects
11/2021 – 06/2021	**Manhica Health Reseach Center**
	Coordenador de estudos
1/2015 – 10/2017	**Laboratory of Parasitology and Molecular Biology (INS/MISAU-Moçambique**
	Professional internship within the "National Surveillance of Acute Diarrhoea in Children".
4 - 8/2016	**Interdisciplinary Medical Research Laboratory , (IOC/FIOCRUZ/RJ, Brasil)**
	Academic Internship - Research in Cellular and Parasite Biology
1/2003 – 12/2016	**Maputo Military Hospital , Maputo-Moçambique**
	Laboratory Technician and Biologist Parasitoloty and Microbilogy

Languages

Portuguese	Native speaker
Changana	Native speaker
English	Good command / good working knowledge

Publications

Farnham, A., Loss, G., Lyatuu, I., **Cossa, H**., Kulinkina, A. V., & Winkler, M. S. (2023, May 31). A roadmap for using DHIS2 data to track progress in key health indicators in the Global South: experience from sub-saharan Africa. *BMC Public Health, 23*(1), 1030. https://doi.org/10.1186/s12889-023-15979-z

Magaço, A., Cumbane, C., & **Cossa, H.** (**2022**). Dataset for the attitudes and practices regarding COVID-19 preventive measures in diverse settings of Mozambique: a qualitative study. *F1000Research, 11*. https://doi.org/10.12688/f1000research.111150.1

Leuenberger, A., Winkler, M. S., Lyatuu, I., **Cossa, H.,** Zabré, H. R., Dietler, D., & Farnham, A. (2022). Incorporating community perspectives in health impact assessment: A toolbox. *Environmental Impact Assessment Review, 95*, 106788. https://doi.org/https://doi.org/10.1016/j.eiar.2022.106788

Cossa, H., Dietler, D., Macete, E., Munguambe, K., Winkler, M. S., & Fink, G. (2022, Jan 31). Assessing the effects of mining projects on child health in sub-Saharan Africa: a multi-country analysis. *Global Health, 18*(1), 7. https://doi.org/10.1186/s12992-022-00797-6

Cossa, H., Scheidegger, R., Leuenberger, A., Ammann, P., Munguambe, K., Utzinger, J., Macete, E., & Winkler, M. S. (2021). Health Studies in the Context of Artisanal and Small-Scale Mining: A Scoping Review. *International Journal of Environmental Research and Public Health*, *18*(4). https://doi.org/10.3390/ijerph18041555

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Leuenberger, A., Farnham, A., Azevedo, S., **Cossa, H**., Dietler, D., Nimako, B., Adongo, P. B., Merten, S., Utzinger, J., & Winkler, M. S. (2019). Health impact assessment and health equity in sub-Saharan Africa: A scoping review. *Environmental Impact Assessment Review*, *79*, 106288. https://doi.org/10.1016/j.eiar.2019.106288

Leuenberger, A., Winkler, M. S., Cambaco, O., Cossa, H., Kihwele, F., Lyatuu, I., Zabre, H. R., Farnham, A., Macete, E., & Munguambe, K. (2021). Health impacts of industrial mining on surrounding communities: Local perspectives from three sub-Saharan African countries [Research Article]. *PLOS ONE, 16*(6), e0252433. https://doi.org/10.1371/journal.pone.0252433

Farnham, A.; **Cossa, H.;** Dietler, D.; Engebretsen, R.; Leuenberger, A.; Lyatuu, I.; Nimako, B.; Zabre, H.R.; Brugger, F.; Winkler, M.S. Investigating health impacts of natural resource extraction projects in Burkina Faso, Ghana, Mozambique, and Tanzania: Protocol for a mixed methods study. *JMIR Res Protoc* **2020**, *9*, e17138. https://doi.org/10.2196/17138

Cossa-Moiane, I., **Cossa, H.,** Bauhofer, A. F. L., Chilaule, J., Guimaraes, E. L., Bero, D. M., Cassocera, M., Bambo, M., Anapakala, E., Chissaque, A., Sambo, J., Langa, J. S., Manhique-Coutinho, L. V., Fantinatti, M., Lopes-Oliveira, L. A., Da-Cruz, A. M., & de Deus, N. (2021). High Frequency of Cryptosporidium hominis Infecting Infants Points to A Potential Anthroponotic Transmission in Maputo, Mozambique. *Pathogens*, *10*(3). https://doi.org/10.3390/pathogens10030293

Conference proceedings

Cossa-Moiane ILC, Chilaule JJ, **Cossa HFH**, Cassocera M, Guimarrães E, De Deus N. Parasitic infections in children presenting with acute diarrhea in Mozambique: national surveillance data (2013 – 2015). In: 17th International Congress on Infectious Diseases [Internet]. Hyderabad, India: International Journal of Infectious Diseases; 2016. p. 1–477. https://doi.org/10.1016/j.ijid.2016.02.767

Hermínio COSSA; Idalécia COSSA-MOIANE, Maria FANTINATTI, Alda M DA-CRUZ, & Nilsa de DEUS. Genetic Characterization and Associated Factors for Cryptosporidium Spp. Infection in Children with Diarrhoea. X Conferência Científica da UEM, 2018.

Hermínio COSSA; Idalécia COSSA-MOIANE, Jorfélia CHILAULE, Esperança GUIMARÃES, Marta CASSOCERA, Miguel BAMBO, Eva JOÃO, Jerónimo LANGA, Diocreciano BERO, Elda ANAPAKALA, Júlia SAMBO, Lena MANHIQUE, Maria FANTINATTI, Luiz António LOPES-OLIVEIRA, Alda M DA-CRUZ, & Nilsa de DEUS. *Cryptosporidium hominis* infection among children admitted in two general hospitals in Maputo city Mozambique. Poster in Conference: 4ª Conferencia Nacional de Medicina Tropical. Portugal. April 2017

Skills with softwares

Statistical Analysis Programme | IBM SPSS

Microsoft Office (Word, Excel, Outlook, PowerPoint)

Statistical Analysis Programme | STATA

Qualitative Data Analysis Software for Researchers | NVivo (QSR International)

Source Geographic Information System | QGIS (Quantum GIS)

Personal Skills

Innovation Capacity – 80%
Creative – 85%
Teamwork – 95%

Organisation – 95%
Hobbies – 40%