Impact of mining projects on environmental determinants of health and associated health outcomes in sub-Saharan Africa: insights for guiding impact assessment practice

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Summary

Background: About one quarter of the global burden of disease is attributed to environmental risk factors, commonly termed environmental determinants of health (EDH). Spanning across all three dimensions of sustainable development – economy, environment and society– the EDH are a cross-cutting theme in the 2030 Agenda for Sustainable Development and its 17 Sustainable Development Goals (SDGs). They include, for example, air and water pollution, housing quality, and climate factors. Sub-Saharan Africa (SSA) is among the regions carrying the largest health burden from the EDH. Large industrial mining projects can have substantial positive and negative impacts on the EDH and associated health outcomes, and hence on the SDGs, through a variety of direct and indirect pathways. Directly, mining projects can for example increase air or water pollution. Indirectly, the development of a mining project can provide livelihood opportunities that may trigger investments in housing, and improvements in water or sanitation infrastructures. Mines also attract large numbers of people potentially leading to overcrowded settlements and overburdened public infrastructures. Ideally, potential health impacts of these different pathways are systematically assessed in health impact assessments (HIA). However, the use of HIA in SSA is limited. For promoting its application, a deeper understanding of positive and negative effects of mining projects on EDH is needed.

Objectives: The overarching aim of this PhD thesis was to assess the impact of mining projects in SSA on the EDH and associated health outcomes in affected communities. More specifically, with a focus on SSA, the objectives of the thesis were to (i) quantify annual settlement growth patterns in rural mining settlements; (ii) study associations between mining projects and housing conditions and respiratory diseases in children; (iii) assess impacts of mining projects on water and sanitation infrastructures and associated child health outcomes; and (iv) determine how health is integrated in impact assessment practice of mining projects.

Research partnerships: The research is embedded in the “Health impact assessment for sustainable development” (HIA4SD) project. Six PhD students and project partners in a governance work stream conducted research on different aspects around health in resource extraction regions in different parts of SSA, supplemented with literature reviews.

Methods: The methods applied include a machine learning application for quantifying annual settlement growth patterns in mining areas. Land use classifications were done using support vector machine classifiers. Historic Google Earth imagery served as training data for the classifier that was applied to a stack of Landsat imagery to derive annual land use maps. For the assessment of the impacts of mines on household and child health indicators, all Demographic and Health Survey (DHS) datasets from SSA were merged with a comprehensive list of mines in SSA. Regression analyses were used to compare the temporal and spatial trends between impacted and comparison areas. The inclusion of health aspects in impact assessment practice was studied by a documentary analysis of impact assessment reports. These were obtained through a systematic online search and by contacting mining companies and ministries. Lastly, three videos were produced outlining the research approach and sharing community voices on the perceived impacts of mines on health.

Results: The merging of DHS data with the information on mines yielded the largest available dataset on household and child characteristics in SSA, comprising of data on more than 40,000 households and 30,000 children from 23 countries used for longitudinal analyses. Furthermore, the land use classification achieved overall accuracies between 58.5% and 95.1%, depending on training data availability and climatic conditions. The analyses showed that in mining areas, (i) no increased annual settlement growth or evidence for overcrowding was observed; (ii) access and quality of infrastructures increased; (iii) indoor smoking rates increased; and (iv) some health indicators, such as stunting and underweight, improved while wasting, diarrheal diseases, and acute respiratory infections did not differ from comparison areas. Furthermore, large differences in these impacts between countries and across socioeconomic strata were observed. In general, people from poorer households benefited less from the positive impacts on infrastructures. Screening of 44 impact assessment reports showed that (i) impact assessment practice in SSA had a strong environmental focus, putting little attention to health outcomes; (ii) there was a lack of transparency in impact assessment in the mining sector; and (iii) the collection of primary data as baseline indicators for health outcomes was rare.

Conclusions and significance: The positive impacts of mining projects on infrastructures underline the potential of the mining sector to promote community development in producer regions. However, for these positive impacts to firstly reach all societal strata and secondly translate into better health outcomes, the shortcomings of current impact assessment practice need to be addressed. Firstly, a broader consideration of health outcomes, as well as the inclusion of the wider determinants of health, should be promoted in national and international policies and legislations. Secondly, the considerations of environmental health aspects in impact assessments should look beyond the mine as only source of pollution and recognize the different indirect pathways how mining projects could affect environmental pollution. Thirdly, the particular health needs of vulnerable population groups should be addressed in an equitable manner. This should include an assessment of the root causes determining the unequal distribution of risks and benefits. Lastly, the disadvantages of secondary data identified in this thesis warrant an increased collection of primary data for impact assessment. Taken together, the findings of this PhD thesis suggest that with the right policy frameworks in place, the mining sector has the potential to make positive and substantial contributions towards achieving the 2030 Agenda for Sustainable Development. Having entered the

"Decade of Action" to achieve the SDGs by 2030 while facing the challenges of a global pandemic, this opportunity should not be missed.

Résumé

Contexte: Environ un quart de la charge mondiale de morbidité peut être attribuée à des causes environnementales, communément appelées les déterminants environnementaux de la santé (DES). Les DES sont impliqués dans les trois dimensions du développement durable – économie, environnement et société – et représentent une thématique récurrente dans l'agenda 2030 sur le développement durable et de ses 17 Objectifs de Développement Durable (ODDs). Ces derniers portent notamment sur les domaines de pollution de l'air et des eaux, qualité du logement et autres facteurs climatiques. L'Afrique sub-saharienne (ASS) est l'une des régions les plus touchées par la charge liée aux DES. En particulier, les projets d'extraction minière industrielle à grande échelle jouent un rôle important au niveau des impacts – positifs comme négatifs – sur les DES et leurs conséquences en matière de santé, et de ce fait également de façon directe et indirecte sur les ODDs. Les projets d'extraction minière peuvent par exemple agir directement sur la pollution de l'air et des eaux. De façon indirecte, le développement de projets miniers peut offrir des opportunités de revenus et de ce fait être à l'origine d'investissements dans le domaine du logement ainsi que d'améliorations des infrastructures sanitaires et des eaux. Les sites miniers ont également tendance à attirer un grand nombre de personnes et sont ainsi potentiellement à l'origine de lieux de résidence surpeuplés, contribuant à la surcharge des infrastructures publiques. Idéalement, les effets sanitaires liés aux trois mécanismes décrits ci-dessus sont systématiquement traités par l'évaluation de l'impact sur la santé (EIA). Toutefois, dans la pratique, l'usage de l'EIA reste limité en ASS. Une compréhension approfondie des effets positifs et négatifs de l'EIA sur la santé est nécessaire afin de promouvoir son usage à plus large échelle.

Objectifs : L'objectif principal de cette thèse de doctorat est d'évaluer l'impact des projets d'extraction minière en ASS sur les DES et ses conséquences sur la santé des communautés affectées. Concentrés sur le contexte de l'ASS, les objectifs spécifiques de cette thèse sont les suivants : (i) quantifier l'accroissement annuel des lieux de résidence autour des exploitations minières rurales ; (ii) étudier les associations entre les projets miniers et les conditions de logement et les maladies respiratoires chez les enfants ; (iii) évaluer les impacts des projets miniers sur les infrastructures sanitaires et des eaux ainsi que leurs conséquences sur la santé des enfants ; (iv) déterminer comment la santé est intégrée dans la pratique de l'évaluation de l'impact des projets miniers.

Partenariats de recherche : Cette thèse de doctorat fait partie du projet de recherche « Health impact assessment for sustainable development » (HIA4SD). Six doctorants et partenaires de projet dans le cadre d'un volet de travail sur la gouvernance ont mené des recherches sur différents aspects de la santé dans différentes régions d'extraction minière en ASS, complémentées par des revues de littérature scientifique.

Méthodes : Les méthodes appliquées comprennent l'utilisation de machine learning techniques afin de quantifier la croissance annuelle des lieux de résidence autour des sites miniers. Une classification de l'occupation du sol a été effectuée au moyen d'outils tels que les machines à vecteurs de support. Des données historiques de l'imagerie Google Earth ont servi de données d'entraînement pour les classificateurs, appliquées à un bloc de données d'imagerie Landsat afin de dériver des cartes annuelles de l'occupation du sol. Pour l'évaluation des mines sur les logements et les indicateurs de santé infantile, toutes les bases de données de l'Enquête sur la Démographie et la Santé (Demographic and Health Survey, DHS) d'ASS ont été fusionnées avec une liste complète des mines en ASS. Des analyses de régression ont été utilisées afin de comparer les tendances temporelles et spatiales entre les régions affectées et des régions témoins. Une analyse des rapports d'évaluation d'impact a servi à l'étude de l'inclusion des aspects de santé dans la pratique de l'évaluation d'impact. Ces derniers ont été obtenus au moyen d'une recherche en ligne et en contactant des compagnies minières ainsi que des ministères. En dernier lieu, trois vidéos ont été produites afin de mettre en évidence cette approche de recherche et pour partager les voix de la communauté sur les impacts perçus des projets miniers sur la santé.

Résultats : La fusion des donnés DHS avec les informations sur les mines a permis de créer la plus large base de données disponible sur les logements et caractéristiques des enfants en ASS, avec plus 40,000 foyers et 30,000 enfants de 23 pays, utilisés pour des analyses longitudinales. De plus, la classification de de l'occupation du sol a permis d'atteindre des niveaux de précision variant entre 58.5% et 95.1%, en fonction des données d'entraînement disponibles et des régions climatiques. Les analyses ont montré les résultats suivants dans le contexte des projets miniers : (i) aucune augmentation de la croissance annuelle des lieux de résidence ou évidence de surpopulation n'ont été observées ; (ii) l'accès et la qualité des infrastructures a augmenté ; (iii) les taux de fumée en lieux clos ont diminué ; (iv) certains indicateurs de santés, tels que le rachitisme et la sous-alimentation se sont améliorés, alors que d'autres, comme l'émaciation, les infections diarrhéiques et les infections respiratoires aiguës n'ont pas évolué par rapport aux régions témoins. De plus, de grandes différences ont été observées au niveau de ces impacts entre les différents pays et les couches socio-économiques. En général, les personnes provenant de foyers plus modestes avaient tendance à moins bénéficier des impacts positifs que les autres. L'examen de 44 rapports d'évaluation d'impact ont montré que (i) la pratique de l'évaluation d'impact en ASS accordait une grande importance à l'environnement et s'attardait moins sur conséquences sanitaires; (ii) l'évaluation d'impact dans le contexte minier manquait de transparence, et (iii) la collecte de données comme indicateurs de base de la santé était rare.

Conclusion et pertinence : Les effets positifs des projets miniers sur les infrastructures mettent en évidence le potentiel du secteur minier comme promoteur du développement des communautés dans les régions productrices. Toutefois, il est nécessaire de combler les lacunes dans la pratique de l'évaluation d'impact afin que les effets positifs observés puissent d'une part atteindre toutes les couches de la société et d'autre part se traduire en conséquences positives sur la santé. Tout d'abord, une vision globale des effets sur la santé ainsi que l'utilisation de plus larges déterminants de la santé doivent être promus au niveau des lois et politiques nationales comme internationales. Ensuite, les considérations sanitaires et environnementales des évaluations de santé doivent surpasser la simple vision des mines comme source de pollution et reconnaître les différentes voies indirectes par lesquelles les projets miniers peuvent affecter la pollution environnementale. Troisièmement, les besoins sanitaires particuliers des populations les plus vulnérables doivent être abordés de façon équitable. Ceci passe notamment par une évaluation précise des éléments à l'origine de la distribution inégale des risques et bénéfices. Finalement, les inconvénients liés aux sources de données secondaires identifiés dans ce travail mettent en lumière l'importance de la collecte primaire de données pour l'évaluation de l'impact. Considérés dans leur ensemble, les résultats de cette thèse de doctorat suggèrent que, à condition de bénéficier de cadres politiques et légaux appropriés, le secteur minier a le potentiel d'apporter une contribution importante à la réalisation des objectifs de l'agenda 2030 sur le développement durable. Alors que nous venons d'entrer dans la « décade d'action » pour atteindre les ODDs en 2030 tout en étant confrontés à une pandémie mondiale, il serait inconcevable de manquer cette opportunité.

Resumo

Contexto: Cerca de um quarto da carga de doenças a nível global é atribuída a fatores de risco ambientais, comumente denominados determinantes ambientais da saúde (DAS). Abrangendo as três dimensões do desenvolvimento sustentável - economia, meio ambiente e sociedade - as DAS são um tema transversal na Agenda 2030 de Desenvolvimento Sustentável e seus 17 Objetivos de Desenvolvimento Sustentável (ODS). Eles incluem, por exemplo, a poluição do ar e da água, a qualidade da habitação e fatores climáticos. A África Subsariana (ASS) está entre as regiões do mundo em que as DAS causam maior impacto na saúde. Grandes projetos de mineração industrial podem ter impactos positivos e negativos substanciais nas DAS e nos resultados de saúde associados e, assim, nos ODS, por meio de uma variedade de caminhos diretos e indiretos. Diretamente, os projetos de mineração podem, por exemplo, aumentar a poluição do ar ou da água. Indiretamente, o desenvolvimento de um projeto de mineração pode fornecer oportunidades de subsistência que podem desencadear investimentos em habitação e melhorias nas infraestruturas de água ou saneamento. As minas também atraem um grande número de pessoas, o que pode levar povoações superlotadas e infraestruturas públicas sobrecarregadas. Idealmente, os potenciais impactos dessas diferentes vias na saúde são avaliados sistematicamente em avaliações de impacto na saúde (AIS). No entanto, o uso de AIS na ASS é limitado. Para promover a sua aplicação, é necessário um entendimento mais profundo dos efeitos positivos e negativos dos projetos de mineração nas DAS.

Objetivos: O objetivo geral desta tese de douturamento foi avaliar o impacto dos projetos de mineração na ASS nas DAS e nos resultados de saúde associados nas comunidades afetadas. Mais especificamente, e com foco na ASS, os objetivos desta tese foram: (i) quantificar os padrões de crescimento anual de povoações de mineração rural; (ii) estudar associações entre projetos de mineração e condições de habitação e doenças respiratórias em crianças; (iii) avaliar os impactos dos projetos de mineração nas infraestruturas de água e saneamento e os resultados de saúde infantil associados; e (iv) determinar como a saúde é integrada na prática de avaliação de impacto de projetos de mineração.

Parcerias de pesquisa: Este trabalho está inserido no projeto “Avaliação do impacto na saúde para o desenvolvimento sustentável” (HIA4SD). Seis estudantes de douturamento e parceiros de projeto conduziram pesquisa sobre diferentes aspectos da saúde em regiões de extração de recursos em diferentes partes da ASS, complementadas com revisões da literatura.

Métodos: Os métodos aplicados incluem a aplicação de apredizagem automática de uma máquina para quantificar os padrões de crescimento de povoação anual em áreas de mineração. As classificações de uso da terra foram feitas usando classificadores de máquinas de vetores de suporte. Imagens históricas do Google Earth serviram como dados de treino para o classificador que foi aplicado a uma pilha de imagens Landsat para derivar mapas anuais de uso da terra. Para a avaliação dos impactos das minas nos indicadores de saúde familiar e infantil, todos os conjuntos de dados da Pesquisa Demográfica e de Saúde (Demographic and Health Survey, DHS) da ASS foram combinados com uma lista abrangente de minas na ASS. Análises de regressão foram usadas para comparar as tendências temporais e espaciais entre as áreas impactadas e de comparação. A inclusão de aspectos de saúde na prática de avaliação de impacto foi estudada por meio de uma análise documental de relatórios de avaliação de impacto. Estes foram obtidos através de uma sistemática pesquisa online e através do contato com empresas de mineração e ministérios. Por último, três vídeos foram produzidos delineando a abordagem da pesquisa e partilhando as vozes da comunidade sobre os impactos reconhecidos das minas na saúde.

Resultados: A fusão dos dados do DHS com as informações sobre as minas gerou o maior conjunto de dados disponível sobre as características das famílias e das crianças na ASS, incluindo dados sobre mais de 40.000 famílias e 30.000 crianças de 23 países usados para análises longitudinais. Para além disso, a classificação do uso da terra alcançou uma precisão geral entre 58.5% e 95.1%, dependendo da disponibilidade de dados de treino e das condições climáticas. As análises mo straram que nas áreas de mineração (i) não foi observado um aumento do crescimento anual de povoações ou evidência de superlotação; (ii) houve um aumento do acesso e qualidade das infraestruturas; (iii) houve um aumento das taxas de fumo em ambientes fechados; e (iv) alguns indicadores de saúde, como desnutrição crónica e baixo peso melhoraram enquanto que desnutrição aguda, doenças diarreicas e infecções respiratórias agudas não diferiram das áreas de comparação. Também foram observadas grandes diferenças dos impactos entre países e entre estratos socioeconómicos. Em geral, as pessoas de famílias mais pobres beneficiaram menos dos impactos positivos nas infraestruturas. A triagem de 44 relatórios de avaliação de impacto mostrou que (i) a prática de avaliação de impacto na ASS tinha um forte foco ambiental, dando pouca atenção aos resultados de saúde; (ii) havia falta de transparência na avaliação de impacto no setor de mineração; e (iii) a colheita de dados primários como indicadores básicos para resultados de saúde era rara.

Conclusões e significância: Os efeitos positivos dos projetos de mineração nas infraestruturas sublinham o potencial do setor de mineração para promover o desenvolvimento comunitário nas regiões produtoras. No entanto, para que esses impactos positivos alcancem, em primeiro lugar, todas as camadas da sociedade e, em segundo lugar, se traduzam em melhores resultados de saúde, as deficiências da prática atual de avaliação de impacto

precisam de ser abordadas. Em primeiro lugar, uma consideração mais ampla dos resultados de saúde, bem como a inclusão dos determinantes mais amplos da saúde, deve ser promovida nas políticas e legislações nacionais e internacionais. Em segundo lugar, as considerações dos aspectos de saúde ambiental nas avaliações de impacto devem olhar além da mina como única fonte de poluição e reconhecer os diferentes caminhos indiretos pelos quais os projetos de mineração podem afetar a poluição ambiental. Em terceiro lugar, as necessidades específicas de saúde dos grupos vulneráveis da população devem ser atendidas de maneira equitativa. Isso deve incluir uma avaliação das causas que determinam a distribuição desigual de riscos e benefícios. Por último, as desvantagens dos dados secundários identificados nesta tese justificam uma maior colheita de dados primários para avaliação de impacto. Num todo, os resultados desta tese de douturamento sugerem que, com as estruturas políticas corretas em vigor, o setor de mineração tem o potencial de fazer contribuições positivas e substanciais para o cumprimento da Agenda 2030 de Desenvolvimento Sustentável. Visto que entrámos na “Década de Ação” para alcançar os ODS até 2030 enquanto enfrentamos os desafios de uma pandemia global, esta oportunidade não deve ser perdida.

Muhtasari

Utangulizi: Robo ya magonjwa yanayotaarifiwa ulimwenguni hunasababishwa na sababu hatarishi zitokanazo na mazingira ambazo hujulikana kama viashiria vya afya kutoka katika mazingira (Environmental Determinant of Health - EDH). Viashiria hivi vimegusa pande kuu tatu za maendeleo endelevu. Pande hizo ni uchumi, jamii na mazingira, vyote vikiwa ni mada mtambuka katika Ajenda ya Maendeleo Endelevu 2030 (Sustainable Development Goals, SDG 2030) na Malengo yake 17 ya Maendeleo Endelevu. Kwa mfano, viashiria hivi hujumuisha uchafuzi wa hewa na maji, ubora wa makazi au sababu za hali ya hewa. Kusini mwa Jangwa la Sahara (Sub Saharan Africa, SSA) ni miongoni mwa eneo linalobeba mzigo mkubwa zaidi wa afya kutoka katika viashiria hivi vya afya hatarishi vitokanavyo na mazingira. Miradi mikubwa ya madini na viwandani inaweza kuwa na athari chanya na hasi kwa matokeo yanayohusiana ya afya mojakwamoja au kupitia njia anuwai na zisizo za moja kwa moja. Kwa mfano, miradi ya madini inaweza kuongeza uchafuzi wa hewa au maji au vilevile ukuzaji wa mradi wa madini unaweza kutoa fursa za kujipatia riziki ambazo zinaweza kusababisha uwekezaji katika miundombinu ya makazi, maji au usafi wa mazingira. Kwa upande mwingine, migodi pia huvutia idadi kubwa ya watu wanaoweza kusababisha makazi kuwa na watu wengi na miundombinu ya umma iliyoelemewa. Tofauti hizi za matokeo hasi ama chanya unaweza pimwa kwa utarabitu maalumu ujulikanao kama tathmini za athari za kiafya (Health Impact Assessment, HIA). Walakini, matumizi ya HIA katika SSA ni mdogo. Ili kuwezesha kukuza matumizi yake, uelewa mzuri wa athari chanya na hasi za miradi ya madini kwenye viamua vya afya ya mazingira unahitajika.

Malengo: Lengo la shahada hii ya uzamivu ni kutathmini athari za miradi ya madini katika SSA kwenye EDH na matokeo ya afya yanayohusiana katika jamii zilizoathiriwa. Hasa haswa, kwa kuzingatia (i) kuangalia ni jinsi gani elimu ya afya imejumuishwa katika mazoezi ya tathmini ya athari ya miradi ya madini; (ii) kupima viwango vya ukuaji wa makazi ya kila mwaka katika makazi karibu na machimbo ya madini; (iii) kutathmini athari za miradi ya madini kwenye miundombinu ya maji na usafi wa mazingira na matokeo ya afya ya mtoto; na (iv) kujifunza namna sahihi ya kuhusisha miradi ya uchimbaji madini na mfumo mzima wa afya.

Ushirikiano wa utafiti: Utafiti umeingizwa katika mradi wa "Tathmini ya athari za kiafya kwa maendeleo endelevu" (HIA4SD). Wanafunzi sita wa shahada ya uzamivu na washirika wa mradi katika mkondo wa kazi ya utawala walifanya utafiti juu ya nyanja tofauti karibu na afya katika maeneo ya uchimbaji rasilimali.

Mbinu: Mbinu zilizotumika ni pamoja na uchambuzi wa maandishi wa ripoti za tathmini ya athari zilizokusanywa kutoka kwa kampuni za madini, wizara na vyanzo vya mkondoni kupitia mchanganyiko wa njia za kimfumo. Ripoti zilizopatikana zilichunguzwa kwa ujumuishaji wa nyanja tofauti za kiafya. Kwa kupimia mifumo ya ukuaji wa makazi ya kila mwaka katika maeneo ya madini, uainishaji wa matumizi ya ardhi ulipatikana kwa kutumia vigeuzi vya mashine. Picha za kihistoria kutoka vyanzo vya kisetilaiti kama Google Earth viilitumika kama taarifa ya mafunzo kwa kitambulishaji. Uainishaji wa matumizi ya ardhi ulifanywa kwenye gombo la picha za Landsat. Kwa tathmini ya athari za migodi kwenye viashiria anuwai vya afya ya kaya na watoto, hifadhidata zote za Utafiti wa Idadi ya Watu na Afya (DHS) kutoka SSA ziliunganishwa na orodha kamili ya migodi katika SSA. Uchunguzi wa ukandamizaji ulitumiwa kulinganisha mwenendo wa muda juu ya awamu tofauti za migodi kati ya maeneo yaliyoathiriwa na kulinganisha. Pia, video tatu zilitengenezwa zikielezea njia ya utafiti na kushiriki sauti za jamii juu ya athari zinazoonekana za migodi kwa afya.

Matokeo: Kuunganishwa kwa takwimu za afya na habari juu ya migodi kulizalisha mfumo wa takwimu kubwa zaidi inayopatikana kwenye sifa za kaya na watoto katika ukanda wa SSA, takwimu inayojumuisha zaidi ya kaya 40'000 na watoto 30'000 kutoka nchi 23 zilizotumiwa kwa uchambuzi wa muda mrefu. Zaidi ya hapo, uainishaji wa matumizi ya ardhi ulifikia usahihi wa jumla kati ya 58.5% na 95.1%, kulingana na upatikanaji wa takwimu ya mafunzo na mazingira ya hali ya hewa. Uchambuzi huo ulionyesha kuwa katika maeneo ya madini (i) hakuna ushahidi wa msongamano wa watu uliozingatiwa; (ii) upatikanaji na ubora wa miundombinu umeongezeka; (iii) viwango vya uvutaji sigara ndani vimeongezeka; na (iv) viashiria vingine vya afya, kama vile kudumaa na uzito wa chini, kuboreshwa wakati wa kupoteza, magonjwa ya kuhara na maambukizo ya kupumua kwa papo hapo hayakutofautiana na maeneo ya kulinganisha. Kwa kuongezea, tofauti kubwa katika athari hizi kati ya nchi na matabaka ya kijamii zilionekana. Kwa ujumla, watu kutoka kaya masikini walinufaika kidogo na athari nzuri kwa miundombinu. Uchunguzi wa ripoti 44 za tathmini ya athari ilionyesha kuwa (i) mazoezi ya upimaji wa athari katika SSA yalikuwa na mwelekeo mzuri wa mazingira, bila kuzingatia sana matokeo ya afya; (ii) kulikuwa na ukosefu wa uwazi katika tathmini ya athari katika sekta ya madini; na (iii) ukusanyaji wa data ya msingi kama viashiria vya msingi vya matokeo ya afya haikuwa kawaida.

Hitimisho: Athari chanya za miradi ya madini kwenye miundombinu inasisitiza uwezo wa sekta ya madini kukuza maendeleo ya jamii katika mikoa ya wazalishaji. Walakini, kwa athari hizi nzuri kwanza kufikia matabaka yote ya jamii na pili kutafsiri kuwa matokeo bora ya kiafya, mapungufu ya mazoezi ya sasa ya tathmini ya athari yanahitaji kushughulikiwa. Kwanza, kuzingatia kwa upana matokeo ya kiafya, pamoja na ujumuishaji wa viashiria mtambuka vya afya, inapaswa kukuzwa katika sera na sheria za kitaifa na kimataifa. Pili, kuzingatia mambo ya afya ya mazingira katika tathmini ya athari inapaswa kuangalia zaidi ya mgodi kama chanzo tu cha uchafuzi wa mazingira na kutambua njia tofauti za moja kwa moja jinsi miradi ya madini inaweza kuathiri uchafuzi wa mazingira. Tatu, mahitaji fulani ya kiafya ya vikundi vya watu

walio katika mazingira magumu yanapaswa kushughulikiwa kwa usawa. Hii inapaswa kujumuisha tathmini ya sababu kuu zinazoamua usambazaji usio sawa wa hatari na faida. Mwishowe, hasara za data za sekondari zilizoainishwa katika hati hii ya nadharia mkusanyiko ulioongezeka wa data ya msingi kwa tathmini ya athari. Walakini, matokeo ya nadharia hii ya shahada hii ya uzamivu yanaonyesha kuwa na mifumo sahihi ya sera iliyopo, sekta ya madini inaweza kuwa mshirika mzuri katika kuelekea kufanikisha Ajenda ya Maendeleo Endelevu 2030.

List of abbreviations

ASM	artisanal and small-scale mining
CSR	corporate social responsibility
DALY	disability-adjusted life year
DHIS2	District Health Information System 2
DHS	Demographic and Health Survey
EDH	environmental determinant of health
EIA	environmental impact assessment
EPFI	Equator Principles Financial Institutions
GIS	geographic information system
HIA	health impact assessment
HIA4SD	Health impact assessment for sustainable development
HIV	human immunodeficiency virus
IFC	International Finance Corporation
LMIC	low- and middle-income country
$PM_{2.5}$	fine particulate matter
r4d	Research for Development
SDC	Swiss Agency for Development and Cooperation
SDG	Sustainable Development Goal
SEA	strategic environmental assessment
SIA	social impact assessment
SNSF	Swiss National Science Foundation
SSA	sub-Saharan Africa
SSP	sanitation safety planning
WHO	World Health Organization
WP	work package
WSP	Water safety planning

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1 Introduction

1.1 Environmental determinants of health and the 2030 Agenda for Sustainable Development

1.1.1 Environmental determinants of health and environmental health

Globally, nearly one quarter of the total burden of disease is caused by environmental factors (Prüss-Üstün et al, 2016; Prüss-Ustün et al, 2017). These factors that affect the attainment of good health and well-being or lead to ill-health are commonly termed environmental determinants of health (EDH) (Dahlgren & Whitehead, 1991). The EDH comprise "all the physical, chemical, and biological factors external to a person and all the related factors impacting behaviors" (Prüss-Üstün et al, 2016). They include for example air pollution, chemical contamination of drinking water, housing quality, suitability for vector breeding, climate factors, road networks (Prüss-Üstün et al, 2016). Reducing the exposure to these factors and hence promoting environmental health could significantly improve health and well-being globally (Landrigan et al, 2017; Prüss-Ustün et al, 2017).

1.1.2 The environmental determinants of health in the 2030 Agenda for Sustainable Development

Launched in 2015, the 2030 Agenda for Sustainable Development sets the direction for public action towards a more sustainable world (UN, 2015). Spanning across different sectors and disciplines, the EDH are at the nexus of the three dimensions of sustainable development – economy, environment and society (Dora et al, 2015). Hence, the public health challenges posed by the EDH are featured throughout the 2030 Agenda for Sustainable Development and its 17 Sustainable Development Goals (SDGs) (Buse & Hawkes, 2015; UN, 2015). Most prominently, SDG 3 addresses health aspects that are directly or indirectly affected by the EDH by aiming to "ensure healthy lives and promote well-being for all at all ages" (UN, 2015). The EDH are further tackled under other SDGs (Buse & Hawkes, 2015; ICSU & ISSC, 2015). For example, SDG 6 addresses access to clean water and sanitation, SDG 7 affordable and clean energy and SDG 11 promotes sustainable cities and communities, including access to adequate housing infrastructures and reductions in air pollution (Buse & Hawkes, 2015; ICSU & ISSC, 2015; UN, 2015).

1.1.3 Inequities in the environmental determinants of health

Following the motto “leaving no one behind”, the 2030 Agenda for Sustainable Development aims to reduce health inequities, including in environmental health (Marmot & Bell, 2018). However, currently the public health burden from the EDH is not equally distributed, both across regions and within societies (Landrigan et al, 2017). The underlying factors that contribute to these inequities, commonly termed the social determinants of health, are largely affected by unequal distribution of power and resources (WHO Commission on Social Determinants of Health, 2008).

Due to the close interlinkages between the EDH and the social determinants of health, environmental pollution disproportionally affects the poor and most vulnerable (Landrigan et al, 2017; Prüss-Üstün et al, 2016; WHO Commission on Social Determinants of Health, 2008). For example, low- and middle income countries account for more than 90 % of the global pollution-related deaths (Landrigan et al, 2017). Among them, the highest disease and mortality burden due to pollution is carried by the low-income countries in sub-Saharan Africa (SSA) (Forouzanfar et al, 2015). Within countries, age, gender and poverty affect the level of exposure to environmental pollutants. For example, because of their leading role in domestic food production women are disproportionally exposed to household air pollution from unclean cooking fuels, particularly in SSA (Forouzanfar et al, 2015; Gordon et al, 2014). Furthermore, poor rural areas in this region fall short in access to improved water and sanitation infrastructures compared to urban settlements (Roche et al, 2017).

1.1.4 Mining projects as an opportunity to foster investments in environmental determinants of health

To reduce these inequities in the EDH and to promote the environmental health-related SDGs, large investments are needed (Schmidt-Traub, 2015; Stenberg et al, 2017). Particularly in SSA, there is a large funding gap for achieving the health-related SDGs (Stenberg et al, 2017). Tough, many of these countries are rich in natural resources and thus host large potentials for investments from the private sector (United Nations Economic Commission for Africa, 2011). These potentials will even be strengthened in the future as economic development, population growth and industrial development are expected to increase the demand for metals and minerals (Ali et al, 2017b). Furthermore, higher electrification rates and a stronger reliance on low-carbon energy sources and storage will lead to a growing market for natural resources (Arrobas et al, 2017; Vidal et al, 2013). These developments further underscore the potential of the resource extraction sector to boost economies in SSA (United Nations Economic Commission for Africa, 2011).

Hence, together with other industries natural resource extraction projects, such as mining projects, have the potential to be an effective partner in working towards the environmental health-related SDGs in SSA by promoting development through diverse pathways (Aust et al, 2020; Scheyvens et al, 2016). Firstly, public revenues through taxes and royalties from mining companies facilitate increased investments in public infrastructure, such as health facilities (SDG 3) or water and sanitation infrastructures (SDG 6) (Admiraal et al, 2017; Carter & Danert, 2003; Cawood et al, 2006; von der Goltz & Barnwal, 2019). Secondly, thriving mines also create livelihood opportunities that contribute to poverty reduction (SDG 1) and improvements in housing conditions (SDG 11), which in turn can reduce exposure to environmental pollution (Cawood et al, 2006; Jacobs, 2011; Langston et al, 2015; Tusting et al, 2020; von der Goltz & Barnwal, 2019). Finally, mining projects can also directly engage in public health promotion and disease prevention programs that aim at reducing the environmental health burden, such as vector control (SDG 3) or the provision of water infrastructures (SDG 6) (Admiraal et al, 2017; Asante et al, 2011; Kleinschmidt et al, 2009; Knoblauch et al, 2017a; Knoblauch et al, 2014; Overgaard et al, 2012).

1.2 Potential impacts of mining projects on environmental health

Alongside economic development, the establishment of a mine also leads to changes the physical, natural and social environments (IFC, 2009b; Mancini & Sala, 2018; Porgo & Gokyay, 2017). These changes can positively and negatively affect the EDH and associated health outcomes in mining communities (see Figure 1-1). Beyond the direct impacts on the EDH, mining projects also have the potential to influence intermediate factors that themselves affect the EDH and health.

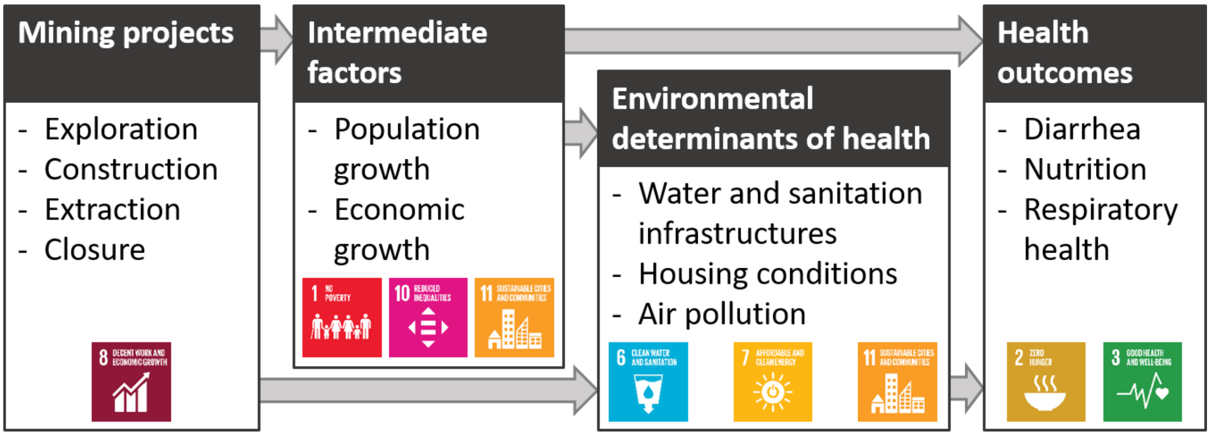

Figure 1-1 Causal pathway of mining-related impacts on environmental determinants of health and associated health outcomes. The symbols depict the potential links to the Sustainable Development Goals (SDGs) of the 2030 Agenda for Sustainable Development.

1.2.1 Changes in local economies in mining areas

Changes in household wealth can affect the level of exposure to other determinants of health, such as air pollution, housing or water infrastructures and hence contribute to environmental health inequities (Armah et al, 2018; Landrigan et al, 2017; Schrecker et al, 2018; Tusting et al, 2020). The impact of resource extraction projects on local economies is subject to scholarly debate (Gamu et al, 2015). On the one hand, mines can boost local economies through formal employment in areas that are commonly dominated by informal labor and subsistence farming (Gamu et al, 2015; Wegenast & Beck, 2020). Indeed, research indicates that mines can increase household wealth in households close to mining operations in developing countries (Aragón & Rud, 2013; von der Goltz & Barnwal, 2019; Zabsonré et al, 2018). However, large mining enterprises can also defer local economies away from other forms of income, such as agriculture or artisanal and small-scale mining (ASM) (Hilson, 2002). In contrast to multi-national mining corporations, the benefits from these traditional sources of income commonly remain in the local communities (Gamu et al, 2015; Langston et al, 2015). With large-scale operations, benefits from the extraction of natural resources are often transferred abroad to satisfy the demands of foreign investors or diverted to national government agencies, rather than residing with the local population or being reinvested for local development (Langston et al, 2015). Furthermore, the economic developments in mining areas can lead to rising food prices, potentially hampering food security (Rhee et al, 2018).

1.2.2 Changes in population size and structure

Mining projects require a large workforce for project development, mainly during the construction phase (IFC, 2009b). Beyond the directly employed workforce, secondary markets are created providing additional job opportunities, such as for food vendors or small-scale service providers (Gamu et al, 2015; Loayza et al, 2003). The formal and informal livelihood opportunities offered by large mining projects often attract a large number of people to migrate to rural areas (Jackson, 2018; Marais et al, 2020; Nyame et al, 2009). These migratory patterns lead to rapid population growth, transforming rural villages into small towns within a short period of time (Marais et al, 2020; Winkler et al, 2012b).

The rapid influx of people to previously rural areas in regions comes with a set of direct and indirect consequences for public health and its underlying determinants of health (IFC, 2009b; Mactaggart et al, 2018). Directly, the migrating population can introduce and spread communicable diseases, such as sexually transmitted infections or malaria (Corno & de Walque, 2012; Knoblauch et al, 2017b; Mactaggart et al, 2018). Indirectly, rapid population growth in areas can increase demand in public services, such as health services, water infrastructures or waste and sanitation management systems (IFC, 2009b). In areas with limited capacity of these services, the additional strain of the in-migrating population groups can lead to a variety of environmental health issues that affect public health in general (IFC, 2009b; Petkova et al, 2009).

1.2.3 Access to improved water and sanitation and associated health outcomes

Water and sanitation infrastructures are among the EDH that can be impacted by the development of mining projects (Admiraal et al, 2017; IFC, 2009b). Progress in providing access to improved water and sanitation infrastructures are major contributors to the improvements in public health seen worldwide (Fink et al, 2011). However, particularly SSA lags behind in working towards SDG 6 to achieve "universal access to improved and reliable water and sanitation for all" by 2030 (Roche et al, 2017; UN, 2015; UNICEF & WHO, 2017).

The establishment of a mine has the potential to improve water and sanitation infrastructures, by fostering public investment (Admiraal et al, 2017; Carter & Danert, 2003). Mining companies can increase the quality of these services either directly through the provision of housing to their employees and direct investments as part of corporate social responsibility (CSR) programs or indirectly by providing income to local populations (Admiraal et al, 2017; Fordham et al, 2018). However, access to clean water and improved sanitation in mining areas can also be hampered through direct and indirect pathways. Directly, toxic chemicals released by mining operations can enter freshwater sources that are used for drinking and other domestic purposes (Ali et al, 2017a; Bridge, 2004; Mensah et al, 2015). Indirectly, resource extraction and processing are highly water demanding operations that increase the competition for water sources between the companies and other water users in the community (Bridge, 2004; Kemp et al, 2010). The competition for water can be further exacerbated by the in-migrating population that put additional strain on water and sanitation infrastructures of the host community (Hilson, 2002; Marais et al, 2018; Pelders & Nelson, 2018). The local water and sanitation infrastructure is often not capable of meeting these rapidly increasing demands, leading to a high percentage of people using unimproved water sources and widespread open defecation practices (Basu et al, 2015).

Access to improved water and sanitation are crucial EDH (Fink et al, 2011; Fuller et al, 2015; Humphrey et al, 2019). Inadequate water and sanitation, together with environmental pollution, hampers child development and increases the risk for diarrhea (Dangour et al, 2013; Fink et al, 2011; Gizaw & Worku, 2019; Prüss-Ustün et al, 2014). Among children under 5 years in low- and middle-income countries (LMIC), 34 % and 20 % of diarrhea cases are attributed to the lack of inadequate drinking water and sanitation infrastructures, respectively (Prüss-Üstün et al, 2016). Furthermore, together with hygiene and climate change, these infrastructures contribute to 15 % of the health burden from malnutrition (Prüss-Üstün et al, 2016). Combined, the manifestations of insufficient food, stunting, wasting and underweight, account for more than 1.4 million annual deaths and 130 million disability-adjusted life years (DALYs) (Gakidou et al, 2017). Together with South Asia, SSA is the most affected region in the world (Grantham-McGregor et al, 2007). Repeated diarrheal episodes deteriorate the nutritional status of children which in turn weakens their immune system and hence their susceptibility to diarrheal infections (Guerrant et al, 1992). Changes in water and sanitation infrastructures in mining areas can therefore positively or negatively act on the cycle between diarrheal disease and malnutrition (Dangour et al, 2013; Gizaw & Worku, 2019).

The direct impacts of mines on water quality are well described. Many studies showcase the impacts of mining operations on pollution loads in water bodies around mining sites (Khan et al, 2020; Rakotondrabe et al, 2018). For example, heavy metals, ammonium, phosphates and other toxic chemicals have been found in drinking water samples from mining sites (Babayan et al, 2019; Basu et al, 2015; Hendryx, 2015; Khan et al, 2020). Contrarily, the evidence for the indirect impacts of mines on the access of neighboring communities to improved water and sanitation infrastructures is weak. The findings from the few studies with a focus on access to these infrastructures are inconclusive. For example, a case study in Peru found positive associations with water and sanitation infrastructures (Bury, 2005). Others found that shared toilets were less common in mining areas in Tanzania compared to non-mining areas (Chuhan-Pole et al, 2017). On the other hand, negative impacts of mines on sanitation infrastructures were observed in Mali and Tanzania (Polat et al, 2014). In other contexts in Ghana, Mali and Tanzania, no significant associations between mining projects and water and sanitation infrastructures were found (Chuhan-Pole et al, 2017). A better understanding of how the mining sector affects the access to improved water and sanitation infrastructures is needed in order to engage mining projects to minimize potential negative impacts and foster positive impacts on SDG 6 (Kemp et al, 2010).

Similarly, only a few studies looked at the associations between mining operations, child nutrition and diarrheal diseases and their findings are inconclusive (Chuhan-Pole et al, 2017). For example, case studies comparing diarrhea prevalences among children under 5 years before and after the opening of a mine found a reduction in diarrhea burden in Mali whereas increased levels of diarrhea were found in Ghana (Chuhan-Pole et al, 2017). Similar to the results in Mali, other studies found a reduction in child diarrhea in mining areas (Knoblauch et al, 2020b; Polat et al, 2014). Similarly, associations between mines and anthropometric indicators varied across studies. While some found positive impacts on child nutrition, others found no or even negative associations (Knoblauch et al, 2017a; Polat et al, 2014; von der Goltz & Barnwal, 2019). Furthermore, negative impacts on food security and diet diversity among children in areas with internationally-controlled mines in SSA were seen (Wegenast & Beck, 2020). Gender and age played an important role in these dynamics, with women and children being more strongly affected (Wegenast & Beck, 2020).

1.2.4 Housing conditions, air pollution and associated health outcomes

The quality of housing is an important determinant of health (Tusting et al, 2020). Underlining its importance, SDG target 11.1 sets the goal "to ensure access for all to adequate, safe and affordable housing and basic services" (UN, 2015). Mining projects attract a large number of people, both of formal employees and job seekers migrating for potential employment opportunities (IFC, 2009b). The arriving populations are housed in worker camps set up by the mining companies, lodge in existing accommodations or hostels within the communities or set up informal settlements, often located in the proximity to the mining sites (Cloete & Marais, 2020; Demissie, 1998; Marais et al, 2018; Marais et al, 2020).

The arrival of large numbers of migrants to previously rural areas can lead to overcrowding and poor housing conditions in host communities (Marais et al, 2018; Morrison et al, 2012; Pelders & Nelson, 2018). Furthermore, economic development and the increase in demand for accommodation can drive up housing prices and ultimately hamper the affordability of adequate housing in mining communities (Contreras et al, 2019; Morrison et al, 2012). The increased housing prices add to the already existing challenges to provide adequate housing in SSA, contributing to the formation of informal settlements around mines (Littlewood, 2014; Marais et al, 2018). The wealth benefits can on the other hand also facilitate financing improvements in housing infrastructures (Jønsson et al, 2019).

The existing literature on housing quality in mining areas predominantly focuses on conditions in workers camps (Pelders & Nelson, 2018). Studies looking at living conditions from a community perspective are scarce (Segerstedt & Abrahamsson, 2019). In a South African mining town, households in informal settlements housed more people per room (Marais et al, 2018). Further, houses in large-scale industrial mining towns in Tanzania are more commonly built from modern building materials and housed a larger number of people compared to the national average for urban settlements (Jønsson et al, 2019; National Bureau of Statistics (NBS) [Tanzania] & ICF Macro, 2011).

The location and quality of housing infrastructures also determine the exposure to indoor and outdoor air pollution (WHO, 2018). Mining projects release chemicals in the air during extraction processes as well as through increased traffic volumes during the construction and operation phases (Chaulya, 2004; Cheng et al, 2017; Ncube et al, 2012). Consequently, households located around large mines are exposed to increased levels of outdoor air pollution (Asif et al, 2018; Herrera et al, 2016). Beyond the direct and proximal impacts of mining projects on outdoor air pollution, their indirect effects on air pollution sources in households within the neighboring communities are far less understood. Household air pollutants mainly originate from the inefficient combustion of traditional fuels, such as wood, coal or charcoal, for heating and cooking or waste burning, but also indoor smoking has detrimental effects on child health (Shupler et al, 2020; Tielsch et al, 2009; Wright et al, 2020; Zhou et al, 2014). Despite tremendous progress in the provision of clean cooking stoves, particularly LMIC fall short in achieving SDG 7 to “ensure access to affordable, reliable, sustainable and modern energy for all” (IEA, 2017; UN, 2015). While the potential economic benefits from mining projects could indeed have a positive impact on the access to such modern energy sources for cooking, no study has to date looked into this topic. With regards to smoking, some studies found higher smoking rates in mining areas (Hendryx et al, 2008). However, whether this practice is also done within households around mines is not described.

Exposure to air pollution, both indoors and outdoors, is a leading cause of disease worldwide, causing 7.6 % of deaths worldwide (Anenberg et al, 2018; Cohen et al, 2017; Heft-Neal et al, 2018). While around 4 million of these deaths are attributable to ambient air pollution, the exposure to air pollutants from the use of solid fuels for cooking in the household account for 2.5 million deaths (Gakidou et al, 2017). Inadequate housing further increases the risk for acute respiratory infections in children (Tusting et al, 2020).

Indeed, different studies found elevated risks for respiratory diseases as well as other non-communicable diseases associated with air pollution among workers and people living in proximity to extractive industries (Heinrich et al, 1999; Hendryx, 2013; Hendryx & Ahern, 2008; Hendryx & Luo, 2014; Herrera et al, 2016; Nelson et al, 2011; Nkosi et al, 2015; Saha et al, 2011). For example, in children living around a mine in Chile, a spatial trend in respiratory diseases were found with significant hampered health outcomes up to a distance of 1.8 km (Herrera et al, 2016).

While in SSA the negative impacts of mining on ambient air pollution are well described, literature on the indirect impacts of mines on other sources of air pollution, such as access to clean cooking fuels, is scarce. Further research is needed to better understand the magnitude and mechanisms of these alternative pathways of mining-related air pollution exposure and associated child health impacts in mining areas in SSA (Hendryx 2008, Sahu 2018).

1.3 Addressing health impacts in mining areas

1.3.1 Impact assessment

For the extractive sector to contribute to the work towards the SDGs, it is crucial to reduce their negative and foster their positive impacts on these various EDH and health outcomes (Landrigan et al, 2017; RMF & CCSI, 2020). To address this challenge, a set of impact assessment tools has been developed and used since the 1970s, such as environmental impact assessment (EIA), social impact assessment (SIA), strategic environmental assessment (SEA) or health impact assessment (HIA) (Esteves et al, 2012; Harris-Roxas et al, 2012; Morgan, 2012). Impact assessments are conducted prior to project development as a decision-support tool (Harris-Roxas et al, 2012). As part of the assessment of health impacts, mitigation strategies for unintended negative impacts and opportunities for disease prevention and health promotion are identified (Harris-Roxas et al, 2012).

1.3.2 The five guiding principles of HIA

First introduced by the World Health Organization (WHO), revised by Quigley *et al.* and currently being adapted by Winkler and colleagues, HIA is guided by five guiding principles (Quigley et al, 2006; WHO Regional Office for Europe & European Centre for Health Policy, 1999; Winkler et al, 2021):

- Comprehensive approach to health: HIA should include an appraisal of the likely impacts on the wider determinants of health, recognizing their importance for attaining good health and well-being;
- Sustainability: HIA should inform about short- and long-term impacts for promoting informed decision-making for advancing the work towards the SDGs;
- Participation: people should be given the opportunity to influence the decisions that potentially affect their lives through active involvement, participation and transparent communication;
- Equity and equality: HIA should strive to reduce unequal distribution of health risks and opportunities between population groups, with special consideration of potentially marginalized or vulnerable population groups;
- Ethical use of evidence: HIA should use the best available evidence and apply sound methodologies in an impartial manner.

1.3.3 HIA practice in sub-Saharan Africa

Health aspects can be covered either in HIA as a stand-alone approach or integrated in other forms of impact assessment, such as EIA, environmental and health impact assessment (EHIA) or environmental, social and health impact assessment (ESHIA) (Bhatia & Wernham, 2009; Harris-Roxas et al, 2012; Nigri & Michelini, 2019; Winkler et al, 2020). Although the HIA approach has increasingly been taken up over the past two decades in high-income countries, HIA practice in LMIC is lagging behind (Erlanger et al, 2008; Pereira et al, 2017; Winkler et al, 2020). There is currently no country in Africa that requires HIA (Winkler et al, 2013). The HIA approach is however promoted by the International Finance Corporation (IFC) through their Performance Standards on Environmental and Social Sustainability, which have been adopted by a large consortium of multilateral lending institutions known as the Equator Principles Financial Institutions (EPFI) (Equator Principles; IFC, 2012; The Equator Principles Association, 2020). Yet, an increasing share of mining projects in Africa are funded by other financial institutes outside the EPFI that do not formally request HIA (Krieger et al, 2012).

EIA on the other hand is required by legislation in virtually every country in the world (Winkler et al, 2013). Hence, the integration of public health considerations in EIA could be a promising approach in LMIC (Bhatia & Wernham, 2009; Morgan, 2012). However, experiences from high-income countries show that the scope of health impacts when integrated in other forms of impact assessment is limited (Baumgart et al, 2018; Fischer et al, 2010; Harris et al, 2009; Riley et al, 2018; Riley et al, 2020; Steinemann, 2000). More specifically, predominantly direct impacts on environmental health determinants, such as air and water pollution, were included, while the indirect impacts of the projects (e.g. community and household infrastructures) and its impacts on community health were less commonly included (Fischer et al, 2010; Harris et al, 2009; Riley et al, 2018; Riley et al, 2020; Steinemann, 2000). Adding to the scarce literature on the inclusion of health in other forms of impact assessments from LMIC, Pham and colleagues found similar patterns (Pham et al, 2018).

1.4 Identified research gaps

Studies from high-income countries suggest that the scope of health aspects covered in impact assessment practice is limited when integrated in other approaches than HIA. However, no study has been conducted investigating whether health is sufficiently addressed in EIAs and other forms of impact assessments in SSA. The growing role of the extractive sector and the complex social-ecological context determining public health in SSA warrant a thorough consideration of the diverse health impacts of mining projects. Against this background, a better understanding of the role of health in impact assessment in SSA can inform policy and practice around impact assessment for promoting health in resource extraction areas.

For informed decision-making by policy-makers and project developers wishing to mitigate potential negative impacts and improve environmental health, a sound evidence base is needed. As a foundation for the provision of adequate public infrastructures and resource allocation promoting environmental health, an understanding of the settlement growth dynamics in mining areas is needed (Stevens et al, 2015; Tatem, 2014; Wardrop et al, 2018). Today, policy makers in SSA, often rely on census data for information on population size in their constituencies for allocation of fiscal resources and development planning (UN, 2017). With a temporal resolution of commonly around 10 years, this data is however not capable to capture the rapid changes in mining settlements (UN, 2017). Hence, for growing settlements in remote mining areas in SSA to be built sustainably and inclusively, novel approaches for tracing settlement growth at high temporal and spatial resolutions are needed (Farnham et al, 2020a; Tatem, 2014; Tatem et al, 2012).

The impacts of mines on some of the environmental health determinants, such as air and water pollution, have been extensively described in the literature. However, there is a limited understanding of how mining projects indirectly affect these EDH and potential community exposures to such pollution. Hence, research on the environmental health impacts of mines need to look beyond the mine as the only source of pollution and explore the different pathways mining projects affect environmental health. These include changes in local infrastructures, such as housing, water and sanitation facilities, as well as alternative sources of pollution, such as from cooking with polluting fuels. In light of the scarce and inconclusive evidence on the overall impacts on associated health outcomes mainly stemming from case studies and single-country analyses, further research that explores these connections at a larger scale is needed.

Finally, the findings on the diverse impacts of mining projects on health need to be accessible for informing HIA policy and practice. Innovative approaches for research communication can help to convey these findings to a multi-disciplinary set of stakeholders that are involved in impact assessment.

2 Aim and objectives of the PhD project

The overarching aim of this PhD project was to assess the impacts of mining projects in SSA on EDH and associated health outcomes in affected communities.

Based on the identified research gaps, four distinct objectives were pursued within this PhD project:

1. to develop and apply novel approaches to quantify annual settlement growth patterns in rural mining settlements in SSA using freely available satellite imagery;
2. to study the associations between mining projects and housing infrastructures and respiratory diseases in children.
3. to evaluate the impacts of mining projects in SSA on water and sanitation infrastructures and associated child health outcomes;
4. to determine how health is integrated in impact assessment practice of mining projects in SSA;

These objectives formed the working packages (WP) 1-4 and served as a starting point for the manuscripts produced in the frame of this PhD project (see Figure 2-1). In addition, materials facilitating research communication with the diverse stakeholders in mining areas were produced throughout the PhD project (WP 5).

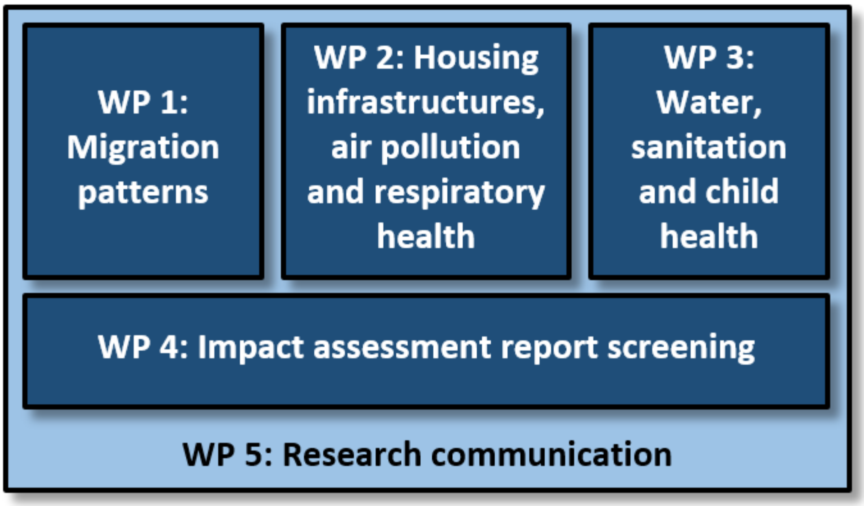

Figure 2-1 Work packages (WP) framing the work pursued under this PhD project.

3 Overall methodology

3.1 Health impact assessment for sustainable development (HIA4SD) project

This PhD project is embedded within a larger research project entitled: "Health impact assessment for sustainable development" (HIA4SD) funded by the Swiss National Science Foundation (SNSF) and the Swiss Agency for Development and Cooperation (SDC) within the frame of the Research for Development (r4d) funding scheme (Farnham et al, 2020a; Winkler et al, 2019). The overarching goal of the HIA4SD project is to generate a sound evidence-base on the role of natural resource extraction projects in the progress towards the health-related SDG targets. The project is being implemented by two research institutions in Switzerland in collaboration with partner institutes in four countries in SSA, namely Burkina Faso, Ghana, Mozambique and Tanzania (see Table 3-1).

Table 3-1 Composition of the "Health impact assessment for sustainable development" (HIA4SD) project consortium

Partner Institute	Name (role)	PhD Students (and topic)
Switzerland		
Swiss Tropical and Public Health Institute	Dr. Mirko Winkler (PI, overall project coordinator)	Andrea Leuenberger (Social determinants of health) Dominik Dietler (Environmental determinants of health)
NADEL, Center for Development and Cooperation, ETH Zurich	Dr. Fritz Brugger (Co-PI)	
Burkina Faso		
Institut de Recherches en Sciences de la Santé	Prof. Serge Diagbouga (Co-PI)	Hyacinthe Zabré (Health economics)
Ghana		
University of Health and Allied Sciences	Prof. Fred Binka (Co-PI)	Belinda Nimako (Health systems)
Mozambique		
Centro de Investigação em Saúde de Manhiça	Dr. Eusebio Macete (Co-PI)	Herminio Cossa (Childhood and maternal health)
Tanzania		
Ifakara Health Institute	Dr. Fredros Okumu (Co-PI)	Isaac Lyatuu (Morbidity and mortality)

In total, six PhD students work under the project, each focusing on a different thematic focus that complement each other (Table 3-1). This approach allows for triangulation of the findings (e.g. comparison of impacts on social and environmental determinants of health at the local and national-level). The findings of the present and the five other PhD theses will inform a policy dialogue at the national (in the four project countries) and international-level to strengthen the application of impact assessment as a regulatory mechanism.

3.2 Data used for the PhD project

While the project is predominantly implemented in the four partner countries in SSA (Burkina Faso, Ghana, Mozambique and Tanzania), this PhD thesis draws from different secondary data sources to inform the research questions under the different objectives. The findings from these analyses were contextualized by the experiences gained from field experiences in industrial mining sites in Burkina Faso and in ASM sites in Ghana. Video materials from these insights have further been used for the development of short clips that were produced in collaboration with the digital storytellers project of the r4d programme (see links in Chapter 8).

For all manuscripts developed under this PhD thesis, the Standard & Poor’s Global Market Intelligence Mining Database provided information on the location and other characteristics of the mines in SSA (Standard & Poor's Global). The list of mines provided by this dataset allowed selecting the case study sites for testing the novel remote sensing approach for tracing settlement growth in mining sites (article 1; see Chapter 4). Further, the location and the information on the operational status allowed selecting household and child data around mining sites, which served for studying the impacts of mines on water, sanitation, and housing infrastructures as well as associated health outcomes (articles 2, 3, and the vHealth communication; see Chapters 5, 0, and 8). It also provided the list of companies to be contacted for requesting impact assessment reports (article 4; see Chapter 7).

For article 1, satellite imagery from Landsat and Google Earth was used. The Landsat archive provides satellite imagery dating back to the early 1970s and was opened up to the public in 2008, providing unique opportunities for research (Woodcock et al, 2008; Wulder et al, 2012).

For articles 2 and 3 and the vHealth communication, data from Demographic and Health Surveys (DHS) is used. DHS have been conducted in many developing countries worldwide since the late 1980s allowing for comparisons over time and between countries.

Additionally, the vHealth communication drew on a mixed-methods approach, using data from mapped water infrastructures and information from the focus group discussions conducted during the HIA4SD field missions in Tanzania.

3.3 SDG tagging

The different thematic areas that were covered as part of this PhD thesis were categorized according to the corresponding SDGs. Most prominently, the SDGs that were relevant in the articles that were developed under this PhD project were tagged. The methodology for SDG tagging was developed in collaboration with other researchers at Swiss TPH, United Kingdom Research and Innovation, and the University Hospital Heidelberg (see Annex, Section 11.1). The editorial outlines the ongoing efforts by the journal *Tropical Medicine and International Health* to increase the visibility of the contributions of science to advance the work towards the SDGs.

4 Article 1: Quantification of annual settlement growth in rural mining areas using machine learning

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Article

Quantification of Annual Settlement Growth in Rural Mining Areas Using Machine Learning

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Abstract: Studies on annual settlement growth have mainly focused on larger cities or incorporated data rarely available in, or applicable to, sparsely populated areas in sub-Saharan Africa, such as aerial photography or night-time light data. The aim of the present study is to quantify settlement growth in rural communities in Burkina Faso affected by industrial mining, which often experience substantial in-migration. A multi-annual training dataset was created using historic Google Earth imagery. Support vector machine classifiers were fitted on Landsat scenes to produce annual land use classification maps. Post-classification steps included visual quality assessments, majority voting of scenes of the same year and temporal consistency correction. Overall accuracy in the four studied scenes ranged between 58.5% and 95.1%. Arid conditions and limited availability of Google Earth imagery negatively affected classification accuracy. Humid study sites, where training data could be generated in proximity to the areas of interest, showed the highest classification accuracies. Overall, by relying solely on freely and globally available imagery, the proposed methodology is a promising approach for tracking fast-paced population dynamics in rural areas where population data is scarce. With the growing availability of longitudinal high-resolution imagery, including data from the Sentinel satellites, the potential applications of the methodology presented will further increase in the future.

Keywords: Landsat; Google Earth; rural settlement; land use classification; machine learning; remote sensing; mining; migration

1. Introduction

Large infrastructure projects, such as industrial mining projects, act as a strong pull factor for migration in low- and middle-income countries [1,2]. The main driver of in-migration into project areas is often the large workforce required, particularly during the construction phase [3]. In addition, multiplier effects on local employment, including petty traders and small-scale service providers, lead to an even higher number of people profiting from the mine than merely the direct mining employees [4]. As a result, sparsely populated remote areas can be transformed into busy semi-urban environments within a few years [5].

In these areas, the rapid influx of migrants can strain local health systems, food and water supplies, sanitation and waste management systems, as well as other public services such as education, and thus lead to a diverse set of environmental, social and health impacts [3,6]. It is therefore of crucial importance for policy makers to understand the spatial and temporal population growth patterns within their constituency for adequate resource allocation, development planning or disaster management [7–9].

In sub-Saharan Africa, keeping track of migration and population growth is usually done through censuses [10]. The implementation of censuses is costly and therefore usually conducted only once in a decade [10]. This temporal resolution is, however, not sufficient to identify the fast-paced migratory patterns associated with large infrastructure developments.

In the absence of reliable population data, remote sensing applications have the potential to help trace settlement changes in remotely located mining areas in sub-Saharan Africa [8,9,11,12]. The opening of the Landsat archive in 2008 together with freely available software has created opportunities for researchers and public institutions in resource-poor areas to use remote sensing techniques for population tracking [13,14].

Indeed, over the last few decades, Landsat imagery has been increasingly used for land use classification [15]. Combining Landsat imagery with auxiliary data, different approaches have been developed to trace urban growth at high temporal resolutions. For example, Gong and colleagues produced annual maps of settlements over China for a 40-year period in conjunction with night-time light data [16]. While they achieved high accuracies in the urban coastal regions, the accuracy in the sparsely populated areas in the backcountry was considerably lower [16]. Other approaches include using zonal plans, very high-resolution satellite imagery, aerial photographs or ground-truth information from field visits as auxiliary data [8,11,17]. However, in rural areas in sub-Saharan Africa, this data is either not applicable for land use classification or not available on a larger scale. Alternatively, visual interpretations of Landsat imagery by experts can serve as training data for land use classification [12]. But at the 30 m pixel size Landsat imagery provides, this is hardly feasible in areas with scattered settlements lacking tarred roads or large building complexes, inherent to many rural places in sub-Saharan Africa.

Historic Google Earth imagery could serve as a cheap and widely available information source to derive multi-annual training datasets. Different studies have successfully incorporated this data source to produce land use maps [12,18–21]. Most prominently, Gong et al. [21] used Google Earth imagery to generate training datasets for a global land cover product at 30 m resolution. Further, Schneider has identified stable land uses for studying land use changes around major Chinese cities [18]. However, the vast majority of existing studies have either had a focus on densely populated urban and peri-urban areas [20,22–26], produced land use classifications at lower temporal resolution [24,26,27], or relied on auxiliary ground-truth data and datasets that are not freely available in remote locations of sub-Saharan Africa [17,23,28,29].

In summary, as a foundation for policy making and impact assessment practice in the context of large mining projects, methods are needed for tracking population growth at a high spatial and temporal resolution [30,31]. For the method to be widely applicable, it should (i) only incorporate freely available data; (ii) rely on imagery with high geographical and temporal coverage; and (iii) perform well in a rural setting. Therefore, the overarching objective of this study is to use freely available data from the Landsat archive in conjunction with historic Google Earth imagery to quantify annual settlement growth patterns in rural settlements in sub-Saharan Africa. The specific research questions are: (i) Is suitable satellite imagery and training data available for the time period of interest? (ii) Is the classification result of built-up areas comparable between the different years? (iii) Can migration patterns be detected in industrial mining areas and at what geographical extent?

2. Materials and Methods

2.1. Study Area Selection

Four large industrial gold mines in Burkina Faso were selected as study areas. The location and main characteristics of each mine are available in Figure 1. Additionally, to identify the growth patterns unique to mining areas, two comparison areas without natural resource extraction activity were chosen for each mining area. The areas were matched based on the estimated population size within a 10 km radius from the mines. For estimating the population, data on population size per commune from the latest census in 2006 [32] were combined with the location of settlements retrieved from Open Street Maps. To do so, a data layer containing the type (village, town, city, etc.), location and population size of the different settlements was obtained from www.geofabrik.de. This dataset was used to estimate the ratio in population size between the settlement types. Then, equally spaced 10 km buffers were created and the number of cities, towns, villages, and hamlets within these buffers was counted. Finally, this number was multiplied with the standardized population size for the respective settlement within the given commune and summed up to get an estimate of the population within the 10 km buffer. For each mining area, two buffers with an estimated population size of ±10% located within the same Landsat scene were chosen as comparison areas.

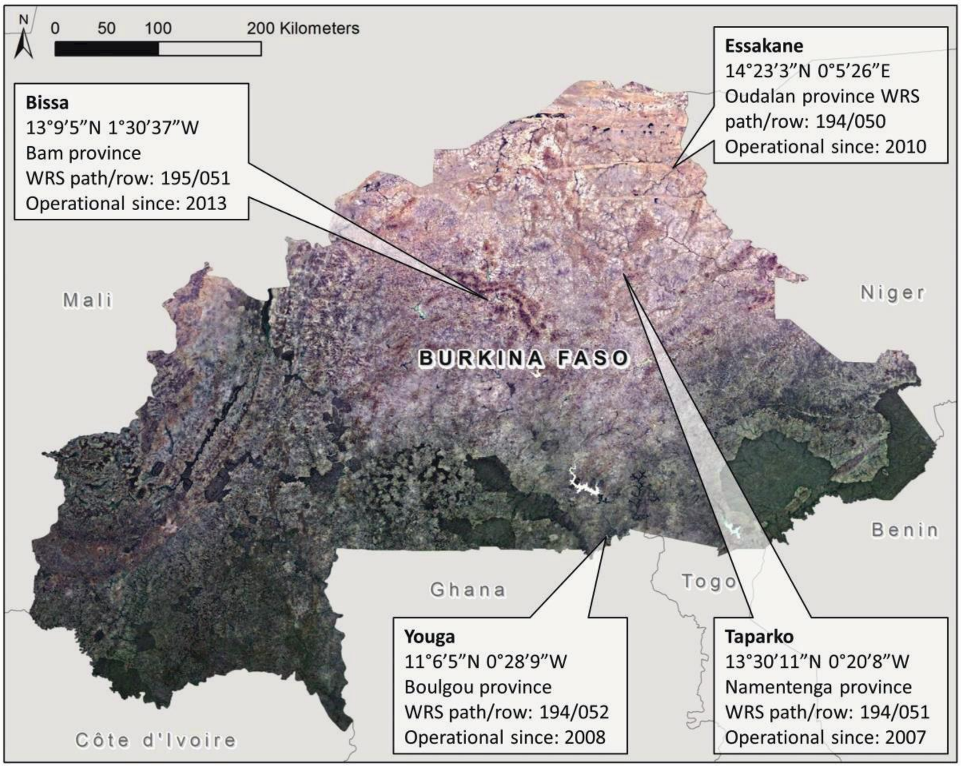

Figure 1. Location of gold mining areas included in this study.

2.2. Data Sources

For the classification, freely available Level-2 surface reflectance imagery from the Landsat 5 Thematic Mapper (TM), 7 Enhanced Thematic Mapper Plus (ETM+) and Operational Land Imager (OLI) sensors with a ground resolution of 30 m were used. These images are geometrically and atmospherically corrected. The mining areas were located within four scenes. The images downloaded captured data between 2002 and 2016, had less than 10% of the scene's land mass covered by clouds and covered the Worldwide Reference System (WRS) scenes of the mines. For Landsat 5 and 7 scenes, spectral bands 1–5 and 7 were used; for Landsat 8 scenes, bands 1–7 were included.

Training data comprised of historic high-resolution images from Google Earth Pro Version 7.1.7.2606 in the beginning and end of the study period. For comparing the impact of training data site selection on classification accuracy, two approaches were pursued. For WRS 195/051 (Bissa) and WRS 194/051 (Taparko), images were extracted from anywhere within the respective Landsat scenes. In the other two scenes (i.e., WRS 194/050 (Essakane) and WRS 194/052 (Youga)), Google Earth imagery was only retrieved within a 25 km buffer around the mining and comparison areas. For this approach, the study period was adapted due to the limited availability of historic Google Earth imagery of sufficient resolution in the beginning of the study period.

2.3. Land Use Classification

The preparation, classification and post-classification steps to derive urban growth metrics from satellite imagery applied in this study are explained in the following sections and visualized in Figure 2.

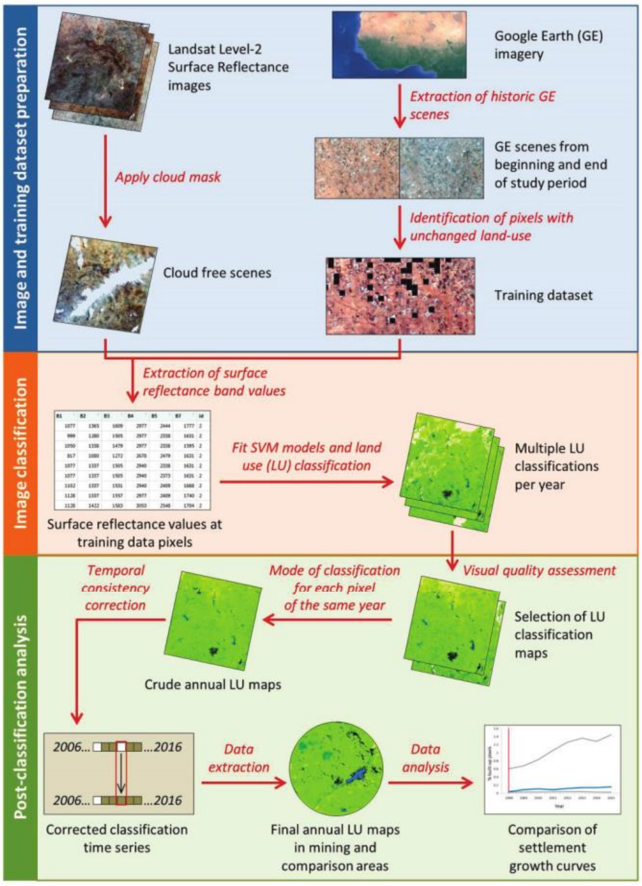

Figure 2. Data sources and methodological flowchart. GE: Google Earth. SVM: support vector machine. LU: land use.

2.3.1. Image and Training Dataset Preparation

The Landsat Level-2 Pixel Quality Assessment band was used to create a cloud mask. The pixels that are interpreted as cloud or cloud shadow were removed from the original images using the "mask" function in the "raster" package in the statistical program R (Version 3.4.4, R Foundation for Statistical Computing, Vienna, Austria).

For the generation of a training dataset, suitable Google Earth scenes from the beginning and end of the study period were manually searched. By extracting imagery at different viewing heights, an optimal distance of 5.5 km was found to be ideal to still detect the different land uses while covering a large area. The Google Earth images were exported into ArcGIS (Version 10.5, ESRI, Redlands, CA, USA). In ArcGIS these scenes were then georeferenced to the Landsat scenes. Subsequently, a grid layer outlining the extents of the 30 m pixels of the Landsat scene was overlaid. Then, grid cells with stable land uses were identified for the following classes: water, grassland/agricultural land, forest, barren land, and built-up land, similar to Gong et al. (2015). Similar to the definition in other studies, a cell was assigned to a class if at least 50% of its area was composed of the respective land use class in the beginning and end of the study period [18,33,34].

Two different approaches were used to generate the training data. For the scenes covering the Bissa and Taparko mines, as well as their comparison areas, pixels from the whole scene were included as potential training data areas. For the other two scenes, which included the Essakane and Youga mines, the Google Earth images for generating the training data pixels were retrieved in the proximity of the areas of interest, i.e., within a 25 km buffer from the mining and comparison areas.

2.3.2. Image Classification

For the selection of the classification model, the performance of five different classifiers (random forest (RF), k-Nearest Neighbors, decision tree (KNN), support vector machine (SVM), linear discriminant analysis (LDA) and a classification and regression tree model (CART)) was tested on one randomly selected scene. Overall accuracy (OA) and the Kappa coefficient were determined by a 10-fold cross-validation with three resampling schemes. The highest accuracy was achieved by the SVM classifier (OA = 92.0%; K = 0.872) as compared to RF (OA = 88.4%; K = 0.799), KNN (91.9%; K = 0.870), LDA (OA = 84.6%; K = 0.754) and CART (OA = 79.5%; K = 0.677). Hence, the final classification method for predicting the land use classes consisted of fitting a separate SVM model ("svmRadial" function in "caret" R package) trained for each Landsat scene in the dataset. The algorithm was implemented using a radial kernel with hyperparameters set by default by the "caret" package. The Landsat surface reflectance band values at the training data pixel locations were extracted and used as input data for the learning of the hyperplane. Hence, 6 continuous input variables were used for Landsat 5 and 7 imagery; 7 variables for Landsat 8.

2.3.3. Post-Classification Processing

Three post-classification strategies were used to improve the accuracy and consistency of the classification. Firstly, the quality of each land use classification scene was assessed visually by the first author. Scenes with apparent misclassification due to haze, mist or other factors were excluded. Secondly, among all remaining scenes from the same year, the most commonly predicted land use class was taken at each pixel (i.e., mode) [35]. Random allocation to one of the classes was done in case of draws. Lastly, an adopted method from Chai et al. was applied to ensure temporal consistency [20]. It is based on the assumption that the conversion from built-up land to other land uses is highly unlikely and therefore assumed to be irreversible. Therefore, non-built-up pixels were reclassified as built-up if this was the assigned land use class in the two previous and the following year. Similarly, built-up pixels that appear isolated in a time series (i.e., pixels that were not built-up in the two years before and the following year) were reassigned the class of the previous year.

2.4. Accuracy Assessment

For each of the four scenes a separate validation dataset was created using Google Earth imagery. Reference data was only obtained in the study areas (i.e., within a 25 km buffer from the mine or comparison sites). In general, the same methodology as for the training dataset was used (see Section 2.3.1). However, due to the limited availability reference data in Google Earth covering the different land use classes, the accuracy assessment was only done for one year within the study period and merges the non-built-up classes into one "other" class.

The validation data was overlaid with the final classification result for the respective year to extract the OA, producer's accuracy (PA), user's accuracy (UA) and the Kappa coefficient.

2.5. Data Analysis

After excluding the mining area from the final classification, the number of built-up pixels within the mining and comparison buffers was extracted and the percentage of built-up pixels of the whole buffer zone calculated for each year. Annual settlement growth patterns were compared visually both between mining and comparison areas and between the years before and after mine opening. Based on previous studies and expert opinion on the likely impact radius of mining projects in remote settings, a 10 km and 25 km buffer was tested to determine the geographical extent of mining-related settlement growth [36].

3. Results

3.1. Availability of Landsat Satellite Imagery

Across sensors and study areas, 716 images with cloud cover below 10% were available (Table 1). The total number of downloaded images was 101, 428, and 187 from the Landsat 5, 7, and 8 missions, respectively. Until 2013, images from the Landsat 5 mission were available and the Landsat 8 satellite was launched in 2013. The Landsat 7 satellite provided images throughout the study period. However, since a failure in the Scan Line Corrector (SLC) in early 2003, the images show stripes of missing data.

Table 1. Available Landsat images with <10% cloud cover by study area and Landsat mission. Numbers in parentheses indicate the number of retained images after the visual quality assessment of the initial land use classification.

Landsat Mission	Bissa	Taparko	Essakane	Youga	Total
Landsat 5	25 (6)	28 (13)	27 (8)	21 (6)	**101 (33)**
Landsat 7	133 (27)	117 (35)	95 (32)	83 (32)	**428 (126)**
Landsat 8	46 (14)	48 (13)	53 (10)	40 (15)	**187 (52)**
Total	**204 (47)**	**193 (61)**	**175 (50)**	**144 (53)**	**716 (211)**

Figure 3 depicts the capture dates of the retained satellite images that yielded high-quality land use maps using our approach. In total, 211 images were included for the post-classification steps (see Table 1). Of note, the vast majority of retained images were taken in the beginning (i.e., January and February) or the end (i.e., October–December) of the calendar year. These months coincide with the dry season in Burkina Faso.

For most years enough Landsat images could be retained. However, in a few instances only two useful images were available (e.g., in the Bissa area in 2012). In the case of disagreement between the two classifications, the modal value of the two initial land use classes was randomly assigned. Further, in some instances when only a few images were retained in the image stack, patches of missing data remained due to cloud coverage and gaps in SLC-off Landsat 7 scenes.

3.2. Availability of Historic Google Earth Imagery

More challenging than getting satellite imagery was to obtain Google Earth images to generate a training dataset valid for the entire study period. The availability of high-resolution imagery varied strongly depending on the location of the study area so that the start date of the study needed to be shifted. In general, older images were available over the capital Ouagadougou. In the more remote and rural areas, historic Google Earth imagery of sufficient resolution for determining land use was only available from around 2006/2007. Even in these instances, finding images covering all land use classes was cumbersome for that period. It was particularly challenging to delimit seasonal water bodies that partly or entirely dry out towards the end of the dry season.

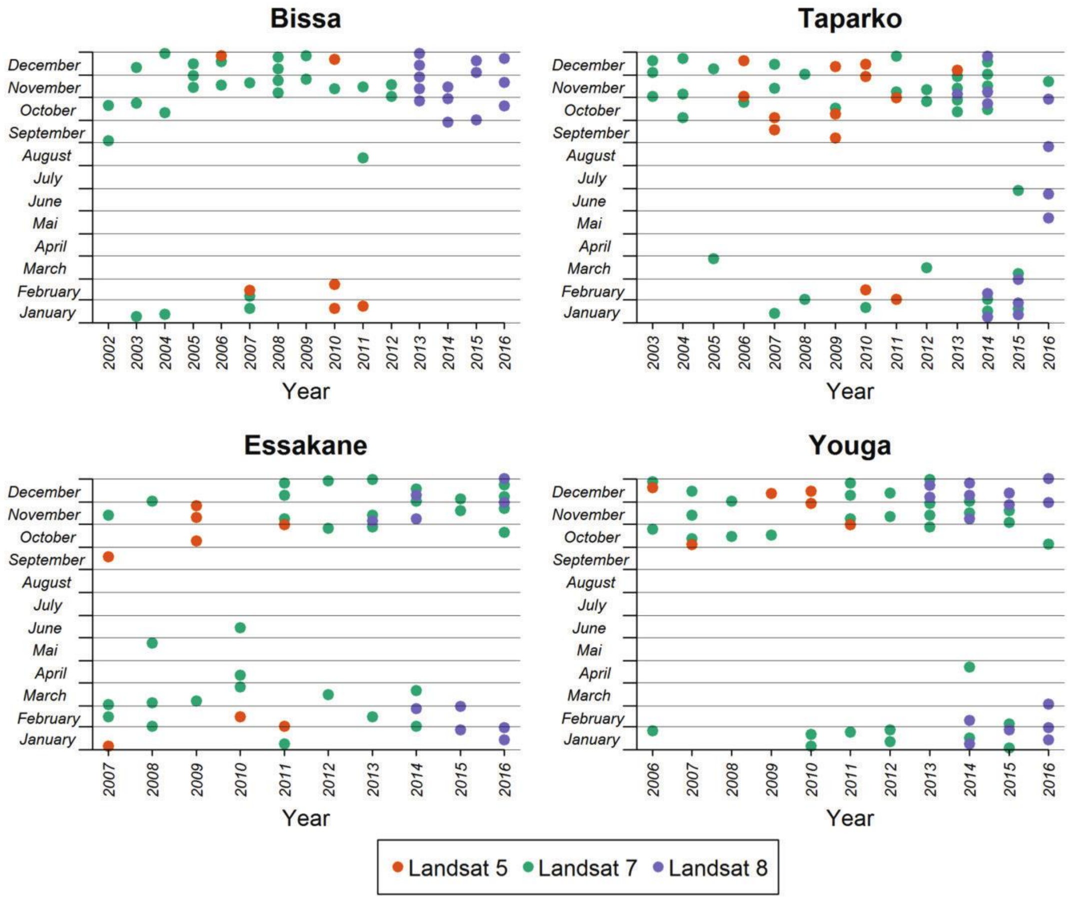

Figure 3. Capture dates of images retained after the visual quality assessment for each study site and year.

3.3. Settlement Growth in Mining and Non-Mining Areas

The percentage of built-up areas over time in the four mining areas and their comparison areas are depicted in Figure 4. Overall, differences in the variability of the growth curves were observed. In the areas where training data was obtained from anywhere within the satellite scene (i.e., Bissa and Taparko), a higher variability was observed. Indeed, there were a number of outliers in the classification in Bissa and Taparko leading to negative growth of settlements. For example, the raw classification for the Taparko scene in 2016 featured particularly few urban pixels and thereby leading to negative settlement growth in the previous year through the temporal consistency correction. Further, in the Bissa scene only two images were retained for 2009 and 2012 with extreme numbers of classified urban pixels. Visual inspection of the raw classification maps revealed that in these cases the misclassified urban pixels were mainly over barren and rocky ground. After application of the temporal consistency correction, the number of misclassified pixels could be reduced (see Figure 5).

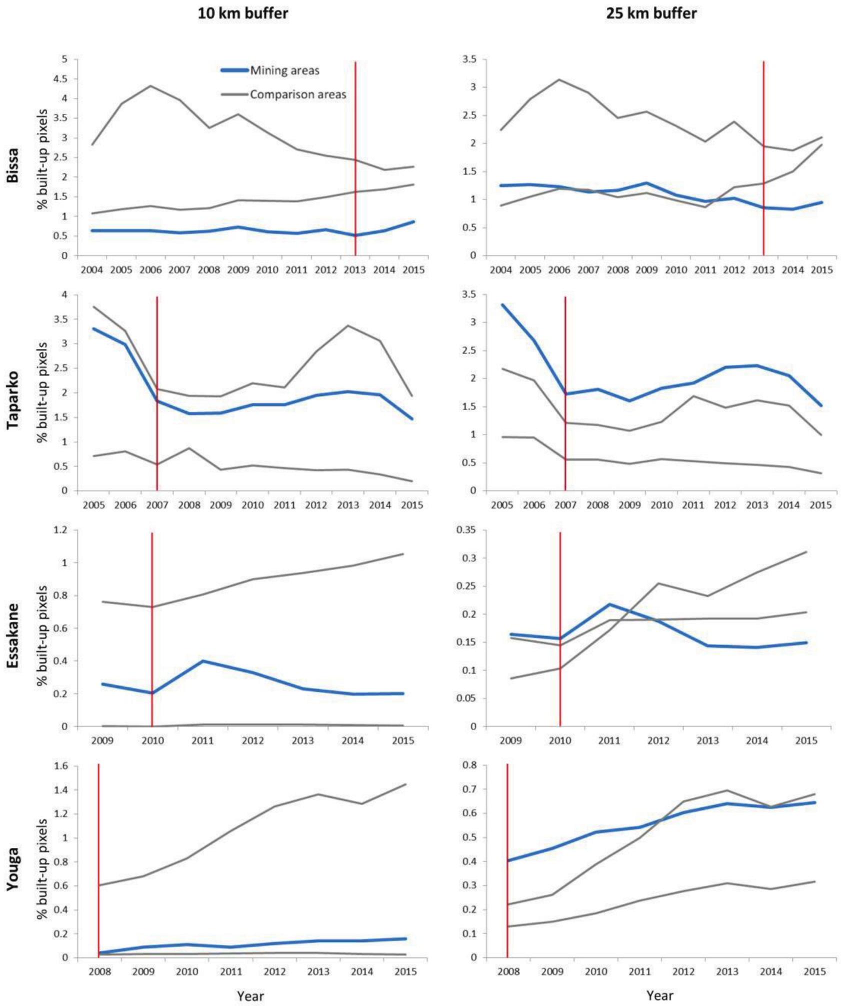

Figure 4. Comparison of the percentage of built-up pixels over time. Blue lines depict settlement growth in mining areas over time. Gray lines show settlement growth in comparable nearby districts within a 10 km (left panels) and 25 km (right panels) radius. Red vertical bars indicate the opening year of the mine.

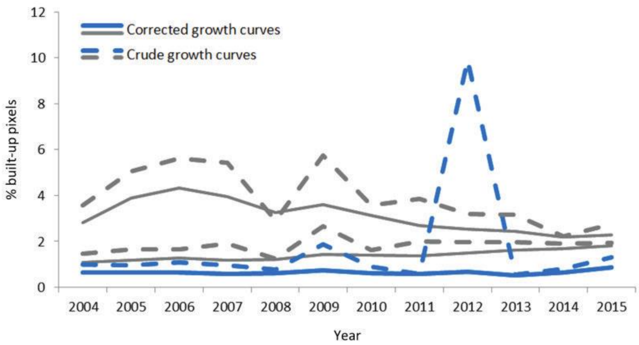

Figure 5. Visualization of the impact of the temporal consistency correction. Crude growth curves are depicted with dashed lines; corrected growth curves with solid lines. This example shows the trends in the 10 km buffer around the Bissa mine (blue line) and its comparison areas (grey lines).

Generating training data in the proximity of the areas of interest (i.e., Essakane and Youga) led to more stable results classification results over the years. Only in a few instances were negative growth years observed. In these areas a general urbanization trend, at different paces, was seen.

The growth curves showed different slopes both throughout the study period and across study areas. However, no clear pattern could be observed that could indicate strong in-migration to the studied mining areas. Although in some areas the settlements are at a greater distance from the mines, the growth patterns were similar in the different geographical extents.

3.4. Accuracy Assessment

Table 2 shows the result of the accuracy assessment. The OA for the different scenes were 86.4%, 58.5%, 80.3%, and 95.1% for Bissa, Taparko, Essakane, and Youga, respectively. Overall, there were large differences between the two approaches used for training data generation and between the study areas. The Kappa coefficient of the individual study areas ranged from as low as 0.176 to 0.902. Only in Youga was the classification sufficiently sensitive in detecting built-up pixels. In all scenes, only few non-built-up pixels were misclassified as built-up. Obtaining training data in the proximity of the study areas (approach 2) improved the accuracy substantially. However, in the Essakane scene only 30.4% of the built-up pixels in the reference dataset were correctly classified. Visual inspection of misclassified pixels revealed that most errors occurred in the less densely populated fringes of villages and at isolated clusters of buildings (see Figure 6).

Table 2. Accuracy assessment by training data generation approach and study area. Approach 1 refers to obtaining training data within the whole scene. In approach 2 training data was only generated from the proximity of the study areas. Overall accuracy (OA), producer's accuracy (PA), user's accuracy (UA) and the Kappa coefficient are reported.

Approach 1	**Classification**			**Approach 2**	**Classification**		
Reference	Built-up	Other	**PA**	**Reference**	Built-up	Other	**PA**
Built-up	130	197	39.8%	Built-up	438	99	81.6%
Other	27	462	94.5%	Other	3	703	99.6%
UA	82.8%	70.1%		**UA**	95.0%	87.7%	
OA = 72.5%				**OA = 91.8%**			
Kappa = 0.375				**Kappa = 0.829**			
Bissa	**Classification**			**Taparko**	**Classification**		
Reference	Built-up	Other	**PA**	**Reference**	Built-up	Other	**PA**
Built-up	70	52	57.4%	Built-up	60	145	29.3%
Other	4	285	98.6%	Other	23	177	88.5%
UA	94.6%	84.6%		**UA**	72.3%	55.0%	
OA = 86.4%				**OA = 58.5%**			
Kappa = 0.632				**Kappa = 0.176**			
Essakane	**Classification**		**PA**	**Youga**	**Classification**		**PA**
Reference	Built-up	Other		**Reference**	Built-up	Other	
Built-up	24	55	30.4%	Built-up	414	44	90.4%
Other	0	200	100%	Other	3	503	99.4%
UA	100%	78.4%		**UA**	99.3%	92.0%	
OA = 80.3%				**OA = 95.1%**			
Kappa = 0.385				**Kappa = 0.902**			

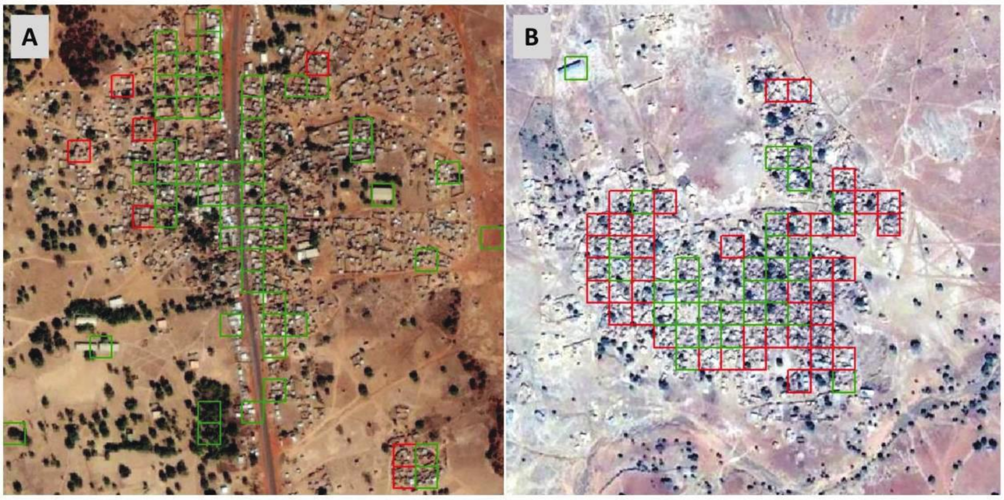

Figure 6. Examples of correctly (green) and incorrectly (red) classified pixels (30 × 30 m). (**A**) Extent near the Bissa mine with high accuracy. (**B**) Undetected urban pixels at the fringes of a settlement in Taparko area.

4. Discussion

High-resolution Google Earth and 716 Landsat images were used to estimate annual settlement growth in rural mining areas in Burkina Faso. While the number of satellite images from Landsat was sufficient, finding adequate training data among historic Google Earth imagery was challenging. Indeed, in our study areas high-resolution imagery before 2006 was only available over larger urban areas. Still, using training data in proximity to the areas of interest reduced the inter-annual variability and resulted in higher classification accuracy. Overall accuracy of the four scenes ranged from 58.5% to 95.1%. These results show that with local training data and relatively humid environments the proposed methodology can yield stable and accurate estimates of settlement growth over time. However, due to the limited number of accurately classified study areas, no apparent differences in settlement growth patterns between mining and comparison areas were observed.

When comparing the growth curves of the predominantly rural areas selected for this paper with those of mainly urban areas reported in other publications, three patterns were observed: (i) the availability of Google Earth imagery influenced the classification accuracy; (ii) negative growth was observed in some study areas; and (iii) there is limited potential for additional post-classification correction approaches in our study setting. Each of these observations is discussed separately in the subsequent paragraphs.

Regarding the varying accuracy, it is noteworthy that the availability of historic high-resolution Google Earth imagery was limited. The available Google Earth scenes in the beginning and end of the study period had to be used as training data in order to meet the required sample size for fitting the SVM model [37]. When training data were located in cropped cloud areas or extents with remaining haze coverage, classification accuracy was low, leading to the exclusion of a substantial number of scenes during the visual quality assessment. Further, the accuracy assessment was limited to one extent in one year for each site because of the limited availability of Google Earth imagery. Still, the assessment indicates that for most scenes the number of undetected built-up pixels was substantially higher than in other studies [16,18], but also that the classification of the Youga scene provided very high accuracies. This scene differed in two aspects. Firstly, training data was obtained more closely to the area of interest, and secondly it is located further south in a tropical savanna climate. The lower accuracies in the other scenes may be caused by the similar spectral signatures of urban areas and natural bare surfaces (e.g., low normalized difference vegetation index (NDVI), an indicator for healthy vegetation) [29,34]. These similarities may be more pronounced in the semi-arid regions of northern Burkina Faso, where vegetation is sparse and the corrugated sheet roofs are often covered by a sand layer. Indeed, the vast majority of available cloud-free scenes used in this study were taken in the dry Harmattan season, characterized by dusty trade winds. Purposively selecting scenes shortly after the growing season might alleviate this problem.

A few other studies have also reported negative or absent settlement growth within their study period, although to a lesser degree [17,27]. Whether this was due to actual removal of buildings or misclassification errors is however not discussed. The higher variability found in the present study can partly be explained by the low percentage of built-up pixels in relatively small geographical areas. Hence, misclassification of, e.g., a patch of rocky ground into the built-up class will lead to a significant spike in the number of urban pixels in that year. Further, the absence of accelerated growth patterns in mining areas may also be due to a densification of housing within the existing settlement extents, which is difficult to detect at 30 m pixel size.

Regarding post-classification approaches, other studies observed that more robust results were obtained when incorporating spatial consistency checks, in addition to the temporal consistency correction as applied in this study [33,38]. This approach includes a calculation of the probability of a pixel to be urban as a function of the surrounding pixels. Although this may reduce the "salt and pepper" effect in scattered sparsely populated areas in rural sub-Saharan Africa where building clusters only cover a few pixels, this may lead to an underestimation of the built-up areas.

The strength of the method used in this study is the reliance on globally and freely available data and its relatively straight-forward workflow relying on few image pre-processing steps. This could make it useful for researchers and public institutions with limited technical expertise to track settlement changes in areas where reliable and up-to-date population data is scarce. In these cases, the Google Earth training data could be complemented with additional ground-truth points from field observations.

As the repositories are continuously built up, Landsat and high-resolution Google Earth imagery will become increasingly available for longer periods allowing for long-term tracking of population growth remote areas. Additionally, other imagery from more recently launched satellite missions could be incorporated in the workflow. For example, the Sentinel-2 satellites provide freely available imagery at a 10–60 m resolution on a nearly global coverage since 2015 [39]. While this timeframe was not sufficient for the present study, it could serve as a good baseline for future endeavors for multi-annual land use classifications [27,39]. Still, the increased resolution could reduce the problem of pixels featuring multiple land use classes.

Future studies should also investigate the performance of the approach in remote areas in other climatic zones, potentially incorporating other spectral indices, such as NDVI or natural built-up index (NDBI). Additionally, in order to determine the magnitude of mining-related population growth, more long-term studies covering a higher number of mining areas are needed.

5. Conclusions

The applicability of the proposed methodology depends on the availability of historic Google Earth imagery and climatic factors. High accuracy in annual estimation of rural settlement growth was achieved when two conditions were met: (i) training data were available in proximity to the areas of interest; and (ii) the setting was located in the relatively humid areas in southern Burkina Faso. Hence, in humid climate zones and locations with high quality satellite imagery in proximity to the area of interest, the developed methodology can be readily applied for further investigating the impacts of mining and other large infrastructure projects on population growth in remote locations. Indeed, the increasing availability of long-term high-resolution satellite imagery through Google Earth, but also new data sources such as imagery from the Sentinel missions, will further increase the potential applications of the developed methodology.

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M.S.W.; supervision, A.F., K.d.H. and M.S.W. All authors have read and agreed to the published version of the manuscript.

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5 Article 2: Housing conditions and respiratory health in mining communities: an analysis of data from 27 countries in sub-Saharan Africa

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Housing conditions and respiratory health in children in mining communities: An analysis of data from 27 countries in sub-Saharan Africa

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ABSTRACT

Background: Poor housing conditions, such as poor building materials and weak structures as well as high levels of indoor air pollution, are important risk factors for a broad range of diseases, including acute respiratory infections (ARI). In mining areas, research on the determinants of respiratory health predominantly focuses on exposures to outdoor air pollutants deriving from mining operations. However, mining projects also influence the socioeconomic status of households, which, in turn, affect housing quality and individual behaviors and, thus, housing quality and levels of indoor air pollution. In this study, we aimed to determine how proximity to an industrial mining project impacts housing quality, sources of indoor air pollution, and prevalence of ARI.
Methods: We merged data from 131 Demographic and Health Surveys (DHS) with georeferenced data on mining projects in sub-Saharan Africa (SSA) to determine associations between housing quality, indoor air pollution sources, and child respiratory health. Spatial differences in selected indicators were explored using descriptive cross-sectional analyses. Furthermore, we applied a quasi-experimental difference-in-differences (DiD) approach using generalized linear mixed-effects models to compare temporal changes in household and child health indicators at different operational phases of mining projects and as a function of distance to mines.
Results: For cross-sectional analyses, data of 183,466 households and 141,384 children from 27 countries in SSA were used, while 41,648 households and 34,406 children from 23 SSA countries were included in the DiD analyses. The increase in the share of houses being built from finished building materials after mine opening was more than 4-fold higher (odds ratio (OR): 4.32, 95% confidence interval (CI): 2.98–6.24) in close proximity to mining sites (i.e., $\leq$ 10 km) compared to areas further away (i.e., 10–50 km). However, these benefits were not equally distributed across socioeconomic strata, with considerably weaker effects observed among poorer households. Increases in indoor tobacco smoking rates in close proximity to operating mines were twice as high as in comparison areas (OR: 2.06, 95% CI: 1.15–3.68). The cross-sectional analyses revealed that traditional cooking fuels (e.g., charcoal, dung, and wood) were less frequently used (OR: 0.27, 95% CI: 0.23–0.31) in areas located in close proximity to mines than in comparison areas. Overall, no statistically significant association between mining operations and the prevalence of symptoms related to ARI in children under the age of 5 years was observed (OR: 0.78, 95% CI: 0.29–2.07).
Conclusions: Mines impact known risk factors for ARI through diverse pathways. The absence of significant changes in ARI symptoms among children is likely the result of counteracting effects between improvements in housing infrastructure and increased exposures to air pollutants from outdoor sources and tobacco smoking. For mining projects to unfold their full potential for community development, we recommend that impact assessments move beyond the mere appraisal of mining-related pollution emissions and try to include a more comprehensive set of pathways through which mines can affect ARI in exposed communities.

Abbreviations: ARI, acute respiratory infection; CI, confidence interval; DHS, Demographic and Health Survey; DiD, difference-in-differences; HH, household; IRR, incidence rate ratio; OR, odds ratio; PCA, principal component analysis; SSA, sub-Saharan Africa.

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1. Introduction

Housing conditions that promote health and wellbeing need to provide shelter, protect from environmental pollution, encompass access to essential services (e.g., clean water, improved sanitation, and electricity), and support healthy life-styles (e.g., access to green spaces and public transport options) (WHO, 2018). Poor housing conditions have been shown to hamper child development and are important risk factors for a broad range of communicable and non-communicable diseases, such as diarrhea, malaria, respiratory diseases, and cardiovascular diseases (Tusting et al., 2015, 2020; WHO, 2018).

A key aspect in the housing environment is indoor air quality (WHO, 2018). Most household air pollutants originate from indoor waste burning, cooking, and heating with traditional fuels (e.g., charcoal, dung, and wood) (Shupler et al., 2020; Tielsch et al., 2009; Zhou et al., 2014). In addition, indoor tobacco smoking can further deteriorate the quality of indoor air (Tielsch et al., 2009). Exposure to in-house air pollutants is attributable to a considerable burden of disease (Gordon et al., 2014). Indeed, globally, indoor air pollution from solid cooking fuels accounts for more than 2.5 million deaths every year (Gakidou et al., 2017). It is estimated that more than 600,000 deaths worldwide were caused by exposure to second-hand tobacco smoke (Öberg et al., 2011).

Around a quarter of the deaths due to indoor air pollution stem from acute respiratory infections (ARI), such as pneumonia and bronchitis (Gakidou et al., 2017). Children are particularly at risk for ARI from indoor air pollution, firstly due to their higher sensibility to exposures to air pollutants and secondly because they spend a large part of their time in and around the household, and are thus exposed to air pollutants from cooking facilities (Landrigan et al., 2017; Wright et al., 2020). Furthermore, inadequate housing conditions, such as overcrowded settlements, contribute to the high burden of ARI in low- and middle-income countries (Kristensen and Olsen, 2006; Nkosi et al., 2019).

Particularly in sub-Saharan Africa (SSA), predominantly solid fuels are used for food preparation and the associated health burden from ARI remains high (Chafe et al., 2014; Zulu and Richardson, 2013). As a region characterized by high urbanization rates and relatively small increases in income levels, the provision of adequate housing remains a challenge (World Bank Group, 2015). Wealth gains through economic development, such as the establishment of large resource extraction projects in the mining, oil, and gas sector, hold promise to boost local economies, and hence, improve housing conditions in underserved areas (Cawood et al., 2006; von der Goltz and Barnwal, 2019). On the other hand, the prospect of livelihood opportunities in mining areas can trigger rapid in-migration, which can lead to the formation of informal settlements and slums (Jackson, 2018; Marais et al., 2018, 2020). These settlements are usually characterized by makeshift low quality housing infrastructures, reduced service availability, and overcrowding (Contreras et al., 2019; Pelders and Nelson, 2018). Alongside exposures to air pollutants from the mines, poor housing conditions can negatively affect respiratory health of people living in mining communities (Hendryx and Luo, 2014; Nkosi et al., 2015).

Research on the impacts of mines on housing conditions and associated health outcomes in children has mainly focused on case studies or on particular population groups, such as mine workers or slum dwellers (Marais et al., 2020; Pelders and Nelson, 2018). Furthermore, studies on air pollution exposures and associated health outcomes in mining areas predominantly look at direct exposure pathways to air pollutant emissions from mining operations, without consideration of impacts on other potential exposure pathways in the community, such as indoor air pollutants (Boyles et al., 2017; Herrera et al., 2016). Similarly, in impact assessments, an approach to anticipate and manage potential impacts of projects as part of the licensing process (Harris-Roxas et al., 2012), the assessment of risk factors for respiratory diseases has a strong focus on the direct impacts of air pollutants from the mines (Dietler et al., 2020c; Riley et al., 2020). In contrast, housing conditions and associated health outcomes have received less attention in impact assessment practice (Dietler et al., 2020c; Pham et al., 2018; Riley et al., 2020). A deeper understanding of such indirect impacts on housing in mining areas could provide valuable insights for guiding impact assessments practice of mining projects.

The purpose of this study was to identify associations between mines and housing conditions in mining communities of SSA, and to determine whether these affect respiratory health of children. To do so, we used a large pseudo-panel of georeferenced health data across SSA to compare healthy housing indicators cross-sectionally at different distances from mines, and also longitudinally over time within areas where data prior and after the opening of mines were available.

2. Material and methods

2.1. Data and study design

Data from all 131 Demographic and Health Surveys (DHS) conducted in SSA that were readily available in March 2020 were combined with a comprehensive dataset on mining projects (Standard & Poor's Global, 2020; USAID, 2020). The DHS data feature a large set of household and child indicators. From the mining dataset, the location of major mines in SSA and their operational activities since the early 1980s were extracted.

The opening year, and for some mines also the closure year, were determined using either the information on annual extraction and production volumes or the reported opening and closure year in the dataset. As opening year, the first year with reported extraction was set, unless an earlier opening year was specifically indicated. Similarly, as closure year, the last year with reported operation or the reported closure year was taken, whichever was later. If no information on closure of a mine was available and the project status was labelled as "active", operation until the end of the study period (i.e., 2019) was assumed. The mines were considered as "active" during all years between opening (i.e., the first year commodities were extracted) and closure (i.e., the last year with reported extraction). Before mine opening and after mine closure, the mines were classified as "pre-operational" or "closed", respectively.

For each level of analysis (household- and child-level), two types of datasets were constructed, as shown in Fig. 1. Firstly, a cross-sectional dataset comprising of all data within a distance of 100 km from mining projects that were active at the time of the survey was created. This dataset was used to derive descriptive statistics and explore associations between the Euclidian distance to the mine and the different household indicatory and symptoms of ARI in children under the age of 5 years. Secondly, a pseudo-panel dataset was created. Only data within a 50 km radius from isolated mines (i.e., mines that were at least 100 km away from other mines) were included, regardless of the activity status of the mines at the time of the survey. The resulting dataset comprised data collected at different operational phases of the mines, allowing for longitudinal analyses of changes over time.

From all datasets, data from households that were located within the boundaries of large cities (i.e., $\geq$ 100,000 inhabitants) were excluded. The size of the city boundaries were determined by a visual appraisal of satellite images of a random set of differently sized cities listed in a dataset from Natural Earth (Natural Earth, 2020). The resulting buffer sizes around the city centers were 5 km for cities with a population size of 0.1–0.5 million, 7.5 km for 0.5–1 million, 15 km for 1–5 million, and 40 km for $>$ 5 million. Merging of the datasets and exclusion of data within cities were done using ArcGIS Pro version 2.2.4 (Environmental Systems Research Institute; Redlands, CA, USA) and StataSE version 16 (StataCorp LLP; College Station, TX, USA).

2.2. Variables

2.2.1. Exposure variable

In the cross-sectional dataset, the Euclidian distance between the

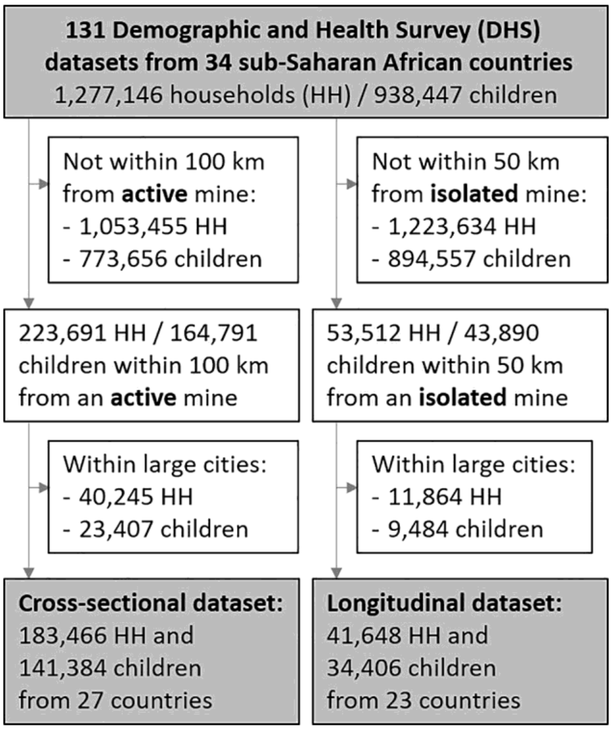

Fig. 1. Flowchart showing the selection of household (HH) and child data from within the proximity of mines and outside city boundaries.

DHS cluster and the closest active mine was the main exposure variable. The distance was categorized into 7 groups: ≤ 5 km, 5–10 km, 10–20 km, 20–30 km, 30–40 km, 40–50 km, and 50–100 km. The last group was used as reference in the analysis. In the longitudinal difference-in-differences (DiD) analysis, an interaction term between distance to and operational status of the mine at the time of the survey was created to assess the effect of a mine opening and closure at various distances from the mine. The distance variable was dichotomized, using ≤ 10 km as "close proximity" and 10–50 km as "comparison" area. The operational status was coded as pre-operational, active, and closed. The exposure definition was a combination of the distance ("close proximity" vs. "comparison") and activity status of the mine ("pre-operational" vs. "active" vs. "closed"), captured by a multiplicative interaction term "close proximity * operational" and "close proximity * closed", respectively.

2.2.2. Outcome variables

Household size

DHS data include information on the number of people residing in the household and the number of rooms used for sleeping. For our analysis, the number of *de jure* household members was used, indicating the number of people usually sleeping within the household. Households indicating zero *de jure* household members were excluded from analyses.

Housing infrastructures

The main construction materials used for flooring, walls, and roofing were categorized as finished or un-finished. Finished materials include, for example, cement, carpet, or parquet for floors; cement, bricks, or covered adobe for walls; and iron sheets, cement, or tiles for roofs. Households were considered as "built from finished materials" if at least two of the three structures were classified as finished (Tusting et al., 2019).

Indoor air pollution sources

Two indicators were used as a proxy for air pollution from indoor sources. Firstly, cooking fuels were categorized into clean and traditional sources. Clean sources include natural gas, biogas, electricity, and liquefied petroleum gas. All other sources were considered, including coal, wood, and other solid fuels, as traditional fuels. Households using unknown fuels or that did not prepare food in the house were excluded. Information on cooking fuels was only available since the beginning of DHS phase 4 in 1997.

As a second indicator, the prevalence of tobacco smoking indoors was used. All households that were characterized by at least one member smoking inside at least once a month, were considered polluted by tobacco smoke. The collection of smoking-related information only began in DHS phase 6 around 2008.

Acute respiratory infection

The definition of symptoms of ARI in children below the age of 5 years has changed over the course of the DHS program. Until the end of DHS phase 4 (around 2000) symptoms of ARI were defined as having cough accompanied by rapid breathing. In DHS carried out later on, information on whether symptoms were chest-related was also gathered and included in the definition. To allow comparison over time, the former definition was used.

2.2.3. Covariates

For each level of analysis, different variables were adjusted for. At the household-level, an indicator for household wealth was created. Since the wealth index included in the DHS data was built on some of the variables that were used as separate indicators in the analyses of this study, specific indexes that excluded these variables were created. Separately for each survey, a principal component analysis (PCA) was conducted to construct the index using information on water and sanitation infrastructures, access to electricity, ownership of a radio, television, telephone, fridge, bicycle, motorcycle, car, or bank account, and educational attainment of the household head. The first component of the PCA was used to create wealth quintiles (Filmer and Pritchett, 2001). Furthermore, the survey year and population density at the household location were included. At the child-level, the age and sex of the child (as categorical variables) were additionally included as covariates.

2.3. Statistical analysis

2.3.1. Cross-sectional analyses

The cross-sectional data were mainly used to explore the associations between the distance to mining sites and the different outcomes. For quantifying these associations, generalized linear mixed-effects models were employed. For the models with binary outcome variables (housing infrastructures, indoor air pollution sources, and ARI symptoms), logistic regression models, while for numeric outcomes (household size), negative binomial regression models were fitted. The models using household characteristics (e.g., housing infrastructures and indoor smoking) as outcome variables included population density, survey year, and household wealth as fixed effects. The models with symptoms of ARI as outcome were additionally adjusted for child age and sex. In all models, random intercept terms for the survey and region were included to account for clustering in the DHS data. The random intercept terms, child age and sex were included in the adjustment sets *a priori*. For population density and survey year terms, likelihood ratio tests were performed to assess their effect on model fit using cooking fuels as outcome (population density: $X^2(1) = 10{,}621$, $p < 0.001$; survey year: $X^2(1) = 805.36$, $p < 0.001$).

To compare impacts across socioeconomic groups, subgroup analyses were done for poorer households (lower two wealth quintiles) and wealthier households (upper two wealth quintiles). Because the motivation of the stratified analysis was to compare impacts among wealthier and poorer households, data from the middle wealth quintile as intermediary group were not further analyzed.

2.3.2. Longitudinal analyses

The repeated cross-sectional data allowed the extraction of data collected around the same mine at different points in time. Following a

DiD approach (Bärnighausen et al., 2017), we compared how the changes in our outcome variables across the different mining phases differed between areas in close proximity to the mines (i.e., ≤ 10 km from the mine) and comparison areas located further away (i.e., between 10 and 50 km). Hence, the main exposure variable was the multiplicative interaction term between distance and operational status of the mine. The same regression models, adjustment sets, and stratified analyses as for the cross-sectional analyses were performed, with the only difference that the regional-level random intercept term was replaced by mine-level random intercepts to account for the repeated cross-sectional structure of the data deriving from the different mining areas.

For all models, households or children with missing data were excluded from analyses. Where applicable, estimates are reported with their corresponding 95% confidence intervals (CIs). All statistical analyses were performed in R version 3.5.1 (R Core Team, 2018) using the lme4 package (Bates et al., 2015).

3. Results

Data from almost 1.3 million households with more than 900,000 children under the age of 5 years were obtained for the period 1990–2019 and were combined with information on 711 mines in 34 SSA countries (Fig. 1). In the cross-sectional datasets, the countries included Angola, Burkina Faso, Burundi, Côte d'Ivoire, Democratic Republic of the Congo, Eswatini, Ethiopia, Gambia, Ghana, Guinea, Kenya, Lesotho, Liberia, Madagascar, Malawi, Mali, Mozambique, Namibia, Niger, Namibia, Senegal, Sierra Leone, South Africa, Tanzania, Uganda, Zambia, and Zimbabwe. No data from close to isolated mines for the longitudinal datasets from Côte d'Ivoire, Eswatini, Lesotho, and Senegal were available. Overall, 52 of the mines were considered as isolated and used as the pseudo-panels in the longitudinal dataset. After selecting observations in close proximity to mining sites and excluding data collected within the boundaries of large cities, the cross-sectional datasets comprised of 183,466 households and 141,384 children, while the longitudinal datasets included 34,406 children from 41,648 households (Fig. 1).

The basic characteristics of the different datasets are summarized in Table 1. The percentage of wealthy and poor households are shown in Table 2. The percentage of wealthy households in close proximity to mining sites increased from the pre-operational to the active phase of the mine. It further increased after closure of mines. Among households located further away, this percentage remained relatively stable over time. The inverse pattern was seen for the percentage of poor households in close proximity to the mining sites.

3.1. Housing conditions and ARI at different distances from mines

The average household within 5 km from a mine comprised of 2.0 rooms for sleeping and housed 4.2 people (Fig. 2). At a distance of 50–100 km, 5.0 people slept in 2.2 rooms on average. Hence, on average, households close to the mines housed 2.1 people per room, while further away, 2.3 people shared one room for sleeping.

Overall, household structures improved closer to the mines. In particular, finished building materials were more commonly used in close proximity to mining sites. The stratified analyses revealed that among the poorer households, the positive associations between the presence of a mine within 5 km and housing materials was not seen (odds ratio (OR): 1.14, 95% CI: 0.90–1.46), but slightly improved further away (e.g., OR at 5–10 km: 1.23, 95% CI: 1.05–1.43; Fig. *A*1). Among wealthier households, much stronger positive associations were seen in the area closest to the mines (OR: 2.28, 95% CI: 1.70–3.05), but not further away.

Households in close proximity to mines relied much less on

Table 1

Summary of household and child indicators in the cross-sectional and longitudinal datasets. The datasets comprise a selection of data from 131 Demographic and Health Surveys (DHS) collected within 100 km from active mines (cross-sectional datasets) and 50 km from isolated mines (longitudinal datasets), respectively. The household dataset includes information from all households. The indicators presented for the child dataset only comprise data from households with at least one child. The surveys were conducted between 1990 and 2019.

	Household data		Child data	
	Cross-sectional dataset (N = 183,466)	Longitudinal dataset (N = 41,648)	Cross-sectional dataset (N = 141,384)	Longitudinal dataset (N = 34,406)
Distance to mine				
≤ 5 km	2812 (1.5%)	n.a.	1756 (1.2%)	n.a.
5–10 km	5506 (3.0%)	n.a.	3615 (2.6%)	n.a.
10–20 km	12,809 (7.0%)	n.a.	8919 (6.3%)	n.a.
20–30 km	15,593 (8.5%)	n.a.	12,113 (8.6%)	n.a.
30–40 km	19,541 (10.7%)	n.a.	14,468 (10.2%)	n.a.
40–50 km	20,447 (11.1%)	n.a.	15,513 (11.0%)	n.a.
50–100 km	106,758 (58.2%)	n.a.	85,000 (60.1%)	n.a.
Mine near (≤ 10 km)	n.a.	2857 (6.8%)	n.a.	2016 (5.9%)
Mine status				
Pre-operational	n.a.	21,143 (54.9%)	n.a.	18,889 (59.0%)
Operational	n.a.	8873 (23.0%)	n.a.	7023 (21.9%)
Closed	n.a.	8517 (22.1%)	n.a.	6086 (19.0%)
Household members (median)	4	5	6	6
Sleeping rooms (median)	2	2	2	2
Finished building materials	100,603 (65.1%)	20,252 (57.8%)	71,867 (59.8%)	15,408 (54.9%)
Use traditional cooking fuels	147,468 (85.5%)	36,047 (95.2%)	122,537 (91.7%)	30,663 (97.7%)
Indoor smoking	19,784 (22.5%)	4635 (22.4%)	17,032 (24.8%)	3659 (21.2%)
Wealth quintile				
Poorest	36,001 (19.6%)	8652 (20.8%)	29,420 (20.8%)	7333 (21.3%)
Poor	41,066 (22.4%)	8330 (20.0%)	33,519 (23.7%)	7013 (20.4%)
Middle	41,887 (22.8%)	9295 (22.3%)	34,019 (24.1%)	8023 (23.3%)
Rich	37,349 (20.4%)	8993 (21.6%)	27,686 (19.6%)	7492 (21.8%)
Richest	27,163 (14.8%)	6378 (15.3%)	16,740 (11.8%)	4545 (13.2%)
Symptoms of ARI	n.a.	n.a.	9828 (9.3%)	3064 (12.1%)
Age (mean) in years	n.a.	n.a.	1.9	1.9
Female	n.a.	n.a.	69,785 (49.4%)	16,934 (49.2%)

Denominators for the calculation of the percentages included only cases with non-missing information
ARI = acute respiratory infection; n.a. = not applicable.

Table 2
Percentage of households (N = 41,648) classified as wealthy (upper two wealth quintiles) and poor (lower two wealth quintiles) by distance to the closest mine and mining phase. The data stem from 131 Demographic and Health Surveys (DHS) collected within 50 km from isolated mines, respectively. The surveys were conducted between 1990 and 2019.

Mining phase	% wealthy households		% poorer households	
	Close (≤ 10 km)	Comparison (10–50 km)	Close (≤ 10 km)	Comparison (10–50 km)
Pre-operational	26.2	33.5	54.5	44.4
Active	59.1	29.8	32.2	49.4
Closed	71.9	39.0	10.8	39.5

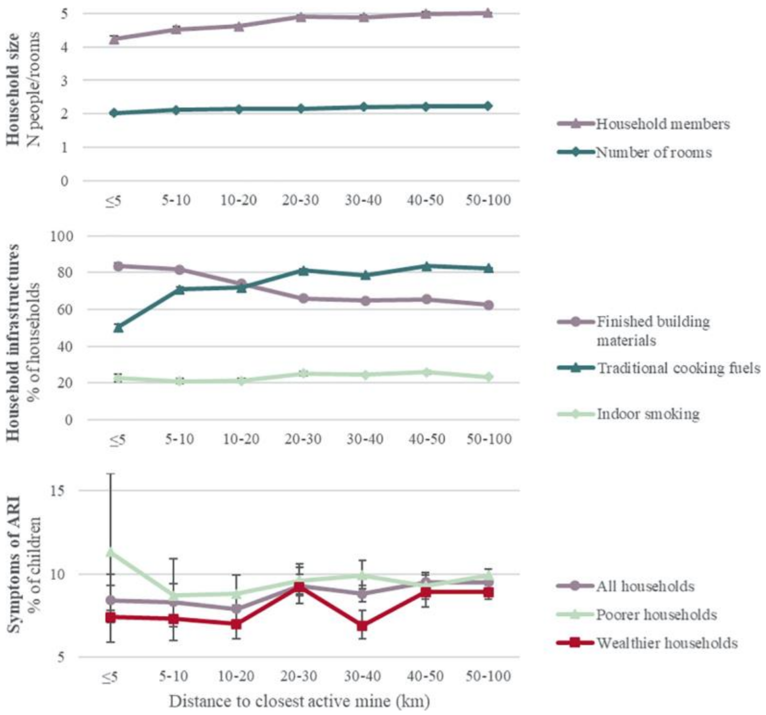

Fig. 2. Household indicators and prevalence of acute respiratory infection (ARI) symptoms in children below the age of 5 years at different distances from mines. For ARI symptoms, the dataset was stratified into children from poorer (lower two wealth quintiles) and wealthier (upper two wealth quintiles) households.

traditional cooking fuels. More specifically, 50.2% of households closest to the mines (i.e., ≤ 5 km) used traditional cooking fuels, compared to 82.3% of households located furthest away (i.e., 50–100 km; Fig. 2). The results from the regression models showed a similar pattern. There were marked differences between wealthier and poorer households. The reduction in the use of traditional cooking fuels in close proximity to the mines was largely attributable to the wealthier households. Among them, the OR for the use of traditional cooking fuel adjusted for survey year, population density, country, and regional-level differences was 0.42 (95% CI: 0.35–0.50) and 0.83 (95% CI: 0.72–0.97) within a ≤ 5 km and 5–10 km radius, respectively. Among the poorer households, these associations were not seen at ≤ 5 km distance (OR at ≤ 5 km: 1.10, 95% CI: 0.70–1.73) and use of traditional cooking fuels was even higher in poor households at 5–10 km (OR: 1.71, 95% CI: 1.27–2.29; Fig. *A*1). No clear trends in smoking rates were seen.

No marked differences in symptoms of ARI at different distances from the mine were evident (Fig. 2). Still, a statistically significant reduction in ARI prevalence at medium distances (i.e., between 10 and 20 km and between 30 and 40 km) compared to children below the age of 5 years living at a distance of 50–100 km from the closest mine was found (Fig. *A*1). Among children living in poorer households, there was a sharp increase in ARI symptoms in close proximity to the mines (≤ 5 km). However, this pattern was not statistically significant.

3.2. *Changes in healthy housing indicators and ARI after mine opening*

The size of the households is largely the same among the different distances (Fig. 3). Larger differences were seen in the percentage of households being built from finished materials. While in the years before mine opening these shares were similar, the percentage of households built from finished materials continued to rise after mine opening in areas in close proximity (i.e., ≤ 10 km) to the mine, while it remained relatively stable in areas further away (i.e., 10–50 km). Indoor smoking prevalence decreased in comparison areas from 25.0% prior to mine opening to 22.8% during the operational phase. Contrarily, in impacted areas, indoor smoking became more frequent, rising from 21.0% to 26.9%. For the percentage of children showing ARI symptoms in the 2 weeks prior to the survey, no clear temporal trend was observed. Before mine opening, households relied almost entirely on traditional fuels for cooking. Fitting of the models looking at temporal trends in use of cooking fuels was not possible. Therefore, this outcome was excluded from the longitudinal analyses.

The results from the regression analyses incorporating an interaction term capturing the impact of having a mine in close proximity during the different operational phases are depicted in Fig. 4 and listed in Table 3. Overall, no statistically significant impacts of the opening of a mine on household sizes were seen, though wealthier households in close proximity to the mine during the operational phase showed a slight reduction in the number of people per household (incidence rate ratio (IRR): 0.84,

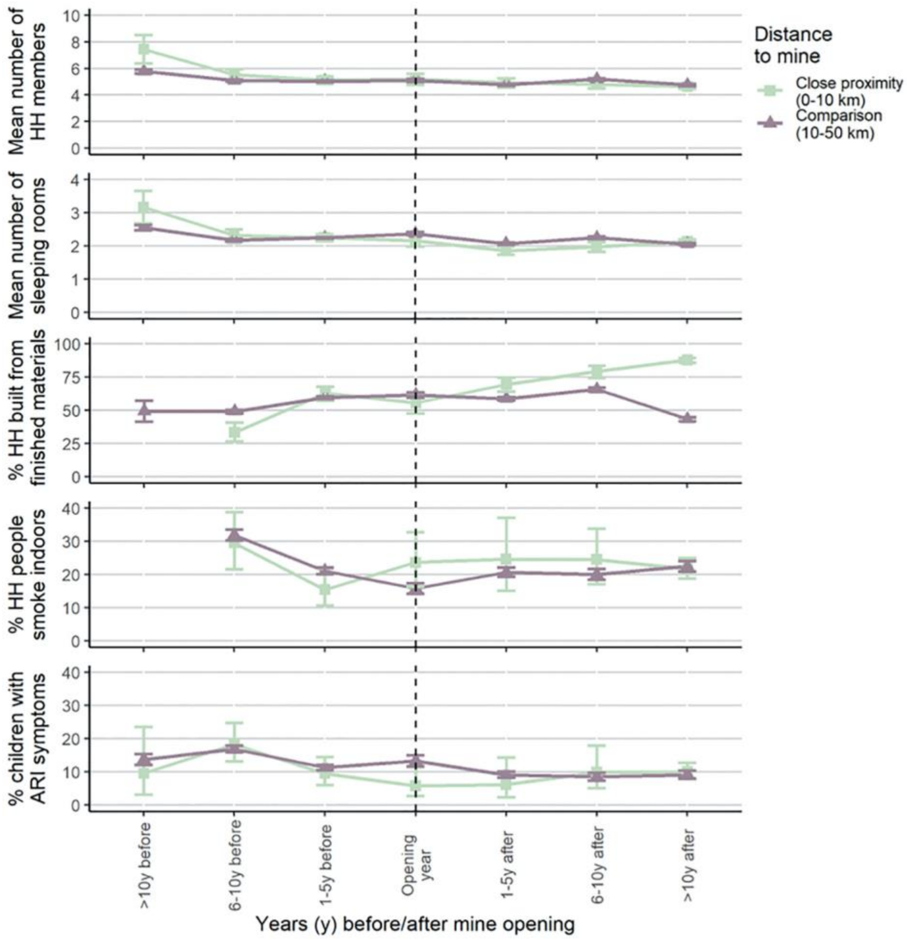

Fig. 3. Changes in household (HH) indicators and prevalence of acute respiratory infection (ARI) symptoms among children below the age of 5 years relative to the opening year of the closest mine at different distances from the mine (≤ 10 km vs. 10–50 km). The x-axis shows the difference between the survey year and the opening year of the mine. For housing materials, no data were available from mines more than 10 years before mine opening.

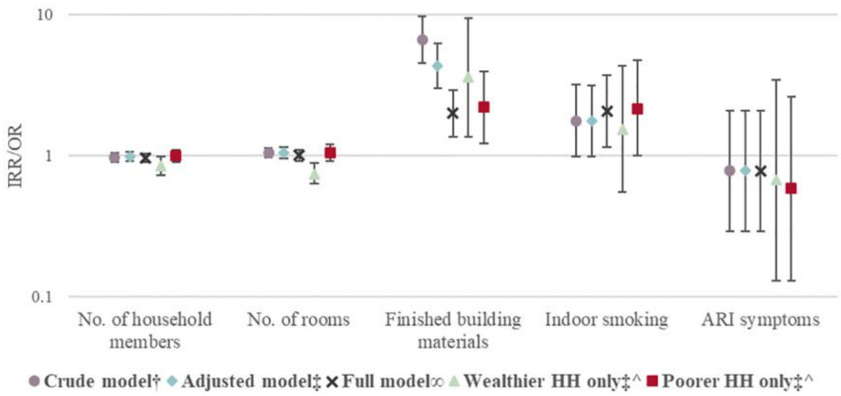

Fig. 4. Incidence rate ratios (IRR; for count data) and odds ratios (OR; for binary outcomes) for the effect of the interaction between the factor close proximity to a mine (i.e., ≤ 10 km compared to 10–50 km) and the mine being active (compared to pre-operation) on the different household indicators and symptoms of acute respiratory infections (ARI) in children under the age of 5 years using the longitudinal datasets. The estimates are plotted on a log-scale.

† Survey-level and mine-level random intercepts only.

‡ Additionally adjusted for survey year and population density (for household indicators); additionally adjusted for survey year, child age and sex (for ARI symptoms).

∞ Additionally adjusted for household (HH) wealth quintile (for household indicators); additionally adjusted for household wealth quintile, population density and household size (for ARI symptoms).

^ Stratified analyses using only data from the two lower wealth quintiles (poorer households) and the two upper wealth quintiles (wealthier households), respectively.

95% CI: 0.72–0.98) and rooms (IRR: 0.74, 95% CI: 0.63–0.88). Furthermore, building materials of houses in close proximity to mining sites improved upon mine opening (OR (full model): 1.98, 95% CI: 1.35–2.90; Fig. 4). This effect persisted after mine closure (Table 3).

Adjusting for all covariates, the share of households with indoor smokers doubled (OR: 2.06, 95% CI: 1.15–3.68) after mine opening close to the mines compared with comparison areas. Although only marginally significant, this effect was predominantly seen in poorer households.

During the operational phase, changes in the prevalence of symptoms of ARI did not differ between children living in close proximity and in comparison sites. After mine closure, however, children from wealthier households located in close proximity to mines showed increased odds of ARI symptoms, compared to the pre-operation phase.

Table 3
Exponentiated regression coefficients of the interaction between the factor close proximity to a mine (i.e., ≤ 10 km compared to 10–50 km) and activity status (top: active vs. pre-operational; bottom: closed vs. pre-operational).

Operational status	Outcome	OR/IRR (95%CI) for interaction near*operational status				
		Crude model†	Adjusted model‡	Full model∞	Wealthier HH only‡, ^	Poorer HH only‡, ^
Active	Number of HH members	0.97 (0.90–1.05)	0.98 (0.91–1.06)	0.96 (0.89–1.03)	0.84 (0.72–0.98)*	0.99 (0.89–1.10)
	Number of sleeping rooms	1.04 (0.96–1.13)	1.04 (0.95–1.14)	1.00 (0.91–1.10)	0.74 (0.63–0.88)**	1.04 (0.91–1.19)
	Finished building materials	6.61 (4.53–9.64)**	4.32 (2.98–6.24)**	1.98 (1.35–2.90)*	3.57 (1.36–9.40)*	2.19 (1.22–3.92)*
	Indoor smoking	1.76 (0.98–3.16)	1.75 (0.98–3.13)	2.06 (1.15–3.68)*	1.53 (0.55–4.29)	2.15 (0.99–4.69)
	ARI symptoms	0.78 (0.29–2.08)	0.78 (0.29–2.07)	0.78 (0.29–2.06)	0.67 (0.13–3.45)	0.58 (0.13–2.61)
Closed	Number of HH members	0.92 (0.87–0.98)*	0.94 (0.89–1.00)	0.92 (0.87–0.98)*	0.84 (0.76–0.93)*	0.87 (0.78–0.97)*
	Number of sleeping rooms	0.96 (0.90–1.03)	0.97 (0.90–1.04)	0.94 (0.87–1.01)	0.85 (0.76–0.96)*	0.96 (0.84–1.10)
	Finished building materials	7.98 (6.16–10.33)**	3.73 (2.85–4.87)**	2.19 (1.66–2.90)**	2.81 (1.67–4.72)**	2.08 (1.31–3.32)*
	Indoor smoking	0.95 (0.64–1.40)	1.05 (0.71–1.55)	1.27 (0.85–1.88)	1.04 (0.54–2.01)	1.55 (0.77–3.11)
	ARI symptoms	1.30 (0.85–1.99)	1.31 (0.86–2.00)	1.42 (0.93–2.18)	2.06 (1.04–4.06)*	0.67 (0.13–3.45)

OR = odds ratio (for the binary outcomes building materials, smoking, and ARI symptoms); IRR = incidence rate ratio (for number of household (HH) members and sleeping rooms).
† Survey-level and mine-level random intercepts only.
‡ Additionally adjusted for survey year and population density (for household indicators); additionally adjusted for survey year, child age, and sex (for ARI symptoms).
∞ Additionally adjusted for household (HH) wealth quintile (for household indicators); additionally adjusted for household wealth quintile, population density, and household size (for ARI symptoms).
^ Stratified analyses using only data from the two lower wealth quintiles (poorer households) and the two upper wealth quintiles (wealthier households), respectively.
* $p < 0.05$
** $p < 0.001$

4. Discussion

Data from almost 1.3 million households were combined with information on 711 mines to create the largest available multi-national dataset on household and child characteristics in mining areas in SSA. We found that housing conditions, including the quality of construction materials and access to clean cooking fuels, improved over the course of mining activities, while household density did not change. The positive effects were less pronounced in poorer households. Furthermore, the potential reduction in indoor air pollution from traditional cooking fuels was offset by a higher rate of tobacco smoking within the households close to mining sites. Indoor tobacco smoking rates increased more than 2-times more after mine opening in households in close proximity to operational mining sites compared to households located further away. In our sample, these potential positive and negative impacts in indoor air pollution exposure in mining sites were not reflected by changes in symptoms of ARI in children under 5 years of age. Taken together, the positive impacts of mines on housing conditions are promising. However, the unequal distribution of these benefits within the mining communities and the absence of improvements in respiratory health warrant further scientific inquiry.

4.1. Improvements in housing conditions in mining areas

The marked improvements in housing conditions, both in terms of building materials and access to clean cooking fuels, underline the potential of mining projects to promote social and economic development in the surrounding of mining sites (United Nations Economic Commission for Africa, 2011; von der Goltz and Barnwal, 2019). Indeed, in our analyses, adjustment for household wealth explained a large part of the improvements in housing conditions. In addition, the longitudinal analyses revealed that the share of wealthier households in communities near mines is substantially larger when mines are operational. Our findings are in line with other studies that have shown positive effects of mining projects on household wealth and livelihoods (Bury, 2005; von der Goltz and Barnwal, 2019). For example, people living in close proximity to mining sites in Peru have been found to have increased economic resources, as well as improved access to financial services potentially fostering investments in housing infrastructures (Bury, 2005). Furthermore, a recent study in SSA showed that water and sanitation infrastructures improve after the development of a mining project in close proximity of the community (Dietler et al., 2020b).

4.2. Potential formation of informal settlements around mining sites

Overall, we found no evidence of overcrowding in household in mining areas. This finding is surprising, since many studies and international guidelines describe the potential for rapid migration and overcrowding effects upon mine development (IFC, 2009; Jackson, 2018; Nyame et al., 2009; Pelders and Nelson, 2018). Yet, other studies have found no differences in settlement growth between mining and non-mining areas (Dietler et al., 2020a). It is therefore possible that the overcrowding effect only affects very specific mining communities (e.g., village or town where recruitment is done by the mining project), which are not detected when using aggregated data. Parallel development in settlement structures, with formal and informal settlements being built up simultaneously, has been reported both in mining areas and around urbanizing centers in other parts of Africa (Bah et al., 2018; Gough et al., 2019). In our sample, the poor households within a 10 km radius with comparably little or no improvements in housing quality and reduced access to clean cooking fuels may be an indication of the development of informal settlements close to the mining sites. No or inadequate infrastructures in these settings can contribute to a high disease burden of informal settlement dwellers (Shortt and Hammett, 2013; Snyder et al., 2013). Our findings underline the importance of an equity focus in the management of mining-related impacts on communities (Leuenberger et al., 2019).

4.3. Changes in indoor air pollution sources in mining areas

Indoor air pollution in mining sites may change in both directions – they might improve due to the reduced use of traditional cooking fuels or worsen because of increased tobacco smoking. Studies on these sources in mining settings are rare, though some studies have described high smoking rates in mining communities (Hendryx, 2009; Rajaee et al., 2015). In Zambian mining areas, increased smoking prevalence was seen among people with lower educational attainment, which could explain the increased smoking rates, particularly among the poor (Zyaambo et al., 2013). Furthermore, increases in disposable income could be a potential reason for the increased uptake of tobacco smoking in mining settings (Ukuhor and Abdulwahab, 2018; Zyaambo et al., 2013).

Research on access to clean cooking fuels as a source of indoor air pollution is scarce. Contrary to our findings, access to electricity – a clean energy source potentially used for cooking – was found to be lower in close proximity to mining sites in Tanzania but not in Mali (Polat et al., 2014). The paucity of research warrants further investigation on the driving forces of these positive and negative changes in indoor air pollution sources in mining areas. Geospatial analyses, combining outdoor air pollution measurements with information on indoor air pollution sources, could help to better understand the changes of the diverse respiratory health risks in mining projects.

4.4. Impacts of mining projects on respiratory health

Respiratory health in mining areas can be impacted by a variety of factors, including indoor and outdoor air pollution and housing conditions (Gordon et al., 2014; Hendryx, 2015; Hendryx and Luo, 2014). The overall absence of positive or negative impacts on ARI symptoms may potentially be the result of the counteracting effects of reduced pollution from traditional cooking fuel and better construction materials on the one hand, and the increased pollution levels from indoor smoking and outdoor pollution from mining operations on the other hand (Asif et al., 2018; Gordon et al., 2014; Herrera et al., 2016; Öberg et al., 2011; Pless-Mulloli et al., 2000). Indeed, when focusing on poorer households, where the positive impacts on ARI risk factors were less pronounced or absent, a slight, statistically not significant increase in ARI symptoms at close proximity to the mines was observed. A study on respiratory diseases in a mining site found that respiratory health impacts are limited to an area up to 1.8 km distance from the mine (Herrera et al., 2016). The artificially introduced spatial errors in DHS data may have reduced statistical power and concealed potential impacts at a smaller scale (Elkies et al., 2015). Furthermore, the increased reporting rates of child health outcomes among better educated caregivers might explain the increased odds of ARI in wealthier households after mine closure (Manesh et al., 2007). Nevertheless, our results show the significance of alternative air pollution pathways to be considered for the management of potential health impacts of mines.

4.5. Addressing respiratory health risks in mining areas

Impact assessments commonly serve as foundations for predicting and managing such different direct and indirect impacts of mines on air pollution and respiratory health (Harris-Roxas et al., 2012; Winkler et al., 2020a). In this process, impacts of mining projects on outdoor air pollution are commonly assessed for the identification of mitigation strategies to reduce air pollution emissions and the subsequent monitoring of air quality impacts (Baumgart et al., 2018; Dietler et al., 2020c; Pham et al., 2018; Riley et al., 2018, 2020). However, other aspects such as smoking or housing infrastructures receive less attention in current impact assessment practice (Dietler et al., 2020c). Hence, the unequal distribution of benefits on housing infrastructures, the increases in smoking rates, and the absence of improvements in respiratory health in mining areas warrant a comprehensive assessment of potential impacts on the diverse determinants of respiratory health, with a particular focus on the most vulnerable population groups (Leuenberger et al., 2019; Quigley et al., 2006; Winkler et al., 2020b).

4.6. Strengths and limitations

While our study provides new insights into diverse impacts of mines on housing-related determinants of respiratory health using a large multi-national dataset, we acknowledge several limitations. Firstly, the data stem from cross-sectional surveys, which did not follow the same people over time. Using the DiD approach, we could adjust for some factors that changed over time, such as population density. However, the population composition is likely to have changed over the course of a mining project and populations may differ in the time they have resided in a mining area. Hence, it is conceivable that the changing population had different unmeasured characteristics that influenced our outcome variables. These changes may also include the composition of the different socioeconomic strata. Although the wealth index was created using the whole sample of households for the given survey, “being poor” could have a different meaning in operational mining areas. The poor in mining areas could, for example, include marginalized population groups living in informal settlements, comprising of migrants. Furthermore, respondents with higher educational attainment tend to more often report child health outcomes in DHS surveys (Manesh et al., 2007). Hence, the potentially higher reporting rates among wealthy households may be an explanation of the increases in ARI after mine closure. Lastly, the spatial offsets introduced in the global positioning system coordinates in DHS may have led to non-differential exposure misclassification. This random error is likely to have diverted the estimates towards the null (Elkies et al., 2015).

5. Conclusion

The findings from our continental analysis of a comprehensive multinational dataset on household and child health indicators in mining areas revealed an overall positive impact of mines on housing conditions, although poorer households generally benefitted less from these developments. We found no evidence of overcrowding upon mine opening, as previously described in the literature. While the risk of indoor air pollution from traditional cooking fuels is reduced in active mining sites, smoking rates increased after mine opening. Hence, considerable environmental health risks persist in some population groups in mining communities, although the resulting burden of respiratory disease among children under the age of 5 years remained unchanged. New research on how the changes in housing quality, including indoor air pollution sources, are impacting respiratory health in mining communities is needed. Finally, these diverse underlying pathways of respiratory health outcomes need to be comprehensively assessed in impact assessments of mining projects to attain an equal distribution of mining-related benefits and promote public health in mining communities.

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Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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6 Article 3: Impact of mining projects on water and sanitation infrastructures and associated health outcomes in children: a multi-country analysis of Demographic and Health Surveys in sub-Saharan Africa

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Impact of mining projects on water and sanitation infrastructures and associated child health outcomes: a multi-country analysis of Demographic and Health Surveys (DHS) in sub-Saharan Africa

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Abstract

Background: Access to improved water and sanitation infrastructures are key determinants of health. The sub-Saharan African region in particular is lagging behind the ambitious goal of the 2030 Agenda for Sustainable Development to ensure universal access to improved and reliable water and sanitation for all (Sustainable Development Goal (SDG) 6). Large mining projects can promote economic growth and hence investments in water and sanitation infrastructures, but at the same time lead to rapid population growth and environmental degradation. In turn, these changes can pose risks and opportunities for child health (SDG 3). In this study we aim to quantify the impacts of mining projects on access to water and sanitation infrastructure as well as diarrhea and malnutrition among children using data from 131 Demographic and Health Surveys from sub-Saharan Africa.

Results: From a sample of around 1.2 million households, data within the proximity of 52 mine-panels were selected for longitudinal analyses, resulting in 41,896 households and 32,112 children. Improvements in access to modern water and sanitation infrastructures after mine opening were much larger in households near mining sites than in comparison areas located further away (adjusted relative risk ratio (aRRR) water: 18.60, 95 % confidence interval (CI): 13.08–26.46 and aRRR sanitation: 2.56, 95 % CI: 1.32–4.99). However, these associations were weaker among poorer households. In areas close to the mining sites, stunting and underweight prevalence decreased more strongly upon mine opening (adjusted odds ratio (aOR) stunting: 0.62, 95 % CI: 0.43–0.90; aOR underweight: 0.55, 95 % CI: 0.36–0.84). No differential changes were seen for wasting and diarrhea. Large impact heterogeneity was observed both within and across countries.

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Conclusions: Our results suggest that the opening of mines is associated with improvements in access to modern water and sanitation infrastructures (SDG 6) as well as in some health outcomes (SDG 3). However, the large impact heterogeneity suggests that the assessment and management of mining-related impacts on communities should have an increased equity-focus, in order to "leave no one behind" in the work towards the 2030 Agenda for Sustainable Development. Overall, the findings of this study underscore that the resource extraction sector has the potential to make positive and substantial contributions towards achieving the SDGs.

Keywords: Child health, Diarrhea, Drinking water, Malnutrition, Natural resource extraction, Sanitation

Introduction

Despite major improvements in the provision of clean drinking water and improved sanitation infrastructures in the last decades, substantial gaps in access persist [1]. In 2017, 2.2 billion people lacked access to safely managed drinking water and 4.2 billion people lacked access to safely managed sanitation facilities [1]. The 2030 Agenda for Sustainable Development ambitiously demands "universal access to improved and reliable water and sanitation for all" (Sustainable Development Goal (SDG) 6) by 2030 [2]. Such improvements do however require substantial resources, which remain particularly scarce in world regions that are currently far from achieving SDG 6 [3].

Some of the poorest countries, particularly in sub-Saharan Africa (SSA), are extremely rich in mineral and metal resources, such as diamonds, gold, iron and copper [4]. The development of large mining projects creates unique opportunities for economic development, which in turn can promote better public and private infrastructures [5–9]. Investments at the community and household-level could for example include the expansion of drinking water distribution networks, protection of wells, septic systems or improved toilet facilities [5]. On the other hand, depending on the type of resources extracted, the mining technology applied and environmental management in place, extracting and processing minerals is highly water-intense and can lead to environmental pollution [10–14]. At the same time, mining projects can result in rapid population growth [15, 16]. Hence, mining projects can put additional strains on often already overburdened water and sanitation systems in affected communities [11, 12, 17, 18].

Evidence on the impacts of mining projects on water and sanitation infrastructures is inconclusive. A case study conducted in a mining area in Peru showed positive impacts on water and sanitation infrastructures, while other studies found negative impacts in Mali and Tanzania [19, 20]. In a study focusing on Ghana, Mali and Tanzania, no significant impact of mining activities on access to improved water and sanitation infrastructures was found [21].

Changes in water and sanitation infrastructures can potentially improve health and well-being, even with additional environmental pollution (SDG 3) [22, 23]. Children are particularly vulnerable to the health consequences of the lack of access to these infrastructures [24]. In low- and middle-income countries, a third of the childhood diarrhea burden is attributable to inadequate drinking water and one in five diarrhea cases are attributed to the lack of sanitation [23]. Repeated diarrheal episodes negatively impact the nutritional status of children, which increases their vulnerability to diarrheal infections. Improvements in water and sanitation infrastructure can help to break this "vicious cycle" by lowering the risk of diarrheal diseases and improving nutritional status in children[22, 25, 26].

The effect of mines on childhood diarrhea and malnutrition is not well understood. In a large sample of children around mines and ore smelters in multiple developing countries, von der Goltz et al. found that children in mining areas are taller for their age than children in comparable areas without mining projects [8]. Evidence from single-country analyses point at positive impacts of mining projects on child nutrition in Mali but negative effects in Tanzania [20], while in a case study in Zambia no effect was found [27]. Similarly, the findings on the impact on diarrheal diseases are inconclusive [20, 21, 28]. In Zambia, the burden of diarrhea-causing parasitic infections decreased in mining areas [28]. Other studies found diarrheal incidence to be lower in mining areas in Mali but unchanged in Tanzania or Ghana [20, 21].

In this study [29], we use the largest currently available dataset to systematically assess the impacts of large mining projects on access to water and sanitation infrastructure and associated health outcomes in sub-Saharan Africa. More specifically, we use a quasi-experimental difference-in-differences design to test whether mining projects affect access to water and sanitation infrastructures as well as whether these changes have an impact on water and sanitation-related child health outcomes.

Methods

Data

Demographic and Health Survey (DHS) data

The Demographic and Health Surveys (DHS) program has been conducting nationally-representative cross-sectional household surveys in low- and middle-income countries since the 1980 s [30]. Households are selected through a two-stage cluster sampling methodology. At the first stage, clusters (typically villages in rural areas or blocks in urban areas) are sampled using a probability proportional to population size strategy. At the second stage, all households are listed in the selected area and then 25–30 households are randomly selected for the interviews. This strategy allows to obtain a representative sample of households at the regional-level as well as for urban and rural areas. For most surveys, Global Positioning System (GPS) data of the clusters are available. To ensure the privacy of respondents, these coordinates are shifted at random up to 2 km for urban clusters and up to 5 km for rural clusters (10 km for 1 % of rural clusters). In the present study, all household and child data from surveys in sub-Saharan Africa with GPS data available as of March 2020 were included.

Mining

Data on the type and location of mines were derived from the Standard & Poor's (S&P) Global Market Intelligence Mining Database [31]. The database contains the location and basic characteristics of all major mines in the world. Information on historic mining activities is provided in two ways. Firstly, the opening and closing years of the mines are reported. Secondly, annual extraction and production information since 1980 was available. The first operational year was set as the earlier of the reported opening year or the first year with reported production/extraction. Thus, the opening year marked the start of the operation phase of a mine, not including the construction phase. The last operation year was set as the last year with reported production/extraction unless a later closing year was explicitly reported. If both were not available and the mine was listed as "active" the last operation year was set as 2019. During the period between the first and last operation year the mines were considered operational. Furthermore, for longitudinal analysis, a variable was created indicating whether the mine was geographically isolated or located in proximity to other mines. Mines were considered as being isolated if they were at least 100 km away from other mines.

Data merging

To merge the mining with the DHS data, the locations of all DHS clusters and mines were mapped using ArcGIS Pro (Version 2.2.4, Environmental Systems Research Institute, Redlands, CA, USA). Information on the distance to the closest mine and their activity status between 1980 and 2019 were extracted at each cluster location.

Given that in urban areas, a broad variety of factors influence water and sanitation infrastructure access and child health, data from DHS clusters located in cities with more than 100,000 inhabitants were excluded. For this, the coordinates of the center points of cities in sub-Saharan Africa from Natural Earth [32] were integrated in the map. Around each city center, circles of different radii were drawn to represent their approximate boundaries. The size of the radii varied depending on the number of inhabitants (5 km for cities with 0.1–0.5 million inhabitants, 7.5 km for 0.5-1 million, 15 km for 1–5 millions and 40 km for more than 5 millions). These distances were determined by measuring the size of built-up area using satellite imagery over a random selection of cities in each category. DHS clusters within the city boundaries were excluded from analysis.

Two datasets were created for analysis at the household-level and child-level, respectively (see Fig. 1). For household-level analyses, the combined spatial information (mining activity, location within larger city) was merged with the household recode dataset. For child-level analyses, the child recode dataset was complemented with the spatial information in the DHS cluster dataset and the basic household characteristics in the household recode files.

Study design

In this study, we first used the cross-sectional datasets to explore the spatial relationships between the mines and water and sanitation infrastructures and associated child health outcomes. In a second step, we created a longitudinal dataset covering households living close to mines that opened during the study period. This dataset was used to estimate the impacts of the development of a mine on these outcomes (see Fig. 1). The household data were used for analyses of the impacts on water and sanitation infrastructures and the child data were used for health outcomes, respectively.

Cross-sectional analysis

We computed the distance to the closest active mine for each cluster/household. Clusters outside of a 100 km radius of a mine were excluded. This limit was set to obtain a similar comparison group for the clusters located closer to the mine. Clusters further away may be differently affected by external factors influencing access to water and sanitation infrastructures and child health than clusters closer to the highly impacted areas. Furthermore, survey data obtained before mining activities have started or after closure of the mines were excluded.

Longitudinal analysis

Many DHS clusters were located close to multiple mines that opened and closed at different time points. As for these clusters the determination of the start of mining activities in their proximity would be challenging, we focused in the longitudinal analysis on isolated mines. For the longitudinal analysis only data from clusters within a 50 km distance from isolated mines were included,

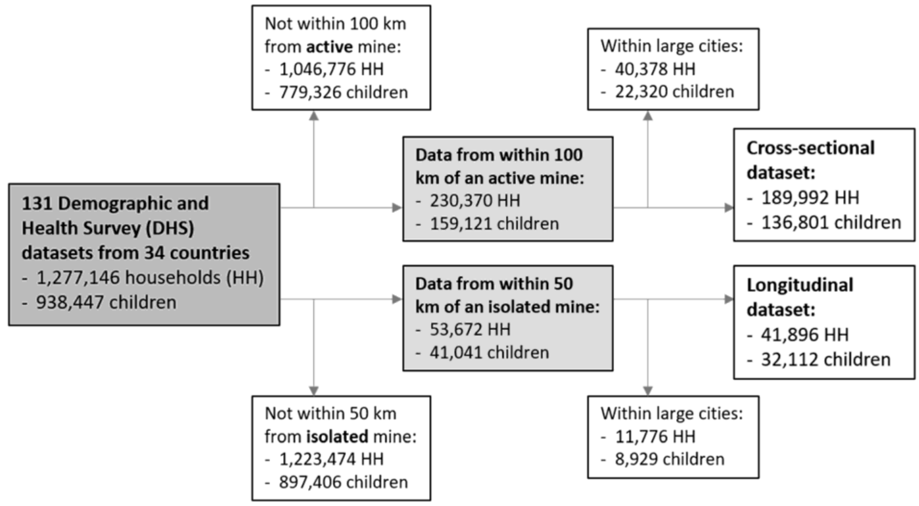

Fig. 1 Flow chart of data used for analyses. Only data of households and children located within the proximity of mines and outside the boundaries of large cities were included. Household and child data around active mines were used for the cross-sectional analyses, data from around isolated mines for the longitudinal analyses

regardless the operational status of the respective mine. This cut-off ensured that the clusters were only located in the proximity of a single mine. Using this data, a pseudo-panel dataset was created comprising of repeated cross-sectional data from the different survey rounds spanning the time frame before and after mine opening.

Variables

Exposure variable

For cross-sectional analyses, the distance between the DHS cluster and the closest active mine during the time of the survey was used. The variable was grouped into 7 categories: ≤5 km, 5–10 km, 10–20 km, 20–30 km, 30–40 km, 40–50 km and 50–100 km. Based on previous studies and field experience of the author team, the impacts of the mines were expected to be limited to the area within a limited travel distance (i.e. around 10 km) [7, 8, 33]. Therefore, this variable was dichotomized in the longitudinal analyses, using ≤ 10 km as impacted area and 10–50 km a comparison area. Furthermore, a variable was created indicating whether the household was surveyed before or after mine opening. The primary exposure variable was the interaction between living in close proximity to the mining project and the mine's activity status.

Outcome variables

Water and sanitation infrastructure All DHS surveys collected data on access to water infrastructures through the same question ("what is the main source of drinking water for members of your household?"). DHS sanitation questions on the other hand have changed slightly over time [34]. Prior to 2003, "what kind of toilet facilities does your household have?" was used. Since then, the question was reworded to "what kind of toilet facility do members of your household usually use?" Furthermore, some countries used additional codes for country-specific types of water and sanitation infrastructure. Nevertheless, the DHS data define broader categories that are applicable to all countries and survey rounds. Therefore, water and sanitation infrastructures were categorized into "basic", "intermediate" and "modern" [35]. For water sources, surface water and springs were classified as "basic", well water as "intermediate" and piped water as "modern". Similarly, no sanitation facility was coded as "basic", latrines as "intermediate" and flush toilets as "modern". Other types of water and sanitation infrastructure, such as bottled water, were excluded from analysis.

Health outcomes Based on literature on the impacts of water and sanitation infrastructures on child health, we focused on diarrhea and anthropometry as primary outcomes [25, 26]. All DHS ask caregivers to report diarrheal episodes in the two weeks preceding the survey for children under the age of five years. For a subset of children living in the interviewed households anthropometric data were collected. Children's height and weight were normalized using the 2006 World Health Organization growth reference standards. A child with a height-for-age z-score below − 2 was considered as stunted. Children with a weight-for-height z-score below − 2 were classified as wasted. Similarly, weight-for-age z-scores below − 2 were considered as underweight.

Covariates
Different covariates were integrated in the statistical models, depending on the type of analysis. At the household-level, household wealth was considered as a covariate. The wealth index provided by DHS integrates water and sanitation infrastructure among other household assets for deriving the wealth quintiles. To avoid collinearity with the outcome variables for this study, separate wealth indexes were created. Following the approach proposed in Filmer and Pritchett [36], a principal component analysis with a reduced set of variables (i.e. possession of a car, motorcycle, bicycle, television, radio, fridge, telephone and bank account, access to electricity, wall, flooring and roofing materials, type of cooking fuel, and educational attainment of the head of the household) was conducted. Given that household wealth is both a potential outcome of newly opened mines and a confounding factor, separate models were run with and without the wealth quintile as covariate. Furthermore, stratified analyses were conducted using only the two lower and the two upper wealth quintiles, respectively. Additionally, the number of household members was included as separate covariate at the household-level. At the child-level, age in years (as categorical variable) and gender (female/male) were included in the models. A list of potential covariates were selected a priori and included in the final models based on likelihood ratio tests.

Statistical analysis
Beyond descriptive statistics for the different outcomes at different distances from active mines, regression models were developed. These differed depending on the outcome and type of analysis. The methodology for the different analyses were developed over the course of the study, without a predefined analysis plan.

Cross-sectional descriptive analyses
The cross-sectional dataset was used to describe the average outcome variables at different distances from the mines. To assess the cross-sectional distance associations, multi-level multinomial logistic regression models were used for water and sanitation infrastructure outcomes and multi-level logistic regression models for binary health outcome indicators (see Equation A1 and A2 in Additional file 1). The proximity to active mines was the main exposure of interest. All models included a survey-level random intercept term, accounting for the spatial (between countries) and temporal (between survey rounds) variability. Separate models were run with and without adjustment for the household wealth quintiles. In models for child health outcomes, additional household-level covariates (i.e. household size, access to water and sanitation infrastructures) and child-level covariates (i.e. age and gender) were adjusted for. Additionally, the cross-sectional dataset was used to describe cross-country differences in the associations between mining and the different outcomes. Distances between the households and the mines of up to 10 km were considered as impacted, while households located between 20 and 100 km were used as comparison. The regression models adjusting for household-level and child-level (for child health outcomes only) covariates were used for this analysis.

Longitudinal analyses
Our main impact analysis explored a quasi-experimental difference-in-difference (DiD) design. The repeated random samples of households in the DHS allowed us to observe infrastructure and child outcomes in close proximity to mines and in neighboring areas over time. If the location and timing of mine openings are not systematically correlated with other factors affecting our outcomes of interest, identical trends in outcome variables before and after the mine opening would be expected in the absence of a causal change induced by the mine itself [37]. While we could not directly verify this assumption of common trends, we can test equality of trends prior to the mine opening empirically. By comparing trends in mining areas to nearby locations, we could account for factors specific to the study site or survey methodology (e.g. urbanization, seasonality). The equations in Additional file 1 show the estimated equations for the household for child-level analyses. Our main variable of interest was the interaction term between being located in close proximity (≤ 10 km) a mine and the mine being active. We included a mine-level random intercept term instead of the survey-level term to account for the pseudo-panel structure of the data using repeated measurements around the different mines.

Multi-level multinomial logistic regression models (for water and sanitation infrastructure) were estimated using the generalized structural equation modelling suite in StataSE version 16 (StataCorp LLP, College Station, TX, USA). R version 3.5.1 [38] was used for running the multi-level logistic regression models with binary outcomes (for child health outcomes). Statistics were reported with their associated 95 % confidence intervals (CI), where applicable.

Results
In total, data from 1,277,146 households in 34 countries were included in the study (Fig. 1). The countries included Angola, Burkina Faso, Benin, Burundi, Cameroon, Central African Republic, Chad, Comoros, Côte d'Ivoire, Democratic Republic of the Congo, Eswatini, Ethiopia, Gambia, Ghana, Guinea, Kenya, Liberia, Lesotho, Madagascar, Malawi, Mali, Mozambique, Namibia, Niger, Nigeria,

Rwanda, Senegal, Sierra Leone, South Africa, Tanzania, Togo, Uganda, Zambia, and Zimbabwe. Household and geographical information was available for 938,447 children. Overall, there were 2,016 mines in the mining dataset. For 711 mines, information on operational activities were reported between 1980 and 2019. After selection of clusters located within 100 km of active mines and exclusion of data from larger cities, 189,992 households and 136,801 children from 27 countries were included in the cross-sectional analyses. In Benin, Cameroon, Central African Republic, Chad, Comoros, Rwanda and Togo no active mine with DHS clusters was present. Of the 711 mines with activity status information, 52 were more than 100 km away from the next mine and were therefore included to create the pseudo-panels for longitudinal analyses. In the Côte d'Ivoire, Eswatini, Lesotho and Senegal the mines were not isolated and hence, data from these countries not included in the longitudinal datasets. The final dataset, consisting of repeated cross-sectional survey data around these isolated mines, comprised 41,896 households and 32,112 children from 23 countries. Basic descriptive statistics for household and child health indicators for the four datasets are presented in Table 1. Changes in the percentage of households categorized as wealthy or poor are shown in Additional file 2. In areas close to the mines, the percentage of poor households decreased substantially after mine opening, while it remained comparably constant in comparison areas.

Access to water and sanitation infrastructures

Associations between distance to mine and water and sanitation infrastructures

Figure 2 shows average access to water and sanitation infrastructure by distance to active mines. The share of households having access to modern drinking water sources was almost 40 % points higher close to the mines (i.e. up to 5 km) than outside a 20 km radius. In contrast, households located further away relied more often on water from wells (intermediate) or surface water sources (basic). These trends were seen up to a distance of 20 km.

Similarly, there was also a trend towards more modern sanitation infrastructures closer to the mines. For example, while 43.5 %, 95 % CI: 41.7 – 45.4 %, of households located up to 5 km from an active mine had access to a modern sanitation facility, only 10.8 %, 95 % CI: 10.6 – 11.0 %, of households at a distance between 50 and 100 km had access to such facilities. On the other hand, basic infrastructures were more widespread in the areas located further away from the mines.

These trends were also seen in the results from the regression models (see Additional files 3, 4 and 5). The associations between the proximity to mines and access to modern water and sanitation infrastructures were significant up to a distance of 20 km from the mines.

Impact of mine opening on access to water and sanitation infrastructures

Figure 3 shows the change in access to water and sanitation infrastructures relative to the opening year of the mine stratified by distance between the household and the mine. Shortly after mine opening, the share of households in the proximity (i.e. at a ≤ 10 km distance) using modern drinking water sources increased sharply, while for sanitation infrastructures, marked changes occur after 10 years or later. In households located further away (i.e. between 10 and 50 km from the mine), the improvements in access to modern water and sanitation facilities over time were less pronounced.

The regression analyses using the longitudinal dataset compared the impact of the proximity to mines on water and sanitation infrastructures before and after mine opening (see Fig. 4; Table 2). In line with the results from the cross-sectional analyses, the opening of mining projects had strong and positive impacts on access to modern water infrastructures of the households in their proximity. More specifically, the change in the access to modern water infrastructures (compared to basic infrastructures) upon mine opening was 18.6-times higher in households near mines than households located in comparison areas (adjusted relative risk ratio (aRRR): 18.60, 95 % CI: 13.08–26.46). These positive effects were more pronounced among the wealthier households compared to the poorer households. Particularly for the wealthier households, the use of basic water infrastructures was very low after mine opening, leading to high aRRR estimates. Furthermore, stronger associations were found when excluding data collected during a potential transition phase two years before and two years after mine opening (see Additional file 6).

Also for the sanitation categories, the establishment of a mining project had a positive impact as seen in the longitudinal analyses (Fig. 4; Table 2). Overall, the households closer to the mine had increased access to more modern sanitation facilities after the mines became active. Stratified analyses revealed that this effect was only seen among the wealthier households (RRR comparing modern vs. basic sanitation infrastructures: 13.20, 95 % CI: 3.43–50.89) but not among the poorer households (RRR comparing modern vs. basic sanitation infrastructures: 0.71, 95 % CI: 0.17–2.94).

Child nutrition and diarrhea

Associations between distance to mine and child health outcomes

Figure 5 shows the differences in child health indicators at different distances from the mine Stunting was less common within a 5 km radius from the mines (26.1 %,

Table 1 Descriptive statistics for different household and child indicators

	Household data		Child data	
	Cross-sectional dataset (*N*=189 992)	**Longitudinal dataset (*N*=41 896)**	**Cross-sectional dataset (*N*=136 801)**	**Longitudinal dataset (*N*=32 112)**
Distance to mine				
≤5 km	2 893 (1.5%)	n.a.	1 722 (1.3%)	n.a.
5-10 km	5 654 (3.0%)	n.a.	3 505 (2.6%)	n.a.
10-20 km	13 527 (7.1%)	n.a.	8 902 (6.5%)	n.a.
20-30 km	15 927 (8.4%)	n.a.	11 539 (8.4%)	n.a.
30-40 km	20 581 (10.8%)	n.a.	14 177 (10.4%)	n.a.
40-50 km	21 341 (11.2%)	n.a.	15 223 (11.1%)	n.a.
50-100 km	110 069 (57.9%)	n.a.	81 733 (59.7%)	n.a.
Mine close (≤10 km)	n.a.	2 857 (6.8%)	n.a.	1 894 (5.9%)
Mine active	n.a.	17 805 (45.7%)	n.a.	12 738 (42.5%)
Water infrastructures				
Basic (surface water)	35 802 (19.1%)	11 052 (26.7%)	28 484 (21.1%)	8 794 (27.6%)
Intermediate (well)	85 141 (45.4%)	19 130 (46.2%)	68 828 (50.9%)	15 549 (48.8%)
Modern (piped/tap)	61 967 (33.1%)	10 812 (26.1%)	35 940 (26.6%)	7 390 (23.2%)
Sanitation infrastructures				
Basic (no facility)	50 061 (26.8%)	12 859 (31.3%)	40 037 (29.8%)	10 883 (34.4%)
Intermediate (latrine)	112 190 (60.2%)	25 461 (61.9%)	82 219 (61.2%)	19 363 (61.2%)
Modern (flush toilet)	24 233 (13.0%)	2 807 (6.8%)	12 152 (9.0%)	1 402 (4.4%)
Household size (median)	4	5	6	6
Wealth quintile				
Poorest	38 064 (20.0%)	8 714 (20.8%)	27 586 (20.6%)	6 714 (20.9%)
Poor	41 949 (22.1%)	8 381 (20.0%)	30 730 (22.9%)	6 604 (20.6%)
Middle	42 330 (22.3%)	9 067 (21.7%)	31 607 (23.6%)	7 144 (22.3%)
Rich	38 700 (20.4%)	9 037 (21.6%)	27 296 (20.4%)	7 189 (22.4%)
Richest	28 949 (15.2%)	6 609 (15.8%)	16 792 (12.5%)	4 433 (13.8%)
Stunted	n.a.	n.a.	22 402 (34.0%)	5 878 (40.8%)
Wasted	n.a.	n.a.	4 697 (7.2%)	1 224 (8.6%)
Underweight			10 918 (16.3%)	3 211 (22.0%)
Diarrheal episode[a]	n.a.	n.a.	16 121 (15.2%)	4 585 (18.4%)
Age (mean/years)	n.a.	n.a.	1.9	1.9
Female	n.a.	n.a.	67 876 (49.6%)	15 866 (49.4%)

Data from 131 Demographic and Health Surveys from 34 sub-Saharan Africa collected between 1990 and 2019 within 100 km from active mines (cross-sectional datasets) or within 50 km from isolated mines (longitudinal dataset) were included. Only households or children with non-missing data were used as denominators for the percentages
n.a. not applicable
[a]Presence of a diarrheal episode during the two weeks prior to the survey

95 % CI: 23.4–29.1 %) compared to children living further away (e.g. 50–100 km: 34.3 %, 95 % CI: 33.8–34.7 %). A slight increasing trend in the 2-week prevalence of diarrhea among children under five years was seen closer to the mines. Wasting prevalence ranged from 6.4 to 8.0 %. Highest percentages were observed closest to the mines. For underweight, the lowest percentages of around 12.5 % were seen within a 10 km radius from the mines. Further away, underweight rates increased up to 17 % at a distance of 50–100 km.

In the regression models, the associations between mining projects and child health outcomes were less clearly seen (see Additional files 7 and 8). In the models adjusted for child-level covariates, an increase in child wasting was seen in proximity to the mines, while for

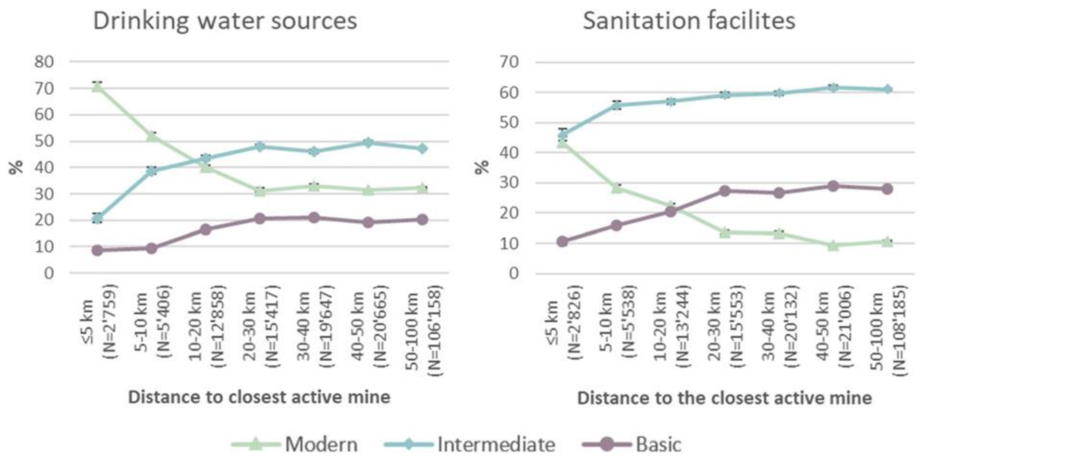

Fig. 2 Percentage of drinking water sources and sanitation facilities by distance to the closest active mine. Error bars show 95 % confidence intervals

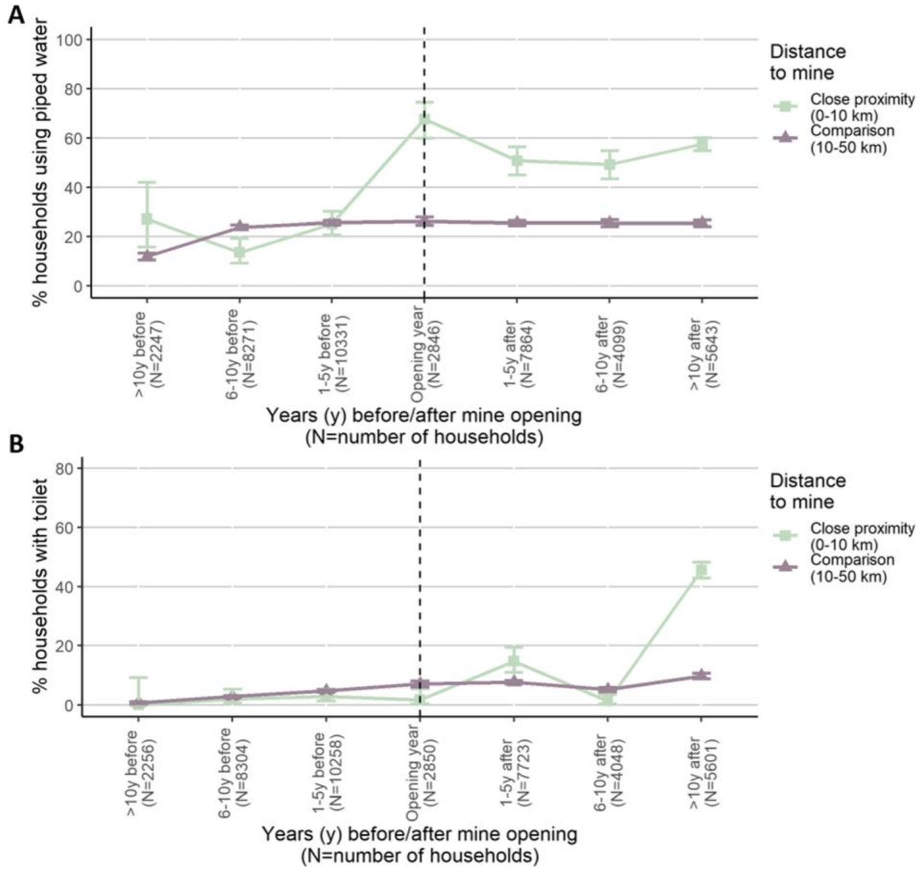

Fig. 3 Percentage of households having access to piped water (panel **A**) and flush toilets (panel **B**). The x-axis shows the time period of the survey relative to the opening year of the mine. Separate graphs are shown for each distance category (≤ 10 km vs. 10–50 km from the mine). Error bars show 95 % confidence intervals

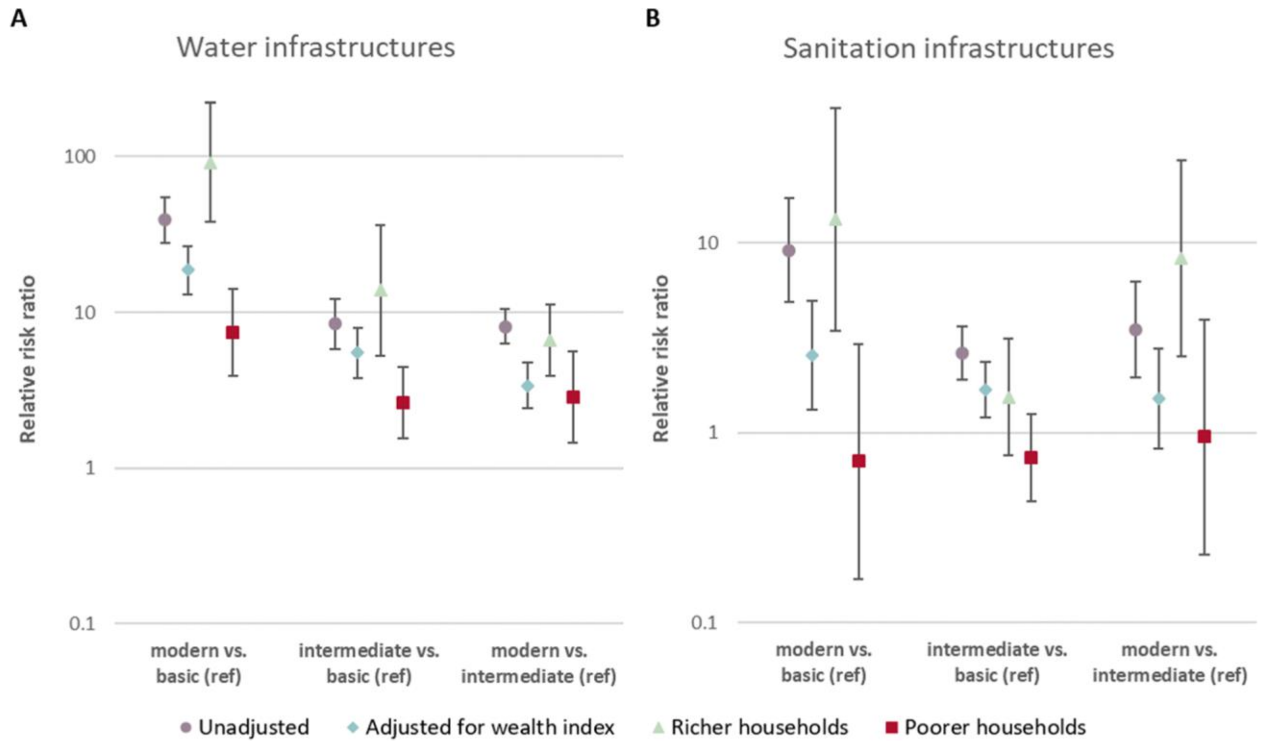

Fig. 4 Estimates of the relative risk ratios (RRR) for the interaction of mining activity (before vs. after mine opening) and proximity to the mine (≤ 10 km vs. 10–50 km) on access to water (panel **A**) and sanitation (panel **B**) infrastructures using the longitudinal household dataset. The RRR and their corresponding 95 % confidence intervals were derived using the generalized structural equation modelling suite in Stata and plotted on the log-scale

Table 2 Relative risk ratios (RRR) for the effect of the interaction between mining activity (before vs. after mine opening) and proximity to the mine (≤10 km vs. 10-50 km) on access to water and sanitation infrastructures using the longitudinal household dataset

	RRR (95%CI) for interaction close proximity*active			
	Crude[a] (N_{water}=38,088) ($N_{sanitation}$=38,190)	**Adjusted[b] (N_{water}=38,088) ($N_{sanitation}$=38,190)**	**Rich[a,c] (N_{water}=14,099) ($N_{sanitation}$=14,264)**	**Poor[a,c] (N_{water}=15,605) ($N_{sanitation}$=15,563)**
Water: modern vs. basic (ref)	39.25 (28.02 - 54.97)**	18.60 (13.08 - 26.46)**	91.73 (38.09 - 220.87)**	7.46 (3.92 - 14.16)**
Water: intermediate vs. basic (ref)	8.43 (5.84 - 12.17)**	5.48 (3.79 - 7.92)**	13.83 (5.28 - 36.23)**	2.63 (1.55 - 4.47)**
Water: modern vs. intermediate (ref)	8.12 (6.29 - 10.47)**	3.39 (2.41 - 4.79)**	6.61 (3.88 - 11.24)**	2.84 (1.44 - 5.58)*
Sanitation: modern vs. basic (ref)	9.15 (4.91 - 17.04)**	2.56 (1.32 - 4.99)**	13.20 (3.43 - 50.89)**	0.71 (0.17 - 2.94)
Sanitation: interme-diate vs. basic (ref)	2.63 (1.91 - 3.62)**	1.69 (1.21 - 2.37)*	1.54 (0.76 - 3.14)	0.74 (0.44 - 1.26)
Sanitation: modern vs. intermediate (ref)	3.47 (1.95 - 6.20)**	1.52 (0.83 - 2.78)	8.28 (2.54 - 26.97)**	0.96 (0.23 - 3.92)

The estimates and their corresponding 95% confidence intervals (95% CI) were derived using the generalized structural equation modelling suite in Stata
[a]mine-level random intercept only
[b]adjusted for household wealth quintile
[c]stratified analyses using only data from the two lower wealth quintiles (poorer households) and the two upper wealth quintiles (wealthier households), respectively
* $p < 0.05$; ** $p<0.001$

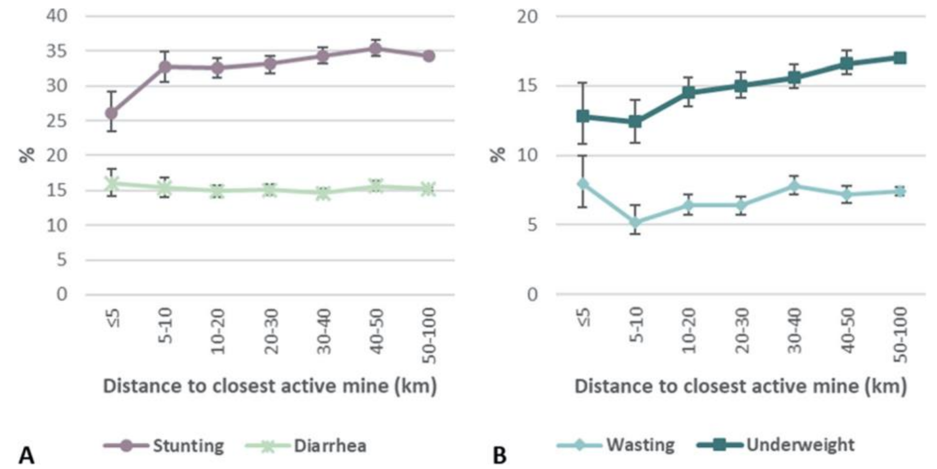

Fig. 5 Prevalence of anthropometric indicators and 2-week diarrheal prevalence among children under five years near mines. Results are stratified by distance to the closest active mine. Error bars show 95 % confidence intervals

stunting a reduction in the odds at this distance was observed.

Impact of mine opening on child health outcomes

Figure 6 summarizes the estimated mining impact on child health outcomes. On average, child health outcomes in areas close to mines were substantially worse in the surveys conducted more than 5 years prior to the mine opening, but looked relatively similar in the 5 years before the mine became active. Stunting, wasting and underweight prevalences declined more rapidly in areas close to mines after mining activities commence,

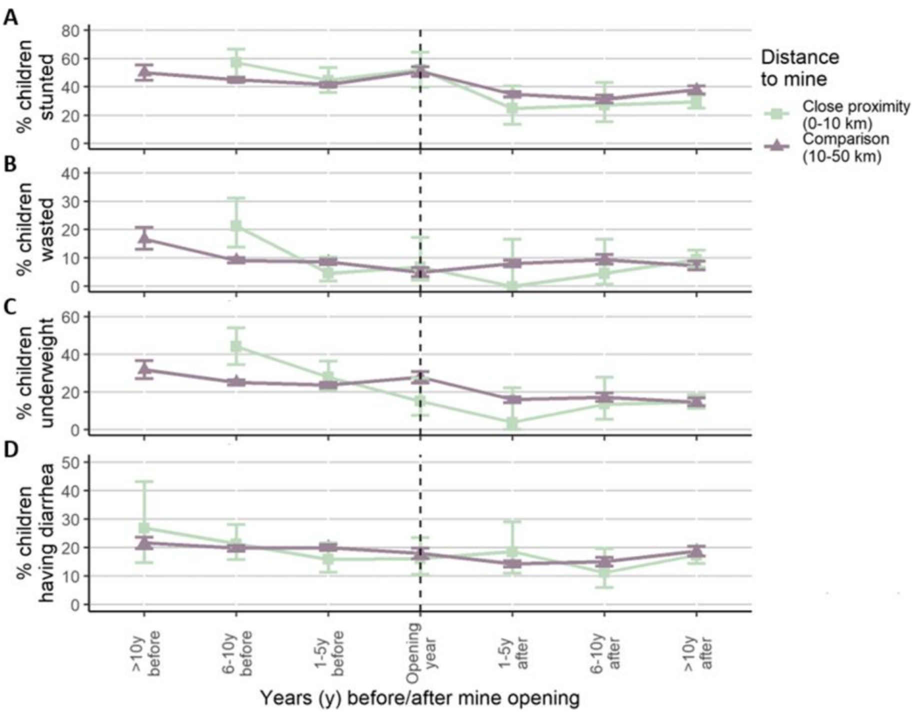

Fig. 6 Percentage of children stunted (panel **A**), wasted (panel **B**), underweight (panel **C**) and suffering from diarrhea in the two weeks prior to the survey (panel **D**). The x-axis shows the time period of the survey relative to the opening year of the mine. Separate graphs are shown for each distance category (≤ 10 km vs. 10–50 km from the mine). Error bars show 95 % confidence intervals. No anthropometric data were available in the close areas from more than 10 years before mine opening

with fading differences over time. Diarrhea prevalences were similar before and after mining operations were launched.

The results from the regression analyses drawing from the longitudinal dataset comprising of repeated cross-sectional survey data are shown in Fig. 7; Table 3. Adjusting for child-level factors, the opening of a mine reduced the odds of stunting and underweight by 38 and 45 %, respectively relative to the comparison areas (adjusted odds ratio (aOR) for stunting: 0.62, 95 % CI: 0.43–0.90; aOR for underweight: 0.55, 95 % CI: 0.36–0.84). For wasting, the interaction term between mining proximity and activity was not statistically significant, although when excluding data from a potential transition period, a significant reduction in wasting was observed (see Additional file 9). Furthermore, among children in poorer households, a reduction in the odds of wasting was seen using the complete dataset (aOR: 0.40, 95 % CI: 0.16–0.99). For diarrhea, children in better-off households in close proximity to active mines experienced increased odds of sickness relative to control areas (aOR: 2.05, 1.11–3.76). Other associations were not statistically significant.

Cross-country differences

Figure 8 shows the associations between the distance to the mines and the different types of water and sanitation infrastructures as well as associated health outcomes by country. Large differences in the point estimates between the different countries were seen for all comparisons. For the comparisons modern vs. basic of both water and sanitation infrastructures the majority of countries showed positive associations with mining projects. Still, in some countries households close to mines were less likely to have access to modern water and sanitation infrastructures. Also for the health outcomes, there were marked differences in the OR between the countries. However, only in few countries statistically significant associations were seen. For example, a reduction of stunting rates was seen in Senegal, Mali, Tanzania and the Democratic Republic of Congo. On the other hand, increased odds for stunting close to the mines were seen in Zambia and Burundi. Some countries had to be excluded from the analyses due to the low case numbers in close proximity to mines, particularly for wasting.

Discussion

In the present study, the largest dataset integrating household and child health data from 34 sub-Saharan African countries together with a comprehensive list of mines was used for comparing trends in household infrastructure and child health in areas close to mines as well as neighboring areas over time. The results indicate that access to modern water infrastructures improved rapidly after mine opening, while positive changes in sanitation infrastructures started to manifest after 10 years of operation. Some improvements in child health outcomes were seen, such as in stunting and underweight prevalences. No clear trends in wasting or diarrhea were observed. Changes in household wealth seemed to play an important role in determining the distribution of benefits. Furthermore, large cross-country differences were observed, both for the associations between mining and water and sanitation infrastructures and the child health indicators. In summary, despite the positive impacts of mines on water and sanitation infrastructures, related child health indicators in mining communities only partially improved. These findings suggest that factors other than water and sanitation infrastructures also affect child health in mining communities.

The trends in access to sanitation found in the present study are in line with another study focusing on data

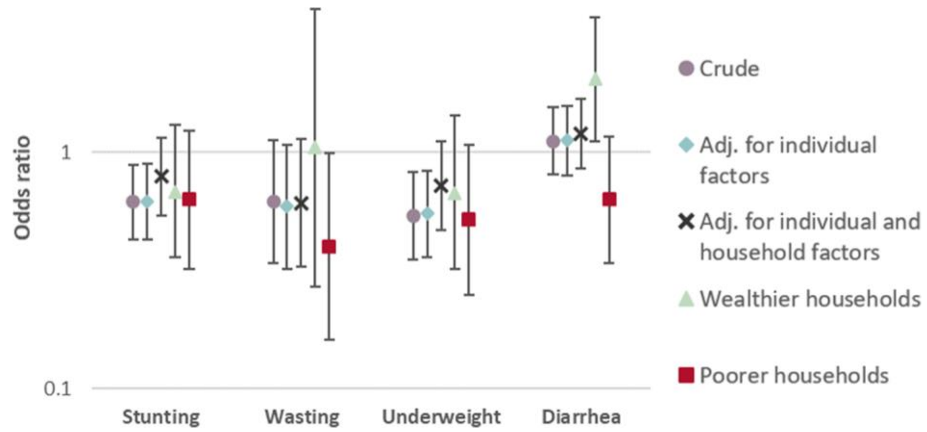

Fig. 7 Estimates of the odds ratios (OR) and corresponding 95 % confidence intervals for the interaction of mining activity (before vs. after mine opening) and proximity to the mine (≤ 10 km vs. 10–50 km) on child health indicators using the longitudinal dataset on children under 5 years

Table 3 Odds ratios (OR) and 95% confidence intervals (95% CI) for the effect of the interaction between mining activity (before vs. after mine opening) and proximity to the mine (≤10 km vs. 10-50 km) on childhood health outcomes using the pseudo-panel household dataset

	OR (95%CI) for interaction close proximity*active				
	Crude model[a]	Adj. for ind. factors[b]	Adj. for ind. and HH factors[c]	Wealthier HH only[bd]	Poorer HH only[bd]
Stunting	0.62 (0.43 - 0.89)*	0.62 (0.43 - 0.90)*	0.79 (0.54 - 1.16)	0.68 (0.36 - 1.31)	0.63 (0.32 - 1.24)
Wasting	0.62 (0.34 - 1.13)	0.59 (0.32 - 1.08)	0.61 (0.33 - 1.14)	1.05 (0.27 - 4.06)	0.40 (0.16 - 0.99)*
Underweight	0.54 (0.35 - 0.83)*	0.55 (0.36 - 0.84)*	0.72 (0.47 - 1.11)	0.67 (0.32 - 1.43)	0.52 (0.25 - 1.08)
Diarrhea	1.12 (0.81 - 1.56)	1.13 (0.80 - 1.58)	1.20 (0.85 - 1.69)	2.05 (1.11 - 3.76)*	0.63 (0.34 - 1.17)

[a]mine-level random intercept only
[b]adjusted for individual-level factors (child age and sex)
[c]adjusted for individual and household-level factors (wealth, access to water and sanitation, household size)
[d]stratified analyses using only data from the two lower wealth quintiles (poorer households) and the two upper wealth quintiles (wealthier households), respectively
*$p < 0.05$; ** $p<0.001$

from Mali [21]. Although their estimates were not significant, they also found similar trends with better infrastructures close to the mines but decreased access to modern facilities at intermediate distances (30–60 km). On the other hand, Ouoba et al. found no effect on water and sanitation infrastructure around mines in Burkina Faso [39], and Polat and colleagues even found negative impacts [20]. Potential reasons for the different results could be that the former study analyzed data at a relatively coarse spatial resolution (regional-level) while the latter used data at a much larger distance from the mines (i.e. up to 250 km) as comparison group and did not exclude larger cities. This may potentially have led to more urban comparison areas than the predominantly rural mining sites.

The positive impacts of mining projects on water and sanitation infrastructures were less seen among the poorer households, particularly for access to modern sanitation. Poor households in mining areas potentially constitute of a selected group of people that remains poor despite overall economic development or include migrants that settle in informal dwellings with particularly low access to water and sanitation infrastructures [18, 40, 41]. Hence, the poor living in mining areas may differ from people living in poor households elsewhere [40]. As a result, despite the overall improvements in infrastructures in mining areas, informal settlements remain underserved. Furthermore, access to modern sanitation infrastructures improved at a slower pace than water infrastructures. This may indicate that while investments in local water infrastructures are often part of mining project's corporate social responsibility programs, investments in sanitation infrastructures are less common [5]. Hence, improvements in sanitation infrastructures are only seen later, potentially as a result of rising household wealth in mining communities. This is in accordance with an analysis of impact assessment reports of mining projects in sub-Saharan Africa that revealed that efforts to improve access to sanitation infrastructures were less frequently included in mitigation plans than for water infrastructures [42]. The large variations in associations found across the different studies, as well as across and within countries, underlines the importance of assessing local-level trends around mining projects in order to promote an equitable distribution of foster potential positive impacts on sustainable development in mining communities [43]. Identification of vulnerable population sub-groups in mining communities in the management of mining projects would contribute to a more equitable distribution of their benefits [44].

As water and sanitation infrastructures are important contributors to health and wellbeing, progress towards SDG 6 could directly or indirectly also promote SDG 3 ("good health and wellbeing") [45]. Quantitative studies indicate that improvements in water and sanitation infrastructures have been shown to reduce child mortality, malnutrition and diarrhea [22, 46]. However, in our study improvements in child health indicators were less evident. For example, diarrheal diseases did not decrease in mining areas as seen in other studies [20, 21, 28]. As our results suggest, the associations between the proximity to a mine and childhood diarrhea varies by country, which could also explain the ambiguous findings of case studies focusing on individual countries [21]. Further, these variations may also be the reason for the absence of significant associations when using the multi-country dataset. Another explanation for both the absence of an association and the variations between countries may be that diarrhea episodes were self-reported by the mothers. Self-reported diarrhea is subject to recall and reporting bias and the concept and terminology of diarrheal diseases varies between geographical regions [47]. Research has shown that diarrheal diseases are more often recognized and reported by literate mothers or by care-givers living in households with access to improved water sources [48]. Although these effects are directly or indirectly (through the household wealth index) adjusted for, it is possible that this source of bias has concealed the

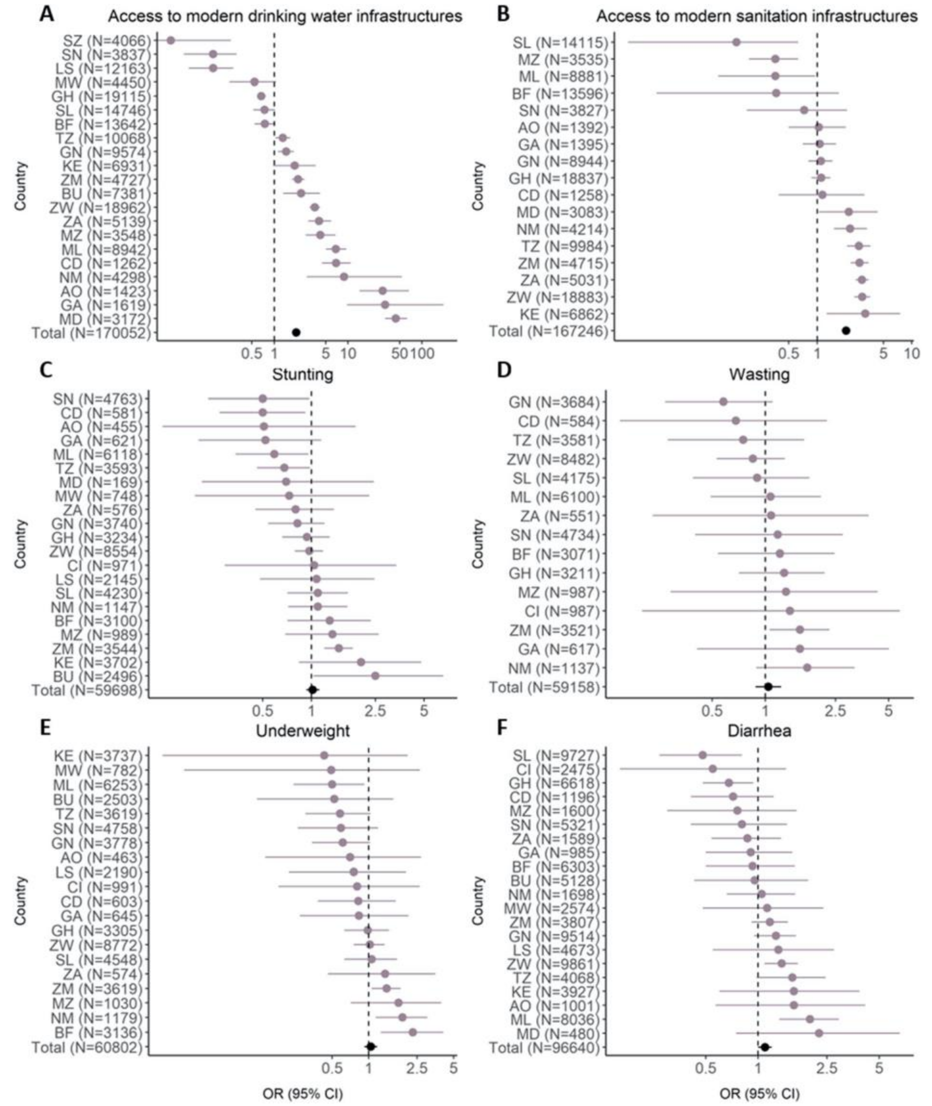

Fig. 8 Country-level analysis of the impact of mines on water and sanitation infrastructures and child health. The forest plot shows the odds ratios (OR) and corresponding 95 % confidence intervals (95 % CI) for the association between distance to a mine (≤ 10 km vs. 20–100 km) and modern water (panel **A**) and sanitation (panel **B**) infrastructures, stunting (panel **C**), wasting (panel **D**), underweight (panel **E**) and diarrhea (panel **F**) among children under 5 years stratified by country. Some countries were excluded due to the low number of households in the respective categories close to the mines. The overall OR for all countries in the dataset is shown in black color. AO = Angola; BF = Burkina Faso; BU = Burundi; CD = Democratic Republic of Congo; CI = Ivory Coast; GA = Gabon; GH = Ghana; GN = Guinea; KE = Kenya; LS = Lesotho; MD = Madagascar; ML = Mali; MW = Malawi; MZ = Mozambique; NM = Namibia; SL = Sierra Leone; SN = Senegal; SZ = Eswatini; TZ = Tanzania; ZA = South Africa; ZM = Zambia; ZW = Zimbabwe

beneficial effects of the improved access to modern water and sanitation infrastructure in mining areas. However, it is also possible that other pathways of diarrheal infections are affected by the establishment of mining projects, such as hampered water quality, increased population density or changes in transport and storage practices of drinking water [15, 49]. More in-depth research is needed to elucidate what factors contribute to childhood diarrhea in mining areas, ideally drawing from longitudinal data of cohorts.

Anthropometric data on the other hand are less prone to bias, as they are measured by trained investigators according to standardized procedures. Indeed, in our study we found reduced rates of childhood stunting and underweight. Contrarily, we find higher rates of acute malnutrition (wasting) in the proximity (i.e. ≤5 km) to mining projects in the cross-sectional dataset. However, these associations were not seen at larger distances from the mines. Similarly to our findings, von der Goltz et al. found reduced stunting rates in a large-scale analysis using a similar dataset around mines in developing countries [8]. Further, a study in Zambia has found similar results, although these results were only marginally significant [27]. On the other hand, higher levels of stunting among children under five years in Tanzania but lower rates in Mali were found in another study [20]. Studies on wasting and underweight rates in mining areas are rare and evidence is inconclusive. In a study in Zambia no marked differences were seen for wasting or underweight [28], while in Tanzania and Mali, lower rates of underweight were observed in areas close to mines [20]. The overall lower chronic but higher acute malnutrition rates found in the present study could potentially be explained by land use and life style changes around large mines, away from subsistence agriculture [50, 51]. This may decrease the quality of the children's diet and decrease household's resilience to short-term fluctuations in food availability [50]. However, this hypothesis merits further investigation in agricultural practices and changes in dietary patterns in mining regions.

The overall positive impacts on water and sanitation infrastructures underline the potential of mining projects to promote the 2030 Agenda for Sustainable Development [52]. However, for these impacts to improve community health as well as for ensuring an equitable distribution of these benefits, appropriate regulatory and policy frameworks need to be in place [44, 53]. Health impact assessment or inclusion of health in other forms of impact assessment can be a suitable tool for addressing health issues during the licensing process and subsequent management of the risks and opportunities of mining projects [54].

Our results are subject to a set of limitations. First, the focus was set only on industrial mines and did not differentiate between the types of commodities extracted. Artisanal and small-scale mines that are often located in proximity to larger mines can by themselves attract a large number of people and have a series of environmental, social and health impacts [55, 56]. Second, in our analyses we considered the mine opening year as the time impacts are expected. However, during the construction phase, often characterized by a peak in the demand of workforce, potential impacts could already start to manifest [57]. The sensitivity analyses, masking out data during a theoretical transition period before and after mine opening, addressed this shortfall. Yet, accurate data on construction duration would be needed to test for any differential impacts during the different mining phases. Third, the cross-sectional nature of the data does not allow for assessing causation of the associations found. Fourth, there is potential for unmeasured confounding from factors inherent to mining areas, such as increased levels of urbanization. To address this, larger cities were excluded from analyses. Additionally, population density estimates were tested as covariates in the regression models. However, they did not improve model fit. Fourth, survey data can be prone to recall and reporting bias. Furthermore, the DHS questionnaires have slightly changed over time and local understanding of the questions may vary. Hence, only a rough classification of water and sanitation infrastructures was possible, clustering some infrastructures together that would be classified into different categories if the established water and sanitation service ladders were used [35, 58, 59]. Lastly, inaccuracy of GPS data, both the systematic errors introduced in the DHS data and the random errors in the mining projects dataset, could have diluted our results and reduce statistical power [60]. However, the resulting bias is expected to be non-differential.

Conclusions

Our results suggest that mining projects can have a positive contribution to the work towards "universal access to improved and reliable water and sanitation for all" (SDG 6) and improved child health (SDG 3). Given that the risks and benefits of mines vary strongly between countries and across socio-economic strata, it is crucial that health is adequately addressed in the licensing process of mining projects. A rigorous assessment and management of potential health impacts can not only ensure that benefits are equitably distributed throughout all social strata, but also to expand the potential health benefits of the mining sector to impacted communities. With the right policy framework in place, mining projects have substantial potential to be an important contributor in the work towards achieving the goals of the 2030 Agenda for Sustainable Development, helping to achieve the ultimate goal to "leave no one behind".

Abbreviations

aOR: Adjusted odds ratio; aRRR: Adjusted relative risk ratio; CI: Confidence interval; DHS: Demographic and Health Survey; DiD: Difference-in-difference; HH: Household; GPS: Global Positioning System; OR: Odds ratio; RRR: Relative risk ratio; SDC: Swiss Agency for Development and Cooperation; SDG: Sustainable Development Goal; SNSF: Swiss National Science Foundation; SSA: Sub-Saharan Africa; S&P: Standard & Poor's

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s12992-021-00723-2.

Additional file 1. Equations.

Additional file 2. Percentage of households being classified as wealthy and poor.

Additional file 3. Spatial trend of the relative risk ratios for the association between the distance to the closest mine and water and sanitation infrastructures.

Additional file 4. Results from the regression models for the association between distance to mine and water infrastructures.

Additional file 5. Results from the regression models for the association between distance to mine and sanitation infrastructures.

Additional file 6. Sensitivity analysis for the interaction effect on water and sanitation infrastructure.

Additional file 7. Spatial trend of the odds ratios for the association between the distance to the closest mine and stunting, wasting, underweight and 2-week diarrheal prevalence.

Additional file 8. Results for the association of distance to mine with child health outcomes.

Additional file 9. Sensitivity analysis for the interaction effect on water and sanitation infrastructure.

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Authors' contributions
Conceptualization (D.D., G.F., M.S.W.); Formal Analysis (D.D.); Methodology (D.D., A.F., G.L., G.F., M.S.W.); Visualization (D.D.); Supervision (M.S.W.); Writing – Original Draft Preparation (D.D.); Writing – Review & Editing (A.F., G.L., G.F., M.S.W.). The author(s) read and approved the final manuscript.

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Availability of data and materials
The datasets supporting the conclusions of this article are available on request from the DHS website (https://dhsprogram.com/).

Declarations

Ethics approval and consent to participate
Permission for the use of DHS data for secondary analysis was obtained from the DHS programme.

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests exist.

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7 Article 4: Inclusion of health in impact assessment: a review of current practice in sub-Saharan Africa

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Inclusion of Health in Impact Assessment: A Review of Current Practice in Sub-Saharan Africa

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Abstract: Natural resource extraction projects, including those in the mining sector, have various effects on human health and wellbeing, with communities in resource-rich areas in sub-Saharan Africa (SSA) being particularly vulnerable. While impact assessments (IA) can predict and mitigate negative effects, it is unclear whether and to what extent health aspects are included in current IA practice in SSA. For collecting IA reports, we contacted 569 mining projects and 35 ministries regulating the mining sector. The reports obtained were complemented by reports identified in prior research. The examination of the final sample of 44 IA reports revealed a heavy focus on environmental health determinants and included health outcomes were often limited to a few aspects, such as HIV, malaria and injuries. The miniscule yield of reports (1.6% of contacted projects) and the low response rate by the contacted mining companies (18%) might indicate a lack of transparency in the IA process of the mining sector in SSA. To address the shortcomings identified, policies regulating IA practice should strengthen the requirements for public disclosure of IA reports and promote a more comprehensive inclusion of health in IA, be it through stand-alone health impact assessment or more rigorous integration of health in other forms of IA.

Keywords: environmental impact assessment; extractive industry; health impact assessment; low- and middle-income countries; mining sector; sub-Saharan Africa

1. Introduction

Impact assessment (IA) is an established approach to minimize adverse environmental, social and health impacts of projects, policies and programs, while fostering opportunities for equitable and sustainable development [1–3]. The first legislation promoting IA dates back more than 50 years, when legislation on environmental impact assessment (EIA) was introduced in the United States [3]. Passed in 1969, this legislation required human health to be included as part of the assessment. Since then, the field of IA has evolved and diversified. During the 1970s, the social impact assessment (SIA) approach was established, placing particular emphasis on the interrelations between the environmental and social impacts, including health [1,3]. With the aim to more specifically address potential impacts of projects, programs, plans and policies on human health as a stand-alone process, health impact assessment (HIA) was introduced in the late 1980s/early 1990s [2,4–6]. Over the past 30 years, the methodology and approach for assessing health impacts has been further developed [7]. At present, many different forms and typologies of IA exist, including integrated IA, such as environmental and social impact assessments (ESIA), or environmental, social and health impact assessments (ESHIA) [8].

Health aspects lack standardized integration in different forms of IA [3,5]. Broadly speaking, two strategies exist to consider health in the IA process. First, health is considered in a specific HIA, as a comprehensive, stand-alone approach [2]. Second, health can be addressed as part of EIA, or integrated IA, such as environmental and health impact assessment (EHIA) or ESHIA [9,10]. The inclusion of health in EIA holds particular promise, since it is promoted by national legislation in most countries [3]. However, research on the inclusion of health in EIA and other forms of IA from high-income countries shows that health is, in general, insufficiently considered, with the exception of stand-alone HIA [8,11–16]. In other forms of IA, the spectrum of health aspects assessed is narrow and centered around environmental determinants of health, often neglecting the various impacts on social and institutional factors that inherently affect health [11–16].

It is encouraging that HIA has gained in popularity in the recent past; yet, there are considerable differences regarding the use of HIA from one world region to another [2,17,18]. The practice of HIA is particularly lacking in sub-Sahara Africa (SSA), which might be explained by an absence of legal frameworks promoting HIA and a paucity of trained practitioners [18,19]. The absence of HIA in SSA is an issue, as this region is particularly vulnerable to adverse health impacts governed by social-ecological contexts (e.g., widespread poverty, low capacity of public infrastructure, favorable conditions for the transmission of vector- and water-borne diseases, high prevalence of infectious diseases and vulnerabilities to climate change) [20–22]. At the same time, many countries in SSA are rich in natural resources. In turn, there is a large and growing number of projects in the mining sector [23,24]. Their development is associated with a broad range of potential positive and negative impacts on health outcomes (e.g., increased rates of HIV or malaria) [25–28] and health determinants (e.g., increased household income, increased public education investment, in-migration and environmental degradation) [29–34]. The proper management of potential negative impacts of projects in this rapidly growing sector holds promise for improving public health and promoting sustainable development in the mining sector [23,32,35].

Against this background, a thorough assessment of health impacts of mining projects is particularly salient in SSA. However, whether and to what extent and quality health has been included in different forms of IA in the mining sector of SSA needs to be investigated. We analyzed IA reports of mining projects in SSA and determined the scope and quality of the inclusion of health. More specifically, the following research questions were addressed. First, are health aspects included in different types of IA reports and if so, which ones? Second, what kind of data sources are used as evidence-base for HIA or health in other forms of IA?

2. Materials and Methods

In this study, IA reports were obtained from several sources. The reports that fulfilled our inclusion criteria described below were systematically screened for specific health aspects.

2.1. *Strategy for Identification of Relevant Reports*

IA reports of large mining projects in SSA were collected from three different sources in order to maximize the number of reports (Figure 1).

2.1.1. Online Contacts within Mining Companies and Ministries

A standardized message (see online Supplementary File S1) was sent to 569 mining projects in SSA that were listed in the Standard & Poor's (S&P) Global Market Intelligence Mining Database [36] on 26 October 2018. The contacts were asked for access to IA reports, emphasizing strict confidentiality and offering to sign a non-disclosure agreement. Additionally, an adapted version of the message (see online Supplementary File S2) was sent to ministries regulating the mining sector (e.g., Ministry of Mines and Ministry of Environment) in 35 countries of SSA known to host industrial mining projects.

For member countries of the Extractive Industries Transparency Initiative (EITI), a request to their contact person was sent. All messages were sent either through a contact form on the company/ministry web page or directly by e-mail. A maximum of two reminders at an interval of at least 2 weeks were sent if the contacts did not respond to the initial message. The messages to the companies were sent between November 2018 and May 2019, those to the ministries and EITI representatives between May and July 2019.

2.1.2. Online Search

Publicly available reports were searched online through Google and company web pages. In the Google search engine, a systematic online search was conducted using Boolean operators. Separately for each country in SSA, the term "impact assessment" and terms representing an activity of natural resource extraction projects ("natural resource OR mine OR mining OR dam OR drilling OR gas OR hydrocarbon OR oil OR petrol OR hydroelectricity OR hydropower OR biofuel OR electricity OR exploration OR exploitation OR extraction") were combined with the different spellings for the respective country (e.g., "Côte d'Ivoire" OR "Ivory Coast"). Initial piloting of the search methodology revealed that most of the relevant documents were found among the first 50 hits. Of note, this search terminology also served another research component that systematically searched contents of IA reports of a broader spectrum of large natural resource extraction projects [37]. For the current analysis, the full sample of reports retrieved was reduced to include mining projects only. The search was carried out in October and November 2018 in Switzerland. Additionally, the web pages of the contacted companies were visited to check the public availability of IA reports. If no direct link to the company was available in the mining database, the project and the company operating or owning the project were searched on Google. All web pages were visited in May 2019.

2.1.3. Case Studies

An ongoing research initiative, the "health impact assessment for sustainable development" (HIA4SD) project [38,39] aims at generating a deeper understanding of health impacts of natural resource extraction projects in Burkina Faso, Ghana, Mozambique and Tanzania. As part of the research activities, in-country project partners established contacts with mining companies and ministry representatives and obtained reports between March 2018 and January 2019. As a result, IA reports were made available either directly by the companies or by the national environmental authorities.

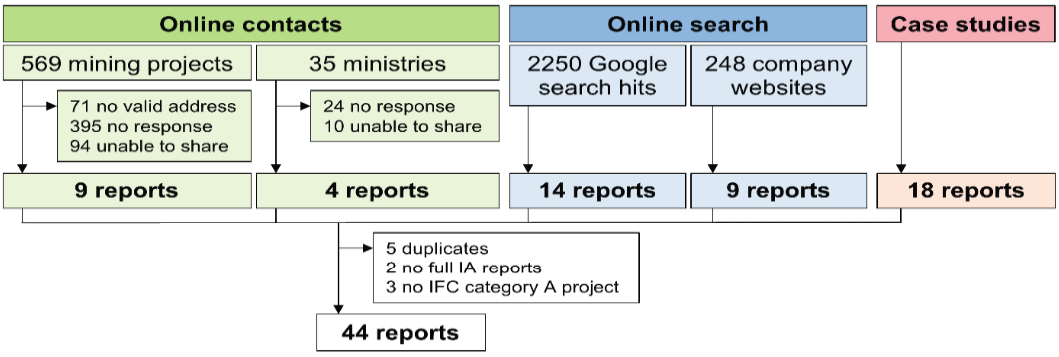

Figure 1. Sources and flow chart of impact assessment reports. IA = impact assessment; IFC = International Finance Corporation.

2.2. *Screening of IA Reports*

In a first step, the eligibility of the reports was assessed. Reports were excluded if (i) not all IA reports were available for projects for which multiple assessments were conducted (e.g., only SIA was available that was conducted in connection with an EIA); (ii) it represented only a summary of the assessment (e.g., environmental impact statement); or (iii) the project was not rated as a category A project according to the International Finance Corporation (IFC)'s environmental and social categorization, so that the sample includes only projects "with potential significant adverse environmental or social risks and/or impacts that are diverse, irreversible, or unprecedented" [40,41]. Category A projects, such as most large-scale mining projects, are required to conduct a comprehensive IA, including a thorough assessment and data collection for informing potential health impacts [40,42]. More specifically, in contexts where availability and quality of health-related data are limited, the collection of primary data in affected communities is indicated for ensuring a robust evidence-base for the IA and enabling monitoring of health impacts over time [43].

The second step comprised of examining the full IA reports for their consideration of different health factors. Additionally, to assess the completeness of the executive summaries, the summaries of the IA reports found through the Google search were screened separately. The screening followed the same methodology for both, the full IA reports and the sample of executive summaries. For each report section (e.g., baseline, impact assessment, mitigation measures and monitoring plan), information on the inclusion of different health aspects was extracted. An adapted analysis framework from Quigley et al. [44], the IFC HIA guidelines [43] and Winkler et al. [20] was used, which comprised 4 health determinant categories (Table A1) and 10 health outcome groups (Table A2). In total, 23 specific health determinants and 35 health outcomes were identified. Furthermore, the data sources that the IAs used for the health baseline assessment were categorized into different primary and secondary data source categories. The primary data sources consisted of key informant interviews (KIIs), focus group discussions (FGDs), household surveys (HHS) and biological or environmental samples, including field observations. The options for the secondary data sources included routine health surveillance data (e.g., health facility data, District Health Information System 2 (DHIS 2) data), national and regional surveys (e.g., Demographic and Health Surveys (DHS) and Multiple Indicator Cluster Surveys (MICS)), official government statistics (national or local), peer-reviewed articles and grey literature. Other data sources that might be relevant were classified as "other primary data source" and "other secondary data source".

Full reports that were electronically available were screened by two authors (D.D. and R.L.), while executive summaries were examined by a third author (S.A.). Case study reports that were only available in printed form were examined by the HIA4SD project research associates in the respective countries. Parallel screening of the reports and validation of the results ensured the consistent application of the methodology across all assessors. To facilitate data entry during the screening stage, the assessors used an online survey tool (www.surveymonkey.com).

2.3. Data Extraction and Analysis

The survey data were extracted and summary statistics generated using R version 3.5.1 (R Foundation for Statistical Computing, Vienna, Austria) [45]. The unit of analysis were the projects. Hence, if more than one IA report was available for a specific project (e.g., a HIA was conducted together with an EIA), the health aspects included in the different reports were combined. The statistics are presented for different aspects for each health determinant and outcome. Comparisons were made between the different report sections and report types (health-specific IA (HIA and ESHIA) vs. non-health-specific IA (EIA, SIA or ESIA)).

3. Results

As shown in Figure 1, a total of 54 IA reports were obtained. Reaching out to contacts of 569 mining projects and representatives from ministries in 35 countries of SSA yielded only 9 and 4 reports, respectively. Through the systematic Google search, 14 reports were found. Additionally, the IA reports of 9 companies were readily available on company web pages. The sample was completed by 18 reports obtained from case studies in the HIA4SD project. Among the case study reports, 2 were also found on the company web pages and 2 were made available by company contacts. Furthermore, 1 report was shared directly by a company contact and publicly on the web page. Two reports were excluded from the analysis because only part of the IA documents were available. Additionally, 3 reports considered only the expansion of existing projects and, thus, did not necessarily require a full IA (i.e., not category A projects). Our final sample included 44 IA reports.

3.1. Report Characteristics

Panel A in Figure 2 shows the geographic distribution of the 44 included IA reports as well as the location of the 569 contacted mining projects in SSA. Reports from 18 different countries were obtained. Most reports stemmed from the HIA4SD project countries, namely Ghana (n = 8), Burkina Faso (n = 4), Mozambique (n = 4) and Tanzania (n = 3). Furthermore, a sizable number of reports of projects in Malawi (n = 5) and the Democratic Republic of the Congo (n = 4) were shared. Of note, despite hosting the vast majority of mines listed in the S&P mining database (n = 263) very few reports (n = 3) could be retrieved from South Africa.

A broad variety of IA report types were collected (see Figure 2, Panel B). For some projects, more than one type of IA report was available. Most of the reports were EIAs (n = 28), which were often conducted alongside SIA, HIA and ESIA. Only 8 reports were obtained that addressed health by design (i.e., HIA and ESHIA).

A temporal pattern is visible in the publication year of the IA reports (see Figure 2, Panel C). Most of the reports were published in 2010 or later (n = 28). Only 3 of the reports were published before 2000.

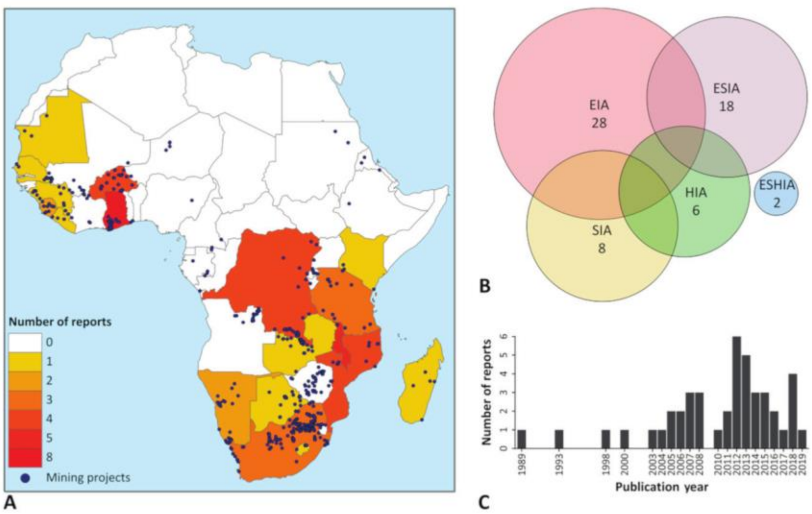

Figure 2. Characteristics of the 44 included impact assessment (IA) reports. (**A**) Country of included reports and location of contacted projects, listed in the Standard & Poor's Global market intelligence mining database [36] on 26 October 2018; (**B**) type of report (overlaps indicate projects for which more than one type of IA was conducted); (**C**) publication year. EIA = environmental impact assessment; ESHIA = environmental, social and health impact assessment; ESIA = environmental and social impact assessment; HIA = health impact assessment; SIA = social impact assessment

3.2. Inclusion of Health Aspects

3.2.1. Inclusion of Health Determinants

Figure 3 provides an overview of the percentage of IA reports considering the screened health determinants. Large differences were observed between the health determinants. While the environmental determinants were considered in most IA reports, the social determinants and institutional factors were less often included. Some particular aspects received little attention, including the capacity of maternal and child health services, as well as access and capacity of traditional health services. The impacts on individual health risk factors, such as alcohol consumption, tobacco or drug use, were least frequently assessed.

Overall, the number of health determinants considered decreased with later sections of the IA reports (i.e., mitigation and monitoring plan). The average percentages of health determinant items included were 65.4%, 61.2%, 54.7% and 39.3% in the baseline description, impact assessment section, mitigation plan and monitoring plan, respectively (see Table A3).

3.2.2. Inclusion of Health Outcomes

Health outcomes were less frequently included in the IA reports than health determinants (Figure 3 and Table A4). Overall, a third (35.9%) of health outcomes were considered across the report sections, compared to 76.8% for the health determinants. In the IA chapters, only 19.4% of health outcomes were included.

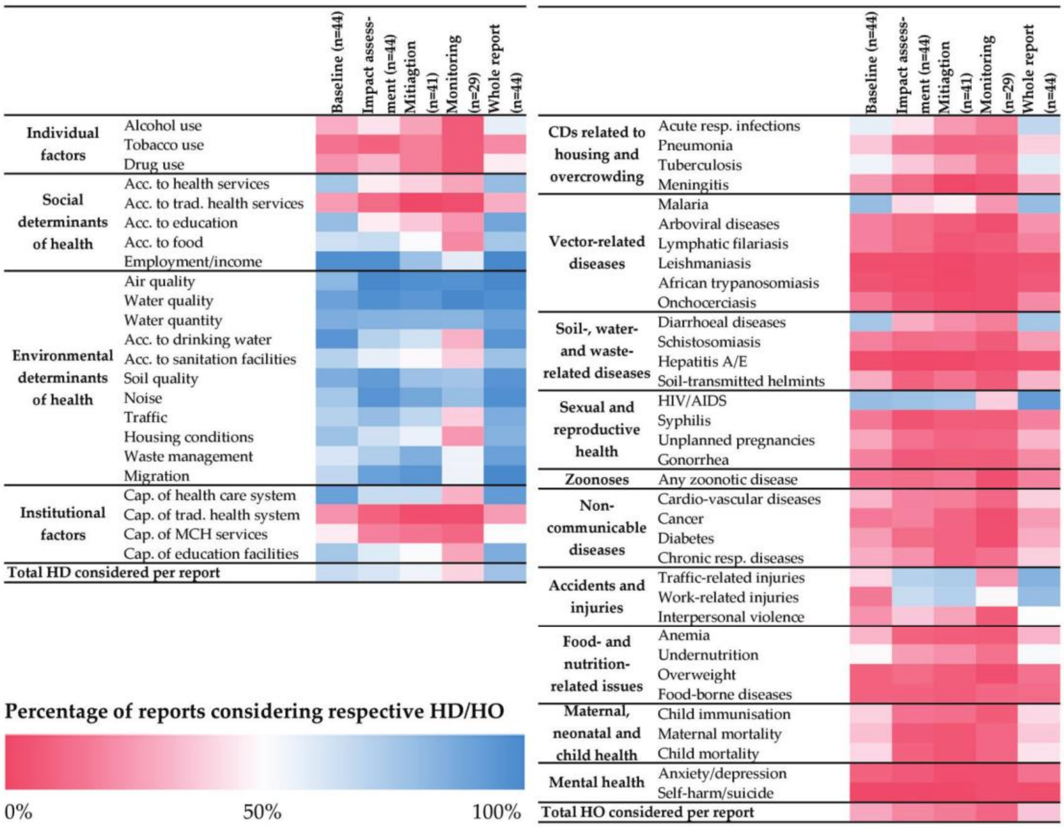

Figure 3. Inclusion of health determinants (HD; left panel) and health outcomes (HO; right panel) in impact assessment reports. Colors represent the percentage of reports or report sections considering the specific health aspect. Red shading indicates percentages below 50%, blue shadings above 50%. Acc. = access; Cap. = capacity; CD = communicable disease; MCH = maternal and child health; resp. = respiratory; trad. = traditional.

Only 8 health outcomes were included in more than 50% of the reports. Among them were, in decreasing order, HIV/AIDS, traffic-related injuries, work-related injuries, malaria, diarrhea, acute respiratory infections, tuberculosis and undernutrition. Zoonoses, mental health, non-communicable diseases and vector-borne diseases other than malaria received less attention.

Similarly to the health determinants, health outcomes were more often considered in the baseline and impact assessment chapters than in the mitigation and monitoring plans. Mitigation measures for specific health outcomes were proposed in few of the IA reports.

3.3. Data Sources

Figure 4 shows the percentages of different data sources used as baseline indicators among the IA reports considering the respective health determinants or outcomes. Overall, primary data were collected predominantly for the health determinants. For measuring health outcome indicators, primarily secondary data sources were used. Collection of primary data pertaining on baseline conditions among the potentially affected communities through participatory approaches, such as KIIs, FGDs or HHS, was rare (see also Table A5). For all health-related aspects, peer-reviewed literature was consulted in only a few instances.

For the assessment of environmental determinants (e.g., air quality, water quality and quantity or noise) a comprehensive sample collection was often conducted. In some cases, these aspects were even assessed in separate specialist reports. In contrast, qualitative information from KIIs and FGDs were more often used to assess the social determinants of health. For some aspects related to access and capacity of public services (e.g., health and education), secondary data, such as official statistics, were also used.

In most cases, secondary information for the baseline of specific health outcome indicators stemmed from health facility data or official statistics. If primary data were used, it was mostly qualitative data obtained from KIIs or FGDs.

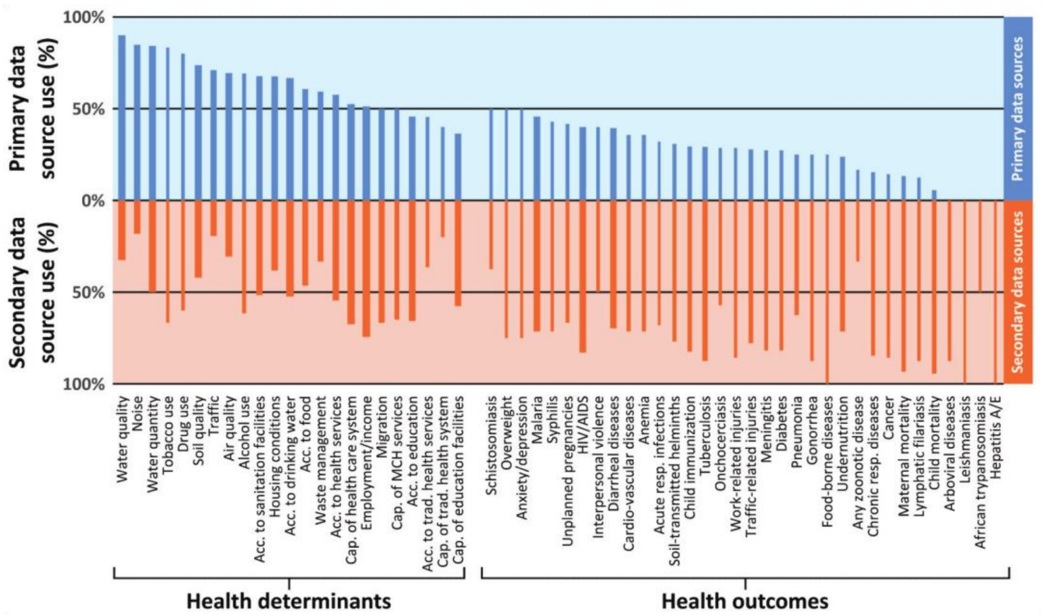

Figure 4. Data sources used for assessing health aspects in impact assessment reports. The height of the bars indicate the percentage of reports using any primary (blue bars) and any secondary (red bars) data source for the different health aspects. Bar widths indicate the number of reports considering the specific health aspect (used as denominator for determining the bar height of the respective aspect). Acc. = access; Cap. = capacity; MCH = maternal and child health; resp. = respiratory; trad. = traditional

3.4. Comparison between IA Report Types

The differences in the percentages of IA reports addressing the various health aspects in health-specific IA (i.e., HIA and ESHIA; n = 8) and non-specific IA (i.e., EIA, ESIA and SIA; n = 36) are shown in Figure 5. Almost all health determinants and outcomes were more prominently featured in the IA reports addressing health by design. Among the health determinants, aspects related to access and capacity of traditional health services were included more frequently in health-specific IA reports. The differences were less pronounced for the environmental determinants of health. With regards to the health outcomes, 32 of 35 studied items were more often considered in projects for which a health-specific IA was conducted. Differences of at least 50 percentage points were observed for tuberculosis, arboviral diseases (e.g., chikungunya, dengue and yellow fever), the non-communicable diseases diabetes and chronic respiratory diseases, anemia and tuberculosis. On the other hand, work-related injuries were featured more often in projects for which no health-specific IA was conducted.

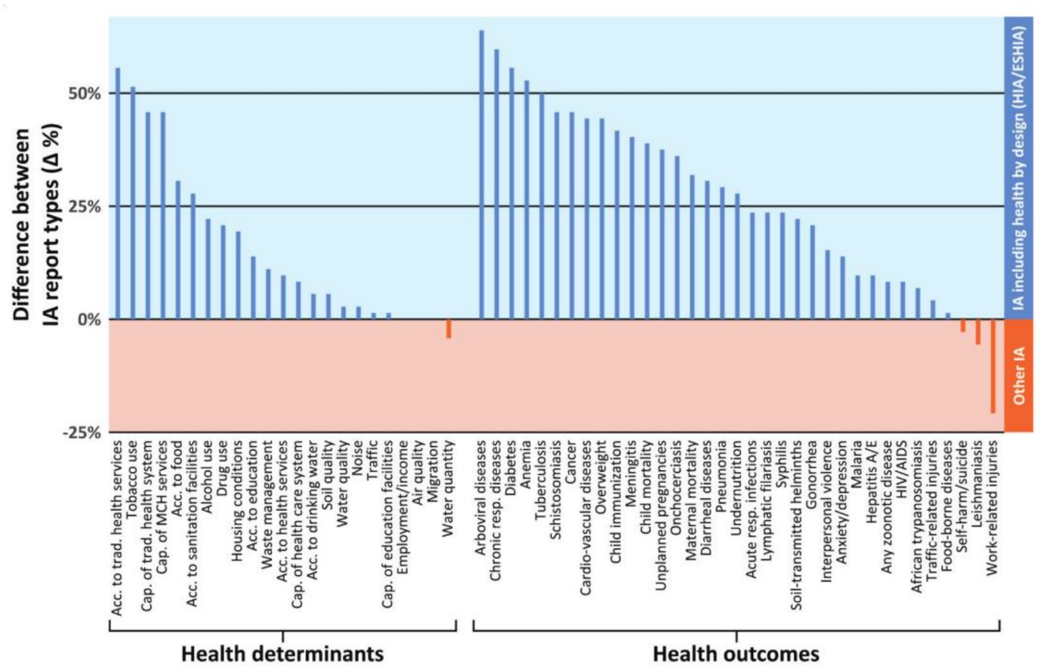

Figure 5. Difference in percentages of impact assessment (IA) reports including the different health determinants and health outcomes between health-specific IA reports and non-health-specific IA reports. Blue bars indicate more frequent consideration of the respective health determinant/health outcome in health-specific IA reports; red bars indicate more frequent consideration in non-health-specific IA reports. Missing bars indicate a difference of 0%. Acc. = access; Cap. = capacity; ESHIA = environmental, social and health impact assessment; HIA = health impact assessment; MCH = maternal and child health; resp. = respiratory; trad. = traditional.

3.5. Completeness of Executive Summaries

The representation of health aspects in the executive summaries of the IA reports was analyzed and compared to their corresponding full reports (Figure 6). The executive summaries frequently omitted information on the different health determinants and health outcomes, although they were included in the full texts. Similar to the full texts, the executive summaries mainly featured information on environmental determinants of health. Some health outcome categories, such as soil-, water- and waste-related diseases, non-communicable diseases, food- and nutrition-related diseases, maternal and child health or mental health, were not included in the executive summaries despite some full reports having considered these aspects (indicated as missing bars in Figure 6). Leishmaniasis, hepatitis A/E, food-borne diseases and self-harm/suicide were excluded from this analysis because they were not considered in any of the full texts.

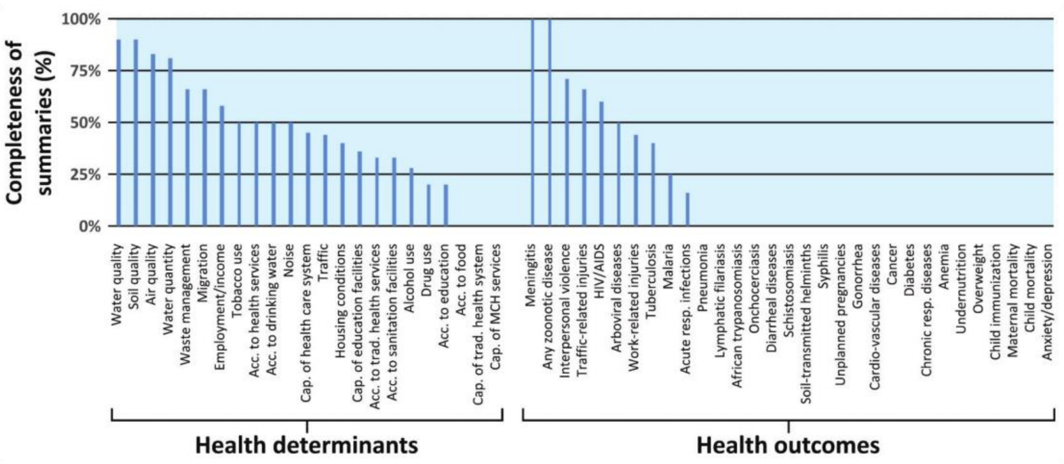

Figure 6. Inclusion of health aspects among the 12 analyzed executive summaries of IA reports. Percentages (bar heights) indicate the number of executive summaries addressing the health aspects relative to the number of full texts considering that aspect. Bar widths indicate the number of full texts addressing the respective health aspect (used as denominator for the bar heights). Missing bars indicate 0% inclusion in the summaries. Acc. = access; Cap. = capacity; MCH = maternal and child health; resp. = respiratory; trad. = traditional

4. Discussion

Overall, 44 IA reports from 18 countries in SSA were obtained from various sources and analyzed for the inclusion of health. We reached out to as many as 569 mining projects and 35 ministries. However, only 13 reports were obtained from these contacts and sources. Public access to IA reports on the internet was also limited; only 21 IA reports were readily accessible online. Screening of the reports revealed a heavy focus on environmental determinants of health. Health outcomes were considered to a lesser extent than the health determinants. Still, some health outcomes, such as malaria, HIV, diarrheal diseases or injuries, were more frequently included. Furthermore, other health aspects, such as zoonoses, mental health issues, non-communicable diseases and food- and nutrition-related issues, received little attention. Reports that had a specific focus on health (i.e., HIA and ESHIA) addressed substantially more health aspects than other reports. Primary data were frequently collected along with secondary data as indicators for the health determinants, particularly for environmental factors. For health outcomes, primary data collection was the exception rather than the norm. Participatory data collection approaches with affected communities through KIIs, FGDs or HHS were rarely conducted.

The IFC's Sustainability Framework through its Performance Standards on Environmental and Social Sustainability sets out the requirements for the management of environmental and social risks of industrial investment projects [42]. The IFC Performance Standards have been adopted by the Equator Principles Financial Institutions (EPFI), a consortium that currently embraces more than 100 banks and financial institutions [46,47]. Since the IFC's Sustainability Framework is considered an international benchmark for identifying and managing environmental, social and health risks [48,49], this standard is also applied in this discussion chapter for reflecting on our findings stemming from a comprehensive review of the available IA reports.

4.1. *Lack of Transparency*

The IFC Performance Standards require projects to publicly disclose information on project-related risks and impacts to affected communities [42]. The scope of this information can range from full IA reports to short summaries of findings, depending on the project size and magnitude of anticipated impacts [42]. For IFC-funded projects, the bank itself publishes a summary of the main findings of the IA [50]. In our study, only a miniscule 1.6% of the 569 contacted large-scale mining projects shared their report, while more than 80% did not respond at all to our data inquest, despite an offer of strict confidentiality. The extremely low yield of IA reports indicates that there is a lack of transparency in current IA practice in the mining sector of SSA.

Research on public disclosure in IA practice from low-human development index (HDI) countries is scarce. In Myanmar, a lack of public disclosure of EIA reports conducted for the oil and gas sector was described, although improvement has been seen in recent years [51]. Instead of disclosing the full IA reports, often, only the executive summaries are published, thereby fulfilling the minimum requirements set out in the IFC Performance Standards. However, our results indicate that these summaries do not offer sufficient insights to inform the public about the potentially broad set of impacts on health. Hence, more stringent requirements for public disclosure of the full IA reports would contribute to increase the accountability of large industrial mining companies and other large-scale infrastructure projects [51]. Hence, in addition to legal texts regulating IA practice, the need for public disclosure of full IA reports for projects should also be more explicitly demanded in policies and guidelines of international financing institutions (e.g., IFC), industry peak bodies (e.g., International Council on Mining and Metals) and private companies.

4.2. Narrow Range of Health Aspects Considered

For large-scale projects (i.e., category A) the IFC Performance Standards [42] and the World Bank's operational policies [40] further require a comprehensive assessment of the project impacts, including aspects of human health and safety. Furthermore, different guidance and scientific documents promote a comprehensive approach to health in HIA, covering the full spectrum of aspects determining human health, especially in complex social-ecological contexts of SSA [44,52,53]. In our sample of IA reports, on average only about a third of investigated health outcomes were included and among the health determinants there was a strong focus on the physical environment. Moreover, when health was integrated in other types or IAs (i.e., EIA, ESIA and SIA), a more narrow range of health aspects were covered. This pattern has been seen in other parts of the world. For example, a lack of inclusion of health aspects was found in EIA reports from the United States [11], Australia [12,15,16] and Vietnam [54]. Furthermore, the assessment of health impacts within EIAs from Australia was mainly limited to risks related to the physical environment [12]. Consistently, in HIAs from low- and middle-income countries, a lack of consideration of the social determinants of health was seen [55]. This may be linked to the limited technical expertise to conduct HIA in many parts of the world [7]. In order to address this constraint, HIA capacity building efforts are needed that do not only aim to build up technical capacity among IA practitioners but also provide trainings to regulators in governments and international financing institutions to appraise IA reports from a health perspective [7,53]. The strengthening of regulatory frameworks that specify under what circumstances HIA is required, and to what extent, could be an important initial step for triggering the demand in HIA capacity building in resource-rich countries of SSA [7,18]. Finally, in light of the health aspects currently not included in IA practice, it should be reflected whether national and international IA guidance documents provide sufficient details on the scope of health to be considered in the IA process.

4.3. Lack of Primary Data Collection

A comprehensive assessment of health impacts, as required by the IFC Performance Standards, comprises data collection on health aspects in affected communities [42,43]. Particularly in mining areas in low-HDI countries, the demographic, social-economic, environmental and epidemiological characteristics further warrant the collection of additional local-level data [56]. However, in the IA reports obtained and scrutinized in the present study, primary data were predominantly collected for aspects related to the physical environment. For health outcomes, the assessments often relied on secondary data sources, such as coarse national and regional-level statistics or local health facility data. Although these data sources hold considerable potential for monitoring health indicators, they are prone to low data quality [55,57]. The collection of local-level data by means of KIIs, FGDs and HHS is an additional means to engage affected groups in the IA process and can help identify and address local health impacts among vulnerable and marginalized populations [58–63]. Comprehensive baseline health data collection requires broad public health expertise among practitioners conducting the IA [26,64,65]. However, health specialists in countries of SSA are rarely engaged in IA and often have limited awareness and knowledge about the IA process [19]. For the health sector to be more actively engaged in HIA, capacity building efforts should reach out beyond the public health sector (e.g., actors in overseeing ministries) to increase the understanding of the skill set required for conducting a thorough assessment of health impacts [19,53].

4.4. Limitations

For this study, we attempted to pursue the different options that affected community members have at their disposal for accessing IA reports. Physical contacts with project proponents or local authorities within the countries may potentially have increased the yield of reports. However, given that only 18% of companies responded to our data inquiry indicates that project representatives are difficult to approach. The resulting small and geographically clustered sample of IA reports limits the representativeness of our sample from which we derive our conclusions.

Furthermore, the analysis only assessed whether and to what extent health issues were addressed. An analysis of the interrelationships between the different health aspects or of the quality of the assessment itself (e.g., the necessity of primary data collection) was beyond the scope of our study. For conclusively judging the appropriate use of different data sources, a more in-depth study is needed, taking into account local characteristics and the quality of alternative data sources.

5. Conclusions

This comprehensive review of IA reports of mining projects in SSA points at three main shortfalls of current IA practice: (i) lack of transparency; (ii) narrow scope of considered health aspects, with a strong focus on the physical environment; and (iii) lack of local-level primary data collection on health outcomes. There are different potential approaches to address these shortcomings at the national and international level. At the national level, ministries overseeing IA should reconsider how health is addressed in regulatory frameworks and policies regulating IA practice. This should include critical reflections on whether there is sufficient specificity provided in terms of methodological guidance on how to assess health impacts (i.e., the width (range of potential impacts) and depth (quality of the evidence-base) of the assessment) either in HIA as a stand-alone approach or integrated in other forms of IA. Furthermore, there is a need to understand whether existing frameworks provide sufficient guidance as to which expertise is needed for leading the assessment of health impacts. In addition, regulatory frameworks should be revised if they do not sufficiently promote disclosure of IA findings, with particular considerations for health-related information.

At the international level, financing institutions, such as the IFC and the members of the EPFI, can play a crucial role in closing the identified gaps. This can be done by setting and enforcing more stringent requirements for public disclosure of full IA reports along with strengthening guidance on how health needs to be included in different forms of IA in order to achieve consistency in quality. Finally, any efforts in promoting more rigorous inclusion of health in IA must be coupled with HIA capacity building, which appears particularly salient in the currently environment-dominated impact assessment practice in SSA. Improving international standards for HIA lays a foundation to improve global relationships; health outcomes for local communities need to be prioritized in order to create long-term, sustainable economic investment opportunities. We encourage other groups who pursue IA in the mining and other sectors in SSA and elsewhere to specifically address health, which cannot be emphasized enough in the current COVID-19 pandemic.

Supplementary Materials: Supplementary materials can be accessed at: http://www.mdpi.com/1660-4601/17/11/4155/s1.

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Appendix A

Table A1. Health determinant categories.

Health Determinant Categories	Description
Individual factors	Factors related to the individual's biology and behavior. These comprise for example gender, age, ethnicity, dietary intake, level of physical activity, tobacco use, alcohol intake, personal safety, sense of control over own life, employment status, educational attainment, self-esteem, life skills, stress levels, resilience and risk behavior.
Social determinants of health	Conditions in which people are born, grow, live, work and age. These include access to services and community (health, education, nutrition, institutional and social support, social and health insurance); income/unemployment rate; distribution of wealth; empowerment of women; sexual customs and tolerance; racism; attitudes to disability; trust; sites of cultural and spiritual significance.
Environmental determinants of health	Physical, chemical, and biological factors external to a person, and all the related factors impacting behaviors, such as exposure to heavy metals, pesticides and other compounds, solvents or spills and releases from road traffic; air pollution (indoor and outdoor); noise pollution and exposure to malodors. It also includes factors, such as inadequate housing, water and sanitation services, and the mixing of population groups with different levels of communicable diseases which can be associated with in-migration.
Institutional factors	Availability of services, including (traditional) health services, transport and communication networks; educational and employment; environmental and public health legislation; environmental and health monitoring systems; laboratory facilities; social and health insurance schemes.

Table A2. Health outcome categories.

Health Outcome Categories	Description
Communicable diseases related to housing and overcrowding	Transmission of communicable diseases (e.g., acute respiratory infections, pneumonia, tuberculosis, meningitis, plague, leprosy, etc.) that can be linked to inadequate housing design, overcrowding and housing inflation
Vector-related diseases	Mosquito, fly, tick and lice-related diseases (e.g., malaria, dengue, yellow fever, lymphatic filariasis, leishmaniasis, human African trypanosomiasis, onchocerciasis, etc.)
Soil-, water- and waste-related diseases	Diseases that are transmitted directly or indirectly through contaminated water, soil or non-hazardous waste (e.g., diarrheal diseases, schistosomiasis, hepatitis A and E, poliomyelitis, soil-transmitted helminthiases, etc.)
Sexual and reproductive health	Sexually-transmitted infections such as syphilis, gonorrhea, Chlamydia, hepatitis B and, most importantly, HIV/AIDS
Veterinary medicine and zoonotic diseases	Diseases affecting animals (e.g., bovine tuberculosis, swinepox, avian influenza) or that can be transmitted from animal to human (e.g., rabies, brucellosis, Rift Valley fever, monkey pox, Ebola, leptospirosis, etc.)
Non-communicable diseases	Cardiovascular diseases, cancer, diabetes, that can be linked to changes in lifestyle, exposure to hazardous materials in air, water or soil, and noise
Accidents/injuries	Road traffic or work-related accidents and injuries (home and project related); drowning; unintentional poisoning
Food- and nutrition-related issues	Adverse health effects such as malnutrition, anemia, micronutrient deficiencies or obesity due to e.g., changes in agricultural and subsistence practices, or food inflation; gastroenteritis, food-borne trematodiases, etc.
Maternal and child health	Prenatal, natal and postpartum health conditions, infant and child health and immunization
Mental health	Psychological health conditions linked to resettlement of populations or changes in lifestyles (e.g., anxiety, depression, stress symptoms, suicide)

Table A3. Inclusion of health determinants in impact assessment reports.

Health Determinant Categories		Baseline (n = 44)	Impact Assessment (n = 44)	Mitigation (n = 41)	Monitoring (n = 29)	Whole Report (n = 44)
Individual factors	Alcohol use	29.5	43.2	26.8	6.9	56.8
	Tobacco use	13.6	9.1	17.1	6.9	20.5
	Drug use	22.7	31.8	17.1	6.9	45.5
Social determinants of health	Access to health services	75.0	45.5	39.0	27.6	79.5
	Access to trad. health services	25.0	11.4	0	3.4	29.5
	Access to education	79.5	45.5	36.6	24.1	88.6
	Access to food	63.6	65.9	51.2	20.7	75.0
	Employment/income	97.7	97.7	78.0	58.6	100
Environmental determinants of health	Air quality	81.8	100	97.6	96.6	100
	Water quality	90.9	98.0	95.1	100	98.0
	Water quantity	86.4	84.1	82.9	82.8	90.9
	Access to drinking water	95.5	70.5	63.4	31.0	95.5
	Access to sanitation facilities	70.5	56.8	48.8	37.9	77.3
	Soil quality	86.4	93.2	78.0	75.9	95.5
	Noise	75.0	95.5	87.8	79.3	97.7
	Traffic	70.5	79.5	68.3	37.9	86.4
	Housing conditions	77.3	63.6	56.1	24.1	84.1
	Waste management	61.4	72.7	85.4	55.2	90.9
	Migration	68.2	90.9	95.1	55.2	100
Institutional factors	Cap. of health care system	90.9	65.9	65.9	31.0	93.2
	Cap. of traditional health system	22.7	9.1	2.4	3.4	25.0
	Cap. of MCH services	45.5	18.2	14.6	10.3	50.0
	Cap. of education facilities	75.0	59.1	51.2	27.6	86.4
Total health determinants considered per report		65.4	61.2	54.7	39.3	76.8

Cap. = capacity; MCH = maternal and child health; trad. = traditional.

Table A4. Inclusion of health outcomes in impact assessment reports.

Health Outcome Categories		Baseline (n = 44)	Impact Assessment (n = 44)	Mitigation (n = 41)	Monitoring (n = 29)	Whole Report (n = 44)
Communicable diseases related to housing and overcrowding	Acute respiratory infections	56.8	43.2	24.4	17.2	68.2
	Pneumonia	36.4	15.9	9.8	10.3	38.6
	Tuberculosis	54.5	36.4	26.8	13.8	59.1
	Meningitis	25.0	11.4	0	3.4	29.5
Vector-related diseases	Malaria	79.5	40.9	46.3	24.1	79.5
	Arboviral diseases	18.2	11.4	7.3	3.4	22.7
	Lymphatic filariasis	18.2	11.4	4.9	6.9	18.2
	Leishmaniasis	2.3	2.3	0	3.4	4.5
	African trypanosomiasis	4.5	2.3	0	3.4	6.8
	Onchocerciasis	15.9	6.8	2.4	3.4	20.5
Soil-, water- and waste-related diseases	Diarrheal diseases	75.0	29.5	22.0	17.2	75.0
	Schistosomiasis	18.2	11.4	12.2	6.9	25.0
	Hepatitis A/E	2.3	0	0	3.4	4.5
	Soil-transmitted helminths	29.5	9.1	14.6	6.9	31.8
Sexual and reproductive health	HIV/AIDS	79.5	77.3	75.6	37.9	93.2
	Syphilis	15.9	4.5	7.3	6.9	18.2
	Unplanned pregnancies	27.3	13.6	9.8	10.3	31.8
	Gonorrhea	18.2	6.8	7.3	6.9	20.5
Zoonoses	Any zoonotic disease	13.6	11.4	14.6	3.4	18.2
Non-communicable diseases	Cardio-vascular diseases	31.8	18.2	17.1	10.3	38.6
	Cancer	15.9	18.2	9.8	3.4	25.0
	Diabetes	25.0	11.4	9.8	3.4	29.5
	Chronic respiratory diseases	29.5	22.7	9.8	13.8	38.6
Accidents and injuries	Traffic-related injuries	40.9	70.5	73.2	24.1	84.1
	Work-related injuries	15.9	65.9	70.7	48.3	79.5
	Interpersonal violence	22.7	36.4	26.8	6.9	50.0
Food- and nutrition-related issues	Anemia	31.8	9.1	7.3	6.9	31.8
	Undernutrition	47.7	25.0	22.0	13.8	52.3
	Overweight	9.1	11.4	7.3	3.4	13.6
	Food-borne diseases	9.1	9.1	7.3	10.3	11.4
Maternal, neonatal and child health	Child immunization	38.6	13.6	12.2	6.9	40.9
	Maternal mortality	34.1	6.8	4.9	10.3	36.4
	Child mortality	40.9	9.1	4.9	10.3	43.2
Mental health	Anxiety/depression	9.1	6.8	2.4	3.4	13.6
	Self-harm/suicide	0	0	0	3.4	2.3
Total health outcomes considered per report		28.4	19.4	16.3	10.5	35.9

Table A5. Data sources for health determinants and health outcomes used for measuring baseline conditions in impact assessment reports.

Health Determinant and Health Outcome Categories		Any Primary Data Source	Any Secondary Data Source	Key Informant Interviews	Focus Group Discussions	Household Surveys	Env. Sample, Observation	Routine Health Surveillance	National/Regional Surveys	Official Statistics	Peer-Reviewed Literature	Grey Literature	Unknown, Other
Individual factors	Alcohol use (*n* = 13)	69.2	61.5	38.5	38.5	30.8	7.7	15.4	7.7	23.1	0	23.1	0
	Tobacco use (*n* = 6)	83.3	66.7	33.3	16.7	50	16.7	16.7	33.3	33.3	0	16.7	0
	Drug use (*n* = 10)	80	60	50	40	30	10	20	0	30	0	20	0
Social determinants of health	Access to health services (*n* = 33)	57.6	54.5	24.2	24.2	21.2	6.1	18.2	12.1	24.2	3	15.2	24.2
	Access to trad. health services (*n* = 11)	45.5	36.4	27.3	9.1	27.3	9.1	9.1	0	18.2	9.1	9.1	27.3
	Access to education (*n* = 35)	45.7	65.7	17.1	11.4	25.7	5.7	2.9	5.7	42.9	2.9	28.6	25.7
	Access to food (*n* = 28)	60.7	46.4	25	25	28.6	17.9	0	7.1	21.4	0	25	17.9
	Employment/income (*n* = 43)	51.2	74.4	23.3	18.6	27.9	4.7	2.3	9.3	44.2	0	34.9	27.9
Environmental determinants of health	Air quality (*n* = 36)	69.4	30.6	5.6	8.3	11.1	58.3	0	0	2.8	0	27.8	22.2
	Water quality (*n* = 40)	90	32.5	10	12.5	7.5	82.5	0	2.5	5	2.5	27.5	10
	Water quantity (*n* = 38)	84.2	50	10.5	10.5	10.5	63.2	0	5.3	13.2	2.6	36.8	10.5
	Access to drinking water (*n* = 42)	66.7	52.4	26.2	14.3	28.6	28.6	0	9.5	23.8	0	33.3	14.3
	Access to sanitation facilities (*n* = 31)	67.7	51.6	25.8	22.6	32.3	16.1	3.2	12.9	29	0	29	9.7
	Soil quality (*n* = 38)	73.7	42.1	13.2	10.5	2.6	65.8	0	5.3	7.9	5.3	28.9	10.5
	Noise (*n* = 33)	84.8	18.2	9.1	9.1	15.2	75.8	0	3	3	0	15.2	12.1
	Traffic (*n* = 31)	71	19.4	19.4	6.5	6.5	45.2	0	3.2	6.5	0	12.9	19.4
	Housing conditions (*n* = 34)	67.6	38.2	20.6	14.7	26.5	20.6	0	11.8	11.8	0	26.5	17.6
	Waste management (*n* = 27)	59.3	33.3	25.9	14.8	18.5	3.7	0	3.7	14.8	0	18.5	22.2
	Migration (*n* = 30)	50	66.7	23.3	6.7	20	3.3	0	10	36.7	3.3	33.3	16.7
Institutional factors	Capacity of health care system (*n* = 40)	52.5	67.5	20	15	7.5	22.5	15	5	25	0	30	22.5
	Capacity of trad. health system (*n* = 10)	40	20	20	20	0	0	0	0	10	0	10	50
	Capacity of MCH services (*n* = 20)	50	65	25	5	10	20	15	5	40	5	15	5
	Capacity of education facilities (*n* = 33)	36.4	57.6	18.2	9.1	0	18.2	3	0	33.3	0	27.3	21.2
CDs related to housing and overcrowding	Acute respiratory infections (*n* = 3)	32	68	16	16	12	0	36	4	20	4	20	32
	Pneumonia (*n* = 16)	25	62.5	6.2	6.2	12.5	0	37.5	6.2	25	6.2	6.2	31.2
	Tuberculosis (*n* = 24)	29.2	87.5	12.5	8.3	12.5	0	33.3	8.3	25	4.2	33.3	20.8
	Meningitis (*n* = 11)	27.3	81.8	18.2	9.1	9.1	0	18.2	9.1	27.3	0	27.3	0
Vector-related diseases	Malaria (*n* = 35)	45.7	71.4	17.1	25.7	25.7	5.7	31.4	5.7	22.9	2.9	28.6	34.3
	Arboviral diseases (*n* = 8)	0	87.5	0	0	0	0	37.5	0	25	12.5	12.5	12.5
	Lymphatic filariasis (*n* = 8)	12.5	87.5	0	0	12.5	12.5	50	0	50	25	12.5	12.5
	Leishmaniasis (*n* = 1)	0	100	0	0	0	0	0	0	100	0	0	0
	African trypanosomiasis (*n* = 2)	0	50	0	0	0	0	0	0	0	0	50	50
	Onchocerciasis (*n* = 7)	28.6	57.1	14.3	0	14.3	0	28.6	0	28.6	0	14.3	14.3
Soil-, water- and waste-related diseases	Diarrheal diseases (*n* = 33)	39.4	69.7	12.1	15.2	24.2	0	33.3	6.1	15.2	0	27.3	24.2
	Schistosomiasis (*n* = 8)	50	37.5	25	12.5	0	25	25	0	12.5	12.5	0	25
	Hepatitis A/E (*n* = 1)	0	100	0	0	0	0	0	0	100	0	0	0
	Soil-transmitted helminths (*n* = 13)	30.8	76.9	7.7	0	7.7	15.4	38.5	0	23.1	7.7	30.8	7.7
Sexually-transmitted infections	HIV/AIDS (*n* = 35)	40	82.9	22.9	8.6	17.1	0	25.7	22.9	28.6	2.9	42.9	20
	Syphilis (*n* = 7)	42.9	71.4	14.3	14.3	14.3	14.3	14.3	0	57.1	0	14.3	14.3
	Unplanned pregnancies (*n* = 12)	41.7	66.7	8.3	33.3	16.7	0	50	8.3	16.7	0	0	8.3
	Gonorrhea (*n* = 8)	25	87.5	12.5	0	12.5	0	37.5	0	50	0	12.5	12.5

Table A5. *Cont.*

Health Determinant and Health Outcome Categories		Any Primary Data Source	Any Secondary Data Source	Key Informant Interviews	Focus Group Discussions	Household Surveys	Env. Sample, Observation	Routine Health Surveillance	National/Re-gional Surveys	Official Statistics	Peer-Reviewed Literature	Grey Literature	Unknown, Other
Zoonoses	Any zoonotic disease (n = 6)	16.7	33.3	16.7	0	0	0	16.7	0	16.7	16.7	16.7	83.3
Non-communicable diseases	Cardio-vascular diseases (n = 14)	35.7	71.4	14.3	14.3	0	14.3	28.6	0	21.4	7.1	28.6	14.3
	Cancer (n = 7)	14.3	85.7	14.3	0	0	0	28.6	0	14.3	0	57.1	14.3
	Diabetes (n = 11)	27.3	81.8	27.3	9.1	0	0	45.5	0	18.2	9.1	18.2	18.2
	Chronic respiratory diseases (n = 13)	15.4	84.6	15.4	0	0	0	30.8	0	38.5	0	23.1	15.4
Accidents and injuries	Traffic-related injuries (n = 18)	27.8	77.8	16.7	16.7	5.6	0	27.8	0	27.8	0	38.9	11.1
	Work-related injuries (n = 7)	28.6	85.7	0	0	28.6	0	42.9	0	42.9	0	28.6	0
	Interpersonal violence (n = 10)	40	50	30	20	10	0	20	0	10	0	20	20
Food- and nutrition-related issues	Anemia (n = 14)	35.7	71.4	14.3	0	14.3	14.3	42.9	7.1	28.6	0	7.1	28.6
	Undernutrition (n = 21)	23.8	71.4	23.8	14.3	4.8	14.3	33.3	14.3	23.8	0	23.8	23.8
	Overweight (n = 4)	50	75	25	25	25	25	25	25	25	25	25	0
	Food-borne diseases (n = 4)	25	100	25	0	0	0	75	0	50	0	0	0
MNCH	Child immunization (n = 17)	29.4	82.4	11.8	5.9	11.8	0	23.5	17.6	29.4	5.9	29.4	17.6
	Maternal mortality (n = 15)	13.3	93.3	6.7	6.7	6.7	0	33.3	13.3	46.7	0	20	13.3
	Child mortality (n = 18)	5.6	94.4	0	0	5.6	0	27.8	16.7	44.4	0	27.8	16.7
Mental health	Anxiety/depression (n = 4)	50	75	25	25	25	0	0	0	25	0	50	0
	Self-harm/suicide (n = 0)	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.

CDs = communicable diseases; Env. = environmental; MCH = maternal and child health; MNCH = maternal, neonatal and child health; n.a = not applicable; trad. = traditional. Percentages are illustrated on a color scale from red to blue. Red shading indicates percentages below 50%, blue shadings above 50%.

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8 Communication materials

8.1 Article 5: Water infrastructure and health in mining settings in sub-Saharan Africa: a mixed-methods geospatial visualization

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Video clip: https://www.youtube.com/watch?v=4EcJ2rDQEuU

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Abstract

Industrial mining transforms local landscapes, including important health determinants like clean water and sanitation. In this paper, we combine macro-level quantitative and micro-level qualitative data to show how mining projects affect water infrastructures and ultimately health of affected communities. Although we observed a positive trend of improved water infrastructure in mining settings, surrounding communities are also characterized by water scarcity and water quality degradation. The video at the core of this publication showcases inter-linkages of the findings obtained at the macro- and micro-level and embeds our results in their geospatial context. Our study shows that while mining projects can have positive impacts on development of local water infrastructure, improved management of negative impacts of mining projects is needed for promoting "Good health and well-being" and "Clean water and sanitation" as promulgated by the Sustainable Development Goals of the 2030 Agenda.

Keywords

Extractive industries, health, impact assessment, mixed-methods, WASH

Introduction

Water security is one of the key public health issues of the 21st century (Boretti and Rosa, 2019). The importance of water is also reflected in the 2030 Agenda for Sustainable Development, aiming for "universal and equitable access to safe and affordable drinking water for all" under the sixth Sustainable Development Goal (SDG) (United Nations, 2015). Access to water is intrinsically linked to the attainment of good health and well-being – prominently featured in the 2030 Agenda for Sustainable Development under SDG 3. Achieving these ambitious goals requires collaboration between different sectors – including extractive industries.

Large resource extraction projects, such as industrial mines, are an important economic driver in many of the countries where water scarcity is an acute problem (Admiraal et al., 2017). The implementation of mining projects can have a positive effect on local water infrastructures through direct investments and local economic growth (von der Goltz and Barnwal, 2019). On the other hand, mining activities can increase the demand of local water resources or cause water pollution, and therefore, negatively affect access to clean water in local communities (Kemp et al., 2010; Schrecker et al., 2018). Rapid in-migration of job seekers to the often remote and rural areas can additionally strain the often weak water infrastructures and limited water resources (Pelders and Nelson, 2018). Hence, as a key determinant of health, changes on local water resources are closely interlinked with the health and well-being of affected populations (Marcantonio et al., 2021).

To assess these positive and negative impacts of large infrastructure projects on water resources and health, environmental impact assessments (EIAs) are conducted in virtually all countries in the world (Morgan, 2012). EIAs aim to determine how to mitigate potential negative environmental impacts along with maximising potential benefits for society prior to project development (Morgan, 2012). Hence, impact assessment can serve as a tool to engage mining companies toward the attainment of the 2030 Agenda for Sustainable Development (Winkler et al., 2020).

To inform impact assessment practice, it is important to better understand in which direction and to what extent water infrastructures are impacted in mining settings and ultimately how this affects the health of surrounding communities. To date, studies on the impacts of mining projects on water often focus on environmental effects, while the inclusion of health implications for surrounding communities remains weak. Particularly, research triangulating qualitative and quantitative data at both supra-national and local level data is scarce. In this paper, we utilized a mixed-methods approach to better understand how mining affects access to safe and affordable water and how this affects the health status of local communities in sub-Saharan Africa.

Methods

In the frame of a multi-country research project, we combined quantitative and qualitative data (Figure 8-1) (Farnham et al., 2020; Winkler et al., 2020). Quantitative data were used to analyse the trends in access to different water sources (i.e. piped water, wells, surface water) from a macro-level perspective. Based on qualitative data, water reliability and quality were described on a micro-level as perceived by affected community members. Together with insights from EIA reports, we triangulated all our findings to present a comprehensive overview of the complex and dynamic relationship between mining projects, water infrastructures and community health. The video at the core of this publication allowed us to embed our results in their geospatial context and to showcase linkages of the findings obtained at the different levels.

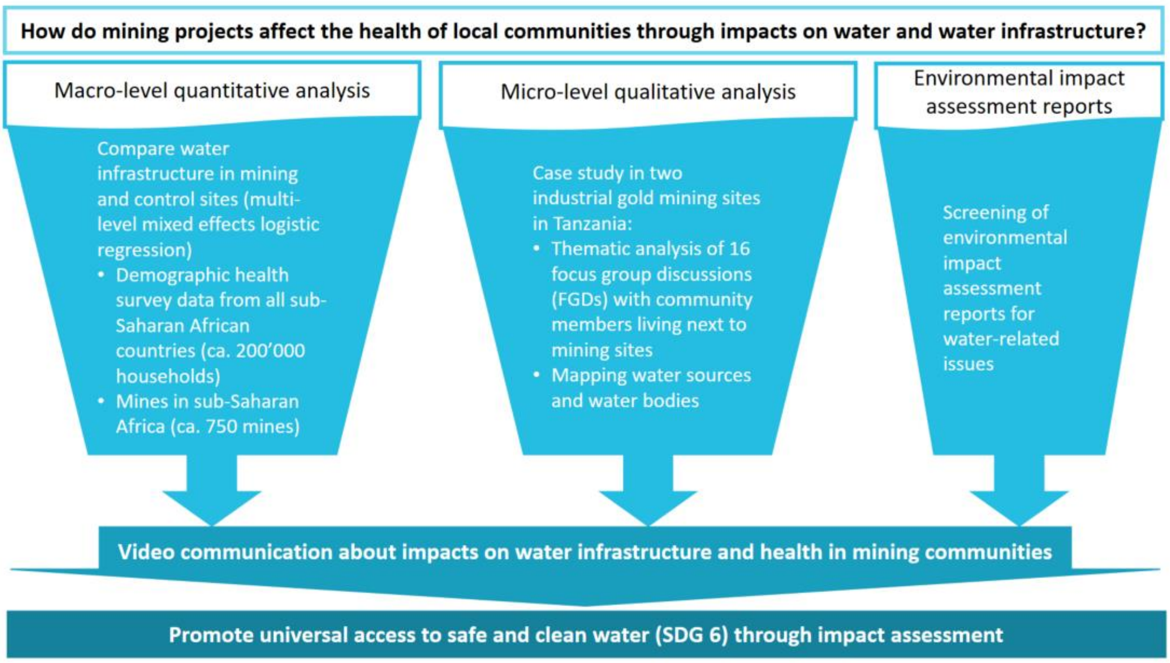

Figure 8-1 Overview of methodological approach to investigate and map water infrastructure for community health in mining settings (SDG: Sustainable Development Goal)

Macro-level: regional trends on water infrastructure around industrial mining sites

For quantifying the impacts of the mines on water infrastructure at the national and supra-national level, data from all Demographic and Health Surveys (DHS) conducted in 34 sub-

Saharan African countries were combined (Dietler et al., 2021). DHS data is generated through repeated standardized household surveys, allowing for comparison of access to water in mining areas both across and within countries over time.

The Standard & Poor's Global Market Intelligence Mining Database featuring all large mines in Africa was used to select the more than 189,992 DHS households located within a 100 km distance of an industrial mine (Dietler et al., 2021). The households were grouped depending on their distance to the mining site. Households located within a radius of 5 km from a mining project were classified as impacted. Households at a distance of 50-100 km from the closest mine were used as comparison group. Households located in larger cities were excluded from analyses. Using multi-level multinomial logistic regression models, the impact of proximity to a mine on access to water infrastructures and diarrheal incidence in the two weeks prior to the survey was analysed.

Micro level: perceived impacts on water and health of communities living around industrial mining sites

For better understanding the impacts of mining companies on local water infrastructure, we collected primary data in two industrial gold mining sites in north-western Tanzania. More precisely, we engaged with communities around the Buzwagi and Bulyanhulu Gold mine. Rooted in "Qualitative GIS" (qualitative geographic information system), we first conducted focus group discussions (FGDs), followed by a thematic analysis to extract statements related to water. Subsequently, we geo-referenced the water sources mentioned during the discussions (Lechner et al., 2019; Leuenberger et al., 2021).

Data triangulation and visualization

Based on the individual quantitative and qualitative research related to this work, we identified, extracted and combined findings on emerging water and health issues for this data triangulation. Additionally, we contextualised the findings with insights from EIA reports of the two mines in the selected study sites, which were systematically screened for water-related issues. We visualised our findings from the different data sources and levels of data analysis, including spatial components in a short video clip. This approach allowed us to contrast and contextualise our findings from the different levels by portraying the situation on the ground. The main purpose of our visualization was to create a tangible communication tool to present our mixed methods research approach and findings to a broad audience.

Results

Based on the quantitative data, we found that across all included countries in sub-Saharan Africa, households located closer to a mine were almost 4-times more likely to have access to modern drinking water sources, such as piped water, while relying less on surface water. However, stratified analyses revealed that mainly the wealthier households profited from these overall positive trends in mining regions (Dietler et al., 2021).

These findings from the DHS data analysis were mirrored by the qualitative data collected in two mining areas in north-western Tanzania (Leuenberger et al., 2021). In both study sites, the mine supported the construction of water access points, such as taps, pumps or drilled wells for surrounding communities. However, FGDs participants raised concerns about water accessibility. Additionally, we observed several abandoned or not operational pumps, which were originally implemented by mining companies. This confirms participants' notion on the lack of sustained improvements water infrastructure. Besides technical aspects, participants from both study sites reported negative impacts of the mining operations on the availability and quality of drinking water from traditional water sources, such as open wells and rain water collection systems. Further, they linked the scarcity of water and poor water quality with adverse effects on their health status. For example, some participants perceived an increase in diarrhoeal diseases due to the polluted water. On the other hand, quantitative data on the incidence of childhood diarrhoea shows no association between the location of the mines and incidence of diarrhoeal diseases (Dietler et al., 2021). This may be explained by the diversity of factors influencing diarrhoea incidence, including nutritional status, personal hygiene and access to safe drinking water and food.

Screening of the impact assessment reports of the two mining projects revealed that besides various community development initiatives, interventions related to water infrastructures were considered in both mining sites. Both reports included aspects related to water quality and availability in surrounding communities. However, the planned interventions to mitigate these impacts around the Buzwagi mine were more comprehensive compared to the Bulyanhulu mining project. Despite these mitigation plans, our results from the micro-level analyses suggest that communities around Bulyanhulu benefited more from investments in water infrastructure compared to the communities around Buzwagi. This indicates a potential gap between mitigation plans and actual implementations.

Conclusion and outlook

By combining quantitative and qualitative data, this study highlights differences in impacts of mining companies on water infrastructure and related health effects from a macro- and micro-level perspective. The triangulation of these different perspectives allowed us to identify pockets in society that did not profit from the overall positive impacts by the mines on water infrastructure. These developments could potentially be driven by direct investments by the mine, but also be the result of overall economic development and increased engagement of the local government in the water sector (Admiraal et al., 2017). Yet, more research is needed to better understand how positive impacts can be maximized and focussing on exposure pathways of local communities to these chemicals. Nevertheless, our results show that mines play a major role for both positive and negative impacts on water availability and quality for local communities and their health.

This data triangulation was realized within the frame of a larger research project, aiming to generate sound scientific evidence to promote the use of Health Impact Assessment (HIA) in sub-Saharan Africa (Farnham et al., 2020; Winkler et al., 2020). This visualization along with other audio-visual material was produced to communicate the multi-layered research results to a broad audience and facilitate an informed and effective policy dialogue. In particular, this vHealth communication can increase accessibility and raise awareness of public health science in traditionally non-health sectors. Reducing the barriers between different sectors and disciplines can foster intersectoral collaboration. This type of intersectoral collaboration between public health practitioners and researchers, international policymakers and local communities is key to achieving SDG 3 "Good health and well-being for all" and SDG 6 "Clean water and sanitation" by 2030.

Box 1: Motivation

- Create a tangible communication tool to present our mixed methods research approach and resulting findings to a broad audience
- Visualize and integrate different data sources and levels of data analysis, including geospatial aspects
- Show the different types of water infrastructures commonly found in mining areas on the African continent

Box 2: Software used

- Content visualization and animations: Microsoft Power Point 2016 (Microsoft Corporation, Edmond; WA, USA)
- Three-dimensional fly troughs: Google Earth Pro version 7.3.14507 (Google, Inc., Mountain View, CA, USA)
- Video editing: DaVinci Resolve 15 (Blackmagic Design, free download available here)

Story grid

#	Text	Image
1	This is *Buzwagi*. On this site a large gold mine was established in 2001.	- Buzwagi mine (far away shot filmed from the car)
2	Whenever large infrastructure projects, such as mines, are developed in a rural area, like *Buzwagi,* local communities experience changes in their social and physical environments. Positively, the mine can boost the local economy, or contribute to community development overall. Such changes could potentially improve community health and well-being in the long term.	- Picture of market/gold seller - Nice housing
3	Negatively, the arrival of a mine can also increase contamination of air, water and soil. This, and a rapid influx of people can add to the strain on often weak and overburdened public infrastructures. When infrastructures are under strain, diseases spread more.	- Mine (GGM) - School with many children (e.g. BF)
4	One factor large mines can positively and negatively affect is local water infrastructure. Clearly, safe and clean water is key to good health and well-being.	- Woman pumping water in BF
5	Before such big projects are developed, their potential impacts should be assessed. So called "impact assessments" identify positive and negative impacts, including health aspects. The final impact assessment report includes a mitigation plan. The aim of such a mitigation plan is to minimize negative impacts and maximize potential benefits for local communities.	
6	Where natural resources are extracted assessments show if the impact on the water infrastructure is positive or negative and	- Water/dam where kids are playing

	how big these positive and negative impacts are. Ultimately, the impact assessment shows how the new mine affects the local water and how this affects the health of communities. To understand these connections, we combine quantitative and qualitative data.	- Top box of methods overview figure
7	With the quantitative data we analyze the settings from a macro-level. This is complemented by micro-level qualitative data. To quantify the mines' impacts on water infrastructure at the national and supra-national levels, we combined data from all Demographic and Health Surveys, short DHS, in sub-Saharan Africa.	- Rest of methods overview figure animated
8	We then used another dataset, featuring all large mines in Africa to select approximately 200'000 households located in proximity to a mine. Using regression models, we analyzed the impact of having a mine nearby.	- Rest of methods overview figure animated
9	To better understand the impacts of mining projects on local water infrastructure, we visited two industrial gold mining sites in northwestern Tanzania. In villages around the Buzwagi and Bulyanhulu Gold mines, we engaged with community members.	- Research team in a car (on a shaky road)
10	One year later, we visited the villages again to map and observe water sources and water bodies mentioned by the community members.	- Figure: Methods overview (animated)
11	Additionally, we screened Environmental Impact Assessment reports for water related issues.	- Figure: Methods overview (animated)
12	The quantitative data showed that the mines had a positive impact on water infrastructure across all included countries in sub-Saharan Africa. The closer the households were to a mine the more improved water sources, such as piped water, were available. Overall, the households in the first 5 kilometers from a mine were around 4-times more likely to have access to piped water than households further away. However, these benefits were not distributed equally, with poorer households profiting less.	- Far-away GE imagery highlighting the countries that were covered with DHS data - (pop-up) Graph showing percentages of different water sources by distance
13	The same pattern exists when focusing only on Tanzania.	- Zoom to Tanzania (whole country) on GE

14	These findings from the DHS data were mirrored by the qualitative data from our visits to Buzwagi and Bulyanhulu. In both sites the mine installed or financially supported many different water access points for surrounding communities. These included taps and pumps. Zooming to the two sites, we see the locations of some of these investments.	- Zoom to Buly+Buzwagi, potentially explaining the colours and symbols in the narration
15	Community members living around the Bulyanhulu mine said how important new and reliable drinking water sources, such as taps and drilled wells, were.	- Bulyanhulu taps
16	For example, one participant told us: *there is a drilled well also constructed by the mining company and we are using water from this well for drinking. Also the well is fenced and there is a tap, it is a modern one.*	- Bugando source video with quotation showing up
17	Around the Buzwagi mine, more than a dozen new pumps were installed in several villages. However, participants reported that some pumps are not operational and we found several pumps abandoned.	- Buzwagi and Iboja Pump (Buzwagi site)
18	Besides technical aspects, participants from both sites reported negative impacts on the water availability and quality. They described that their wells are dried-up and suspected the reason was that the mine needs more water. More importantly, they complained about the poor water quality. They said the water in their wells is smelly, salty or oily. According to the participants, chemicals get into their unprotected wells through the air or penetrate their water sources underground.	- Julius well
19	They said: *Through blasting activities where the water from the poison dams can penetrate underground and enter in our water sources.*	- Same as above: video continues, quotation showing up
20	Also, local residents were afraid to use the rain water, which they traditionally collect as drinking water. Blasting in the mines sends black particles into the air that land on their roofs. This dust is washed directly into their water collecting systems.	- Rainwater collection system (Chapulwa Primary School)
21	In the words of a participant from Kakola Number 9: *You cannot fetch rainy water because it is black*	- Quotation showing up

	because of the dust stacked on the roof, you cannot drink it.	
22	Further, participants linked these problems with the water to their health. As another participants said: *The water is not safe […]. That water causes miscarriage, causes diseases like urinary tract infections and stomach diseases, so we do not trust the water that we use.*	- More images from water sources/water fetching - Same as above: video continues, quotation showing up
23	We then wanted to know if better results can be explained by better mitigation plans in impact assessment. But when we looked at the impact assessment reports of the two mining projects we saw that this was not the case. Both reports included aspects related to water quality and quantity. But the outcome in Bulyanhulu was better even though the mitigation plan in the Bulyanhulu report covered less than the Buzwagi-report.	- Methods figure - Tap with woman Acacia
24	To sum up, this study combined quantitative and qualitative data, and offered macro- and micro-level perspectives. The findings indicate different impacts of mining companies on water infrastructure and on health. From the macro-perspective, we found overall positive impacts of mines on local water infrastructure. So, water infrastructure around mining projects is more developed compared to non-mining regions. On the other hand, both the macro and the micro-level analysis showed that there are pockets in society that do not profit from these positive impacts.	- Figure: methods – now with visuals from findings (graph, wells)
25	Although the mines build new water access points, availability and access to clean water is still a major issue. Particularly when the mine uses chemicals that pollute the environment, this is a major concern for the residents of the surrounding communities. Taken together, we can conclude that mines play a big part in both positive and negative impacts on water for local communities and their health.	- Dirty dam
26	Impact assessment could be a promising tool to manage these impacts. Our results point out that this tool should be used to address communitie's needs in an equitable manner – this includes the health and well-being of the most vulnerable	- ASGM community meeting Ghana

	populations. Most importantly, anticipating future impacts is not enough. In addition, ongoing and collaborative management and monitoring are essential to ensure any positive effects.	
27	In the spirit of the 2030 Agenda for Sustainable Development – “leave no one behind” - inclusive impact assessment of mining projects together with community liaison activities could make it possible to strive towards universal access to water for all as a key element for health and well-being.	- Woman riding off with jerry can on her bike - SDG Wheel

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8.2 Digital storytellers videos

8.2.1 Video: A Multidisciplinary Approach to Researching Health Impacts of Large Mines - Community Voices

Link to video: https://www.youtube.com/watch?v=yznfib03nj8& (produced in collaboration with Andrea Leuenberger)

Figure 8-2 Screenshot of digital storytellers video on the overarching "Health impact assessment for sustainable development" (HIA4SD) project

8.2.2 Video: How can community health around large mines be improved? - Community Voices

Link to video: https://www.youtube.com/watch?v=sj6v5FMYVVI&t

Figure 8-3 Screenshot of digital storytellers video on the perceived health impacts in mining communities in Burkina Faso

9 Discussion

The aim of my PhD thesis was to assess the impact of mining projects in SSA on EDH and associated health outcomes in affected communities. The four manuscripts presented in Chapter 4-7 and published in or prepared for publication in the peer-reviewed literature, build the core of the thesis. The papers detail the potential direct and indirect pathways of mining projects on EDH and associated health outcomes (Chapter 4, 5, and 0) as well as a review studying how health is addressed in impact assessment reports (Chapter 7). In addition, the development of a vHealth communication piece and two short video clips provide further perspectives on health issues in mining areas from the field missions in the frame of the overarching HIA4SD project (Chapter 8).

The discussion of the findings from these manuscripts starts with reflections on the impacts on settlements and access to essential infrastructures, such as quality housing and improved water and sanitation infrastructures (Section 9.1). In Section 9.2 follows a discussion on the different pollutants mining populations are potentially exposed to within and around their houses. The next Section (9.3) draws the link to the different health outcomes that are associated with the EDH that were investigated in this PhD project. Against the findings on the diverse impacts on environmental health and the results from the screening of impact assessment reports, Section 9.4 contrasts the current state of impact assessment against its five core values. This includes reflections on the suitability of the data used in this PhD project for impact assessment and a broader discussion on the relation of mining projects with the 2030 Agenda for Sustainable Development. The next section draws overall conclusions of the thesis and proposes options on how impact assessment practice could be further improved for unfolding its full potential (Section 9.5). Lastly, potentials for further research are outlined in Section 9.6.

Together and individually, the activities under this PhD project contribute to the value chain promoted at Swiss TPH – from innovation and validation to application. Innovation corresponds to the development of new tools and methods. Validation refers to the testing of such tools and methods in real-world settings. In the application step, the rigorously validated tools, methods and concepts are integrated in the health system or transformed into policies. The contributions of the different manuscripts developed under this PhD project to the core activities of Swiss TPH are summarized in Table 9-1.

Table 9-1 Contributions of the different manuscripts developed under this PhD project to the core activities of Swiss TPH: innovation, validation and application

Chapter	Innovation	Validation	Application
4: Migration	- Development of an approach for annual quantification of settlement growth using only freely available data	- Testing and fine-tuning of the workflow on one mining site	- Application of method in three other mining sites in Burkina Faso
5: Housing infrastructures and indoor air pollution		- Combination of large datasets for impact evaluation at the continental-scale	- Findings will inform and facilitate policy dialogue to promote the use of HIA
6: Water and sanitation infrastructures			
7: Health in impact assessment practice	- Innovative approaches to gather impact assessment reports through semi-systematic Google search and contacting schedule for companies - Development of a framework and a screening methodology to efficiently assess the inclusion of health in impact assessment reports	- Validation of suitability of the different approaches to obtain impact assessment reports	- Findings will inform and facilitate policy dialogue to promote the use of HIA
8: vHealth communication on water infrastructures in Tanzania and other video materials	- Triangulation of quantitative and qualitative findings - Visualization of research findings using modern communication techniques		- Application of a qualitative GIS approach to contextualize findings from FGDs in the broader environment - Development of communication tools for use in the policy dialogues, stakeholder meetings and teaching

9.1 Impacts of mining projects on overcrowding

The potential for rapid in-migration of job-seekers to mining sites has been described by different case studies as well as international guidance documents for HIA (IFC, 2009b; Jackson, 2018). These dynamics can overburden public infrastructures and lead to the establishment of overcrowded informal settlements comprised of makeshift housing with little access to services promoting environmental health, such as water and sanitation infrastructures (IFC, 2009b; Marais et al, 2018; Pelders & Nelson, 2018). Surprisingly, in our analyses, such overcrowding effects were not observed. Firstly, no marked differences in population growth rates between mining and comparison areas were observed and secondly, household sizes were comparable between mining and comparison sites. On the contrary, even positive impacts on settlements were observed. Households in close proximity to mining projects were characterized by increased use of finished construction materials and improved access to essential services, such as improved water and sanitation. However, it is possible that overcrowding effects are mainly seen in specific areas around mining projects, such as villages where mine employees are recruited, which are not readily detected at the large-scale in household survey or satellite data.

Many countries in SSA are facing the challenge to provide adequate housing and living conditions (World Bank Group, 2015). This challenge is likely to be further exacerbated by the overall growing population on the sub-continent (UN, 2019). Indeed, SSA is expected to account for the largest population growth in the world in the next decades (UN, 2019). As the significance of the mining sector is likely to grow in the future, these positive associations between mines and housing infrastructures are promising for the work towards more healthy living environments (World Bank, 2017).

Wealth emerged as a potential mediating factor for the positive impacts of mining projects on the different infrastructures. In the statistical models, the level of wealth explained a large part of the variation in the infrastructure indicators. Potentially, jobs created by the establishment of a mine increase household wealth overall (Gamu et al, 2015; von der Goltz & Barnwal, 2019; Wegenast & Beck, 2020). Since mines also create secondary markets for food vendors or small-scale service providers, these benefits could even be shared beyond the directly employed workforce (Gamu et al, 2015; Loayza et al, 2003). Household wealth in turn has been found to determine access to better housing and other infrastructure promoting environmental health, such as improved water and sanitation facilities (Armah et al, 2018; Tusting et al, 2019; Zeeb et al, 2017). Overall, our findings add to the current scientific and political debate on whether producer regions benefit from the extraction of their natural resources. While we do not draw the direct link between mining and wealth, our results nevertheless point at important non-financial benefits for households in mining regions. Yet, in all these associations, ASM operations can also play a significant role (Langston et al, 2015). However, in the absence of comprehensive and reliable data on the ASM-sector, an evaluation of their specific contribution to overall wealth is challenging.

The central role of wealth also sheds light on the population groups that are left behind in these overall positive developments in mining communities. Indeed, among the poorer households, no positive impacts on construction materials and sanitation infrastructures were observed, while the improvements in water infrastructures were less pronounced than among the wealthier households. The overall positive trends seen in clustered data from nationally representative household surveys may mask the potentially adverse effects among some subgroups within the communities. The establishment of an industrial mining project may trigger two opposing dynamics in the development of settlements among the poor. On the one hand, the mines can contribute to local economic benefits and can lift some less affluent households out of poverty and thereby trigger improvements in housing quality and infrastructures (Gamu et al, 2015; von der Goltz & Barnwal, 2019). On the other hand, the households in mining areas that remain poor after mine opening are left out from overall positive developments and migrants who settle in informal dwellings may even live in worse environmental conditions than elsewhere (Bury, 2005; Marais et al, 2018). Particularly people in informal settlements in mining areas who are not employed by the mine are more likely to be marginalized from access to essential infrastructures (Marais et al, 2018). Such differences in impacts in housing and water infrastructures were also observed on the field missions to Burkina Faso and for the production of the vHealth communication video clip in Tanzania (see Figure 9-1, panel A). For example, communities that were initially located on the mining premises were resettled to modern brick houses that were regularly maintained (houses shown in the video in Section 8.2.2), while the brick walls of households located right outside the fence-line of the mine often got destroyed as a consequence of the vibrations from the mining operations (see Figure 9-1, panel B). Overall, these findings underline the importance to stratify population groups for studying impacts on potentially vulnerable population groups and to promote environmental health equity in mining areas (Leuenberger et al, 2019).

Figure 9-1 Water sources in a mining village in northern Tanzania (panel A; © Fadhila Kihwele); destroyed brick houses located in close proximity to an industrial mine in Burkina Faso (panel B; © Dominik Dietler)

Apart from indirectly promoting improvements in housing infrastructures and access to water and sanitation through changes in local household economies, mining projects also have different direct entry points for fostering community development (Admiraal et al, 2017; Littlewood, 2014). Firstly, they can provide housing infrastructures to mine workers or for resettled communities (Cloete & Marais, 2020; Knoblauch et al, 2020b; Pelders & Nelson, 2018). Secondly, mines can engage in community development through their CSR activities (Gardner et al, 2012; Littlewood, 2014). These could include, for example, funding of drinking water or sanitation infrastructures (Littlewood, 2014). The analyses of the changes in different household indicators in mining areas showed that particularly water infrastructures improved rapidly after mine opening while improvements in housing and sanitation infrastructures occur after some years of operation. Furthermore, among poorer households, only access to modern water infrastructures improved significantly. This could be an indication that mining companies directly invest in water infrastructures, while housing and sanitation infrastructures are predominantly financed through wealth gains accumulated over longer periods.

However, CSR initiatives also have potential pitfalls (Gardner et al, 2012; Littlewood, 2014). Firstly, sustainability of these investments can be challenging, if the financial means and sense of ownership among the community and other stakeholders are lacking (Campbell, 2012; Littlewood, 2014). Particularly when mining activities cease, infrastructures funded through CSR initiatives are often not maintained (Littlewood, 2014). Top-down planning of CSR activities with little involvement of local communities are root causes of unsustainable interventions (Campbell, 2012; Littlewood, 2014; Mutti et al, 2012). The large number of dysfunctional and abandoned water pumps found in the mining sites in northern Tanzania could be an indication of such shortfalls. Secondly, access to modern drinking water sources does not necessarily guarantee that the water is free from contamination (Kolala & Bwalya

Umar, 2019). The observations in the field mirror these shortfalls. In the FGDs conducted with local residents in mining sites in Tanzania, quality concerns were frequently reported. Similarly, in Burkina Faso, local residents in a resettled community with mine-funded drinking water wells feared infiltration of chemicals from the mine into ground water aquifers. In summary, direct investments in infrastructures, such as water infrastructures, clearly are a potent means of promoting environmental health in mining areas. However, these need to be carefully planned in collaboration with the affected populations in order to address their specific needs and ensure sustainability.

9.2 Impacts of mining projects on environmental pollution in and around households

Improvements in key factors determining environmental pollution improved significantly stronger in mining communities compared to other areas. These include factors affecting drinking water safety, such as the availability of piped water sources and improved sanitation facilities, as well as the use of cleaner cooking fuels reducing potential indoor air pollution emissions. However, the potential improvements in indoor air pollution through the increased use of clean cooking fuels may be offset by increased smoking rates inside houses in mining areas. Nevertheless, these developments show that mines can also positively affect environmental quality through indirect effects. These can potentially counteract some of the negative impacts of mines on water and air pollution that are extensively described in the literature (Herrera et al, 2016; Kemp et al, 2010).

Water and air pollutants from the mines are not directly comparable with pollutants from community sources though (Weiss et al, 2016). With regards to drinking water, the pollutants of concern in areas with low access to improved water and sanitation infrastructures constitute predominantly of microbial contaminants (Back et al, 2018; Bain et al, 2014; Cho et al, 2016). Water pollutants from mining sites primarily include chemical pollutants, such as cyanide, sulfuric acid and heavy metals (Knoblauch et al, 2020a; Schwarzenbach et al, 2010; Weiss et al, 2016). Similarly, the chemical profiles can differ between indoor air pollutants and mine-related air pollution, depending on their sources (Aneja et al, 2012; Lai et al, 2019). The diverse air and water pollutants in mining sites pose different environmental and health risks (Manisalidis et al, 2020; Schwarzenbach et al, 2010; Weiss et al, 2016). It is therefore crucial to comprehensively consider all sources of air and water pollution, both at the mining site and within affected communities, for environmental management of mining operations (Ndombe et al, 2007).

The impacts on the community sources of environmental pollutants, such as the use of traditional cooking fuels with unimproved cooking stoves, indoor tobacco smoking or open defecation, were not evenly distributed across the socioeconomic strata. It is likely that the households being excluded from the positive developments in the communities are spatially clustered, potentially in informal settlements or in low-quality worker camps (Cloete & Marais, 2020; Pelders & Nelson, 2018). For example, studies showed that people with poorer educational attainment are less likely to use clean cooking stoves (Wolf et al, 2017). This could lead to pollution hotspots among marginalized households characterized by increased health risks from environmental pollution. However, air and water pollutants do not remain at their source but can disperse through water bodies, soils or by wind (Back et al, 2018; Lai et al, 2019; Ndombe et al, 2007). The formation of such pollution hotspots may therefore also affect the wider community, even if they are characterized by overall increased access to infrastructures, such as modern toilets or clean cooking fuels.

Furthermore, industrial mining sites are often flanked by ASM sites. Being subject to less governmental oversight, ASM can add to the environmental health burden for the surrounding communities (Dietler et al, 2020; Knoblauch et al, 2020a). The unavailability of comprehensive data on ASM operations and the limitations of spatial information in the DHS data (artificially introduced errors in GPS coordinates and aggregation of households into clusters) do not allow to test for such small-scale spatial relationships between the different pollution sources (Elkies et al, 2015). Hence, more spatially disaggregated data is needed to facilitate research on the spatial distributions of the exposure to environmental pollutants from mining and non-mining sources.

9.3 Impacts of mining projects on environmental health outcomes

In light of the overall improvements in housing quality, the increased access to water and sanitation infrastructures and the more widespread use of clean cooking fuels, positive impacts on child health indicators would be expected (Fink et al, 2011; Gakidou et al, 2017; Tusting et al, 2020). At the same time, the increased prevalence of indoor tobacco smoking in mining households could pose negative impacts on respiratory health (Öberg et al, 2011). In our analysis, a reduction in stunting and undernutrition among children in mining areas was observed, which is in line with the findings from another large-scale analysis of child data in mining areas (von der Goltz & Barnwal, 2019). However, no clear patterns in other health indicators, such as wasting, diarrhea or symptoms of acute respiratory infections were observed. Potential reasons for the absence of some of these associations are manifold, including potential bias, lack of statistical power and counteracting impact pathways.

In general, the data used for health indicators were derived from DHS datasets. While the DHS survey design aims to ensure comparability between countries and over time, local concepts and understandings of the different diseases can vary (Manesh et al, 2007; Schmidt et al, 2011). Moreover, reporting of child morbidity increases with higher maternal education and with increased access to improved water sources (Manesh et al, 2007). Hence, there is a risk of diarrheal diseases and symptoms of acute respiratory diseases being underreported by the poor and marginalized households in mining areas. This source of bias is likely to have led to an underestimation of potential improvements in these child health outcomes.

Another issue with DHS data is the accuracy of the geographical coordinates for the sampling clusters. The coordinates are displaced from their true location by up to 2 km for urban clusters and up to 5 km for rural clusters (with up to 10 km positional error for an additional 1% of rural clusters) (USAID, n.d.). As a consequence, the average distance between the clusters and the mines is systematically overestimated (Elkies et al, 2015). These errors could have led to some clusters crossing the boundaries between areas that were classified as impacted or used as comparison in the statistical analyses. The resulting point estimates are expected to be underestimations of the true effects of mining projects on the different health indicators (Elkies et al, 2015).

Apart from these potential sources of bias in the DHS data, the health outcomes considered in this study can also be impacted by the environmental health risks posed by ASM operations (Dietler et al, 2020; Knoblauch et al, 2020a; Kyaw et al, 2020). Exposure to highly toxic chemicals, such as mercury or lead, has been shown to hamper child development (Bansa et al, 2017; Gibb & O'Leary, 2014; von der Goltz & Barnwal, 2019). Further, poor pulmonary function and high levels of respiratory diseases have been found in miners and non-miners (Knoblauch et al, 2020a; Rajaee et al, 2017). Lastly, diarrheal risks from poor sanitary conditions in ASM sites have been reported (Yakovleva, 2007). Such negative impacts of ASM activities may in part have counteracted the potentially positive health impacts from the improvements in infrastructures in mining communities.

Other than ASM, disease-specific impact pathways for the different health outcomes in industrial mining areas may also play a significant role. For child nutrition for example, the shift of economic activities away from subsistence farming can reduce agricultural productivity due to environmental pollution and the increase in food prices can reduce food security in industrial mining areas (Aragón & Rud, 2016; Wegenast & Beck, 2020). Indeed, reduced food availability among women and decreased food diversity among children in mining areas have been observed (Wegenast & Beck, 2020). Furthermore, resettlement to clear land for resource extraction can strip rural communities that predominantly live from subsistence farming off their livelihoods (Andrews, 2018). Such concerns were also expressed by the local residents in a resettled village during the field visits in Burkina Faso. While they acknowledged the provision of quality housing and drinking water, they lost their fertile agricultural land as important source of food and income (see video in section 8.2.2). For respiratory diseases, the negative impacts of air pollutants from the mines and the observed increases in indoor smoking rates could oppose the potentially positive effects of the increased use of clean cooking fuels (Hendryx & Luo, 2014; Herrera et al, 2016; Nkosi et al, 2020). For diarrheal risks, having piped water sources does not necessarily mean that the water provided is safe to drink (Bain et al, 2014). Due to the different codes used to describe water sources in DHS data, the classification into basic, intermediate and modern water sources potentially clustered some improved and unimproved sources together (UNICEF & WHO, 2017). Although, a large-scale comparison of fecal contaminants in different water sources showed overall quality improvements in piped water (Bain et al, 2014), a case study in a Zambian mining community found high levels of pollution in piped water provided by the mine (Kolala & Bwalya Umar, 2019). Furthermore, the capacity of wastewater treatment systems, hygiene practices, as well as the transport, storage and treatment of drinking water can potentially affect the risk for diarrheal disease from drinking water in mining regions (Prüss-Üstün et al, 2016; Wolf et al, 2018).

In summary, the pathways through which the environmental determinants interact with the other determinants of health and ultimately shape health outcomes in industrial mining areas are highly complex. Further, ASM operations that are often located close to these sites can potentially further exacerbate the environmental health risks. The absence of improvements in some health outcomes, despite the overall improvements in underlying environmental determinants, underscores the importance to consider these diverse pathways when managing potential impacts of mining projects to foster their full potential to promote progress towards SDG 3. However, further research is needed to determine the direction and magnitude of the impacts of mining projects on these alternative pathways.

9.4 Shortcomings in addressing health in current impact assessment practice

The variation in environmental health impacts of industrial mining projects between countries and between socioeconomic strata within mining communities raises the question about the policy and regulatory context in which these projects operate. Policy makers can draw from impact assessments for informed decision-making in the licensing phase of mining projects (Harris-Roxas et al, 2012; Winkler et al, 2021). Impact assessment is an approach to identify and minimize adverse impacts on affected communities, while maximizing potential opportunities (Harris-Roxas et al, 2012; Winkler et al, 2021). In the following sections, the shortcomings identified through systematically screening impact assessment reports of mining projects are discussed in light of the findings from the analyses on mining-related impacts on of the EDH and associated health outcomes. The discussion is guided by the currently revised five guiding principles of HIA (Quigley et al, 2006; Winkler et al, 2021).

9.4.1 Comprehensive approach to health

As one of the five guiding principles of HIA, "comprehensive approach to health" demands for the consideration of the wider determinants of health as well as their inter-relationships in the impact assessment process. In current impact assessment practice of mining projects in SSA, there is a strong focus on the physical environment. Health outcomes were only marginally considered and limited to a few topics, such as human immunodeficiency virus (HIV) infections, accidents, diarrheal diseases, malaria, malnutrition or respiratory infections. Hence, some environmental health issues are indeed covered in current impact assessment practice. Still, there are three major shortfalls in regards to how environmental health aspects are included in impact assessments. First, in relation to other health outcomes, some environmental health outcomes are commonly addressed in impact assessments. However, still the share of impact assessment reports failing to mention these health outcomes at all in any part of the report was around a quarter for diarrheal diseases, a third for acute respiratory infection and about half of the reports for malnutrition. Second, the assessment was mostly limited to a baseline description of these health outcomes, predominantly relying on secondary data from routine health surveillance data or national statistics. Third, an assessment of the likely impacts of mining projects on health outcomes through changes in health determinants were less common. These shortcomings may also serve as an explanation for the lack of associations between the mines and some of the associated health outcomes in the analyses of the manuscripts in Chapters 5 and 0.

It is therefore important to thoroughly assess the different pathways between the mining projects and these health outcomes. Furthermore, the dispersion of environmental pollutants underlines the importance of assessing the spatial dimensions of these diverse impacts (Ndombe et al, 2007). Water safety planning (WSP) and sanitation safety planning (SSP) could help linking the water-related EDH with associated health outcomes (Bartram et al, 2009;

WHO, 2016b). The aim of these approaches is to identify the diverse health risks of water pollution along the entire water supply and sanitation chain (Winkler et al, 2017). Although WSP and SSP are commonly initiated by drinking water and sanitation service providers, mining companies could integrate concepts of these approaches in the impact assessment process (WHO, 2016a; b). The application of some of the steps of WSP and SSP, such as the systematic characterization of the water and sanitation system and identification of potential exposure groups within the community, could serve as a baseline for subsequent prospective assessment of potential impacts of mining projects on these pathways. This could also include the potential risks from ASM operations in close proximity of industrial mining operations (Kyaw et al, 2020). The considered communities include not only drinking water consumers, but also the downstream users of wastewaters, such as farmers who are potentially affected by changes in sanitary conditions in mining areas (Aragón & Rud, 2016; Winkler et al, 2017). Hence, similar to the impact assessment approach, WSP and SSP can be means to engage different stakeholders along the water and sanitation chain in the design of suitable management plans (Winkler et al, 2017).

Addressing health comprehensively as a complex cross-cutting theme in HIA requires broad public health expertise (Harris-Roxas et al, 2012; Winkler et al, 2020). However, technical capacity among impact assessment practitioners is limited globally (Chilaka & Ndioho, 2020; Winkler et al, 2020). Furthermore, studies show that the health sector is only marginally included in the impact assessment process and that the awareness and capacity for conducting HIA among health professionals is low (Chilaka & Ndioho, 2020; Fischer et al, 2010; Winkler et al, 2013). Hence, promoting a comprehensive approach to health in impact assessment in SSA needs to go hand-in-hand with initiatives for strengthening technical capacities of practitioners to conduct HIA (Harris-Roxas et al, 2012; Povall et al, 2013; Winkler et al, 2013). In addition, increased HIA capacity building among policy makers and regulators involved in the revision of impact assessment documents is needed for judging the adequacy of the scope of the health aspects considered (Harris-Roxas et al, 2012; Povall et al, 2013).

To promote a comprehensive consideration of health in impact assessment, regulatory mechanisms and technical guidance are needed. For industrial mining projects, the integration of health impacts in the impact assessment process is required by international funding organizations, such as the IFC or the members of the EPFI (IFC, 2012; The Equator Principles Association, 2020). They further promote a broad inclusion of health aspects through their HIA guidance (IFC, 2009a). Hence, the IFC could use its leverage to more specifically determine and enforce a comprehensive scope in HIA. However, given the increasing role of investors in the mining sector in SSA that are not committed to the IFC performance standards, resource-rich countries should critically reflect whether their regulatory and legislative frameworks promote sufficient consideration of health in the management of resource extraction projects (Harris-Roxas et al, 2012; Krieger et al, 2012).

9.4.2 Equity and equality

The evidence of the stratified analyses and the triangulation with qualitative data showed that, while overall positive impacts on infrastructures prevail, still some population groups, particularly the poor, do not benefit equally. These findings could potentially be an indication of a limited consideration of the specific needs of vulnerable populations in HIA described in the literature (Buse et al, 2019; Leuenberger et al, 2019). A recent review showed that equity concerns in the scientific HIA literature are predominantly focused on describing socioeconomic health differentials, rather than aiming to understand the underlying causes for these inequities (Buse et al, 2019). Such information would, be crucial for developing tangible solutions for promoting health equity in mining areas.

The analysis of the DHS data underlined that caution has to be taken when quantifying impacts at a higher geographical scale. While these overall associations provide valuable insights on the impacts at the population level, the aggregation of data can potentially conceal specific impacts on small population subgroups. For the assessment of the different health impacts on vulnerable populations, spatially (e.g. relative location to the mine and informal settlements) and socially (e.g. socioeconomic strata) disaggregated data are needed (Leuenberger et al, 2019; Povall et al, 2013; Winkler et al, 2011). The experiences from the application of a "qualitative geographic information system (GIS)" approach, triangulating qualitative and quantitative data with spatial information, highlighted the potential for generating an increased understanding of the particular concerns of affected communities (Lechner et al, 2019).

9.4.3 Participation

The guiding principle on "participation" of HIA calls for an active involvement of affected populations, including their right to be informed and influence decision-making processes (Winkler et al, 2021). It connects to the equity principle by promoting community engagement, a key tool for promoting health equity in the impact assessment process (den Broeder et al, 2017).

Transparency in the impact assessment process is another aspect of ensuring involvement of affected communities (Winkler et al, 2021). As outlined in Chapter 7, transparency seems to be an issue in impact assessment practice in SSA. Increased transparency has the potential to, at least in theory, increase accountability of resource extraction projects for their environmental and social performance (Aung, 2017; Li, 2009). The lack of completeness of potential health impacts outlined in the executive summaries of impact assessment reports warrant to expand disclosure requirements to include the full impact assessment reports. The IFC, having a leading role in setting international benchmarks for environmental, social and health management standards, could spearhead such regulatory changes (Franks & Vanclay, 2013; Krieger et al, 2010). While the full impact assessment reports are technical, and hence, predominantly of interest to researchers or advocates, alternative forms of communication can be suitable for conveying the findings of impact assessments to affected communities. Modern communication materials, such as the videos produced as part of the digital storytellers program, could be useful for spreading the results from impact assessments to a wider audience.

9.4.4 Ethical use of evidence

For informed decision-making on the design and management of mining projects, evidence on their likely impacts needs to be generated synthesizing different information sources and using sound methodologies. Currently, impact assessment practice relies predominantly on secondary data sources for health outcome indicators, while environmental factors, such as air and water pollution, are commonly measured in the field using a variety of sampling techniques. In this PhD thesis, different data sources and methodologies were tested for quantifying the impacts of mines on EDH at the household-level and associated health outcomes. The following paragraphs include a reflection on the suitability of using such data as a baseline or as monitoring data in impact assessment.

Satellite imagery was used to quantify changes in settlement growth. In the absence of reliable information on population dynamics, such remote sensing approaches could provide valuable estimates to monitor the extent of mining-related in-migration (Tatem, 2014). However, the current workflow using Landsat and Google Earth imagery achieved only satisfactory accuracy levels under certain conditions. While the satellite data sources were the most suitable data sources for retrospectively tracking settlement patterns in the past, newer imagery sources, such as from the Sentinel-2 mission, could be useful for prospective impact assessment. However, new research is needed to test, whether the higher ground resolution of Sentinel-2 allows for more accurate detection of settlement growth in rural locations, such as mining sites (Wulder et al, 2015). Furthermore, the identification of suitable data for training data generation using historic Google Earth imagery was laborious for some remote study sites. Hence, currently, there is limited applicability for land-use classification for impact assessment practice. Nevertheless, image repositories are continuously built up with higher-resolution imagery, which could be promising for remote sensing to be a viable approach for prospectively tracking settlement growth in the future (Schug et al, 2018).

Another potential application for remote sensing techniques is air pollution monitoring (Beloconi et al, 2018; Beloconi & Vounatsou, 2020; Hammer et al, 2020). Exploratory analysis in the preparation of the manuscript presented in Chapter 5 revealed that remotely sensed ambient air pollution data did not capture increases in mining sites. The differences in air pollution levels were likely to be too small to create a large enough signal in estimates of average annual fine particulate matter ($PM_{2.5}$) levels at a resolution of 1 km, particularly in areas where dust from the Sahara desert constitutes a large fraction of the air pollutants in the air (van Donkelaar et al, 2016). Data on air pollution collected by most of the mines either at baseline or during subsequent monitoring could be more insightful. Public disclosure of such data could not only increase the accountability of the companies, but would also open potentials for research to combine ambient air pollution data with information on indoor air pollution sources establishing their different roles in determining respiratory health in mining areas.

Household and health indicators from DHS surveys are potent secondary data sources for impact assessment and have been used as baseline indicators in some of the screened impact assessment reports. The wide implementation of these surveys, the broad set of indicators and the geospatial information provided with the DHS data rendered the dataset useful for the impact evaluation studies. However, the spatial error hampers its applicability for providing reliable data on specific potentially affected communities for impact assessments of individual mining projects. Such data is needed for identifying and mitigating the varying impacts on different population groups (Povall et al, 2013). Hence, for promoting health equity in mining communities, collection of primary data through participatory qualitative research or household surveys are more suitable (Leuenberger et al, 2019; Winkler et al, 2012a).

Data from routine health information systems, such as the District Health Information System 2 (DHIS2), could have potentials for monitoring selected health indicators over time (Farnham et al, 2020b). Today, the system is used in more than 70 LMICs (DHIS2, n.d.). However, currently three potential shortfalls limit its usefulness for monitoring health in mining areas. Firstly, accessibility of data in a format and quality for use in scientific analyses is a challenge, additionally hampered by limited internet connectivity (Farnham et al, 2020b). Secondly, definitions of indicators can change over time (Farnham et al, 2020b). Exchanges with local administrators of the DHIS2 platform in Burkina Faso underscored the importance of contextual knowledge for understanding the unique properties of the different health indicators. Thirdly, some of the indicators include raw case counts for the different disease conditions in a specific district. While this kind of data is crucial for health system management, information on the population denominator is necessary in order to study trends over time in areas with potential high fluctuation in district population (Tatem, 2014). If these shortcomings could be overcome, the system has great potential for informing impact assessment practice (Farnham et al, 2020b).

In summary, secondary data have potential for some aspects of impact assessment and subsequent monitoring. However, when focusing on individual projects and for identifying vulnerable population groups, the scope and depth of information that can be obtained through primary qualitative and quantitative data collection in the field remains uncontested.

9.4.5 Sustainability

HIA can help to guide decisions that ultimately help advance the work towards the health-related SDGs (Winkler et al, 2021). Good HIA practice should include considerations of the long-term effects of projects and hence, promote sustainable development (Winkler et al, 2021). Figure 9-2 summarizes the impacts of mining projects in SSA with the different goals under the 2030 Agenda for Sustainable Development. Among the environmental health determinants considered in this study, the mining sector has overall made positive contributions towards achieving the corresponding SDGs. Additionally, improvements in some of the health indicators were seen.

Figure 9-2 Summary of impacts of mining projects on selected Sustainable Development Goals (SDGs) found in this PhD project

The SDGs sets a shared vision for transforming our world (UN, 2015). Reporting on the SDGs can enhance the visibility of the contribution of the mining sector on the progress towards this vision (Galli et al, 2020). Indeed, different initiatives have started linking the impacts of the mining sector to the SDGs (CCSI et al, 2016; IPIECA et al, 2017; RMF & CCSI, 2020). Furthermore, also mining companies have started to use the SDGs to report on their social and environmental performance as well as CSR activities (RMF & CCSI, 2020). However, there has been indications of “SDG-washing” by some mining companies (RMF & CCSI, 2020), meaning that instead of the SDG-framework guiding their community liaison activities, they selectively link their positive impacts to individual SDGs, while concealing any negative impacts. Nevertheless, if such reporting is done across the sector and if negative impacts are included in the reporting as well, the SDGs and its indicators could serve as a common language to track and compare the contributions of mining projects to sustainable development.

The diverse impacts on a broad variety of SDGs underscore the strong interlinkages between the environment, society and health. HIA is a useful tool to comprehensively act on the wider determinants of health and hence, also contribute to the work towards achieving other goals than SDG 3 (Thondoo & Gupta, 2020). HIA, as a stand-alone approach or integrated in other impact assessments, can provide a platform for inter-sectoral collaboration (Dannenberg et al, 2008; Thondoo & Gupta, 2020). Similarly, the 2030 Agenda for Sustainable Development with its 17 SDGs requires people from different sectors and disciplines to work together (Dietler et al, 2019). In light of the inter-connectedness of the three dimensions of sustainable development – economy, environment and society –, a stronger integration of the different impact assessment approaches should be considered, recognizing the connectedness between the environmental, social and health issues (Harris et al, 2015; Thondoo & Gupta, 2020). If impact assessment of mining projects adheres to the five guiding principles for HIA, the mining sector has potential to improve the health-related SDGs in the spirit of the 2030 Agenda for Sustainable Development "leave no one behind".

9.5 Conclusions and recommendations for HIA practice

At the core of this PhD thesis is a series of analyses of impacts of mining projects in SSA on EDH and associated health outcomes. They provide valuable quantitative insights to the limited understanding of settlement growth patterns, water, sanitation and housing infrastructures, and indoor air pollution sources in mining areas as well as their links with child nutrition, respiratory health, and diarrheal diseases. Overall improvements in the studied EDH were observed. However, these were only partly reflected by improvements in associated health outcomes. Furthermore, large differences in these impacts between countries and across socioeconomic strata were observed. These findings raise the question about the role of health in current impact assessment practice of mining projects. A comprehensive screening of impact assessment reports of mining projects in SSA revealed a lack of transparency, a narrow consideration of health factors and a lack of primary health data collection in current impact assessment practice.

In light of these findings, the following recommendations for addressing the shortcomings of current impact assessment practice in the mining sector in SSA are offered for consideration:

- Although the EDH were prominently featured in impact assessment reports, gaps in the consideration of associated health outcomes persist. International regulatory frameworks, such as the Performance Standards put forth by the IFC, can serve as benchmark for setting minimal requirements for the scope of health in impact assessment of mining projects. However, considering the increasing role of foreign investors in Africa's mining sector, national authorities should also reflect whether health aspects are sufficiently addressed in impact assessment policies and regulatory frameworks at the national-level. The insights from the analyses on the role of HIA in the legislative process of mining projects conducted by the HIA4SD governance stream should be factored in to this discussion.

- The findings suggest likely reductions in air and water pollution from community sources in mining areas. However, some population groups seem to be excluded from these developments. The diverse pathways determining the environmental health risks need to be recognized. For the assessment of these indirect pathways of mining projects on health, spatially disaggregated data on potential exposures are needed. In addition to the mine as source for pollution, different pollution sources in the communities need to be included in the assessments. Integration of other established approaches, such as WSP or SSP could be tested for their capability to identify and manage such exposure pathways on the different population groups. Such endeavors could include potential impacts of ASM operations.
- The unequal distribution of the benefits of mining projects warrant an increased equity focus in impact assessment. For this, the assessment of impacts on environmental health outcomes needs to be conducted conjointly with considerations of the social determinants of health. Recognizing these inter-connections between different health determinants can allow identifying the root causes of the different impacts experienced by the different population groups in mining areas. As a foundation for promoting health equity in impact assessment, data needs to be available that allows for systematic stratification of the community subgroups. Further research is needed to inform such considerations in future impact assessment practice.
- Baseline data on health outcome indicators in impact assessment stem primarily from secondary sources. As identified in this PhD thesis, many of these sources, however, lack the spatial resolution and accuracy or the depth of information for adequately assess health impacts. For addressing the specific health needs of vulnerable population groups, primary data collected through household surveys or using qualitative methods are preferable. Repeated follow-up data collection rounds should be considered to guide the design and to monitor the effectiveness of mitigation plans.
- For addressing these shortcomings, increased awareness and technical capacity for HIA among practitioners and policy-makers is needed. To strengthen its application, all efforts to promote HIA should therefore be made together with training and capacity building.
- Finally, impact assessment reports are difficult to obtain and monitoring data are rarely published. Public disclosure of the process and findings of impact assessment reports should therefore promoted by regulating bodies. This could not only increase the accountability of the mining sector for potential negative impacts, but could also increase the visibility of their positive contributions towards the 2030 Agenda for Sustainable Development.

In summary, apart from the negative direct impacts from environmental pollution, mining projects exhibit considerable potential to improve environmental health through indirect pathways. HIA can help fostering the positive impacts on these indirect pathways, while mitigating potential health risks to ultimately promoting the work towards the health-related SDGs. The clock is ticking for achieving the SDGs by 2030. Having entered the "Decade of Action" while facing the challenges of a global pandemic, the opportunities provided by mining projects to accelerate the work towards the SDGs are not to be missed. By addressing the identified shortcomings and adhering to its guiding principles, HIA has the potential to foster this potential and to ensure that the positive contributions of mining projects to the SDGs adhere to the spirit of the 2030 Agenda for Sustainable Development – "leave no one behind".

9.6 Outlook and further research needs

The HIA4SD project is in the transition to the communication and application phase. During the next 2 years, the project proponents will aim to induce a policy dialogue at the national and international level to promote the use of impact assessment in countries that are rich in natural resources. The combined findings gained in this PhD project, by the other five PhD students under the HIA4SD project, and the results from other research activities under the governance work stream will inform the policy dialogue. Hence, a crucial activity in preparation of this phase will be to compile all the information gained during the first phase of the project between 2017 and 2020. Potential formats that could to be useful for communicating these findings to policy makers could include policy briefs or other communication materials, such as the development of the project website and the production of video materials. Furthermore, data triangulation efforts, drawing from the insights of the different studies, could be published in peer-reviewed journals and policy briefs.

More specifically, with regards to the research focus of this PhD project, the following research topics emerged:

- Assess the effectiveness of good HIA practice to improve health. For this, the information on the quality of inclusion of health in impact assessment reports could be combined with the household and child indicators provided in the DHS datasets. Selecting data from different DHS rounds in areas with good and bad examples of HIA practice could provide insights in potentially different trajectories in health indicators over time.

- Identify how and why certain population subgroups are differently impacted by the mining projects. This could include the application of a mixed-methods approach, including the integration of the qualitative and quantitative findings in a GIS.
- Systematically assess the changes in different water pollution pathways, including from ASM sites, by testing the application of approaches of WSP and SSP in the context of HIA.
- Further develop the approach for tracking settlement growth in rural areas using remote sensing. The revised workflow could include new satellite data sources, such as from Sentinel-2. The application of the method in areas with reliable population data could help validating the estimated settlement growth rates.
- Identify key drivers of change in food security in mining areas. Data sources for such investigations could be a combination of repeated cross-sectional household surveys, with an expanded analysis of land use classification data for changes in agricultural land.
- Explore impacts on additional health outcomes affected by settlement and population changes, such as HIV or malaria.

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11 Annex

11.1 Editorial: Tropical Medicine and International Health and the 2030 Agenda for Sustainable Development

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Editorial

Tropical Medicine and International Health and the 2030 Agenda for Sustainable Development

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keywords 2030 Agenda for Sustainable Development, health and well-being, inequity, partnership, Sustainable Development Goal

Sustainable Development Goals (SDGs) SDG 1 (no poverty), SDG 2 (zero hunger), SDG 3 (good health and well-being), SDG 4 (quality education), SDG 5 (gender equality), SDG 6 (clean water and sanitation), SDG 7 (affordable and clean energy), SDG 8 (decent work and economic growth), SDG 9 (industry, innovation and infrastructure), SDG 10 (reduced inequalities), SDG 11 (sustainable cities and communities), SDG 12 (responsible consumption and production), SDG 13 (climate action), SDG 14 (life below water), SDG 15 (life on land), SDG 16 (peace, justice and strong institutions), SDG 17 (partnerships for the goals)

Introduction

In September 2015, at the general assembly of the United Nations, all 193 member states approved the 2030 Agenda for Sustainable Development – the 2030 Agenda in short [1]. At the heart of the 2030 Agenda are 17 Sustainable Development Goals (SDGs) with 169 targets. The 2030 Agenda provides a negotiated and undisputed framework with a normative vision for humanity. It should serve as a shared compass to transform our world into a better, more equitable and solidary place for current and future generations [1,2]. Academia and the scientific community are pressed to pay their share and lead the way towards achieving the SDGs. Indeed, researchers from all disciplines, together with other stakeholders and civil society, are invited to co-create and test new approaches to advance sustainable development [3]. Importantly, the newly generated knowledge must be transformed into actionable and scalable solutions to address the wicked problems that are inherent to sustainable development in a globalised world [4–6].

Monitoring progress towards the SDGs and its targets is critical, and the urgency of taking action from the current unsustainable path to the desired sustainable development cannot be emphasised enough [7]. This calls for academia and the scientific community to act expediently and all over the world. While new journals have been launched (e.g. *Nature Sustainability*; see: https://www.nature.com/natsustain/) and special issues have been published in multi-, inter- and transdisciplinary journals (e.g. *GAIA*, June 2019 issue; see: https://www.oekom.de/zeitschrift/gaia-2/), a systematic classification of scientific outputs in the peer-reviewed literature according to their contribution to the SDGs is called for but currently missing [8]. We take this issue forward and propose a subtle yet significant transformation of how research is being reported and disseminated in *Tropical Medicine and International Health*.

Introducing a new SDG reporting scheme in *Tropical Medicine and International Health*

As of January 2020, *Tropical Medicine and International Health* adds a novel feature to original research articles, reviews and editorials. As part of the submission process, prospective authors must specify the contribution of their research to one or several of the SDGs. This information will increase the visibility of the journal's contribution towards the SDGs and allows for monitoring short-, mid- and long-term trends of dynamically shifting research

*Contributed equally.

foci. The SDG(s) addressed will appear on the title page, just after the abstract (if any) and the keywords. This novel reporting feature will help promote the 2030 Agenda and encourage authors and readers to become more cognizant about the SDGs and their interconnectedness. In turn, the new reporting feature might foster innovative solutions towards achieving the 2030 Agenda. Moreover, the reporting scheme will allow for a regular and quantitative appraisal of the different SDGs targeted by research published in *Tropical Medicine and International Health*.

Apart from SDG 3 ('Ensure healthy lives and promote well-being for all at all ages'), other SDGs are directly or indirectly interacting with health and thus promote or jeopardise health and well-being [9]. The complex interlinkages of the SDGs can be visualised and novel solutions sought at the interface of SDGs.

SDGs addressed in previous research published in *Tropical Medicine and International Health*

To assess the specific contributions of recently published articles in *Tropical Medicine and International Health* to the 2030 Agenda, we systematically screened the titles and abstracts of the 216 articles published between January 2018 and July 2019. First, SDGs were independently assigned by two of the authors (AG and AL), using the SDG targets as main reference (Appendix). In this short-

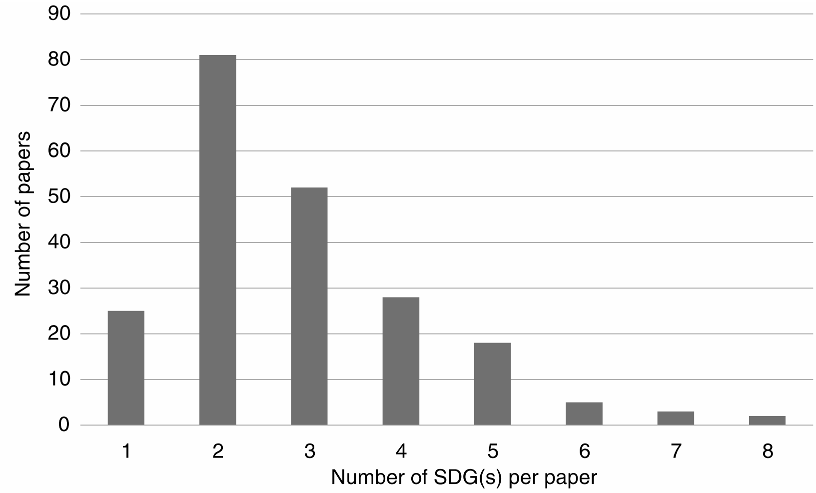

Figure 1 Frequency of numbers of SDG(s) addressed in 216 papers published in *Tropical Medicine and International Health* between January 2018 and July 2019.

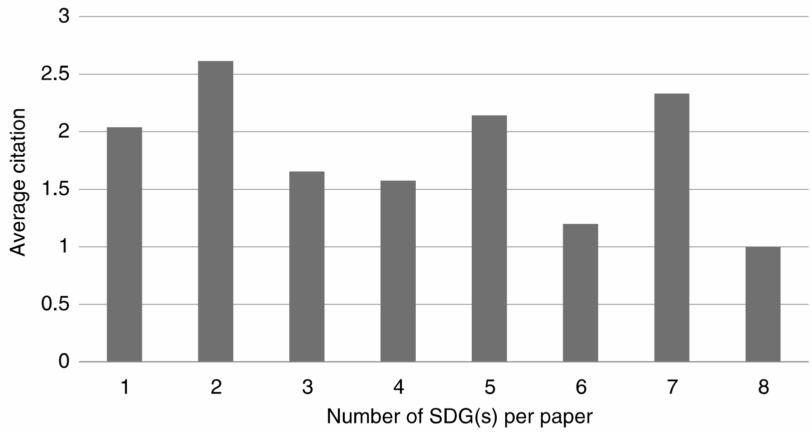

Figure 2 Average citation by number of SDG(s) addressed per paper in 216 papers published in *Tropical Medicine and International Health* between January 2018 and July 2019 (average time since manuscript publication 15 months).

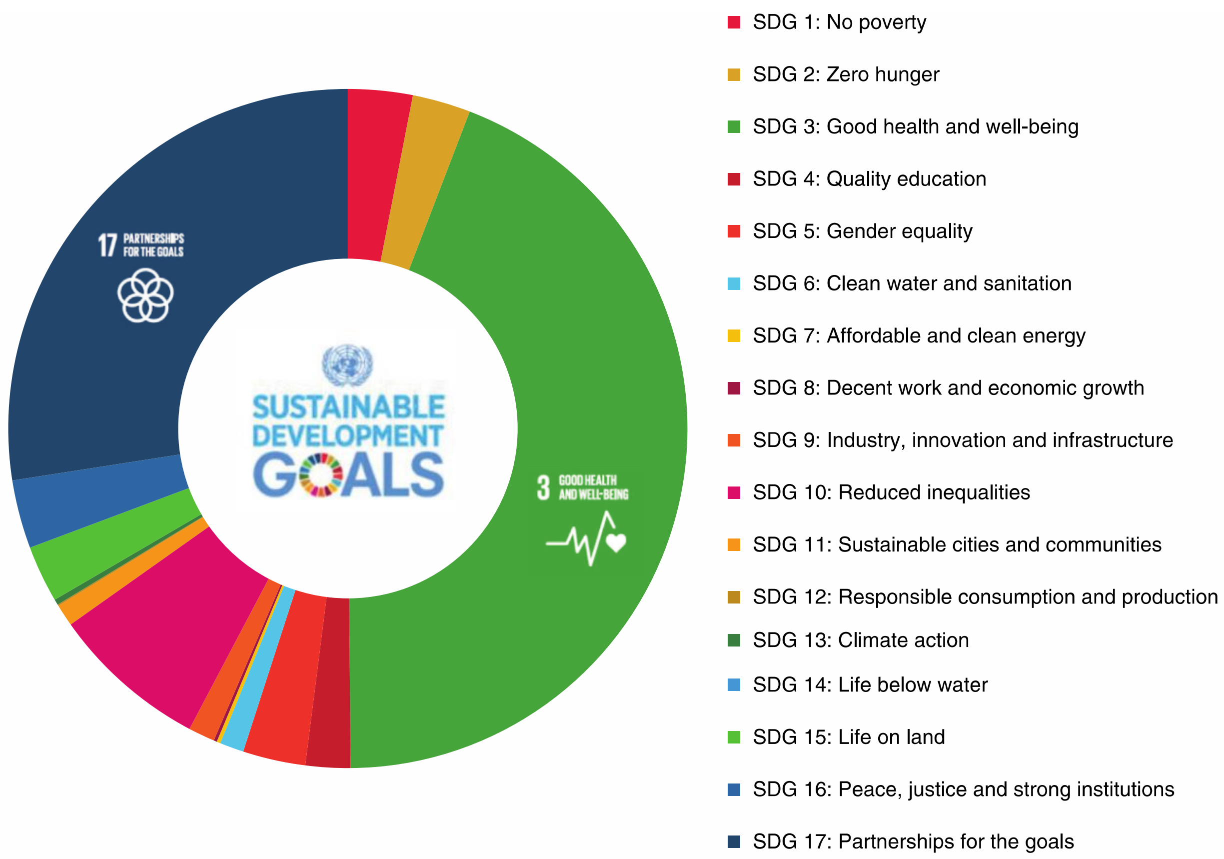

Figure 3 Doughnut chart indicating frequencies of SDGs addressed by 216 papers published in *Tropical Medicine and International Health*, between January 2018 and July 2019 weighted by the number of SDGs assigned per paper.

term analysis the mean time from publication to citation sampling was 15 months (range 5-23 months). To assign SDG 17 (‘Strengthen the means of implementation and revitalize the global partnership for sustainable development’), authors’ affiliations were scrutinised for collaboration across countries and disciplines. Second, after assigning SDGs independently for the first 20 papers, discrepancies were discussed to generate a mutual understanding of the criteria. Third, one author (AG) continued assigning SDGs to the remaining 196 papers and discussed uncertainties with a second author (AL). Finally, a second independent screening of 10 randomly selected papers confirmed the consensus about assigning SDGs and thus assured internal consistency of our database.

For subsequent analyses, the assigned SDGs were weighted by the total number of SDGs addressed by individual papers: if a single SDG was addressed, it received a weight of 1; if two SDGs were addressed, each received a weight of 0.5, and so on. Additonally, manuscript citation scores were sampled for each manuscript from online.wiley.com in mid-December 2019. Citation rates between papers targeting different SDGs or different numbers of SDGs were compared by one-way ANOVA.

Results

The number of SDGs addressed in our sample of 216 papers published in *Tropical Medicine and International Health* between January 2018 and July 2019 ranged from one to eight [10,11]. More than a third of the papers (n = 81, 37.5%) targeted two SDGs (Figure 1). There was no difference in manuscript citation rate by number of SDGs targeted, indicating that addressing multiple SDGs does not penalise citation rate in the short term (Figure 2).

The SDG most often addressed was SDG 3, followed by SDG 17 and SDG 10 (‘Reduce inequality within and among countries’). None of the papers screened was classified as having addressed SDG 14 (‘Conserve and sustainably use the oceans, seas and marine resources for

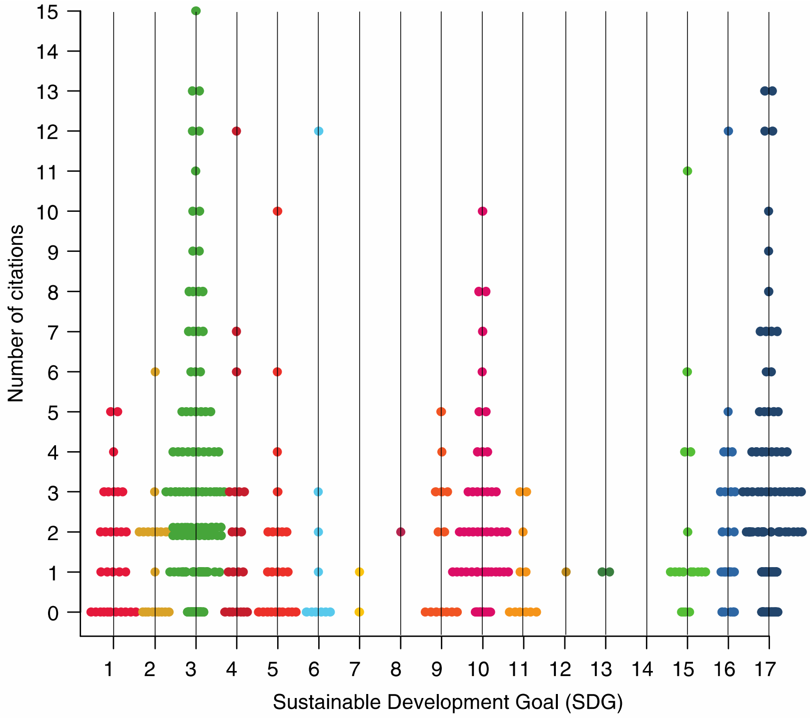

Figure 4 Citation of papers published in *Tropical Medicine and International Health* between January 2018 and July 2019, as of mid-December 2019 (average time since manuscript publication 15 months), stratified by SDG.

sustainable development') (Figure 3). There were no significant differences in manuscript citation rate across the different SDGs addressed (Figure 4).

SDGs where *Tropical Medicine and International Health* has particular visibility, as measured by manuscript citation rate, include SDG 4 ('Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all'), SDG 5 ('Achieve gender equality and empower all women and girls'), SDG 15 ('Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss') and SDG 16 ('Promote peaceful and inclusive societies for sustainable development, provide access to justice for all and build effective, accountable and inclusive institutions at all levels'). Common themes emerged in publications addressing SDG 3 (good health and well-being), along with other SDGs. For example, research that also tackled SDG 4 (quality education) predominately focused on assessing the effectiveness of public health interventions delivered through the education sector. For SDG 5 (gender equality), research focused on maternal health or explored gender differences in disease susceptibility or treatment response. For SDG 15 (life on land), research predominantly focused on the impact of land use on insect vectors and the transmission of vector-borne disease. SDG 16 (peace, justice and strong institutions) explored the delivery of health care to poor, marginalised or stigmatised populations.

Figure 5 shows the connections between different SDGs in our sample of 216 papers published in *Tropical Medicine and International Health* over an 18-month period starting in January 2018. Given the fact that SDGs 3, 10 and 17 were the most prominent ones, a triangle emerges. Further strong relationships between SDG 1 ('End poverty in all its forms everywhere') and SDG 10 (reduced inequalities), between SDG 5 (gender equality) and SDG 17 (partnerships for the goals), between SDG 4 (quality education) and SDG 17 (partnerships for the goals) and between SDG 3 (good health and well-being) and SDG 16 (peace, justice and strong institutions) become apparent.

Based on our experiences from assigning SDGs to already published articles, a method to assign SDGs for papers that will be published in future issues of *Tropical Medicine and International Health* is provided in Box 1. Prospective authors will be guided to this box, so that they

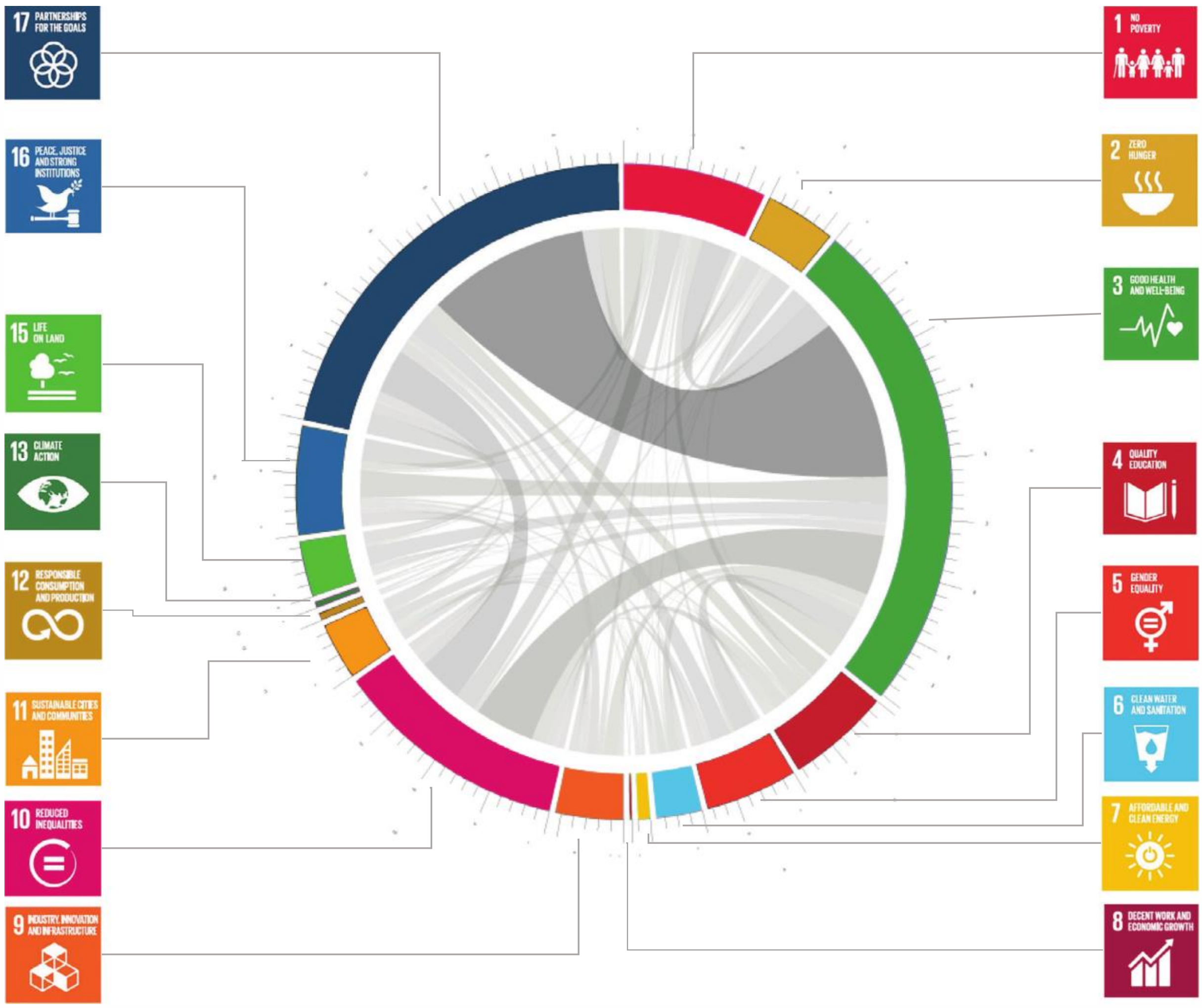

Figure 5 Circular plot indicating frequencies and interactions of SDGs assigned from 216 papers published in *Tropical Medicine and International Health* between January 2018 and July 2019.

can readily assign relevant SDGs to their forthcoming publications. The editors will assist should challenges arise.

Discussion

The observation that SDGs 3 and 17 (good health and well-being and partnerships for the goals) were the most prominent SDGs in recently published articles in *Tropical Medicine and International Health* is not surprising. The predominance of SDG 3 reflects that *Tropical Medicine and International Health* is a journal in the health area, with an emphasis on (i) tropical medicine and (ii) public, environmental and occupational health. Moreover, this finding sheds light on the journal's policy to welcome particularly authors from low- and middle-income countries, and hence, to strengthen research partnerships.

The strong connection between SDGs 10 and 17 (reduced inequalities and partnerships for the goals), obvious in Figure 5, indicates their essential interlinkage in striving for sustainable development and reduced poverty. Hence, a pathway originating in improving health may be extended through partnerships that consequently could reduce inequalities and poverty. Our screening of more than 200 published articles in *Tropical Medicine and International Health*, revealed

Box 1 Guideline for *Tropical Medicine and International Health* authors: How to assign SDGs to their work

1 Look at the SDG keyword list derived from the 169 SDG targets (see Appendix) and identify the SDGs addressed in your paper.
2 The topics of the SDGs addressed have to be mentioned in your text. You can either aim for them with your research or report on them as outcomes of your research. E.g.
   - If you investigate water and sanitation, add SDG 6.
   - If you found that hookworm-infected children cannot attend school regularly, add SDG 4.
3 Look at the author affiliations. If your authors come from more than one country or from institutions in different disciplines (e.g. health research institute and ministry of environment), add SDG 17.
4 Select all identified SDGs from the drop-down menu in the online submission system.

quantitative evidence of such interlinkages, highlighting the importance of equitable partnerships in achieving the SDGs.

We see no significant difference in manuscript citation rate by SDG addressed or by the total number of SDGs addressed, indicating that work which tackles a diversity of SDGs does not suffer a penalty in citation rate. However, in this short-term analysis the mean time since publication was only 15 months (range 5–23 months). Tracking manuscript citation rate over longer time frames for the SDGs will provide a measure of the visibility and reach of SDG-focused research as we approach 2030.

Prior research has investigated the interlinkages and synergies between the SDGs [4,9]. For example, SDG 3 (good health and well-being) has strong synergies with SDGs 1 (no poverty), 4, 5, 6, 9, 10 and 11 [4,9]. These interactions are clearly reflected in the recent body of publications in *Tropical Medicine and International Health*. The interlinkages between SDG 3 and others underline the importance of fostering co-benefits through inter- and transdisciplinary research partnerships [12,13].

An additional strength of *Tropical Medicine and International Health* is research on SDG 15 (life on land), in particular the impact of land use on insect vectors and the transmission of vector-borne disease and SDG 16 (peace, justice and strong institutions) exploring the delivery of health care to poor, marginalised or stigmatised populations. These interlinkages between SDGs 3, 15 and 16 have not been highlighted in previous analyses of health research but reflect the aim of *Tropical Medicine and International Health*, which welcomes diverse research and research led by authors from low- and middle-income countries.

Conclusion

In order to achieving sustainable development in its three dimensions – economic, social and environmental – in a balanced and integrated manner, research on SDGs needs to be more easily identifiable to inform governments, business and civil society [14]. The unique and participatory reporting scheme of *Tropical Medicine and International Health* will reveal the contribution of the health and life sciences to the achievement of the 2030 Agenda and will allow for monitoring the thematic focus of *Tropical Medicine and International Health*, within the SDG framework.

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Appendix

Keyword list to assign SDGs

SDG	Title	Keywords from the targets to assign SDGs
1 NO POVERTY	End poverty in all its forms everywhere	• Eradicate extreme poverty • Social protection systems • Coverage of the poor and the vulnerable • Equal rights to economic resources • Equal rights to access to basic services • Equal rights to ownership and control over land and other forms of property • Equal rights to inheritance • Equal rights to natural resources • Equal rights to appropriate new technology • Equal rights to financial services including microfinances • Build resilience of the poor • Reduce exposure and vulnerability to climate-related extreme events • Reduce exposure and vulnerability to economic, social and environmental shocks and disasters • Development cooperation
2 ZERO HUNGER	End hunger, achieve food security and improved nutrition and promote sustainable agriculture	• End hunger • Access to safe, nutritious and sufficient food all year round • End all forms of malnutrition (also stunting and wasting) • Address nutritional needs of adolescent girls, pregnant and lactating women and elderly • Agricultural productivity and incomes • Equal access to land and other productive resources • Sustainable food production • Resilient agricultural practices increasing productivity and production • Strengthen capacities for adaption to climate change • Progressively improve land and soil quality • Maintain genetic diversity of seeds, plants and animals • Seed and plant banks • Equitable sharing of benefits from utilization of genetic resources and associated traditional knowledge • Functioning food community markets • Limit extreme food price volatility

Appendix (*Continued*)

SDG	Title	Keywords from the targets to assign SDGs
3 GOOD HEALTH AND WELL-BEING	Ensure healthy lives and promote well-being for all at all ages	• Reduce global maternal mortality • End preventable deaths of new-borns and children under 5 years • Reduce neonatal mortality • End epidemics of AIDS, tuberculosis and neglected tropical diseases • Combat hepatitis, water-borne diseases and other communicable diseases • Reduce premature mortality from non-communicable diseases • Promote mental health and well-being • Prevention and treatment of substance abuse (narcotics and alcohol) • Reduce deaths and injuries from road traffic accidents • Universal access to sexual and reproductive health-care services (including family planning) • Achieve universal health coverage • Financial risk protection • Access to quality essential health-care services • Access to safe, effective, quality and affordable essential medicines and vaccines • Reduce deaths/illness due to hazardous chemicals and air, water and soil pollution and contamination • Tobacco control • Research and development of vaccines and medicines • Access to medicines for all • Strengthen health financing • Strengthen health workforce • Early warning systems for national and global health risks
4 QUALITY EDUCATION	Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all	• Free, equitable and quality primary and secondary education (girls and boys) • Access to pre-primary education and early childhood development and care • Access to affordable and quality technical, vocational and tertiary education, including universities for men and women • Increased number of youth and adults with relevant skills • Eliminate gender disparities in education • Access to all levels of education also for the vulnerable (persons with disabilities, indigenous peoples and children in vulnerable situations) • Achievement of literacy and numeracy • Build and upgrade education facilities • Expand number of scholarships for enrolment in higher education • Supply of qualified teachers

Appendix (*Continued*)

SDG	Title	Keywords from the targets to assign SDGs
5 GENDER EQUALITY	Achieve gender equality and empower all women and girls	• Eliminate all forms of discrimination against all women and girls everywhere • Eliminate violence against all women and girls (including trafficking and sexual and other types of exploitation) • Eliminate harmful practices (child, early and forced marriage and female genital mutilation) • Recognize and value unpaid care and domestic work • Promotion of shared responsibility within the household • Women's full and effective participation • Equal opportunities for leadership • Universal access to sexual and reproductive health • Reproductive rights • Equal rights for women to economic resources • Access for women to ownership and control over land/property • Access for women financial services • Access for women to inheritance • Access for women to natural resources • Use of enabling technology promoting empowerment of women
6 CLEAN WATER AND SANITATION	Ensure availability and sustainable management of water and sanitations for all	• Access to safe and affordable drinking water • Access to sanitation and hygiene • End open defecation • Improve water quality (reduction of pollution, elimination of dumping and the release of hazardous chemicals and materials, reduction of untreated waste water, improve recycling) • Increase water-use efficiency • Address water scarcity • Reduce water scarcity • Implement integrated water resource management • Protect and restore water-related ecosystems • Expand international cooperation and capacity building in water- and sanitation-related activities • Strengthen participation of local communities in water and sanitation management
7 AFFORDABLE AND CLEAN ENERGY	Ensure access to affordable, reliable, sustainable and modern energy for all	• Universal access to affordable, reliable and modern energy services • Increase share of renewable energy • Improvement in energy efficiency • Access to clean energy research and technology • Expand infrastructure and upgrade technology for modern and sustainable energy

Appendix (*Continued*)

SDG	Title	Keywords from the targets to assign SDGs
8 DECENT WORK AND ECONOMIC GROWTH	Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all	• Sustain per capita economic growth • Higher levels of economic productivity (diversification, technological upgrading and innovation) • Policies supporting productive activities • Policies supporting decent job creation • Policies supporting entrepreneurship • Policies supporting creativity and innovation • Policies supporting growth of micro-, small and medium-sized enterprises • Improve global resource efficiency • Decouple economic growth from environmental degradation • Achieve full and productive employment and decent work for all (women, men, young people, persons with disabilities) • Equal pay for work of equal value • Reduce proportion of youth not in employment, education or training • Eradicate forced labour • End modern slavery and human trafficking • End child labour • End recruitment and use of child soldiers • Protect labour rights • Promote safe and secure working environments • Promote sustainable tourism • Capacity strengthening of domestic financial institutions • Access to banking, insurance and financial services for all • Aid for trade support for developing countries • Develop global strategy for youth employment
9 INDUSTRY, INNOVATION AND INFRASTRUCTURE	Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation	• Develop quality, reliable, sustainable and resilient infrastructure • Access for all to the infrastructure • Inclusive and sustainable industrialization • Significantly raise industry's share of employment and gross domestic product • Access to financial services for small-scale industrial and other enterprises • Affordable credit • Integration into value chains and markets of small-scale industrial and other enterprises • Upgrade infrastructure and retrofit industries • Increase resource-use efficiency • Adoption of clean and environmentally sound technologies • Enhance scientific research and upgrade the technological capabilities of industrial sectors • Encourage innovation • Increase number of research and development workers • Facilitate sustainable and resilient infrastructure development • Support domestic technology development, research and innovation in developing countries • Significantly increase access to information and communications technology • Universal access to the Internet

Appendix (*Continued*)

SDG	Title	Keywords from the targets to assign SDGs
10 REDUCED INEQUALITIES	Reduce inequality within and among countries	• Income growth of the bottom 40% of the population • Empower and promote the social, economic and political inclusion of all • Ensure equal opportunity • Eliminate discriminatory laws, policies and practices • Promote appropriate legislation, policies and action • Adopt policies, especially fiscal, wage and social protection policies leading to greater equality • Improve the regulation and monitoring of global financial markets and institutions • Enhance representation and voice for developing countries in decision-making in global international economic and financial institutions • Regular and responsible migration and mobility of people through well-managed migration policies • Special and differential treatment for developing countries • Encourage official development assistance and financial flows, including foreign direct investment • Reduce the transaction costs of migrant remittances
11 SUSTAINABLE CITIES AND COMMUNITIES	Make cities and human settlements inclusive, safe, resilient and sustainable	• Access for all to adequate, safe and affordable housing and basic services • Upgrade slums • Access to safe, affordable, accessible and sustainable transport systems • Improve road safety • Expand public transport • Inclusive and sustainable urbanization • Protect world's cultural and natural heritage • Reduce deaths and people affected by decrease of economic losses caused by disasters • Reduce the adverse per capita environmental impact of cities • Pay attention to air quality in cities • Pay attention to municipal and other waste management • Safe, inclusive and accessible, green and public spaces • Links between urban, per-urban and rural areas • Build sustainable and resilient buildings utilizing local materials
12 RESPONSIBLE CONSUMPTION AND PRODUCTION	Ensure sustainable consumption and production patterns	• Sustainable consumption and production • Sustainable management and efficient use of natural resources • Reduction of per capita global food waste at the retail and consumer levels • Reduction of food losses along production and supply chains • Manage chemicals and all wastes throughout their life cycle • Reduce release of chemicals and wastes to air, water and soil • Reduce impact of chemicals and wastes on human health and environment • Reduce waste generation through prevention, reduction, recycling and reuse • Encourage companies to adopt sustainable practices • Encourage companies to integrate sustainability information into their reporting cycle • Promote sustainable public procurement practices • Ensure information and awareness for sustainable development for all people • Strengthen the scientific and technological capacity to achieve sustainable patterns of consumption and production • Monitor sustainable development impacts for sustainable tourism • Rationalize inefficient fossil-fuel subsidies

Appendix (*Continued*)

SDG	Title	Keywords from the targets to assign SDGs
13 CLIMATE ACTION	Take urgent action to combat climate change and its impacts	• Strengthen resilience and adaptive capacity to climate-related hazards and natural disasters • Integrate climate change measures into national policies, strategies and planning • Improve education and awareness-raising on climate change (mitigation, adaption, impact reduction and early warning) • Effective climate change-related planning and management in least developed countries
14 LIFE BELOW WATER	Conserve and sustainably use the oceans, seas and marine resources for sustainable development	• Reduce marine pollution • Protect marine and coastal ecosystems • Strengthen the resilience of marine and coastal ecosystems • Minimize and address the impacts of ocean acidification • End overfishing, illegal, unreported and unregulated fishing and destructive fishing practices • Implement science-based fishing management plans • Sustainable management of fisheries, aquaculture and tourism • Increase scientific knowledge and technology to improve ocean health and marine biodiversity • Provide access for small-scale artisanal fishers to marine resources and markets
15 LIFE ON LAND	Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss	• Conservation and restoration of terrestrial and inland freshwater ecosystems and their services (forests, wetlands, mountains and drylands) • Halt deforestation • Restore degraded forests • Combat desertification • Restore degraded land and soil • Ensure the conservation of mountain ecosystems • Halt the loss of biodiversity • Prevent the extinction of threatened species • Promote fair and equitable sharing of the benefits arising from the utilization of genetic resources and promote appropriate access to such resources • End poaching and trafficking of protected species • Address both demand and supply of illegal wildlife products • Prevent the introduction of invasive alien species (plants and animals) • Control or eradicate the priority alien species • Integrate ecosystem and biodiversity values into national and local planning, development processes, poverty reduction strategies and accounts • Mobilize financial resources for the conservation of biodiversity and ecosystems • Combat poaching • Vector ecology

Appendix (*Continued*)

SDG	Title	Keywords from the targets to assign SDGs
16 PEACE, JUSTICE AND STRONG INSTITUTIONS	Promote peaceful and inclusive societies for sustainable development, provide access to justice for all and build effective, accountable and inclusive institutions at all levels	• Reduce all forms of violence and related death rates • End abuse, exploitation, trafficking and all forms of violence against and torture of children • Equal access to justice for all • Reduce illicit financial and arms flows • Combat all forms of organized crime • Reduce corruption and bribery • Develop effective, accountable and transparent institutions at all levels • Ensure responsive, inclusive, participatory and representative decision-making at all levels • Strengthen the participation of developing countries in the institutions of global governance • Provide legal identity for all, including birth registration • Ensure public access to information • Protect fundamental freedoms • Prevent violence and combat terrorism and crime • Promote and enforce non-discriminatory laws and policies
17 PARTNERSHIPS FOR THE GOALS	Strengthen the means of implementation and revitalize the global partnership for sustainable development	• Collaboration across nations (authors should come from at least two countries) • Collaboration across disciplines (different disciplines within the medical field are not considered as transdisciplinary; cooperation of ministries or governmental institutions with academics are considered as transdisciplinary) • Finance (domestic resource mobilization and help financing developing countries) • Technology (cooperation: north-south, south-south or triangular; spread environmentally sound technologies; technology in least developed countries) • Capacity building (capacity building in developing countries through above mentioned cooperations) • Trade (universal trading system; increase exports of developing countries; duty-free and quota-free market access) • Systemic issues (global partnerships for sustainable development; macroeconomic stability; partnerships across public; private and civic society sectors)

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11.2 Curriculum Vitae

Personal details

Name:	Dominik Dietler
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Work experience

1/2021 – today	**Swiss Tropical and Public Health Institute, Basel** Scientific collaborator in the Health Impact Assessment research group
9/2017 – 12/2020	**Swiss Tropical and Public Health Institute, Basel** Short-term consultant in various projects along PhD studies
3/2017 – 8/2017	**World Health Organisation (WHO), Geneva** Consultant for the “Health and Climate Change” team
9/2016 – 2/2017	**Gesellschaft für Internationale Zusammenarbeit (GIZ), Bonn** Internship in the global programme “climate change adaptation in the health sector”
9/2015 – 4/2016	**Swiss Tropical and Public Health Institute, Basel** Internship in the research group “Ecosystem Services, Climate and Health“
6/2014 – 7/2014	**Institute for Environmental Medicine, Karolinska Institutet, Stockholm** Internship in the nutritional epidemiology research group
3/2013 – 7/2013	**Youth psychiatry, Basel** Civil service
2/2013 – 3/2013	**Wohngemeinschaft Leo, Pratteln** Civil service
7/2010 – 1/2013	**Lonza AG, Basel** Intern (20%) in the Supply Chain Services unit (interrupted between August 2011 and Mai 2012 for studies and language study travel)
1/2009 – 1/2016	**High school Kirschgarten and Leonhard, Basel** Substitute teacher in economics and law, PE and biology (irregularly)

Education

9/2017 – 12/2020	**Swiss Tropical and Public Health Institute** PhD in Epidemiology Thesis title: “Impact of mining projects on environmental determinants of health and associated health outcomes in sub-Saharan Africa: insights for guiding impact assessment practice”
8/2013 – 6/2015	**Karolinska Institutet, Stockholm** Master of Medical Science, Major in Public Health Epidemiology Master thesis: “Mapping vulnerabilities for malaria and diarrhoea from water and sanitation deficiencies after a flood: a cross-sectional study in Kaédi, Mauritania”
9/2009 – 1/2013	**University of Basel** Bachelor of Science in Biology, Major in Integrative Biology

Publications

Dietler, D.; Loss, G.; Farnham, A.; de Hoogh, K.; Fink, G.; Utzinger, J.; Winkler, M.S. Housing conditions and respiratory health in children in mining communities: An analysis of data from 27 countries in sub-Saharan Africa. *Environ Impact Asses* **2021**, *89*, 106591.

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Language skills

German	Native speaker
English	C1 (TOEFL iBT overall score 109 points in 2013)
French	C1/B2 (co-managed data collection activities in Burkina Faso in 2018)
Swedish	B1

Software skills

ArcGIS, QGIS, STATA, R, IBM SPSS, Microsoft Office (Word, Excel, Outlook, PowerPoint, Access)