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Original research paper

Spatial mobility and large-scale resource extraction: An analysis of community well-being and health in a copper mining area of Zambia

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ABSTRACT

We examine population mobility around a newly-developed large-scale copper mine in Zambia and analyse how socioeconomic and health indicators differed amongst migrants, resettled households, and non-mobile local (e.g. non-migrant/-resettled) populations. Two cross-sectional household surveys in 2015 and 2019 collected quantitative data on health, socioeconomic indicators, and resettlement and migration status. A wealth index for the pooled sample ($N = 990$ households) was computed using a simplified list of household assets adapted from the Zambia Demographic and Health Survey. Logistic regression models were conducted to assess associations with health outcomes. In-migrants were younger than non-mobile locals (mean age of household head 33.9 vs. 37.7 years), more highly educated (34.3% of household heads completed secondary school vs. 7.3%), had higher employment (43.8% vs. 15.8%), and higher mean wealth (3.6 vs. 3.0). The odds of having a child <5 years diagnosed with malaria (OR: 0.53, 95% CI: 0.40, 0.71) or classified as stunted (OR: 0.66, 95% CI: 0.50, 0.87) were significantly lower for migrants during the construction phase, even after adjusting for family wealth score. Migrant and resettled households had greater wealth and assets even after adjusting for age, education, and employment, suggesting spatial mobility is associated with improved socioeconomic status and disease prevention.

1. Introduction

Natural resource extraction is highly important to the economies of many countries in sub-Saharan Africa. In addition to the economic revenue these mines represent (Cust and Poelhekke, 2015), they may also cause major changes in surrounding communities, including an influx of workers and opportunity seeking migrants, resettlement of the host populations (Jønsson et al., 2019), new infrastructure that can significantly alter the local landscape, transformation of local demographics (Owen and Kemp, 2015), changes in local disease patterns (Knoblauch et al., 2017; Knoblauch et al., 2020) and community wealth (Zabré et al., 2021). Managing successful economic partnerships with the mining sector is of key importance to achieving sustainable development in sub-Saharan Africa (Ghebremusse, 2020). An essential part of achieving sustainable development is understanding how the changing demographics and population mobility induced by the opening of a new large mine affect the socioeconomic status and health of both locals and migrants living nearby.

In the case of Zambia, long one of the most strategic mineral producers in sub-Saharan Africa, copper mining is an economic mainstay (Kragelund, 2020). Zambia is the second largest copper producer in sub-Saharan Africa (Jayasinghe and Ezpeleta, 2020) and copper currently accounts for 66% of Zambian exports (Schuler and Lokanc, 2015). Despite its positive contribution to Zambia's economy, corrupt financial practices and transfer prices mean that the government revenues collected from copper mining remain relatively low (Jayasinghe and Ezpeleta, 2020). While local manufacturing was given a boost by the copper industry in the 1970s and 1980s, the profits from copper mining have largely not achieved broad-based social and economic development in Zambia (Kragelund, 2020). The opening of new mines in the

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Copperbelt region of Northwestern Province starting in the early 2000s has caused enormous in-migration, but local infrastructure has largely not kept pace (Kesselring, 2018). In recent years, there have been increasing calls for resource-based development, which include the promotion of a new Local Content Strategy in 2018 by the Zambian Ministry of Commerce Trade and Industry to promote development through use of local suppliers of goods and services (Kragelund, 2020) and initiatives to protect the rights of women in areas affected by mining (Jayasinghe and Ezpeleta, 2020).

While the mining sector represents an opportunity for economic growth for host countries, the presence of abundant natural resources has also been linked with negative outcomes such as weaker political and economic institutions and increased corruption at the national level (Van der Ploeg, 2011; Frankel, 2012). There is less research on the effects of the mining industry on socioeconomic and health indicators at the local community level, and what exists suggests both positive and negative effects. Some studies in Africa have found that mine development can have a positive impact on local women, enabling them to transition from agriculture to more diverse job opportunities, increasing access to healthcare, decreasing infant mortality, and decreasing tolerance for domestic violence (Aragón and Rud, 2013; Kotsadam and Tolonen, 2016; A. Benshaul-Tolonen, 2019; A. Benshaul-Tolonen, 2019). Other studies suggested that the copper boom in Zambia has been associated with reduced risky sexual behaviour (Wilson, 2012) or more testing for HIV (Knoblauch et al., 2017). However, other evidence indicates that increasing environmental pollution may reduce local agricultural productivity and increase stunting in children and anaemia in women, and therefore have negative effects on local welfare and well-being (Aragón and Rud, 2013; Aragón and Rud, 2016; von der Goltz and Barnwal, 2019).

Few papers have looked simultaneously at both socioeconomic and health indicators in local communities after the opening of a large mine, although some qualitative research indicates negative community perceptions of economic and health impacts of new mines (Abuya and Odongo, 2020; Leuenberger et al., 2021). One study found an average increase in household assets along with higher incidence of stunting in children and anaemia in women in 44 developing countries in areas in close proximity to mineral mines (von der Goltz and Barnwal, 2019). To our knowledge, none have examined how socioeconomic and health indicators differ between the host population and those who became mobile as a result of the mine development, either by in-migration to the mining area or through nearby resettlement of those who were displaced by the mine. This resettlement occurs when pressure for land due to the mine development results in the displacement of previously existing communities, both physically by the mine itself or economically due to increased distance from school, work, agricultural fields or other markets (Owen and Kemp, 2015). In addition, previous literature has suggested that the development of new mines may draw migrants seeking employment, but many are unable to obtain mining work and instead pursue less stable informal economic activities (Gilberthorpe et al., 2016; Gough et al., 2019). It may also be that such migrants can bring new ideas and businesses to the local economy, benefiting the host communities (Vorlaufer and Vollan, 2020). However, it is unknown whether migration during certain phases of the mine development process confers greater benefits to the migrants or host communities.

We aim to address the evidence gap in the changes in health and socioeconomic indicators of different groups associated with spatial mobility induced by a newly developed mine by analysing quantitative household survey data collected in the context of a health impact assessment (HIA) from communities surrounding the Trident copper mine in Kalumbila district of North-Western Zambia Sentinel Production Statistics 2021. Specifically, we aim to (i) identify when and why spatial mobility (e.g. in-migration, resettlement) in the mining area occurred, (ii) describe the differences in the health, socioeconomic, and wealth status of the (iia) non-mobile locals that did not move during the study period (e.g. non-migrant/-resettled), (iib) members of resettled households, and (iic) 'newly settled' migrants immediately before, during, and after mine development, and (iii) identify whether the period of migration is associated with the health, socioeconomic, or wealth status of the migrant population.

We first describe the methods we used to conduct and analyse the study, including the study design and sampling strategy, the health and socioeconomic indicators that were collected, and the statistical approaches used (Section 2). Next, we discuss the results, including the characteristics of the study population, the timing and reasons for spatial mobility in the study area, and how socioeconomic and health indicators changed in the three primary groups we are interested in (e.g. migrants, resettled households, and non-mobile locals) (Section 3). Finally, we discuss the implications of our findings, including given limitations of our approach (Section 4).

2. Methods

2.1. Participants and study design

This study was conducted as part of an HIA commissioned by the Trident project. The Trident project is a greenfield mine development in a previously undeveloped region in North-Western province in Zambia, operated by First Quantum Minerals Limited (FQML). The baseline definition and monitoring programme of the HIA aimed to recruit a cross-sectional sample of households from villages surrounding the Trident project at three different time periods: June-July 2011 (baseline survey), July 2015 (first follow-up survey), and June-July 2019 (second follow-up survey). The villages were sampled semi-purposively, intentionally including physically resettled communities and areas impacted by the mine. Nine villages considered impacted by the mine (e.g. by resettlement, in-migration directly related to the mine labour force, opportunity seeking migrants, or other social and environmental determinants) were selected. Four comparison villages were selected that were not directly impacted by the mine or that did not benefit directly from mine sponsored health interventions. Within each village, households were randomly sampled until they reached 25–35 households per village. In the larger communities of Chisasa, Musele, and Kanzala, random sampling of households continued until a sample of 50-70 was reached (Knoblauch et al., 2017; Knoblauch et al., 2018). This resulted in an overall sample size for all three survey rounds of 990 households representing 3188 individuals.

Cross-sectional surveys were conducted at the household level. To be eligible for the study, participants were required to consent and at least one woman with a child <5 years must have been present in the household. One interview was conducted with the mother in each household and, if present, a male in the household. Study design and setting are described in detail elsewhere (Knoblauch et al., 2017; Knoblauch et al., 2017; Knoblauch et al., 2018; Knoblauch et al., 2020). There were three phases of the mine development process: the exploration and feasibility phase (2008–2011), the construction phase (2012–2015), and the operational phase (2015 onwards). In this analysis, we were interested in households that migrated into the study area before and after construction on the mine began (e.g. between 2008 and 2019), or who were physically resettled by the mine. These two groups (migrants and physically resettled households) were considered two different types of population mobility and thus always analysed separately. Households were mainly physically resettled into two communities (Shenengene and Northern Resettlement) and the resettlement was accompanied by a livelihood restoration programme conducted by FQML (Fig. 1). Housing for resettled households was provided by the mine.

2.2. Health and socioeconomic indicators

In the questionnaire surveys, the female respondents were asked questions on various household sociodemographic indicators (e.g. age,

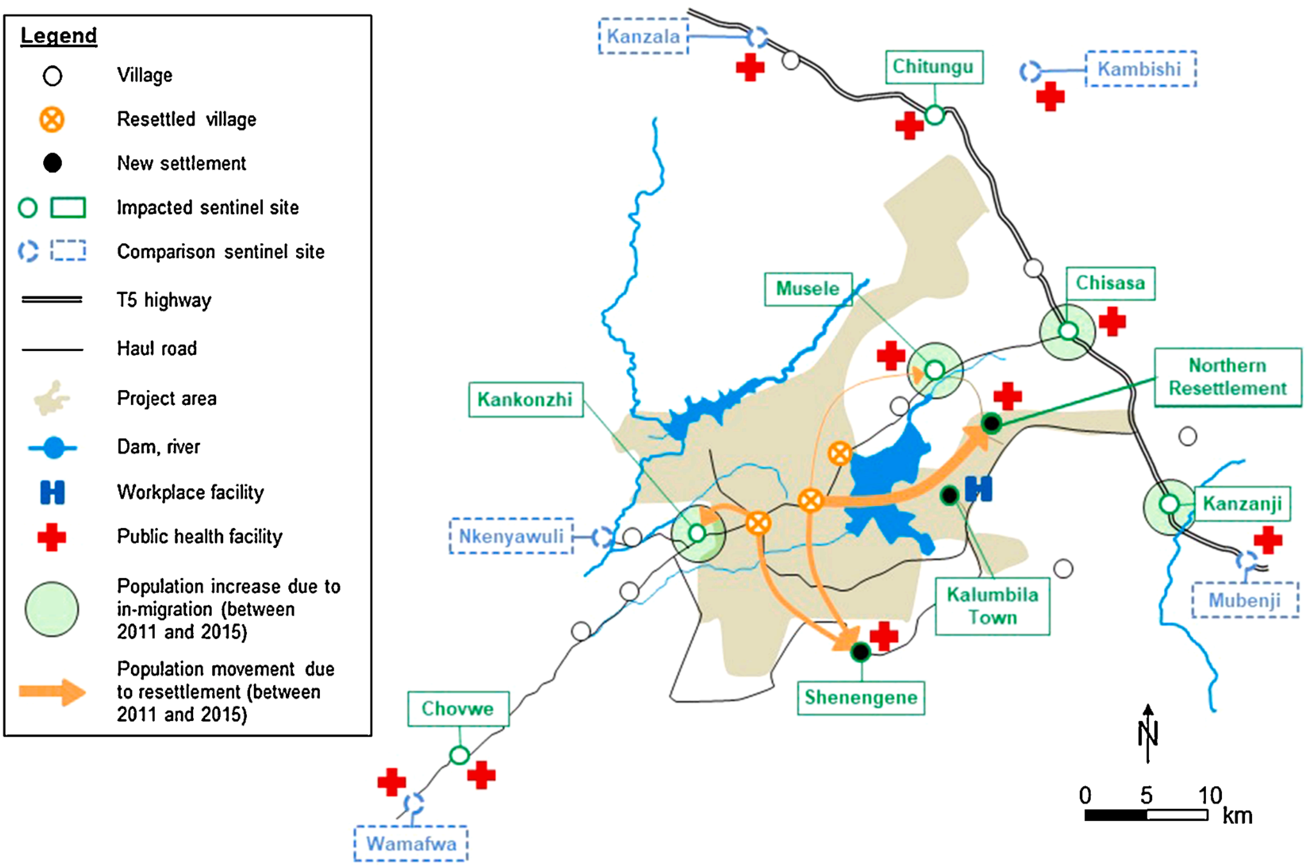

Fig. 1. Map of the study site.

education, employment of the female respondent and the household head), and an inventory of household assets and amenities based on the tool developed by the Demographic and Health Survey (DHS) for Zambia (Rutstein et al., 2004). The inventory used in this study was reduced in length to include only the most important inventory items to reduce the survey length for study participants. The items asked about included the number of household members per sleeping room, the source of drinking water, the type of floor, roof and wall material, the type of cooking fuel, and ownership of key household assets (e.g., radio, television, bicycle, phone and bank account). Participants were also asked how many years they had resided at their current residence and whether they had been resettled by the mine; the year that they had moved to their current location was considered their year of migration or resettlement. Participants were defined as being migrants if they self-reported having moved to their current location after 2007, when the exploration and feasibility phase of the mine began, and were not physically resettled by the mine. If they self-reported migrating between 2008 and 2011, they were considered to be migrants during the exploration and feasibility phase. If they migrated between 2012 and 2015, they were considered to be migrants during the construction phase. If they migrated after 2015, they were considered to be migrants during the operational phase of the mine. Participants were defined as resettled if they answered yes to the question, "Were you resettled for the Project (Trident, Kalumbila mine, KML)?" Participants were defined as non-mobile locals if they had settled in the area prior to 2008 and answered no to the resettlement question. If the respondent reported moving in the five years prior to the interview (so after 2009 in the 2015 survey and after 2013 in the 2019 survey), they were asked their reasons for migrating (e.g. seeking a labour job, seeking a job in artisanal mining, family reunification, fleeing from previous place, service provider to the project, former resident of the area, provider of goods and services to the local population, resettlement, or no particular reason). Participants could report more than one principal occupation or reason for migration.

Data on important health indicators in the local population identified as part of the HIA were also collected. During the survey, biomedical samples were collected from all children <5 years and women of reproductive age (15–49 years). To assess infection with *Plasmodium falciparum* in children aged 6–59 months, a rapid diagnostic test (RDT) was used (SD Bioline Malaria Ag Pf Rapid Test, Standard Diagnostics, Macmed Healthcare Ltd.; Nairobi, Kenya). To diagnose anaemia in mothers and children aged 6–59 months, haemoglobin levels were measured using the HemoCue® test (HemoCue AB; Ängelholm, Sweden). Syphilis testing was conducted using the Alere Determine™ Syphilis TP antibody test (Abbott; Abbott Park, Chicago, IL, USA). The height and weight of the children aged 0–59 months and women were also measured, following WHO anthropometric guidelines.

Questionnaire survey data were collected on Open Data Kit via tablet devices. Additional information on the data collection methods is reported elsewhere (Knoblauch et al., 2017; Knoblauch et al., 2018; Knoblauch et al., 2020).

2.3. Statistical analysis

As a first step, we conducted descriptive analyses comparing migrants who had moved to the area after 2007 and households resettled by the mine with non-mobile locals of the villages in terms of age, sex, employment, wealth, educational attainment, and other sociodemographic indicators. Migrants who had moved into the area were always considered separately from resettled households, which were members of the local population that had been physically resettled by the mine. Counts and proportions and means and standard deviations (SD) were reported where appropriate. T-tests and corresponding p-values were used to compare group means.

Table 1
Demographic characteristics of study population [n (%) or mean (SD)]. Participants missing the variable are omitted from the denominator.

	Overall study population (n = 3188, HH = 990)	Non-mobile locals (resided in area prior to 2008) (n = 1637, HH = 482)	Migrants since 2008 (n = 1163, HH=388)	Resettled by mine (n = 385, HH = 120)
Age household head	36.0 (10.6)	37.7 (11.4)	33.9 (9.2)	35.9 (10.5)
Feale household head	206 (20.8%)	112 (23.2%)	69 (17.8%)	25 (20.8%)
Household size	3.8 (2.0)	4.1 (2.1)	3.4 (1.9)	3.8 (1.9)
Education household head				
<Primary	432 (43.6%)	255 (52.9%)	123 (31.7%)	54 (45.0%)
Completed primary school	363 (36.7%)	188 (39.0%)	130 (33.5%)	45 (37.5%)
Completed secondary school	185 (18.7%)	35 (7.3%)	133 (34.3%)	17 (14.2%)
Missing	10 (1.0%)	4 (0.8%)	2 (0.5%)	4 (3.3%)
Age female respondent	28.2 (7.6)	28.8 (8.1)	27.5 (7.0)	28.3 (7.5)
Female respondent married	818 (82.7%)	379 (78.8%)	337 (86.9%)	102 (85.0%)
Households with at least 1 household member employed	303 (30.6%)	76 (15.8%)	170 (43.8%)	57 (47.5%)
Principal occupation men interviewed*				
No occupation	72 (27.8%)	39 (27.3%)	23 (25.6%)	10 (38.5%)
Agriculture	141 (54.4%)	91 (63.6%)	38 (42.2%)	12 (46.2%)
Mining	28 (10.8%)	6 (4.2%)	17 (18.9%)	5 (19.2%)
Government employee	4 (1.5%)	0	4 (4.4%)	0
NGO	2 (0.8%)	1 (0.7%)	1 (1.1%)	0
Business	24 (9.3%)	7 (4.9%)	15 (16.7%)	2 (7.7%)
Casual/Manual labour	30 (11.6%)	19 (13.3%)	7 (7.8%)	4 (15.4%)
Other	7 (2.7%)	3 (2.1%)	3 (3.3%)	1 (3.9%)
Principal occupation women with children <5*				
No occupation	355 (35.9%)	134 (27.8%)	172 (44.3%)	49 (40.8%)
Agriculture	517 (52.2%)	316 (65.6%)	143 (36.9%)	58 (48.3%)
Mining	12 (1.2%)	0	7 (1.8%)	5 (4.2%)
Government employee	3 (0.3%)	0	3 (0.8%)	0
NGO	0	0	0	0
Business	160 (16.2%)	63 (13.1%)	80 (20.6%)	17 (14.2%)
Casual/Manual labour	90 (9.1%)	56 (11.6%)	25 (6.4%)	9 (7.5%)
Other	13 (1.3%)	5 (1.0%)	7 (1.8%)	1 (0.8%)
Wealth index	3.35 (0.86)	3.01 (0.64)	3.58 (0.97)	4.0 (0.62)

*Participants could report more than one occupation.

A household wealth score was calculated using the reduced inventory of household assets and amenities collected during the household surveys. A principal component analysis (PCA) was then conducted to create a single dimension asset score, as outlined by the DHS methodology (Rutstein and Staveteig, 2014). To make our data nationally comparable, the PCA was conducted together with the raw 2007, 2013–14, and 2018 Zambia DHS data. Household wealth quintiles were calculated based on the first principal component of the PCA.

To analyse whether migrant households were on average better off, a linear model was conducted with the wealth score as the outcome and the phase of migration as the predictor, with non-mobile local households as the reference group. Resettled households were omitted from this analysis, as they were not considered migrants into the area but were also different from non-mobile locals. The model was adjusted for education, employment status and age of the household head as potential confounding factors; both adjusted and unadjusted differences were reported. Mean wealth of resettled households was reported separately.

To determine how the period of migration is associated with the risk of illness (i.e. children 6-59 months being diagnosed with malaria, syphilis amongst women of reproductive age, anaemia amongst children 6-59 months, anaemia amongst women of reproductive age, and stunting amongst children <5 years), five logistic models were set up with previous diagnosis of the illness as the outcome and the phase of migration as the predictor (non-mobile locals as the reference category, resettled households were omitted). Similarly, five logistic models were conducted with previous diagnosis of the illness as the outcome and being resettled as the predictor (non-mobile locals were the reference category, migrant households were omitted). All models were adjusted for the household wealth score.

Study data were stored using a server at the Swiss Tropical and Public Health Institute (Swiss TPH; Basel, Switzerland) and encrypted with a secure sockets layer. Data were analysed using R Version 3.6.1 (The R Foundation; Vienna, Austria).

Study protocols and survey tools were approved by the ethics review committee of the Tropical Disease Research Centre in Ndola, Zambia (TRC/ERC/04/07/2011, TRC/C4/07/2015 and TRC/C4/01/2019). Communities were sensitised in advance to the objectives and activities of the surveys. A written informed consent (i.e., signature, or fingerprint for illiterate individuals) was obtained from the head of the household, participating women aged 15–49 years for themselves and their children <5 years.

3. Results

3.1. Study population

In 2015, 482 households were sampled from 13 villages for a total of 1546 participants in all households. In 2019, 509 households were sampled from 13 villages for a total of 1642 participants in all households. In the 2015 survey, one household with three participants was missing the year of migration and therefore omitted from further analysis. In total, there were 990 households with 3188 participants across the two survey rounds.

In total, 39.2% ($n = 388/990$) of the households in the study population had migrated to their current village after 2007, when the mine exploration and feasibility phase began, and an additional 12.1% ($n = 120/990$) of study households had been resettled by the mine. 91.8% ($n = 356/388$) of migrant households reported where they moved from. Most migrant households (73.9%, $n = 263/356$) reported moving from elsewhere in North-Western Province or from elsewhere in Zambia (24.4%, $n = 87/356$), with only six (1.7%) international migrant households (all from the Democratic Republic of the Congo).

Demographics of the study population are described in Table 1. Overall, migrants (individuals who arrived in the area in 2008 or later and were not physically resettled by the mine) were younger than non-mobile locals (mean age of household head 33.9 years vs. 37.7 years), more highly educated (34.3% of household heads had completed secondary school vs. 7.3% of non-mobile locals), had higher rates of employment (43.8% vs. 15.8% of households with at least one household member employed), smaller average household size (3.4 vs. 4.1 members), and a higher mean wealth index (3.58 vs. 3.01). Migrants were much less likely to work in agriculture (42.2% vs. 63.6% amongst men and 36.9% vs. 65.6% amongst women) and more likely to work in the mining sector (18.9% vs. 4.2% of men and 1.8% vs 0.0% of women).

Resettled households had on average a more highly educated

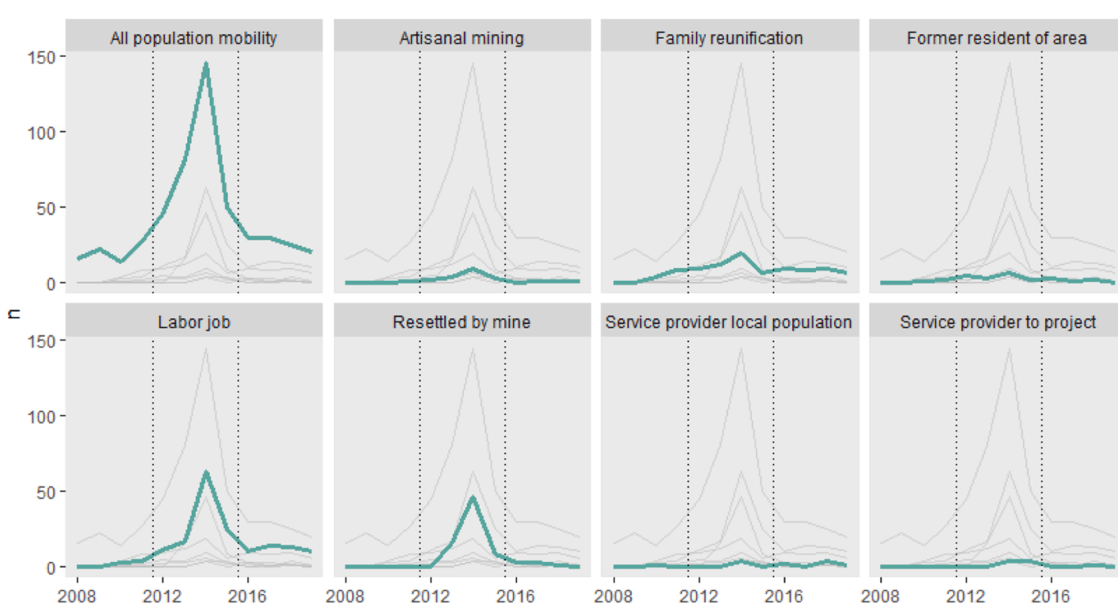

Fig. 2. Total numbers of resettled and migrant households and main reasons for mobility in the study area by year. Dashed lines represent the different phases: exploration and feasibility (2008–2011), construction (2012–2015), and operational (2016–2019).* Multiple answers were possible for the main reasons they migrated to the area. ** Note that only those who had reported migrating in the five years before the interview were asked about their reason for migrating ($n = 403$ households).

Table 2
Differences in socioeconomic indicators according to mobility status and year of migration. Household variables are calculated based on the number of households that migrated each year.

	Year migrated	HH (n)	Mean wealth index score (SD)	HH head: <primary education(n (%))	HH head : secondary education complete (n (%))	Households >=1 person employed	Households >= 1 person working for mine
Non-mobile locals		482	3.0 (0.6)	255 (52.9%)	35 (7.3%)	76 (15.8%)	6 (1.2%)
Resettled by mine		120	4.0 (0.6)	54 (45.0%)	17 (14.2%)	57 (47.5%)	10 (8.3%)
Migrants Exploration and Feasibility Phase	2008	16	3.3 (0.6)	9 (56.2%)	2 (12.5%)	4 (25.0%)	0
	2009	22	3.3 (0.8)	11 (50.0%)	2 (9.1%)	2 (9.1%)	0
	2010	14	3.1 (0.7)	4 (28.6%)	5 (35.7%)	4 (28.6%)	0
	2011	26	3.3 (0.7)	17 (65.4%)	5 (19.2%)	5 (19.2%)	0
	Total	**78**	**3.3 (0.7)**	**41 (52.6%)**	**14 (17.9%)**	**15 (19.2%)**	**0**
Migrants Construction Phase	2012	37	3.5 (0.8)	9 (24.3%)	11 (29.7%)	18 (48.6%)	5 (13.5%)
	2013	55	3.6 (1.0)	16 (29.1%)	20 (36.4%)	24 (43.6%)	3 (5.5%)
	2014	81	3.9 (1.0)	19 (23.5%)	35 (43.2%)	48 (59.3%)	3 (3.7%)
	2015	39	3.8 (1.2)	4 (10.3%)	22 (56.4%)	24 (61.5%)	3 (7.7%)
	Total	**212**	**3.8 (1.0)**	**48 (22.6%)**	**88 (41.5%)**	**114 (53.8%)**	**14 (6.6%)**
Migrants Operational Phase	2016	27	3.5 (0.9)	9 (33.3%)	7 (25.9%)	10 (37.0%)	3 (11.1%)
	2017	27	3.7 (1.1)	8 (29.6%)	12 (44.4%)	13 (48.1%)	2 (7.4%)
	2018	25	3.3 (0.9)	11 (44.0%)	6 (24.0%)	11 (44.0%)	1 (4.0%)
	2019	19	3.3 (0.8)	7 (36.8%)	7 (36.8%)	7 (36.8%)	3 (15.8%)
	Total	**98**	**3.5 (1.0)**	**35 (35.7%)**	**32 (32.7%)**	**41 (41.8%)**	**9 (9.2%)**

household head than non-mobile local households (14.2% completed secondary school vs. 7.3%). The proportion of households with at least one member employed was highest amongst the resettled population, and similar to the proportion of migrant households (47.5% vs 43.8%, respectively).

3.2. Timing and reasons for spatial mobility in the mining area

Overall, the majority of the migration ($n = 212$ households, 54.6% of total migrant households since 2008) occurred during the construction phase of the mine (2012–2015; Fig. 2). Similar numbers of migrants arrived during the exploration and feasibility phase (2008–2011, 20.1% of migrants) and operational phase (2016–2019, 25.3% of migrants). See Fig. 2 for the number of migrants in the last ten years arriving in each year.

Those households that reported moving in the five years prior to the interview in either 2015 or 2019 (403 of the 990 study households, or 40.7%) were also asked about their reason for moving. Overall, most mobile households moved seeking labour ($n = 170/403$ households, 42.2%), followed by family reunification ($n = 90/403$, 22.3%), resettlement by the mine ($n = 77/403$, 19.1%), being a former resident of the area ($n = 25/403$, 6.2%), and artisanal mining ($n = 22/403$, 5.5%). A small number reported moving to be a service provider for the project ($n = 9/403$, 2.2%), to flee their previous location ($n = 10/403$, 2.5%), and to provide goods and services to the local population ($n = 12/403$, 3.0%). See Fig. 2 for the trends in when migrants moved to the area for different reasons. During the exploration and feasibility phase, family reunification was the most cited reason for mobility (48.0% of mobile households reporting reason in 2008–2011). In the construction phase, most mobile households were seeking labour jobs (42.5%), followed by resettlement by the mine (25.6%). In the operational phase, most households again moved seeking labour jobs (44.8%), followed by family reunification (30.5%).

3.3. Levels and changes of socioeconomic and health indicators

Overall, migrants had a higher wealth index than non-mobile locals (Table 1). The wealth index amongst resettled households was the highest of the three groups (4.0 vs. 3.58 amongst migrant households and 3.01 amongst non-mobile local households). Patterns also emerged according to the year of migration into the study area, with those who migrated during the construction phase (2012–2015) having the highest mean wealth index score (3.8 vs. 3.3 in the exploration and feasibility phase and 3.5 during the operational phase, Table 2). Education levels of the household head were lowest for migrants during the early exploration and feasibility phase (only 17.9% completed secondary school during the exploration and feasibility phase vs. 41.5% in the construction and 32.7% in the operational phases). Similarly, the percentage of households with at least one person employed was lowest for migrants during the early exploration and feasibility phase, with similarly high levels of employment for migrants in the two later phases (19.2% employment for migrants during the exploration and feasibility phase vs. 53.8% employment for the construction phase and 41.8% employment for migrants during the operational phase). Virtually all households with at least one person currently working for the mine reported migrating during the construction or operational phases or having been

Table 3
Association of phase of migration with wealth index score in a linear model after adjusting for education. Reference groups are non-mobile locals and less than a primary school education. The full model is adjusted for education of household head, household employment, and age of household head.

	Unadjusted model			Education adjusted			Full model		
Variable	Beta	SE	p-value	Beta	SE	p-value	Beta	SE	p-value
Migrant Status									
Migrant exploration phase	0.25	0.1	0.01*	0.16	0.09	0.07	0.21	0.08	0.01*
Migrant construction phase	0.75	0.07	<0.001***	0.4	0.06	<0.001***	0.26	0.06	<0.001***
Migrant operational phase	0.45	0.09	<0.001***	0.2	0.09	0.01*	0.17	0.08	0.03*
Education of household head									
Completed primary	0.23	0.06	<0.001***	0.19	0.05	<0.001***	0.13	0.05	0.01*
Completed secondary	1.2	0.07	<0.001***	1.03	0.07	<0.001***	0.68	0.08	<0.001***
>=1 household member employed	1.09	0.05	<0.001***				0.75	0.06	<0.001***
Age of household head	−0.003	0.003	0.25				0.004	0.002	0.07

*Adjusted R^2 value of full model: 0.43.
**Note: these comparisons use the pooled sample (i.e. data from the 2015 and 2019 survey rounds).

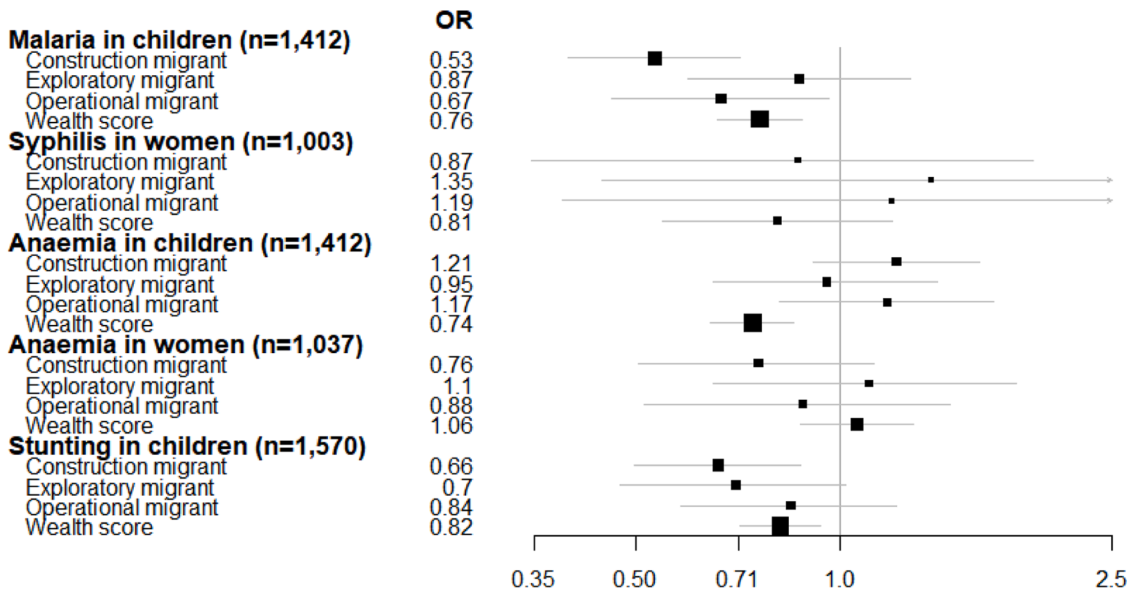

Fig. 3. Associations between diagnosis with malaria, syphilis, anaemia, and stunting and migration status after adjusting for household wealth score in women of reproductive age (18–49 years) and children. The reference group is non-mobile locals.

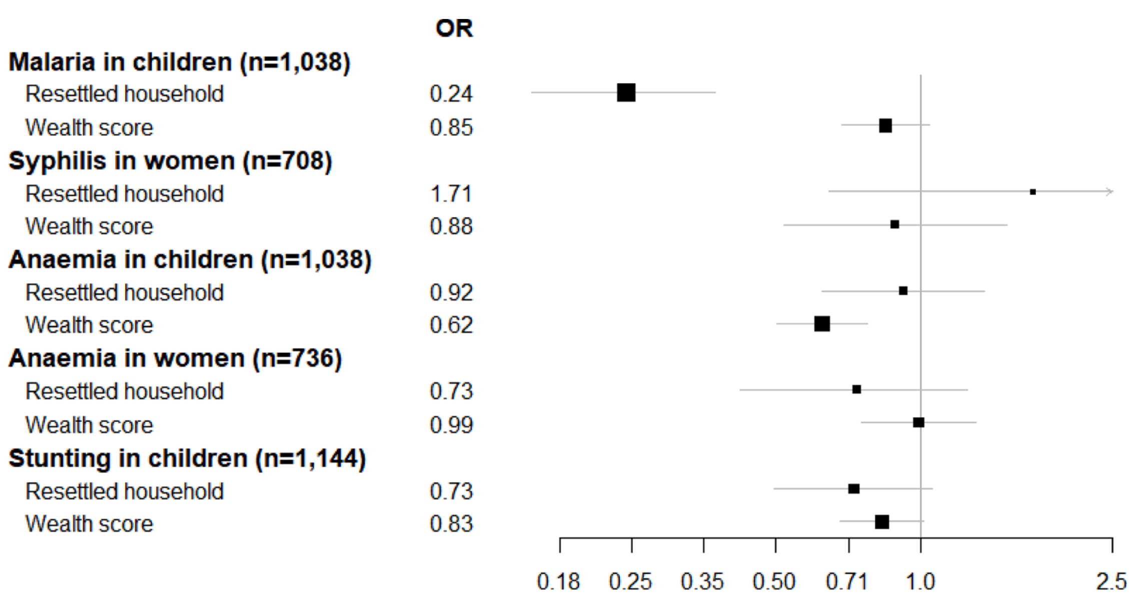

Fig. 4. Associations between diagnosis with malaria, syphilis, anaemia, and stunting and resettlement by the mine after adjusting for household wealth score in women of reproductive age (18–49 years) and children. The reference group is non-mobile locals.

resettled by the mine. No migrants during the exploratory and feasibility phase and only 1.2% of non-mobile local households currently worked for the mine. Those who reported at least one family member working for the mine (n = 39 households, 3.9% of the study population) had a mean wealth score of 4.36, significantly higher than that of the rest of the study population that did not work at the mine (mean: 3.31, $p < 0.001$). Households with members working at the mine were also significantly better off than migrant households without mine workers (mean: 3.51, $p < 0.001$) and resettled households without mine workers (mean: 3.95, $p = 0.001$). However, when restricting the analysis to only those households without workers directly employed by the mine, spatially mobile households still had a significantly higher wealth score than locals that were not mobile (migrant households had a mean wealth of 3.51 vs. 3.18 in non-mobile local households ($p < 0.001$), resettled households had a mean wealth of 3.94 vs. 3.22 in non-mobile local households ($p < 0.001$).

Non-mobile local households had a lower wealth score, education level, and proportion of employed adults versus migrants in any phase (Table 2). In a linear model, being a migrant during the exploration and feasibility, construction, and operational phases of the mine development significantly predicted a higher wealth index score compared to being a non-mobile local after adjusting for education, sex and age of the household head (Table 3). Adjusting for employment status and education explained the most difference in the coefficients in the unadjusted and full models, although migration status remained significantly associated with wealth (Table 3).

Mean wealth score varied amongst households who moved for different reasons. The highest mean wealth scores were amongst those who moved for artisanal mining (4.23, SD: 0.69), followed by as a service provider for the project (4.22, SD: 0.69), for a labour job (4.12, SD: 0.89), resettlement by mine (3.90, SD: 0.58), fleeing previous place (3.6, SD: 0.70), and as a provider of goods and services to the local population

(3.58, SD: 0.67). The lowest mean wealth scores were amongst those who moved for family reunification (3.02, SD: 0.75) and as a former resident of area (3.12, SD: 0.73).

In logistic models for the association between disease diagnosis and migration status, malaria and stunting in children <5 years were found to be significantly associated with migration status (Fig. 3). The odds of a child being diagnosed with malaria were significantly lower for both migrants during the construction (OR: 0.53, 95% CI: 0.40, 0.71; 32.3% of children were diagnosed with malaria) and operational phases (OR: 0.67, 95% CI: 0.46, 0.96; 38.9% of children were diagnosed with malaria), even after adjusting for family wealth score. 51.3% of the children of non-mobile locals were diagnosed with malaria.

The odds of having a child diagnosed with stunting were marginally lower for migrants during the exploration and feasibility phase (OR: 0.70, 95% CI: 0.48, 1.02; 30.1% of children were diagnosed with stunting), significantly lower for migrants during the construction phase (OR: 0.66, 95% CI: 0.50, 0.87; 27.8% of children were diagnosed with stunting) and lower in the operational phase (OR: 0.84, 95% CI: 0.58, 1.21; 34.0% of children were diagnosed with stunting). 39.6% of the children of non-mobile locals were diagnosed with stunting.

Syphilis in reproductive aged women, anaemia in children and anaemia in reproductive aged women do not appear to be associated with migration status. However, overall, only a small number of women had a past or current syphilis infection (4.1%, $n = 43/1040$). Increasing household wealth score was significantly associated with decreased risk of malaria in children (OR: 0.76, 95% CI: 0.66, 0.88), anaemia in children (OR: 0.74, 95% CI: 0.65, 0.85), and stunting in children (OR: 0.76, 95% CI: 0.66, 0.88).

In logistic models for the association between disease diagnosis and being resettled by the mine, malaria in children was found to be significantly associated with being resettled (Fig. 4), even after adjusting for the wealth index. The odds of having a child diagnosed with malaria were significantly lower amongst resettled households (OR: 0.24, 95% CI: 0.16, 0.37; 17.8% of children from resettled households were diagnosed with malaria vs. 51.3% of children from non-mobile local households). Syphilis and anaemia in reproductive aged women and stunting and anaemia in children <5 years were not associated with being resettled (Fig. 4).

4. Discussion and conclusion

Our findings indicate that the development of a large copper mining project in Zambia was associated with large population and demographic shifts in the local community. Furthermore, we show that wealth as measured by household assets is unequally shared between migrants, physically resettled households, and the non-mobile locals. Almost half (40%) of the study population migrated to the area in the ten-year study period from the exploration and feasibility phase to five years into the operational phase. The number of migrants depended heavily on the phase of the mine, with the construction phase drawing by far the highest number of migrants. The main drivers of migration also shifted over time, with labour-seeking the most important motive during the construction and particularly the operational phase, and family reunification becoming more important as time went on.

The results of the study show that overall, migrants were younger (mean age of household head 33.9 years vs. 37.7 years), more educated, and more likely to be employed than non-mobile locals of the area, similar to other studies that have found that in-migrants tend to be more highly skilled (Loayza and Rigolini, 2016). Even after adjusting for these factors, migrants were still better off in terms of wealth and assets. Somewhat surprisingly, similar patterns were found for resettled households. Those households with at least one member directly employed by the mine showed the highest benefits in terms of household wealth, but population mobility was still associated with significantly improved household wealth even without direct employment by the mine, perhaps due to increased opportunities for other employment. Migrants and resettled households were much more likely than non-mobile locals to have at least one household member with employment outside the house, and were more likely to be working for the mine itself. Households that had been resettled had the highest overall mean household wealth score of the three groups. The high household wealth score of resettled households reflects especially the improvement in their housing situation after the resettlement, and may also reflect the benefits of the livelihood support programmes of the mine. While there may have been some additional education benefit for this group as well, it is unlikely to be a factor in households where the head was over 30 years old. In addition, most of the households working for the mine were migrants from the construction or operational phases or those who were resettled. Household wealth after implementation of a large mining project is higher in households that are spatially mobile than in households of non-mobile locals. In addition, higher economic status seemed to be especially associated with migration during certain phases of the mine opening.

The economic advantages of migrants during certain phases of the mine development extend as well to disease prevention. Malaria infection in children is particularly reduced in migrant and resettled households, which may suggest that improvements in housing associated with mobility are protective against exposure to malaria (Tusting et al., 2015). This hypothesis is supported by the fact that being resettled by the mine and wealth index score (which incorporates variables on quality of housing and environmental hygiene) are also highly associated with reduced odds of malaria transmission. The dramatically reduced odds of malaria in children from resettled households may reflect the efficacy of the screen windows installed in the housing constructed by the mine, better overall housing structure in the housing constructed by the mine, improved environmental hygiene in areas resettled by the mine, or the health programmes conducted by the mine. These findings confirm those of Knoblauch et al. that found that living in a village impacted by the Trident project significantly lowered the risk of *Plasmodium falciparum* infection as compared with villages not impacted by the mine (OR = 0.68, 95% CI 0.49–0.94) (Knoblauch et al., 2020). Other studies in sub-Saharan African have similarly found a link between improved housing and lower incidence of malaria, amongst child health outcomes, after adjusting for household wealth (Tusting et al., 2017; Tusting et al., 2020; Gao et al., 2021).

We also found a significantly reduced risk of stunting in children <5 years again amongst migrants during the construction phase relative to non-migrant households. This suggests that children of households that moved in particular during the construction phase enjoy better overall nutritional health than the children of non-mobile locals. It is also possible that these migrants may have arrived already healthier than the host population, a form of health selection supported by evidence from other studies (Anglewicz et al., 2017). While the risk of stunting was also reduced in households that migrated during other periods, the confidence intervals were wide. Syphilis and anaemia did not appear to be linked with migration status. Increasing household wealth scores were associated with decreased odds of all three health outcomes measured in children, suggesting that household wealth levels may be an important protective factor against childhood disease. These findings align with those of other studies that have found that household wealth is significantly associated with childhood disease and malnutrition in sub-Saharan Africa (Keino et al., 2014; Ayelign and Zerfu, 2021; Fagbamigbe et al., 2021). The fact that the reduced odds of malaria and stunting in the children of migrants holds true even after adjusting for household wealth score suggests that migration during certain phases of the mine development is associated with concretely better health outcomes. It may also be that the health of the migrants prior to relocating was already better than that of the locals, although due to their young age many of these children were likely born in their current location. Other evidence in children of migrants suggests that their health after migrating is strongly mediated by that of maternal health (Anglewicz et al., 2019), but studies specifically on the health of the children of migrant households remain rare.

The clear patterns in differing socioeconomic indicators and health outcomes in migrants in the different mine opening periods have several potential explanations. First of all, it may reflect that each time period attracts different types of migrants, who may themselves come from different socioeconomic backgrounds or have different earning potential. Some migrants may already be wealthier and healthier than locals prior to arriving in the region. This hypothesis is supported by the differing mean wealth index scores amongst those who moved for different reasons (e.g. those who moved for artisanal mining have a mean wealth index score of 4.23 while those who moved for family reunification only had a mean wealth score of 3.02). However, most households reported that they moved for the purpose of seeking a labour job, and the sample size for other reasons for relocation is too small to generalise. Secondly, it may be that those who move during the construction period of the mine were most able to take advantage of the infrastructure and services that were newly provided by the mine during that period. Third, it may be that the economic benefits that a mine opening provides are mainly concentrated in different time periods, resulting in an unequal distribution of wealth amongst migrants. This conclusion is supported by a study from Peru that found that although mining has a positive impact on overall wealth levels in producing regions, it also produces higher levels of inequality (Loayza and Rigolini, 2016).

In our study, we found that certain benefits of mine development such as improved housing, employment, and disease prevention appear to accrue differentially to separate groups in the local community, with those able to migrate or be resettled benefiting the most. If in fact the economic benefits that a mine bring to a region may also be associated with increasing inequalities in local wealth and health, HIA could play an important role in ensuring equitable distribution of resources (Leuenberger et al., 2019). Projects like Trident represent a "good practices" scenario in terms of prospective tracking of shifts in local health and economic indicators in the local communities over time, but other research has suggested that health equity still remains an insufficiently addressed topic in HIA (Leuenberger et al., 2019). In order to mitigate the risk that mines widen the inequality gap in local communities, special attention should be paid to ensuring that intervention strategies are accessible to all community subgroups.

This study is limited by its cross-sectional nature. It is not possible to make causal statements about migration without more information about temporality; however, the results are still highly suggestive of an association with socioeconomic indicators and health. In the future, a longitudinal study of migrants to mining areas would be of great interest. However, this study still provides important new information on associations between migration and health and socioeconomic indicators through a series of cross-sectional studies in the context of a large-scale mining setting. We are also limited in our ability to directly estimate the rate of resettlement and migration into the mining area as a whole, due to the semi-purposive sampling. Specifically, communities such as the resettlement host site communities and the mining town developed for mine workers and their families were intentionally included, meaning that this is not a fully random sampling of the communities surrounding the mine. However, the semi-purposive sampling allowed us to enrol sufficient numbers of migrants to study this community in detail. Finally, because participants were only asked about their reason for migrating if they had migrated in the five years prior to the interview, those interviewed in 2019 were not asked about their reasons for moving if they moved prior to 2014. Therefore the reasons for migration in the early phase of the mine opening are based on those who were interviewed in 2015. Due to this and the fact that this question was not asked in the earliest survey round in 2011, the mobility dynamic before a certain point is not well understood.

Large resource extraction projects induce population mobility that can have profound effects on health and socioeconomic status in local communities. Our study aimed to analyse patterns in population mobility, socioeconomic status, and health after the opening of the Trident copper mine in Kalumbila district of North-Western Province in Zambia. Overall, the majority of the migration occurred during the construction phase of the mine. Our study finds evidence that resettled and newly arrived migrant households have higher levels of household wealth than those of non-mobile locals. Both malaria infection and stunting in children $<$5 years was reduced in migrant households, while children from resettled households showed particularly reduced odds of malaria infection. Households that migrated during the construction phase had the highest average household wealth and lowest odds of disease. Planning for major changes in population demographics and health should be a key part of promoting sustainable development in the mining sector. Projects like Trident provide an example of how HIA at project initiation can use mitigation strategies to promote better health and well-being in the local communities, and how resettlement projects can bring about economic and health benefits. In the future, special care should be taken that improvements in household wealth and disease prevention programmes should be promoted equitably in both non-mobile local households and newly arrived migrant and resettled households.

Role of the funding source

First Quantum Minerals Limited funded the health impact assessment and supported data collection for the 2011, 2015 and 2019 surveys. The funding sponsor had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, and in the decision to publish the results.

Declarations of Competing Interest

First Quantum Minerals Limited funded the health impact assessment and supported data collection for the 2011, 2015 and 2019 surveys. A.M.K., M.J.D., and M.S.W. have supported the FQML as independent public and occupational health specialists. The corresponding author had full access to all the data of all three surveys. The funding sponsor had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, and in the decision to publish the results.

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Appendix

Total Migration by Year	Year	N HH	% of total migrant HH ($n = 505$)
Exploration and Feasibility Phase	2008	16	3.2%
	2009	22	4.4%
	2010	14	2.8%
	2011	27	5.4%
	Total	**79**	**15.6%**
Construction Phase	2012	45	8.9%
	2013	81	16.0%
	2014	145	28.7%
	2015	50	9.9%
	Total	**321**	**63.6%**
Operational Phase	2016	30	5.9%
	2017	30	5.9%
	2018	25	5.0%
	2019	20	4.0%
	Total	**105**	**20.8%**

Reason for Migrating	year	labour job	Artisanal mining	Family Reunification	Resettled by mine	Former resident of area	Service provider to the project	Provide services local pop
Exploration and Feasibility Phase	2008	0	0	0	0	0	0	0
	2009	0	0	0	0	0	0	0
	2010	3 (30.0%)	0	4 (40.0%)	0	1 (10.0%)	0	1 (10.0%)
	2011	4 (26.7%)	1 (6.7%)	8 (53.3%)	0	2 (13.3%)	0	0
	Total	**7 (28.0%)**	**1 (4.0%)**	**12 (48.0%)**	**0**	**3 (12.0%)**	**0**	**1 (4.0%)**
Construction Phase	2012	11 (42.3%)	2 (7.7%)	9 (34.6%)	0	5 (19.2%)	0	0
	2013	17 (32.7%)	4 (7.7%)	12 (23.1%)	16 (30.8%)	3 (5.8%)	0	0
	2014	63 (43.4%)	9 (6.2%)	19 (13.1%)	46 (31.7%)	6 (4.1%)	4 (2.8%)	4 (2.8%)
	2015	25 (50.0%)	3 (6.0%)	6 (12.0%)	8 (16.0%)	2 (4.0%)	4 (8.0%)	0
	Total	**116 (42.5%)**	**18 (6.6%)**	**46 (16.8%)**	**70 (25.6%)**	**16 (5.9%)**	**8 (2.9%)**	**4 (1.5%)**
Operational Phase	2016	10 (33.3%)	0	9 (30.0%)	3 (10.0%)	3 (10.0%)	0	2 (6.7%)
	2017	14 (46.7%)	1 (3.3%)	8 (26.7%)	3 (10.0%)	1 (3.3%)	0	0
	2018	13 (52.0%)	1 (4.0%)	9 (36.0%)	1 (4.0%)	2 (8.0%)	1 (4.0%)	4 (16.0%)
	2019	10 (50.0%)	1 (5.0%)	6 (30.0%)	0	0	0	1 (5.0%)
	Total	**47 (44.8%)**	**3 (2.9%)**	**32 (30.5%)**	**7 (6.7%)**	**6 (5.7%)**	**1 (1.0%)**	**7 (6.7%)**

Appendix table for Fig. 3. Associations between diagnosis with malaria, syphilis, anaemia, and stunting and migration status after adjusting for household wealth score in women of reproductive age (18–49 years) and children <5 years. The reference group is non-mobile locals.

	OR	95% CI	
Malaria in children ($n = 1412$)			
Construction migrant	0.53	0.40	0.71
Exploratory migrant	0.87	0.60	1.27
Operational migrant	0.67	0.46	0.96
Wealth score	0.76	0.66	0.88
Syphilis in women ($n = 1003$)			
Construction migrant	0.87	0.35	1.92
Exploratory migrant	1.35	0.45	3.39
Operational migrant	1.19	0.39	2.96
Wealth score	0.81	0.55	1.19
Anaemia in children ($n = 1412$)			
Construction migrant	1.21	0.91	1.60
Exploratory migrant	0.95	0.65	1.39
Operational migrant	1.17	0.81	1.68
Wealth score	0.74	0.65	0.85
Anaemia in women ($n = 1037$)			
Construction migrant	0.76	0.50	1.12
Exploratory migrant	1.1	0.65	1.81
Operational migrant	0.88	0.52	1.45
Wealth score	1.06	0.87	1.28
Stunting in children ($n = 1570$)			
Construction migrant	0.66	0.50	0.87
Exploratory migrant	0.7	0.48	1.02
Operational migrant	0.84	0.58	1.21
Wealth score	0.82	0.71	0.94

Appendix Table for Fig. 4. Associations between diagnosis with malaria, syphilis, anaemia, and stunting and resettlement by the mine after adjusting for household wealth score in women of reproductive age (18–49 years) and children <5 years. The reference group is non-mobile locals.	OR	95% CI	
Malaria in children (n = 1038)			
Resettled household	0.24	0.16	0.37
Wealth score	0.85	0.68	1.04
Syphilis in women (n = 708)			
Resettled household	1.71	0.65	4.29
Wealth score	0.88	0.52	1.51
Anaemia in children (n = 1038)			
Resettled household	0.92	0.62	1.35
Wealth score	0.62	0.50	0.77
Anaemia in women (n = 736)			
Resettled household	0.73	0.42	1.25
Wealth score	0.99	0.75	1.30
Stunting in children (n = 1144)			
Resettled household	0.73	0.50	1.05
Wealth score	0.83	0.68	1.01

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