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Changes in socioeconomic determinants of health in a copper mine development area, northwestern Zambia

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ABSTRACT

In 2011, an industrial copper mine was developed in northwestern Zambia. A health impact assessment was conducted to anticipate and address potential health impacts. To monitor these impacts, three community-based surveys were conducted in the area (2011, 2015 and 2019). We analysed these data to determine how household socioeconomic indicators – considered determinants of health – have changed in the area over time. In mine-impacted communities, between 2011 (pre-construction) and 2019, significant changes were observed for: (i) average household size (-0.6 members); (ii) proportion of mothers that have not completed primary school (+20.4%); (iii) ownership of economic assets (e.g. phones +29.3%; televisions +15.6%); (iv) access to safe drinking water (+27.4%); and (v) improved housing structures (e.g. finished roof +58.6%). When comparing changes between 2015 and 2019 in impacted communities to nearby comparison communities, there was (i) an increased proportion of mothers that had not completed primary school in comparison communities vs. no change in impacted communities; and (ii) increased ownership of economic assets in impacted vs. comparison communities in 2019. This study found generally positive changes in the socioeconomic development of impacted compared to comparison communities, with the most pronounced improvements in the early phases of mine development.

Abbreviations

FQML	First Quantum Minerals Limited
HIA	Health Impact Assessment
ODK	Open Data Kit
SD	Standard Deviation
ZDHS	Zambia Demographic and Health Survey

1. Introduction

Natural resource extraction projects constitute a major economic sector in many sub-Saharan African countries, with new mines often creating a large number of jobs and resulting in large-scale investments in the local infrastructure. Zambia has a long history of copper mining, and is the second largest copper producer in Africa (Meller and Simpasa, 2011; Sikamo et al., 2016; World Bank Group, 2015). As in many resource-rich low-income countries, Zambia's economy is heavily dependent on natural resource extraction, which is responsible for 12% of the country's gross domestic product and accounts for more than 80% of the country's exports (World Bank Group 2020).

Large-scale industrial copper mines can have positive economic effects on surrounding local communities, as previous studies show. For example, increased employment rates were observed in municipalities in Norway, Sweden and Finland (Frederiksen and Kadenic, 2020) and better average standards of living were observed in Peruvian mining districts as compared to other districts (Loayza et al., 2013). In Zambia,

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it was estimated that a 10% increase in copper production resulted in a 2% increase in household expenditure and a 3% decrease in the overall unemployment rate between 1996 and 2010 (Lippert, 2014). In contrast, neutral or detrimental impacts of mining on the economy of local communities have also been observed. For example, in Mali, poverty reduction in mining communities was no different than that of non-mining communities (Chuhan-Pole et al., 2017). More generally, the presence of multinational mining companies has been linked to increased food insecurity in Africa (Wegenast and Beck, 2020) and decreases in the wealth of mining-affected households due to costs caused by a surge in uncontrolled infectious diseases (Viliani et al., 2017).

The Trident Copper Project (hereafter referred to as "the Project") operated by First Quantum Minerals Limited (FQML) is a greenfield copper project located in Kalumbila district, North-Western province of Zambia. The Project conducted its feasibility studies between 2009 and 2011 and moved into the construction phase in 2012. As part of the feasibility studies, a health impact assessment (HIA) was conducted in 2010/2011, using a comprehensive approach to health, i.e. considering the physical, socioeconomic, behavioural and biological determinants of health (Winkler et al., 2021). Potential health impacts were systematically anticipated and addressed by the HIA with the ultimate objective of protecting and promoting public health in surrounding communities (Knoblauch et al., 2020). The impact monitoring program defined by the HIA recommended that the Project conduct repeated cross-sectional health surveys every 4 years. The health surveys measured selected health outcomes and determinants of health. These included socioeconomic indicators at the household level to assess socioeconomic status in a nationally comparable way, such as possession of assets, cooking fuel, housing material and drinking water infrastructure (Rutstein and Johnson, 2004).

Findings of the monitoring of selected health indicators are presented elsewhere (Knoblauch et al., 2020). Here, we present the findings of the selected socioeconomic indicators and their changes over time in both, communities affected by the Project and comparison communities. We describe (i) the overall changes in the indicators in six communities impacted by the Project in an eight-year time period between the Project start (2011) and the Project operational phase (2019) and (ii) how trends in the indicators differ in local communities impacted by the Project vs. comparison communities.

2. Methods

2.1. Study area, design and sampling

The Project is located in Kalumbila district, North-Western province of Zambia (Fig. 1). Three cross-sectional surveys were conducted. Following a baseline survey in 2011, two follow-up surveys were conducted in 2015 and 2019, all during the same season (June/July), in communities impacted by the Project as well as comparison communities. Six impacted communities were sampled in all three surveys, namely: Northern Resettlement (previously Wanyinwa), Musele, Chisasa, Kankonzhi, Chovwe and Chitungu. For another six communities, data was only available for 2015 and 2019 (i.e. Kalumbila Town, Shenengene, Kanzanji, Wamafwa, Kanzala, Mubenji) (Table 1) (Knoblauch et al., 2017).

For the 13 communities ever surveyed, nine communities were considered "impacted" because they were affected by the Project development. This could be due to changes intrinsically caused by the mining Project, such as infrastructure investments or community resettlements. For example, Kalumbila Town was developed by the Project to accommodate workers and their families as well as to provide services to these communities, while Shenengene developed as a host site for communities that were physically resettled. In addition, they could be affected due to health and socioeconomic interventions initiated by the Project. These included, for example, programs to prevent sexually transmitted diseases, improvement of drinking water sources, girls' empowerment programs, health infrastructure development,

Table 1
Study populations, Kalumbila district, Zambia (2011, 2015, 2019).

Community	Number of households		
	2011	2015	2019
Impacted communities			
Kalumbila Town	n/s	29	31
Wanyinwa/Northern Resettlement	35	34	30
Shenengene	n/s	32	31
Musele	29	67	65
Chisasa	62	65	66
Kankonzhi	39	30	32
Chovwe	63	32	32
Kanzanji	n/s	32	32
Chitungu	30	33	32
Total impacted communities	**258**	**354**	**351**
Comparison communities			
Nkenyawuli	29	32	31
Wamafwa	n/s	33	32
Kanzala	n/s	30	63
Mubenji	n/s	33	32
Total comparison communities	**29**	**128**	**158**

n/s, not sampled
Adapted from Knoblauch et al. (Knoblauch et al., 2020).

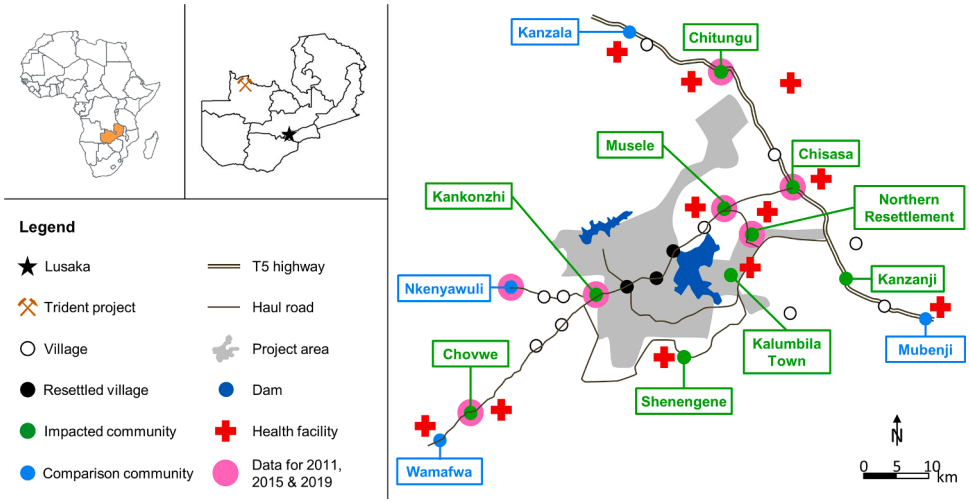

Fig. 1. Map of the study area and surveyed communities, Kalumbila district, Zambia (Adapted from Knoblauch et al. (Knoblauch et al., 2020)).

education, and conservation farming amongst other programs in the communities around the Project (Knoblauch et al., 2017). Another four communities were considered "comparison" because they did not benefit directly from the Project through e.g. Project-initiated health or community development interventions or infrastructure investments (Knoblauch et al., 2017; Knoblauch et al., 2018; Knoblauch, Divall et al., 2017; Knoblauch et al., 2020; Winkler et al., 2012). After the initial assessment, systematic monitoring through periodic surveys was used to assess long-term changes in the area. Moreover, in addition to assessing long-term changes in villages impacted by the mine's activities, systematic monitoring of nearby comparison communities over time was also conducted. Comparison communities were selected because they were similar to impacted communities except for the presence of mine interventions. This was increasing the robustness of our study by providing a comparison point of background changes over time in nearby villages not impacted by the mine (Ferragina, 2021; Krzywinski and Altman, 2014).

Within the selected communities, random sampling was used to select a quota of 25 to 35 households per community (Winkler et al., 2012). In order to increase representativeness, the sample size was doubled in communities with larger population sizes (i.e. Chisasa, Musele and Kanzala) (Knoblauch et al., 2020). Within the selected communities, the household inclusion criteria was the presence of a mother aged 15-49 years with a child under 5 years of age.

2.2. Questionnaire data collection

Data collection at household level included (i) administering a questionnaire to household members aged ≥15 years; (ii) measuring biomedical indicators in children under 5 years of age and women aged 15-49 years; (iii) testing for intestinal parasites and schistosomiasis in school children aged 9-14 years; and (iv) environmental sampling (e.g. water quality). Here, we present data only from the questionnaire and hence, do not introduce the other data collection methods that are described elsewhere (Knoblauch et al., 2020). The household questionnaire included a list of standardized socioeconomic variables used by the ZDHS to calculate a nationally comparable wealth index. These indicators were related to household members, mothers' age and education level, possession of selected household assets (e.g. bank account, bicycle, phone, radio and television), characteristics of the household floor, walls and roof, energy sources for food preparation and main sources of water for drinking. Standard categories for housing structures, drinking water and cooking sources were used in accordance with the ZDHS (ZSA et al., 2019). Data were collected with Open Data Kit (ODK) software on tablets.

2.3. Data analysis

In a first analysis, to determine how the socioeconomic indicators have evolved across impacted communities since baseline, we conducted a cross-sectional analysis to determine overall household socioeconomic change from the pre-project (2011) phase to the operational phase (2019). Importantly, only those impacted communities for which data were available for all three survey rounds were analysed over the entire study period to ensure comparability (n=6). Changes in proportions or mean values between 2011 and 2019 were calculated and tested for significance (t-test or chi-square test).

In a second analysis, the impact of the Project on local communities was measured by comparing the indicators in the impacted (n=9) vs. the comparison (n=4) communities and the change between 2015 and 2019. This comparative analysis was conducted only for the 2015 and 2019 survey rounds because 2011 data included only one comparison community (i.e. Nkenyawuli) (Knoblauch et al., 2020). The changes from 2015 to 2019 were calculated for both the impacted vs. the comparison communities, similar to the first analysis. Then, the difference between impacted and comparison was calculated by subtracting the impacted mean (or proportion) value from the comparison mean value. t-tests and chi-square tests were used to test whether the change in means or proportion, respectively, was significant.

All analyses were done with R software version 3.4.3 (The R Foundation; Vienna, Austria).

2.4. Ethical considerations

The health survey study protocols were approved by the ethics review board of the Center for Tropical Disease Research, Ndola, Zambia (TRC/ERC/04/07/2011, TRC/C4/07/2015, TRC/C4/01/2019). Data were collected after signing informed consent by the heads of households and women participating in this study. For illiterate people, the consent was translated into the local language, read and explained before fingerprinting.

3. Results

3.1. Study population

Table 1 summarizes the number of households interviewed in each survey round and community. For the 2011-2019 trend analysis, data from 258 households in 2011 were compared with data from 257 households in 2019. For the 2015-2019 difference-in-differences analysis, households from nine impacted communities (354 in 2015 and 351 in 2019, respectively) were compared with households from four comparison communities (128 in 2015 and 158 in 2019, respectively).

3.2. Changes in socioeconomic indicators

Changes in key socioeconomic indicators in all six impacted communities followed between 2011 (baseline) and 2019 (8-year follow-up) are summarized in Table 2 and Fig. 2. Average household size decreased from 4.4 persons (±2.4 standard deviations (SD)) in 2011 to 3.8 (±2.3 SD) persons in 2019 (p-value=0.007). The age of participating mothers was similar in both rounds, with marginal increases in the proportion of the 24-28 year old strata of women (+7.8%, p-value=0.06).

The proportion of mothers that did not complete primary education increased from 34.3% to 54.7% (p-value<0.001). There was a corresponding decrease in the proportion of women who completed primary (-11.0%, p-value=0.020) or secondary school (-9.4%, p-value=0.006).

Ownership of bank accounts increased by +9.5% (p-value<0.001), ownership of phones increased from 34.9% to 64.2% (p-value<0.001) and ownership of televisions increased from 11.2% to 26.8% (p-value<0.001). Bicycle ownership decreased by 12.6% (p-value=0.020), from 53.4% to 40.9%.

The type of cooking fuel used changed significantly. The share of households using wood declined from 93.6% to 63.4% (p-value<0.001), while the share of households using charcoal increased from 6.4% to 35.0% (p-value<0.001).

The use of finished materials as opposed to rudimentary materials for the housing structures increased significantly for floors (+15.6%, p-value<0.001), roofs (+58.8%, p-value<0.001) and walls (+47.8%, p-value<0.001). The proportion of household having access to an improved water sources increased from 61.9% to 89.3% (+27.4%, p-value <0.001).

3.3. Changes in socioeconomic indicators between impacted vs. comparison communities

Table 3 shows separate trends for impacted (n=9) and comparison communities (n=4) for the 2015-2019 period. Age of participating mothers increased slightly in impacted communities, where the proportion of 15-23 year olds decreased from 33.9% to 27.6% (p-value=0.08) and that of 24-28 year olds increased by +6.7% from 23.2% to 29.9% (p-value=0.05). In the comparison communities, the proportion

Table 2
Changes in the socioeconomic indicators in the six impacted communities between 2011 (before Project start) and 2019 (Project operational phase)

Indicator	2011 (258 HH)	2019 (257 HH)	Mean Change 2019-2011	p-value comparing 2011 vs. 2019
Household members; mean (±SD)				
Children under 5 years	1.9 (±1.0)	1.8 (±0.9)	-0.1	0.270
Total household size	4.4 (±2.4)	3.8 (±2.3)	-0.6	0.007
Mother's age (years); n (%)				
15-23	70 (27.1)	70 (27.2)	+0.1%	1.000
24-28	60 (23.3)	80 (31.1)	+7.8%	0.060
29-33	57 (22.1)	41 (16.0)	-6.1%	0.100
34-49	58 (22.5)	65 (25.3)	+2.8%	0.590
Missing	13 (5.0)	1 (0.4)	-4.6%	n/a
Educational attainment of mothers; n (%)*				
Not completed primary	70 (34.3)	140 (54.7)	+20.4%	<0.001
Completed primary	95 (46.6)	91 (35.5)	-11.0%	0.020
Completed secondary or higher	39 (19.1)	25 (9.8)	-9.4%	0.006
Household asset possession; n (%)				
Bank account	18 (7.2)	43 (16.7)	+9.5%	0.001
Bicycle	133 (53.4)	105 (40.9)	-12.6%	0.020
Phone	87 (34.9)	165 (64.2)	+29.3%	<0.001
Radio	97 (39.0)	95 (37.0)	-2.0%	0.950
TV	28 (11.2)	69 (26.8)	+15.6%	<0.001
Cooking fuel; n (%)				
Charcoal	16 (6.4)	90 (35.0)	+28.6%	<0.001
Electricity	0 (0.0)	0 (0.0)	+0.0%	1
Gas	0 (0.0)	4 (1.6)	+1.6%	1.130
Wood	233 (93.6)	163 (63.4)	-30.2%	<0.001
Main material of the floor; n (%)				
Finished	26 (10.5)	67 (26.1)	+15.6%	<0.001
Rudimentary	222 (98.5)	190 (73.9)	-15.6%	<0.001
Main material of the roof; n (%)				
Finished	92 (37.9)	246 (95.7)	+58.8%	<0.001
Rudimentary	157 (63.1)	11 (4.3)	-58.8%	<0.001
Main material of the walls; n (%)				
Finished	66 (26.5)	191 (74.3)	+47.8%	<0.001
Rudimentary	183 (73.5)	66 (25.7)	-47.8%	<0.001
Main source of drinking water; n (%)[a]				
Safe/improved sources[b]	169 (61.9)	241 (89.3)	+27.4%	<0.001
Unsafe/unimproved sources[b]	104 (38.1)	29 (10.7)	-27.4%	<0.001

HH, household; n/a: not applicable; SD, standard deviation.
*Mother's missing data on educational attainment were omitted from the denominator.
[a] Multiple drinking water sources possible per household.
[b] Improved sources of drinking water include piped water, public taps, standpipes, tube wells, boreholes, protected dug wells and springs, rainwater, water delivered via a tanker truck or a cart with a small tank and bottled water. Unimproved water sources include unprotected dug wells, unprotected springs and surface water.

of 15-23 year olds increased from 31.2% to 35.4% (p-value=0.61) and thus, a marked difference between the impacted communities and the comparison communities was therefore recorded for the 15-23 year olds (10.5% difference).

In impacted communities, maternal education levels remained relatively constant, while in comparison communities the proportion of mothers with incomplete primary education increased significantly from 54.7% to 68.4% (+13.7%, p-value=0.02) and the proportion of those who have completed primary dropped from 40.6% to 24.7% (-15.9%, p-value=0.005). Overall, basic educational attainment improved slightly in the impacted communities and worsened in the comparison communities.

In 2015, household possession of economic assets was generally higher in impacted communities than in comparison with regard to bank accounts (34.6% vs. 8.6%), phones (77.3% vs. 62.5%), cars (7.4% vs. 3.1%), motorcycles (6.5% vs. 6.3%), radios (48.4% vs. 35.9%) and televisions (36.3% vs. 10.2%). In 2019, the ownership rates were still higher in impacted vs. comparison communities with regard to bank accounts (23.6% vs. 8.9%), phones (68.4% vs. 61.3%), cars (7.9% vs. 3.1%), radios (39.9% vs. 25.9%) and televisions (31.9% vs. 15.8%). In contrast, bicycle and motorcycle ownership in the comparison communities surpassed that of those impacted communities in 2019 (42.4% vs. 39.3% and 8.2% vs. 5.9%, respectively). Importantly, when comparing asset holdings, there were almost universal decreases in both community groups between 2015 and 2019. Decreases were significant in the impacted communities with regard to bank accounts (-11.0%, p-value=0.002), phones (-8.9%, p-value=0.01) and radios (-8.5%, p-value=0.03). In the comparison communities, bicycle ownership decreased from 56.3% to 42.4% (-13.9%, p-value=0.03).

Overall, the biggest differences in the change between 2015 and 2019 in impacted and comparison communities were in the proportion of mothers in the youngest 15-23 year age group (-10.5%), the proportion of mothers that did not complete primary school (-20.6%), possession of bank accounts (-11.0%), bicycles (+12.7%) and TVs (-10.0%), use of charcoal as a cooking fuel (+10.4%) and the use of safe or improved water sources (-19.1%).

Fig. 3 shows the differences in changes in socio-economic indicators between the impacted and comparison communities.

4. Discussion

Using data from three consecutive cross-sectional surveys spaced four years apart (2011, 2015 and 2019), we analysed the changes in selected socioeconomic indicators considered determinants of health in households living near a large-scale copper mining Project in Zambia. Six communities impacted by the Project saw improvements in the selected socioeconomic indicators from the pre-Project implementation phase in 2011 to the Project operational phase in 2019, driven especially by increases in asset ownership such as bank accounts, phones and televisions, use of charcoal instead of wood as cooking fuel and

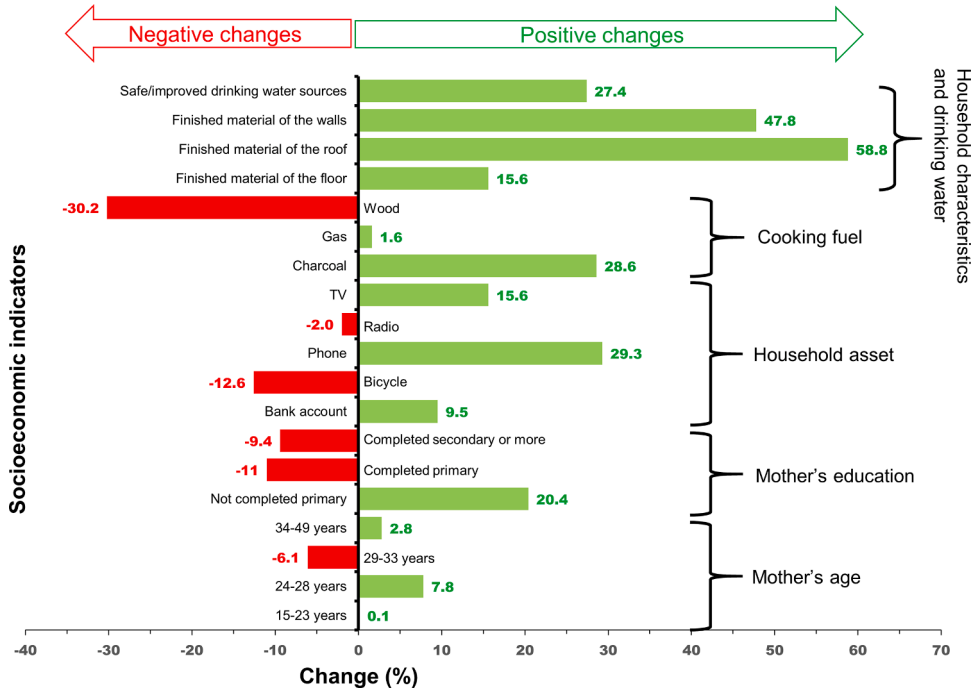

Fig. 2. Changes in the socioeconomic indicators in the six impacted communities between 2011 (before Project start) and 2019 (Project operational phase).

significant improvements in housing and drinking water infrastructure (Dietler et al., 2021b; 2021a). An important exception to this overall positive trend is the educational attainment of mothers, with a decrease in the proportion of mothers who completed primary school. In both 2015 and 2019, educational attainment of mothers, ownership of most assets (especially bank accounts, radios and televisions), use of charcoal as a cooking fuel and having finished floors and using improved water sources were all better for communities that had been impacted by the Project than comparison communities. This overall improvement in socioeconomic status in the study communities driven especially by communities directly impacted by the Project suggests that the impact of the Project on the local economy was predominantely positive. These various positive changes in the impacted communities could be linked to the in-migration induced by the mine, which typically attracts young, healthy people capable of generating household income.

While overall socioeconomic status was higher for most indicators in impacted than in comparison communities in both 2015 and 2019, asset ownership, housing quality and drinking water infrastructure declined slightly or remained the same in impacted communities between 2015 and 2019. This counterintuitive finding suggests that the main gains in the socioeconomic indicators measured in the impacted communities occurred in the Project construction phase, prior to 2015. This finding has important implications for the mechanisms by which mining projects affect local economies.

4.1. Changes in the possession of economic assets of households

The significant changes in the possession of assets revealed by our study between 2011 and 2019 are different from those of the ZDHS between 2013/14 and 2018 in rural areas (bank accounts: +9.5% vs. +0.3%, televisions: +15.6% vs. -1.3%, phones: +29.3% vs. +11.7%, bicycles: -12.6% vs. -5.9%) (CSO et al. 2014; ZSA et al. 2019). Thus, possession of these economic assets was higher in the study area, except for bicycles, suggesting that these changes were not simply improvements in Zambia as a whole and instead improvements driven by the presence of the mining Project. Interestingly, in 2015, ownership of economic assets was higher in the impacted communities than in the comparison communities. Despite a decrease of the possession of assets in impacted communities between 2015 and 2019, ownership levels in impacted communities remained higher in 2019 than in comparison communities. This could potentially reflect a positive impact of the mining Project on the possession of household assets. This aligns with numerous studies that found an increase in the economic level of poor households and employment and higher possession of economic assets in the vicinity of mines (Benshaul-Tolonen et al., 2019; Chuhan-Pole et al., 2017; Lippert, 2014).

The decrease in possession of household assets within the impacted communities between 2015 and 2019 is surprising and may reflect either changing demographics around the Project due to increasing in-migration of poorer residents, or that the positive changes in socioeconomic indicators diminish over time (Chuhan-Pole et al., 2017; Frederiksen and Kadenic, 2020; Gamu et al., 2015; Habiyaremye, 2020; James, 2015; Papyrakis, 2017; Srinivasan and Nuthalapati, 2020; Yang and Ho, 2019). Indeed, Nguyen et al. (Nguyen et al., 2017) found that impacts of mining at the local level are nuanced for the local community in an analysis of data from 63 provinces in Vietnam from 2009 to 2014. To better analyse the complexities of how mines impact on the economies of local communities over time, longitudinal studies such as cohort studies would be useful.

4.2. Changes in mother's education

The educational level of mothers in 2019 in the study were similar to those of the 2018 ZDHS in North-Western province ('not completed primary': 49.0% vs. 62.5%; 'primary completed': 31.8% vs. 27.5%; 'completed secondary or more': 8.7% vs. 9.8%) (ZSA et al., 2019). For those six impacted communities observed at baseline in 2011, educational levels have deteriorated, with 18.6% more women having 'not completed primary' education. However, between 2015 and 2019, trends toward better educational levels were observed in the impacted communities while comparison communities saw a decrease in educational attainment in mothers. Several dynamics could have contributed to these changes in the impacted communities: (i) in-migration of families with lower educational attainment since the baseline; (ii) a better educated population of mothers in the impacted communities added to the sample in 2015; and (iii) the more highly educated women employed

Table 3
Changes in the socioeconomic indicators between 2015 and 2019 in communities impacted by the mining Project and comparison communities.

Indicator	Impacted communities				Comparison communities				Difference in changes [A] - [B]
	2015 (354 HH)	2019 (351 HH)	Change [A]	p-value	2015 (128 HH)	2019 (158 HH)	Change [B]	p-value	
Household members; mean (SD)									
Children under 5 years	1.9 (0.9)	1.8 (0.9)	-0.1	0.31	1.9 (0.9)	1.8 (0.9)	-0.1	0.55	0.0
Total household size	3.7 (1.9)	3.8 (2.2)	+0.1	0.69	3.8 (1.6)	3.8 (2.2)	0.0	0.83	+0.1
Mother age (years); n (%)									
15-23	120 (33.9)	97 (27.6)	-6.3%	0.08	40 (31.2)	56 (35.4)	+4.2%	0.61	-10.5%
24-28	82 (23.2)	105 (29.9)	+6.7%	0.05	28 (21.9)	31 (19.6)	-2.3%	0.75	+9.0%
29-33	82 (23.2)	57 (16.2)	-7.0%	0.03	30 (23.4)	22 (13.9)	-9.5%	0.05	+2.5%
34-49	68 (19.2)	87 (24.8)	+5.6%	0.09	28 (21.9)	44 (27.8)	+5.9%	0.31	-0.3%
Missing	2 (0.5)	5 (1.4)	+0.9%	n/a	2 (1.6)	5 (3.2)	+1.6%	n/a	-0.7%
Educational attainment of mothers; n (%)									
Not completed primary	198 (55.9)	172 (49.0)	-6.9%	0.08	70 (54.7)	108 (68.4)	+13.7%	0.02	-20.6%
Completed primary school	112 (31.6)	121 (34.5)	+2.9%	0.47	52 (40.6)	39 (24.7)	-15.9%	0.005	+18.8%
Completed secondary school or more	42 (11.9)	53 (15.1)	+3.2%	0.25	4 (3.1)	6 (3.8)	+0.7%	1	+2.5%
Missing	2 (0.6)	5 (1.4)	+0.8%	n/a	2 (1.6)	5 (3.2)	+1.6%	n/a	-0.8%
Household asset possession; n (%)									
Bank account	122 (34.6)	83 (23.6)	-11.0%	0.002	11 (8.6)	14 (8.9)	+0.3%	1	-11.3%
Bicycle	143 (40.5)	138 (39.3)	-1.2%	0.83	72 (56.3)	67 (42.4)	-13.9%	0.03	+12.7%
Car	26 (7.4)	88 (7.9)	+0.5%	0.90	4 (3.1)	5 (3.1)	+0.0%	1	+0.5%
Motorcycle	23 (6.5)	21 (5.9)	-0.6%	0.86	8 (6.3)	13 (8.2)	+1.9%	0.75	-2.5%
Phone	273 (77.3)	240 (68.4)	-8.9%	0.01	20 (62.5)	19 (61.3)	-1.2%	0.48	-7.7%
Radio	171 (48.4)	140 (39.9)	-8.5%	0.03	46 (35.9)	41 (25.9)	-10.0%	0.09	+1.5%
TV	128 (36.3)	112 (31.9)	-4.4%	0.27	13 (10.2)	25 (15.8)	+5.6%	0.22	-10.0%
Cooking fuel; n (%)									
Charcoal	81 (22.9)	110 (31.3)	+8.4%	0.01	14 (10.9)	14 (8.9)	-2.0%	0.70	+10.4%
Electricity	28 (7.9)	22 (6.3)	-1.6%	0.48	0 (0.0)	1 (0.6)	+0.6%	1	-2.2%
Gas	0 (0.0)	4 (1.1)	+1.1%	0.13	0 (0.0)	0 (0.0)	0.0%	n/a	+1.1%
Wood	244 (69.1)	215 (61.3)	-7.8%	0.04	114 (89.1)	143 (90.5)	+1.4%	0.84	-9.2%
Main material of the floor; n (%)									
Finished	100 (28.3)	130 (37.0)	+8.7%	0.02	5 (3.9)	18 (11.4)	+7.5%	0.04	+1.2%
Rudimentary	253 (71.7)	221(63.0)	-8.7%	0.02	123 (96.1)	140 (88.6)	-7.5%	0.04	-1.2%
Main material of the roof; n (%)									
Finished	328 (92.9)	340 (96.9)	+4.0%	0.02	117 (91.4)	141 (89.2)	-2.2%	0.68	+6.2%
Rudimentary	25 (7.1)	11 (3.1)	-4.0%	0.03	11 (8.6)	17 (10.8)	+2.2%	0.68	-6.2%
Main material of the walls; n (%)									
Finished	282 (80.1)	273 (77.8)	-2.3%	0.60	97 (75.8)	109 (69.0)	-6.8%	0.25	+4.5%
Rudimentary	70 (19.9)	78 (22.2)	+2.3%	0.48	31 (24.2)	49 (31.0)	+6.8%	0.25	-4.5%
Main source of drinking water; n (%) [a]									
Safe/improved	363 (96.8)	312 (85.0)	-11.8%	0.001	92 (69.7)	124 (77.0)	+7.3%	0.20	-19.1%
Unsafe/unimproved	12 (3.2)	55 (15.0)	+11.8%	<0.001	40 (30.3)	37 (23.0)	-7.3%	0.20	+19.1%

HH, household; n/a: not applicable; SD, standard deviation.
[a] Multiple drinking water sources per household possible.

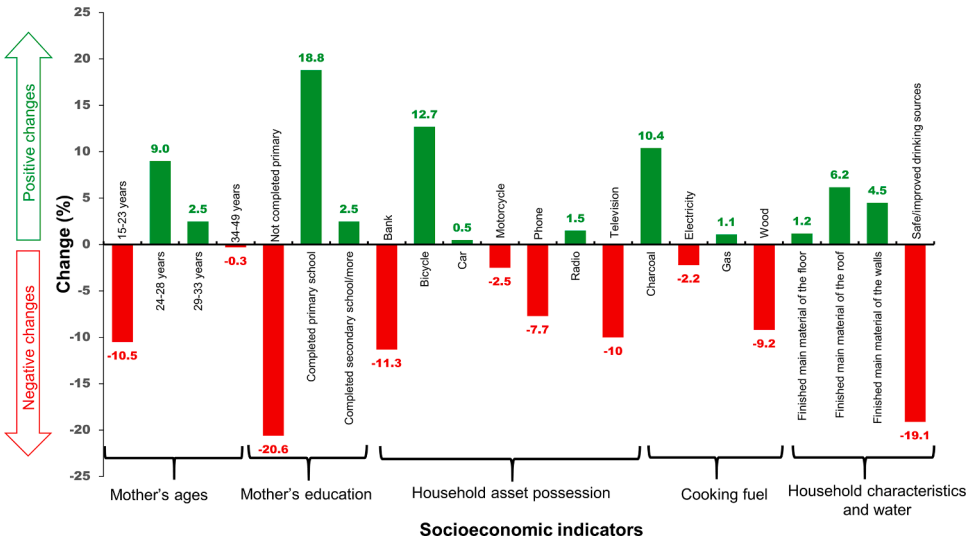

Fig. 3. Differences of changes in socioeconomic indicators between 2015 and 2019 in communities impacted by the mining Project and comparison communities.

by the mining Project were not at home during daytime data collection in 2015 and 2019. With regard to in-migration, it is known that communities such as Kalumbila Town, Shenengene or Northern Resettlement have experienced a high influx of labour-seeking, skilled and semi-skilled in-migrants (CSO et al., 2014; Knoblauch et al., 2017; Knoblauch et al., 2020; ZSA et al. 2019). It may also be possible that in-migration of families with lower educational attainment affected the comparison communities, even if they were not directly impacted by the Project. A more in-depth analysis of the migration background of the respondents would shed light on these changes and the potential impact migration had on the observed levels of maternal education.

4.3. Implications for health impact assessment practice

The current study provides a rare example of continued monitoring of socioeconomic indicators with particular relevance to health in the context of a large-scale greenfield mining project. The findings generated through the periodic collection of data, covering the phases of exploration, construction and operation, were readily incorporated in the health management plan of the Trident Project. Hence, our study underscores the value HIA can add for performance management and auditing of management plans by establishing a framework to monitor and evaluate changes in health early in the project development (Winkler et al., 2021). This was further enhanced through the evaluation of the trends over time in both impacted communities (intervention) and comparison communities, which allowed the disentanglement of Project-related impacts from broader socioeconomic changes in the Project region. In addition to representing an HIA best practice example, the study contributes to the evidence-base on potential impacts of large infrastructure projects being developed and implemented in similar contexts. Indeed, evaluation of impacts is a key aspect of HIA from a management and learning perspective (Quigley and Taylor, 2003), but also for justifying the continued promotion of HIA globally (Winkler et al., 2020).

Longitudinal household cohort studies in mining communities would aid in establishing causality and patterns in changes in determinants of health and health outcomes, but would require substantial financial commitment which might well be beyond the capacities of the proponent and the country. Similarly, another research-driven approach would be to establish a Health and Demographic Surveillance System (HDSS) with a specific focus on understanding the influence of large-scale mines on their surrounding communities (Ali Källestål et al., 2020; Sié, 2021).

Based on the experiences and outputs of the HIA in the Trident Project area presented here and elsewhere, we recommend that other private sector companies use the same or similar methodology for assessing and monitoring impacts of their operations. By promoting health and facilitating data collection in close collaboration with health authorities and research institutions, a win-win-win situation can be created. First, health benefits in communities can be promoted and negative health risks minimised, building healthier communities that can strive for better development. Second, improved monitoring and research will provide governments with tangible evidence for better health policies and prevent downstream health costs caused by the negative health impacts of such a project. Third, a healthier workforce results in higher productivity, benefiting the project (Better data, 2020; Winkler et al., 2020).

4.3.1. Limitations of the study

Our study has several limitations. First, only a selection of indicators was collected in the three surveys, potentially omitting other important socioeconomic indicators. For example, no information on employment was collected in 2011 and thus, this factor was not included in this analysis. Second, several comparison communities were only added to the 2015 sample, thus limiting the comparison between the impacted and the comparison communities to the period between 2015 and 2019 (Knoblauch et al., 2017). Third, it is possible that socioeconomic changes occurred in local communities prior to 2011, meaning that the full extent of socioeconomic changes due to the Project may not have been captured. Similarly, the small sample of comparison communities for the pre-Project baseline makes it difficult to establish whether communities impacted by the mine were already socioeconomically different prior to Project development.

5. Conclusion

Our analysis showed generally higher socioeconomic indicators in the communities impacted by the mining Project compared to the comparison communities and an overall positive trend in socioeconomic status in the study area from before the Project opened until the operational phase. A similar picture is found for the health outcome indicators collected during the same surveys, with impacted communities generally having better health outcomes than comparison communities.

However, the stagnation or slight declines in socioeconomic status between 2015 and 2019 raise concerns about the long-term sustainability of these positive socioeconomic impacts on mining communities, as well as the role that in-migration and changing demographics may have played in these changes. Care is indicated in order to avoid development inequalities and inequities between mine-impacted and non-impacted communities but also between households within the mine-affected communities (Leuenberger et al., 2020). Despite the Project's efforts to support local communities, in the absence of broad policy support from the government, inequalities between those who benefit and those who do not may emerge. Private-public collaboration and shared responsibilities, which are organised around periodic monitoring of key performance indicators at the level of determinants of health and health outcomes, have the potential to promote public health and equal socioeconomic development in the context of large infrastructure project developments.

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Author contributions

Conceptualization, M.J.D., M.S.W.; methodology, H.R.Z., A.M.K., A. F., M.O., M.J.D., M.S.W.; formal analysis, H.R.Z., A.M.K., A.F., M.O.,; writing—original draft preparation, H.R.Z., A.M.K., A.F., M.S.W.; writing review and editing, K.N., M.C., L.Z., G.M., J.U., M.J.D., M.O., S. P.D., G.F., A.F.; supervision, H.R.Z., A.M.K., M.O., K.N., M.C., M.S.W. All authors have read and agreed to the published version of the manuscript.

Declaration of Competing Interest

FQML funded the health impact assessment and supported data collection for the 2011, 2015 and 2019 surveys. A.M.K., M.O., M.J.D. and M.S.W. have supported the Trident Project as independent public health and occupational health specialists. G.M. was previously employed by FQML. M.C. is currently employed by FQML. The corresponding author had full access to all the data of all surveys. FQML 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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