# Assessing and monitoring health impacts of infrastructure development projects in sub-Saharan Africa

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*Mgeni njoo, mwenyeji apone.*

~

*Let the guest come so that the host may benefit.*

- Swahili proverb

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## Summary

**Background:** Health impact assessment (HIA) applies a combination of procedures, methods and tools that systematically judges the potential and sometimes unintended effects of a policy, a programme or a project on the health of a population and the distribution of those effects within the population. HIA therefore seeks to predict health impacts and inform decision-makers on appropriate actions to manage those impacts with the ultimate goal to minimize negative health impacts and promote positive health impacts.

In sub-Saharan Africa (SSA), there are no regulations at national levels that require an assessment of potential health impacts as part of the permitting process for infrastructure development projects. In absence of HIA enforcement mechanisms, multilateral lending institutions investing in projects and industry associations remain the only driving forces for HIA implementation to date. One reason for the limited attention given to HIA is the absence of monitoring and evaluation (M&E) in HIA, particularly in low- and middle-income countries and for private sector projects. Conversely, since the ultimate goal of HIA is to promote positive and mitigate negative health effects, it is a missed opportunity for responsible, accountable and sustainable development if health outcomes and its determinants are not regularly monitored in such highly dynamic settings.

Against this background, this PhD thesis aimed at filling knowledge gaps in assessing and monitoring health impacts of infrastructure development projects in SSA and to evaluate the effectiveness of HIA of projects in mitigating negative health impacts and promoting health benefits.

**Objectives:** The objectives of this PhD thesis were to present case studies implemented in three large-scale extractive industry projects in the Democratic Republic of the Congo (DRC), Côte d’Ivoire and Zambia and one renewable energy project in Sierra Leone. The case studies show (i) the implementation and outcomes of HIA of infrastructure development projects in SSA and (ii) M&E of health outcomes and health-related indicators in communities affected by these projects.

**Research partnerships:** The project work presented in this PhD thesis was conducted in a partnership of the Swiss TPH and SHAPE Consulting Limited (St Peters Port, Channel Islands and Pretoria, South Africa). HIA assignments, providing the database for this research, were sponsored by Randgold Resources, Newcrest Mining Limited, Addax Bioenergy and First Quantum Minerals Limited.

**Methods:** M&E in HIA was achieved through repeated cross-sectional health surveys in semi-purposively selected sentinel sites in the area of influence of a project and in non-impacted comparison communities. The selection of health or health-related indicators depended on factors such as health data gaps found during the HIA scoping step, perceived future impacts, experience from similar contexts and time and financial considerations. Within the sentinel sites, data was collected through (i) a household questionnaire survey in adults aged ≥15 years pertaining to sociodemographic information, health-related knowledge, attitudes and practices and other determinants of health; (ii) a clinical field unit assessing biomedical indicators in children under 5 years of age and adult household members aged ≥15 years; (iii) a parasitological survey in school children aged 9-14 years at school level; and (iv) a drinking water quality survey at household and source level. Households were selected randomly within a sentinel site and the presence of a mother with at least one child under the age of 5 years was the household inclusion criteria.

**Results:** A baseline health survey (BHS) prior to project commencement was conducted in three projects, providing a starting point for serial cross-sectional monitoring. In two of the four projects, a follow-up health survey (FUHS) was implemented 3 and 4 years after the BHS, respectively. The results from these two case studies showed mostly positive health changes between the BHS and the FUHS, overall and especially in the impacted communities as compared to the comparison communities. A multi-regression analysis performed showed that project-related factors at household level such as employment, migration or resettlement background were generally positively associated with improved health outcomes and its determinants in children and adults impacted by a copper mine in Zambia. Furthermore, the data from the surveys helped to initiate new and adapt existing community health interventions. The results from the FUHS have to be interpreted considering the following: (i) the projects are ongoing and will further change the social, economic and ecological environment; (ii) the time intervals were relatively short and certain indicators will change over a longer period; (iii) the construction of the projects and community development initiatives implemented in the project are were gradual, i.e. not all sentinel sites have received the same magnitude of impacts at the time of the surveys; (iv) the semi-purposive sampling of sentinel sites limited the generalisability of the results to communities that were not surveyed; (v) changes might have happened due to chance, normally occurring fluctuations or factors unassessed.

**Conclusions:** The baseline and follow-up health data collection within the HIA framework covering a broad range of biomedical, behavioural, contextual and environmental indicators allowed projects and health authorities to better understand pressuring health needs in the communities and take actions for health promotion. The approach of cross-sectional health surveys used for M&E of health impacts is promising in detecting changing patterns of community health and designing locally adapted health interventions. However, periodic M&E in 3-4 year intervals is not sufficient as certain indicators warrant shorter intervals between measurements. A combination of continuous and cross-sectional monitoring is recommended to the benefit of the individual projects, HIA practice in SSA and most importantly, the affected communities to protect and improve their health. The effectiveness and added value of HIA of infrastructure development projects has yet to be demonstrated. The case studies presented in this PhD thesis, emphasising on the need of a robust M&E component in HIA, support the evaluation and advancement of HIA practice.

## List of Abbreviations

| | |
|---|---|
| ABSL | Addax Bioenergy Sierra Leone |
| ACT | Artemisinin-Based Combination Therapy |
| AIDS | Acquired Immune Deficiency Syndrome |
| AfDB | African Development Bank |
| BGM | Bonikro Gold Mine |
| BHS | Baseline Health Survey |
| BSI | Better Sugarcane Initiative |
| CHMP | Community Health Management Plan |
| CI | Confidence Interval |
| $CO_2$ | Carbon Dioxide |
| CRS | Corporate Social Responsibility |
| DDT | Dichlorodiphenyltrichloroethane |
| DHS | Demographic and Health Survey |
| DRC | Democratic Republic of the Congo |
| EHA | Environmental Health Areas |
| EHS | Environmental, Health and Safety |
| EIA | Environmental Impact Assessment |
| EPFI | Equator Principles Financial Institutions |
| EPG | Eggs Per Gram of Stool |
| EPI | Expanded Programme on Immunization |
| ESHIA | Environmental, Social and Health Impact Assessment |
| ESIA | Environmental and Social Impact Assessment |
| FGD | Focus Group Discussion |
| FUHS | Follow-Up Health Survey |
| FQML | First Quantum Minerals Limited |
| GFATM | Global Fund to Fight AIDS, TB and Malaria |
| GNTD | Global Neglected Tropical Diseases database |

| | |
|---|---|
| GPS | Global Positioning System |
| Hb | Haemoglobin |
| HDSS | Health and Demographic Surveillance System |
| HIA | Health Impact Assessment |
| HIS | Health Information System |
| HIV | Human Immunodeficiency Virus |
| HRIA | Human Rights Impact Assessment |
| HRS | Health Road Show |
| HTC | HIV Testing and Counselling |
| ICMM | International Council on Mining and Minerals |
| IEC | Information, Education and Communication |
| IFC | International Finance Corporation |
| IIA | Integrated Impact Assessment |
| IPIECA | International Petroleum Industry Environmental Conservation Association |
| IPT | Intermittent Preventive Treatment |
| IRS | Indoor Residual Spraying |
| ITN | Insecticide Treated Bednet |
| KAP | Knowledge, Attitudes and Practices |
| KGM | Kibali Gold Mine |
| LLIN | Long-Lasting Insecticidal Nets |
| LMIC | Low- and Middle-Income Countries |
| MAP | Malaria Atlas Project |
| MOH | Ministry of Health |
| MOHS | Ministry of Health and Sanitation |
| MW | Megawatt |
| M&E | Monitoring and Evaluation |
| NCD | Non-Communicable Disease |
| NGO | Non-Governmental Organisation |

| | |
|---|---|
| NEPA | National Environmental Policy Act |
| ODK | Open Data Kit |
| OGP | International Association of Oil & Gas Producers |
| OR | Odds Ratio |
| PAC | Potentially Affected Community |
| PhD | Doctor of Philosophy |
| PHU | Peripheral Health Unit |
| RBM | Roll Back Malaria Partnership |
| RDT | Rapid Diagnostic Test |
| RSB | Roundtable of Sustainable Biofuels |
| SD | Standard Deviation |
| SDG | Sustainable Development Goal |
| SDH | Social Determinants of Health |
| SIA | Social Impact Assessment |
| SSA | sub-Saharan Africa |
| STI | Sexually Transmitted Infection |
| Swiss TPH | Swiss Tropical and Public Health Institute |
| TB | Tuberculosis |
| ToR | Terms of Reference |
| UNDP | United Nations Development Program |
| USA | United States of America |
| WHO | World Health Organization |

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# 1 Introduction

This PhD thesis pertains to health impact assessment (HIA) and associated cross-sectional monitoring of large infrastructure development and management projects in sub-Saharan Africa (SSA). The application of HIA and health monitoring in communities potentially affected by development projects are exemplified through four project case studies in Côte d'Ivoire, the Democratic Republic of the Congo (DRC), Sierra Leone and the Republic of Zambia. This introduction starts with the definition and historical origins of HIA, familiarises with underlying core values and guiding principles and outlines the different steps of the HIA process. An overview on current HIA practice in SSA and elsewhere leads towards research needs, focussing on monitoring and evaluation (M&E) activities within the HIA process.

## 1.1 Health impact assessment

### 1.1.1 Definition and history

The World Health Organization (WHO) defines HIA as "*a combination of procedures, methods and tools by which a policy, programme or project may be judged as to its potential effects on the health of a population, and the distribution of those effects within the population*" [1]. HIA is a prospective approach to integrate health considerations and health targets into the planning, design and implementation of a policy, programme or project [2]. This approach serves as a decision-support tool by systematically providing decision-makers with objective information on existing health needs in the affected population, potential future health consequences caused by the proposed development and appropriate actions to minimise potential adverse effects and promoting health benefits [1, 2].

1970 HIA has its roots in environmental impact assessment (EIA). In 1970, the United
States of America (USA) were the first country to pass a law on environmental
protection through the 'National Environmental Policy Act of 1969' (NEPA) [3]. The
NEPA created a requirement to assess the potential environmental consequences
of human-induced policies, programmes or projects and therefore heralded the
birth of EIA. Thereafter, two parallel movements paved the way towards HIA. First,
1980 in the early 1980s, the 'environmental health impact assessment' was put forth by
WHO to address the largely neglected human health component in the
conventional EIA, which was already implemented for large infrastructure projects
1985 in developing countries [4-6]. Second, in the mid-1980s, the concepts of 'healthy
public policy' and health promotion were manifested in the 'Ottawa Charter for
Health Promotion', recognising the direct and indirect health consequences of a
policy on the affected population [7, 8]. Health was seen as a result of political,

economic, social, cultural, environmental, behavioural and biological factors and health promotion aimed at enabling people to make these factors favourable for
1997 their health [7]. In 1997, the Jakarta declaration recommended that public and private sector policies and projects should perform HIA prior to implementation [9].

Until the late 1990s, health was mostly covered under EIA, whereas the capacity to capture health in its comprehensiveness with this approach was controversial [10-
1999 12]. In reaction, the WHO Regional Office for Europe and the European Centre for Health Policy formulated in 1999 the Gothenburg consensus paper on main concepts and suggested approaches for HIA [1]. The Gothenburg consensus was an attempt to unify the environmental, biomedical, social determinants of health (SDH) and healthy public policy origins of HIA [13, 14]. The objectives were to describe guiding concepts, principles and underlying core values. It also suggested a set of methodologies and tools which needed to be further elaborated, implemented and tested. The overall goal was to promote the use of HIA, strengthen its methodological aspects and to establish HIA as an integrated part of the impact assessment suite, in addition to EIA and social impact assessment (SIA).

Growing demands for natural resources, the search for alternative markets in agriculture, forestry, mining and other sectors, the privatisation of the mining sector in many SSA countries in the 1990s and the improved political stability led to increased direct investments in development projects [15-19]. In the wake of these developments, questions around the accountability of the consequences of project
2003 activities, often operated by multilateral companies, were raised. To keep up with best international practice standards, a first milestone to advance HIA practice was reached with the launch of the Equator Principles in 2003 [14, 20]. Multilateral lending institutions, assembled through the Equator Principles Financial Institutions (EPFIs), set a benchmark for determining, assessing and managing environmental and social risks of projects, which were meant to include public health. The EPFIs "*[…] will not provide project finance or project-related corporate loans to projects where the client will not, or is unable to, comply with the Equator Principles.*" [20]. The Equator Principles encompass 10 principles, which are summarized in brief in Table 12.1 in annex 12.1.

2005 In 2005, the oil- and gas sector was the first sector to produce sector-specific HIA guidelines elaborated by the International Petroleum Industry Environmental Conservation Association (IPIECA) and the International Association of Oil & Gas Producers (OGP) [21].

2006 Since 2006, the International Finance Corporation (IFC), the private sector lending branch of the World Bank, spearheaded the advancement of HIA of private sector
2009 projects. Hence, in 2006 and 2009, two more milestones were set with the "IFC performance standards on environmental and social sustainability" and "IFC introduction to health impact assessment" guidelines [22-24]. Performance standard 4 specifically pertains to "community health, safety and security" and states that: "*The client will evaluate the risks and impacts to the health and safety of the affected communities during the project life-cycle and will establish preventive and control measures consistent with good international industry practice, such as in the World Bank Group Environmental, Health and Safety Guidelines (EHS Guidelines) or other internationally recognized sources. The client will identify risks and impacts and propose mitigation measures that are commensurate with their nature and magnitude. These measures will favour the avoidance of risks and impacts over minimization.*" [24, 25].

The EPFIs fully embraced IFC performance standards and therefore created an HIA enforcement mechanism for projects supported by EPFI member institutions.
2010 In 2010, the International Council on Mining and Minerals (ICMM) released similar guidelines for HIA of sector-specific projects [26]. Overall, the private sector HIA movement produced a number of HIA best practice guidelines which are readily applicable for projects in different sectors in low- and middle-income countries (LMICs). In parallel, numerous scholarly articles supported the dialogue on the implementation and advancement of HIA, however, with a strong focus on high-income countries, especially Europe (see Figure 1.3) [27].

2012 Krieger *et al*. (2010) and later Harris-Roxas *et al*. (2012) called for an updated international consensus on HIA [14, 28]. Through the expansion of HIA in many different disciplines and settings, HIA practice has achieved a common
2014 understanding of the HIA process, but the guiding principles are in need of new principles, such as transparency, health outcome monitoring or external HIA evaluation [29].

### 1.1.2 Core values, guiding principles and framework

HIA is governed by the five core values: democracy, equity, sustainable development, ethical use of evidence and a comprehensive approach to health [1, 2].

(1) The **democracy** value implies the basic right of people to have a say in policies or projects that influence their life and their health.

(2) **Equity** relates to the distribution of health impacts within a population, paying specific attention to vulnerable groups, with the aim to reduce health inequities independently of origin, gender, socioeconomic status or other background features.

(3) **Sustainable development** pertains to the creation of long-lasting benefits and improvements that result from development projects reaching beyond a project's lifespan, rather than short-term gains only.

(4) **Ethical use of evidence** indicates that decisions are based on scientific robust qualitative and quantitative evidence.

(5) The **comprehensive approach to health** takes into account the wider determinants of health, i.e. factors from other sectors of society that influence on well-being.

In support to these core values, HIA applies operating and guiding principles [2, 30-33]:

- HIA is a **systematic approach** comprising a set of procedures, methods, tools through which health risks and opportunities can be identified and mitigation and health promotion measures are addressed upstream in the development planning process.
- HIA is a **cross-cutting tool between sectors**, recognising that other sector developments strongly influence health and its determinants and therefore share responsibility. Collaboration with other sectors creates synergies to promote human health.
- HIA engages in a broad **stakeholder process** and is therefore a participatory approach, including the local community, developers and decision-makers, host governments, health authorities and staff, civil-society organizations, non-government organisations (NGOs), workers and dependents, HIA assessors and any other groups or representatives that are affected by a project. All stakeholders are assigned roles and responsibilities.
- HIA provides the decision-makers with the best available evidence in a timely manner and an appealing format which allows the decision-maker to make an **informed decision**.
- HIA should be **implemented prior to the onset of development of a project**, i.e. in the feasibility or planning phase, to integrate health-related planning at an early stage.

In 2014, Bhatia and colleagues (2014) expanded the general standards to advance an effective HIA practice by the following principles [29]:

- Each HIA process should begin with explicit written goals that can be used to **evaluate the effectiveness and impacts of HIA**.
- Monitoring is an important follow-up activity in the HIA process. In HIA, a **monitoring plan to track the health-related outcomes** of a decision and its implementation should be proposed.

For guiding the systematic analysis of health considerations, the IFC HIA guidelines use an environmental health areas (EHAs) framework [23]. Two main considerations led the IFC to the adaption of the EHA framework for HIA of private sector projects in the tropic: First, a World Bank study estimated that around 44% of the health burden in SSA is preventable through improvements in the housing, water and sanitation, transportation and communication sectors [34, 35]. Hence, rather than looking at diseases and ill-conditions individually, these are organized into groups with common underlying causes or risk factors, such as living conditions,  water-, sanitation- and soil-related diseases, sexually transmitted infections (STIs) or non-communicable diseases (NCDs), EHAs that refer to project-related hazardous materials, noise and malodours, SDHs, health seeking behaviours and traditional health practices and health system issues. The 12 EHAs, adapted from the IFC framework, are summarized in **Error! Reference source not found.** in annex **Error! Reference source t found.** [36]. Second, through the set of EHAs, a linkage between project-related activities and potential positive or negative community-level impacts can be created as the framework incorporates a variety of biomedical, environmental and social determinants of health. Instead of a narrow biomedical framework focusing primarily on disease-specific considerations and outcomes, cross-cutting environmental and social conditions that contain significant health components are identified and local, prevailing health sector issues are integrated [37].

### 1.1.3 HIA process for projects

Guidelines, toolkits and scholarly articles present a variety of stages or steps of the HIA process depending on the requirements or characteristics of the respective sector, although differences refer mostly to formulations or terms used or the composition of the individual tasks within a step [2, 13, 21, 23, 26, 29, 31, 32, 36, 38-40]. The IFC HIA guidelines for development projects in LMIC presented here follow a 6-step process: (1) screening; (2) scoping; (3) risk assessment; (4) mitigation/community health management plan; (5)

implementation and M&E; and (6) the final evaluation [23, 36]. Figure 1.1 displays these steps with reference to the lifecycle of a project.

**Step 1 – screening:** The screening step comprises a situation analysis on the project context and design (e.g. geographical footprint, temporal footprint, planned constructions, etc.), the host country's legislative requirements (e.g. public health and environmental protection laws) and the prevailing health situation at the local level (e.g. endemic diseases, availability of health information system data). This desktop-based situation analysis determines whether a project is likely to affect people's health and thus whether an HIA is necessary. Projects with no significant health impacts are exempt of an HIA (see also Table 12.1 – Equator Principle 1) [37].

**Step 2 – scoping:** Once the screening step established the need for an HIA, the terms of reference (ToR) set the boundaries for the HIA, i.e. the geographical scope, the time scale, the potentially affected communities (PACs) and other stakeholders to be involved [20, 37]. The extent of the HIA is determined among three HIA types: (1) a rapid HIA (desktop-based); (2) a limited in-country HIA; or (3) a comprehensive HIA, depending on the expected impacts, project footprint and social sensitivity. The most important distinguishing feature of a comprehensive HIA compared to the other two types is the collection of additional, primary health data and the participatory stakeholder engagement [23, 41]. Next, the scoping step identifies the whole range of potential project-related health impacts, negative and positive, by using the systematic EHA approach [36, 37]. The evidence-base in HIA is assembled through a literature review (i.e. peer-reviewed and grey literature), collection of available routine health information system (HIS) data, direct observations during in-country visits (e.g. infrastructure of health facilities, housing conditions in communities) and stakeholder consultations (e.g. with health authorities, health staff, PACs) [42]. A subsequent gap analysis informs whether the data available in the PACs is of sufficient quantity and quality, or, in case of data gaps, if baseline data collection is warranted [42]. If the required evidence-base is available, with or without additional data collection, the risk assessment step follows.

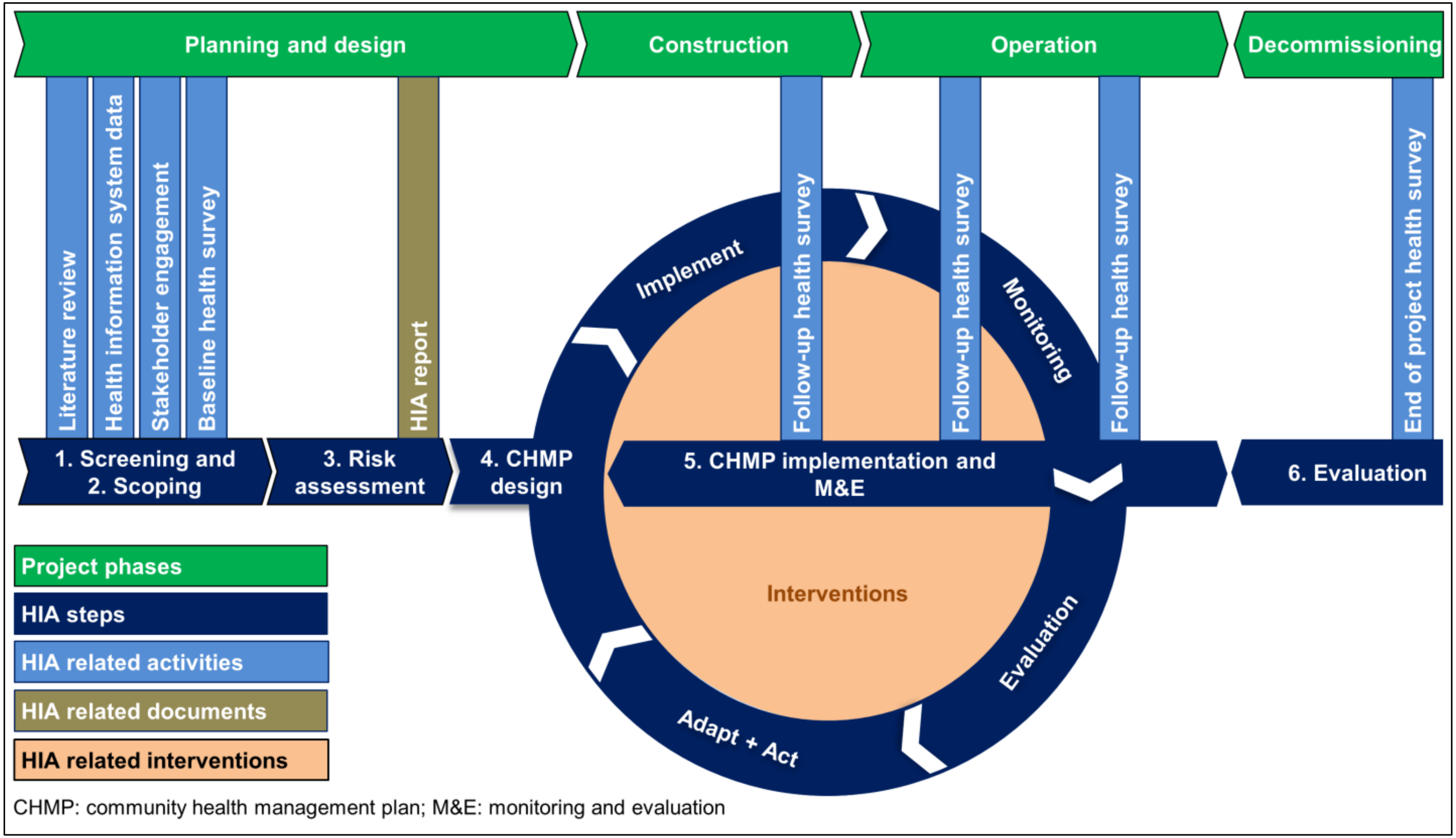


**Figure 1.1: Project phases and health impact assessment related steps, activities, documents and interventions**

**Step 3 – risk assessment:** The risk assessment, or impact appraisal step, has the goal to determine the significance of the previously identified health impacts by applying a semi-quantitative ranking method. It is semi-quantitative because it entails qualitative elements of expert judgement and prediction from the assessor and the quantitative part relates to the use of a risk-ranking-matrix. A rudimentary matrix was proposed in the IFC which was further developed by Winkler *et al*. (2010) (Figure 1.2) [23, 36]. The following 4-step process is carried out for all potential health impacts across the EHAs.

(1) For each potential health impact identified in the scoping, its extent, intensity, duration and the nature of the health effect (i.e. the four consequences) are scored according to their impact level (scoring 0 (low) to 3 (very high)).

(2) The scores of the four consequences are summed, resulting in the impact severity score classified as follows: low (0-3), medium (4-6), high (7-9) and very high (10-12).

(3) The likelihood of the impact to occur, classified as improbable (up to 40% likelihood of occurrence), possible (40-70% likelihood of occurrence), probable (70–90% likelihood of occurrence) and definite (90% likelihood of occurrence).

(4) The overall significance ranking is calculated as the results from steps 2 and 3, i.e. the intersection of the impact severity and the likelihood of occurrence.

| Step 1 | | | | | Step 2 | Step 3: Likelihood | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Consequences | | | | | | | | |
| Impact level (Score) | A – Extent | B – Intensity | C – Duration | D – Health Effect | Impact severity (Score range of A + B + C + D) | Improbable (< 40%) [a] | Possible (40% - 70%) [a] | Probable (70% - 90%) [a] | Definite (> 90%) [a] |
| | | | | | | Step 4: Significance ranking | | | |
| **Low** (0) | Punctual<br>Rare individual cases | Minor intensity | Very short-term: < 1 month | Health effect is not perceptible | **Low** (0 – 3) | ♦ | ♦ | ♦ | ♦♦ |
| **Medium** (1) | Local: small and limited<br><br>A small number of households is affected | Those impacted will be able to adapt to the health impact with ease and maintain pre-impact level of health | Short-term: 1-12 month<br><br>Low frequency | Health effect resulting in annoyance, minor injuries or illness that does not require hospitalisation | **Medium** (4 – 6) | ♦ | ♦♦ | ♦♦ | ♦♦♦ |
| **High** (2) | Project area: medium but localised<br><br>Village level | Those impacted will be able to adapt to the health impact with some difficulty and will maintain pre-impact level of health with support | Medium term: 1-6 years<br><br>Medium or intermittent frequency | Health effect resulting in moderate injury or illness that may require hospitalisation | **High** (7 – 9) | ♦♦ | ♦♦♦ | ♦♦♦ | ♦♦♦♦ |
| **Very high** (3) | Extends beyond the project area<br><br>Regional level | Those impacted will not be able to adapt to the health impact or to maintain pre-impact level of health | Long-term/irreversible: > 6 years<br><br>Constant frequency | Health effect resulting in loss of life, severe injuries or chronic illness that may require hospitalisation | **Very high** (10 – 12) | ♦♦♦ | ♦♦♦♦ | ♦♦♦♦ | ♦♦♦♦ |

**Figure 1.2: Risk-ranking matrix (adapted from Winkler *et al*., 2010)**

If the significance is ranked low (♦), the impact is sufficiently small, within an acceptable magnitude and/or the receptor has a low susceptibility. Hence, mitigation is desirable but not required. If the significance is ranked medium (♦♦), the impact is insufficient by itself to prevent the implementation of a project but mitigation is strongly recommended and careful attention to mitigation and monitoring are warranted. If the impact is considered high (♦♦♦), this signifies a major and usually a long-term change and is an unacceptable risk. Hence, mitigation is required, including rigorous monitoring. With a very high significance ranking (♦♦♦♦), the impact is long-term and/or extensive and/or irreversible/permanent and is an unacceptable risk. Mitigation is required, including rigorous monitoring. Health benefits, i.e. positive health impacts, are coloured in green and their significance can be graded likewise (♦-♦♦♦♦).

It is important that the significance ranking is performed for the individual project phases as well as for the different PACs separately [43]. Moreover, for each EHA, the predictive tool can outline three significance ranking scenarios: (i) the baseline situation before project activities; (ii) the predicted situation if no health mitigation measures are implemented; and (iii) the predicted situation if mitigation measures are implemented, i.e. the residual situation. Table 1.1 shows a random example of the significance ranking output for three EHAs.

**Table 1.1: Significance ranking for project phases, PACs and scenarios**

| EHA | Project phases | | | | | Affected PACs | | | | | Scenarios | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | F | C | O | D | | PAC 1 | PAC 2 | PAC 3 | PAC 4 | | Baseline | Without mitigation | With mitigation |
| **EHA 1** | | X | X | X | | X | X | | | | ♦♦♦ | ♦♦♦♦ | ♦♦ |
| **EHA 4** | | X | X | X | | X | X | X | X | | ♦♦ | ♦♦♦♦ | ♦♦ |
| **EHA 12** | | X | X | X | | X | X | X | | | ♦♦ | ♦♦♦ | ♦♦ |

F, feasibility phase; C, construction phase; O, operations phase; D, decommissioning phase

After the risk assessment step, the project decision-makers usually receive an HIA report comprising the (i) evidence-base for the assessment; (ii) the impact definition; (iii) the risk assessment; and (iv) a set of recommendations that supports prioritising and planning of health mitigation measures [44, 45].

**Steps 4 and 5 – community health management plan (CHMP) design, implementation and M&E:** This step is alternatively referred to as 'mitigation recommendations', 'health action plan' or 'community health management plan', depending on the source [23, 31, 45]. The challenge for project decision-makers remains to translate the mitigation recommendations into concrete health interventions whereas the final selection of interventions is further influenced by the available human resource, financial, institutional and infrastructural capacities. To shape technically sound, socially acceptable, economically feasible and sustainable mitigation measures, the CHMP should outline intervention components such as target populations, temporal boundaries, local acceptability, health system capacities, collaborations, responsibilities, health outcomes to be measures (indicators) and methods and frequency of monitoring thereof [2, 23, 29]. Importantly, the CHMP is a dynamic process and needs adaptations to the continuously changing environment and altered health determinants [46].

**Step 6 – final evaluation:** At project decommissioning, a final evaluation of the overall HIA process and the associated CHMP will round up the HIA process. This specifically relates to whether the predictions made in the HIA report were accurate and whether the recommendations made led to mitigations that improved health outcomes in the PACs. This final step of the HIA process can evaluate its overall effectiveness, credibility and, finally, justify the future use of HIA [29, 47, 48].

## 1.2 Current HIA practice

Up to this point of the thesis, the HIA process with all its elements was narrated from a best practice perspective. In HIA implementation, however, there are shortcomings and challenges related to every element of HIA. In the following, the current practice of HIA is broadly reviewed, with a special focus on shortcomings of HIA implementation in LMIC.

HIA found increased and broad application and demonstrated flexibility to adapt to different contexts, settings and allowed for additional elements resulting in various HIA guidelines and scholarly articles [13, 49-51]. Meanwhile, the underlying HIA process with its steps is firmly established and applied across all disciplines [50, 52]. To become familiar with the ongoing HIA practice globally and in the different sectors, a keyword search on “health impact assessment” in the title, keywords or abstract covering the time period from January 2000 until March 2016 was performed on the Web of Science database. Of note, this literature search was not systematic, performed with one single database and included only articles published in English language. Therefore, other peer-reviewed articles published on HIA and HIA grey literature were likely missed [53]. Nevertheless, these are proxy findings for the overall body of peer-reviewed HIA literature.

The search yielded 294 hits, whereby 76 (26.4%) articles were excluded after screening of the abstract. The remaining 218 articles were included and categorised regarding to their country and sector of implementation (Figure 1.3). Most of the published HIA literature were from project, policy and programme case studies implemented in high-income countries (n=138; 63.8%). Only 12.8% (n=28) were addressing HIA in LMICs (n=28). In addition, only a small percentage of literature pertains to HIA in the private sector (6.0%; n=13) of which five are case study publications from projects in LMIC with involvement of the Swiss Tropical and Public Health Institute (Swiss TPH) HIA research group. The majority of HIA were done for public projects, policies or programmes (61.5%, n=134).

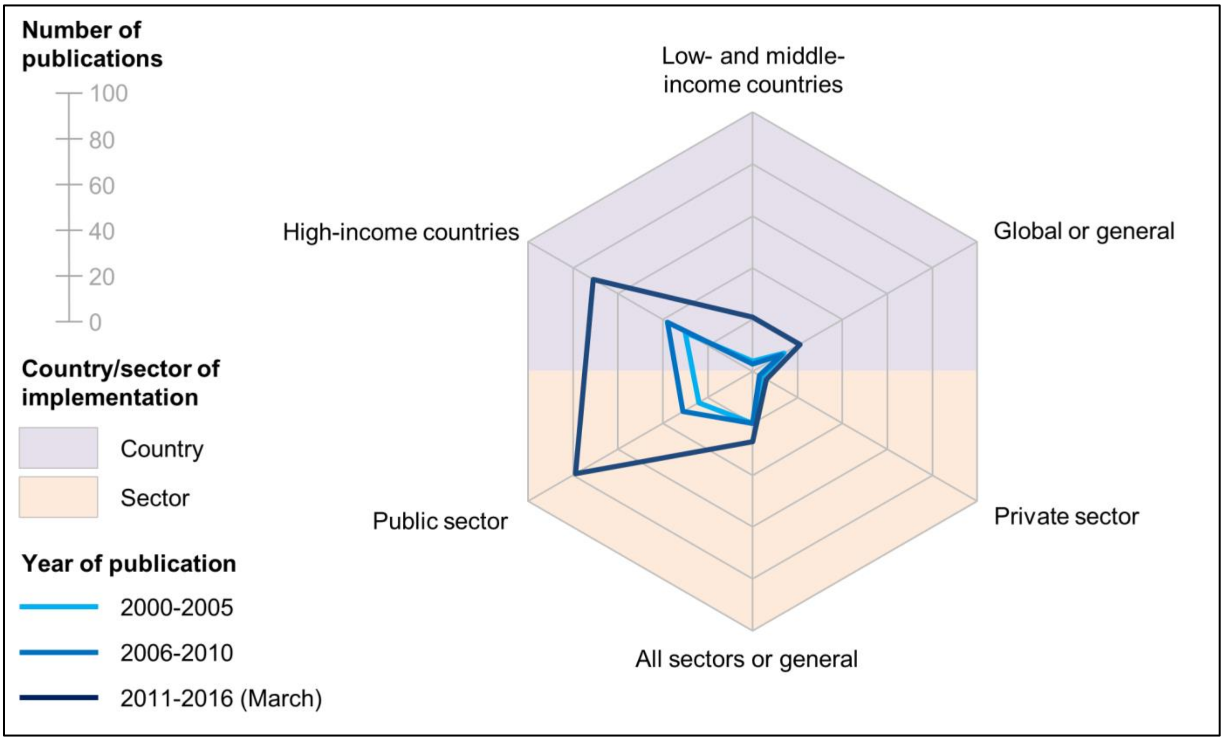


**Figure 1.3: Literature search “Health impact assessment” (2000-March 2016) stratified by country focus, sector and years**

Evidently, there is little publicly available literature and data, especially from (i) private sector HIA and (ii) LMIC contexts [44]. The reasons for this include (i) lack of regulations to pursue an HIA [54]; (ii) lack of requirements to make HIA results publicly available; (iii) lack of funding for making HIA reports and results available through the peer-review literature [55]; and (iv) lack of (voluntarily) transparency requirements [56, 57]. However, HIA grey literature in LMIC is expected to be substantial, considering the large number of private sector projects implemented. In SSA, as of March 2016, the IFC was supporting ~180 projects in the natural resource extraction, energy, agriculture, transportation and water management sectors which were required to apply IFC performance standards [58].

A distinct shortcoming is the paucity of case studies from the implementation of steps 4, 5 and 6 of the HIA process, hence in the project operations and decommissioning phases [47]. For steps 4 and 5, few case studies are publicly available that show the CHMP implementation and M&E activities as HIAs are often discontinued after the reporting step when funding requirements are secured, debts are repaid or initial baseline data have been collected [59, 60]. Thereafter, community health management is often done outside a continuous HIA framework [61-63]. For step 6, the HIA evaluation, answering questions such as the extent to which HIA had influenced the decision-making, what factors contributed to its success, whether the research and methods applied fulfilled the minimum quality standards or if HIA helped to mitigate negative impacts, is under-practiced to date, especially in LMIC [29, 47, 64, 65]. Yet, the evaluation of the HIA effectiveness (process, impacts and outcomes) is crucial for a proposed project as well as for the justification and advancement of HIA practice [31, 47, 66, 67]. Consequently, HIA evaluation is demanded by all involved parties, i.e. decision-makers, impact assessors, researchers and HIA critics, to increase the quality and credibility of HIA itself [27, 31, 44, 68-70]. Case studies presenting HIA implementation and M&E results in LMIC provide a chance to judge its effectiveness [31, 71].

## 1.3 Monitoring and evaluation of HIA

### 1.3.1 Definitions and frameworks

There is discrepancy in literature between the different HIA evaluation frameworks in general and regarding process, impact and outcome evaluation in particular. A number of definitions for M&E in the context of HIA used by experts in the field are presented in chronological order in Table 1.2 below (non-exhaustive list).

**Table 1.2: Definitions and frameworks of M&E in HIA**

| **Source** | **Definitions and explanations** | | |
|---|---|---|---|
| | **Process evaluation** | **Impact evaluation** | **Outcome evaluation** |
| Quigley *et al*. (2003) [47] | HIA evaluation should focus on the process of HIA and the impact that it has on the decision-making process, rather than attempting to evaluate long-term health outcomes. | | |
| | Steps of the HIA process<br>Utility of the HIA process | Influence on decision-making | Health outcomes<br>Accuracy of predictions<br>*(Not HIA evaluation)* |
| Mindell *et al*. (2003) [72] | HIA evaluation is, as per definitions below, a mixture of process, impact and outcome evaluation. | | |
| | Utility of the HIA process | Influence on decision-making | Health outcomes |
| Parry and Kemm (2005) [66] | HIA evaluation is the examination of the way in which the HIA was conducted. Must be clearly distinguished from the separate but related issue of evaluation of the decision. | | |
| | Steps of the HIA process<br>Influence on decision-making | *(None given)* | Accuracy of predictions<br>Stakeholder engagement<br>Influence on decision-making<br>*(Not HIA evaluation)* |
| Wismar *et al*. (2007) [65] | HIA evaluation seeks to determine whether an HIA has influenced the decision-making, which is different from evaluation of whether the decision affected health outcomes. | | |
| | Influence on decision-making<br>Evaluation of methods | *(None given)* | Health outcomes<br>*(Not HIA evaluation)* |
| Harris-Roxas *et al*. (2013) [73] | HIA evaluation should focus on HIAs effectiveness on decision-making, implementation and related activities rather than health outcomes per se. | | |
| | The broader decision-making context (e.g. values, purpose and goals, parameters, triggers) | Influence on decision-making | Health outcomes<br>*(Not HIA evaluation.)* |
| Bhatia *et al*. (2014) [29] | (HIA) evaluation of the HIA process, impacts and outcomes is necessary for field development and practice improvement. | | |
| | Steps of the HIA process | Influence on decision-making<br>Extent of implementation of recommendations | Health outcomes and determinants<br>(also called monitoring) |

This summary illustrates that there is no consensus on what HIA evaluation entails, neither the aspects of process, impact and outcome evaluation, or whether ‘health outcome monitoring/evaluation’ is part of HIA evaluation or not. Four out of the six presented frameworks introduced in Table 1.2 specifically exclude HIA outcome evaluation, i.e. measurement or monitoring of health outcomes, from the overall HIA evaluation. There are two main reasons for this.

First, in the understanding that HIA is a decision-support tool, the HIA evaluation should evaluate the process leading to a decision, not the decision itself [47, 65, 66]. However, due to the constantly changing social, economic and physical environments, HIA decisions continue and HIA should be a continuous process accompanying a project throughout its lifespan [60, 74]. This is increasingly recognised and more recent guidelines specifically include measuring of health outcomes within the scope of HIA [29, 38, 45].

Second, HIA outcome evaluation, i.e. M&E of health outcomes, was perceived as challenging by many HIA practitioners, due to the time delay of certain health effects, the inability to measure an intervention scenario against a non-intervention scenario and attributing changing health to a project, the inability to test whether predictions were accurate and the necessity of baseline data collection prior to project commencement [29, 47, 65, 66, 72, 73, 75]. However, because health effects present with a time-lag is not a justification not to monitor them and changing patterns of community health, including short-, medium- and long-term health effects, must be continuously observed for responsible and sustainable development [73]. Furthermore, a study design with comparison communities not impacted by a project can help to distinguish changes due to the project form changes that occurred overall [76]. The prediction of three significance ranking scenarios (baseline, without mitigation, with mitigation; see Table 1.1) supports the evaluation of predictive accuracy. As per definition, HIA is a prospective approach which should be initiated during a project’s planning and design phase and can therefore include pre-development data collection [31]. The collection of baseline health data especially in remote settings with health data gaps has been found practically feasible, reproducible and supportive of HIA and associated community health management initiatives and encourages broader application [61, 62, 77, 78].

### 1.3.2 Practice and shortcomings of M&E in HIA

The shortage of case studies available for steps 4-6 of the HIA process is exemplified in the case of the involvement of the Swiss TPH HIA research group in HIA assignments between 2008 and 2015 (Figure 1.4). HIA-related work, e.g. rapid HIA and/or scoping studies, have been done for more than 25 projects in SSA. A large fraction of these projects have conducted a cross-sectional baseline health survey (BHS) during the HIA process. However, after HIA reporting was completed, only two projects have, so far and to our knowledge, conducted monitoring health data through the means of a cross-sectional follow-up health survey (FUHS).

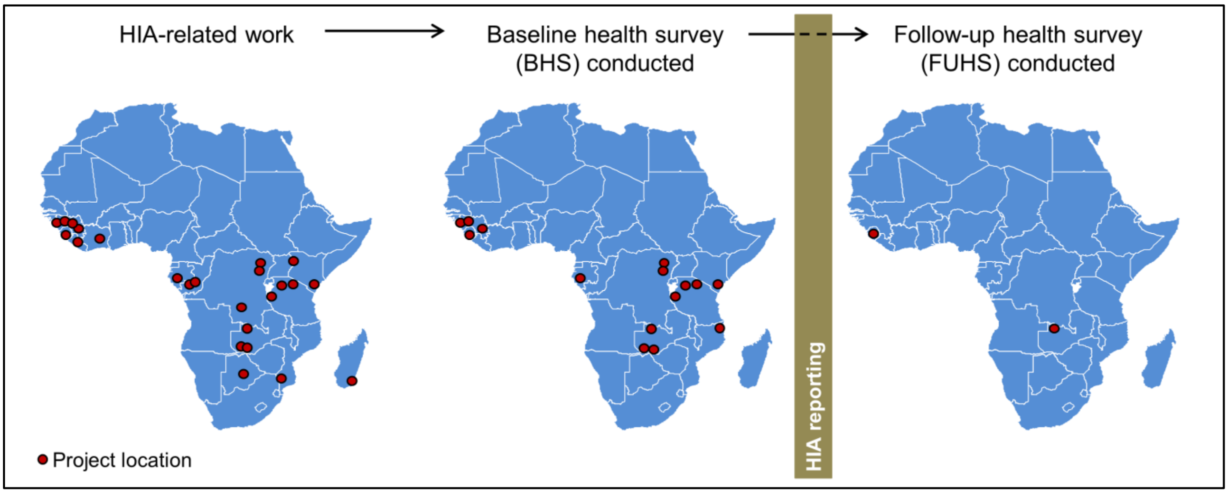


**Figure 1.4: HIA projects with involvement of the Swiss TPH HIA group (2008-2015)**

The need for quantifying impacts or health outcomes in HIA differs between disciplines and settings [13, 79]. The collection of baseline health data is recommended in case data gaps are identified in the scoping step but in practice this largely depends on the assessors' recommendation and the project decision-makers rather than being systematically directed [80, 81]. Obstacles to collect health data can be budgetary limitation or unfamiliarity of the assessors with quantification methods outside the chemical hazard spectrum [13, 40]. Increasingly though, decision-makers want to rely on quantified evidence, especially baseline information at community level, for accountability, transparency, financial and reputational reasons [37, 51, 82].

In summary, HIA process and impact evaluations are needed to promote and guide future HIA, and also as a means of quality control and justification of HIA in a typical LMIC context [49]. While process and impact evaluations are important, since the HIA process itself carries many potential benefits such as awareness rising and partnership building, questions whether it is reasonable to neglect the M&E of the predicted health impacts were raised [83, 84]. Conversely, since the ultimate goal of HIA is to promote positive and mitigate negative health effects, it is a missed opportunity for responsible, accountable and sustainable development if health outcomes and SDHs in the PACs are not monitored.

Against this background, case studies of HIA implementation and the results of follow-up M&E activities provide a unique opportunity to showcase effectiveness of HIA of large-scale development projects in SSA by assessing if HIA had (i) an impact on decision-making and (ii) whether project activities and accompanying mitigation measures or other community development initiatives have impacted on the health status of the PACs.

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## 2 Goal and objectives of the thesis

The goal of this PhD thesis was to assess and monitor health impacts of infrastructure development and management projects in SSA and to evaluate the effectiveness of HIA of large-scale infrastructure development projects to mitigate negative health impacts and promote health benefits. The objectives of this PhD thesis research were to present case studies from complex eco-epidemiological settings on (i) implementation and outcomes of HIA of infrastructure development projects in SSA and on (ii) M&E of health outcomes and health-related indicators in communities potentially affected by these projects.

Chapter 3 outlines the methods used for the M&E activities within HIA for large-scale projects in SSA. The manuscripts in chapters 4 to 10 present the process of HIA for different case study projects and the results of associated M&E activities, mostly related to cross-sectional, primary health data collection. The objectives or repeated cross-sectional health surveys are:

- to monitor trends of the health status of communities affected by a project over time;
- to monitor trends of the health status of project-affected communities compared to non-impacted, comparison communities;
- to measure the impact of implemented health mitigation interventions and community development initiatives; and
- to identify the underlying causes of changing health.

The evaluation of the methods and tools used during the HIA process for the four case study projects is discussed in chapter 11, with the objectives:

- to judge whether project decision-makers used HIA for health-related decisions in project design and planning;
- to evaluate if mitigation recommendations in the HIA report translated into a CHMP with concrete interventions; and
- to identify shortcomings and opportunities of currently available tools and methods used during the HIA process for the four case study projects.

# 3 Methods

## 3.1 Case study projects


**Figure 3.1: Case study project locations**

Figure 3.1 shows the locations of the four projects where case studies were carried out in the frame of this PhD thesis work.

The **Kibali Gold Mine (KGM)**, a joint-venture between Randgold Resources, Anglo Gold Ashanti and the Congolese SOKIMO, is located in the Haut-Uélé province in north-western DRC [1]. The US$ 2.5 billion investments comprises and open pit, underground operation and a processing plant and is one of the largest gold mines in Africa. Production started in 2013. By 2016, and the KGM is employing 3,617 local employees and contractors [2].

The HIA scoping study was commissioned in 2008. Subsequently, a modular BHS conducted in August 2010. This produced data on a variety of health outcomes and determinants. Characteristic for this area of the DRC is the paucity of epidemiological survey data in general and for schistosomiasis and soil-transmitted helminth infections in particular [3]. The BHS data pertaining schistosomiasis and soil-transmitted helminth infections were made publicly available in a scholarly article (chapter 4) and represent the first epidemiological survey data from this region. Therefore, the importance and value of primary data collected in the private sector is striking.

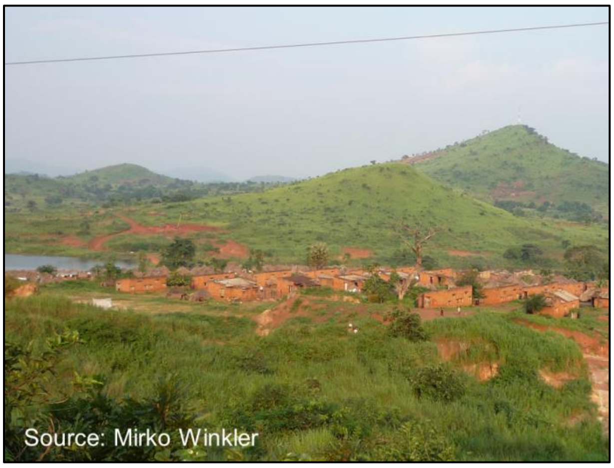


**Figure 3.2: Kibali Gold Mine surroundings, 2010**


**Figure 3.3: Biomedical sampling during the Kibali Gold Mine BHS, 2010**

The **Bonikro Gold Mine (BGM)**, operated by LGL Mines CI SA, is located in south-central Côte d'Ivoire [4]. LGL Mines CI SA is owned by 89.9% by Newcrest Mining Limited, 10% by the government of Côte d'Ivoire and 0.1% by minority shareholders. After receiving the environmental permit, project construction started in 2007 [5]. The project relies solely on open pit mining and first production was in 2008. By early 2016, the project had around 1,000 local employees and contractors.

The project signed an agreement with the United Nations Development Program (UNDP) to develop and implement a sustainable community development programme in the project area through a partnership that will ensure financial leverage from other donors. Implementation of the partnership started in January 2012 with the UNDP agreeing to a local development plan in collaboration with all the stakeholders.

A malaria and anaemia survey was conducted in August 2012 as the operator needed a status update on these to guide malaria control interventions in the mine workforce and surrounding communities. Hence, in a second scientifically published article (chapter 0), results of malaria and anaemia prevalence rates in children under 5 years of age are presented.


**Figure 3.4: Haul road to the resettled village of Bonikro, near the Bonikro Gold Mine, 2011**


**Figure 3.5: Fogging for mosquito control at Hiré camp, Bonikro Gold Mine, 2012**

The **Addax Bioenergy Sierra Leone (ABSL) project**, operated by Addax Bioenergy, is located in Northern Sierra Leone, near Makeni [6]. The project consists of sugarcane plantations, an ethanol distillery and a biomass power plant covering an area of ~14,000 ha. Project investment was €455 million funded by the African Development Bank (AfDB) and European development finance institutions. The project therefore applies IFC performance standards, Equator Principles and the AfDB policies and adopts best international standards as a member of the Roundtable of Sustainable Biofuels (RSB) and the Better Sugarcane Initiative (BSI). The project became fully operational in 2014 and as of March 2015, the project employed 3,600 national staff [7].

Between 2008 and 2010, the ABSL project had a thorough feasibility phase comprising 13 environmental and social specialist studies. The resulting Environmental and Social Impact Assessment (ESIA) was rejected because health was neglected and the finance institutions specifically requested the conduction of an HIA for project approval. The final Environmental, Social and Health Impact Assessment (ESHIA) has been recognized ‘the gold standard of impact assessments' by a study comparing 19 impact assessments in biofuel projects commissioned by the European Union Commission.

The HIA was initiated in 2009 with a scoping study. Within the HIA, a BHS was conducted in 2010 and ABSL has committed to repeated cross-sectional FUHS every 3 years [8]. The first FUHS was then conducted in 2013. The ABSL In chapters 6 and 7, results from biomedical key indicators assessed during those surveys are presented and discussed in the context of this large-scale plantation, associated community development initiatives and the Sierra Leonean health system.

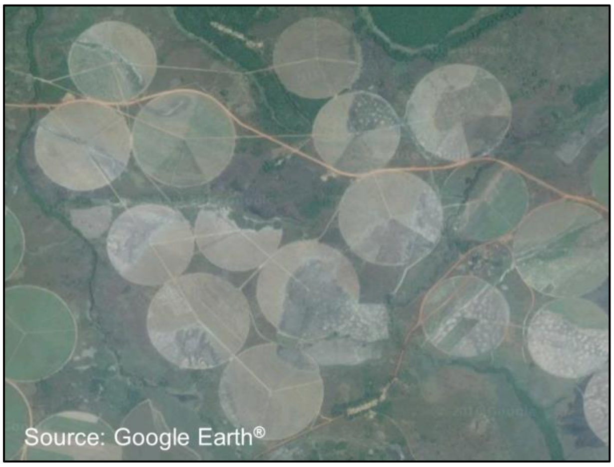


**Figure 3.6: Sugarcane fields from space (2013) in the ABSL project area, 2013**


**Figure 3.7: Questionnaire interview during the FUHS 2013 in the ABSL project area, 2013**

The **Trident project**, operated by First Quantum Minerals Limited (FQML), is located in Northwestern province of Zambia [9]. The US$ 2 billion development is the single largest project investment in Zambia's history. Development so far (early 2016) has employed around 3,000 Zambians of which 50% are from the vicinity of the project.

A HIA scoping study was conducted in August 2010, which identified data gaps at the local level in this originally rural, forestry area. Hence, in July 2011, a BHS was conducted and incorporated in the evidence-base for the HIA. Since the feasibility phase, the project permanently employs an external HIA expert at 10% to support the ongoing HIA and health promotion team. The primary output of the HIA was a CHMP which had components of both continuous surveillance and cross-sectional health monitoring activities. Human Immunodeficiency Virus / Acquired Immune Deficiency Syndrome (HIV/AIDS) and other STIs were ranked as very high significant impacts and the Trident project implemented an HIV/AIDS intervention package early on, with HIV testing and counselling (HTC) as the main component. In chapter 8, the results from HTC offered in the workforce and the communities in the project area between 2012 and 2015 are presented. In 2015, a FUHS was conducted as the HIA report recommended to repeat the cross-sectional exercise after 3-5 years into project development. Due to resettlement and extensive influx, the study population changed drastically between 2011 and 2015. The epidemiological surveys conducted (BHS and FUHS) are introduced in chapters 9 and 10 of this thesis and findings in children and women are compared.


**Figure 3.8: Kalumbila mine copper conveyor belt, Trident project, 2015**


**Figure 3.9: Clinical field laboratory during the FUHS 2015 of the Trident project, 2015**

### 3.2 Health survey data collection

A rigorous definition of the baseline health status of PACs sets the basis for M&E of potentially project-impacted health determinants and outcomes of affected populations and assures efficient health interventions [10-12]. The absence of baseline health data was reported as a concern in projects that later triggered significant health impacts [10, 13]. Hence, health data for the PACs must be available in sufficient quantity and of adequate quality. If this is not the case, primary (baseline) health data collection, prior to project development, is recommended [11, 14, 15]. Furthermore, projects that will trigger resettlement and migration should collect baseline data collection [16, 17]. Baseline health data is ideally collected prior to any project developments, i.e. in the feasibility phase of a project although speculative migration may have already occurred at that stage. The absence of baseline health data has repeatedly been reported as a major failure by projects, assessors and other stakeholders [10, 18, 19]. The modular BHS method presented by Winkler *et al*. (2012) is specifically adapted for large-scale development projects located in remote, constraint settings [11]. This survey method is easily reproducible and can therefore be adapted for FUHS. The method is introduced in the following to the extent necessary in order not to repeat methodologies that are introduced in the manuscripts in chapters 4 to 10.

### 3.2.1 Study design and sampling

A cross-sectional study design was used for the BHS and FUHS. A semi-randomized, semi-purposive sentinel site sampling strategy followed a four-step procedure [11].

In a first step, the different PACs as identified through the community profiling in the scoping step of the HIA were selected (see 1.1.3). In brief, all villages in a given project area were identified and grouped into PACs based on the magnitude and nature of project-related impacts (e.g. resettled communities, communities along transport corridors) to grasp the heterogeneity of the setting. These PACs are recognized as a temporal model that can evolve and change during the course of the HIA process, as they may evolve as the demographic structure in the communities change or new settlements appear. An example of PACs selected for an extractive industry project in SSA is outlined below (Figure 3.10).

PACs in a HIA study area:

- PAC 1: Villages A, B and C that are in the mine permit area and will be resettled;
- PAC 2: Villages D, E and F (i.e. the resettlement host site). These communities are more likely to be impacted by the location of mine camp, the plant and haul roads.
- PAC 3: The community G and its proximity to the plant area and especially the tailings storage facility.
- PAC 4: Other villages in study area that will have less direct impacts, namely H and I.
- PAC 5: J, the most urban settlement in the area
- PAC 6: Villages along the transportation route N5 to the port.

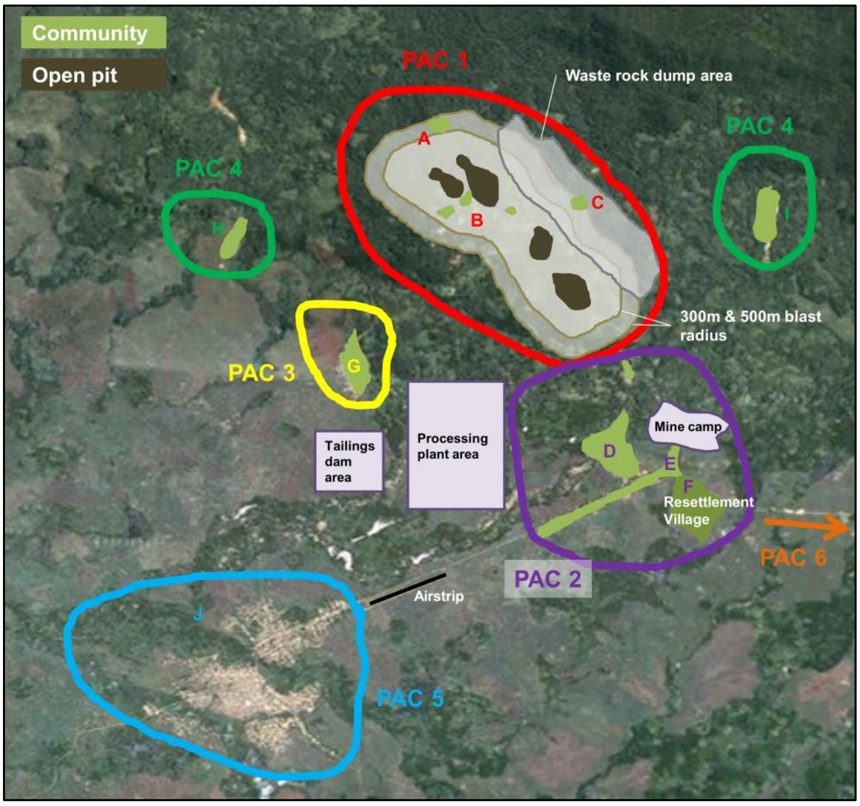


**Figure 3.10: Example of community profiling with PACs**

In a second step, sentinel sites were either randomly selected within the different PACs or at times, purposively picked as they were considered important sites to survey based on the perceived future impacts [20]. The purposive sampling at sentinel site level was chosen as this allowed for (i) sampling of smaller communities that are highly impacted but could have gone unnoticed with a sampling proportional to population size and (ii) an addition of sentinel sites in communities that have grown extensively, newly appeared or gained importance. The number and selection procedure of the sentinel sites is further governed by financial and human resources and operational considerations.

In a third step, comparison sites were chosen based on similarity to impacted sentinel sites but under the condition of not being exposed to project impacts such as in the project area, having received project-implemented health interventions or being place of residence to project employees.

In a final step, in absence of a reliable sampling frame, an adaption of the method used by the Expanded Programme on Immunization (EPI) was applied [21, 22]. A quota of at least 25 households was randomly selected within the sentinel sites. A multi-directional top, usually with four directions for four interviewers, was spun at a central or strategical point within the sentinel site, depending on the structure of the sentinel site, to determine randomly selected directions. Subsequently, households along these directional lines until the peripheral border of the sentinel site were counted. The first household in each direction was selected at random and proximity sampling was adopted thereafter. The household inclusion criteria was the presence of a mother (≥15 years) with at least one child under the age of 5 years. Figure 3.11 shows the households sampled and key features in a village (sentinel site) recorded by global positioning system (GPS) and mapped on Google Earth®.

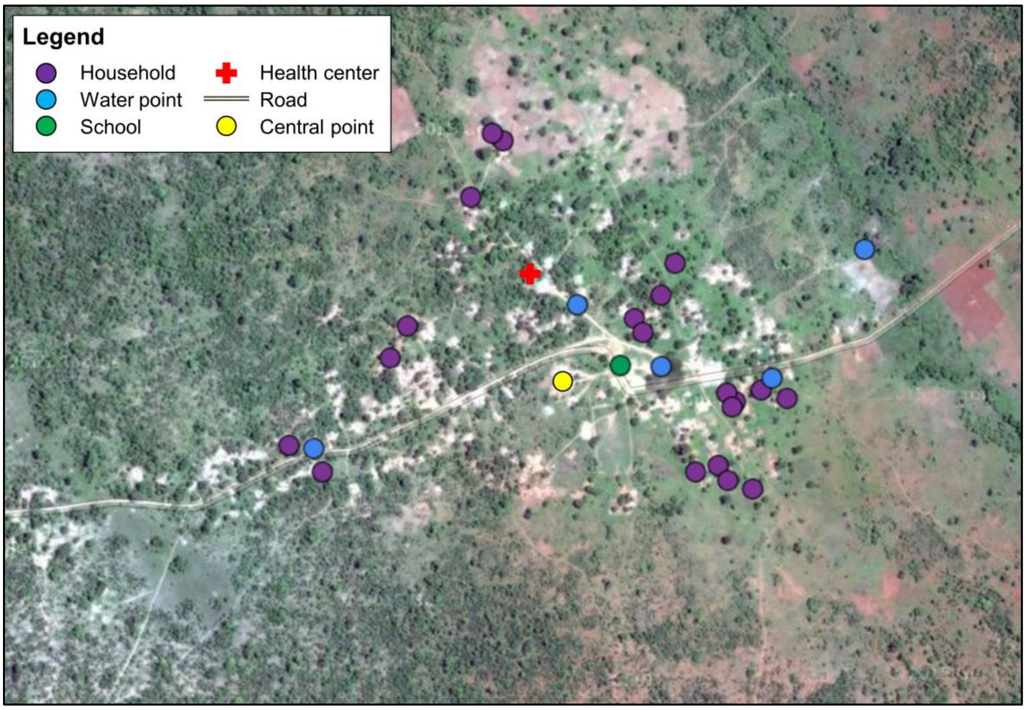


**Figure 3.11: Example of household sampling in a sentinel site**

In our case studies, the surveys included a school survey axis, to determine parasitic schistosomiasis and soil-transmitted helminth infection rates in schoolchildren aged 9-14 years (see sub-chapter 3.2.3). For this purpose, the primary school in the selected sentinel sites were sampled. Selection of a quota of at least 30 children was randomized among all children present on the survey day, considering a gender and age category balance (9-10 years, 11-12 years and 13-14 years).

### 3.2.2 Sample size calculation

Children under the age of 5 years are the primary focus for biomedical measurements in the surveys. Due to its overall significance on child health, anaemia rate in children aged 6–59 months was selected as the primary outcome for sample size calculation. With the formula for normal approximation to binomial distribution without finite sample correction (level of confidence 95%; expected prevalence 50%; precision 5%), the sample size was calculated at 385. An estimated number of 2.5 children aged 6–59 months per household and a drop-out rate of 20% led to the target sample of at least 185 households. Experience from previous BHS with the same logistical and field-staff setup revealed that 25 households can be sampled in one day at a single sentinel site.

### 3.2.3 Selection of indicators and survey axes

The selection of the data collected, i.e. the health or health-related indicators, is done based on factors such as (i) health data gaps and necessity for quantification; (ii) perceived future impact; (iii) experience from similar contexts; (iv) feasibility and reproducibility for data collection; and (v) budget considerations.

Data was collected within the sentinel sites at three different levels:

i) individual level, e.g. gender, age, educational level, health-related knowledge, attitudes and practices (KAP) or biomedical indicators;
ii) household level, e.g. household assets, housing and sanitary conditions or quality of drinking water; and
iii) community level, e.g. access to health infrastructures and services, quality of source water or local vector entomology.

Within our four case studies, data was collected through different survey axes at various locations within a sentinel site:

i) questionnaire survey at household level;
ii) clinical field unit located in the community;
iii) parasitological survey in schools;
iv) drinking water quality at household and community level; and
v) health service and infrastructure assessment at health facility level.

Additional survey axes, such as entomological or rodent surveys, can be added depending on the local needs. The detailed materials and methods used for data collection activities in the different surveys are explained in the respective manuscripts presented in chapters 4 to 10.

## 3.3 Partnerships and assignments

The project work presented in this PhD thesis was conducted in a partnership of the Swiss TPH with SHAPE Consulting Limited (St Peters Port, Channel Islands and Pretoria, South Africa). HIA-related assignments, providing the database for the present PhD research, were sponsored by Randgold Resources, Newcrest Mining Limited, Addax Bioenergy and FQML.

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# 4 Schistosomiasis and soil-transmitted helminth infections in schoolchildren in north-eastern Democratic Republic of the Congo

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SHORT COMMUNICATION

# Schistosomiasis and soil-transmitted helminth infections in schoolchildren in north-eastern Democratic Republic of the Congo

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**Background:** There is a paucity of epidemiological data pertaining to schistosomiasis and soil-transmitted helminth (STH) infections in the Democratic Republic of the Congo (DRC).

**Methods:** A cross-sectional survey was carried out in the north-eastern part of DRC enrolling 400 schoolchildren aged 9–14 years. Stool and urine samples were subjected to standard diagnostic methods and examined under a microscope for helminth eggs.

**Results:** Four out of five children were infected with at least one helminth species. *Schistosoma mansoni* was the predominant species (57.8%). Urine examinations were all negative for *S. haematobium*.

**Conclusions:** *S. mansoni* and STH infections are highly endemic in the surveyed part of the DRC, calling for interventions in school-aged children.

**Keywords:** Cross-sectional survey, Democratic Republic of the Congo, Schistosomiasis, Soil-transmitted helminthiasis

## Introduction

The Democratic Republic of the Congo (DRC) is considered a high-burden country for schistosomiasis and soil-transmitted helminthiasis, yet this claim is based on very scattered data.[1–4] We present findings from a cross-sectional survey carried out in nine villages in the Watsa health zone in the north-eastern part of DRC. School-aged children were subjected to standard, quality-controlled diagnostic methods and results were fed into the open-access Global Neglected Tropical Diseases database.[5]

## Materials and methods

The study area is situated in north-eastern DRC in the Watsa health zone in Haut-Uélé province, approximately 190 km north-west of the town of Bunia. A cross-sectional survey was carried out in August 2010, during the rainy season, in primary schools in nine villages around the settlement of Durba (see Supplementary Figure 1). In each school, a minimum of 30 children aged 9–14 years were randomly selected. In total, 400 children were sampled, comprising 213 boys (53.3%) and 187 girls.

From each child, a fresh morning stool sample and a mid-day, post-exercise urine sample were collected. The samples were processed using standard, quality-controlled methods. For stool samples, a single 41.7 mg Kato-Katz thick smear was prepared on slides and analysed under a microscope.[6] The number of eggs of *Schistosoma mansoni*, *Ascaris lumbricoides*, hookworm, and *Trichuris trichiura* were counted and multiplied by a factor of 24 to obtain an infection intensity measure; i.e., eggs per gram of stool (EPG).[6] Urine samples were examined for *S. haematobium*, using a 10 ml centrifugation method.[7]

Statistical analyses were performed with STATA, version 13 (StataCorp., College Station, TX, USA). Descriptive statistics for frequency, including 95% confidence intervals, were prepared. Geometric mean intensity of helminth infection was used in the analysis. The p-values were calculated using Pearson's $\chi^2$ test of proportions.

## Ethical approval

The purpose and procedures of the study were explained to village leaders, school teachers, and schoolchildren. Written informed consent was obtained from school directors and teachers, while children assented orally. At the end of the survey, all children received albendazole (single dose, 400 mg) against soil-transmitted helminthiasis, whilst children with a confirmed *S. mansoni* infection were treated with praziquantel (single dose, 40 mg/kg).

## Results

*S. mansoni* was the predominant helminth species; 231 children were found with egg-positive Kato-Katz thick smears, thus resulting in a prevalence estimate of 57.8% (Table 1). The prevalence increased with age (e.g., children aged 9–10 years had a prevalence of 48.2%, while children in the oldest age group, 13–14 years, had a prevalence of 69.9%; p=0.001). No *S. haematobium* eggs were found in urine samples subjected to a filtration method.

Hookworm was the most common soil-transmitted helminth (STH) species (prevalence: 48.5%). Boys had a significantly higher hookworm prevalence than girls (55.4% vs 40.6%, p=0.003). *T. trichiura* was found at a relatively low level (5.0%), while no *A. lumbricoides* were found.

Among the *S. mansoni*-infected children, more than half (52.8%) were heavily infected (≥400 EPG), whilst an additional 28.6% had a moderate infection intensity (100–399 EPG). For hookworm, most infections were of light intensity with fewer than 2000 EPG (85.1%).

Overall, 140 children (35.0%) were infected with at least two species of intestinal helminths (data not shown). *S. mansoni*-hookworm co-infection affected more than a quarter of the study participants (25.5%). Nine children (2.3%) were found with a triple species infection (i.e., *S. mansoni*, hookworm and *T. trichiura*).

## Discussion

We found high prevalence and intensity of *S. mansoni* infection among 9- to 14-year-old school-going children (overall prevalence was 57.8%) during a cross-sectional survey conducted in August 2010 in the north-eastern part of DRC. Compared with previous studies, our findings suggest that this part of north-eastern DRC is more highly endemic for *S. mansoni* than expected.[8,9] Discrepancies between modelled and surveyed estimates for *S. mansoni* were also found in highly urbanised settings of DRC.[4,9] Furthermore, we did not find a single *S. haematobium* infection, which is in contrast to previous estimates made by WHO that suggested that between 10 and 50% of children in this province are infected with *S. haematobium*.[9]

The infection prevalence for *T. trichiura* (5.0%) and *A. lumbricoides* (0.0%) were considerably lower than previously modelled rates.[3,10] The hookworm prevalence (48.5% in this study) was found within the range of previous predictions by Karagiannis-Voules et al. who modelled a rate above 50%.[3]

Although DRC is one of three high-burden countries in Africa for helminthiases and other neglected tropical diseases, the country has yet to set-up a national control programme for neglected tropical diseases.[2,8] The lack thereof was underscored by local health and education authorities reporting that none of the schools had ever received preventive chemotherapy against schistosomiasis and soil-transmitted helminthiasis.

**Table 1.** Prevalence of *Schistosoma mansoni* and soil-transmitted helminth infection in the Durba study area, Democratic Republic of the Congo, 2010

| | n | *Schistosoma mansoni* | Hookworm | *Trichuris trichiura* | Any helminth |
|---|---|---|---|---|---|
| Prevalence of infection, % (95% CI) | | | | | |
| Sex | | | | | |
| Male | 213 | 60.1 (53.5–66.7) | 55.4 (48.7–62.1) | 6.6 (3.2–9.9) | 83.1 (77.4–87.9) |
| Female | 187 | 55.1 (47.9–62.2) | 40.6 (33.5–47.7) | 3.2 (0.6–5.8) | 78.1 (71.5–83.8) |
| Age (years) | | | | | |
| 9–10 | 193 | 48.2 (41.1–55.3) | 36.8 (29.9–43.7) | 2.1 (0.0–4.1) | 72.0 (65.1–78.2) |
| 11–12 | 114 | 64.0 (55.1–73.0) | 57.0 (47.8–66.2) | 7.9 (2.9–12.9) | 87.7 (80.3–93.1) |
| 13–14 | 93 | 69.9 (60.4–79.4) | 62.4 (52.3–72.4) | 7.5 (2.1–13.0) | 90.3 (82.4–95.5) |
| Total | 400 | 57.8 (52.9–62.6) | 48.5 (43.6–53.4) | 5.0 (2.9–7.1) | 80.1 (76.5–84.5) |
| Geometric mean EPG, n (95% CI) | | | | | |
| Total | 400 | 397.8 (327.9–482.6) | 456.1 (366.3–567.9) | 118.5 (73.4–191.1) | NA |
| Intensity of infection, % (95% CI) | | | | | |
| Infected, n | | 231 | 194 | 20 | NA |
| Light[a] | | 18.6 (13.8–24.2) | 85.1 (79.2–89.8) | 100.0 (83.1–100.0) | NA |
| Moderate[b] | | 28.6 (22.8–34.9) | 6.2 (3.2–10.6) | 0.0 (0.0–0.0) | NA |
| High[c] | | 52.8 (46.2–59.4) | 8.8 (5.2–13.7) | 0.0 (0.0–0.0) | NA |

EPG: eggs per gram of stool; NA: not applicable.
[a] Hookworm 1–1999 EPG; *T. trichiura* 1–999 EPG; *S. mansoni* 1–99 EPG.
[b] Hookworm 2000–3999 EPG; *T. trichiura* 1000–9999 EPG; *S. mansoni* 100–399 EPG.
[c] Hookworm ≥4000 EPG; *T. trichiura* ≥10 000 EPG; *S. mansoni* ≥400 EPG.

Our study has limitations that are offered for consideration. First, the data presented here were obtained from a cross-sectional survey in selected villages, and hence, cannot be generalised for a wider area as infection with *Schistosoma* spp. and STHs show focal distribution. Second, the true prevalence rates are likely to be higher due to the low sensitivity of single Kato-Katz thick smears.[11]

### Conclusions

Our findings from an undersurveyed area suggest that helminth infections are widespread in north-eastern DRC and that polyparasitism is common. Previous, modelled estimates for the study area did not fully corroborate with our results. The data have been georeferenced and fed into the open-access Global Neglected Tropical Diseases database for subsequent risk profiling, which will help shape spatial targeting of control interventions.[5]

## Supplementary data

Supplementary data are available at Transactions online (http://trstmh.oxfordjournals.org/).

**Authors' contributions:** CA, SS, MJD and MSW conceived the study and designed the study protocol; AMK, CA, MO, MJD and MSW carried out the field study; AMK, CA and MSW analysed and interpreted data. AMK and MSW drafted the manuscript; AMK, MJD, JU and MSW critically revised the manuscript for intellectual content. All authors read and approved the final manuscript. AMK and MSW are the guarantors of the paper.

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**Competing interests:** None declared.

**Ethical approval:** The study was approved by the health district of Haut-Uélé East, Orientale province, Ministry of Health (reference no. 771/047/BDS/HU-E/WAT/2010).

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# 5 The epidemiology of malaria and anaemia in the Bonikro mining area, central Côte d'Ivoire

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# The epidemiology of malaria and anaemia in the Bonikro mining area, central Côte d'Ivoire

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## Abstract

**Background:** The epidemiology of malaria and anaemia is characterized by small-scale spatial and temporal heterogeneity, which might be influenced by human activities, such as mining and related disturbance of the environment. Private sector involvement holds promise to foster public health, including the prevention and control of malaria and anaemia. Here, results from a cross-sectional epidemiological survey, conducted in communities that might potentially be affected by the Bonikro Gold Mine (BGM) in Côte d'Ivoire, are reported.

**Methods:** In December 2012, a cross-sectional survey was carried out in seven communities situated within a 20-km radius of the BGM in central Côte d'Ivoire. Capillary blood samples were obtained from children aged six to 59 months. Samples were subjected to a rapid diagnostic test (RDT) for *Plasmodium falciparum* detection, whilst haemoglobin (Hb) was measured to determine anaemia. Additionally, mothers were interviewed with a malaria-related knowledge, attitudes and practices questionnaire.

**Results:** A total of 339 children and 235 mothers participated in the surveys. A positive RDT for *P. falciparum* was found in 69% of the children, whilst 72% of the children were anaemic (Hb <11 g/dl). *Plasmodium falciparum* infection was significantly associated with anaemia (odds ratio (OR) 7.43, 95% confidence interval (CI) 3.97-13.89), access to a health facility (OR 5.59, 95% CI 1.81-17.32) and age (OR 0.04, 95% CI 0.01-0.12; youngest (six to 11 months) *versus* oldest (48-59 months) age group). Less than a quarter of mothers knew that malaria is uniquely transmitted by mosquitoes (22.3%, 95% CI 16.8-27.7%). Misconceptions were common; most of the mothers believe that working in the sun can cause malaria.

**Conclusions:** Malaria and anaemia are highly endemic in the surveyed communities around the BGM project area in Côte d'Ivoire. The data presented here provide a rationale for designing setting-specific interventions and can be utilized as a benchmark for longitudinal monitoring of potential project-related impacts due to changes in the social-ecological and health systems.

**Keywords:** Malaria, Anaemia, *Plasmodium falciparum*, Mining, Private sector, Côte d'Ivoire

## Background

The extractive industry, especially mining, is an important economic sector in many African countries [1]. Meanwhile, Africa is the continent most heavily affected by malaria, which drains the social and economic development [2-4]. Knowledge about whether and to what extent the epidemiology of malaria is altered in the face of extractive industry projects in high endemicity areas is limited. Mining and other natural resources development and management projects are believed to influence local disease patterns, including malaria, through a variety of proximal and distal factors. For example, environmental manipulation to accommodate project-related infrastructure developments can create favourable habitats for malaria vectors, most importantly *Anopheles gambiae* [5,6]. Mining projects attract workers and camp followers who might live in poorly constructed houses with inadequate sanitation. Lack of drainage, along with peri-urban water bodies (e.g. swamps), might increase

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vector breeding and human-vector contact [7,8]. On the other hand, mining projects create opportunities for the prevention and control of malaria as the companies have an interest in keeping their workforce healthy, and thus productive. This may, at the same time, positively impact on surrounding communities, as has been shown in the Zambian copperbelt in the 1930s and 1940s, and elsewhere [9,10]. Moreover, corporate social responsibility has become part of international good practice for companies operating in resource-constraint settings [11]. In remote areas in developing countries, where health systems are notoriously weak and understaffed, the success of national control efforts depends on the coordination and communication among different stakeholders (e.g. government, non-governmental organizations, international institutions and the private sector) [12,13]. In such settings, the private sector can play a pivotal role in fostering public health, as emphasized by the World Health Organization (WHO) [14].

The Bonikro Gold Mine (BGM) project in central Côte d'Ivoire is planning malaria control efforts to mitigate health risks of the workforce, but is simultaneously exploring opportunities to support sustainable development initiatives in the communities surrounding the BGM project. However, there was a paucity of data regarding malaria prevalence, vector and parasite species composition and insecticide resistance in the project area. As this limited the ability to design control interventions, studies were commissioned on the following grounds: (i) the malaria prevalence is showing small-scale spatial heterogeneity [15-18]; (ii) a deeper understanding of the epidemiology of malaria in the study area will facilitate the development of targeted interventions [19]; and (iii) a detailed characterization of the baseline situation allows for longitudinal monitoring and evaluation of project impacts [20], and malaria-specific interventions. Additionally, the concurrent assessment of anaemia was considered important, as it serves as an indicator for general health and well-being [21-23].

Against this background, the following activities were undertaken: (i) a malaria and anaemia prevalence survey among children aged six to 59 months to determine the prevalence of *Plasmodium falciparum* and the magnitude of anaemia; (ii) a knowledge, attitudes and practices (KAP) survey related to malaria among mothers; and (iii) an entomology and insecticide susceptibility survey in order to identify effective insecticides for potential indoor residual spraying (IRS) and other vector control interventions. Here, the findings of the malaria and anaemia prevalence surveys and mothers' KAP study are presented. Detailed findings of the entomology and insecticide resistance surveys will be communicated elsewhere.

## Methods

### Ethical considerations

Ethical clearance was obtained from the 'Comité National d'Ethique et de la Recherche' of Côte d'Ivoire (reference no. 01/MSLS/CNER-dkn). Communities were given detailed information about the purpose and procedures of the study, the extent of their involvement, the right to withdraw anytime without further obligation and to receive free treatment based on the results of the measurements or tests done. Written informed consent was obtained from all participating mothers in the questionnaire survey before conducting any interviews, which included the approval to take capillary blood samples from their children aged six to 59 months in a mobile clinic. Individuals with a *P. falciparum* infection or anaemia were treated according to national guidelines, free of charge. Children who had a positive RDT result for *P. falciparum* were given artesunate/amodiaquine (Camoquin Plus; Pfizer, New York, USA) for uncomplicated malaria (if no prior treatment was received). Anaemic children were provided with iron supplements (Ferrostran; Teofarma, Valle Salimbene, Italy) and severe cases were referred to health care centres. Independent of the test results, all participating children aged above three years received a multi-vitamin suspension (Alvityl; Laboratoires URGO, Chenôve Cedex, France).

### Study area

The study was carried out in the health districts of Oumé and Divo in central Côte d'Ivoire. The study area comprised two major towns, Oumé and Hiré, and several smaller villages around the BGM project (between latitudes 6°11' and 6°22' N and longitudes 5°17' and 5°24' W). A map of the study area, including estimated population sizes for 2011, is provided in Figure 1. The total population residing in the surveyed sentinel sites is estimated at 12,000, whereas in Oumé and Hiré, the respective neighbourhood population, not the entire urban population, was counted.

### Study design and household selection

A cross-sectional household survey was carried out in December 2012, at the end of the rainy season. Based on *P. falciparum* prevalence rates found among young children in previous studies conducted in central and south-central Côte d'Ivoire [16,17,24,25] and in consultation with local health staff, the prevalence of malaria in the study area was estimated at 70% ($p = 0.7$). With a 95% level of confidence and a precision of 5%, the sample size was calculated at 336.

The sampling methodology applied was adapted to the specific project setting and was based on a sentinel survey approach. Given the considerable demographic differences in the study area (see population sizes in Figure 1), sampling proportional to size was not considered

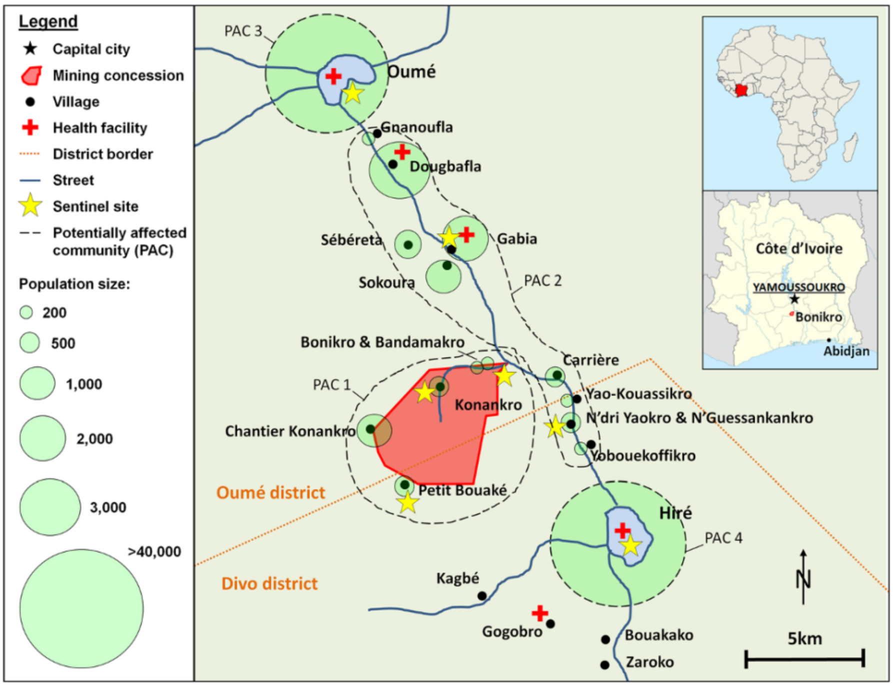


**Figure 1** Study area and surveyed sentinel sites, including estimated population sizes, Côte d'Ivoire, 2012.

appropriate, as smaller villages in proximity to the project area were believed to be more directly affected by project activities than larger towns further away. Instead, villages and towns were grouped into potentially affected communities (PACs), purposely defined as specific geographical entities that are considered to be similarly impacted by project-related activities (see Figure 1, dashed line) [20]. For the BGM project, the following PACs were defined: (1) the immediate project area (potentially affected through infrastructure developments and resettlement); (2) the access road between Oumé, Hiré and the project site (potentially affected by migration and increased traffic); and (3) and (4) the urban centres of Oumé and Hiré, respectively (potentially affected through migration and potential economic shifts and representative of most of the BGM workforce). Within these four PACs that take into consideration specific project exposure, seven sentinel sites were randomly selected; thee in PAC 1, two in PAC 2, and one each in PAC 3 and PAC 4.

Within sentinel sites, a random sampling procedure at the unit of the household was applied. Firstly, trained interviewers were sent in four random directions from a central location [20]. Secondly, interviewers counted the number of houses up to the border of the sentinel site. Thirdly, the field manager determined, through a random procedure, the first household to be interviewed in each direction. The interviewer then proceeded to interview the next household until the targeted number (minimum of 25 households per day) was achieved. The two criteria for household inclusion were: (i) household inhabited by at least one child under the age of five years; and (ii) willingness of the child's mother to respond to a questionnaire.

### Survey activities

Mothers were first interviewed using a pretested KAP questionnaire. The questionnaire focussed on household demographics, malaria awareness and knowledge, modes of transmission, preventive measures, including ownership and utilization of insecticide-treated nets (ITNs), IRS and treatment-seeking behaviour for malaria. All questions were closed-ended and drawn from international standard surveys, such as Demographic and Health Surveys (DHS), to facilitate subsequent comparison with regional and national data.

Once the KAP questionnaire was completed, participating mothers were invited to bring their children aged below five years to a mobile clinic, located at a central place in each sentinel site. Capillary blood samples were collected from children aged six to 59 months. Following this, tests were conducted to determine haemoglobin (Hb) levels using a portable HemoCue device (HemoCue® Hb 201 System; HemoCue AB, Ängelholm, Sweden) and presence of *P. falciparum* infection using an RDT (Paracheck Pf device cassette; Orchid Biomedical Systems, Goa, India).

### Statistical analysis

Data were recorded using Microsoft Excel version 2010 (Microsoft Corporation; Redmond, USA) and EpiData version 3.1 (EpiData Association; Odense, Denmark). Statistical analyses were done using Stata version 10 (StataCorp.; College Station, USA). Prevalence rates were averaged for background characteristics, such as age and sex. Adjusted odds ratios (ORs) with their corresponding 95% confidence intervals (CIs) were calculated using multivariate logistic regression analysis for child and household attributes associated with *P. falciparum* infection and anaemia. P-values below 0.05 were considered statistically significant.

## Results

### Study compliance and respondents' characteristics

Overall, 574 individuals participated in the study (Figure 2). There were 242 households visited and 235 mothers had complete data records from the questionnaire survey. Without exception, mothers visited the mobile clinics, readily accompanied by their children. Overall, there were 385 children aged below five years (on average 1.44 children per mother). Among these, 339 children had a blood sample subjected to an RDT for *P. falciparum* and measuring Hb level. The mean age of the mothers interviewed was 27.9 years (standard deviation (SD), 7.4 years). Slightly more than half of the mothers (123/235, 52.3%) had no formal education, whereas 80 mothers (34.0%) had primary education and the remaining 32 mothers (13.6%) attained secondary education or higher.

### *Plasmodium falciparum* infection

The prevalence of *P. falciparum* in children aged six to 59 months was 69.0% (95% CI 64.1-74.0%) (Table 1) and varied by age. The youngest age group (six to 11 months) showed the lowest infection prevalence (47.8%; 95% CI 32.8-62.8%), whilst the oldest age group had the highest prevalence (48-59 months; 83.9%, 95% CI 74.5-93.3%). Similar prevalences were found for boys and girls.

**Table 1 Malaria prevalence by rapid diagnostic tests in children aged six to 59 months, stratified by sex and age group in central Côte d'Ivoire in 2012**

| | *Pf* positive by RDT | |
|---|---|---|
| | n/N (%) | 95% CI |
| **Sex** | | |
| Male | 112/164 (68.3) | 61.1-75.5 |
| Female | 122/175 (69.7) | 62.8-76.6 |
| **Age (months)** | | |
| 6-11 | 22/46 (47.8) | 32.8-62.8 |
| 12-23 | 52/80 (65.0) | 54.3-75.7 |
| 24-35 | 54/82 (65.9) | 55.4-76.3 |
| 36-47 | 54/69 (78.3) | 68.3-88.2 |
| 48-59 | 52/62 (83.9) | 74.5-93.3 |
| Total | 234/339 (69.0) | 64.1-74.0 |

CI, confidence interval; *Pf, Plasmodium falciparum*; RDT, rapid diagnostic test.

### Prevalence and severity of anaemia

The prevalence and severity of anaemia, stratified by sex and age group, are summarized in Table 2. Anaemia, defined as Hb <11 g/dl, was recorded in 72.0% of the surveyed children. The prevalence of anaemia decreased with age (84.8% in children aged six to 11 months; and 64.5% in children aged 48-59 months). Slightly less than half of the children were moderately anaemic (Hb 7.0-9.9 g/dl; 47.5%). Severe anaemia (Hb <7 g/dl) was highest in the 24- to 35-month-old age group (4.9%), followed by the youngest age group (six-to 11-month-old; 4.6%). Boys and girls were equally affected by anaemia.

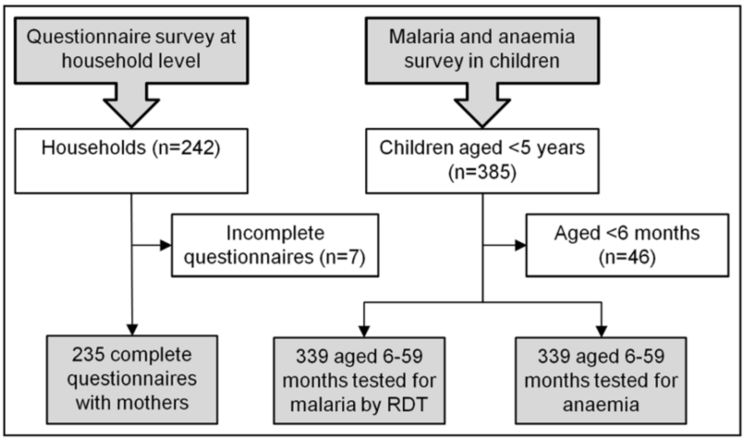


**Figure 2** Study compliance.

**Table 2 Prevalence and severity of anaemia in children aged six to 59 months, stratified by sex and age group in central Côte d'Ivoire in December 2012**

| | Mild anaemia (Hb 10.0-10.9 g/dl) | Moderate anaemia (Hb 7.0-9.9 g/dl) | Severe anaemia (Hb <7 g/dl) | Any anaemia (Hb <11 g/dl) | |
|---|---|---|---|---|---|
| | n/N (%) | n/N (%) | n/N (%) | n/N (%) | 95% CI |
| **Sex** | | | | | |
| Male | 31/164 (18.9) | 83/164 (50.6) | 4/164 (2.4) | 118/164 (72.0) | 65.0-78.9 |
| Female | 43/175 (24.6) | 78/175 (44.6) | 5/175 (2.9) | 126/175 (72.0) | 65.2-78.7 |
| **Age (months)** | | | | | |
| 6-11 | 7/46 (15.2) | 30/46 (65.2) | 2/46 (4.6) | 39/46 (84.8) | 74.0-95.6 |
| 12-23 | 14/80 (17.5) | 45/80 (56.3) | 2/80 (2.5) | 61/80 (76.3) | 66.7-85.8 |
| 24-35 | 25/82 (30.5) | 31/82 (37.8) | 4/82 (4.9) | 60/82 (73.2) | 63.4-83.0 |
| 36-47 | 17/69 (24.6) | 27/69 (39.1) | 0/69 (0.0) | 44/69 (63.8) | 52.1-75.4 |
| 48-59 | 11/62 (17.7) | 28/62 (45.2) | 1/62 (1.6) | 40/62 (64.5) | 52.3-76.8 |
| Total | 74/339 (21.8) | 161/339 (47.5) | 9/339 (2.7) | 244/339 (72.0) | 67.2-76.7 |

CI, confidence interval; Hb, haemoglobin.

### Findings of the KAP survey

Key results of the KAP survey are shown in Table 3. While awareness of malaria was high (97.5%), knowledge of the disease was considerably lower. For example, when asked about causes of malaria, almost half of the mothers (47.6%) mentioned – without prompting – that mosquitoes transmit malaria. However, "being in the sun" was presented as the cause of malaria by more than half of the respondents (52.4%). Consequently, consistent knowledge on malaria transmission, i.e. malaria is solely transmitted through mosquito bites, was low (22.3%). Similarly, mothers' knowledge pertaining to malaria prevention was poor. Possible prevention measures included "avoiding mosquito bites" (10.9%) and "avoid exposure to the sun" (30.6%). Most of the mothers reported to have taken intermittent preventive treatment (IPT) during their last pregnancy (87.2%).

Among the households visited, 77.4% owned at least one ITN and the mean number of ITNs per household was 2.1 (95% CI 1.9-2.4). Of the children below the age of five years, 61.5% slept under an ITN the night preceding the survey. The IRS coverage at household level was 10.6% (25 out of the 235 structures visited were sprayed within 12 months before the current survey).

Most of the mothers reported that they sought medical advice in a formal health facility during the last fever episode of their child (79.1%). Additionally, use of traditional medicine was quite common; among all respondents, 39.0% had consulted a traditional healer at some point with a sick child.

### Results from logistic regression analysis

Results from the logistic regression analysis for child and household attributed factors associated with *P. falciparum* infection and anaemia are summarized in Table 4. Age was significantly associated with *P. falciparum* infection, with younger age groups having a lower odds of infection (OR, 0.04; 95% CI 0.01-0.12 for the six to 11 months age group; OR, 0.14, 95% CI 0.05-0.38 for the 12-23 months age group; and OR, 0.17, 95% CI 0.06-0.47 for the 24-35 months age group) compared to the oldest age group (48-59 months). There was a strong association between *P. falciparum* infection and Hb level. Children who tested *P. falciparum* positive had a more than seven-fold higher odds of being anaemic (OR, 7.43; 95% CI 3.97-13.89) than their non-infected counterparts. Lack of access to a health care facility was positively associated with *P. falciparum* infection. Children living in villages with no health facility had a 5.59 times higher odds of *P. falciparum* infection. Consistent knowledge of respondents regarding transmission (i.e. malaria uniquely transmitted by mosquito bites) showed a negative association with *P. falciparum* infection among children (OR, 0.27; 95% CI 0.14-0.53).

Children in sentinel sites who received an ITN through the private sector distribution campaign six months prior to the current cross-sectional survey (i.e. Bonikro, Bandamakro, Petit Bouaké and Konankro) were at about half the odds of *P. falciparum* infection when compared to the other sentinel sites (OR, 0.47; 95% CI 0.15-1.50). Sleeping under an ITN the night preceding the survey and educational status of the mother were found to be non-significant ($p > 0.05$) for all attributes.

Child age was found to be strongly associated with anaemia. Children younger than 35 months were at a significantly higher odds of anaemia than their older counterparts. The odds for anaemia in children aged six to 11 months was eight times higher than for the oldest age group (OR, 7.98; 95% CI 2.61-24.43).

**Table 3 Knowledge, attitudes and practices related to malaria and health-seeking behaviour among mothers aged 15-49 years in central Côte d'Ivoire in December 2012**

| | n/N (%) | 95% CI |
|---|---|---|
| **Malaria awareness** | | |
| Ever heard about malaria | 229/235 (97.5) | 94.5-99.1 |
| **Malaria transmission** | | |
| Consistent knowledge on malaria transmission[a] | 51/229 (22.3) | 16.8-27.7 |
| Knowledge that mosquitoes transmit malaria | 109/229 (47.6) | 41.1-54.1 |
| Belief that exposure to sun can cause malaria | 120/229 (52.4) | 45.9-58.9 |
| **Malaria symptoms** | | |
| Fever stated as main malaria symptom | 111/229 (48.5) | 41.9-55.0 |
| **Malaria prevention** | | |
| Avoid mosquito bites | 25/229 (10.9) | 6.8-15.0 |
| Avoid exposure to the sun | 70/229 (30.6) | 24.6-36.6 |
| Mothers having received $IPT_p$ during the last pregnancy | 205/235 (87.2) | 82.9-91.5 |
| **Ownership and use of ITNs** | | |
| **Mean number of ITNs per household (n)** | 2.1 | 1.9-2.4 |
| Households owning at least one ITN | 182/235 (77.4) | 71.6-82.6 |
| Children aged <5 years who slept under an ITN the night preceding the survey[b] | 235/382 (61.5) | 56.4-66.4 |
| **Indoor residual spraying** | | |
| Households that had IRS within the 12 months preceding the survey | 25/235 (10.6) | 7.0-15.3 |
| **Health seeking behaviour** | | |
| Mothers who sought medical advice or treatment at a formal health facility the last time the youngest child had fever[c] | 167/211 (79.1) | 73.0-84.4 |
| Mothers who ever consulted a traditional healer when child was sick[d] | 90/231 (39.0) | 32.6-45.6 |

[a]Knowing that malaria is only transmitted through mosquito bites; [b]includes all children aged < five years; [c]of all children who ever had fever; [d]of all children who had ever been sick; CI, confidence interval; $IPT_p$, intermittent preventive treatment during pregnancy; IRS, indoor residual spraying; ITN, insecticide-treated net.

## Discussion

This study found high prevalences of *P. falciparum* (69.0%) and anaemia (72.0%) in children aged six to 59 months and limited knowledge on malaria transmission and prevention among children's mothers in communities located in the zone of influence of the BGM project area in central Côte d'Ivoire. The comparison of the observed *P. falciparum* prevalence with reports in previous surveys from central and south-central Côte d'Ivoire [16-18,24,25] underscores that malaria is highly endemic but that small-scale heterogeneity is considerable. For example, Koudou *et al.* [16] conducted several cross-sectional entomological and parasitological surveys in two villages in central Côte d'Ivoire (distance between the villages is approximately 80 km) to better understand the transmission of malaria. In surveys conducted in August 2005, the authors found prevalences of 62% and 82% in children aged six years and below in the two study villages, as determined by Giemsa-stained blood films examined microscopically. Righetti *et al.* [17,26] reported *P. falciparum* prevalences of 45.3% and 78.2% (using RDTs) among two cohorts of children consisting of (i) six- to 23-month-old infants and (ii) six- to eight-year-old schoolchildren, respectively, in three settings of the Taabo health and demographic surveillance system in south-central Côte d'Ivoire in a cross-sectional survey done in April 2010. Comparing the RDT results presented here for the same age group with data from the central-western region of Côte d'Ivoire obtained during the 2011/2012 national DHS [18] revealed a considerable difference: 69% (current study) *versus* 43% (DHS). The observed differences might partly be explained by seasonality [27,28]. However, the local social-ecological contexts, potentially affected by population influx, might also play a role. For example, several studies reported an adaptation of *An. gambiae* to polluted water bodies [8,29].

Interestingly, *P. falciparum* prevalence was found to be associated with three non-behavioural factors (i.e. anaemia status, host age and access to health care) and one behavioural factor (i.e. consistent knowledge of respondents regarding malaria transmission). The association between anaemia and malaria is widely acknowledged in the literature [22,30]. In the current study area, the sentinel sites that do have health facilities are somewhat more urbanized. Hence, access to health care is likely to be linked to other socio-economic and health systems factors that differ between the urban and rural settings. The fact that knowledge of malaria transmission by mothers is associated with lower odds of *P. falciparum* infection may imply that mothers who are aware of the risk take measures to protect their children, or have better treatment-seeking practices.

Anaemia was highly prevalent in the six- to 59-month-old children in this survey (72.0%). A similarly high prevalence was found in the same age group during the recent DHS at the national level (75%), but it is somewhat lower than the regional average for the central-western region (83%) [18]. Righetti *et al.* [17] reported an anaemia prevalence of 78% among six- to 23-month-old infants and 47% among schoolchildren aged six to eight years. Anaemia is multifactorial, with malnutrition, intestinal parasite infections (most importantly hookworm) and malaria being the key drivers [22,31,32]. The current study did not investigate concurrent helminth infections and micronutrient deficiencies, and hence it is not possible to quantify the differential contribution of these factors to the high rate of anaemia. The observed association of anaemia with child age has been reported before, and the proposed, underlying mechanism is that

**Table 4 Results from multivariate logistic regression analysis of child, household and mother attributes associated with malaria and anaemia**

| | Malaria | | | Anaemia | | |
|---|---|---|---|---|---|---|
| **Attribute** | **(%)** | **Adjusted OR[a] (95% CI)** | **p-value** | **(%)** | **Adjusted OR[a] (95% CI)** | **p-value** |
| **Sex** | | | | | | |
| Male | 68.3 | 1.00 | - | 72.0 | 1.00 | - |
| Female | 69.7 | 1.02 (0.58-1.80) | 0.948 | 72.0 | 1.04 (0.61-1.78) | 0.891 |
| **Age (months)** | | | | | | |
| 6-11 | 47.8 | 0.04 (0.01-0.12) | <0.001* | 84.8 | 7.98 (2.61-24.43) | <0.001* |
| 12-23 | 65.0 | 0.14 (0.05-0.38) | <0.001* | 76.3 | 3.10 (1.34-7.20) | 0.008* |
| 24-35 | 65.9 | 0.17 (0.06-0.47) | 0.001* | 73.2 | 2.51 (1.11-5.70) | 0.028* |
| 36-47 | 78.3 | 0.50 (0.17-1.47) | 0.209 | 63.8 | 1.04 (0.48-2.30) | 0.913 |
| 48-59 | 83.9 | 1.00 | - | 64.5 | 1.00 | - |
| ***P. falciparum* infection** | | | | | | |
| RDT negative | - | - | - | 49.5 | 1.00 | - |
| RDT positive | - | - | - | 82.1 | 7.43 (3.97-13.89) | <0.001* |
| **ITN use[b]** | | | | | | |
| Yes | 66.3 | 1.00 | - | - | - | - |
| No | 73.0 | 1.50 (0.83-2.69) | 0.180 | - | - | - |
| **Access to health care** | | | | | | |
| Health facility | 57.0 | 1.00 | - | 64.9 | 1.00 | - |
| No health facility | 80.5 | 5.59 (1.81-17.32) | 0.003* | 78.7 | 1.20 (0.68-2.11) | 0.535 |
| **ITN distribution[c]** | | | | | | |
| Not received | 63.5 | 1.00 | - | - | - | - |
| Received | 77.9 | 0.47 (0.15-1.50) | 0.203 | - | - | - |
| **Education of mother** | | | | | | |
| Some formal education | 64.0 | 1.00 | - | 72.1 | 1.00 | - |
| No formal education | 73.6 | 1.15 (0.64-2.08) | 0.635 | 71.9 | 0.83 (0.48-1.43) | 0.503 |
| **Consistent knowledge of mother[d]** | | | | | | |
| No | 76.6 | 1.00 | - | - | - | - |
| Yes | 45.8 | 0.27 (0.14-0.53) | <0.001* | - | - | - |

[a]Multivariate logistic regression odds ratio (OR); [b]children aged six to 59 months who have slept under an ITN the night preceding the survey according to the mother; [c]households that received an ITN during the private sector ITN distribution in June 2012; [d]knowing that malaria is only transmitted through mosquito bites; *significant p-value; CI, confidence interval; Hb, haemoglobin; ITN, insecticide-treated net; RDT, rapid diagnostic test.

iron requirements are related to growth rate, and hence iron demand declines with age [25,33].

In Côte d'Ivoire, ITN coverage, defined as households owning at least one ITN, has been intensely scaled up from less than 10% in 2005 to 60% in 2011 [14]. After the most recent distribution campaign in 2011/2012, preceding the current survey in December 2012, the coverage of the central-western region had further increased to 77.4% according to DHS data [18]. The study area had a comparable household coverage of ITNs with 76.7%, though the utilization among children below the age of five years lagged behind in both the current survey (61.5%) and the DHS (50.6% in central-western region) [18,34]. It is interesting to note that no clear association between ITN ownership and/or use and *P. falciparum* infection prevalence was found, but this may be explained by other confounding factors. The KAP survey highlighted important inadequacies in malaria-related knowledge, its transmission and prevention. Misconceptions on causes of malaria are common, as revealed here with more than 50% of the interviewed mothers mentioning working in the sun. On the other hand, the correct cause (i.e. transmission of malaria is uniquely due to mosquito bites) was stated by less than half of the mothers. Taken together, these findings clearly indicate that intervention campaigns of any kind (e.g. ITN distribution) and introduction of RDTs should go hand-in-hand with setting-specific information, education and communication (IEC) strategies in order to enhance the impact of ITNs.

In July 2012, five months prior to this survey, an entomology and insecticide resistance survey found that *An. gambiae s.s.* is the main vector in the study area. Wild caught female mosquitoes (n = 211) from Oumé and Hiré towns were exposed for one hour to either 0.05% deltamethrin, 4% malathion, 0.1% bendiocarb or 4% dichlorodiphenyltrichloroethane (DDT) [35]. Mortality 24 hours after exposure was 15.1% for deltamethrin, 10.4% for malathion, 6.9% for bendiocarb and 10.5% for DDT. Further, knock-down resistance, both east and west resistance alleles, were found in 83% and 96% of mosquitoes (n = 111), respectively, and G119S mutations in 37%. These findings confirmed earlier indications of high resistance to insecticides in Côte d'Ivoire and in neighbouring countries [36-38]. Based on these results, IRS was initiated by BGM, which led to a relatively high IRS coverage in the study area (10.6%) compared to the regional average for the central-western region (0.5%). All structures surveyed in Bonikro and Bandamakro were sprayed through the BGM IRS programme. Outside these sites, only two of the interviewed households reported that they had undergone IRS, resulting in an overall coverage of 0.9%, which is comparable with data from the recent DHS. The combined protective effects of IRS and ITNs have been documented in the literature with some inconsistency [39,40]. Corbel and colleagues [41], for example, concluded that IRS combined with ITNs in an endemic, high pyrethroid-resistance area in Benin, had no beneficial effect. However, the combination of IRS and case management has proven successful in a malaria control programme on Bioko Island, Equatorial Guinea [42]. A significant reduction in malaria prevalence (42% less infections within two years) has been observed in locations where spray intervals and coverage were optimized. The programme demonstrated the benefits of collaboration between the private sector (Marathon Oil) and local government (the Government of Equatorial Guinea).

## Conclusion

The surveyed communities in a major mining area of central Côte d'Ivoire are significantly affected by malaria and anaemia, whilst access to health care, IEC strategies and prevention measures are limited. The effectiveness and sustainability of malaria control interventions can be enhanced through intersectoral collaboration, including public-private partnerships. The private sector has direct business interests and social cooperate responsibility to support malaria control in the project area. The data presented here provide a rationale for setting-specific interventions. Follow-up surveys pertaining to *Plasmodium* infection and anaemia in the PACs will allow for long-term monitoring of potential project-related impacts pertaining to environmental and socio-economic changes and the effect of malaria control interventions, such as ITN distribution, IRS or IEC activities [20,43].

**Competing interests**
This study received financial support from Newcrest Mining Limited. The funder had no role in the study design, data collection and analysis, decision to publish or preparation of the manuscript. RMY and PAY were employees of Newcrest Mining Limited at the time of the survey. All other authors declare that they have no competing interests.

**Authors' contributions**
AMK conceived the study design and data collection of the malaria and anaemia prevalence and knowledge, attitudes and practices surveys. AMK and CA managed the field activities. MJD was the overall study coordinator. AMK and MO conducted the statistical analysis. AMK and MSW drafted the manuscript. RMY was the medical director of the study, assisted in obtaining ethical clearance and was in charge of sensitizing the local health authorities. RMY and PAY supported the sensitization of the communities and assisted with data collection. CA, MJD, MO and JU contributed to the interpretation of the data, manuscript writing and revisions. All authors read and approved the final manuscript.

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# 6 Baseline health conditions in selected communities of northern Sierra Leone as revealed by the health impact assessment of a biofuel project

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ORIGINAL ARTICLE

# Baseline health conditions in selected communities of northern Sierra Leone as revealed by the health impact assessment of a biofuel project

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**Background:** As biofuel projects may be associated with positive and negative effects on people's health and wellbeing, a health impact assessment was performed for the Addax Bioenergy Sierra Leone (ABSL) project. We present data from the baseline health survey, which will provide a point of departure for future monitoring and evaluation activities.

**Methods:** In December 2010, a cross-sectional survey was carried out in eight potentially affected communities. A broad set of clinical and parasitological indicators were assessed using standardised, quality-controlled procedures, including anthropometry and prevalence of anaemia, *Plasmodium falciparum* and helminth infections.

**Results:** Complete datasets were obtained from 1221 individuals of 194 households and eight schools. Of children aged <5 years (n=586), 41.8% were stunted, 23.2% were underweight and 4.8% were wasted. Very high prevalences of anaemia and *P. falciparum* were found in children aged 6–59 months (n=571; 86.1% and 74.0%, respectively). Overall, 73.7% of women of reproductive age (n=395) were anaemic. In school-aged children (n=240), 27.9% had light- to moderate-intensity hookworm infections, whereas *Ascaris lumbricoides*, *Trichuris trichiura* and *Schistosoma mansoni* were rare (<3% each).

**Conclusions:** The detailed description of the baseline health conditions, in combination with future health surveys, will deepen the understanding of how a biofuel project impacts on community health in a rural setting in sub-Saharan Africa.

**Keywords:** Anaemia, Health impact assessment, Helminth infection, Malaria, Nutritional status, Sierra Leone

## Introduction

The potential role of biofuel as an alternative energy source to fossil fuels has to be weighed against the potential negative effects of its use on the environment and people's health and livelihoods.[1,2] Indeed, biofuel development projects are met with controversy and generate considerable debate among proponents, environmentalists and other stakeholders. Potential adverse effects on the health of local populations may occur as a result of reduced access to land, increased demand put upon water resources, altered disease vector ecology and strains on already weak health systems.[3,4] Improved socioeconomic status, better road infrastructure, increased access to the power grid and agricultural extension services associated with biofuel development projects may result in positive impacts.[5] However, the scientific evidence on local-level health impacts of biofuel projects is generally weak. The current lack of evidence hampers an objective evaluation of proposed mitigation measures and best practice principles that have been suggested by various organisations, including the International Finance Corporation (IFC).[6]

The Addax Bioenergy Sierra Leone (ABSL) project will cultivate sugarcane for the production of ethanol for export to Europe (an estimated 85 000 $m^3$ per annum) and electricity (100 000 MWh per annum).[7] The generated electricity will supply the refinery and the irrigation system for the sugarcane estates. A capacity of up to 15 MW of power will be supplied to the national grid of Sierra Leone. An environmental, social and health impact assessment (ESHIA) was conducted, encompassing 14 specialist studies, including a health impact assessment (HIA). HIA is an evidence-based approach that aims to guide interventions and actions to mitigate negative effects and enhance positive effects.[8,9] A scoping study was carried out in the ABSL project area in February 2010, with the objectives of identifying likely impacts on the health of potentially affected communities (PACs), and defining the terms of reference of the HIA. This early phase of the HIA followed a systematic approach that included the collection of information from different sources (i.e. publicly available information, project stakeholders and local data).[10] Characterising the baseline health situation of PACs is a crucial component of the scoping phase.[11] Additionally, monitoring and evaluation of potential project-related health impacts relies on the quality and accuracy of baseline health data. In developing countries, local-level data on community health are often scarce and of varying quality. Hence, primary data collection and characterisation of the baseline situation becomes an integral part of many HIA.[12] By means of a gap analysis it was determined whether sufficient data are available for the subsequent steps of the HIA. This included a critical appraisal of the quality of data from different sources, with a particular focus on health outcomes and determinants of major concern. This process identified important data gaps that made primary data collection a necessity, and thus part of the terms of reference for the overall HIA. Major potential health impacts of the ABSL project, associated principal impact pathways and proposed key health indicators are presented in Table 1. Depending on the proposed key health indicators, different data collection strategies are indicated, such as cross-sectional baseline health surveys (BHS), routine health information system data and environmental sampling. A summary of the findings of the ESHIA is available elsewhere.[13]

Here we report findings from the cross-sectional BHS carried out in communities that will be affected by the ABSL project. Our data cover a wide range of clinical and parasitological indicators that will serve as a benchmark for monitoring and evaluation of changes and dynamics in the communities that may be attributable to the ABSL project. Moreover, comparison of our findings with aggregated data at regional and national levels will deepen the understanding of health challenges and needs of communities in northern Sierra Leone.

## Materials and methods

### Ethical considerations

The study was approved by the Sierra Leone Ethics and Scientific Review Committee of the Ministry of Health and Sanitation. Written, informed consent (or a fingerprint in the case of illiterate individuals) was obtained from household heads and mothers for the questionnaire survey and sampling at the clinical field unit and from head teachers in the primary schools. Children with a *Plasmodium falciparum* infection were treated with an artemisinin-based combination therapy (i.e. artemether-amodiaquine), in line with national guidelines. Mildly to moderately anaemic children (haemoglobin [Hb] 7–11 g/dl) were provided with multivitamin supplements. Children diagnosed with severe anaemia (Hb <7 g/dl) were referred to a hospital and treated according to national policies, free of charge. Moderately to severely anaemic women were counselled, and referred to a health facility if indicated by their clinical condition. All participating school-aged children received empirical treatment with albendazole (400 mg) and those with confirmed *Schistosoma* infection received praziquantel (40 mg/kg).

### Study area

The ABSL project is located 15 km southwest of Makeni in the Chiefdoms of Makari Gbanti and Bombali Shebora in Bombali district, and in the Chiefdom of Malal Mara in Tonkolili district (geographic coordinates: lat 8°38′–8°49′N, long 12°20′–12°07′W).[7] The study area covers 14 300 ha, of which approximately 10 000 ha will be developed for sugarcane plantations. Approximately 14 000 people live in the 60 villages of this area and 95% of households participate in small-scale slash and burn subsistence farming, practising crop cultivation, bee keeping, charcoal production, hunting, fishing and animal husbandry.[13] The study area is a large, gently undulating plain limited by the Lunsar–Makeni highway to the north and by the Rokel River to the south (Figure 1).

### Study design and sampling method

The study methodology was specifically developed for HIA of large industrial projects.[12] The modular, cross-sectional BHS is based on a sentinel survey approach, combining a two-stage sampling procedure adapted to the prevailing eco-epidemiological characteristics of the setting. With the exception of the soil-transmitted helminths and *Schistosoma* infection survey, the clinical indicators assessed for the BHS are exactly the same as those used in the 2008 Sierra Leone Demographic and Health Survey (DHS), which will allow for comparison of the results from the ABSL project area with regional-level data.[14]

Anaemia, because of its multifactorial aetiology (e.g. prevalence of sickle cell disease, intake and absorption of dietary iron, *Plasmodium* infection and parasitic worm infections) is considered an important indicator when monitoring trends in the general health status. The anaemia rate in children aged 6–59 months was selected as the primary outcome for sample size calculation. With the formula for normal approximation to binomial distribution without finite sample correction (level of confidence 95%; expected prevalence 50%; precision 5%), the sample size was calculated at 385. An estimated number of 2.5 children aged 6–59 months per household and a drop-out rate of 20% led to the target sample of at least 185 households. Experience from previous BHS with the same logistical and field-staff setup revealed that 25 households can be sampled in one day at a single sentinel site.[12]

Eight sentinel sites were selected (Figure 1) to be representative of the PACs by geographical distribution and exposure to the ABSL project. Additionally, the availability of a health facility was a criterion; we selected four sentinel sites that had a health facility to determine whether access to healthcare is associated with better health indices. Random sampling of 25 households within the sentinel sites was done by a quota sampling method. In brief, four directions were randomly determined by spinning a top at a central place within the sentinel site; households along these directional lines were counted to the border of the sentinel site, and the first household to be interviewed was selected at random. Proximity sampling was applied, with interviewers moving from one household to the next, until 25 households were sampled. The presence of a mother with at least one child aged <5 years was the ultimate household inclusion criterion.

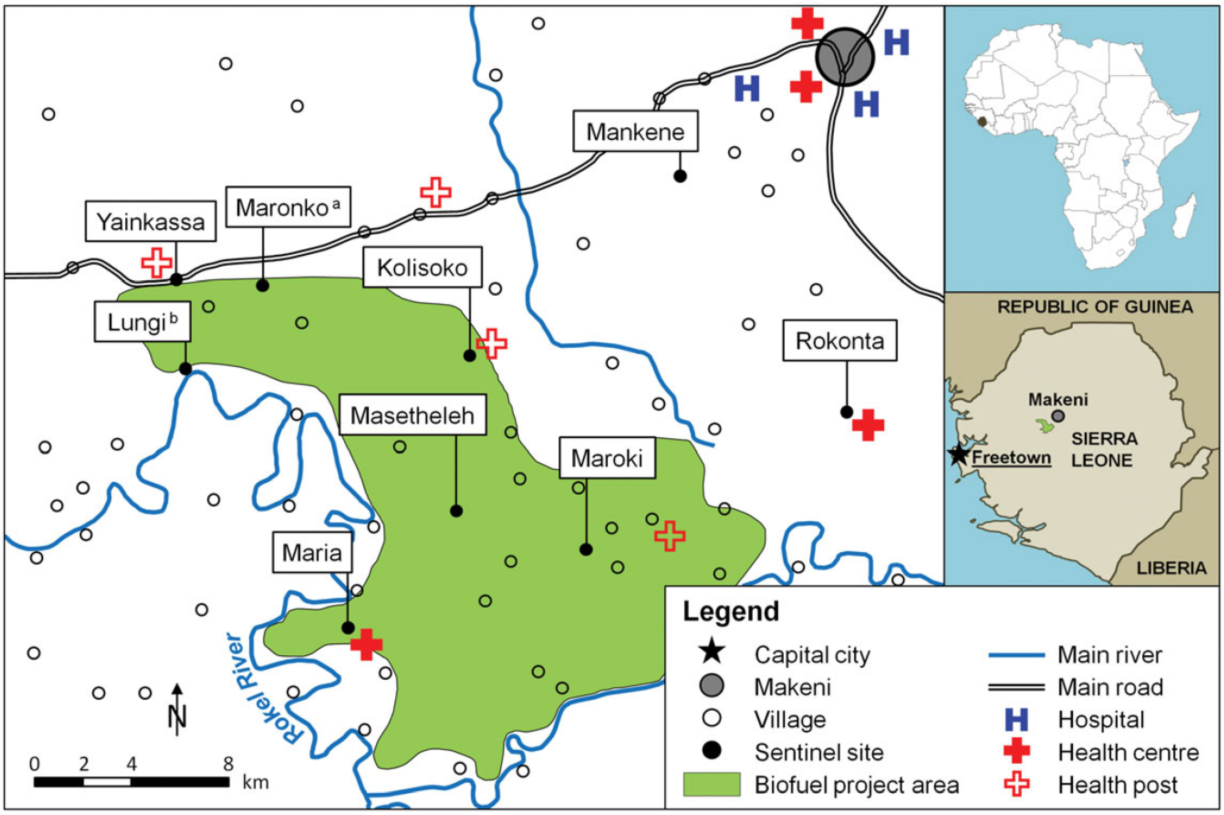
**Table 1.** Major potential health impacts of the Addax Bioenergy Sierra Leone (ABSL) project, associated principal impact pathways and proposed key health indicators

| Major potential health impact[a] | Principal impact pathways[a] | Proposed key health indicators[b] |
|---|---|---|
| Burden of malnutrition | More disposable income and improved farming practices can improve nutritional status. Reduced access to agricultural land for local populations can increase the burden of malnutrition | Wasting, stunting and underweight in children aged <5 years; prevalence and intensity of anaemia in children aged 6–59 months and women of reproductive age; knowledge, attitudes and practices (KAP) related to nutritional practices |
| Malaria and other vector-related diseases | Increased levels of income and better road infrastructures can improve access to vector control measures and healthcare. Irrigation of sugarcane fields can increase the number of mosquito breeding sites | Incidence and prevalence of *P. falciparum* infection in children aged 6–59 months; coverage and use of insecticide-treated nets (ITNs); KAP related to malaria transmission and prevention |
| Sexually transmitted infections (STIs), including HIV/AIDS | More income may promote transactional sex practices. Long distance truck drivers are a high-risk group for the transmission of STIs and HIV/AIDS | Incidence and prevalence of STIs and HIV/AIDS; KAP related to transmission and prevention of STIs and HIV/AIDS |
| Transmission of communicable diseases due to overcrowding | Project-induced in-migration can result in overcrowding at household level, which favours the transmission of communicable diseases such as TB | Incidence of respiratory diseases; TB incidence; KAP related to TB transmission and prevention |
| Access to safe sanitation and drinking water | Project-induced in-migration may place pressure on existing sanitation and drinking water systems, which poses a risk for the transmission of diarrhoeal diseases and intestinal parasites. The project, by nature of its activities will use, and potentially contaminate, water resources in the area | Prevalence and intensity of soil-transmitted helminths and *Schistosoma* infections in school-aged children; drinking water availability and quality at source and household level; KAP related to sanitation, drinking water and personal hygiene |
| Burden of non-communicable diseases | Improved socioeconomic conditions can promote lifestyle-related diseases such as obesity, hypertension, diabetes and cancer | Incidence and prevalence of obesity, hypertension, diabetes and cancer; KAP related to the causes and prevention of non-communicable diseases |
| Lassa fever transmission | Clearing of land and crowded conditions can increase the presence of rodents, which poses a major risk for Lassa fever transmission in the ABSL project region | Incidence of Lassa fever cases; KAP related to the transmission and prevention of Lassa fever |
| Road traffic accidents | Augmented traffic loads on transport corridors in and outside the project area will increase the risk of road traffic accidents | Incidence of road traffic accidents (general and project-related) |
| Exposure to air pollutants, noise and malodours | The cultivation of sugarcane fields and project-related traffic will increase exposure to air pollutants, noise and malodours | Air quality; exposure to noise and malodours; self-reported level of well being and stress |
| Access to health care and quality of services | More income and improved road infrastructures can improve access to healthcare. Project-induced in-migration may put further stress on the limited capacities of the local health system | Target population of health facilities; quality and range of services provided; KAP related to access to and use of healthcare services among different population groups |

[a] Additional potential health impacts and impact pathways were considered in the ESHIA. The table lists only the most important ones.
[b] Health-relevant sociocultural, economic and environmental key indicators are not included in this table.

## Data collection

The BHS was carried out in December 2010, early in the dry season. After informed consent was obtained, a questionnaire was administered to determine demographic characteristics. Subsequently, mothers took their children aged <5 years to the clinical field unit, where their height and weight were measured using a digital scale (Seca 877; Seca, Hamburg, Germany) and a height measuring board, adhering to standard protocols.[15] *Plasmodium falciparum* infection in children aged 6–59 months was determined from a finger-prick blood sample, using a rapid




[a] No school available and therefore no helminth survey conducted.
[b] Only helminth survey conducted.

**Figure 1.** Communities and the eight selected sentinel sites in the Addax Bioenergy Sierra Leone and surroundings project area (note: Maronko and Lungi are considered as a single sentinel site). The prevalence of malnutrition, anaemia and *Plasmodium falciparum* was assessed in children aged <5 years and women of reproductive age (only anaemia), randomly selected at village level at the eight sentinel sites. The prevalence and intensity of soil-transmitted helminths and *Schistosoma* infection was assessed in 30 children aged 10–15 years, randomly selected from the schools at the eight sentinel sites.

diagnostic test (RDT) (ICT malaria cassette test ML01; ICT Diagnostics, Cape Town, South Africa). Hb concentration was determined in children aged 6–59 months and women of reproductive age (15–49 years) using a HemoCue portable device (HemoCue Hb 201 System; HemoCue AB, Ängelholm, Sweden), which was quality-assured using bovine blood prior to the survey. The pregnancy status of women was investigated, and recorded by the treatment officer on the basis of verbal report. As a means of quality control, questionnaire and clinical data were checked and entered into the database on the spot and any missing information obtained before leaving the site.

The prevalence and intensity of soil-transmitted helminths and *Schistosoma* infection was assessed in children aged 10–15 years. In each of eight schools, 30 children were randomly selected, to give a total of 240 children. As there is no school at one site (Maronko), we sampled the schoolchildren in Lungi, a neighbouring village. A single fresh morning stool sample and a mid-day, post-exercise urine sample were collected from each child. One slide per stool sample was prepared and examined by the Kato–Katz technique (using 41.7 mg templates).[16] The slides were microscopically examined by experienced laboratory technicians and the number of eggs of *Schistosoma mansoni* and of soil-transmitted helminths (*Ascaris lumbricoides*, hookworm and *Trichuris trichiura*) counted and recorded separately. Intensity of infection was calculated as the number of eggs per 1 g of stool (epg).[17] Urine samples were examined for *S. haematobium*, using the centrifugation method.[18] 10% of the Kato–Katz thick smears were randomly selected and re-examined by a senior laboratory technician for quality control.

## Statistical analysis

Data were entered using EpiData Entry V.3.1 (EpiData Association; Odense, Denmark), Microsoft Excel version 2007 (Microsoft Corporation; Redmond, USA) and EpiInfo V.3.4.1 (Centers for Disease Control and Prevention; Atlanta, USA). Statistical analyses were performed with Stata version 10 (StataCorp.; College Station, TX, USA) and with Anthro version 3.2.2 (WHO; Geneva, Switzerland).

Anaemia was defined as Hb <11.0 g/dl in children and pregnant women and <12.0 g/dl in non-pregnant women, according to WHO guidelines.[14,19] Height-for-age (stunting, chronic malnutrition), weight-for-height (wasting, acute malnutrition) and weight-for-age (underweight) were calculated for children aged <5 years. Moderate and severe stunting, wasting and underweight were defined as <−2 SDs and <−3 SD, respectively.

We used a generalised linear model to determine variables that best predict the outcome (i.e. Hb concentration). Household was integrated as random effect and we checked for potential interactions between explanatory covariates. Coefficients are reported including 95% CIs, and Wald-test p-value. Candidate explanatory variables for the multivariate models were age (in years), sex, village, *P. falciparum* infection, stunting, wasting and presence of a health facility in the village. A backward stepwise procedure was computed, removing non-predicting covariates (up to a significance level of 0.2), one at a time. The remaining covariates were included in the final models.

## Results

### Study compliance

Overall, 1231 individuals from 198 households and eight schools participated in the different study arms (Figure 2). Questionnaire and clinical data were available from 591 children aged <5 years and 400 women aged 15–49 years. Stool and urine samples from 240 school-aged children were examined. Complete datasets were available for 1221 individuals from 194 households and eight schools.

### Nutritional status of children <5 years of age

Table 2 shows the nutritional status of children <5 years of age. Overall, 41.8% (245/586; 95% CI 37.7–45.9%) were stunted with 16.9% (99/586; 95% CI 13.7–20.0%) severely stunted. Children aged 24–35 months had the highest prevalence of stunting (52.6% [83/158]; 95% CI 44.4–60.7%).

Overall, 4.8% (28/586; 95% CI 3.0–6.6%) of children aged <5 years were wasted, with 1.4% (8/586; 95% CI 0.3–2.4%) severely wasted. Wasting was highest among children aged <6 months (13% [2/16]; 95% CI 0–32%) or between 6 and 11 months (10% [6/61]; 95% CI 2–18%).

Overall, 23.2% of children aged <5 years (134/586; 95% CI 19.7–26.7%) were underweight, and 7.7% (45/586; 95% CI 5.4–9.9%) severely underweight. The highest prevalence of underweight was in those aged 24–35 months (31.0% [49/158]; 95% CI 23.5–38.5%). There was no significant difference for any of these nutritional parameters by sex (all p>0.05) or setting (all p>0.05).

### *Anaemia and P. falciparum infection in children aged 6–59 months*

Overall, 86.1% (492/571; 95% CI 83.1–88.9%) of the children aged 6–59 months were anaemic. Of those, 20.3% (114/571; 95% CI 17.1–23.9%) were mildly anaemic, 56.2% (321/571; 95% CI 52.0–60.3%) were moderately anaemic, and 9.6% (55/571; 95% CI 7.3–12.4%) were severely anaemic (Table 3). The prevalence of anaemia decreased with age, from 90% (55/61; 95% CI 80–96%) in children aged 6–11 months to 82% (78/95; 95% CI 73–89%) among children aged 48–59 months. Children aged 12–23 and 24–35 months had the highest prevalence of severe anaemia; 14.0% (18/129; 95% CI 8.5–21.2%) and 13.9% (20/151; 95% CI 8.8–20.5%), respectively. Children living in villages with a health facility were significantly less likely to be anaemic than their counterparts in villages without a health facility (p<0.001), although the prevalence was still above 80%.

Overall, 74.0% (423/571; 95% CI 70.2–77.5%) children aged 6–59 months tested positive for *P. falciparum.* We observed an increase with age from 46% (28/61; 95% CI 33–59%) in the youngest age group (6–11 months) to 88% (84/95; 95% CI 80–94%) in the oldest age group (48–59 months). Children aged 6–59 months in villages with a health facility were significantly less likely to be infected with *P. falciparum* (65.6% [205/313]; 95% CI 60.0–70.9%) than children from villages without a health facility (84.1% [217/258]; 95% CI 79.1–88.3%) (p<0.001).

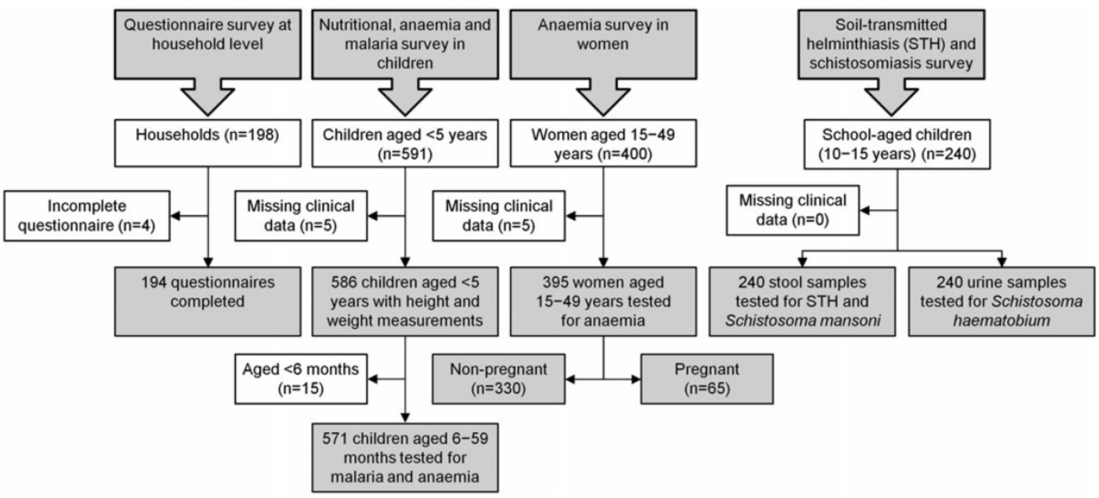



**Figure 2.** Participation and adherence in the different arms of the baseline health survey in the Addax Bioenergy Sierra Leone (ABSL) study area. In December 2010, 991 people (591 children aged <5 years and 400 women aged 15–49 years) from 198 households and 240 children aged 10–15 years from eight schools were invited to participate. Complete datasets were available for 1221 individuals from 194 households and eight schools.

**Table 2.** Percentage of children aged <5 years classified as malnourished according to anthropometric indices, in the Addax Bioenergy Sierra Leone (ABSL) study area in northern Sierra Leone, December 2010

| | No. of children | Stunting (height-for-age) | | Wasting (weight-for-height) | | Underweight (weight-for-age) | |
|---|---|---|---|---|---|---|---|
| | | Moderate[a] % (95% CI) | Severe[b] % (95% CI) | Moderate[a] % (95% CI) | Severe[b] % (95% CI) | Moderate[a] % (95% CI) | Severe[b] % (95% CI) |
| Setting | | | | | | | |
| With health facility | 270 | 41.4 (35.8–47.0) | 16.2 (12.0–20.5) | 5.7 (3.0–8.4) | 1.6 (0.0–3.1) | 23.1 (18.3–27.9) | 6.0 (3.2–8.8) |
| Without health facility | 316 | 42.3 (36.2–48.4) | 17.6 (12.8–22.4) | 3.7 (1.3–6.1) | 1.1 (0.0–2.5) | 23.3 (18.1–28.6) | 9.6 (5.9–13.3) |
| Sex | | | | | | | |
| Females | 312 | 40.6 (35.0–46.3) | 14.8 (10.7–19.0) | 4.8 (2.3–7.4) | 1.0 (0.0–2.2) | 23.1 (18.2–27.9) | 8.3 (5.1–11.6) |
| Males | 274 | 43.2 (37.1–49.3) | 19.2 (14.3–24.1) | 4.7 (2.0–7.4) | 1.8 (0.1–3.6) | 23.4 (18.2–28.6) | 6.9 (3.7–10.1) |
| Age (months) | | | | | | | |
| <6 | 15 | 13.3 (0.0–33.9) | 0.0 (0.0–3.3) | 12.5 (0.0–31.8) | 0.0 (0.0–3.1) | 20.0 (0.0–43.6) | 0.0 (0.0–3.3) |
| 6–11 | 61 | 21.3 (10.2–32–4) | 3.3 (0.0–8.6) | 9.8 (1.5–18.1) | 4.9 (0.0–11.2) | 18.0 (7.6–28.5) | 8.2 (0.5–15.9) |
| 12–23 | 126 | 41.9 (32.8–51.0) | 20.2 (12.7–27.6) | 7.9 (2.8–13.0) | 3.1 (0.0–6.6) | 29.4 (21.0–37.7) | 7.9 (2.8–13.1) |
| 24–35 | 158 | 52.6 (44.4–60.7) | 24.4 (17.3–31.4) | 1.9 (0.0–4.4) | 0.6 (0.0–2.2) | 31.0 (23.5–38.5) | 8.9 (4.1–13.6) |
| 36–47 | 129 | 48.8 (39.8–57.9) | 20.2 (12.8–27.5) | 1.6 (0.0–4.1) | 0.0 (0.0–0.4) | 17.8 (10.8–24.8) | 9.3 (3.9–14.7) |
| 48–59 | 97 | 32.3 (22.4–42.2) | 7.3 (1.6–13.0) | 5.2 (0.2–10.2) | 0.0 (0.0–0.5) | 13.4 (6.1–20.7) | 4.1 (0.0–8.6) |
| Total | 586 | 41.8 (37.7–45.9) | 16.9 (13.7–20.0) | 4.8 (3.0–6.6) | 1.4 (0.3–2.4) | 23.2 (19.7–26.7) | 7.7 (5.4–9.9) |

[a] <−2 SD.
[b] <−3 SD.



**Table 3.** Percentage of children aged 6–59 months classified as anaemic and *Plasmodium falciparum* prevalence, in the Addax Bioenergy Sierra Leone (ABSL) study area in northern Sierra Leone, December 2010

| | No. of children | Anaemia status by haemoglobin level | | | | *P. falciparum* infection % (95% CI) |
|---|---|---|---|---|---|---|
| | | Mild[a] % (95% CI) | Moderate[b] % (95% CI) | Severe[c] % (95% CI) | Any anaemia % (95% CI) | |
| Setting | | | | | | |
| With health facility | 313 | 20.4 (16.1–25.3) | 55.0 (49.3–60.6) | 7.3 (4.7–10.8) | 82.7 (78.1–86.8) | 65.6 (60.0–70.9) |
| Without health facility | 258 | 20.2 (15.4–25.6) | 57.8 (51.5–63.9) | 12.4 (8.6–17.1) | 90.4 (86.0–93.6) | 84.1 (79.1–88.3) |
| Sex | | | | | | |
| Females | 304 | 22.4 (17.8–27.5) | 54.6 (48.8–60.3) | 9.2 (6.2–13.0) | 86.2 (81.8–89.9) | 73.7 (68.4–78.5) |
| Males | 267 | 18.0 (13.6–23.1) | 58.1 (51.9–64.0) | 10.0 (6.8–14.4) | 86.1 (81.4–90.1) | 74.3 (68.6–79.5) |
| Age (months) | | | | | | |
| 6–11 | 61 | 14.8 (6.9–26.1) | 68.9 (55.7–80.1) | 6.6 (1.8–15.9) | 90.3 (79.8–96.3) | 45.9 (33.1–59.2) |
| 12–23 | 129 | 20.9 (14.3–29.0) | 52.7 (43.7–61.6) | 14.0 (8.5–21.2) | 87.6 (80.6–92.7) | 67.4 (58.6–75.4) |
| 24–35 | 151 | 17.9 (12.1–24.9) | 53.0 (44.7–61.1) | 13.9 (8.8–20.5) | 84.8 (78.0–90.1) | 76.8 (69.3–83.3) |
| 36–47 | 135 | 22.2 (15.5–30.2) | 58.5 (49.7–66.9) | 6.7 (3.1–12.3) | 87.4 (80.6–92.5) | 80.0 (72.3–86.4) |
| 48–59 | 95 | 24.2 (16.0–34.1) | 54.7 (44.2–65.0) | 3.2 (0.6–9.0) | 82.1 (72.9–89.2) | 88.2 (79.8–93.9) |
| Total | 571 | 20.3 (17.1–23.9) | 56.2 (52.0–60.3) | 9.6 (7.3–12.4) | 86.1 (83.1–88.9) | 74.0 (70.2–77.5) |

[a] 10.0–10.9 g/dl Hb.
[b] 7.0–9.9 g/dl Hb.
[c] <7.0 g/dl Hb.

**Table 4.** Percentage of women aged 15–49 years classified as anaemic, in the Addax Bioenergy Sierra Leone (ABSL) study area in northern Sierra Leone, December 2010

| | No. of women | Anaemia status by haemoglobin level | | | |
|---|---|---|---|---|---|
| | | Mild[a] % (95% CI) | Moderate[b] % (95% CI) | Severe[c] % (95% CI) | Any anaemia[d] % (95% CI) |
| Setting | | | | | |
| With health facility | 225 | 49.8 (43.1–56.5) | 22.7 (17.4–28.7) | 0.8 (0.1–3.2) | 73.3 (67.1–79.0) |
| Without health facility | 170 | 47.7 (39.9–55.4) | 24.1 (17.9–31.3) | 2.4 (0.6–5.9) | 74.2 (66.9–80.5) |
| Age (years) | | | | | |
| 15–19 | 26 | 53.9 (33.4–73.4) | 23.1 (9.0–43.6) | 0.0 (0.0–13.2) | 77.0 (56.4–91.0) |
| 20–29 | 219 | 47.0 (40.3–53.9) | 26.9 (21.2–33.3) | 2.7 (1.0–5.9) | 76.6 (70.5–82.1) |
| 30–39 | 119 | 54.6 (45.2–63.8) | 16.0 (9.9–23.8) | 0.0 (0.0–3.1) | 70.6 (61.5–78.6) |
| 40–49 | 31 | 35.5 (19.2–54.6) | 25.8 (11.9–44.6) | 0.0 (0.0–11.2) | 61.3 (42.2–78.2) |
| Maternity status | | | | | |
| Pregnant | 65 | 29.2 (18.6–41.8) | 53.8 (41.0–66.3) | 4.6 (1.0–12.9) | 87.6 (77.2–94.5) |
| Non-pregnant | 330 | 52.7 (47.2–58.2) | 17.3 (13.4–21.8) | 0.9 (0.2–2.6) | 70.9 (65.7–75.8) |
| Total | 395 | 48.9 (43.8–53.9) | 23.3 (19.2–27.8) | 1.5 (0.5–3.3) | 73.7 (69.0–77.9) |

[a] Non-pregnant women: 10.0–11.9 g/dl Hb; pregnant women: 10.0–10.9 g/dl Hb.
[b] All women: 7.0–9.9 g/dl Hb.
[c] All women: <7.0 g/dl Hb.
[d] Non-pregnant women: <12.0 g/dl Hb; pregnant women: <11.0 g/dl Hb.

*Anaemia in women of reproductive age*

Overall, 73.7% (29/395; 95% CI 69.0–77.9%) of women of reproductive age were anaemic (Table 4), of which 48.9% were mildly anaemic (193/395; 95% CI 43.8–53.9%), 23.3% (92/395; 95% CI 19.2–27.8%) were moderately anaemic and 1.5% (6/395; 95% CI 0.5–3.3%) were severely anaemic. Severe anaemia was uniquely detected in women aged 20–29 years (2.7% [6/219]; 95% CI 1.0–5.9%). Three out of the six severely anaemic women were pregnant at the time of the survey.

*Helminth infection among school-aged children*

Hookworm was the most common helminth infection (27.9% [37/240]; 95% CI 22.3–34.1%) (Table 5). Other helminths were rarely found: *S. mansoni*, 2.5% (6/240; 95% CI 0.9–5.4%); *T. trichiura*, 2.1% (5/240; 95% CI 0.7–4.8%), and *A. lumbricoides*, 1.3% (3/240; 95% CI 0.3–3.6%). No *S. haematobium* eggs were found in any of the urine samples.

According to WHO classifications, infections with hookworm and *T. trichiura* were either of light or moderate intensity. Heavy intensity infections were observed in a few individuals for *S. mansoni* and *A. lumbricoides*.

*Results from multivariate linear regression analysis*

A significant positive association was found between Hb concentration and age ($p<0.001$) and presence of a health facility ($p<0.001$) (Table 6). *P. falciparum* infection was significantly associated with lower Hb concentration ($p<0.001$). There was a significant interaction between *P. falciparum* infection and the presence of a health facility; children infected with *P. falciparum* infection in villages without a health facility had a significantly lower mean Hb concentration (coefficient: –2.02; 95% CI –2.68 to –1.36) in comparison with their counterparts in villages with a health facility (coefficient: –0.93; 95% CI –1.30 to –0.56).

## Discussion

The findings revealed that the PACs in the ABSL project area are characterised by high prevalences of anaemia in children <5 years old and women of reproductive age, of stunting and *P. falciparum* infection in children aged <5 years and hookworm in school-aged children. Comparison with the 2008 DHS for the Northern region of Sierra Leone can be made.[14] First, the prevalences of stunting and underweight in children aged <5 years are similar (41.8% and 23.2% in our survey vs 39.5% and 23.5% in the 2008 DHS, respectively). Second, the prevalence of wasting in children <5 years old is somewhat lower (4.8% in our survey vs 8.6% in the 2008 DHS). Third, the overall prevalence, and that of moderate and severe anaemia in children aged 6–59 months, was somewhat higher (86.1% and 9.6% in our survey vs 79.3% and 4.1% in the 2008 DHS, respectively). Fourth, the prevalence of anaemia in women of reproductive age was considerably higher (73.7% in our survey vs 45.3% in the 2008 DHS). The DHS was carried out between April and June 2008 (end of the dry season) when levels of wasting and malaria are generally lower than in December (end of the rainy season, also known as the hungry months) when the current BHS was conducted.[14] The observed high prevalences of stunting, anaemia and malaria are critical in view of the nature of the ABSL project, which will transform an estimated 10 000 ha of arable land into sugarcane estates.[1,20] Climatic and environmental

**Table 5.** Prevalence and intensity of soil-transmitted helminths and *Schistosoma mansoni* infections in school-aged children (10–15 years), in the Addax Bioenergy Sierra Leone (ABSL) study area in northern Sierra Leone, December 2010

| | No. of children | *Ascaris lumbricoides* | Hookworm | *Trichuris trichiura* | *Schistosoma mansoni* |
|---|---|---|---|---|---|
| Prevalence rates [% (95% CI)] | | | | | |
| Village with health facility | 120 | 0.0 (0.0–3.0) | 21.7 (14.7–30.1) | 0.8 (0.0–4.5) | 2.5 (0.5–7.1) |
| Village without health facility | 120 | 2.5 (0.5–7.1) | 34.2 (25.8–43.3) | 3.3 (0.9–8.3) | 2.5 (0.5–7.1) |
| Males | 119 | 0.8 (0.0–4.6) | 31.1 (22.9–40.2) | 1.7 (0.2–5.8) | 1.7 (0.2–5.9) |
| Females | 121 | 1.7 (0.2–5.8) | 24.8 (17.4–33.5) | 2.5 (0.5–7.2) | 3.3 (0.9–8.2) |
| Total | 240 | 1.3 (0.3–3.6) | 27.9 (22.3–34.1) | 2.1 (0.7–4.8) | 2.5 (0.9–5.4) |
| Geometric mean egg count [n (95% CI)] | | 461.5 (3.3–65311.4) | 244.7 (183.2–327.0) | 204.2 (103.5–402.5) | 108.7 (30.1–393.0) |
| Intensity of infection (% [95% CI]) | | | | | |
| No infection | 240 | 98.7 (96.4–99.7) | 72.1 (65.9–77.7) | 97.9 (95.2–99.3) | 97.5 (94.6–99.1) |
| Light intensity[a] | 240 | 0.0 (0.0–1.5) | 27.5 (22.0–33.6) | 2.1 (0.7–4.8) | 0.8 (0.1–3.0) |
| Moderate intensity[b] | 240 | 0.0 (0.0–1.5) | 0.4 (0.0–2.3) | 0.0 (0.0–1.5) | 1.3 (0.3–3.6) |
| Heavy intensity[c] | 240 | 1.3 (0.3–3.6) | 0.0 (0.0–1.5) | 0.0 (0.0–1.5) | 0.4 (0.0–2.3) |

[a] *A. lumbricoides:* 1–4999 eggs per g of stool (epg); hookworm: 1–1999 epg; *T. trichiura:* 1–999 epg; *S. mansoni*: 1–99 epg.
[b] *A. lumbricoides:* 5000–49 999 epg; hookworm: 2000–3999 epg; *T. trichiura:* 1000–9999 epg; *S. mansoni*: 100–399 epg.
[c] *A. lumbricoides*: ≥50 000 epg; hookworm: ≥4000 epg; *T. trichiura:* ≥10 000 epg; *S. mansoni*: ≥400 epg.

**Table 6.** Association between haemoglobin (Hb) and demographic, parasitic, nutritional and geographical variables in children aged <5 years in Sierra Leone, December 2010[a]

| Outcome: Hb (g/dl) | Coefficient | p-value | 95% CI |
|---|---|---|---|
| Age (years) | 0.27 | <0.001 | 0.16 to 0.38 |
| *P. falciparum* infection[b] | -1.22 | <0.001 | -1.55 to -0.89 |
| Presence of a health facility[b] | 1.28 | <0.001 | 0.71 to 1.85 |
| Stunting[b,c] | -0.24 | 0.066 | -0.50 to -0.02 |
| Village | | | |
| Yainkassa | 1 | | |
| Kolisoko | -0.76 | 0.007 | -1.31 to -0.21 |
| Maronko | 0.26 | 0.498 | -0.49 to 1.00 |
| Mankene | 0.49 | 0.056 | -0.01 to 0.99 |
| Maroki | -0.74 | 0.012 | -1.32 to -0.16 |
| Maria | -1.39 | <0.001 | -2.01 to -0.78 |
| Masetheleh | 0.00 | | |
| Rokonta | -0.85 | 0.003 | -1.40 to -0.30 |
| Intercept | 9.04 | <0.001 | 8.57 to 9.51 |

[a] The interaction term between health facility and malaria status is significant.
[b] Binominal variables.
[c] Explanatory co-variable.

conditions, food security and care-giving resources are significant determinants of nutritional status, and therefore new means to reduce poverty, foster nutrition-sensitive agriculture and improve access to hygiene education, clean water and adequate sanitation in PACs should be explored.[21] The ABSL project has the potential to address the immediate causes of children's sub-optimum growth and development (e.g. promotion of breastfeeding, dietary diversification and disease prevention and control) and improve people's health and livelihoods through increased employment rates, farmers' development programmes and improved social and physical infrastructures.[5]

To our knowledge, the most recent study that investigated malaria prevalence in Sierra Leone dates back to the post-war years (Sierra Leone experienced a decade of civil war over the period 1991–2002); children aged 4–36 months were tested by means of RDT for malaria in two refugee camps near the Liberian border in November 2003.[22] The reported *P. falciparum* prevalences of 54% (n=831) and 45% (n=779) were lower than those we found for a similar age group in our study area. In this hyperendemic setting *P. falciparum* prevalence may decline nationally following the universal distribution of insecticide-treated nets (ITNs), which started in December 2010. The ITN distribution campaign was ongoing in the study area and elsewhere at the time of the survey, so we did not report ITN coverage in this paper, as the figures might be misleading. Irrigation may result in highly localised new mosquito breeding sites, with potential for increases in malaria transmission. However, a comprehensive review of studies that assessed the effect of irrigation found no conclusive evidence of higher malaria prevalence in villages practising irrigated farming compared to non-irrigated villages in stable malaria transmission settings.[23]

Linear regression analysis revealed a significant relationship between Hb concentration and age, *P. falciparum* infection and presence of a health facility in children aged <5 years. We found no significant difference in anaemia prevalence between women living in villages with and without a health facility. The prevalence of *P. falciparum* infection was higher – and the negative association between *P. falciparum* infection and Hb concentration stronger – among children <5 years old living in sites with no health facility compared with their counterparts living in sites with a health facility. These findings indicate that access to health services may play a critical role in malaria and anaemia prevention and control strategies.[24,25]

In 2009, Sierra Leone's National Neglected Tropical Diseases Programme and Helen Keller International introduced preventive chemotherapy targeting schistosomiasis and soil-transmitted helminthiasis in endemic districts, including Bombali and Tonkolili, following WHO guidelines.[26] The prevalence of helminths, and absence of *S. haematobium* infections, matches with the spatial prediction for southern/western chiefdoms in these districts.[27] The low overall prevalence of *S. mansoni* suggests that there is no or very little local transmission, which depends on the presence of intermediate host snails *Biomphalaria* spp. and human–water contact.[28,29] Should *Schistosoma*-infected workers and *Biomphalaria* spp. migrate into the study area, the development of the ABSL project could potentially alter the risk of schistosomiasis. A malacological survey of the local snail fauna is indicated. The use of sprinkler irrigation systems employed by the ABSL project poses little risk of establishing and spreading the transmission of schistosomiasis.[30] Irrigated farming in central Sierra Leone in the 1980s did not result in an increase in schistosomiasis transmission.[31,32]

## Limitations of the study

The findings are specific for the selected sentinel sites, and not representative for a wider area that might be affected by more distal or cumulative effects of project developments. *P. falciparum* prevalence rates and wasting show seasonal fluctuation in northern Sierra Leone. As we conducted a single cross-sectional survey early in the dry season, future monitoring and evaluation surveys should be implemented with similar timing to be comparable with the baseline. Only single stool and urine samples were examined from each participant, which may underestimate the true prevalence of helminth infections.[33]

## Conclusions

The findings show that the ABSL project is located in an area with a high burden of malnutrition, malaria, anaemia and hookworm infection. Whether and how the local epidemiological profiles will change over the course of the project needs to be determined, including in- and out-migration, help-seeking behaviour, health systems and equity issues. Clearly, there is a a broad set of potential negative health impacts to be set against probable project-related health benefits linked to improved socioeconomic status, farmers development programmes and ongoing health interventions, but it needs to be ascertained that the most vulnerable groups benefit from these measures. The BHS data provided an important basis for a comprehensive HIA of the ABSL project, which was an integral part of the full ESHIA. Recommendations of the HIA were incorporated in the environmental and social management plans, so that ABSL project impacts can be monitored and managed correctly and potential health benefits are maximised. Future monitoring and health surveys can be compared to the BHS data reported here, together with regional data. Indeed, the ABSL project has committed to periodic 3-year follow-up health surveys in PACs. Such evidence-based evaluation of project-related health impacts could also make an important contribution to the development of benchmarks and policies for responsible bioenergy projects in sub-Saharan Africa and elsewhere.

**Authors' contributions:** MSW and MJD conceived the study design. MSW coordinated the field work. MMK, IF and HT led the field and laboratory work. MSW, AMK and MHH supervised the research assistants. MJD and MHH were the overall study coordinators. MSW, AMK and AAR performed the statistical analysis and drafted the manuscript. JU and MHH contributed to the interpretation of the data, manuscript writing and revisions. All authors read and approved the final manuscript. MSW and JU are the guarantors of the paper.

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# 7 Changing patterns of health in communities impacted by a bioenergy project in northern Sierra Leone

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*Article*

# Changing Patterns of Health in Communities Impacted by a Bioenergy Project in Northern Sierra Leone

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**Abstract:** Large private sector investments in low- and middle-income countries are often critically evaluated with regards to their environmental, social, human rights, and health impacts. A health impact assessment, including a baseline health survey, was commissioned by the Addax Bioenergy Sierra Leone project in 2010. As part of the monitoring, a follow-up survey was conducted three years later. A set of health indicators was assessed at six impacted and two control sites. Most of these indices improved, particularly at the impacted sites. The prevalences of stunting, wasting, and *Plasmodium falciparum* in children under five years of age decreased significantly at impacted sites (all $p < 0.05$) and non-significantly at control sites. Anemia in children and in women of reproductive age (15–49 years) decreased significantly at impacted and control sites ($p < 0.05$ and $p < 0.001$, respectively). Health facility-based deliveries increased significantly at the impacted sites ($p < 0.05$). The prevalences of helminth infections in children aged 10–15 years remained approximately at the same levels, although focal increases at the impacted sites were noted. Access to improved sanitation decreased significantly ($p < 0.05$) at control and non-significantly at impacted sites. Water quality remained poor without significant changes. The epidemiologic monitoring of a bioenergy project provides a useful contribution for evidence-based decision-making.

**Keywords:** anemia; bioenergy; health impact assessment; helminth infection; malaria; nutritional status; Sierra Leone

## 1. Introduction

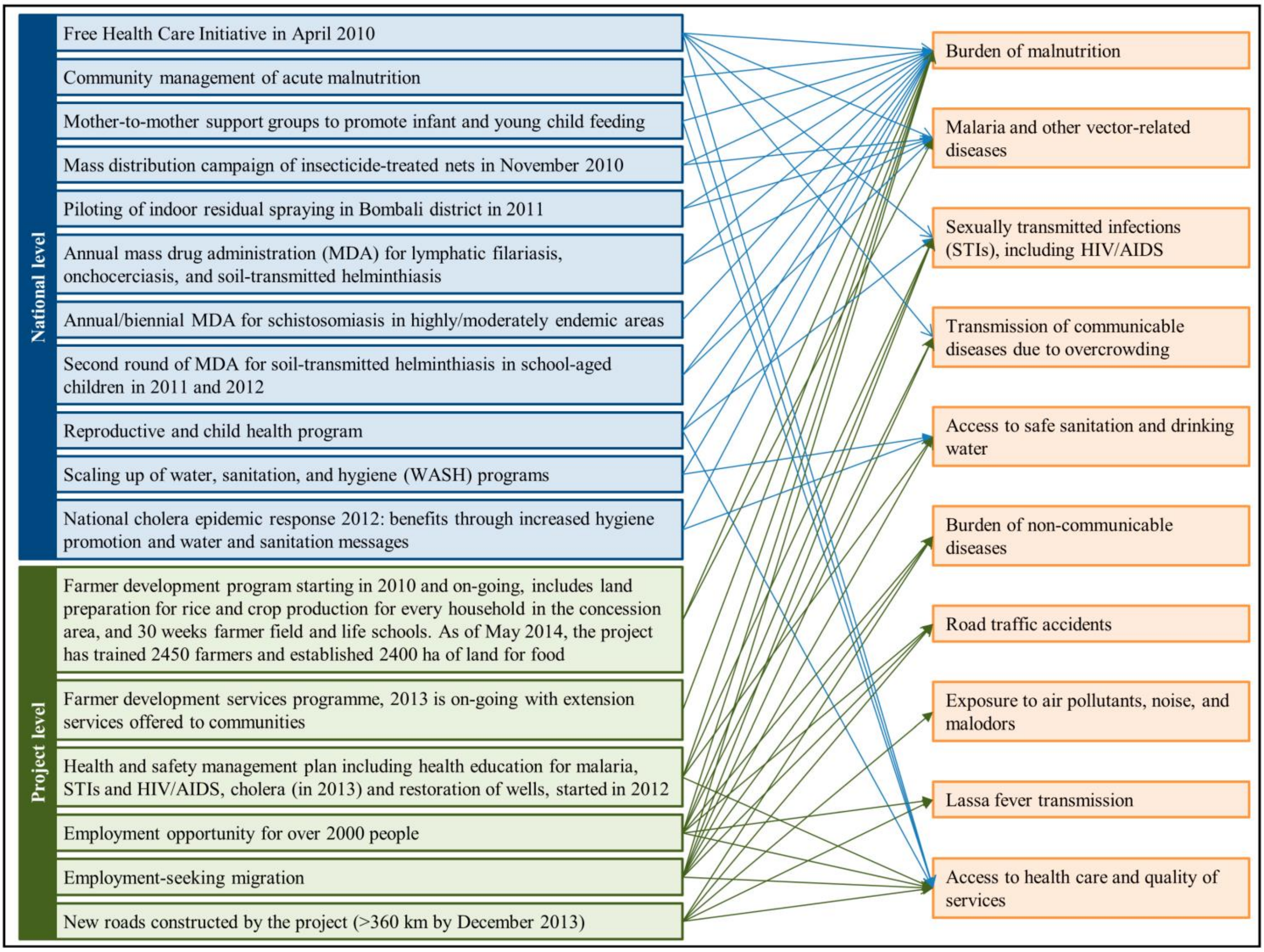
Large private sector investments in low- and middle-income countries, including agricultural, water resources development and management, and extractive industry projects, are increasingly being developed in remote areas, often associated with vulnerable communities and, thus, subject to international scrutiny [1,2]. The discussion revolves around potential project-related impacts on the environment, people's health, social cohesion, and human rights [3–5]. Proponents and opponents have different views on the extent of positive and negative impacts [6,7]. Potential positive impacts include improved public infrastructure, capacity building, socioeconomic benefits, and better health [8,9]. Potential negative impacts may involve loss of land, environmental degradation, disruption of social cohesion, and widening of wealth disparities [2,10–12].

The development and operation of the Addax Bioenergy Sierra Leone (ABSL) ethanol and power project is an example that highlights these challenges and opportunities [13–15]. Located near Makeni in Northern Sierra Leone, the ABSL project holds a land lease of 14,300 ha, which is used as a sugarcane plantation to produce an estimated 85,000 $m^3$ of ethanol annually, which is to be used for export and the local market [16]. By 2016, sugarcane residual processing will produce 32 MW of electricity per year, of which 15 MW are to be fed into the national grid, contributing 20% of the national requirements.

As of May, 2014, 2750 people had signed either permanent (~40%) or temporary (~60%) work contracts with ABSL, of which 12% were female and 53% originated within a 20-km radius of the ABSL project [16,17]. Given the size of the ABSL project and the importance for the region, it sparked discussions on issues like large land leasing (also referred to as "land grabbing") and associated negative consequences, such as reduction in food security and deterioration of local livelihoods [2,13–15]. Health issues are also relevant, as a project of this magnitude is likely to influence people's health through a complex interaction of proximal (e.g., altered ecosystems), distal (e.g., transport routes), and cumulative factors (e.g., employment-seeking migration, the reduction of biodiversity due to altered ecosystems, road construction, and accidents) [3,18,19].

During the feasibility phase of the ABSL project between 2008 and 2010, the group of development finance institutions chosen to fund part of the ABSL project commissioned the company to conduct an environmental, social, and health impact assessment (ESHIA) in compliance with the International Finance Corporation's (IFC) performance standards [16,20,21]. Within the ESHIA, ABSL commissioned a cross-sectional baseline health survey (BHS) to determine health conditions in communities that could potentially be affected by the project. This BHS was conducted in December 2010, prior to the commencement of the main construction activities [22]. Potential health impacts related to the ABSL project have been described elsewhere [20,22]. Since 2010, numerous public health interventions have been implemented by the Sierra Leonean health sector [23–26]. Additionally, community and infrastructural developments within the area have been launched by the ABSL project. The characteristics of these interventions and their potential impact on health are conceptualized in Figure 1.

**Figure 1.** National interventions or programs and interventions initiated by the Addax Bioenergy Sierra Leone (ABSL) project between 2010 and 2013 and the associated health impacts.




In order to monitor changing patterns of people's health and to determine the potential health impacts of ABSL activities, the HIA recommended ABSL to conduct cross-sectional health surveys once every three years as part of the environmental and social monitoring. Here, we report findings from the first follow-up health survey, conducted three years after the initial BHS and implemented at the same sentinel sites [22]. A range of health indicators serve for comparison of the baseline status with the three-year follow-up. Moreover, findings at sentinel sites impacted by the ABSL project are compared with findings at control sentinel sites. The methodology employed is discussed in the context of current practice in health impact assessment (HIA).

## 2. Materials and Methods

### *2.1. Ethical Considerations*

Approval for the study was provided by the Sierra Leone Ethics and Scientific Review Committee of the Ministry of Health and Sanitation (MoHS). Community sensitization was performed through meetings with leaders followed by informed consent (signed or fingerprinted) obtained from participating heads of households and mothers/caregivers. For the school survey, written informed consent was given by teachers, whilst children assented orally. Children found with mild or moderate anemia (hemoglobin (Hb) 7–11.0 g/dL) or severe anemia (Hb < 7 g/dL) were provided with iron supplements or referred to a regional hospital for further investigation, respectively. Artemisinin-based combination therapy (ACT), using artesunate-amodiaquine, was given to children who were found positive for *Plasmodium falciparum*. Children found with concurrent *P. falciparum* infection and anemia were treated with the required ACT dosage, followed by iron supplements. Moderately to severely anemic women were counseled and referred to a health facility if indicated based on their clinical condition. School-age children with confirmed *Schistosoma* infection received praziquantel (40 mg/kg). Treatment was administered by the community health officer in collaboration with the MoHS peripheral health unit (PHU) staff. In adherence to MoHS regulations, all treatments were given free of charge and provided by the PHU, which recorded the identity of recipients and outgoing stock.

### *2.2. Study Area*

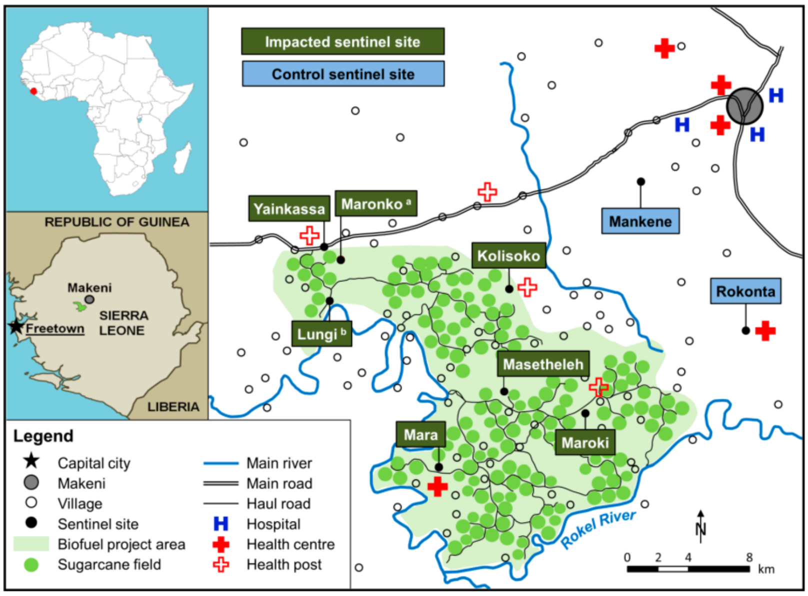
The ABSL project is located in the Northern region of Sierra Leone in Bombali and Tonkolili districts, west of Makeni town [16]. The project area uses about 10,000 ha for sugarcane plantation, and an additional 4300 ha has been designated for infrastructural build-up, farming fields, and ecological conservation areas. An estimated 30,000 people reside within the project area, which is limited by the Lunsar-Makeni highway to the north and by the Rokel River to the south and west (Figure 2) [27].

### *2.3. Study Design and Sampling Methodology*

The three-year follow-up survey used the same modular, cross-sectional study design and sentinel sites as the BHS [22,28]. The sentinel site selection procedure took into consideration: (i) the prevailing eco-epidemiologic characteristics in the study area; (ii) the exposure to ABSL project activities (e.g., infrastructural developments or community development initiatives); and (iii) the presence of health facilities. These criteria led to the selection of six sentinel sites within the ABSL project area (designated as impacted sites; Yainkassa, Maronko, Kolisoko, Masetheleh, Maroki, and Mara) and two sentinel sites outside the project area, serving as controls (Mankene and Rokonta; Figure 2). Four sites had a health facility. Of note, the two control sites are within 10 km of the ABSL project, but not directly impacted by its activities (e.g., road developments, employment). In order to control for the effect of seasonal fluctuations on specific health conditions (e.g., malaria and wasting), the two surveys, spaced three years apart, were both carried out in mid-December.

Within these sites, households served as the primary sampling units. Four study interviewers selected households using a random sampling procedure for the first household, followed by proximity sampling (i.e., next-door household) [28]. The inclusion criterion for a household was the presence of a mother with at least one child under five years of age.

**Figure 2.** Sentinel sites of the follow-up health survey in the ABSL project study area in Northern Sierra Leone, 2013.




Mothers/caregivers were invited to respond to a pre-tested questionnaire investigating sociodemographic and health issues. After completion of the questionnaire, all household members were invited to visit a clinical field unit located at a central place within the sites. Children under five years of age had their weight (digital scale, Seca 877; Hamburg, Germany) and their height measured (portable stadiometer, Seca 213; Hamburg, Germany) [29]. Following a capillary blood sample from a finger-prick, children aged 6–59 months were tested for *P. falciparum* infection using a rapid diagnostic test (RDT; First Response®, Premier Medical Corporation Ltd; Nani Daman, India) [30]. Additionally, Hb concentration was determined using a HemoCue® 201+ testing device (HemoCue Hb 201 System; HemoCue AB, Ängelholm, Sweden) [31]. Females aged 15–49 years also provided a finger-prick sample to determine Hb concentration, and their pregnancy status was recorded by the clinical health officer based on verbal reporting. For quality control, clinical data were checked for completeness and entered into a database directly in the field. Inconsistencies or incomplete information were managed and corrected by returning to the respective households.

School-going children aged 10–15 years were randomly selected from schools serving the selected sentinel sites to assess the prevalence and intensity of soil-transmitted helminths and *Schistosoma* infections. There is no school in Maronko, so children in Lungi school serving this site were sampled. At each school, fresh stool and mid-morning urine samples were collected from 30 children; 15 boys and 15 girls. One stool sample per child was examined by microscopy, using the standard Kato–Katz technique [32], to assess the prevalence of infection for *Schistosoma mansoni*, *Ascaris lumbricoides*, hookworm, and *Trichuris trichiura*. *Schistosoma haematobium* was assessed in urine samples using the centrifugation method [33].

A water quality analysis was carried out to assess the presence/absence of coliform bacteria as an indicator organism for fecal contamination. By means of sterile 100-mL bottles, one drinking water sample was collected in 10 randomly selected participating households and all drinking water collection points in each sentinel site, in both the BHS and the follow-up survey. In the BHS, the presence/absence of coliform bacteria and *Escherichia coli* were determined, using a Colitag™ water test (CPI International; Santa Rosa, CA, USA) [34]. In the 2013 follow-up survey, the presence/absence and quantity of coliform bacteria were determined using the DelAgua® portable water quality testing kit (DelAgua Water Testing Limited; Marlborough, UK) [35].

### *2.4. Statistical Analysis*

Data were recorded directly in the field using EpiData version 3.1 (EpiData Association; Odense, Denmark) and Excel (Microsoft Office; Redmond, DC, USA). Statistical analysis of the biomedical and questionnaire survey data were carried out in STATA (Stata Corp LP; College Station, TX, USA). Data obtained from biomedical samples were adjusted for intra-cluster correlation at the household level, using a generalized estimating equation model, since multiple individuals from the same household participated. Anemia was defined as Hb <11 g/dL in children and pregnant women and as Hb <12 g/dL in non-pregnant women, according to WHO guidelines [36,37]. Two indicators from the questionnaire survey were evaluated: (i) "place of delivery of last born child"; and (ii) "household access to improved sanitation". Standard categories were used in accordance with the Demographic and Health Survey (DHS) Sierra Leone [38].

Anthropometric data were analyzed using WHO Anthro version 3.2.2 (WHO; Geneva, Switzerland). Wasting (weight-for-height), stunting (height-for-age), and being underweight (weight-for-age) were defined as <−2 standard deviation (SD) scores with reference to the WHO standard population [39]. Water quality was categorized into "absence of coliforms" (0 coliforms/100 mL) and "presence of coliforms" (>0 coliforms/100 mL).

Comparisons between the BHS and the three-year follow-up survey, stratified by impacted and control sites, were made using the $\chi^2$ test of proportions, including a 95% confidence interval (CI). A $p$-value <0.05 was interpreted as a significant difference.

## 3. Results

### *3.1. Study Compliance*

Overall, 187 households participated in the follow-up health survey; 137 at the impacted and 50 at the control sites. A total of 1222 individuals (604 children under five years of age, 241 children aged 10–15 years, and 377 women of reproductive age) provided biomedical samples. Drinking water samples were collected and analyzed for a total of 80 households and 25 sources. Figure 3 shows the study compliance during the follow-up survey. Table 1 summarizes sample demographics for the BHS and the three-year follow-up survey, stratified by impacted and control sites.

**Figure 3.** Participation and adherence in the different survey arms of the three-year follow-up health survey in the ABSL project study area, 2013.

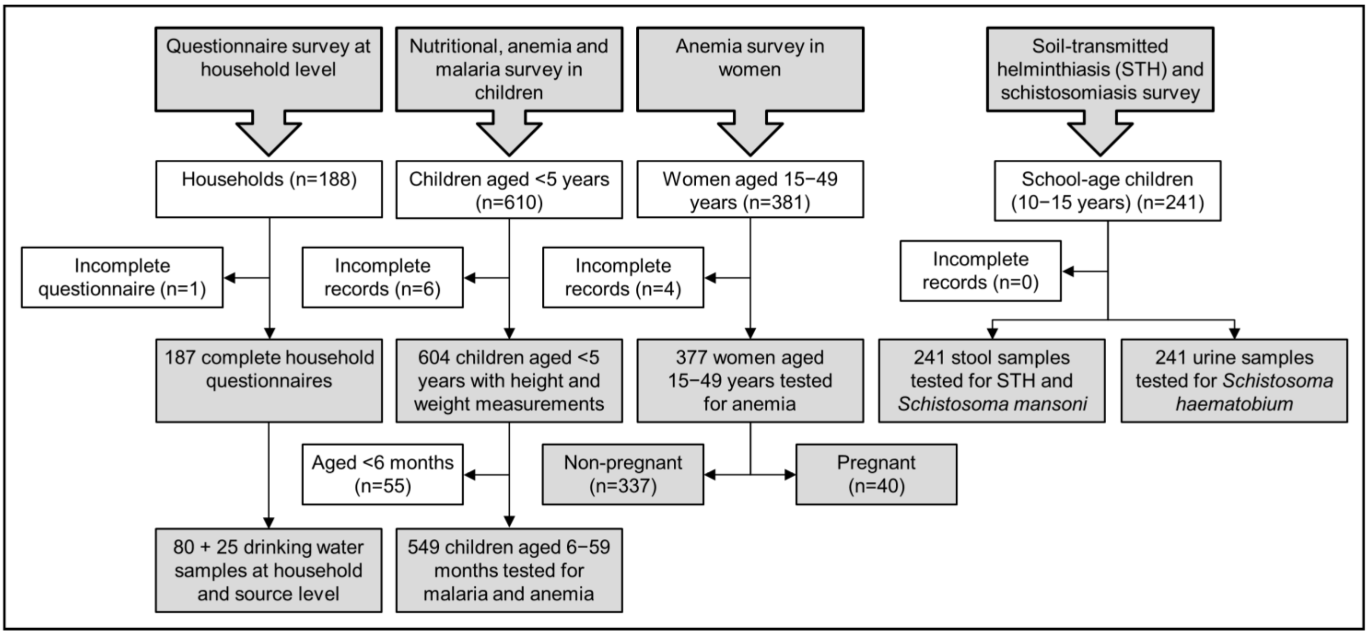



**Table 1.** Sample sizes at the impacted and the control sentinel sites, in the ABSL project study area, 2010 and 2013.

| Characteristics | Impacted Sentinel Sites | | Control Sentinel Sites | |
|---|---|---|---|---|
| | 2010 | 2013 | 2010 | 2013 |
| Sentinel sites | 6 | 6 | 2 | 2 |
| Households | 143 | 137 | 51 | 50 |
| Children aged <59 months | 421 | 390 | 164 | 214 |
| Children aged 6–59 months | 409 | 350 | 161 | 199 |
| School-going children aged 10–15 years | 180 | 181 | 60 | 60 |
| Women aged 15–49 years | 284 | 255 | 113 | 122 |
| Non-pregnant | 234 | 230 | 97 | 107 |
| Pregnant | 50 | 25 | 16 | 15 |

### *3.2. Anthropometric Indicators in Children Aged <59 Months*

As shown in Table 2 and Figure 4A–C, the prevalences of wasting, stunting, and being underweight have decreased over the three-year period at the sentinel sites. Wasting decreased significantly in the impacted sites from 5.7% to 2.8% ($p$ = 0.044), while remaining stable at the control sites (4.2% in 2010 and 4.3% in 2013; $p$ = 0.976). Stunting decreased significantly at the impacted sites (41.8% in 2010 and 32.1% in 2013; $p$ = 0.004) and non-significantly at the control sites (42.1% in 2010 and 40.7% in 2013; $p$ = 0.781). Being underweight decreased significantly from 23.0% to 13.3% at the impacted and from 25.0% to 15.0% at the control sites (both $p$ < 0.001).

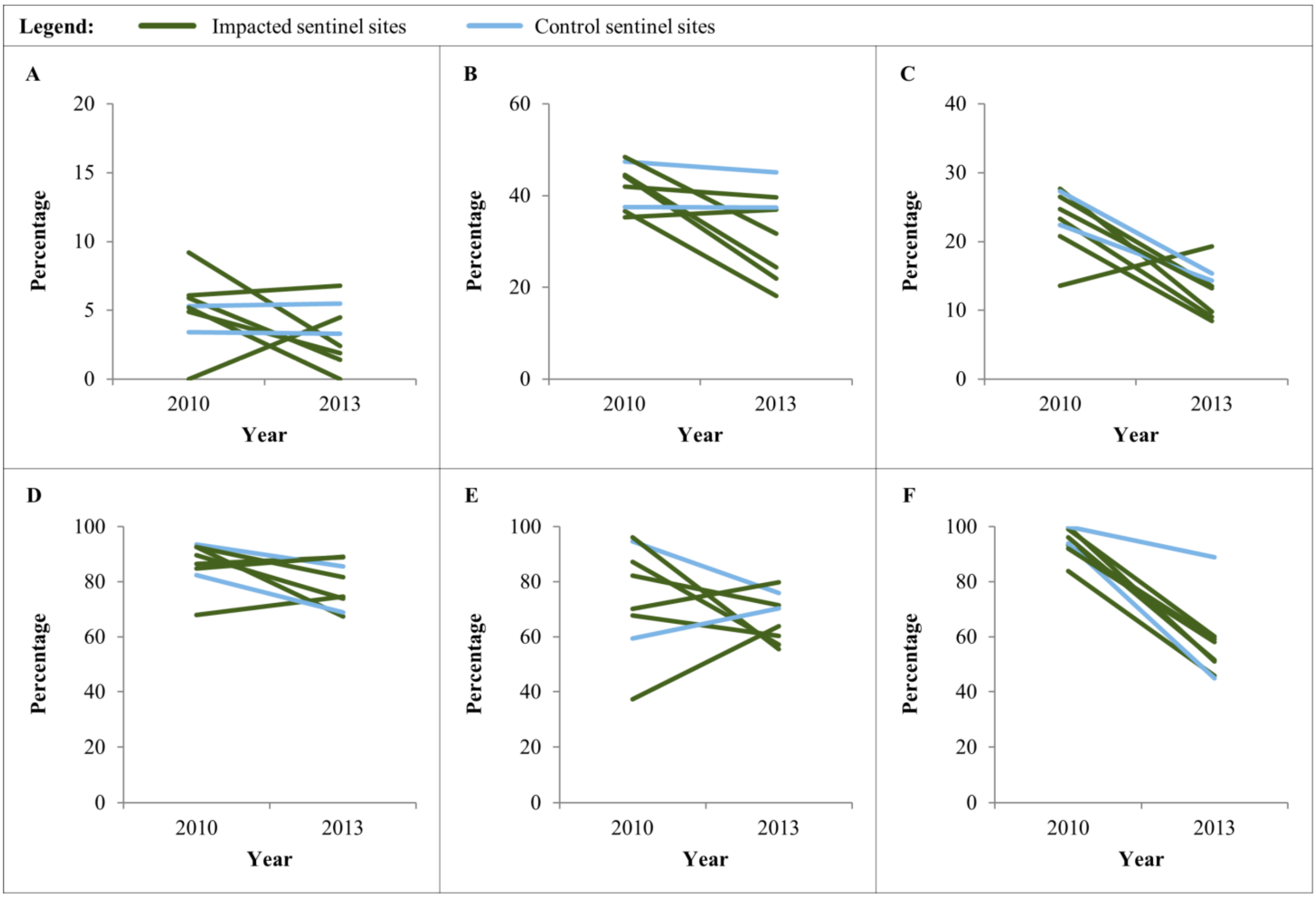
**Table 2.** Key health indicators at the impacted and the control sentinel sites, in the ABSL project study area, 2010 and 2013.

| | | Impacted Sentinel Sites | | Control Sentinel Sites | |
|---|---|---|---|---|---|
| | | **2010** | **2013** | **2010** | **2013** |
| **Indicators in children aged <59 months** | | | | | |
| **Sample size (*n*)** | Individuals | 421 | 390 | 164 | 214 |
| | Households | 149 | 131 | 52 | 50 |
| | Sentinel sites | 6 | 6 | 2 | 2 |
| | Mean/sentinel site (range) | 68 (24–99) | 58 (21–91) | 81 (75–86) | 100 (83–116) |
| **Wasting** | Prevalence (95% CI) | 5.7 (3.4–8.0) | 2.8 (1.0–4.6) | 4.3 (0.9–7.7) | 4.2 (1.3–7.1) |
| | Range | 0.0–9.2 | 0.0–6.8 | 3.4–5.3 | 3.3–5.5 |
| | *p*-value | | 0.044 | | 0.976 |
| **Stunting** | Prevalence (95% CI) | 41.8 (37.0–46.6) | 32.1 (27.3–36.8) | 42.1 (34.2–49.9) | 40.7 (33.8–47.5) |
| | Range | 35.3–48.5 | 18.2–39.6 | 37.5–47.4 | 37.4–45.1 |
| | *p*-value | | 0.004 | | 0.781 |
| **Underweight** | Prevalence (95% CI) | 23.0 (18.9–27.2) | 13.3 (9.8–16.8) | 25.0 (18.1–31.9) | 15.0 (9.9–20.0) |
| | Range | 13.6–27.7 | 8.5–19.3 | 22.4–27.3 | 14.3–15.4 |
| | *p*-value | | <0.001 | | 0.014 |
| **Indicators in children aged 6–59 months** | | | | | |
| **Sample size (*n*)** | Individuals | 409 | 350 | 161 | 199 |
| | Households | 149 | 131 | 52 | 50 |
| | Sentinel sites | 6 | 6 | 2 | 2 |
| | Mean/sentinel site (range) | 68 (24–99) | 58 (21–91) | 81 (75–86) | 100 (83–116) |
| ***P. falciparum*** | Prevalence (95% CI) | 73.8 (68.6–78.5) | 62.5 (56.4–68.2) | 76.0 (67.4–83.0) | 72.8 (66.5–78.3) |
| | Range | 37.3–96.2 | 55.5–79.7 | 59.3–94.7 | 70.3–75.8 |
| | *p*-value | | 0.001 | | 0.530 |
| **Anemia** | Prevalence (95% CI) | 85.8 (82.0–88.8) | 80.0 (75.3–84.0) | 87.5 (80.9–92.0) | 75.9 (69.5–81.3) |
| | Range | 67.9–92.6 | 67.3–89.0 | 82.4–93.5 | 68.9–85.6 |
| | *p*-value | | 0.033 | | 0.005 |
| **Use of insecticide treated nets** | Prevalence (95% CI) | 94.6 (90.9–96.8) | 55.1 (47.0–63.0) | 96.8 (88.0–99.2) | 67.1 (53.9–78.1) |
| | Range | 83.8–100.0 | 45.8–60.2 | 93.9–100.0 | 44.8–88.8 |
| | *p*-value | | <0.001 | | <0.001 |
| **Indicators in children aged 10–15 years** | | | | | |
| **Sample size (*n*)** | Individuals | 180 | 181 | 60 | 60 |
| | Sentinel sites | 6 | 6 | 2 | 2 |
| | Mean/sentinel site (range) | 30 (30–30) | 30 (30–30) | 30 (30–30) | 30 (30–30) |
| ***S. mansoni*** | Prevalence (95% CI) | 1.7 (0.0–3.6) | 3.9 (1.0–6.7) | 5.0 (0.0–10.7) | 8.3 (1.1–15.5) |
| | Range | 0.0–3.3 | 0.0–13.3 | 3.3–6.7 | 6.7–10.0 |
| | *p*-value | | 0.203 | | 0.464 |
| ***A. lumbricoides*** | Prevalence (95% CI) | 1.1 (0.0–2.7) | 11.1 (6.4–15.6) | 1.7 (0.0–5.0) | 1.7 (0.0–5.0) |
| | Range | 0.0–3.3 | 3.3–40.0 | 0.0–3.3 | 0.0–3.3 |
| | *p*-value | | <0.001 | | 1.000 |
| **Hookworm** | Prevalence (95% CI) | 23.9 (17.6–30.2) | 28.7 (22.1–35.4) | 40.0 (27.2–52.8) | 41.7 (28.8–54.5) |
| | Range | 3.3–50.0 | 10.0–63.3 | 33.3–46.7 | 36.7–46.7 |
| | *p*-value | | 0.296 | | 0.853 |

**Table 2.** *Cont.*

| | | Impacted Sentinel Sites | | Control Sentinel Sites | |
|---|---|---|---|---|---|
| | | **2010** | **2013** | **2010** | **2013** |
| **Indicators in children aged 6–59 months** | | | | | |
| ***T. trichiura*** | Prevalence (95% CI) | 2.2 (0.1–4.4) | 1.1 (0.0–2.6) | 1.7 (0.0–5.0) | 0.0 (0.0–0.0) |
| | Range | 0.0–3.3 | 0.0–6.7 | 0.0–3.3 | 0.0–0.0 |
| | *p*-value | | 0.406 | | 0.315 |
| **Indicators in women aged 15–49 years** | | | | | |
| **Sample size (*n*)** | Individuals | 284 | 255 | 113 | 122 |
| | Sentinel sites | 6 | 6 | 2 | 2 |
| | Mean/sentinel site (range) | 47 (20–76) | 43 (21–58) | 57 (52–61) | 61 (58–64) |
| **Anemia** | Prevalence (95% CI) | 72.8 (67.2–77.8) | 40.5 (34.4–46.8) | 75.9 (68.4–82.0) | 33.4 (25.5–42.5) |
| | Range | 53.8–84.0 | 30.4–48.0 | 70.2–80.3 | 22.3–43.6 |
| | *p*-value | | <0.001 | | <0.001 |

**Figure 4.** Indicators in children under five years of age in the ABSL study area, stratified by sentinel site, 2010 and 2013. (**A**) Prevalence of wasting (<−2 SD) in children aged <59 months; (**B**) prevalence of stunting (<−2 SD) in children aged <59 months; (**C**) prevalence of being underweight (<−2 SD) in children aged <59 months; (**D**) prevalence of anemia in children aged 6–59 months; (**E**) prevalence of *Plasmodium falciparum* in children aged 6–59 months; and (**F**) insecticide treated net use in the night preceding the survey in children aged 6–59 months.



### *3.3. Anemia and P. falciparum Prevalence in Children Aged 6–59 Months*

Summary statistics for anemia and *P. falciparum* prevalence in children aged 6–59 months at impacted and control sites are shown in Table 2. Variation among sites is illustrated in Figure 4D,E. Significant decreases in the prevalence of anemia were observed at both impacted and control sites (both $p < 0.05$; Table 2). The prevalence *of P. falciparum* infection had decreased significantly at the impacted sites (73.8% in 2010 and 62.5% in 2013; $p = 0.001$) and non-significantly at the control sites (76.0% in 2010 and 72.8% in 2013; $p = 0.530$).

The use of insecticide-treated nets (ITNs) in six- to 59-month-old children decreased significantly at both impacted and control sites ($p < 0.001$; Table 2); specifically, from >80% in 2010 to <60% in 2013.

### *3.4. Anemia and Place of Delivery of the Last Born Child in Women Aged 15–49 Years*

Anemia and place of delivery of the last born child in females of reproductive age were assessed as key indicators for maternal health. There was a significant reduction of anemia in women from both the impacted and the control sites (both $p < 0.001$; Table 2 and Figure 5A).

Women were asked, in the accompanying questionnaire survey, about the place of delivery of the last born child (Table 3 and Figure 5B). Since 2010, there was a significant increase in the proportion of women who gave birth in a formal healthcare facility at the impacted sites ($p < 0.001$), compared to a non-significant increase at the control sites ($p = 0.886$).

**Table 3.** Percentage of mothers giving birth at a health facility and the percentage of households having access to safe sanitation, in the ABSL study area, 2010 and 2013.

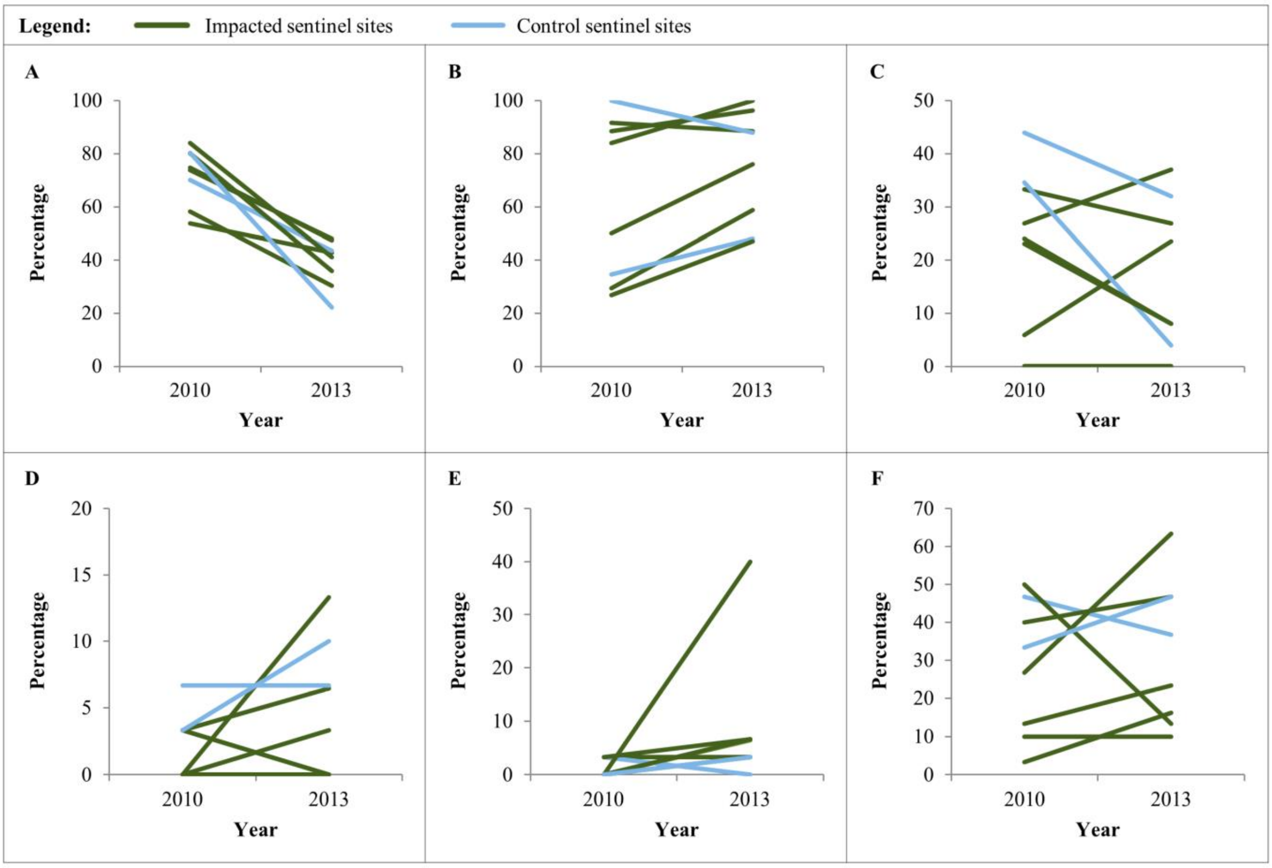
| | | **Impacted Sentinel Sites** | | **Control Sentinel Sites** | |
|---|---|---|---|---|---|
| | | **2010** | **2013** | **2010** | **2013** |
| **Indicators in mothers/households participating in the questionnaire survey** | | | | | |
| **Sample size (*n*)** | Individuals/households | 144 | 137 | 51 | 50 |
| | Sentinel sites | 6 | 6 | 2 | 2 |
| | Mean/sentinel site (range) | 24 (15–26) | 23 (17–27) | 25 (25–26) | 25 (25–25) |
| **% mothers giving birth at a health facility** | Prevalence (95% CI) | 63.2 (54.8–71.1) | 81.0 (73.4–87.2) | 66.7 (52.1–79.2) | 68.0 (53.3–80.5) |
| | Range | 26.9–91.7 | 47.1–100.0 | 34.6–100.0 | 48.0–88.0 |
| | *p*-value | | <0.001 | | 0.886 |
| **% households having access to safe sanitation** | Prevalence (95% CI) | 19.4 (13.3–26.9) | 18.3 (12.2–25.7) | 39.2 (25.8–53.9) | 18.0 (8.6–31.4) |
| | Range | 0.0–33.3 | 0.0–37.0 | 34.6–44.0 | 4.0–32.0 |
| | *p*-value | | 0.798 | | 0.019 |

### *3.5. Helminth Infection among School-Age Children and Household's Access to Improved Sanitation*

Figure 5D–F show trends in *S. mansoni*, *A. lumbricoides*, and hookworm infection rates in school-going children. A localized significant increase was found in *A. lumbricoides* prevalence at one impacted site (Figure 5E), being responsible for an overall increase from 1.1% in 2010 to 11.1% in 2013 ($p < 0.001$; Table 2). *S. mansoni*, *A. lumbricoides*, and *T. trichiura* infection prevalences were of low and hookworm of moderate endemicity at both baseline and the three-year follow-up.

The household questionnaire included questions regarding access to improved sanitation, which was low at both impacted and control sites (18.3% and 18.0%, respectively; Figure 5C and Table 3). There was a non-significant decrease in access to improved sanitation at the impacted sites (19.4% in 2010 and 18.3% in 2013; $p$ = 0.798) and a significant decrease at control sites (39.2% in 2010 and 18.0% in 2013; $p$ = 0.019).

**Figure 5.** Indicators in women of reproductive age (15–49 years) and school-going children aged 10–15 years in the ABSL study area, stratified by sentinel site, 2010 and 2013. (**A**) Prevalence of anemia in women aged 15–49 years (Hb < 11 g/dL in pregnant women; Hb < 12 g/dL in non-pregnant women); (**B**) proportion of women aged 15–49 years who delivered the last child at a health facility; (**C**) proportion of women aged 15–49 years reporting that their household has an improved sanitation facility; (**D**) prevalence of *S. mansoni* in children aged 10–15 years; (**E**) prevalence of *A. lumbricoides* in children aged 10–15 years; and (**F**) prevalence of hookworm in children aged 10–15 years.




## *3.6. Presence/Absence of Coliform Bacteria in Drinking Water Samples*

Overall, no significant changes in drinking water quality in the study area were observed (Table 4). There was a non-significant increase in the proportion of household water samples contaminated with coliform bacteria from 98.6% in 2010 to 100.0% in 2013 at impacted and from 95.8% to 100.0% at control sites ($p$ = 0.359 and $p$ = 0.356, respectively). There was a non-significant decrease in coliform-positive samples from sources at the impacted sites (from 94.4% in 2010 to 87.5% in 2013) and a non-significant increase at the control sites (from 83.3% in 2010 to 88.9% in 2013; $p = 0.476$ and $p = 0.756$, respectively).

**Table 4.** Percentage of drinking water samples at the household and source level positive for coliform, in the ABSL study area, 2010 and 2013.

| | | Impacted Sentinel Sites | | Control Sentinel Sites | |
|---|---|---|---|---|---|
| | | **2010** | **2013** | **2010** | **2013** |
| **Indicators for drinking water quality at household and source level** | | | | | |
| **Sample size (*n*)** | Households | 72 | 60 | 24 | 20 |
| | Sources | 18 | 16 | 6 | 9 |
| | Sentinel sites | 6 | 6 | 2 | 2 |
| **% of household samples positive for coliform** | Prevalence (95% CI) | 98.6 (92.5–99.9) | 100.0 (83.2–100.0) | 95.8 (78.9–99.9) | 100.0 (94.0–100.0) |
| | Range | 91.7–100.0 | 100.0–100.0 | 91.7–100.0 | 100.0–100.0 |
| | *p*-value | | 0.359 | | 0.356 |
| **% of source samples positive for coliform** | Prevalence (95% CI) | 94.4 (72.7–99.9) | 87.5 (61.7–98.4) | 83.3 (35.9–99.6) | 88.9 (51.8–99.7) |
| | Range | 50.0–100.0 | 66.7–100.0 | 75.0–100.0 | 75.0–100.0 |
| | *p*-value | | 0.476 | | 0.756 |

## 4. Discussion

### *4.1. Changes in Health Patterns*

The results of the 2013 follow-up health survey revealed an improvement in most of the measured health indicators over the past three years at both impacted and control sites of the ABSL project. A multitude of contextual factors, such as deworming campaigns, distribution of ITNs by the national malaria control program, the Free Health Care Initiative, and employment seeking migration (see Figure 1), may have influenced these findings and must be taken into consideration for interpreting our data. For example, the Free Health Care Initiative launched in April, 2010, which provides pregnant women, lactating mothers and children under five years of age with free healthcare, may have contributed to positive health trends at both impacted and control sites [40]. In fact, the MoHS documented improved uptake of healthcare services in the target group in 2011, although infrastructural, drug supply, and human resource challenges continue [24,41]. The overall improvement was illustrated by health outcomes that have significantly improved at both the impacted and control sites: (i) being underweight in children under five years of age; (ii) the prevalence of anemia in children aged 6–59 months; and (iii) the prevalence of anemia in women of reproductive age.

In terms of potential project-related impacts, a set of statistically significant positive changes were observed at the impacted but not at the control sites: (i) the prevalence of stunting and wasting in children under the age of five years; (ii) *P. falciparum* prevalence in children aged 6–59 months; and (iii) the proportion of women having delivered their last born child at a healthcare facility. On the other hand, the prevalence of *A. lumbricoides* infection in school-age children showed a significant increase at impacted, but not control, sites.

Wasting in children under five years of age was at 2.8% at the impacted and 4.2% at the control sites in December 2013, at the beginning of the dry season. Seasonal fluctuations are expected to influence acute malnutrition, which is noticeably worse during the rainy season [37,42,43]. Hence, comparison to other surveys, such as the DHS, carried out during the rainy season, is difficult, due to the temporal heterogeneity of the surveys. Similarly, it is challenging to quantify the impact of the community-based management of acute malnutrition (implemented since 2007) or other programs [26].

Stunting, an indicator for chronic malnutrition (32.1% at the impacted and 40.7% at the control sites), is associated with a number of immediate factors (e.g., environmental, economic, and sociopolitical factors restricting access to safe and sufficient food and water) and underlying causes (e.g., inadequate care, limited access to health services, and household food security), with poverty being an overarching determinant for each of these [44].

The significant decrease in wasting and stunting at the impacted compared to the non-significant decrease at the control sites over the three-year period potentially reflects: (i) the ABSL farmer development programs initiated in the ABSL project area (see Figure 1); (ii) people's increased ability to access food, healthcare, and other essential commodities in the ABSL project area; and (iii) the in-migration of children from areas with lower rates of stunting or wasting into the area since 2010.

The prevalence of *P. falciparum* has declined in the study population between 2010 and 2013. Possible contributors include: (i) a decrease in disease transmission due to interventions, such as ITN distribution (in 2010) and focal indoor residual spraying campaigns [23,25,45,46]; (ii) the improved diagnostic capacity using RDTs; (iii) an increased availability (including accessibility and affordability) of ACTs in medicine outlets [24,40,47]; (iv) environmental changes (e.g., change of vegetation, urbanization, and alteration of breeding sites) [48–50]; and (v) an increased awareness of, and improved economic conditions to, utilize protective measures [51]. The national mass-distribution campaign of ITNs was ongoing at the time of the BHS, and a study six months after the distribution found 87.6% of households owned at least one ITN, with 76.5% of households regularly sleeping under an ITN [45]. As per our findings in December 2013, ITN possession decreased to 55.1% at the impacted and 67.1% at the control sites. Reduced ITN coverage is expected over time, as these nets get destroyed, and repeated mass-distributions are therefore needed to maintain and extend coverage [52]. In Sierra Leone, another nation-wide distribution took place in June 2014 [53]. In the study area, the lower rate at the impacted compared to the control sites might be due to the fact that people have migrated into the ABSL project area after the 2010 campaign [17]. Despite the overall lower ITN coverage, *P. falciparum* prevalence among children aged 6–59 months has decreased significantly at the impacted sites, suggesting that the previously-mentioned health system, environmental, and economic changes are at play. Still, two in three children were found to be infected with *P. falciparum*, calling for sustained efforts in vector control and malaria management in the study area.

Despite focal increases in the prevalence rates of helminth infections, most changes were not significant and corresponded with spatial predictions [54]. The significant increase in *A. lumbricoides* can be attributed to a small cluster of children in Masetheleh, a village without a health facility, that had not been effectively reached by the national deworming program [55]. The changes in the prevalence of *S. mansoni* were attributed to children who had migrated from highly endemic areas into the study area, as confirmed by children and teacher interviews. As per Figure 1, national deworming campaigns by the MoHS and restoration of wells initiated by the ABSL project in the area since 2012 should contribute to helminth control. However, the control of helminth infections and other soil- and water-related diseases is only possible if environmental sanitation conditions are extensively improved, complemented with increased access to safe drinking water and behavior change [56,57]. Currently, less than 20% of the households at both impacted and control sites have access to improved sanitation, and over 80% drink fecally contaminated water. The data suggest that project developments have not translated into improved water and sanitation indicators, partly because communities' demands and capacities to take action on their own (e.g., resources and technical expertise) are limited [58,59]. The IFC's performance standards require ABSL to mitigate potential impacts related to its activities and encourage corporate social investment [21,60]. Project-related in-migration bears the risk of worsening the water and sanitation situation in the project area [61]. Thus, it is recommended that ABSL sets water and sanitation-oriented interventions, along with health system strengthening as priorities for corporate social investment, also because such efforts are urgently needed for combating diarrheal and other infectious diseases, including the current Ebola outbreak in West Africa [62].

Anemia serves as an indicator for the general wellbeing of a child, since it is a multi-factorial condition governed by malnutrition, malaria, hookworm, and *Schistosoma* infections, hereditary hemoglobinopathies, and poor socioeconomic status [63]. The significant reduction of anemia at both impacted and control sites might indicate a general improvement of child health in the study area. In 2013, anemia prevalences in children at the impacted (80.0%) and control sites (75.9%) were slightly lower than the Northern region average found in the 2013 DHS (83.4%) [37]. A meaningful reduction of anemia in children requires the reduction of the overall disease burden, an increased individual awareness and capacity to tackle the underlying causes (e.g. investment in protection against parasites), and an understanding of the contribution of hemoglobinopathies.

Maternal health indicators in the study population, anemia in women of reproductive age, and the proportion of deliveries in health facilities had improved since the BHS. Project-induced development of roads might have facilitated accessibility to healthcare structures, as there was a more pronounced increase of the proportion of deliveries at a health facility at impacted compared to control sites [8]. Nevertheless, the increase at the control sites might suggest a cumulative impact of improved road infrastructure, as well as increased levels of income in the study area. In Sierra Leonean healthcare facilities, an increase of 45% of facility-based deliveries was noted in the first 12 months of the Free Health Care Initiative compared to the preceding 12 months, indicating that it was an important factor [24].

### *4.2. Implications for the Health Impact Assessment (HIA) Process*

The three-year follow-up health survey was conducted as an integral part of the HIA, the overall environmental and social monitoring program, and the company's community health and safety management plan. The described study methodology presents a feasible approach for health monitoring in settings where routine health information systems might not reliably pick up the subtle changes at the community level over time [64,65]. The present study is among a few rigorous monitoring approaches based on repeated cross-sectional surveys in sub-Saharan Africa that provide evidence on how a large infrastructure project impacts community health. The baseline data collected provided an indispensable benchmark for monitoring changes in health patterns over time [22]. By conducting repeated cross-sectional surveys, ABSL has created an evidence-base for decision-making and prioritization of its health mitigation measures.

Besides the evidenced-based decision-making and critical monitoring of changing health patterns at impacted sites, the measurement of health outcomes assists the evaluation of the HIA, in particular the prediction accuracy of health impacts made in the risk assessment phase. In fact, process evaluation (*i.e.*, the process leading to a decision on health interventions) and the outcome evaluation (*i.e.*, the outcome of a health intervention) are both important steps to improve the HIA as a decision-support tool, and epidemiological case studies represent an essential tool for the latter [66]. Moreover, the HIA and associated research gain transparency, value, and credibility by undergoing a peer-reviewed process [65].

### *4.3. Limitations of the Study*

The findings are specific for the selected sentinel sites and not representative for a wider area. The type and duration of ABSL impacts may vary among these, since the construction phase of the project was ongoing from 2010 to 2014, meaning that infrastructural and community developments, including road constructions, planting of sugarcane fields, and implementation of the farmer development program, were gradually introduced into the ABSL area [16,17]. To minimize seasonal effects, the BHS and the three-year follow-up study were conducted at the same time of year, but fluctuations due to annual climate variations might still influence health indicators. The study did not control for the in- or out-migration characteristics of the study participants. The diagnosis of helminth infections using the Kato–Katz method with only one specimen and one urine centrifugation has a lower sensitivity than multi-specimen Kato–Katz and concentration methods, and the reported values might be underestimated [67]. Although the DelAgua® testing kit used in 2013 allowed for a precise coliform count and, thus, categorization according to WHO standards (samples with 0–10 coliforms/100 mL are considered as tolerable to drink without prior treatment), only the absence/presence categories were applied here, in order to allow for direct comparison [68].

## 5. Conclusions

The findings of two cross-sectional health surveys, conducted exactly three years apart, show a significant decrease in the prevalence of stunting, wasting, and *P. falciparum* in children under five years of age and a significant increase in the proportion of women having delivered their last child in a healthcare facility at impacted sites, which was not seen at the control sites. The prevalences of being underweight and anemia in children and anemia in women have significantly decreased at both impacted and control sites. Access to improved sanitation decreased significantly at control and non-significantly at impacted sites. Fecal contamination of drinking water at both the source and household level had not changed significantly and, indeed, remained unacceptably high.

Overall, much remains to be done to further improve the overall health and wellbeing of the population in the study area. Periodic follow-up health surveys, as part of the HIA, deepen the understanding of changing health patterns in local communities and allow for adaptations in the community health and safety management plan of the ABSL, including specific health interventions. Since scientific evidence and its ethical use is one of the core values for good practice in HIA [69], the approach of using independent, evidence-based research that allows for an objective and transparent evaluation of changing health patterns could set an example for similar projects elsewhere in sub-Saharan Africa and other low- and middle-income countries in Asia and Latin America [16,22].

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**Author Contributions**

Mirko S. Winkler and Mark J. Divall conceived the study design. Mary H. Hodges, Hamid Turay and Astrid M. Knoblauch coordinated the field work. Jusufu Paye and Mohamed S. Bah led the parasitological field and laboratory work. Astrid M. Knoblauch and Mary H. Hodges supervised the research team. Mary H. Hodges was the overall study coordinator. Astrid M. Knoblauch performed the statistical analysis, and Astrid M. Knoblauch and Mirko S. Winkler drafted the manuscript. Jürg Utzinger, Mary H. Hodges, Mark J. Divall, and Yaobi Zhang contributed to the interpretation of the data, manuscript writing, and revisions. All authors read and approved the final manuscript.

**Conflicts of Interest**

The authors declare no conflict of interest.

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# 8 Experience and lessons from health impact assessment guiding prevention and control of HIV/AIDS in a copper mine project, northwestern Zambia

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# Experience and lessons from health impact assessment guiding prevention and control of HIV/AIDS in a copper mine project, northwestern Zambia

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## Abstract

**Background:** To avoid or mitigate potential project-related adverse health effects, the Trident copper project in Kalumbila, northwestern Zambia, commissioned a health impact assessment. HIV was identified a priority health issue based on the local vulnerability to HIV transmission and experience from other mining projects in Africa. Hence, an HIV/AIDS management plan was developed, including community and workplace interventions, with HIV testing and counselling (HTC) being one of the key components. We present trends in HTC data over a 4-year period.

**Methods:** In 13 communities affected by the Trident project, HTC was implemented from 2012 onwards, using rapid diagnostic tests, accompanied by pre- and post-test counselling through trained personnel. In addition, HTC was initiated in the project workforce in 2013, coinciding with the launch of the mine development. HTC uptake and HIV positivity rates were assessed in the study population and linked to demographic factors using regression analysis.

**Results:** In total, 11,638 community members and 5564 workers have taken up HTC with an increase over time. The HIV positivity rate in the community was 3.0% in 2012 and 3.4% in 2015, while positivity rate in the workforce was 5.2% in 2013 and 4.3% in 2015. Females showed a significantly higher odds of having a positive test result than males (odds ratio (*OR*) = 1.96, 95% confidence interval (*CI*): 1.55–2.50 among women in the community and *OR* = 2.90, 95% *CI*: 1.74–4.84 among women in the workforce). HTC users in the 35–49 years age group were most affected by HIV, with an average positivity rate of 6.6% in the community sample and 7.9% in the workforce sample. These study groups had 4.50 and 4.95 higher odds of being positive, respectively, compared to their younger counterparts (15–24 years).

**Conclusions:** While HTC uptake increased five-fold in the community and almost three-fold in the workplace, the HIV positivity rates were insignificantly higher in 2015 compared to 2012. Our data can be used alongside other surveillance data to track HIV transmission in this specific context. Guided by the health impact assessment, the HIV prevention and control programme was readily adapted to the current setting through the identification of socioeconomic and environmental determinants of health.

**Keywords:** Community health management, Health impact assessment, HIV, Mining, Occupational health, Sexually transmitted infections, Zambia

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## Multilingual abstracts

Please see Additional file 1 for translation of the abstract into the six official working languages of the United Nations.

## Background

Extractive sector projects are central for development and economic growth in many low- and middle-income countries [1]. While these projects usually consider potential environmental and social impacts as part of the permitting process, a specific focus on health is often lacking [2–5]. Yet, in tropical countries with high burden of disease, potential health impacts of development projects are a concern [1, 6]. Indeed, there is growing evidence that project developments often cause a broad range of adverse health effects, such as high incidence rates of sexually transmitted infections, pollution of drinking water or elevated transmission of vector-borne diseases [7–9]. In response to these concerns, the health impact assessment (HIA) is the recommended decision-support tool to anticipate and proactively manage project-related health impacts [10–12]. However, there is absence of policy or regulatory capacity in many low- and middle-income countries that require HIA for private sector projects [5].

This holds true for Zambia, which does not have a legislative requirement to assess potential health impacts of infrastructure projects, despite its longstanding history of small- and large-scale mining and associated adverse effects on human wellbeing [5, 13]. For example, the Copperbelt province – the centre of Zambia's copper mining industry – recorded the highest provincial HIV prevalence in the 2014 Demographic and Health Survey (DHS; 18.2%) compared to 13.3% nationally [14]. Social and economic contexts associated with mining, such as in-migration of mostly young adult males or transactional sex, are believed to have contributed to the high rates of HIV in mining areas, including adjacent villages and along transport corridors [14–17]. To address HIV in this context, the United Nations Development Programme presented an approach of integrating HIV and gender-related issues into the impact assessment process [18].

The Trident greenfield copper project, located in the Northwestern province of Zambia, operated by First Quantum Minerals Limited (FQML), commissioned an HIA as part of the feasibility studies (2008–2012) [19]. In the HIA scoping phase, secondary data (routine health information system data), qualitative data (obtained from community focus group discussions and key informant interviews with health staff) and quantitative data from a cross-sectional baseline health survey were employed [20–22]. Potential health impacts were predicted using a standardised, semi-quantitative risk assessment tool [23]. The transmission of sexually transmitted infections, including HIV/AIDS, was identified as a priority, given the existing community health risks in project-affected communities and precedence in other mining areas [24]. Qualitative data obtained in the frame of the HIA scoping study showed that the local communities are vulnerable to sexually transmitted infections for a number of reasons. First, the low estimated baseline prevalence rate of sexually transmitted infections might rapidly change in face of in-migration from high-prevalence areas. Second, the relatively high socioeconomic vulnerability could encourage women to engage in transactional sex. Third, at the onset of the project, there was little exposure to preventive interventions. Fourth, the available data suggested inequities in access to health care. Fifth, the use of condoms was low, coupled with women's weak negotiating power. Finally, we noted high stigma associated with sexually transmitted diseases, particularly HIV [21]. Hence, as a result of the HIA, the Trident project, in partnership with the Solwezi district health management team, initiated an HIV intervention package. Figure 1 outlines the interventions in both the community and the workforce. Health promotion activities, such as peer education, radio programmes, information, education and communication (IEC) and empowerment campaigns in communities and schools, were implemented. HIV testing and counselling (HTC) was the key feature of the programme, which was offered in communities through specific outreach activities and in the workplace on a continuous basis at various service points. Care and treatment enrolment rounded up the intervention package. The interventions were adapted to the local context and were implemented right from the onset of the mine development.

Here, we present the approaches and outcomes of the community- and workforce-based HTC implemented in this particular copper mining setting over a 4-year period. The objectives of reporting these data are (i) to present HTC uptake and HIV positivity rate over a 4-year period in the workforce and communities affected by a large mining project in sub-Saharan Africa; (ii) to provide supplementary data for national HIV surveillance; and (iii) to provide a publicly available good practice example of HIA and associated health risk mitigation and monitoring. Experience and lessons of HIA in anticipating and managing risks associated with HIV are discussed.

## Methods

### Study area

The Trident project is located in a rural area in Solwezi district, approximately 150 km northwest of Solwezi, the provincial capital (Fig. 2) [19]. The mine development transformed the local environment (e.g. open pit mine,

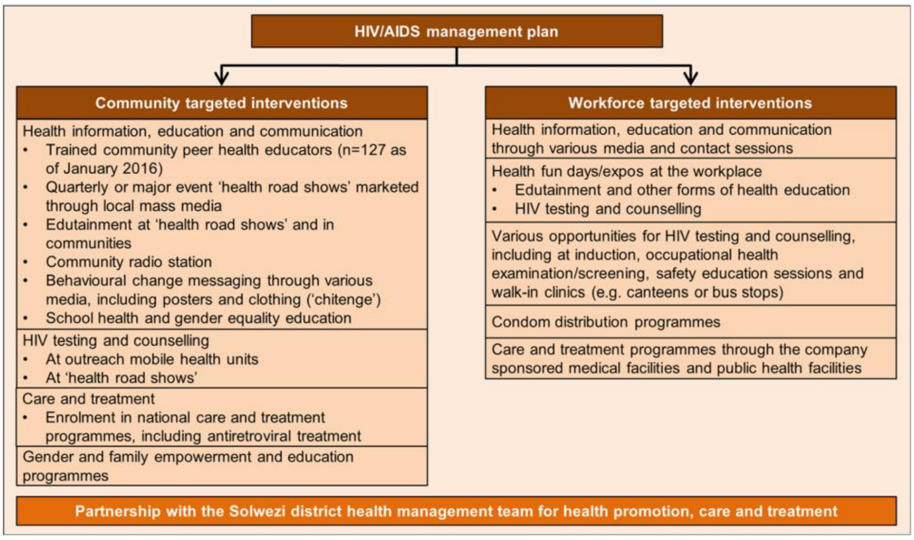


**Fig. 1** HIV/AIDS management intervention package of the Trident project

damming of rivers and construction of new roads), caused population movements (e.g. resettlement and in-migration) and a shift of local occupational activities [25–27].

## Study design and study population

The HTC was offered in communities as mobile outreach activities. Hence, each community visit represents a cross-sectional sample. For analysis, results were pooled over 1-year periods and stratified by community. In 2012, the HTC programme was launched in six communities and gradually expanded to cover as many as 13 communities by 2015 (Fig. 2). For the workforce, HTC was offered continuously at various service points that were readily accessible by mine workers (e.g. work-based health facility, bus stops and canteens). Both community members and workers were offered HTC through a voluntary walk-in concept without any selection or randomisation process being applied.

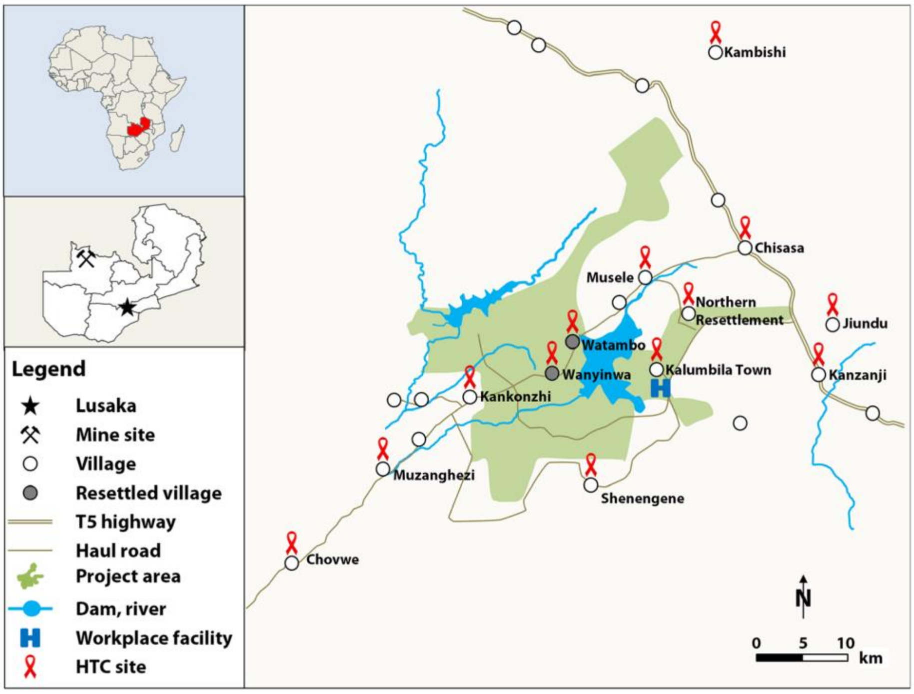


**Fig. 2** Trident project location and perimeter of the HIV intervention package

#### HIV testing

HIV testing was performed following standardised procedures defined by the Zambian Ministry of Health, using two types of approved HIV rapid diagnostic test (RDT) kits: Alere Determine™ HIV-1/2 (Alere Medical Co. Ltd.; Matsudo, Japan) and UniGold HIV (Trinity Biotech Manufacturing Ltd.; Bray, Ireland), detecting HIV 1/2 antibodies in capillary blood samples. A negative RDT test was considered HIV-negative, while a positive result required a second confirmatory test. A second positive test was considered HIV-positive, with a negative second test reported as an intermediate result, requiring further testing. Results were promptly communicated to the participants as part of post-test counselling [28].

#### Data recording and statistical analysis

A standardised form was completed for each participant, including basic demographic information, residential location, occupation, reason prompting the test, any previous tests and test result. The form contained no identifying features other than a unique number linked to a register that was stored securely. Data were entered into EpiData version 1.4.4 (EpiData Association; Odense, Denmark) and analysed in Stata version 13 (StataCorp LP; College Station, USA). Descriptive analysis and multivariate logistic regression were performed to obtain HIV positivity rates and odds ratio (*OR*) statistics, including 95% confidence intervals (*CIs*). Gender, age, marital status, year and type of tester (first-time or repeat) were adjusted for in the regression model as they are either known determinants of HIV infection or included in order to identify higher risk groups [14].

#### Ethical considerations

Pre-test counselling and written informed consent were obtained from all participants prior to the collection of a capillary blood sample to test for HIV. Post-test counselling was performed for all positive and negative results, with participants who tested HIV positive managed in accordance with the Zambian National AIDS Strategic Framework 2011–2015, including referral for registration, determination of CD4 count and enrolment in care and treatment programmes [28]. Cases enrolled for care and treatment in the workforce or their dependents were followed up at the workplace health facility [28].

## Results

#### HTC uptake

HTC uptake is derived from the study population size. In the community, a total of 11,638 individuals, aged 15–49 years, have tested for HIV between 2012 and 2015. Invalid records (e.g. being out of the age range analysed here) were excluded. Background characteristics of the study population per year are shown in Table 1. The majority of testers in the communities were female (>58% in all four years), married or in a long-term relationship (>57% in all four years) and about half (range 48.7–56.5% over the four years) were from the youngest age group (15–24 years).

For the workforce, data were available from 2013 to 2015 with an overall study population of 5564 workers (aged 15–49 years). More than 90% of the participants were males, reflecting the typical gender ratio in mining sites (Table 1). The average age was around 31 years with about half of the participants (range 48.2–53.7%) in the 25–34 year-old age group.

The uptake of HTC in the general community and the workforce, stratified per year, is illustrated in Fig. 3a and 3b, including a differentiation between first-time and repeat testers. The number of community participants increased from 2012 to 2013, decreased in 2014 and was highest, both in males and females, in 2015. Two-thirds of HTC users were repeat testers in 2012 and 2013. This proportion increased to 75% in 2014 and 2015 (Table 1).

In the workforce, uptake continuously increased in males and females. The proportion of first-time testers was comparable in 2013 and 2014 at around 40%. It decreased markedly to 11.8% in 2015.

In both the community and the workforce sample, the main reasons to test were 'just to know' and 'just to make sure', as stated by >90% of males and females (Table 2). Few individuals stated other reasons, such as 'feeling sick' or 'worried about partner behaviour.

#### HIV positivity rate

In the community sample, the overall HIV positivity rate was slightly higher in 2014 and 2015 (3.4% in both years) than the previous years (3.0% in 2012 and 3.3% in 2013; Fig. 4). As shown by logistic regression in Table 3, there was no significant change over time. It needs to be noted that samples of individual years are not independent due to potential repeat testers (although not all repeat testers necessarily tested more than once in the HTC offered by FQML), leading to too narrow *CI* estimates. The HIV positivity rate in females was consistently higher than in males. Overall, females had twice the odds of being tested positive for HIV than males (*OR* = 1.96, 95% *CI*: 1.55–2.50). No significant difference was found in the positivity rate between first-time (3.3%) and repeat testers (3.3%). The ORs of testing positive were significantly higher in the older age groups (i.e. 25–34 and 35–49 years), compared to the youngest age group (15–24 years). Their ORs to test positive were 2.61 (95% *CI*: 2.00–3.40) and 4.50 (95% *CI*: 3.43–5.90), respectively (Table 3).

Trends in the HIV positivity rate, stratified by communities over the 4-year period, are shown in Table 4. In 2015, HIV positivity rates were highest in the

**Table 1** Characteristics of community and workplace HTC users aged 15–49 years, Trident project area, 2012–2015

| Year | 2012 | 2013 | 2014 | 2015 |
|---|---|---|---|---|
| Community (*n*) | 1003 | 2818 | 1853 | 5964 |
| Males (*n*; %) | 365 (36.4) | 1028 (36.5) | 774 (41.8) | 2261 (37.9) |
| Females (*n*; %) | 638 (63.6) | 1790 (63.5) | 1079 (58.2) | 3703 (62.1) |
| Average age in years ± SD | 25.1 ± 7.9 | 26.3 ± 8.4 | 26.3 ± 7.8 | 26.2 ± 8.3 |
| 15–24 years old (*n*; %) | 567 (56.5) | 1457 (51.7) | 902 (48.7) | 3089 (51.8) |
| 25–34 years old (*n*; %) | 295 (29.4) | 835 (29.6) | 636 (34.3) | 1775 (29.8) |
| 35–49 years old (*n*; %) | 141 (14.1) | 526 (18.7) | 315 (17.0) | 1100 (18.4) |
| Married or in long-term relationship (%; 95% *CI*) | 57.9 (54.8–61.0) | 61.3 (59.4–63.1) | 63.6 (61.3–65.8) | 66.6 (65.4–67.8) |
| First-time tester (%; 95% *CI*) | 33.5 (30.5–36.5) | 32.7 (31.0–34.5) | 24.8 (22.8–26.9) | 25.5 (24.4–26.7) |
| Repeat tester (%; 95% *CI*) | 66.5 (63.5–69.5) | 67.3 (65.5–69.0) | 75.2 (73.1–77.2) | 74.5 (73.3–75.6) |
| Average overall HIV positivity rate (%; 95% *CI*)[1] | 3.0 (2.0–4.2) | 3.3 (2.6–3.9) | 3.4 (2.5–4.2) | 3.4 (2.9–3.9) |
| Workforce (*n*) | - | 1011 | 1852 | 2701 |
| Males (*n*; %) | - | 980 (96.9) | 1753 (94.7) | 2555 (94.6) |
| Females (*n*; %) | - | 31 (3.1) | 99 (5.4) | 146 (5.4) |
| Average age in years ± SD | - | 30.9 ± 7.3 | 30.7 ± 6.7 | 31.7 ± 6.8 |
| 15–24 years old (*n*; %) | - | 213 (21.1) | 352 (19.0) | 396 (14.7) |
| 25–34 years old (*n*; %) | - | 487 (48.2) | 995 (53.7) | 1413 (52.3) |
| 35–49 years old (*n*; %) | - | 311 (30.8) | 505 (27.3) | 892 (33.0) |
| Married or in long-term relationship (%; 95% *CI*) | - | 77.9 (75.3–80.5) | 77.4 (75.4–79.3) | 89.0 (87.7–90.1) |
| First-time tester (%; 95% *CI*) | - | 39.2 (36.2–42.3) | 41.4 (39.1–43.8) | 11.8 (10.5–13.1) |
| Repeat tester (%; 95% *CI*) | - | 60.8 (57.7–63.8) | 58.6 (56.2–60.9) | 88.2 (86.9–89.5) |
| Average overall HIV positivity rate (%; 95% *CI*)[1] | - | 5.2 (4.0–6.8) | 3.5 (2.7–4.5) | 4.4 (3.6–5.2) |

*CI*, confidence interval; *SD* standard deviation; –, no data available
[1]Samples of individual years are non-independent due to repeat testers (although not all repeat testers necessarily tested more than once in the HTC offered by FQML) leading to a too narrow *CI* estimate

communities of Northern Resettlement (5.1%), followed by Chisasa (5.0%) and Kanzanji (4.8%).

In the workforce, the HIV positivity rate in males was 5.3% in 2013, 3.1% in 2014 and 4.2% in 2015 (Fig. 4c). An upward trend was observed in the positivity rate in females: one out of 31 (3.2%) women tested positive in 2013; 11 out of 99 (11.1%) in 2014 and 12 out of 146 (8.2%) in 2015. Similar to the community sample, females had almost three times higher odds of a positive HIV test (*OR* = 2.90, 95% *CI*: 1.74–4.84; Table 3). Across all years, first-time testers in the workforce sample had a significantly higher HIV positivity rate than repeat testers (5.0% *vs*. 4.0%, *OR* = 1.48, 95% *CI*: 1.08–2.03). The HIV positivity rate was strongly dependent on the age of workers, as those aged 35–49 years had an almost 5 times higher odds of a positive test compared to the youngest age group (*OR* = 4.95, 95% *CI*: 2.94–8.32).

## Discussion

The findings from HTC from 2012 to 2015 offered in the Trident project mining area suggest a growing trend of HTC uptake, an insignificantly higher HIV positivity rate in 2014/2015 compared to earlier years (2012 and 2013) in the general community and a insignificantly lower rate in the workplace population in 2015 (4.4%) compared to 2013 (5.2%).

### HTC uptake

HTC is one of the key strategies for HIV control but to date, most people in low- and middle-income countries still do not know their HIV status [29, 30]. In Zambia, HTC uptake is promoted at different venues, including facility-, community- and workplace-based HTC [28, 31]. As was previously found in rural communities with weak health infrastructure and HIV programming, the provision of community-based HTC in the 13 communities supported the uptake of HIV testing [32–34]. Since the HTC described here is provider-driven, this can be partly attributed to the extension of activities into newly visited communities and the up-scaling of activities in previously visited communities and partly to an increased demand. In two repeated cross-sectional surveys in seven project-impacted communities, it was found that the proportion of females who have ever performed an HIV test increased from 76.6% in 2011 to 86.1% in 2015 [20, 27]. At the workplace, uptake augmented uniformly every year.

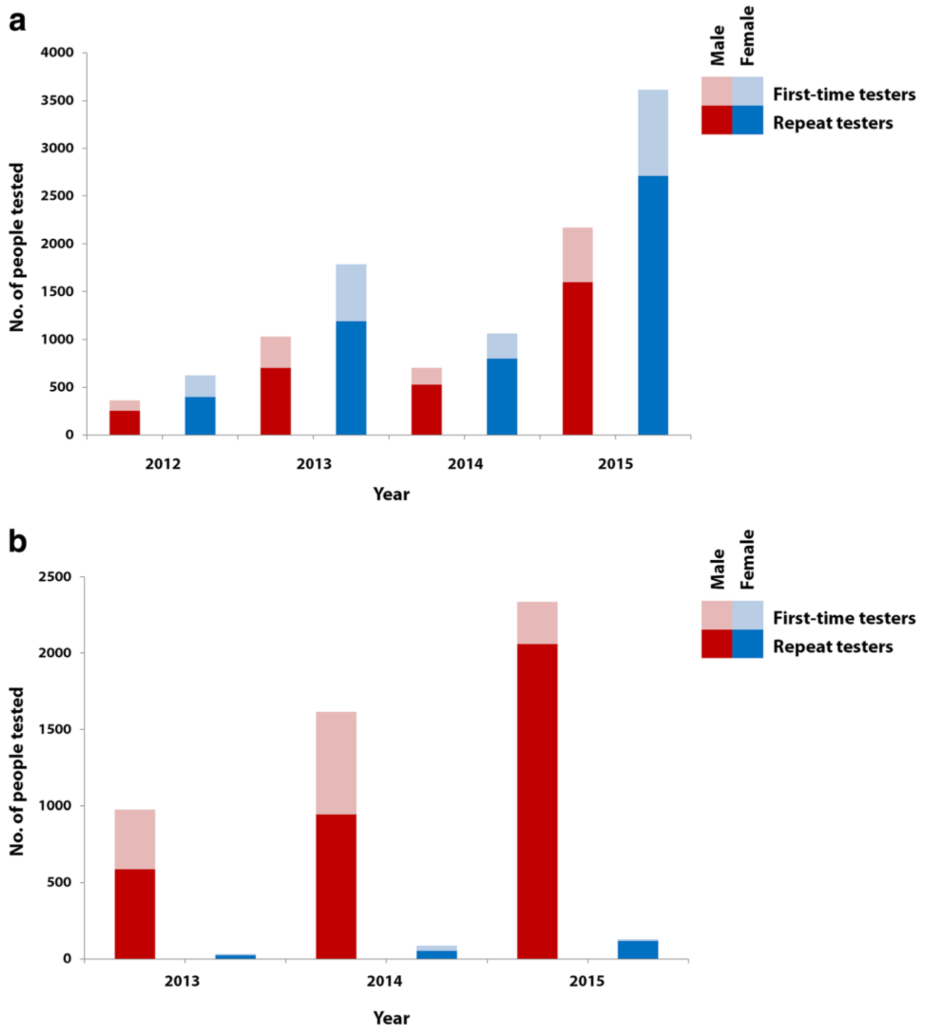


**Fig. 3** Uptake of HTC by first-time and repeat testers aged 15–49 years, Trident project area, 2012-2015. **a** Community; **b** workforce

**Table 2** Self-reported reasons for using HTC services in adults aged 15–49 years, Trident project area, 2012–2015

| Reasons stated for HTC use (%) | Community | | Workforce | |
|---|---|---|---|---|
| Gender | Male | Female | Male | Female |
| *n* | 4224 | 6867 | 5035 | 261 |
| Feeling sick | 0.4 | 0.4 | 0.1 | 0.0 |
| Partner is HIV-positive | 0.1 | 0.1 | 0.1 | 0.0 |
| Expecting parent, potential prevention of mother-to-child transmission | 0.3 | 3.5 | 0.0 | 0.0 |
| Just to make sure | 22.0 | 22.4 | 31.6 | 31.0 |
| Just to know | 77.1 | 73.2 | 68.0 | 68.2 |
| Worried about partner behaviour | 0.1 | 0.2 | 0.1 | 0.4 |
| Other | 0.1 | 0.1 | 0.1 | 0.4 |

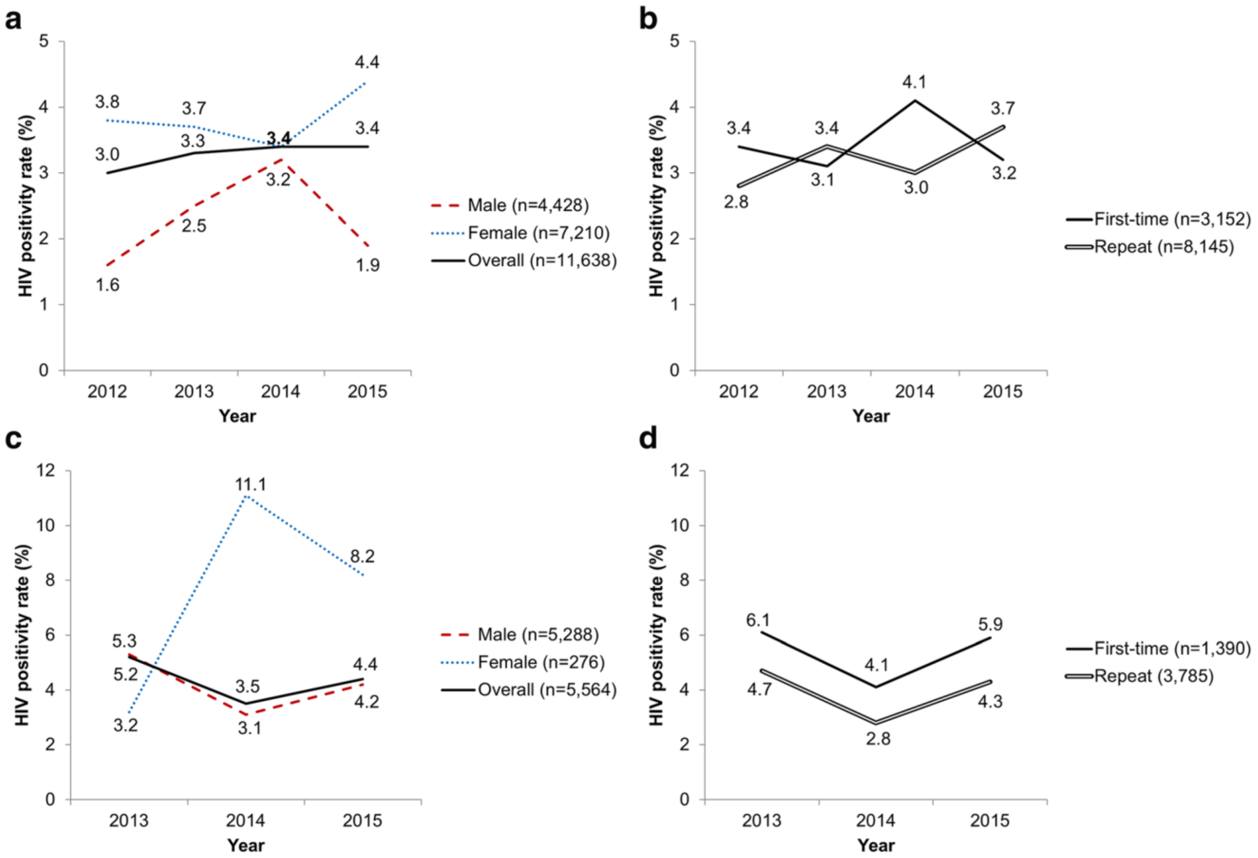


**Fig. 4** HIV positivity rate in HTC users aged 15–49 years, Trident project area, 2012–2015. **a** Community, stratified by sex; **b** community, stratified by first-time and repeat testers; **c** workforce, stratified by sex; **d** workforce, stratified by first-time and repeat testers

**Table 3** Multivariate logistic regression analysis for the HIV positivity rate in HTC users aged 15–49 years, Trident project area, 2012–2015

| | | Community | | | Workforce | | |
|---|---|---|---|---|---|---|---|
| | | *n* | Positivity rate 2012–2015 (%, 95% *CI*)[a] | a*OR*[b] (95% *CI*) | *n* | Positivity rate 2013–2015 (%, 95% *CI*)[a] | a*OR*[b] (95% *CI*) |
| Gender | Male | 4428 | 2.3 (1.8–2.7) | 1.00 | 5288 | 4.0 (3.4–4.5) | 1.00 |
| | Female | 7210 | 4.0 (3.5–4.5) | 1.96 (1.55–2.50) | 276 | 8.7 (5.6–12.7) | 2.90 (1.74–4.84) |
| Year | 2012 | 1003 | 3.0 (2.0–4.2) | 1.00 | n/a | n/a | n/a |
| | 2013 | 2818 | 3.3 (2.6–3.9) | 1.03 (0.67–1.58) | 1011 | 5.2 (3.9–6.8) | 1.00 |
| | 2014 | 1853 | 3.4 (2.5–4.2) | 1.10 (0.69–1.73) | 1852 | 3.5 (2.7–4.4) | 0.61 (0.41–0.90) |
| | 2015 | 5964 | 3.4 (2.9–3.9) | 1.11 (0.75–1.67) | 2701 | 4.3 (3.6–5.2) | 0.89 (0.62–1.27) |
| Type | Repeat tester | 8145 | 3.3 (2.9–3.7) | 1.00 | 3785 | 4.0 (3.3–4.6) | 1.00 |
| | First-time tester | 3152 | 3.3 (2.7–3.9) | 1.03 (0.82–1.31) | 1390 | 5.0 (3.9–6.3) | 1.48 (1.08–2.03) |
| Marital status | Married or long-term relationship | 7457 | 3.4 (2.9–3.8) | 1.00 | 4624 | 4.3 (3.7–4.9) | 1.00 |
| | Other | 4181 | 3.3 (2.7–3.8) | 1.46 (1.17–1.84) | 940 | 3.9 (2.7–5.3) | 1.22 (0.80–1.84) |
| Age group | 15–24 years | 6015 | 1.8 (1.4–2.1) | 1.00 | 961 | 2.0 (1.1–3.0) | 1.00 |
| | 25–34 years | 3541 | 4.0 (3.4–4.7) | 2.61 (2.00–3.40) | 2895 | 2.8 (2.2–3.5) | 1.63 (0.96–2.75) |
| | 35–49 years | 2082 | 6.6 (5.5–7.7) | 4.50 (3.43–5.90) | 1708 | 7.9 (6.6–9.2) | 4.95 (2.94–8.32) |

a*OR*, adjusted odds ratio; *CI*, confidence interval; *n/a*, not applicable
[a]Samples of individual years are non-independent due to repeat testers (although not all repeat testers necessarily tested more than once in the HTC offered by FQML) leading to a too narrow CI estimate
[b]*OR* are mutually adjusted for the variables listed in the table

**Table 4** HIV positivity rate in community members aged 15–49 years using HTC services per community, Trident project area, 2012–2015

| Community | 2012 | | 2013 | | 2014 | | 2015 | |
|---|---|---|---|---|---|---|---|---|
| | *n* | % (95% *CI*)[a] | *n* | % (95% *CI*)[a] | *n* | % (95% *CI*)[a] | *n* | % (95% *CI*)[a] |
| Kankonzhi | 117 | 4.3 (1.4–9.6) | 390 | 1.8 (0.7–3.6) | 281 | 2.1 (0.7–4.5) | 600 | 3.0 (1.7–4.6) |
| Wanyinwa | 240 | 4.6 (2.3–8.0) | 455 | 4.0 (2.3–6.1) | - | - | - | - |
| Musele | 270 | 1.9 (0.6–4.2) | 753 | 3.9 (2.5–5.4) | 347 | 1.7 (0.6–3.7) | 1123 | 3.0 (1.7–4.6) |
| Chisasa | 245 | 3.3 (1.4–6.3) | 621 | 3.4 (2.1–5.1) | 474 | 3.6 (2.1–5.6) | 1193 | 5.0 (3.8–6.4) |
| Chovwe | 74 | 1.4 (0.0–7.3) | 311 | 2.3 (0.9–4.5) | 156 | 4.5 (1.8–9.0) | 563 | 4.3 (2.7–6.2) |
| Muzangezhi | 57 | 0.0 (-.) | - | - | - | - | 226 | 1.7 (0.4–4.4) |
| Watambo | - | - | 288 | 3.5 (1.6–6.2) | - | - | 220 | 0.5 (0.0–2.5) |
| Northern Resettlement | - | - | - | - | 255 | 3.5 (1.6–6.5) | 415 | 5.1 (3.1–7.6) |
| Kalumbila Town | - | - | - | - | 340 | 5.0 (2.9–7.8) | 471 | 3.8 (2.2–5.9) |
| Shenengene | - | - | - | - | - | - | 425 | 2.1 (0.9–3.9) |
| Kanzanji | - | - | - | - | - | - | 230 | 4.8 (2.4–8.3) |
| Jiundu | - | - | - | - | - | - | 336 | 0.6 (0.0–2.1) |
| Kambishi | - | - | - | - | - | - | 162 | 1.2 (0.1–4.3) |
| Overall | 1003 | 3.0 (2.0–4.2) | 2818 | 3.3 (2.6–3.9) | 1853 | 3.4 (2.5–4.2) | 5964 | 3.4 (2.9–3.9) |

CI, confidence interval; -, no data available
[a]Samples of individual years are non-independent due to repeat testers (although not all repeat testers necessarily tested more than once in the HTC offered by FQML) leading to a too narrow *CI* estimate

Convenient access to HTC at multiple workplace locations was previously found to increase HIV testing coverage, especially when linked to HIV care and treatment programmes [35, 36]. In 2015, Solwezi district had by far the highest uptake of HTC, accounting for 55% of the total of 56,902 HTC users in Northwestern province [37]. In both the workplace and community study populations, the proportion of repeat testers increased over time, as in other HTC studies, suggesting an effective programme [34, 38].

### HIV positivity rate

The HIV positivity rate measured through community-based HTC was slightly higher in 2015 (3.4%) than in 2012 (3.0%). This is lower than prevalences measured during the 2013-2014 DHS in Northwestern province in the same age group (6.4%), although comparability with the non-random estimates presented here is limited [14, 39, 40]. Hence, these observations must be interpreted against the following background. First, there is a presumably lower HIV prevalence in the rural study area pre-project, as compared to other areas in the province (e.g. urban centres or mining towns) [14]. Second, the highest HIV prevalence during the DHS was observed in mining towns [17, 41]. Third, we noted targeted HIV management in the study area, in face of potential exclusion of high prevalence groups. Importantly, HTC in our setting was provider- rather than demand-driven, which might explain some of the observed differences over time and space. The highest HIV positivity rates in 2015 were recorded in Northern Resettlement and Chisasa (5.1% and 5.0%, respectively). These communities are dynamic, with extensive in- and out-migration. Northern Resettlement has attracted job-seeking migrants with a high proportion currently employed (in July 2015, 76.5% of households had at least one member employed by the project) [42]. This has led to relative wealth in the community compared to the surrounding rural areas [42]. Chisasa is the main urban settlement outside of the project area and has received the bulk of migrants, with a cross-sectional health survey conducted in mid-2015 reporting that 68% of respondents were resident for less than 5 years [15, 42]. Moreover, Chisasa reported the highest rates of multiple sex partners and transactional sex in the 12 months before the said survey [17, 42]. Data from this study, together with other social and health data, support the identification of hotspot communities and the timely design of preventive measures tailored in response to the needs of these communities.

The overall HIV positivity rate in the workforce was consistently 1–2% above the rate observed in the communities. The effect of labour migration from areas of high HIV prevalence on the observed HIV positivity rates is difficult to assess as participants' migration history was not inquired prior to 2016 [16, 40]. In 2015, 9.7% of people aged 15 years and above were tested positive for HIV during HTC in Solwezi district [37]. These data mainly stem from mining towns, such as Solwezi. Hence, the higher HIV positivity rate in the workforce might be explained by the higher HIV prevalence observed in these labour-sending areas [16, 37]. Whilst the observed trends in HIV positivity rates have not shown significant increases as seen in other mining areas in Africa, rigorous surveillance is warranted to rapidly pick up changing patterns and high-risk groups [43, 44].

Our reported HIV positivity rate data do not shed full light on the true prevalence or incidence. Nevertheless, our data may serve as a benchmark for surveillance in this population affected by a large mining project complementary to other data sources, such as the Zambia national sentinel surveillance system and population-based prevalence surveys [14, 45].

### Experience from HIA

Ending the AIDS epidemic by 2030 is a declared goal in the Sustainable Development Goals (SDGs) era [46]. According to the SDGs agenda, health-related targets are to be considered in developments across all sectors [47]. The HIA provides a means to monitor health and determinants of health indicators and therefore accountability towards the general public, whilst at the same time creating inter-sectoral collaboration and strengthening public-private partnerships. For the Trident project, the HIA guided, through the identification of socioeconomic and environmental determinants of health, the HIV management plan, which was readily adapted to the specific context and supported the Zambian HTC implementation plan, while at the same time mitigating project-related risks [31]. According to experience by project decision-makers, the implementation of the HIV management plan was further promoted through: (i) the continuous support of the HIA by public health professionals; (ii) the close collaboration with the Ministry of Health at national and local level; (iii) adequate and skilled human resources to implement the interventions; (iv) the resident model, i.e. national migrant and expatriate workers reside with their families in the area, as opposed to the rotational model with frequent travel into and out of the area; (v) the consistency of funding and management support from FQML; and, importantly (vi) the partnership and support from traditional authorities and local communities.

### Limitations

First, the data presented here stem from HTC offered on a voluntary basis (i.e. walk-in mobile clinics). Hence, our approach was provider- rather than demand-driven, which might lead to under- or over-representation of particular population groups. Second, community members and workers may use alternative facilities for HTC or test more than once, and hence, the reported HTC uptake and HIV positivity rate might be slightly under- or overestimated. Third, our data do not allow distinguishing between first-time or repeat testers offered by FQML or elsewhere. Due to repeat testers within the FQML HTC, the samples of individual years are non-independent, leading to too narrow CI estimates. Of note, in the Additional file 2, we show HIV positivity rates and CI for first-time testers only. Finally, the HIV positivity rate data in both study populations presented are monitoring trends but caution is warranted when relying on these for estimation of prevalence or detection of sudden changes in transmission, due to the time lag between exposure and testing date and the extent of non-testers.

## Conclusions

Between 2012 and 2015, HTC uptake increased five-fold in the community and almost three-fold in the workforce study populations in the Trident project area in Zambia, whilst the HIV positivity rates was insignificantly higher in 2015 compared to 2012. In the current mining setting, the HIA triggered the continued collection of data which can be used along with other surveillance data sources in tracking HIV trends. There are few examples in the public domain on how HIV/AIDS and other health issues are addressed within an evidence-based impact assessment process for mining or other large-scale projects in sub-Saharan Africa [22, 48, 49]. Good practice case studies on how HIA and associated health monitoring can benefit communities, the host government and projects are needed to increase its visibility and underpin the importance of institutionalizing HIA at the national level in low- and middle-income countries [5, 18]. The current study has several strengths. First, it allows to transparently communicate trends in HTC uptake and HIV positivity rate in the copper mine project area with the public. Second, hotspot-communities that need to be intensively targeted with preventive interventions could be identified. The research effort can serve as a good practice example of HIA and inter-sector collaboration, as advocated by the 2030 SDGs agenda.

## Additional files

**Additional file 1:** Multilingual abstracts in the six official working languages of the United Nations. (PDF 639 kb)

**Additional file 2:** HIV positivity rate of first-time testers in community members and workforce aged 15–49 years, Trident project area, 2012–2015. (DOCX 44 kb)

### Abbreviations

AIDS: Acquired Immune Deficiency Syndrome; CI: Confidence Interval; DHS: Demographic and Health Survey; FQML: First Quantum Minerals Limited; HIA: Health Impact Assessment; HIV: Human Immunodeficiency Virus; HTC : HIV Testing and Counselling; OR: Odds Ratio; RDT: Rapid Diagnostic Test; WHO: World Health Organization

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**Availability of data and materials**
Data pertaining to HIV/AIDS in the study area are attached with issues of stigma and fear. Hence, supporting data are neither shared nor made publicity available. Moreover, the current dataset contains information not presented here, but might be used for additional analyses. Excerpts from the dataset can be made available from the corresponding author upon reasonable request.

**Authors' contributions**
AP, GM, KN, MJD and HG designed the HIV management plan, including the HTC in collaboration with the Solwezi district health management team. First Quantum Minerals Limited is the principal investigator and coordinator of the HTC and data collection activities. MO managed data entry, cleaning and preparation of the database for statistical analysis, supported by the First Quantum Minerals Limited health team. AMK, MJD, MO and MSW wrote the first draft of the manuscript. AMK, MJD, MO, GM, AP, KN, HG, JU and MSW contributed to the draft development. All authors read and approved the final version of the manuscript for submission.

**Competing interests**
First Quantum Minerals Limited and the Trident project funded the health impact assessment and health interventions, including HTC for HIV. MJD, MO, MSW and AMK have all supported First Quantum Minerals Limited and the Trident project as independent public and occupational health specialists. The corresponding author had full access to all the data in the study and had final responsibility for the decision to submit for publication. AP and GM are contractual employees from First Quantum Minerals Limited.

**Consent for publication**
Not applicable.

**Ethics approval and consent to participate**
HIV testing and councelling (HTC) is provided by the private sector in accordance with the Zambian National AIDS Strategic Framework 2011–2015 and the Zambian HTC implementation plan 2014–2016). Pre-test counselling and written informed consent were obtained from all participants prior to the collection of a capillary blood sample to test for HIV. Post-test counselling was performed for all positive and negative results.

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# 9 Monitoring of selected health indicators in children affected by a large-scale copper mine development in northwestern Zambia

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# Monitoring of Selected Health Indicators in Children Living in a Copper Mine Development Area in Northwestern Zambia

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**Abstract:** The epidemiology of malaria, anaemia and malnutrition in children is potentially altered in mining development areas. In a copper extraction project in northwestern Zambia, a health impact assessment (HIA) was commissioned to predict, manage and monitor health impacts. Two cross-sectional surveys were conducted: at baseline prior to project development (2011) and at four years into development (2015). Prevalence of *Plasmodium falciparum*, anaemia and stunting were assessed in under-five-year-old children, while hookworm infection was assessed in children aged 9–14 years in communities impacted and comparison communities not impacted by the project. *P. falciparum* prevalence was significantly higher in 2015 compared to 2011 in both impacted and comparison communities (odds ratio (OR) = 2.51 and OR = 6.97, respectively). Stunting was significantly lower in 2015 in impacted communities only (OR = 0.63). Anaemia was slightly lower in 2015 compared to baseline in both impacted and comparison communities. Resettlement due to the project and migration background (i.e., moving into the area within the past five years) were generally associated with better health outcomes in 2015. We conclude that repeated cross-sectional surveys to monitor health in communities impacted by projects should become an integral part of HIA to deepen the understanding of changing patterns of health and support implementation of setting-specific public health measures.

**Keywords:** anaemia; health impact assessment; hookworm; malaria; migration; stunting; Zambia

## 1. Introduction

Solwezi district in the Northwestern Province of Zambia has traditionally been a rural, sparsely populated area [1]. However, recent mining developments (i.e., the Kansanshi and Lumwana copper mines) have accelerated in-migration and altered the socioeconomic profile of the district [2,3]. In 2009, the Trident project—a copper mine operated by First Quantum Minerals Limited (FQML)—was launched [4,5]. The mine, which became operational in 2015, is a green field development in a previously remote forested area, covering a lease area of approximately 950 $km^2$. The development included construction of an open pit mine, processing plant, power lines, airstrip, maintenance and administrative infrastructure, access roads and a new residential settlement for the mine workforce and their families. The project development spurred socio-demographic and economic changes in the local community, including physical resettlement, influx of job- and opportunity-seeking migrants, shift in livelihood strategies and urbanization [6,7]. Hence, the direct and indirect ecological, social, economic and health impacts placed on the communities living in this area have been considerable [8,9].

Traditionally, studies determining community health impacts associated with mining have focused on HIV and other sexually transmitted infections (STIs), tuberculosis, water and air quality or exposure to hazardous chemical substances [10,11]. Furthermore, malaria is often considered by companies operating in the tropics because of its significant contribution to the local burden of disease and workplace health implications [12]. However, it is less evident how conditions that are especially prevalent in children living in low- and middle-income countries, such as anaemia, diarrhoeal diseases, respiratory tract infections, intestinal parasitic infections or malnutrition are affected by project-related transformations over longer periods of time.

Health impact assessment (HIA) is the recommended approach to predict potential effects of industrial projects on the health of affected populations by considering a broad range of social, cultural, economic and ecological determinants of health [13,14]. As part of the Trident project's feasibility studies, an HIA was commissioned to assist in the identification of potential health impacts and development of a community health management plan to prevent adverse health impacts and maximize health benefits. During the scoping phase of the HIA, a number of health data gaps were identified, which warranted additional primary data collection [15,16]. Hence, a cross-sectional baseline health survey (BHS) was conducted in 2011 [17]. Data from the BHS and secondary data sources (e.g., local health statistics) provided an evidence-base for the subsequent risk assessment phase of the HIA [18]. Therefore, the identified potential health impacts were ranked based on their significance (i.e., impact severity and likelihood of occurrence) using a semi-quantitative risk-ranking matrix [19]. A community health management and monitoring plan was developed that combines continuous and periodic data collection approaches, including district health information system data and repeated cross-sectional health surveys at four-year intervals. While some diseases warrant continuous surveillance depending on their aetiology and significance (e.g., HIV), repeated cross-sectional household surveys at 3–5-year intervals measuring key health indicators are a valid option to observe conditions in communities that may change over longer periods of time (e.g., stunting) and also to allow for assessment of true prevalences as well as knowledge, attitudes and practices (KAP) [20–22].

Here, we present data from two cross-sectional epidemiological surveys: the 2011 BHS, prior to project development, and the first follow-up health survey completed in 2015, hence, four years into project development. Among the broad spectrum of indicators assessed, Table 1 summarizes the ones selected based on their significance for child health and relevance in the current project setting. The paper specifically discusses trends over the four-year period and makes comparisons between impacted communities (i.e., affected by the project development) and non-impacted comparison communities, and describes associated determinants at household and community levels.

**Table 1.** Selected indicators in children and their relevance in the Trident copper mining project area, Zambia.

| Indicator | Definition and Measurement Methods | Relevance to Children's Health and the Local Project Context |
|---|---|---|
| *Plasmodium falciparum* infection prevalence in children aged 6–59 months | *P. falciparum* infection is defined as the detection of the *P. falciparum* histidine-rich protein II antigen in capillary blood using a rapid diagnostic test (RDT; SD BIOLINE Malaria Ag P.f; Standard Diagnostics Inc., Gyeonggi-do, Republic of Korea) [23]. | Improved local economy, vector control measures implemented by the project and better infrastructure (e.g., roads, health facilities) can improve access to vector control measures and health care [12,24]. Environmental alteration due to project activities can potentially increase the number of vector breeding sites [25,26]. Camp follower settlements may develop with poor associated environmental health conditions potentially increasing vector breeding sites and human-vector contact if not managed appropriately [27,28]. |
| Stunting prevalence in in children aged 0–59 months | Stunting, or low height-for-age, is defined as −2 standard deviation units from the WHO reference population median and measured using a digital scale and portable stadiometer (Seca 877; Seca GmbH, Hamburg, Germany) [29]. | Improved local economy can improve nutritional status. Reduced access to agricultural land for local populations and food price inflations due to increased purchasing power can increase the burden of malnutrition |
| Anaemia prevalence in children aged 6–59 months | Anaemia is defined as haemoglobin (Hb) < 11 g/dL in capillary blood assessed using a HemoCue®201+ testing device (HemoCue Hb 201 System; HemoCue AB, Ängelholm, Sweden) [23]. Age was recorded based on the date of birth given in the child's vaccination card, if available, or based on parents report. | Anaemia is used as a proxy indicator for general health and well-being, because of its multifactorial aetiology (e.g., intake and uptake of dietary iron, parasitic infections and prevalence of sickle cell disease) [30–32]. Epidemiology of infectious diseases, access to health care and diets potentially change due to the project development which, in turn, influences rates of anaemia [33]. |
| Hookworm infection prevalence in children aged 9–14 years | Hookworm infection is defined as detection of hookworm eggs in a single thick-smear of a fresh, morning stool sample prepared and examined by the Kato-Katz technique within 20–40 min after slide preparation (using 41.7 mg templates) [34]. Intensity of infection was determined by counting hookworm eggs per slide and multiplied by a factor of 24 to obtain eggs per gram of stool (EPG). | Project-induced in-migration may place pressure on existing sanitation, which poses a risk for the transmission of diarrhoeal diseases and intestinal parasites. Increased income coupled with behaviour change can lead to protection through wearing of footwear. First-time inhabitation of native soil (e.g., new settlements or resettlement), increased use of footwear (due to increased income) and intensive circulation of top soil (due to project-associated activities) can lower exposure to hookworm eggs in the environment. |

## 2. Materials and Methods

### 2.1. Ethical Considerations

The study protocols for the two cross-sectional surveys received approval from the ethics review committee of the Tropical Disease Research Centre (Ndola, Zambia; registration number

00003729). The Solwezi District Health Department supported the studies as a key government partner, with contributions to the study design, community sensitization and fieldwork. At the household level, informed consent (signed or fingerprinted) was obtained from heads of households or mothers/caregivers. At the school level, sensitization activities included school visits prior to the survey. Teachers were informed about the objectives and procedures of the study and consent was obtained by teachers informing parents about the study, who in turn provided written permission to allow their children to participate in the survey. Children assented orally. Children who were found positive for *Plasmodium falciparum* infection using a rapid diagnostic test (RDT) were treated with an artemisinin-based combination therapy, using artemether-lumefantrine, following national protocols. Children found with mild and moderate anaemia (haemoglobin (Hb) 7–11.0 g/dL) were provided with iron and multivitamin supplements, while severe cases (Hb < 7 g/dL, or those with any signs/symptoms of severe anaemia) were referred to the nearest health facility thereby adhering to the public health referral system followed in Zambia. All children who provided stool specimens for parasitological testing were given a single oral dose of albendazole (400 mg).

### 2.2. Study Area and Community Profile

The Trident project is located about 150 km northwest of Solwezi town, the district capital (Figure 1). Chisasa is the major settlement in the study area, at the junction along the T5 highway connecting Solwezi to Mwinilunga district. At the time of the BHS in 2011, over 60% of the adult population was involved in subsistence agriculture and about 2% employed by the project [6]. In 2015, about 35% of the households in the impacted sites had at least one member employed by, or working as a subcontractor for, the project [7].

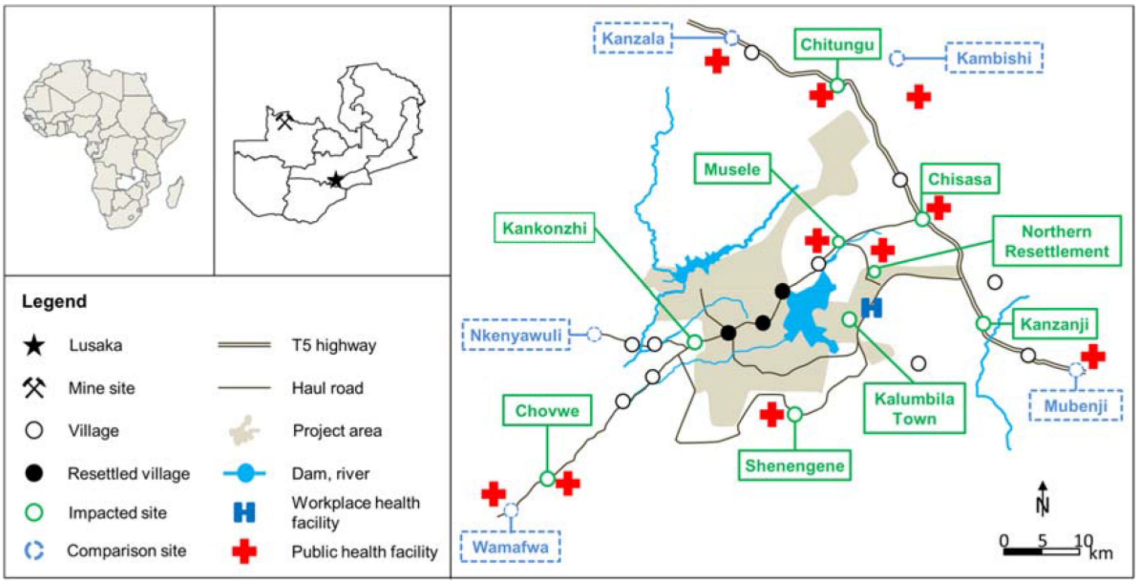


**Figure 1.** Study area and sentinel sites, Trident project, 2011 and 2015, Zambia.

### 2.3. Study Design and Sampling Method

Two cross-sectional, epidemiological surveys were conducted in July 2011 and July 2015, using the same methodology. Considering the heterogeneity in the distribution of project-related health impacts expected across communities, a stepwise, semi-purposive sentinel site sampling strategy, rather than a fully randomised design, was employed in both surveys [17]. In a first step, all villages potentially affected by the project were identified, whereas "potentially" refers to an impact that may or may not occur and "affected" refers to being affected by either a direct impact (e.g., resettlement or project-sponsored health interventions) or an indirect impact (e.g., in-migration along transport corridors) caused by the project [8]. In a second step, impacted sites were semi-purposively selected based on the magnitude and nature of project-related impacts (e.g., resettled communities and communities along transport corridors). Our approach allowed for sampling of smaller, potentially impacted communities that might otherwise have been excluded, had a random cluster sampling proportional to population size been employed [35]. In a third step, comparison sites were chosen based on their socio-demographic and topographic similarity to the impacted sites as well as proximity to the project area, with two inclusion criteria: (i) located outside the project area; and (ii) no or only limited project-associated impacts such as no project-sponsored health interventions in the community or project employees/contractors residing in the community. In the final step, households were randomly selected within the sentinel sites, with the inclusion criteria at the level of the household requiring the presence of a mother (≥15 years) with at least one child under the age of five years. In parallel, schoolchildren from primary schools in the sentinel sites were sampled to screen for hookworm infection, the most prevalent soil-transmitted helminth in the study area [36].

The full list of sentinel sites selected for the 2011 BHS and the 2015 follow-up is shown in Figure 2. In seven sentinel sites, data were collected in both the BHS and follow-up. For an additional seven sentinel sites, data were only available for 2015. This included two impacted sites: the newly developed Kalumbila Town (employee residential area) and Shenengene (a resettlement village). One impacted site was added due to increased importance (Kanzanji became the base of a major mining contractor) and four additional comparison sites were included to augment statistical power for comparison in future surveys. Importantly, findings from Wanyinwa (sampled during the 2011 BHS) are comparable to findings from Northern Resettlement (sampled during the 2015 follow-up) as 97% of the participating households in Northern Resettlement originated from Wanyinwa.

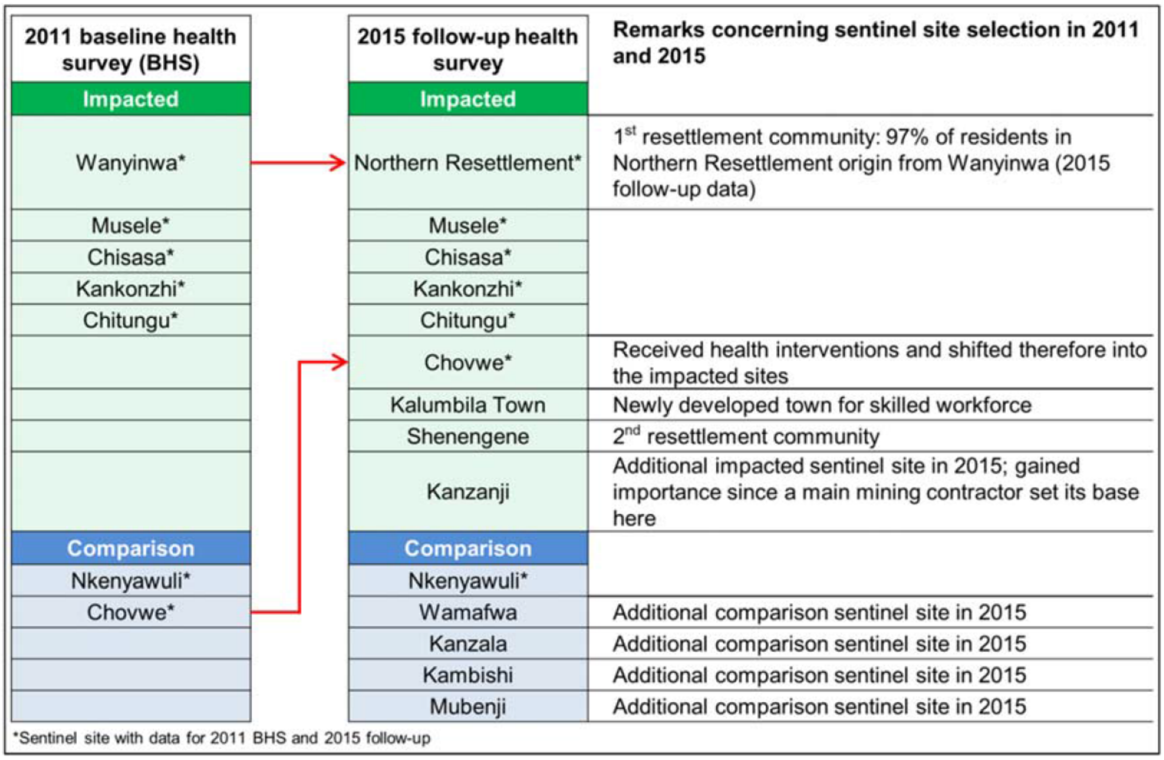


**Figure 2.** Sentinel site selection, Trident project, 2011 and 2015, Zambia.

### 2.4. Data Collection

The surveys included two main data collection methods: (i) a questionnaire interview with caregivers (≥15 years) in the household; and (ii) an assessment of biomedical indicators in children under the age of five years in a mobile field laboratory. The questionnaire focused on KAP related to issues such as health seeking behaviour, maternal and child health, infectious diseases and participation in health interventions. In addition, basic socio-demographic information was collected, including information on recent in-migration (defined as duration of residency in the current location of less than five years). The questionnaire is provided as a supplementary file S1.

On completion of the questionnaire, caregivers together with their under-five-year-old children were asked to visit the field laboratory for the assessment of biomedical indicators. An RDT was used to assess *P. falciparum* infection from a finger-prick capillary blood sample in children aged 6–59 months (see Table 1). Hb concentration was measured in a capillary blood sample from children aged 6–59 months to determine anaemia (defined as Hb < 11 g/dL). Children aged < 5 years had their weight and height measured.

At each school enrolled in the survey, a quota of at least 15 boys and 15 girls was randomly selected. Therefore, all eligible children (i.e., present at the day of the survey; aged 9–14 years) were listed and numbered and the quota was selected using random number sampling. A fresh morning stool sample was collected and subjected to the Kato-Katz technique. A single 41.7 mg thick-smear was examined within 20–40 min for enumeration of hookworm eggs [34]. Eggs were counted and multiplied by a factor of 24 to determine eggs per gram of stool (EPG).

### *2.5. Data Analysis*

In 2011, questionnaire data were entered into EpiData software (EpiData Association; Odense, Denmark). In 2015, data were collected through electronic tablets using the open data kit (ODK) software. Analysis was performed with Stata (StataCorp LP, College Station, TX, USA). Frequencies and odds ratios (ORs) with corresponding 95% confidence intervals (CIs) were determined. Mixed effects logistic regression models were used taking into account clustering at the levels of sentinel sites and of households. The model included a factor for year to capture potential period effects, a factor for type of site (impacted vs. comparison) and an interaction term between the two factors to assess potential differences in changes of prevalence rates from 2011 to 2015 between impacted and comparison sentinel sites. Of note, for 2011 and 2015 comparisons, only sentinel sites that were sampled in both surveys were considered. For analysis with 2015 data only, all 14 sentinel sites were considered.

## 3. Results

### *3.1. Study Population*

The study populations in 2011 and 2015 are shown in Table 2. In 2011, 289 households were sampled from seven sentinel sites, and in 2015, 516 households were sampled from 14 sentinel sites, with a total sample of 483 and 949 children under the age of five years, respectively. Additionally, 309 (2011) and 477 (2015) children aged 9–14 years were sampled from the selected schools. For 2015 only, the proportions of household with resettlement or migration background and the proportion of households using improved sanitation facilities are shown.

### *3.2. P. falciparum Infection Prevalence*

At baseline, children in impacted sites showed a lower odds for *P. falciparum* infection (OR = 0.33, 95% CI 0.05–2.20; Table 3). There was a significantly higher prevalence in 2015 compared to 2011 in all sites and overall in both the impacted and comparison sites, with ORs of 2.51 (95% CI 1.56–4.02) and 6.97 (95% CI 2.20–22.0), respectively, but with no significant different period effect between impacted vs. comparison (OR = 0.36, 95% CI 0.10–1.23).

**Table 2.** Study populations, Trident project, 2011 and 2015, Zambia.

| Sentinel Sites | Households | | Children Aged < 6 Months | | Children Aged 6–59 Months | | School-Going Children Aged 9–14 Years | | Proportion of Households that Have Been Resettled due to the Project | Proportion of Migrant Households (in the Area for <5 Years) | Proportion of Households that Use Improved Sanitation |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Year | 2011 | 2015 | 2011 | 2015 | 2011 | 2015 | 2011 | 2015 | 2015 | 2015 | 2015 |
| Wanyinwa (2011)/Northern Resettlement (2015) | 35 | 34 | 4 | 7 | 60 | 63 | 35 | 30 | 97.1 | 2.9 | 97.1 |
| Musele [1] | 30 | 66 | 2 | 18 | 43 | 116 | 40 | 59 | 3.0 | 30.3 | 34.9 |
| Chisasa [1] | 66 | 65 | 3 | 16 | 94 | 96 | 44 | 60 | 1.5 | 66.2 | 47.7 |
| Kankonzhi [1] | 36 | 30 | 3 | 7 | 70 | 52 | 35 | 29 | 3.3 | 36.7 | 50.0 |
| Chitungu [1] | 30 | 33 | 1 | 8 | 58 | 43 | 57 | 30 | 0.0 | 0.0 | 21.2 |
| Chovwe [1] | 61 | 32 | 3 | 10 | 91 | 43 | 64 | 30 | 0.0 | 6.3 | 43.8 |
| Kalumbila Town | NA | 30 | NA | 7 | NA | 36 | NA | 30 | 0.0 | 100.0 | 100.0 |
| Shenengene | NA | 32 | NA | 4 | NA | 48 | NA | 30 | 96.9 | 3.1 | 93.8 |
| Kanzanji | NA | 32 | NA | 8 | NA | 51 | NA | 29 | 3.1 | 43.8 | 6.3 |
| Total impacted | 258 | 354 | 16 | 85 | 416 | 548 | 275 | 327 | 19.5 | 34.5 | 52.3 |
| Nkenyawuli [1] | 31 | 32 | 8 | 3 | 43 | 65 | 34 | 30 | 0.0 | 6.3 | 37.5 |
| Wamafwa | NA | 33 | NA | 6 | NA | 66 | NA | 30 | 0.0 | 6.1 | 33.3 |
| Kanzala | NA | 32 | NA | 4 | NA | 52 | NA | 30 | 0.0 | 15.6 | 21.9 |
| Kambishi | NA | 32 | NA | 8 | NA | 51 | NA | 30 | 0.0 | 0.0 | 3.1 |
| Mubenji | NA | 33 | NA | 6 | NA | 55 | NA | 30 | 0.0 | 21.2 | 0.0 |
| Total comparison | 31 | 162 | 8 | 27 | 43 | 289 | 34 | 150 | 0.0 | 9.9 | 19.1 |

[1] Sentinel site with data for 2011 BHS and 2015 follow-up; NA: not available.

**Table 3.** Prevalences and period effects for *P. falciparum* infection and stunting, Trident project, 2011 and 2015, Zambia.

| | P. Falciparum Infection in Children Aged 6–59 Months | | | | Stunting in Children Aged 0–59 Months | | | |
|---|---|---|---|---|---|---|---|---|
| | n | Prevalence (%; 95% CI) | OR | p-Value | n | Prevalence (%; 95% CI) | OR | p-Value |
| **Difference at baseline** | | | | | | | | |
| Comparison (2011) | 43 | 32.5 (19.0–48.5) | 1.00 | | 51 | 39.2 (25.8–53.8) | 1.00 | |
| Impacted (2011) | 416 | 17.5 (14.0–21.5) | 0.33 (0.05–2.20) | 0.25 | 432 | 49.7 (44.9–54.5) | 1.61 (0.77–3.35) | 0.20 |
| **Period effect** [1] | | | | | | | | |
| Comparison (2011) | 43 | 32.5 (19.0–48.5) | 1.00 | | 51 | 39.2 (25.8–53.8) | 1.00 | |
| Comparison (2015) | 65 | 70.7 (58.1–81.3) | 6.97 (2.20–22.0) | <0.01 | 68 | 47.0 (34.8–59.5) | 1.41 (0.58–3.46) | 0.44 |
| **Period effect** [1] | | | | | | | | |
| Impacted (2011) | 416 | 17.5 (14.0–21.5) | 1.00 | | 432 | 49.7 (44.9–54.5) | 1.00 | |
| Impacted (2015) | 413 | 30.9 (26.5–35.6) | 2.51 (1.56–4.02) | <0.01 | 479 | 39.4 (35.0–43.9) | 0.63 (0.46–0.87) | <0.01 |
| **Change over time in impacted vs. comparison sites** | | | | | | | | |
| Comparison (2011–2015) | n/a | n/a | 1.00 | | n/a | n/a | 1.00 | |
| Impacted (2011–2015) | n/a | n/a | 0.36 (0.10–1.23) | 0.10 | n/a | n/a | 0.44 (0.17–1.15) | 0.09 |

[1] Describes the change in prevalence between 2011 and 2015; CI: confidence interval; n: sample size; n/a: not applicable; OR, odds ratio.

In Figure 3a, the prevalences of 2011 (x-axis) and 2015 (y-axis) are plotted against each other. Communities whose prevalence has increased are plotted in the upper left half of the graph coloured in red and communities whose prevalence has decreased are plotted in the lower right half of the graph coloured in green. Communities whose prevalence has remained stable are located on, or close to the grey line. Wanyinwa/Northern Resettlement and Chisasa were least affected by *P. falciparum* infection in both 2011 and 2015. In 2015, both communities exhibited high proportions of resettled households and new settlers and, as illustrated in Figure 4a, children with a resettlement or migration background had significantly lower odds of being infected with *P. falciparum*.

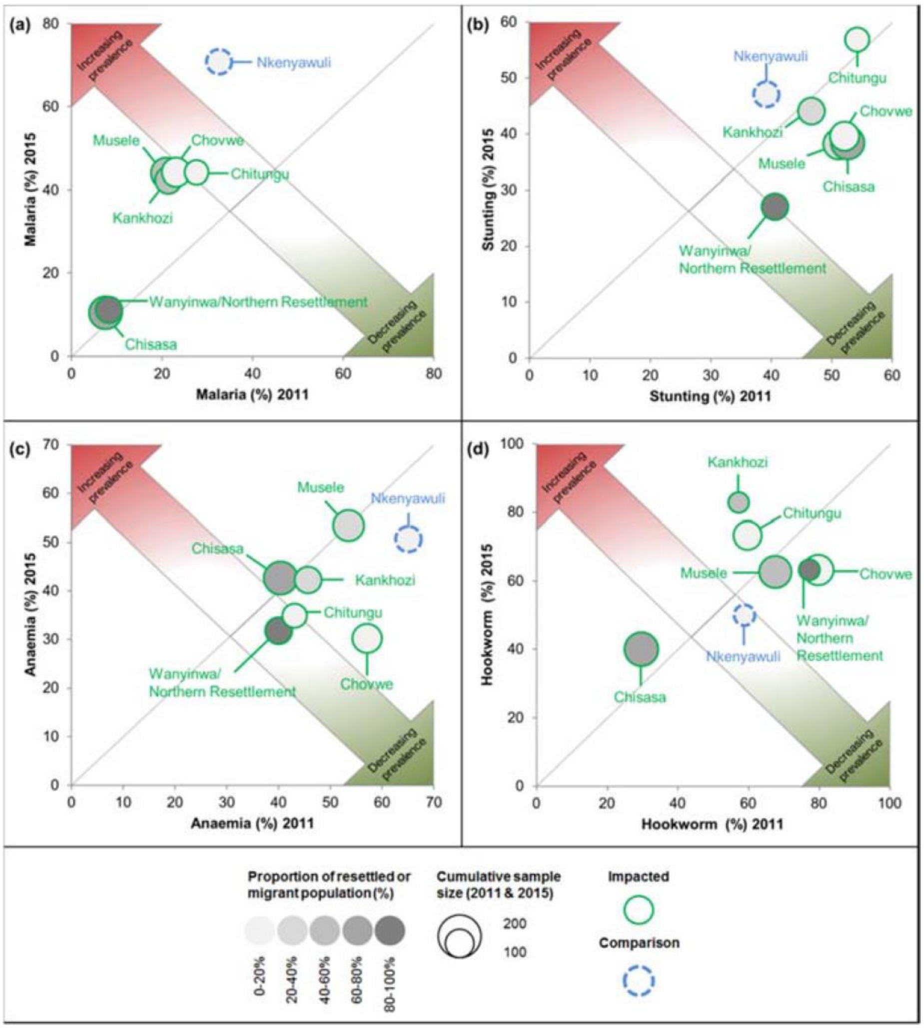


**Figure 3.** Prevalence rates per sentinel site, Trident project, 2011 and 2015, Zambia: (**a**) prevalence of *P. falciparum* in children aged 6–59 months; (**b**) prevalence of stunting in children aged 0–59 months; (**c**) prevalence of anaemia in children aged 6–59 months; and (**d**) prevalence of hookworm in children aged 9–14 years.

### *3.3. Stunting Prevalence*

At baseline, the stunting rate was slightly higher in the impacted compared to the comparison sites but with no statistical significance (OR = 1.61, 95% CI 0.77–3.35; Table 3). In 2015, stunting was significantly lower in the impacted sites compared to 2011 (OR = 0.63, 95% CI 0.46–0.87), whilst in the comparison sites stunting was higher in 2015 (OR = 1.41, 95% CI 0.58–3.46).

Two factors significantly lowered the risk for stunting in the 2015 study population: (i) access to improved sanitation facilities; and (ii) originating from the richest wealth quartile (Figure 4b). In 2015, children from Northern Resettlement were least affected by stunting (Figure 3b).

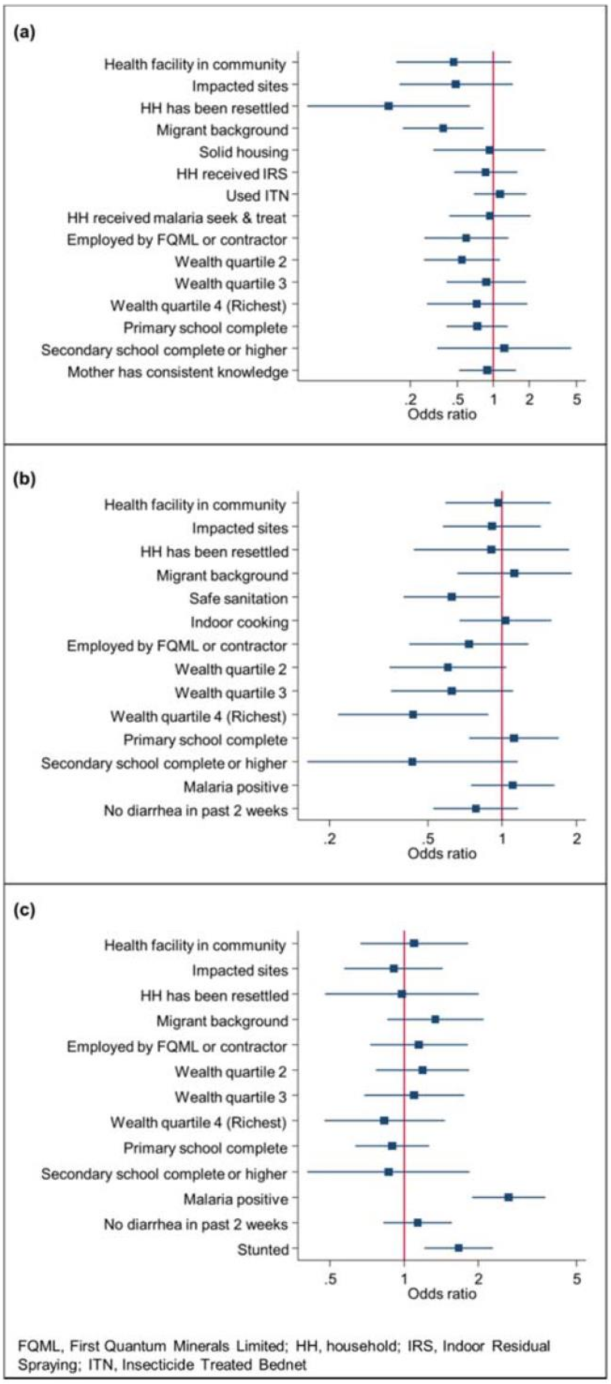


**Figure 4.** Determinants of health outcomes during the 2015 follow-up health survey, with adjusted odds ratios and 95% confidence intervals, Trident project, Zambia: (**a**) determinants of *P. falciparum* in children aged 6–59 months; (**b**) determinants of stunting in children aged 0-59 months; and (**c**) determinants of anaemia in children aged 6–59 months.

### 3.4. Anaemia Prevalence

While the difference in anaemia prevalence between impacted and comparison sites was significant at baseline ($p = 0.04$), there were no significant changes over time in the two categories of sites, although it decreased in both; from 46.6% (194/416) to 41.9% (173/413) in the impacted and from 65.1% (28/43) to 50.8% (33/65) in the comparison sites, respectively (Table 4). Anaemia prevalence was lower in 2015 in all but two sentinel sites (i.e., Chisasa and Musele), where it remained stable (Figure 3c). In 2015, factors significantly associated with anaemia in a child were a concurrent *P. falciparum* parasitaemia and stunted growth (Figure 4c).

**Table 4.** Prevalences and period effects for anaemia and hookworm, Trident project, 2011 and 2015, Zambia.

| | Anaemia in Children Aged 6–59 Months | | | | Hookworm in Children Aged 9–14 Years | | | |
|---|---|---|---|---|---|---|---|---|
| | n | Prevalence (%; 95% CI) | OR | *p*-Value | n | Prevalence (%; 95% CI) | OR | *p*-Value |
| **Difference at baseline** | | | | | | | | |
| Comparison (2011) | 43 | 65.1 (49.0–78.9) | 1.00 | | 34 | 58.8 (40.6–75.3) | 1.00 | |
| Impacted (2011) | 416 | 46.6 (41.7–51.5) | 0.47 (0.22–0.98) | 0.04 | 275 | 62.5 (56.5–68.2) | 1.16 (0.33–4.03) | 0.80 |
| **Period effect [1]** | | | | | | | | |
| Comparison (2011) | 43 | 65.1 (49.0–78.9) | 1.00 | | 34 | 58.8 (40.6–75.3) | 1.00 | |
| Comparison (2015) | 65 | 50.8 (38.0–63.3) | 0.55 (0.24–1.22) | 0.14 | 30 | 50.0 (31.2–68.7) | 0.69 (0.25–1.88) | 0.47 |
| **Period effect [1]** | | | | | | | | |
| Impacted (2011) | 416 | 46.6 (41.7–51.5) | 1.00 | | 275 | 62.5 (56.5–68.2) | 1.00 | |
| Impacted (2015) | 413 | 41.9 (37.0–46.8) | 0.79 (0.60–1.05) | 0.11 | 238 | 60.9 (54.4–67.1) | 1.07 (0.73–1.56) | 0.71 |
| **Change over time in impacted vs. comparison sites** | | | | | | | | |
| Comparison (2011–2015) | n/a | n/a | 1.00 | | n/a | n/a | 1.00 | |
| Impacted (2011–2015) | n/a | n/a | 1.44 (0.62–3.36) | 0.39 | n/a | n/a | 1.54 (0.53–4.46) | 0.42 |

CI, confidence interval; n: sample size; n/a: not applicable; OR, odds ratio; [1] Describes the change in prevalence between 2011 and 2015.

### 3.5. Hookworm Infection Prevalence

The overall prevalence of hookworm infection slightly decreased from 62.5% (172/275) to 60.9% (145/238) in the impacted sites and from 58.8% (20/34) to 50.0% (15/30) in the comparison sites. Hence, the rates of infection did not change significantly over time ($p = 0.71$ and $p = 0.47$, respectively; Table 4). Chisasa had the lowest infection rate in 2015, which was however higher than the rate recorded in 2011 (Figure 3d).

## 4. Discussion

Presented here is a selection of indicators in children from two cross-sectional surveys spaced by four years within the frame of the Trident copper development project in Zambia. Living in an impacted sentinel site or in a resettled household was associated with better health outcomes for *P. falciparum* infection, anaemia and stunting in under-five-year-old children. Improved health outcomes were reported in association with distal factors such as employment or relative household wealth, suggesting that the project development may result in positive effects on the health status of children.

The most noticeable change observed was the higher prevalence of the *P. falciparum* infection rate in 2015 compared to 2011 in all sentinel sites. Nkenyawuli, the only comparison site sampled in both 2011 and 2015, showed a markedly higher prevalence in 2015 compared to the impacted sites. Malaria control interventions have been implemented by the project and district health management teams in the impacted sentinel sites, including indoor residual spraying (IRS), distribution of long-lasting insecticidal nets (LLINs), education and awareness and 'malaria seek and treat' (i.e., active case detection and treatment performed through house-to-house visits at weekly intervals) [37]. These interventions were generally associated with lower odds for *P. falciparum* infection. Children in resettled households showed significantly lower *P. falciparum* infection rates in 2015. In the newly built settlements of Northern Resettlement and Shenengene, prevalences were lowest at 10.9% and 6.3% in 2015, respectively, with the new, solid housing structures having closed eaves and window screens that are associated with lower infection risk as shown before in other malaria-endemic settings [38]. When excluding resettled or migrant households, no other factor was found a determinant for *P. falciparum* infection (see supplementary Figure S2). Nevertheless, across the entire study area, the 2015 follow-up showed higher *P. falciparum* infection prevalence compared to the 2011 baseline. This observation is in line with a wider trend in Northwestern Province found during two consecutive Malaria Indicator Surveys (MIS). Indeed, the prevalence in under-five-year-old children, as assessed by RDT, was 17.3% in 2010, while it was almost double in 2012 (32.5%) [23,39]. The strong increase coupled with the absence of significant associations with common risk factors at household and community level point to an environmental influence. As both surveys were conducted in July, we speculate that there were considerable inter-annual fluctuations, such as changes in the average temperature or precipitation [40,41].

The stunting rate in children is influenced by a multitude of factors such as recurrent infectious diseases (e.g., hookworm infection), persistent enteropathy, access to improved sanitation and safe drinking water, access to food or children migrating from areas with different rates of stunting [42,43]. Overall, the stunting rates in 2015 in the impacted (39.4%) and comparison sites (47.0%) were similar or higher than the average of the Northwestern Province (36.9%), as determined during the 2013/14 Demographic and Health Survey (DHS) [29]. The improvement of stunting between 2011 and 2015 was significant in the impacted sites but not in the comparison sites. Of all the determinants assessed during the 2015 follow-up, wealth and access to improved sanitation were associated with lower stunting rates. Wealth remained a determining factor when excluding resettled or migrant households as well as households with safe sanitation (see supplementary Figure S2). Access to improved sanitation and reduced environmental contamination has been found previously to avert stunting in children [44]. Among the sentinel sites visited in both surveys, Northern Resettlement, where new houses were built with adjoining ventilated improved latrines, had consequently the highest proportion of households with access to safe sanitation in 2015 (97.1%; Table 2) and at the same time the lowest stunting rate.

Anaemia rates in impacted (41.0%) and comparison sites (49.4%) in 2015 were comparable to data obtained during the 2012 MIS for the Northwestern Province, where anaemia was reported in 45.5% in under-five-year-old children [23]. These high rates of anaemia will continue to have long-lasting negative consequences in the study area given that iron deficiency undermines growth, physical fitness and educational performance [30]. Malaria and stunting remained significant determinants for anaemia in multivariate regression models where resettled and migrant households were excluded, respectively (see supplementary Figure S2). This high anaemia rate is a concern, particularly if one considers that health facilities were present in 11 of the 14 sentinel sites (Figure 1) and that health facilities could be most efficient in combating anaemia through the provision of primary health care services, including antimalarial drugs, iron supplementations and growth monitoring [30,45].

To our knowledge, no survey data on soil-transmitted helminths for Solwezi district are publicly available. A recent geostatistical analysis by Karagiannis-Voules et al. (2015) estimated the prevalence of soil-transmitted helminth infections at 50% or higher in the general population in that area, which is in line with our findings (50% in the impacted and 60.9% in the comparison sites, respectively) [36]. Hookworm was the predominant soil-transmitted helminth species in both surveys, with similar prevalences in 2011 and 2015. Most children (94.3%) had mild-to-moderate infection intensities (i.e., <4000 EPG; data not shown) and hookworm infections are therefore expected to play an immaterial role in anaemia burden in the current setting [46]. According to the Solwezi District Health Management team, preventive chemotherapy using albendazole was done seven months prior to each survey—in December 2011 and December 2014. However, breaking transmission of hookworm will remain difficult when children continue to walk barefoot, and hence, are in contact with hookworm egg-contaminated soil in this setting [47].

Migrant populations can be especially vulnerable to ill-health as they face restricted social cohesion and exclusiveness leading to inequalities [48]. However, in the current setting, children with a recent migrant history were generally found in better health than those from host communities. This can be partly explained by the fact that the migrants in this area were labour- or opportunity-seekers as opposed to involuntarily displaced people. For example, migrant children had significantly lower *P. falciparum* infection than children who were born and lived in the study area all along. Interestingly, *P. falciparum* infection prevalence differed greatly between Kalumbila Town (43.2%) and Chisasa (10.4%), the two settings with the highest proportions of migrant households (100% and 65.8%, respectively). While in Chisasa most migrant children came from within Solwezi district (40.9%) or other places in the Northwestern Province (28.8%), most migrant children in Kalumbila Town stem from the Copperbelt Province (43.2%) or Lusaka (8.1%), which are low prevalence areas [23]. For anaemia, however, rates were higher in 2015 compared to 2011 in Chisasa only and remained stable in Kankhozi and Musele, the three sentinel sites with higher proportions of migrants. Potentially new infectious diseases or sudden changes in lifestyle (e.g., feeding habits) coupled with a limited awareness of, and capacity to address, anaemia within the household could explain the slightly higher rates in the migrant population.

The noted differences between migrant and host population of children illustrate the importance of understanding the characteristics of migrant populations (e.g., origin, level of skills, health status, economic means and reasons for migration) and their interplay with the local communities. Despite this, they remain often neglected in HIA, especially when planning public health interventions [49].

The lack of baseline health data is an inherent limitation for monitoring of health in communities subjected to natural resource development and management projects in low- and middle-income countries [50,51]. For the Trident project, the BHS completed in the frame of the HIA provided a strong evidence-base that reflected the health status of communities prior to project development. Supported by this evidence-base, the HIA identified a wide range of health conditions that warranted management and monitoring throughout the project lifecycle. A priority was given to the control of

STIs, including HIV, based on the perceived significant impact, whereas the outcomes of mitigation activities are publicly shared elsewhere [52]. In the absence of a regulation that requires transparent dissemination of HIA outcomes, presenting the findings in the peer-reviewed literature provides an opportunity to adhere to good practice standards such as transparency and the ethical use of evidence, while at the same time producing valuable case studies of HIA practice in the context of natural resource development projects in low- and middle-income countries [53,54]

*Limitations*

There were no data in 2011 for several sentinel sites that were only added in the 2015 follow-up, which obviously restricts "before–after" comparison. However, the five comparison sites surveyed in 2015 should represent a sufficiently large comparison group for future follow-up surveys. The non-random sentinel site sampling strategy allowed for inclusion of sites considered too important to miss but the resulting non-randomised sample and the results are therefore relevant to the selected sentinel sites only. Due to lower sensitivity of a single compared to duplicate Kato-Katz thick smears, the true hookworm prevalence is likely to be higher than presented here [55]. Furthermore, household characteristics and behavioural aspects (e.g., toilet use at school and footwear) were not determined in children participating in the school survey.

## 5. Conclusions

Children living in villages considered impacted by a copper mine development in Northwestern Province of Zambia showed generally better health outcomes for *P. falciparum* infection, anaemia and stunting than children from comparison sites, whereas project-induced changes such as resettlement and employment had a positive influence. These findings though do not infer causality. Through the application of the HIA, health-targets were integrated in a project development that has primarily economic goals, which is in line with the health-in-all sectors approach embraced by the Sustainable Development Goals (SDGs) agenda [56]. Repeated cross-sectional monitoring of key health indicators and determinants of health in communities impacted by projects help to better understand whether and how human health is impacted, which population sub-groups are most vulnerable and help identify underlying risk factors. In collaboration with staff from the local health system, evidence from periodic and longitudinal monitoring generated in the private sector allow for prioritization and adaption of targeted and locally sensitive interventions whereby the public and private sectors share responsibility and synergize efforts in safeguarding human health.

**Supplementary Materials:** The following are available online at www.mdpi.com/1660-4601/14/3/315/s1, supplementary file S1: The questionnaire focused on KAP related to issues such as health seeking behaviour, maternal and child health, infectious diseases and participation in health interventions, supplementary file S2: Wealth remained a determining factor when excluding resettled or migrant households as well as households with safe sanitation.

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# 10 Selected indicators of women's health and associated determinants in the vicinity of a copper mine development in northwestern Zambia

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### 10.1 Abstract

The effects of large-scale development projects in the extractive industry sector on the social, economic and environmental spheres are likely to affect women's health. This includes community development initiatives such as educational programmes, health interventions or upgrading of health facilities supported by a project which are directly associated with woman's wellbeing. In the frame of the health impact assessment (HIA) of the Trident project in Zambia, a baseline (2011) and a follow-up health survey (2015) were conducted to monitor health and health-related indicators in women residing in this copper mining area and in comparison communities not impacted by the project. While all indicators improved between 2011 and 2015 in the impacted and comparison communities, the percentage of mothers giving birth in a health facility, the percentage of women not believing anymore that HIV can be transmitted by witchcraft or other supernatural means, and the percentage of women having ever tested for HIV increased significantly in the impacted but not in the comparison communities. In 2015, better health, behavioural and knowledge outcomes in women were associated with employment by the project (or a sub-contractor thereof), migrant background, increased wealth and higher educational attainment. This example shows that large infrastructure development projects have the potential to positively influence women's health if risks are managed. Cross-sectional monitoring every few years of health outcomes and wider determinants of health needs continuation to judge the project's and the associated HIA's long-term potential for sustainable development and reduction of inequalities.

**Keywords:** Anaemia, health impact assessment, HIV/AIDS, knowledge-, attitudes- and practices (KAP), women and maternal health, migration, mining, resettlement, syphilis, The Republic of Zambia

### 10.2 Background

The sustainable development goals (SDGs) agenda puts health as a central element of all three dimensions of sustainable development, i.e. society, economy and environment, recognizing that health is a most crucial contributor to and beneficiary of development [1, 2]. The SDG agenda specifically pulls other sectors in shared responsibility to safeguard human health through participation, accountability and information sharing mechanisms and thereby promoting synergies between sectors [3]. Along this argument, potential health risks generated by other sectors than health, including the extractive industry sector, should be monitored by means of health-related targets, including social, economic and environmental determinants of health [1, 4].

In 2008, the development of a greenfields copper development, i.e. the Trident project, commenced in the Northwestern province of Zambia [5]. The project is located in a poor, rural area, inclined to a weak and unequal health system rendering the native population especially vulnerable to ill-health [6, 7]. Characteristic to large-scale infrastructure development projects in sub-Saharan Africa, this project has the potential to influence on all three dimensions of sustainable development [8-13]: socially (e.g. through in-migration and disruption of social cohesion) [14-18]; economically (e.g. through shift of occupational activities, increased disposable income or potential inflation of food or goods prices) [9, 19-22]; and environmentally (e.g. through the alteration of existing ecosystems, resettlement, open pit mining and associated infrastructure) [9, 23, 24]. Women's and maternal ill-health might be further exacerbated by such a development for example through economic disadvantages, vulnerability to transactional sex, disruption of social cohesion and mental stress [18, 19, 25-28]. Furthermore, health interventions and community development initiatives (e.g. women empowerment programmes, educational programmes) initiated or supported by projects are another way women's health can be influenced [9, 29-33].

In order to systematically anticipate potential impacts of the project on health outcomes directly or indirectly through effects on the determinants of health from the social, economic and environmental spheres, the project has commissioned a health impact assessment (HIA) as part of the feasibility studies [12, 34]. To monitor the trends of health outcomes and associated factors, to measure the impact of interventions and to generate reliable data for periodic decision-making on health interventions, repeated primary data collection was recommended in the HIA report. To this end, the project conducted a baseline health survey (BHS) in July 2011 and a follow-up health survey (FUHS) in July 2015 covering a broad spectrum of biomedical, environmental, structural, behavioural and knowledge indicators in children and adults residing in the project area. Changes of selected health indicators in children between 2011 and 2015 have been described elsewhere [35].

Here, we present a selection of health outcome, behavioural and knowledge indicators in women of reproductive age. Table 10.1 introduces the indicators assessed and outlines their relevance in the present setting. We compare results from the 2011 BHS and the 2015 FUHS and analyse associated socioeconomic, structural and setting specific factors, such as employment, migration and resettlement. Findings are discussed in the context of HIA applied in infrastructure development projects as an approach to foster sustainable development.

**Table 10.1: Selected indicators in women and their relevance to women's health and the Trident project**

| Indicator | Definition | Relevance to the women's health and the local project context |
|---|---|---|
| Percentage of anaemia in women | Pregnant women: Haemoglobin (Hb) < 11 g/dl;<br>Non-pregnant women: Hb <12 g/dl [36]. | Anaemia has been related to reduced work capacity, fatigue, reduced ability to execute routine daily activities, reduced cognitive function, poor pregnancy outcomes and negative effects on foetal and child health [37-40].<br>Epidemiology of infectious diseases, access to health care and diets potentially change due to the project development which will in turn influence anaemia [41]. |
| Percentage of women with past and current syphilis infection | Antibodies to *Treponema pallidum* assessing past or current syphilis infection [42]. | Syphilis renders women more susceptible to an HIV infection and increases viral loads in HIV-infected individuals [43]. Untreated syphilis causes perinatal deaths and congenital syphilis in children impairing child health [44]. High increases of sexually transmitted infections (STIs) other than HIV have been reported in mining areas [45]. |
| Percentage of women that delivered their last born child at a health facility | Percentage of women that delivered their last born child at a health facility [46]. | Increasing the percentage of births delivered in health facilities is an important factor in reducing deaths arising from complications of pregnancy provided a skilled attendant can manage complications during delivery or refer the mother to the next level of care in a timely manner [46].<br>The project can influence rates of deliveries at health facilities through increased access because of improved roads or increased financial means to pay for maternal health services [47]. |
| Percentage of women with comprehensive knowledge on HIV/AIDS | Comprehensive knowledge means knowing that consistent use of a condom during sexual intercourse and having just one uninfected faithful partner can reduce the chance of getting the AIDS virus, knowing a healthy-looking person can have the AIDS virus, and rejecting the two most common local misconceptions, i.e. HIV can be transmitted by mosquito bites or supernatural means [46]. | Correct knowledge can influence an individual's ability to adopt safer sex practices, reduce stigmatization towards people living with HIV/AIDS and alleviate misconceptions related to HIV/AIDS [46].<br>The increased spread of HIV/AIDS characteristic to mining areas has been widely described [16, 25, 46, 48].<br>In the Trident project HIA, the transmission of STIs, including HIV/AIDS was identified as priority and an HIV/AIDS intervention package was implemented early on in the project development in the workforce and the communities [33]. (See also health road shows below.) |
| Percentage of women that believe HIV can be transmitted by witchcraft or supernatural means | Belief that HIV can be transmitted by witchcraft or supernatural means [46]. | |
| Percentage of women that ever tested for HIV | Percentage of women that ever tested for HIV [46]. | Knowledge of HIV status is important for helping individuals decide to adopt safer sex practices, to reduce their risk of becoming infected or transmitting HIV [46].<br>HIV testing and counselling (HTC) is one of the major health interventions supported by FQML in the framework of the health road shows. |
| Percentage of women that participated in a health road show (HRS) | HRS are 1-day visits to communities in the project area involving information, education and communication (IEC) and biomedical testing for HIV, glycaemia, blood pressure and malaria [33]. | HRS is one of the major health interventions initiated by FQML.<br>While uptake of biomedical testing offered at HRS is recorded, the influence of the IEC campaigns is not known so far. |

## 10.3 Methods

*Ethical considerations*

The health surveys in 2011 and 2015 received ethical approval from the ethics review committee of the Tropical Disease Research Centre, Ndola, Zambia. Signed or fingerprinted informed consent was obtained from participating women. Women found anaemic were given haematinics on the spot while severe cases were referred to the local health facilities. Women found positive for syphilis were treated together with their sexual partner(s) using a stat dose of 2 grams of Azithromycin.

*Study area*

The Trident project is located in the Musele chiefdom, Solwezi district, Northwestern province of Zambia. The project concession area covers 950 km$^2$, which accommodates the open mining pit, project infrastructure (e.g. roads, air strip, offices), 2 newly built dams and a nature and game conservation area. For project development, some villages have been resettled, new settlements were established and roads have been upgraded. In-migration caused population increases in certain settlements. Figure 10.1 gives an overview of the project and surrounding area, including demographic changes that occurred between 2011 and 2015.

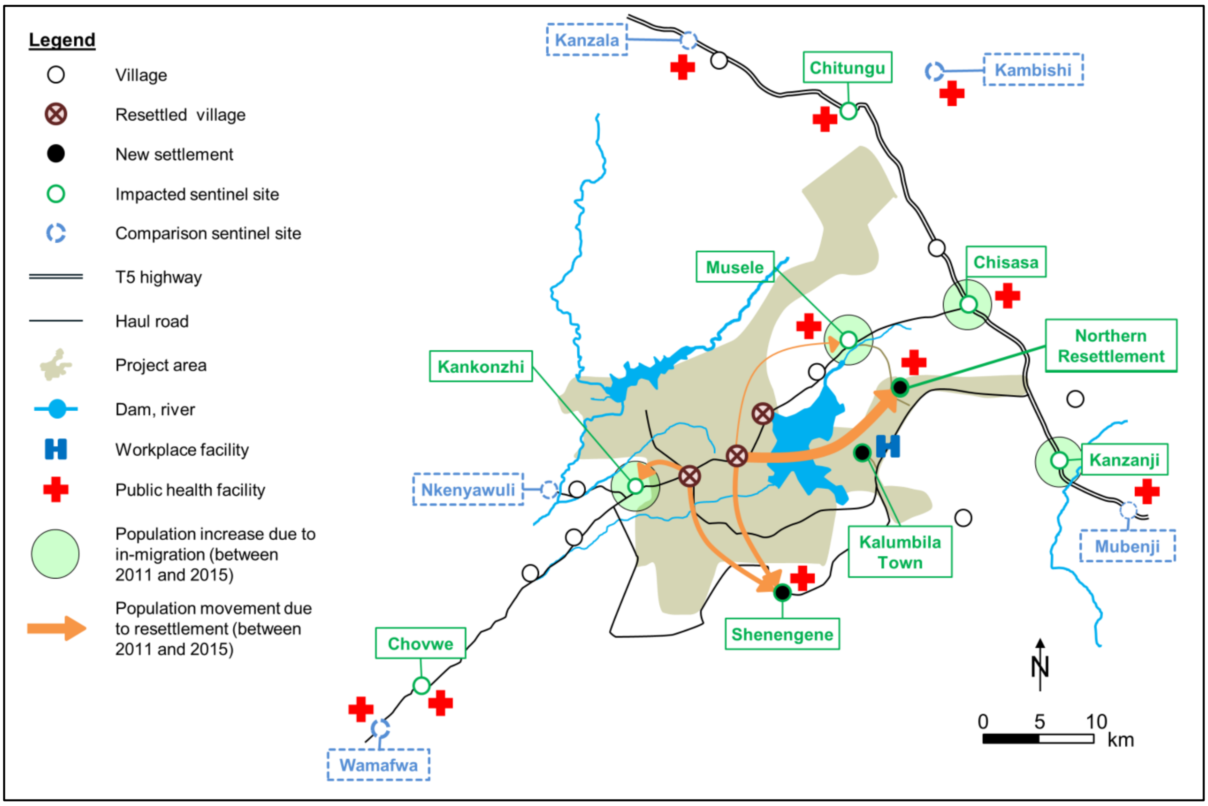


**Figure 10.1: Study area, demographic developments between 2011-2015 and selected sentinel sites, Trident project**

*Sampling method*

A cross-sectional survey design was applied in both 2011 and 2015. A detailed description of the sampling strategy is provided elsewhere [49]. In brief, a sentinel site approach was chosen in order to be able to purposively select certain settlements that are impacted by the project but would have been missed in a probability sampling. Furthermore, comparison sites were selected based on (i) proximity to the project area; (ii) similarity to impacted sentinel sites; and (iii) not being impacted by the project. Within the selected sentinel sites, households were selected randomly using a quota sampling of at least 25 households per sentinel site [49]. The presence of a woman with a child under 5 years of age was the inclusion criteria.

*Data collection*

Eligible women were administered a questionnaire pertaining to basic socio-demographic background information, health-related knowledge, attitudes and practices (KAP), maternal health and exposure to health interventions. Following the questionnaire interview, the woman was asked to visit a mobile field laboratory located within the sentinel site to measure biomedical indicators. First, a HemoCue® 201+ testing device (HemoCue Hb 201 System; HemoCue AB, Ängelholm, Sweden) was used to measure haemoglobin concentration in a capillary blood sample to determine anaemia status [50]. Second, detection of antibodies to *Treponema pallidum* was done using Alere Determine™ Syphilis TP rapid diagnostic test to assess current or past syphilis infection (Alere Determine™ Syphilis; Alere Inc, Waltham, USA).

*Data analysis*

In 2011, data were entered into Epidata software version 1.4.4 (EpiData Association; Odense, Denmark). In 2015, data was collected through electronic tablets using the open data kit (ODK) software [51]. Analysis was performed with Stata version 10 (StataCorp LP; Texas, USA). Principal component analysis based on 18 household assets was used to approximate household wealth assigning households into four wealth quartiles [52].

## 10.4 Results

*Study population*

In 2011, seven sentinel sites were sampled. In 2015, three impacted sentinel sites were added to include newly developed settlements or settlements that gained importance. In addition, four comparison sentinel sites were added to improve the study design leading to a total of fourteen sentinel sites sampled in 2015. The study populations per sentinel site for 2011 and 2015 including resettlement or migration background of the sampled households are shown in Table 10.2. In 2011, 286 households were sampled and in 2015, 516 households were sampled. This yielded to a sample size of 289 and 516 women, respectively.

**Table 10.2: Study populations (2011 and 2015) and community characteristics (2015), Trident project**

| Sentinel sites | Households | | Women aged 15-49 years | | % of HH that have been resettled due to the project | % of migrant HH (in the area for <5 years) | % of HH with at least one HH member being an employee of FQML or a contractor | % of HH in the first wealth quartile |
|---|---|---|---|---|---|---|---|---|
| **Year** | **2011** | **2015** | **2011** | **2015** | **2015** | **2015** | **2015** | **2015** |
| Kalumbila Town | n/a | 30 | n/a | 29 | 0.0 | 100.0 | 79.3 | 100.0 |
| Wanyinwa (2011) / Northern Resettlement (2015) | 35 | 34 | 35 | 34 | 97.2 | 97.2 | 76.5 | 60.0 |
| Shenengene | n/a | 32 | n/a | 32 | 96.9 | 96.9 | 40.6 | 29.0 |
| Musele[a] | 30 | 66 | 30 | 66 | 4.6 | 31.8 | 36.9 | 30.2 |
| Chisasa[a] | 66 | 65 | 63 | 65 | 1.5 | 67.7 | 40.0 | 24.2 |
| Kankonzhi[a] | 36 | 30 | 36 | 30 | 20.0 | 23.3 | 81.5 | 42.9 |
| Chovwe[a] | 61 | 32 | 61 | 32 | 0.0 | 6.3 | 9.4 | 6.3 |
| Kanzanji | n/a | 32 | n/a | 32 | 3.1 | 46.9 | 28.1 | 28.1 |
| Chitungu[a] | 30 | 33 | 30 | 33 | 0.0 | 0.0 | 0.0 | 2.9 |
| **Total impacted** | **258** | **354** | **255** | **353** | **78.3** | **51.8** | **41.8** | **33.2** |
| Nkenyawuli[a] | 31 | 32 | 31 | 30 | 0.0 | 6.3 | 3.1 | 6.9 |
| Wamafwa | n/a | 33 | n/a | 32 | 0.0 | 6.1 | 0.0 | 3.1 |
| Kanzala | n/a | 32 | n/a | 30 | 0.0 | 16.7 | 0.0 | 6.5 |
| Kambishi | n/a | 32 | n/a | 32 | 0.0 | 0.0 | 0.0 | 6.1 |
| Mubenji | n/a | 33 | n/a | 33 | 0.0 | 21.9 | 21.9 | 20.6 |
| **Total comparison** | **31** | **162** | **31** | **157** | **0.0** | **10.1** | **5.0** | **8.8** |

FQML, First Quantum Minerals Limited; HH, household

[a] Sentinel site with data for 2011 and 2015

*HIV-related indicators*

Comprehensive knowledge on HIV/AIDS in women has increased by 6.8% overall but has not changed significantly between the 2011 BHS and the 2015 FUHS (26.2%, 95% CI 21.2-31.7% *versus* 33.0%, 95% CI 29.3-36.8%; Table 10.3). In 2015, women with secondary schooling or higher and women from the richest wealth quartile were found with significantly higher levels of comprehensive knowledge on HIV/AIDS. Overall, still 15.0% (95% CI 12.3-18.1%) of women believed that HIV can be transmitted by witchcraft or other supernatural means in 2015, which was, however, significantly lower than in 2011 (26.2%, 95% CI 21.2-31.7%). Interestingly, participation in the HRS was not positively associated with increased comprehensive knowledge on HIV/AIDS. As seen in Table 10.4, the odds of having comprehensive knowledge on HIV/AIDS were significantly lower in women that participated in HRS (OR=0.62, 95% CI 0.42-0.90).

The proportion of women that ever took an HIV test was significantly higher in 2015 (83.6%, 95% CI 80.4-86.4%) than in 2011 (75.1%, 95% CI 48.6-80.0%). This positive trend was significant in the impacted sites (76.0%, 95% CI 70.3-81.1% in 2011 *versus* 88.3%, 95% CI 84.9-91.1% in 2015) but not in the comparison sites (67.7%, 95% CI 48.6-83.3% in 2011 *versus* 72.9%, 95% CI 66.0-79.0% in 2015). Consequently, the testing coverage in 2015 was significantly higher in the impacted *versus* the comparison sites. In 2015, the odds of ever having taken an HIV test were 4.4 times higher in individuals that participated in a HRS (OR=4.44, 95% CI 2.64-7.45; Table 10.4) compared to those that have not participated. Moreover, women that attained secondary school or higher, have a household member that is employed by FQML or a contractor, have a migrant background or are from the richest wealth quartile yielded significantly higher testing rates than the respective sub-groups.

**Table 10.3: Knowledge and behavioural indicators related to HIV/AIDS in women aged 15-49 years, Trident project, 2011 and 2015**

| | n | | % of women with comprehensive knowledge on HIV/AIDS[1] | | % of women that believe HIV can be transmitted by witchcraft or supernatural means | | % of women who have ever tested for HIV | |
|---|---|---|---|---|---|---|---|---|
| | 2011 | 2015 | 2011 | 2015 | | | 2011 | 2015 |
| **Health road show** | | | | | | | | |
| Not participated | n/a | 294 | n/a | 36.7 (31.2-42.5) | n/a | 12.3 (8.78-16.6) | n/a | 74.4 (69.1-79.3) |
| Participated | n/a | 335 | n/a | 29.8 (24.9-35.0) | n/a | 17.4 (13.5-22.0) | n/a | 91.6 (88.1-94.3) † |
| **Education** | | | | | | | | |
| No education | 100 | 363 | 25.0 (16.8-34.6) | 25.6 (21.2-30.4) | 33.0 (23.9-43.1) | 16.1 (12.4-20.3) ϕ | 71 (61.0-79.6) | 79.6 (75.0-83.6) |
| Primary school | 186 | 212 | 26.8 (20.6-33.8) | 36.7 (30.2-43.6) | 22.5 (16.7-29.2) | 13.3 (9.04-18.6) | 77.4 (70.7-83.2) | 87.7 (82.5-91.8) |
| Secondary of higher | 0 | 54 | n/a | 68.5 (54.4-80.4) † | n/a | 14.8 (6.61-27.1) | n/a | 94.4 (84.6-98.8) † |
| **FQML or contractor employment within the HH** | | | | | | | | |
| No | n/a | 442 | n/a | 31.2 (26.9-35.7) | n/a | 13.1 (10.1-16.7) | n/a | 79.1 (75.0-82.8) |
| Yes | n/a | 187 | n/a | 37.4 (30.4-44.7) | n/a | 19.3 (13.9-25.7) | n/a | 94.1 (89.7-97.0) † |
| **Resettlement** | | | | | | | | |
| No | n/a | 547 | n/a | 32.3 (28.4-36.4) | n/a | 15.3 (12.4-18.7) | n/a | 82.4 (78.9-85.5) |
| Yes | n/a | 82 | n/a | 37.8 (27.3-49.1) | n/a | 12.6 (6.24-22.0) | n/a | 91.4 (83.1-96.4) |
| **Migrant** | | | | | | | | |
| No | n/a | 465 | n/a | 30.1 (25.9-34.5) | n/a | 14.6 (11.5-18.1) | n/a | 81.0 (77.2-84.5) |
| Yes | n/a | 164 | n/a | 41.4 (33.8-49.4) | n/a | 15.4 (10.2-21.9) | n/a | 90.8 (85.3-94.7) † |
| **Asset based wealth index** | | | | | | | | |
| Poorest | n/a | 173 | n/a | 25.4 (19.1-32.6) | n/a | 17.4 (12.0-23.9) | n/a | 75.1 (68.0-81.3) |
| Second | n/a | 140 | n/a | 26.4 (19.3-34.5) | n/a | 16.4 (10.5-23.7) | n/a | 81.4 (73.9-87.4) |
| Third | n/a | 157 | n/a | 33.1 (25.8-41.0) | n/a | 11.7 (7.12-17.9) | n/a | 85.9 (79.5-91.0) |
| Richest | n/a | 159 | n/a | 47.1 (39.2-55.2) † | n/a | 14.4 (9.39-20.9) | n/a | 92.4 (87.1-96.0) † |
| **Health facility within community** | | | | | | | | |
| No | 67 | 115 | 32.8 (21.8-45.3) | 25.2 (17.5-34.1) | 19.4 (10.7-30.8) | 21.4 (14.2-30.1) | 77.6 (65.7-86.8) | 80.1 (71.5-87.1) |
| Yes | 219 | 514 | 24.2 (18.6-30.4) | 34.8 (30.7-39.1) ϕ | 28.3 (22.4-34.7) | 18.3 (15.0-22.0) ϕ | 74.4 (68.1-80.0) | 86.3 (83.0-89.2) ϕ |
| **Impact** | | | | | | | | |
| Impacted | 255 | 437 | 26.2 (20.9-32.1) | 31.5 (27.2-36.1) | 26.6 (21.3-32.5) | 16.3 (12.9-20.2) ϕ | 76.0 (70.3-81.1) | 88.3 (84.9-91.1) ϕ |
| Comparison | 31 | 192 | 25.8 (11.8-44.6) | 36.4 (29.6-43.6) | 22.5 (9.59-41.0) | 11.9 (7.74-17.4) | 67.7 (48.6-83.3) | 72.9 (66.0-79.0) † |
| **Total** | **286** | **629** | **26.2 (21.2-31.7)** | **33.0 (29.3-36.8)** | **26.2 (21.2-31.7)** | **15.0 (12.3-18.1)** ϕ | **75.1 (69.7-80.0)** | **83.6 (80.4-86.4)** ϕ |

[1]Knowing that consistent use of condoms during sexual intercourse and having just one uninfected faithful partner can reduce the chance of getting the AIDS virus, knowing that a healthy-looking person can have the AIDS virus, and rejecting the two most common local misconceptions, i.e. HIV can be transmitted by mosquito bites or supernatural means; † Significant difference between population sub-groups in 2015; ϕ Significant difference between 2011 and 2015

**Table 10.4: Health outcome and behavioural indicators in women aged 15-49 years participating in health road shows, Trident project, 2011 and 2015**

| | Females that participated in Health Road Show | | |
|---|---|---|---|
| | **n** | **Proportion (%, 95% CI)** | **aOR (95% CI)** |
| **Has comprehensive knowledge on HIV** | | | |
| No | 421 | 55.8 (50.9-60.6) | 1.00 |
| Yes | 208 | 48.0 (41.1-55.0) | 0.62 (0.42-0.90) |
| **Has ever tested for HIV** | | | |
| No | 103 | 27.1 (18.8-36.8) | 1.00 |
| Yes | 536 | 57.2 (52.9-61.5) | 4.44 (2.64-7.45) |
| **Used a condom use at last sexual intercourse** | | | |
| No | 499 | 50.3 (45.8-54.7) | 1.00 |
| Yes | 108 | 66.6 (56.9-75.4) | 2.01 (1.24-3.23) |
| **Syphilis status** | | | |
| Negative | 554 | 53.7 (49.5-58.0) | 1.00 |
| Positive | 23 | 47.8 (26.8-69.4) | 0.76 (0.29-1.94) |

aOR, adjusted odds ratio; CI, confidence interval; HIV, human immunodeficiency virus

**Table 10.5: Behavioural and health outcome indicators in women aged 15-49 years participating in health road shows, Trident project, 2011 and 2015**

| | n* | | Delivery at a health facility (%; 95% CI) | | Anaemia (%; 95% CI) | | Syphilis in women aged 15-49 years (%; 95% CI) | |
|---|---|---|---|---|---|---|---|---|
| | **2011** | **2015** | **2011** | **2015** | **2011** | **2015** | **2011** | **2015** |
| **Education** | | | | | | | | |
| No education | 100 | 336 | 49.0 (38.8-59.1) | 75.7 (71.0-80.0) ᶲ | 19.6 (12.7-28.2) | 27.6 (23.0-32.6) | n/a | 5.1 (3.0 -8.0) |
| Primary school | 186 | 188 | 73.6 (66.7-79.8) | 85.3 (79.8-89.8) | 17.1 (12.2-23.0) | 23.9 (18.3-30.2) | n/a | 1.6 (0.34.6) |
| Secondary of higher | 0 | 50 | n/a | 94.4 (84.6-98.8) † | n/a | 16.6 (7.91-29.2) | n/a | 6.0 (1.3-16.5) |
| **FQML or contractor employment within the HH** | | | | | | | | |
| No | n/a | 398 | n/a | 78.2 (74.1-82.0) | n/a | 27.3 (23.1-31.7) | n/a | 4.5 (2.7-7.1) |
| Yes | n/a | 176 | n/a | 86.0 (80.2-90.7) | n/a | 21.0 (15.4-27.6) | n/a | 2.8 (0.9-6.5) |
| **Resettlement** | | | | | | | | |
| No | n/a | 496 | n/a | 81.9 (78.4-85.0) | n/a | 25.7 (22.1-29.7) | n/a | 3.8 (2.3-5.9) |
| Yes | n/a | 78 | n/a | 71.9 (60.9-81.3) | n/a | 23.1 (14.5-33.7) | n/a | 5.1 (1.4-12.6) |
| **Migrant** | | | | | | | | |
| No | n/a | 419 | n/a | 76.9 (72.8-80.7) | n/a | 24.9 (21.0-29.1) | n/a | 4.3 (2.6-6.7) |
| Yes | n/a | 155 | n/a | 90.8 (85.3-94.7) † | n/a | 25.0 (18.5-32.3) | n/a | 3.2 (1.1-7.4) |
| **Asset-based wealth index** | | | | | | | | |
| Poorest | n/a | 150 | n/a | 72.2 (64.9-78.7) | n/a | 28.5 (21.8-36.0) | n/a | 6.0 (2.8-11.0) |
| Second | n/a | 131 | n/a | 77.8 (70.0-84.4) | n/a | 20.2 (13.9-27.9) | n/a | 4.6 (1.7-9.7) |
| Third | n/a | 144 | n/a | 100 (97.6-100) † | n/a | 27.0 (20.2-34.8) | n/a | 2.8 (0.8-7.0) |
| Richest | n/a | 149 | n/a | 100 (97.7-100) † | n/a | 25.0 (18.4-32.5) | n/a | 2.7 (0.7-6.7) |
| **Health facility within the community** | | | | | | | | |
| No | 67 | 110 | 61.1 (48.5-72.8) | 76.5 (67.7-83.9) | 14.2 (7.35-24.1) | 26.3 (18.4-35.6) | n/a | 7.4 (3.3-14.0) |
| Yes | 219 | 507 | 66.2 (59.5-72.4) | 81.5 (77.8-84.7) ᶲ | 19.2 (14.4-24.8) | 25.2 (21.5-29.2) | n/a | 3.2 (1.8-5.3) |
| **Impact** | | | | | | | | |
| Impacted | 255 | 409 | 66.6 (60.5-72.4) | 83.5 (79.7-86.8) ᶲ | 17.1 (12.9-22.0) | 25.3 (21.3-29.7) | n/a | 4.4 (2.6-6.9) |
| Comparison | 31 | 165 | 51.6 (33.0-69.8) | 73.9 (67.1-80.0) | 25.8 (11.8-44.6) | 25.6 (19.5-32.5) | n/a | 3.0 (1.0-6.9) |
| **Total** | **286** | **574** | **65.0 (59.1-70.5)** | **80.6 (77.2-83.6)** | **21.2 (16.8-26.1)** | **25.4 (22.0-29.0)** | **n/a** | **4.0 (2.6-6.0)** |

* Denominators might vary as not all women agreed to biomedical sampling; † Significant difference between population sub-groups in 2015; ᶲ Significant difference between 2011 and 2015

*Place of delivery of the last-born child*

The proportion of women who gave birth to their last-born child at a health facility was significantly higher in 2015 (80.6%, 95% CI 77.2-83.6%) compared to 2011 (65.0%, 95% CI 59.1-70.5%; Table 10.5). This positive trend was significant in the impacted sites (66.6%, 95% CI 60.5-72.4% in 2011 *versus* 83.5%, 95% CI 79.7-86.8% in 2015) and in communities with a health facility (66.2%, 95% CI 59.5-72.4% in 2011 *versus* 81.5%, 95% CI 77.8-84.7% in 2015). In 2015, women with an educational attainment of secondary school or higher, women with a migrant background and women from the second and richest quartile were significantly more often delivering at a health facility than the other sub-groups.

*Health outcomes: anaemia and syphilis*

As shown in Table 10.5, among all women that were measured Hb levels, 21.2% (95% CI 16.8-26.1%) in 2011 and 25.4% (95% CI 22.0-29.0%) in 2015 were found anaemic. Hence, the overall proportion of anaemic women has not changed significantly between 2011 and 2015, although it was higher in 2015 compared to 2011. In 2015, no differences were found between sub-groups stratified by different background characteristics. Women with secondary education or higher were least affected by anaemia (16.6%, 95% CI 7.9-29.2%).

The overall syphilis prevalence in women was 4.0% (95% CI 2.6-6.0%), whereas no significant differences were found when stratified by background characteristics. Women residing in the impacted sites had a higher prevalence (4.4%, 95% CI 2.62-6.06%) compared to the women in the comparison sites (3.0%, 95% CI 0.99-6.92%) although the observed difference was not significant. Women that participated in the health road shows (HRS) were less non-significantly likely to be infected with syphilis (OR=0.76, 95% CI 0.29-1.94; Table 10.4)

## 10.5 Discussion

In women residing in a newly developed copper mining area, a selection of health, behavioural and knowledge outcomes were assessed in two consecutive cross-sectional surveys in 2011 (at baseline) and 2015 (at follow-up). The following indicators have improved significantly in the impacted but not in the comparison sites between baseline and follow-up: (i) the percentage of mothers giving birth in a health facility; (ii) the percentage of women not believing anymore that HIV can be transmitted by witchcraft or other supernatural means; and (iii) the percentage of women having ever tested for HIV. Neither in the impacted nor in the comparison sites negative trends over time were observed in the indicators presented here. In 2015, employment by FQML or a contractor thereof, migrant background, wealth and higher educational attainment were associated with better health, behavioural and knowledge outcomes in women reflecting a social gradient in health [53].

The HRS as a major project-initiated health intervention, predominantly pertaining to prevention of STIs, did not translate in better knowledge on HIV/AIDS in women. Paradoxically, women that did not participate in HRS had higher levels of comprehensive knowledge on HIV/AIDS and lower levels of believing that HIV can be transmitted by supernatural means. Operational research is needed to study the shortcomings and optimise information, education and communication (IEC) campaigns within the HRS [54]. The HRS did however have a positive effect on HIV-testing and condom use at last sexual intercourse, both key prevention methods against STIs. In fact, HIV-testing uptake has increased markedly in the area since the initiation of the HRS and the HIV positivity rate observed in the communities surrounding the project increased insignificantly from 3.0% (95% CI 2.0-4.2%) in 2012 to 3.4% (95% CI 2.9-3.9%) in 2015 [33]. The interplay of HIV with other STIs ought to be considered in this setting. Syphilis renders women more susceptible to an HIV infection and increases viral loads in HIV-infected individuals, which in turn render individuals more infectious [43]. Syphilis infection in the project area was similar to what was found during the 2007 demographic and health survey in Zambia. The prevalence was 3.3% in women in Northwestern province and 3.9% in women living in rural areas compared to overall 4.0% in the 2015 FUHS [55].

The stable anaemia rate over years and the low variation between stratified groups underlines the slow progress made to improve anaemia in women due to persistent micro-nutrient deficiencies, parasitic disease infections, HIV and inherited disorders in the present setting [41]. Still, a quarter of women in the richest quartile was anaemic although they presumably have increased and sufficient energy intake and less infectious diseases compared to other women [56]. A deeper assessment of diet quality in these women can investigate why iron needs are not met [57].

Taken together, the results from women and children presented here and elsewhere (Knoblauch *et al*. (2017) [35]) suggest that the population that migrated into the area is generally healthier than the receiving population. The ‘healthy migrant hypothesis’ speculates that although migrants face disadvantages in a new environment which can affect their health, they are a selectively healthier group compared to non-migrants [58]. This hypothesis cannot be tested in the current setting as pre-migration data are not available but the characteristics of migrants in this area, i.e. young labour-seekers, suggest that they are in good physical health and the data supports the ‘healthy migrant hypothesis’. At the same time, this underlines the particular attention that should be paid to the native population which are predisposed to a situation of economic and social vulnerability, including health, and a low assimilative capacity to changes brought in by migrants [13].

Another finding further raises concerns related to equity; women from households where one or more persons are employed by FQML or a contractor had always better outcomes for the indicators assessed than their counterparts. Economic growth, brought by activities such as industrial mining, does not automatically translate in an equal distribution of benefits but needs social policies to create a fair environment, including health equity [59-61]. Effectively, there are socioeconomic or environmental domains that are outside the influence of project decision-makers [62]. Nevertheless, the HIA's claim to reduce inequalities has yet to be validated [63, 64]. Continued cross-sectional monitoring over the projects lifespan will provide valuable information on HIA's performance if applied in infrastructure development projects in remote rural Africa. So far, the HIA for the Trident project has demonstrated that (i) the community health management plan was tailored based on local health needs; (ii) close collaboration between the private and the health sector was achieved as the project acts as an implementing partner to the district health management team; and (iii) baseline and monitoring data collection is crucial to inform on an updated health status of communities residing in the project area and beyond and evaluate the performance of health interventions [33, 35, 65].

It is too premature at this point to judge the project's overall influence on sustainable development, which is one of the HIA core values [34]. Theoretically, through its systematic approach to health, which includes the wider determinants of health, HIA aligns perfectly with the approaches proposed in the SDGs [1]. However, to validate the impact assessment's promise to support sustainable development around infrastructure development projects, continued, long-term environmental, social and health surveillance and cross-sectional monitoring are indispensable [9, 66].

*Limitations*

The Alere DetermineTM Syphilis TP detects antibodies of all isotypes against *Treponema pallidum*, the syphilis causing bacteria, and is unable to differentiate between active from cured disease [42]. The prevalence rate reported is therefore a combination of past and current infection. Due to the semi-purposive sentinel site sampling, the results have limited generalisability to other communities. In 2011, a number of indicators (e.g. syphilis, employment or migration background) were not assessed and only one comparison site was sampled, which limited a more comprehensive comparability between the years.

### 10.6 Conclusions

Factors associated with the development of a large-scale copper mine in Northwestern province of Zambia, such as employment and an individual's migration background, were associated with better health, behavioural and knowledge outcomes in women of reproductive age residing in the mining area. Although a general improvement of the assessed indicators was observed, the improvements were more articulated in the communities considered impacted by the mine compared to comparison communities outside the area of influence. Also, women with links to project-employment or a migrant background showed generally better outcomes indicating inequities and the need to address the local poor. Nevertheless, the HIA implementation of the Trident project suggests that the development of large-scale infrastructure projects can be an opportunity to improve women's health if health impacts and its risk factors are appropriately managed. The evidence achieved through cross-sectional monitoring is key in observing the health status of communities impacted by projects. In fact, the HIA theoretically entails a health monitoring component which is insufficiently applied in large-scale infrastructure development projects and limits the evaluation on the contributions of such projects to protecting human health and fostering sustainable development [67, 68].

**Conflict of interest**

FQML and the Trident Project funded the HIA and supported health interventions. Mark J. Divall, Milka Owuor, Colleen Archer, Mirko S. Winkler and Astrid M. Knoblauch have all supported by the Trident project as independent public and occupational health specialists. The corresponding author had full access to all the data in both surveys and had final responsibility for the decision to submit for publication.

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# 11 Discussion

The main goal of this PhD thesis was to investigate and strengthen the M&E component in HIA of large infrastructure development projects in SSA. At the core are six cross-sectional epidemiological surveys that were carried out in the vicinity of three extractive industry projects in Côte d'Ivoire (one survey), the DRC (one survey) and Zambia (two surveys) and one renewable energy project in Sierra Leone (two surveys).

Against the background of an M&E framework in HIA developed by Bhatia *et al*. (2014), Figure 11.1 illustrates how this PhD thesis contributes to specific elements of M&E in HIA [1]. In the first section of the discussion (11.1), the research and monitoring approaches applied in the six surveys are discussed with regards to limitations and prospects of cross-sectional health surveys for M&E in HIA. In the second section (11.2), the experiences beyond the pursuit of cross-sectional health surveys contributing to process and impact evaluation in HIA are put in perspective to the opportunities that HIA can unfold.

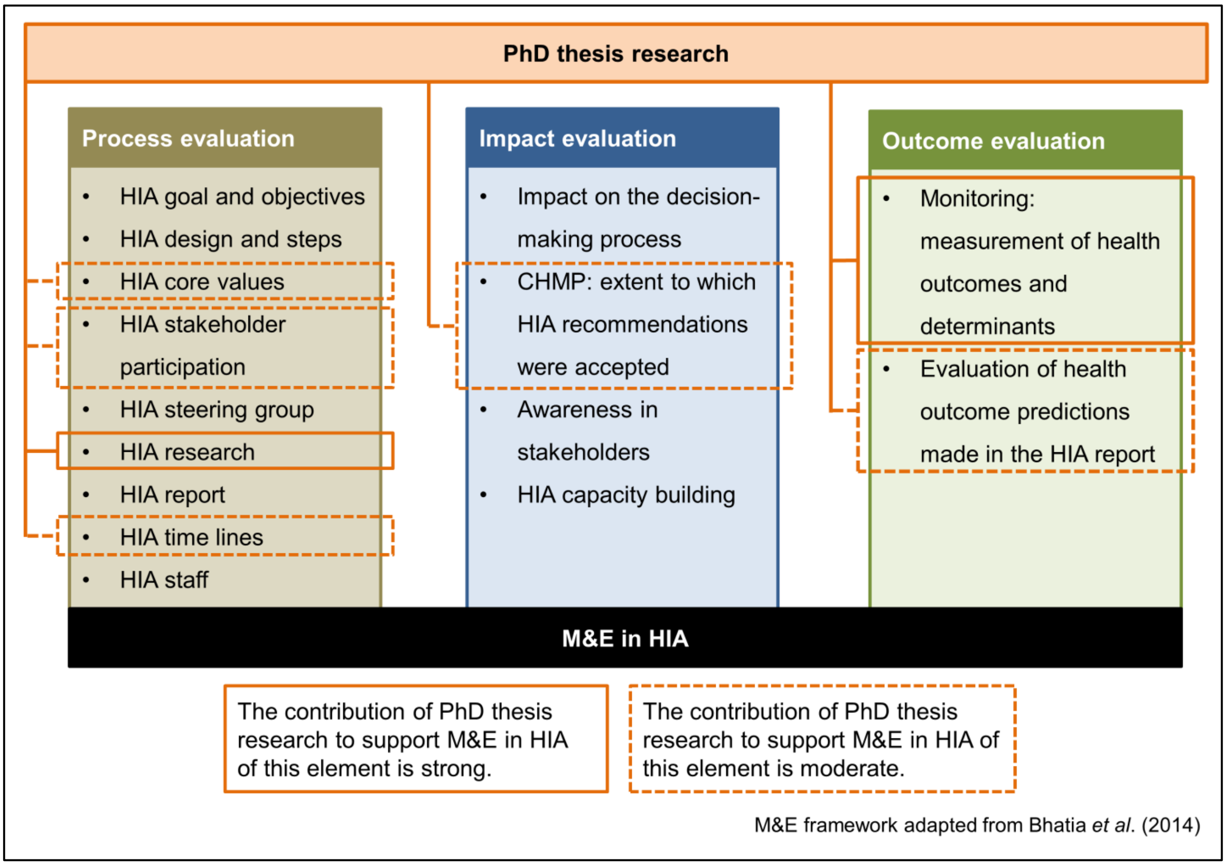


**Figure 11.1: Contribution of the current PhD thesis to M&E in HIA of large infrastructure development projects in sub-Saharan Africa (adapted from Bhatia *et al*., 2014)**

In the third section (11.3), the quantification of health impacts and outcomes in HIA and the opportunities this provides to enhance transparency and accountability issues are discussed. The forth section (11.4) presents a general discussion of current issues and prospects around HIA of infrastructure development projects in SSA. Finally, section 11.5 elaborates on how this PhD thesis contributes to innovation, validation and application, which are key pillars of Swiss TPH along the entire value chain from discovery to policy implication [2]. Concluding remarks in section 11.6 and open research questions section 11.7 round up this PhD thesis.

## 11.1 Limitations and prospects of cross-sectional health surveys for M&E in HIA

Possible options for M&E of health impacts of infrastructure development projects in SSA are shown in Figure 11.2. This section discusses which combination of monitoring or surveillance methods make most sense in consideration of setting-specific characteristics, such as strength of the local routine HIS, the heterogeneity of the setting and the available time, financial and human resources.

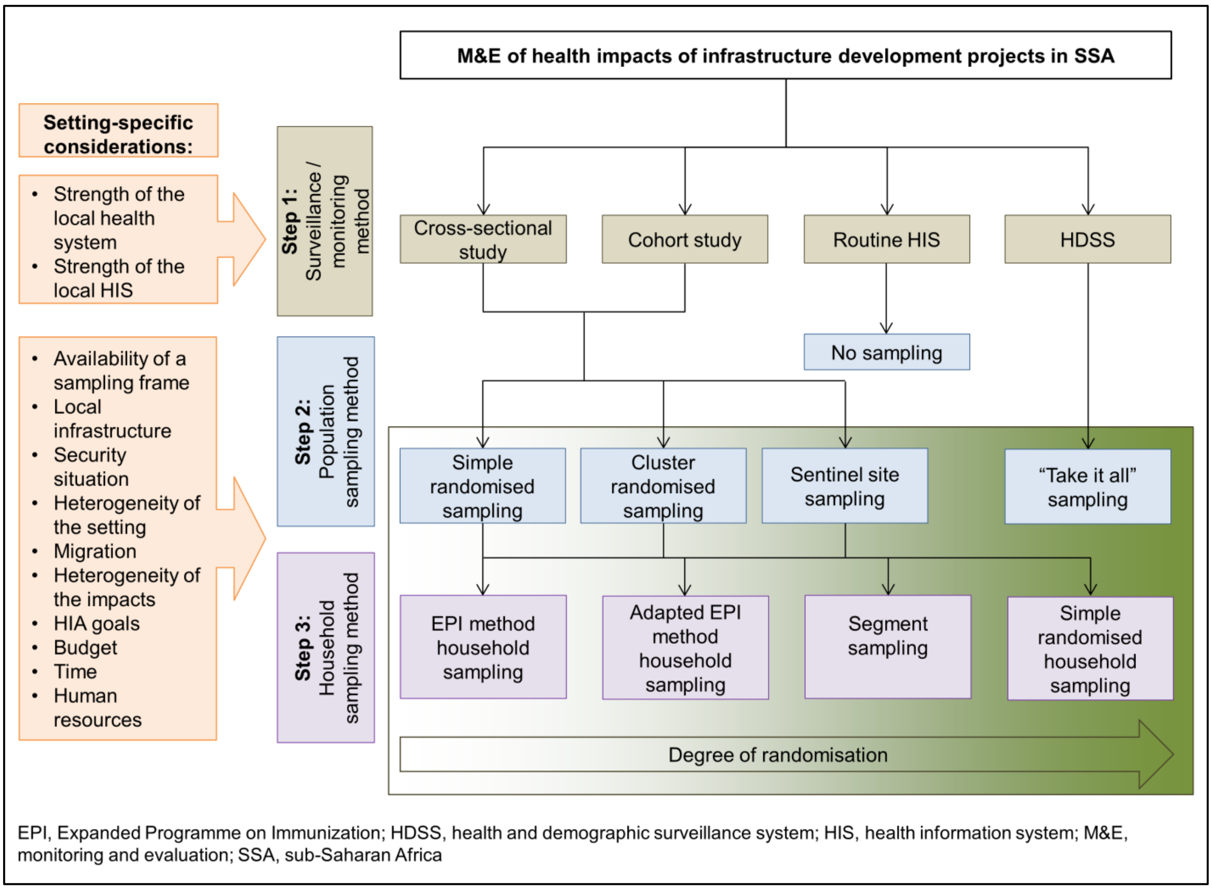


**Figure 11.2: Options for M&E of health impacts of infrastructure development projects in SSA**

In a first step, the monitoring method or surveillance system or a combination thereof needs to be determined. The selection depends on the local circumstances such as strengths of the health system and routine HIS, on the health indicators to be monitored (e.g. chronic, rare or frequent conditions), the objectives (e.g. determination of prevalence rates, incidence rates, cause-effect chain or risk factors) and project management decisions such as commitment to monitoring and the available budget. The scoping step is intended to assess the strength of the routine HIS and will thus influence the selection of the monitoring method.

The routine HIS is a surveillance mechanism to describe the health status, morbidity and mortality of populations, associations between outcomes and risks and health determinants or detect disease outbreaks [3]. The strength of the routine HIS varies greatly between countries, depending, for example, on diagnostic abilities, human resource capacities and the functionality of the reporting system. In places with notoriously weak HIS, such as rural African settings, alternative M&E options need to be implemented if health impacts of development projects ought to be observed in a rigorous manner.

Alternative options include a health and demographic surveillance system (HDSS), a cohort study design or a repeated cross-sectional study design. An HDSS is recording demographic changes (e.g. vital statistics and migration) and any desired indicator in all households included in the HDSS area in a longitudinal manner [4, 5]. Similarly, cohort studies apply longitudinal measurements in the same group of individuals. The advantages of these two options are the ability to measure events in temporal sequences, and hence establishing incidence rates and a strong cause/exposure-effect chain through the calculation of the relative risk ratios [6]. Thus, HDSS and cohort studies deliver continuous data for evidence-based decision-making in HIA and beyond. Limitations related to longitudinal monitoring in this specific setting include: (i) potentially high in- and out-migration causing higher loss to follow-up and excluding in-migrated individuals (in cohort design only); (ii) high financial and time resources needed to maintain a HDSS or cohort; (iv) incentivisation might be needed; (v) survey fatigue; and (vi) the question of responsibility for such comprehensive monitoring (i.e. government *versus* project). In a cross-sectional design, true prevalence or coverage rates in the general population are established, hence, indicators that the other methods are unable to pick up [7]. The cross-sectional design is quicker and less costly than an HDSS or cohort study, loss of follow-up is not an issue and it is able to include migrants. However, the cross-sectional design is (i) weaker to detect rare diseases; (ii) biased towards chronic conditions; and (iii) unable to establish the sequence of events (association *versus* cause-effect) [6, 8].

In conclusion, in view of the complexity and range of direct and indirect health impacts caused by infrastructure development projects, a combination of continuous and cross-sectional data collection for M&E is recommended to convene the specific setting. First, routine health data collection in accordance with the host country's HIS needs to be collected at the project health facility/facilities and ideally channelled back into the public HIS. Second, some indicators warrant continuous surveillance depending on their aetiology and significance. For example, cross-sectional monitoring of the HIV prevalence every few years only would be highly negligent [9]. Third, repeated cross-sectional monitoring at 3- to 5-year intervals are needed to observe indicators that change over longer periods of time (e.g. stunting) and establishing whether or not the changes are attributable to a project [8, 10, 11]. If resources allow, the cross-sectional approach can be extended by a cohort of people native to the area, which allows more precise cause-effect calculations. Forth, and importantly, is the inclusion of a comparison group in the cross-sectional design, which allows differentiating changes caused by a project from changes that occurred overall [7, 10, 11].

In a second step, the sampling method for the study population needs to be determined in case of a cohort or cross-sectional study. A simple randomised sampling is possible if a sampling frame is available, e.g. a complete census or household listing. This is rarely the case in SSA and generating a sampling frame is time- and resource-consuming. In absence of a sampling frame, a randomised cluster sampling or a sentinel site sampling are possible. In the randomised cluster sampling, clusters within a geographical area are randomly selected whereas each cluster has the same probability of selection. In the sentinel site sampling, clusters or sites are selected purposively [12]. With the different sampling methods mentioned here, the degree of randomisation reduces in the order in which they were mentioned and thus also the representativeness the sample has for the general population (see Figure 11.2).

In conclusion, in the specific setting of development projects, a probability sampling reduces the chances of potentially highly impacted communities to be included in the sampling. The semi-purposively sentinel site sampling conversely increases their chances to be included [13]. Especially the need for baseline data in impacted communities outweighs the loss in randomisation from a completely randomised design and therefore, a semi-purposively selection is recommended. In settings where resources allow surveying a high percentage of the population, the degree of randomisation and precision of estimates is improved.

On a third level, again in case of a cohort or cross-sectional study design, the selection of households as the primary sampling unit needs to be determined. A probability sample is desirable to increase randomisation. Again, simple randomised sampling would be the gold standard to achieve a random sample and most precise estimates but a sampling frame is required. With the emergence of Google Earth®, satellite pictures of selected clusters or sentinel sites can be made available and used as a sort of a sampling frame [14]. However, time efforts and feasibility of this method need to be validated, as field conditions such as occupancy of houses or exact village boundaries in case of adjoining villages are not known.

The EPI method, as introduced in chapter 3.2.1, has been widely applied in settings where no sampling frame was available. However, it has known shortcomings [15]. First, houses that are closer to the starting point are overrepresented. Second, the nearest household fulfilling the inclusion criteria is chosen for further sampling. Third, the EPI method was validated for estimating the immunization coverage of children aged 12-23 months which are expected in every 7th households. In contrast, the present surveys consider children under 5 years of age, which are expected to be present in more households. This methods leads to clustering and also accuracy for indicators such as socioeconomic status or child health is reported to be weaker [16]. A further adaption of the EPI method as proposed by Krauth *et al*. (in preparation) and Krauth *et al*. (2015) is to decrease oversampling of central households and clustering [17]. In practice, the selection of 'the next household' can be further randomised in terms of direction and distance. The distance to 'the next household' is selected from a random number between 1 and 20 houses separating the selected households, instead of simply 'the nearest household'. And the direction is chosen randomly after every household visited. Another option is segment sampling, as nowadays increasingly implemented [18]. Therefore, the sentinel site will be sketched and divided in equally sized segments until the predefined size of the sampling segment is achieved [15, 19]. Either a random sampling is done within the segment or the segment is as small as the required sample size and the 'take all' rule is applied [18]. The disadvantage is that it takes time to find the segment, either through a pre-visit of the site or on the survey day itself, which delays commencement of survey activities [19].

In conclusion, the household sampling as currently applied in cross-sectional health surveys needs optimization to increase randomisation and decrease clustering. Both, the approach put forward by Krauth *et al*. (unpublished) and the segment sampling optimize equal probability of households to be selected. In both cases, familiarity with the setting through satellite images can facilitate the sampling processes (e.g. segmentation or localisation of sampling starting point).

The discussion around advantages and limitations of different options for M&E of health impacts caused by infrastructure development projects, together with the findings from the thesis' case studies suggest that repeated cross-sectional surveys every few years have considerable potential to track changes in the health status in project-affected populations. Cross-sectional monitoring every few years by itself is, however, insufficient and monitoring at shorter intervals or a surveillance system are indispensable in order to detect and manage certain health impacts in a timely manner. By purposively considering communities impacted by a project, independent of their population size, the sampling method suffers in degrees of randomisation. However, these impacted communities need representation in the study sample. The degree of randomisation can be increased at the level of household selection and by adding further sentinel sites.

## 11.2 Contribution of PhD thesis research to HIA process and impact evaluation

Covering all elements of M&E in HIA, as displayed in Figure 11.1, was out of scope of this PhD thesis. Nevertheless, the HIA process as a whole was implemented for the infrastructure development projects introduced in this thesis and the experiences gained reach beyond the pursuit of cross-sectional health surveys. These experiences allow to make certain statements on selected elements of HIA process and impact evaluation, which are presented in Table 11.1.

**Table 11.1: Contribution of case studies to HIA process and impact evaluation**

<table>
<tr><th rowspan="2">Elements of HIA process and impact evaluation</th><th colspan="4">PhD thesis case studies</th></tr>
<tr><th>Kibali Gold Mine BHS (2010)</th><th>Bonikro Gold Mine malaria and anaemia survey (2011)</th><th>ABSL project BHS (2010) and FUHS (2013)</th><th>Trident project BHS (2011) and FUHS (2015)</th></tr>
<tr><td>HIA core values (democracy, equity, sustainable development, ethical use of evidence, systematic approach to health)</td><td colspan="4">By applying the IFC's EHA framework, the various HIA reported here supported a comprehensive approach to health, including social, economic, environmental and institutional determinants of health. This is also reflected in the broad range of indicators collected during the surveys at individual, household, community, school and health facility levels and the combination of questionnaire, biomonitoring and environmental sampling. This in turn generated a robust evidence-base which ought to be used by decision-makers. In addition, through peer-reviewed publications, the projects adhered to the transparency principle [20].<br><br>Through the stakeholder engagement, affected populations can participate in issues that affect their health (democracy value) [21-24]. Three of the present case studies involved the communities in the scoping phase through focus group discussions (FGDs) and community consultations and primary health data collection was pursued in all four project areas.<br><br>Equity, including gender considerations, and the integration of migrants and resettlement communities as separate stakeholders and/or PACs remains neglected in HIA, which was partly true in the case studies [25, 26]. However, a learning process took place. For example, in the ABSL FUHS, project-important factors such as migration background were relying on an average estimate by measuring the population size in 2010 (BHS) versus the population size in 2013 (FUHS). In the Trident FUHS (2015), such indicators were assessed at the individual level, which makes exposure-effect statistics more precise.<br><br>For the present case studies, it is still too early to answer the question whether or not the projects contributed to sustainable development.</td></tr>
<tr><td>HIA stakeholder participation</td><td colspan="4">In all case studies, the local public health system partners, e.g. district health management teams or respective counterparts, served as strong partners in planning and implementation of the surveys. Peer-reviewed publications were co-authored and published by local health authorities and partner organisations together with researchers from academic institutions.<br><br>Community acceptance was high in the surveys indicating (i) intact community relations and (ii) good survey sensitization [27]. However, local hospitality was probably the most important reason. The ABSL project was rewarded for its stakeholder engagement process by an independent auditing body [28].</td></tr>
</table>

| **Elements of HIA process and impact evaluation** | **PhD thesis case studies** | | | |
|---|---|---|---|---|
| | **Kibali Gold Mine BHS (2010)** | **Bonikro Gold Mine malaria and anaemia survey (2011)** | **ABSL project BHS (2010) and FUHS (2013)** | **Trident project BHS (2011) and FUHS (2015)** |
| HIA research and continued HIA activities (e.g. community health management, M&E including FUHS) | The research methodology applied in all case studies was similar, as discussed in 11.1. The follow-up activities within HIA varied greatly between the case study projects. Importantly, two case study projects stand out by the fact alone that they did conduct an FUHS. It cannot be ruled out, however, that other projects have similarly rigorous monitoring or surveillance systems in place but the results are not accessible or visible. | | | |
| | Follow-up activities are unknown as there is no information accessible on steps 4-6 of the HIA process.<br>M&E is perhaps done outside the scope of the HIA process. | No comprehensive BHS was conducted which limits the evidence-base for conditions other than malaria and anaemia.<br>M&E is perhaps done outside the scope of the HIA process. | With regards to the methodology, additional comparison sites were added to improve the statistical power of future FUHS.<br>The amount of continued HIA activities is deemed appropriate, with repeated cross-sectional monitoring at short and long intervals. | With regards to the methodology, additional comparison sites were added to improve the statistical power of future FUHS.<br>The amount of continued HIA activities is deemed appropriate, with repeated cross-sectional monitoring at short and long intervals.<br>Contracted HIA expertise on a continued basis (10%). |
| HIA time lines | HIA was initiated before project development. Baseline data were collected during feasibility studies. | Data collection occurred during the operation phase, hence not ideal to assess a true baseline. | HIA was initiated before project development. Baseline data were collected during feasibility studies. | HIA was initiated before project development. Baseline data were collected during feasibility studies. |

Taken together, Table 11.1 shows that important elements of HIA were covered in the case studies but to varying degrees. This depends on the impact assessors' conduct and recommendations and finally on project management decisions. However, the lack of transparency, visibility or continuation of HIA activities hinders a stronger evaluation of HIA elements. For example, for two projects, HIA follow-up activities are largely unknown but might exist. Furthermore, to cover all elements of M&E in HIA as displayed in Figure 11.1, two additional evaluations are needed: (i) quality review of HIA reports covering elements of HIA process evaluation; and (ii) stakeholder consultations covering elements of HIA impact evaluation [29-32]. With the practical knowledge and evidence at hand at the moment, it can be concluded that the implementation of HIA triggered inter-sectoral collaboration (i.e. with the health sector), community engagement and evidence-based decision-making.

## 11.3 Quantification, transparency and accountability in HIA

In 2009, the IFC HIA guidelines stated that '*Due to complex ethical and technical issues, as well as uncertainty associated with linkages between results and exposures, biomonitoring typically is not performed by the private sector as part of HIAs'* [33]. This was preceded by a number of scholarly article emphasising that quantification of impacts and biomonitoring, i.e. quantification of outcomes, are out of the scope or unnecessary for HIA [34, 35]. Due to the assumptive and qualitative approaches of HIA and often incomplete baseline data leading to high levels of uncertainties, quantitative precision was deemed excessive [35].

Especially in LMIC, the collection of primary health data, including biomedical samples, was considered difficult and data on infectious diseases and SDHs were rarely collected [36, 37]. This is probably linked to the fact that HIA was usually covered under EIA and practitioners had limited epidemiological or medical expertise. Therefore, quantification of health impacts was often restricted to measurement of environmental exposures in water, soil and air [37, 38]. Meanwhile, many methods and approaches to quantify impacts and outcomes have been put forward in different disciplines and settings [37, 39-41]. By including human biomonitoring data, a greater precision in exposure and associated risk may be achieved. Moreover, biomonitoring is independent from response bias [7, 39]. The case studies presented here apply standard epidemiological surveys adapted to the specific project setting of infrastructure development projects. The implemented method has demonstrated that quantification of health outcomes and its determinants is possible in remote settings if adequate financial resources are provided. Despite difficult logistic conditions, best practice standards, high quality diagnostics and measurement tools, standard operating procedures and international classification schemes were applied to guarantee quality of measurements [42].

An advantage of quantified health outcomes, especially robust baseline data, consists of having a legal leverage to prosecute health offences and holding projects accountable for impacts that might occur over the course of a project [25, 43, 44]. For projects, accountability, transparency goals, financial and reputational reasons can motivate the collection of health data at baseline and follow-up [45, 46]. The suite of impact assessments, including HIA, EIA, SIA and human rights impact assessment (HRIA) provide a means of monitoring accountability towards the general public and affected population about the impacts of their activities [47, 48]. The notion that governments, national and multinational bodies and corporations need to be held accountable for the impacts of their policies or activities has gained traction in recent years [25, 44, 49, 50]. However, in LMIC, the pursuit of HIA of projects with expected moderate and significant impacts to secure funding are often the only enforcement mechanism for HIA and therein, baseline health data collection is not yet mandatory [20, 33, 51]. In the absence of a regulatory environment, projects not only can operate without adhering to any health standards but also sometimes find themselves safeguarding health with little government support [45].

Transparency, providing information to the public, is a prerequisite for accountability. Data collected in the private sector can supplement HIS data if they are shared with the local health authorities and at times, they provide the only data source in an area [52]. Results from various BHS have been published in the peer-review literature, increasingly so in open-access journals. At times the whole survey reports were made available online [53]. Results from the case studies pertaining to malaria assessments were shared with the Malaria Atlas Project (MAP), while georeferenced survey data pertaining to schistosomiasis and soil-transmitted helminthiasis were shared with the manager of the open-access Global Neglected Tropical Diseases (GNTD) database [54, 55]. The epidemiological survey data therefore make a valid contribution to disease mapping and modelling which will support cost-effective disease control planning.

## 11.4 Prospects of HIA

### 11.4.1 Health-in-all-sectors and HIA

Goal number three of the Sustainable Development Goals (SDGs) agenda pertains to health by stating: “Ensure healthy lives and promote well-being for all at all ages” [56]. The Technical Support Team’s issue brief on ‘health and sustainable development’ explains the central role of health in the economic, social and environmental dimensions of sustainable development [57]. A health-in-all-sectors approach is established, where health-related targets are to be considered in developments across all sectors accompanied by monitoring of health- and SDH-indicators [57]. The monitoring of health impacts has explicitly been declared as one of the five priorities in the framework of the SDGs and governments, scientists and private sectors are called to routinely release their data [58]. The common intentions, goals and approaches between the SDGs and HIA are striking, and hence, the SDGs era creates additional momentum for HIA.

This holds true for the private sector, which could and should play an important role in the economic, healthy and sustainable development of every country [57, 59-62]. The permitting process for development of private sector projects usually considers potential environmental and social impacts, whereas health impacts are often neglected [63-66]. HIA is nowadays often regarded as a necessity by projects because community health issues can affect business performance with significant financial repercussions and productivity loss, but can also affect the company’s reputation [45]. Nevertheless, many projects do not conduct an HIA and private sector projects are therefore called to further raise their health management and sustainability standards [60]. This includes the commission of HIA or similar approaches to safeguard community and workforce health. Corporate social responsibility (CSR) beyond the fence line of a project has become a widely used concept where a company initiates social, economic, environmental and health development initiatives to support sustainable development in communities that are affected by a project [60, 67].

In recent years, major public health agencies, such as the Global Fund to Fight AIDS, Tuberculosis (TB) and malaria (GFATM) and the Roll Back Malaria (RBM) Partnership called for the strengthening of the collaboration with and contribution of the private sector to health promotion and disease control [68, 69]. Overall, HIA provides an opportunity for inter-sectoral collaboration and strengthening of partnerships with the Ministry of Health, donors, implementing organisations and research institutions [70]. Examples of fruitful public-private partnerships showcased how health promotion activities decreased disease burden in the workforce and communities, how cost-saving prevention is compared to curative expenses and how activities can expanded beyond a project’s area of influence [70-72].

### 11.4.2 Situating HIA within the impact assessment suite

HIA has matured since the formulation of the Gothenburg consensus paper in 1999. A process has been established which is applied across all disciplines but at the same time the HIA demonstrated flexibility to adapt to different contexts and allowing for new methodological features or tools [38, 73-81]. Notwithstanding, HIA has not yet reached the same acceptation as EIA or SIA and there is ongoing debate on whether or not health should be covered under EIA [77, 82-88]. The pro-arguments are that: (i) health could be sort of a freeloader in EIA (“piggybacking”), since EIA is a regulatory requirement in many countries and is therefore a catalyst for HIA requirement [35, 86, 89, 90]; (ii) EIA and SIA offer ideal platforms for HIA and a close association prevents HIA of becoming an isolated process [77]; (iii) the core values, intersectoral approach and comparatively higher transparency characteristic to HIA would have beneficial effects for the other impact assessments [86]; (iv) duplication of efforts can be reduced since environment and health are closely linked [91]; (v) an additional assessment could increase impact assessment fatigue [32]; and (vi) the limited evaluation of HIA as a single approach does not yet justify its use [86, 92]. The contra arguments are that: (i) health is often not given the appropriate attention in EIA but is reduced to a single paragraph and lacking depth and comprehensiveness [86, 88, 93-95]; (ii) the environmental risk factors are prominent over social and other determinants of health [35, 82, 87, 88]; (iii) EIA are conducted by environmentalists with little public health training or with inadequate involvement of public health professionals [77, 96]; (iv) the association and collaboration with the health authorities might be overseen when embedding health in EIA; (v) in some countries, where EIA is perceived as a bureaucratic hurdle that delays processes, the rather negative annotation with EIA would be a barrier to the promotion of HIA [90, 97]; and (vi) there is the potential risk to overload the EIA and create confusion on what EIA or HIA entail [90].

The integrated impact assessment (IIA) provides an alternative option to recognise interlinkages and mutual benefits and bring the impact assessments closer together [95]. There is, however, discrepancy on the terminology and understanding of IIA [98]. In some cases, IIA relates again to the integration of health into the 'existing impact assessments', i.e. in EIA or SIA. This is sometimes also referred to as 'environmental HIA' or integrated HIA/EIA [35, 91]. In other cases, as argued by Kemm (2013), two or multiple impact assessments amalgamate without replacing each other or competing [32]. This is also the definition embraced by the IFC, often labelled as ESHIA. Based on Kemm's understanding, the features of an IIA are that (i) impact practitioners form all fields (e.g. environment, cultural heritage, social and health) collaborate closely from the start of the feasibility studies to shape the impact assessment together; and (ii) a consolidated ESHIA report is provided to the decision-makers covering the full range of impacts and the jointly developed mitigation measures [77].

Again within IIA, health has been found to be neglected. For example, in 2005/2006, more than half of the integrated assessments conducted by the European Commission had no mention of health, although this indicates that IIA is probably understood as health being covered under EIA [99]. Once more, most literature on HIA/EIA integration stems from experience in high-income countries. The neglect of health in the permitting process and impact assessments of infrastructure development projects is especially negligent in SSA, which carries high burden of disease with a large proportion of vulnerable and poor population groups [100]. For projects in SSA, the situating of HIA within the impact assessment suite is not yet clearly defined. Whichever approach to health is used, for the future direction of HIA in SSA, either a reform of EIA practice is needed so that it adequately covers health or HIA needs to be established to complement EIA [32].

### 11.4.3 The call for an updated HIA consensus

In view of the diversity of methods, tools, principles and elements that advanced HIA in the different settings, there is a strong argument to take a step back and re-evaluate the core values and guiding principles of HIA as they were formulated from a European perspective in 1999 [101-103]. Krieger *et al*. (2010) argue that for private sector HIA in LMIC, social management and alleviation of inequalities attained through the SDH-based HIA framework is out of scope of the HIA [104]. In their view, an EHA-based framework as proposed by the IFC is more feasible as the project can influence environmental elements more directly [105]. Other experts in the field argue that the two frameworks are not mutually exclusive and have fused over the years [75, 106]. Harris-Roxas and colleagues (2012) believe that the European-shaped HIA consensus is outdated in light of the HIA development over the past 20 years [79]. For example, HIA core values such as ‘comprehensive approach to health’ and ‘ethical use of evidence’ are undisputed, but the degree to which the ‘democracy’ value can be applied in the different settings can be argued. In rural parts of SSA, as elsewhere, community participation is crucial in understanding local behaviours, perceptions and beliefs but the evidence of community participation in improving health outcomes is weak [107, 108]. Moreover, emerging global issues, such as climate change, population growth, urbanization and (re-)emerging infectious diseases need more attention in the future [109, 110]. Consequently, there have been a range of ‘informal’ additions to the guiding principles or characteristics of HIA (e.g. transparency and monitoring) [1, 20, 87, 102, 111]. In a 2014 review, Fakhri *et al*. (2014) discovered 122 characteristics related to HIA and proposed that a overreaching guidance on universal HIA practice is feasible and necessary [102]. In response, Winkler and Utzinger (2014) argued that a new consensus on HIA is needed but it should by no means prevent the unfolding of HIA in many disciplines and settings [103].

Overall, there is some discontent and also excitement among HIA practitioners and researchers who think there is a strong need for the new developments to be endorsed by the WHO in an updated international consensus on HIA. This would provide a new reference document at an official level, by the global public health agency, with clear guidance on HIA.

## 11.5 Thesis contribution to innovation, validation and application

The present PhD thesis pursued at the Swiss TPH contributed to the entire value chain from innovation to application, which forms the foundation of Swiss TPH’s research and development activities. Innovation refers to basic research in the laboratory, development of new tools or drugs and elaboration of concepts and methods for epidemiology and public health. Through validation, newly developed tools, drugs, concepts and methods are tested under ‘real-life’ conditions. Research findings and gained knowledge from the field validation can then be transformed into policies and applied at health system level [2]. The contributions of this PhD thesis to the three domains are summarised in Table 11.2.

**Table 11.2: Contribution of the PHD thesis to the Swiss TPH value chain of “innovation, validation and application”**

| Chapter | Innovation | Validation | Application |
|---|---|---|---|
| Chapter 4 | The modular BHS methodology was specifically developed by Winkler et al. (2010) for large-scale infrastructure development project settings in remote areas and resource constraint settings of SSA. | The BHS conducted in August 2010 in the Kibali Gold Mine was the first validation of the modular BHS methodology developed by Winkler et al. (2010) [112]. | |
| Chapter 5 | | The malaria and anaemia survey conducted in the BGM project area was a validation of the survey methodology with the goal to estimate the true prevalence of two important conditions in children under 5 years of age in this setting. | |
| Chapter 6 | | The effects of a renewable energy project using a large area of arable land on the local food security and nutritional indicators in children was so far not assessed through repeated cross-sectional surveys. Moreover, the results have been publicly released through peer-reviewed scientific literature. | The findings from repeated-cross sectional surveys for the two projects demonstrate the importance and effectiveness of M&E in HIA and the HIA itself.<br>The PhD thesis makes a case for integrating HIA with a robust M&E component as a routine process for infrastructure development projects in SSA.<br>Enforcement mechanisms for HIA at national policy level in SSA have yet to be implemented. |
| Chapter 7 | The FUHS for M&E in HIA is a newly developed element that has not previously been implemented in infrastructure development project settings in SSA. | | |
| Chapters 8 - 10 | The effects of extractive industry projects implemented in SSA with a focus on child and women’s health outside the chemical hazard spectrum was rarely assessed in a repeated cross-sectional manner. | This case study provides one of the few examples on HIA implementation of a project in SSA and its outcomes, in the particular case of HIV/AIDS.<br>The FUHS is an almost unique implementation of repeated cross-sectional monitoring in project settings in SSA where the results have been publicly released through peer-reviewed articles. The methods and tools used proofed valid to detect changes of health outcomes and associated factors. | |

## 11.6 Conclusion

The heart of this PhD thesis is a series of case studies on assessing and monitoring health impacts caused by large infrastructure projects in the renewable energy and extractive industry sectors in SSA. It was driven by the lack of case study examples of HIA implementation in private sector projects in SSA and the monitoring of health outcomes predicted within HIA, despite over 20 years of HIA implementation. Cross-sectional health surveys in communities residing in the respective project areas, including three BHS and two FUHS, were conducted with the goals to (i) observe changing patterns of health in communities affected by specific projects; (ii) identify determinants and factors of changing health; and (iii) support decision-making on health intervention strategies to mitigate negative and promote positive health effects caused by projects.

The approach of cross-sectional health surveys used for M&E of health impacts caused by infrastructure development projects is promising in detecting changing patterns of community health and in supporting locally adapted health interventions. The baseline and follow-up health data collection within the HIA framework of the four case studies generated a combination of biomedical, behavioural, contextual and environmental indicators which allowed projects and health authorities to better understand pressing health needs in the communities or sub-populations and take actions for health promotion. It has been demonstrated that quantification of health outcomes is possible even when resources are constrained, the logistics difficult and the location remote, which was previously deemed doubtful or unnecessary by the HIA community. Yet, at the same time the lack of quantification was declared a weakness of the HIA process. So far, the results from two FUHS conducted in Sierra Leone and Zambia showed generally encouraging results with regards to HIA's impact on projects.

Cross-sectional M&E every few years, however, needs to be complemented by monitoring or surveillance mechanisms with significantly shorter time intervals (e.g. continuous, weekly, monthly) to guarantee rapid response and preventive disease control. Consequently, a combination of routine (continuous) and cross-sectional monitoring at larger intervals is of paramount importance. This is valid not only for the individual projects, but also for HIA practice in LMIC and most importantly, for the affected communities to protect and improve their health. However, without legal requirements or any other means of enforcement at country level, the commissioning of HIA as well as the conduction of baseline and monitoring health data remains ultimately in the hands of projects, industry associations and financial institutions and can therefore be bypassed by a large number of projects that do not rely on third party funding [109].

The monitoring of health outcomes and SDH-indicators performed in this PhD thesis contributed to the validation of steps 4 and 5 and partly step 6 of the HIA process which so far have been largely neglected in practice and literature and supposedly have hampered the establishment of HIA as an integral and equal part of the impact assessment suite. The goals and intentions of HIA, which considers health impacts of projects outside the health sector, are perfectly in line with the SDGs positioning of health as a cross-cutting issue between the social, economic and environmental dimensions of sustainable development. Moreover, the monitoring of health-related targets has been declared as one of the five priorities in the framework of the SDGs. Consequently, there is a strong case to use HIA that has a robust M&E component and demonstrate its effectiveness in promoting health through additional case studies that rigorously evaluate the entire HIA process.

### 11.7 Open research needs

In view of the current HIA practice together with the experience and findings from the present PhD thesis, the following research needs arise:

(i) Recently, M&E in HIA is given more attention in HIA practice. An optimised combination of surveillance and monitoring of health impacts of infrastructure development and management projects in SSA, has yet to be studied. This should also address the attention given to population sub-groups (e.g. migrants or marginalised groups) and the level of integration into the routine HIS.

(ii) An overall evaluation of the HIA process after decommissioning of an infrastructure development project in SSA was, to our knowledge, never done. Such a final evaluation will give insight on the overall impacts, help to evaluate the predictions made in the HIA risk assessment step and evaluate whether the HIA achieved its ultimate goal of minimising negative health impacts and promoting positive health impacts.

(iii) Cost-effectiveness evaluations of health interventions are common. The cost-effectiveness of workplace disease control programmes has also been studied. However, a thorough cost-effectiveness analysis of HIA benefitting the workforce but also the communities they live in would measure whether or not there is a business case for projects to commission an HIA.

(iv) Similarly, a cost-benefit analysis of HIA for large development projects will support host governments to estimate the costs of such activities for the public health system *versus* cost-savings achieved through proactive health prevention approaches such as HIA.

(v) Evidently, projects that impact on health through their activities should be obligated to appropriately manage health risks, for example through the commissioning of an HIA. The reasons for the current absence of HIA enforcement mechanisms in countries in SSA are not well understood. An increased understanding of the political, cultural, institutional or other barriers will help to overcome such barriers and can pave the way for HIA institutionalisation at national levels.

(vi) Conclusions on the contribution of infrastructure development projects on sustainable development, or the absence thereof, cannot be drawn based on a few case studies. A large number of projects need to be evaluated based on a set of key indicators. This will elucidate the overarching effects of infrastructure projects on population health. Moreover, projects that implemented HIA can be compared with projects that did not implement an HIA and differences will reveal if HIA fulfils the promises it holds.

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# 12 Appendices

## 12.1 Equator Principles

**Table 12.1: Equator Principles**

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| *Principle 1 – review and categorisation:* Each project will be categorised based on the magnitude of its potential risks and impacts reaching from A (significant, adverse, irreversible or unprecedented impacts), to B (limited, localized, reversible and addressable), to C (minimal or no adverse impacts). |
| *Principle 2 – environmental and social assessment*: Category A and B projects require the conduction of an impact assessment to address relevant impacts and proposes measures to avoid, minimize and mitigate impacts. |
| *Principle 3 – applicable environmental and social standards*: The project and impact assessment must in any instance comply to host country laws, regulations and permits that pertain to environmental and social issues. |
| *Principle 4 – environmental and social management system and Equator Principles action plan*: a management or action plan is prepared by the project that addresses all issues raised in the impact assessment and incorporates all requirements to comply with laws and regulations. |
| *Principle 5 – stakeholder engagement*: Category A and B projects need to engage in an ongoing stakeholder process with affected communities and if relevant, other stakeholders. |
| *Principle 6 – grievance mechanism*: A grievance mechanism for affected communities should be in place throughout the life of the loan. |
| *Principle 7 – independent review*: The impact assessment process should be reviewed by an independent consultant with no direct link to the project. |
| *Principle 8 – covenants*: All projects will covenant in the financing documentation to comply with all relevant host country environmental and social laws, regulations and permits in all material respects. |
| *Principle 9 – independent monitoring and reporting*: Independent consultants will assess projects with relevance to their compliance with the Equator Principles throughout the life of the loan. |
| *Principle 10 – reporting and transparency*: For all category A and as appropriate for category B projects, as a minimum, a summary of the impact assessment must be publicly accessible online plus the project must publicly report on green-house gas emission levels (if emitting over 100,000 tonnes of $CO_2$ (carbon dioxide) annually). |

As of March 2016, 82 EPFIs in 36 countries have adopted the Equator Principles, covering over 70 percent of international project finance debt in emerging markets.

## 12.2 Environmental health areas

**Table 12.2: Environmental health areas**

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| **EHA 1** | **Communicable diseases linked to the living environment** – Transmission of communicable diseases linked to inadequate housing design, overcrowding and housing inflation. |
| **EHA 2** | **Vector-related diseases** – Diseases that are transmitted via a vector such as mosquito, fly, tick or lice. |
| **EHA 3** | **Soil-, water- and waste-related diseases** – Diseases that are transmitted directly or indirectly through contaminated water, soil or non-hazardous waste. |
| **EHA 4** | **STIs, including HIV/AIDS** – Infections commonly transmitted by sex and caused by ~30 different bacteria, viruses and parasites. |
| **EHA 5** | **Food- and nutrition-related issues** – Adverse health effects such as malnutrition, anaemia or micronutrient deficiencies due to e.g. changes in agricultural and subsistence practices, or food inflation; gastroenteritis, food-borne trematodiases, etc. This also considers feeding behaviours and practices. Access to land plays a major role in developing subsistence farming contexts. |
| **EHA 6** | **Non-communicable diseases** – Non-infections, non-transmissible, often chronic diseases that have individual, lifestyle and environmental risk factors such as smoking, obesity, high blood pressure or other SDH. |
| **EHA 7** | **Accidents and injuries** – Road traffic or work-related accidents and injuries (domestic and project-related) and drowning. |
| **EHA 8** | **Veterinary medicine and zoonotic diseases** – Diseases (i) affecting animals and humans or (ii) diseases that potentially can be transmitted from animal to human. |
| **EHA 9** | **Exposure to potentially hazardous materials, noise and malodours** – This considers the environmental health determinants linked to the project and related activities. It can also include exposure to heavy metals and hazardous chemical substances and other compounds, solvents or spills and releases from road traffic and exposure to mal-odours. |
| **EHA 10** | **SDH** – Including psychosocial stress (due to e.g. resettlement, overcrowding, political, ethnic or economic crisis), mental health, gender issues, domestic violence, suicide, security concerns, substance misuse (e.g. drugs, alcohol, smoking). |
| **EHA 11** | **Health seeking behaviours and cultural health practices** – Role of traditional medical providers, indigenous medicines and cultural health practices. |
| **EHA 12** | **Health systems issues** – Physical health infrastructure (e.g. capacity, equipment, staffing levels and competencies, future development plans); disease control programmes (e.g. malaria-, TB-, HIV/AIDS-initiatives, maternal and child health). |

# Curriculum vitae

## PERSONAL INFORMATION


| | |
|---|---|
| Full name | Astrid M. Knoblauch |
| Email | astrid.knoblauch@swisstph.ch, astrid.knoblauch@me.com |
| Date of birth | 13. December 1985 |
| Place of birth | St. Gallen (SG) |
| Place of origin | Winterthur (ZH) |
| Nationality | Swiss |
| Languages | German (mother tongue), English (fluent), French (fluent), Spanish (beginner) |


## EDUCATION

| | |
|---|---|
| 01/2014 – 06/2016 | PhD in Epidemiology; Department of Epidemiology and Public Health (EPH), Ecosystem Health Science Unit, Swiss Tropical and Public Health Institute (Swiss TPH), University of Basel, Basel, Switzerland<br>Thesis title: "*Assessing and monitoring health impacts of infrastructure projects in sub-Saharan Africa"* |
| 09/2008 – 02/2010 | Master in Epidemiology and Infection Biology, Major in Epidemiology; Swiss TPH, University of Basel, Basel, Switzerland<br>Thesis title: "*Analyse de la Dynamique et des Caractéristiques des Points de Vente des Préservatifs au Cameroun et en République Centrafricaine"* |
| 09/2005 – 08/2008 | Bachelor in Biology, Major in Neurobiology; Université de Fribourg, Fribourg, Switzerland |
| 08/2001 – 07/2005 | High School Kantonsschule am Burggraben, Major in Law and Economics; St. Gallen, Switzerland |

## PROFESSIONAL EXPERIENCE

| | |
|---|---|
| 08/2016 – 06/2017 | Project Associate; Swiss Centre for International Health, Swiss TPH, University of Basel, Switzerland, supervised by Dr. Helen Prytherch |
| 01/2014 – 06/2016 | Public Health Consultant and PhD candidate in Epidemiology; Swiss TPH, University of Basel, Switzerland, supervised by Dr. Mirko Winkler and Prof. Dr. Jürg Utzinger |
| 03/2010 – 12/2013 | Public Health Consultant; SHAPE Consulting Limited, Pretoria, South Africa |
| 02/2009 – 07/2009 | Research Assistant; Association Camerounaise pour le Marketing Social, Yaoundé, Cameroon, and Association Centrafricaine pour le Marketing Social, Bangui, Central African Republic |

## PROJECT EXPERIENCE

| | |
|---|---|
| 04/2017 – 05/2017 | Fastenopfer, Luzern, Switzerland; Health effects of cyanide use in artisanal and small-scale gold miners in Burkina Faso, Kongoussi, Burkina Faso |
| 10/2016 – 05/2017 | The Global Fund to Fight AIDS, Tuberculosis and Malaria (GFATM), Geneva, Switzerland; Data Quality Review and Quality of Care Study in Côte d'Ivoire |
| 09/2015 – 12/2015 | Swiss Centre for International Health, Swiss TPH, Switzerland, and The Special Programme for Research and Training in Tropical Diseases (TDR/WHO), Switzerland; Situation analysis on the use of Global Fund grants for operational research, Democratic Republic of the Congo and Indonesia |
| 06/2015 | First Quantum Minerals, Zambia; Health impact assessment follow-up health survey for the Trident Project |
| 03/2015 | Swiss TPH, Switzerland; Baseline survey coordination for the "Vegetables go to School Project" cross-sectional case studies, Burkina Faso |
| 08/2014 – 09/2014 | Swiss Centre for International Health, Swiss TPH, Switzerland; *Salmonella* Outbreak Investigation in Switzerland, Switzerland |
| 02/2014 – 03/2014 | Swiss Centre for International Health, Swiss TPH, Switzerland; Baseline survey for the Project 'Next Generation: Sexual and |

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|---|---|
| | Reproductive Health in the Great Lakes Region', Democratic Republic of the Congo |
| 12/2013 | Addax Bioenergy Sierra Leone; Health impact assessment follow-up health survey of the Addax Bioenergy Project, Sierra Leone |
| 08/2013 | Exxaro; Health impact assessment scoping study of the Mayoko Iron Ore Project, Republic of Congo |
| 04/2013 | Anadarko Petroleum Corporation; Health impact assessment baseline health study of the Moçambique Area Limitada 1 Project, Mozambique |
| 02/2013 | Ashanti Goldfields Kilo; Health impact assessment baseline health study of the Mongbwalu Project, Democratic Republic of the Congo |
| 12/2012 | Newcrest Mining Limited; Malaria prevalence study of the Bonikro Gold Mine, Côte d'Ivoire |
| 09/2012 | African Barrick Gold; Health impact assessment baseline health study of the North Mara Mine, Republic of Tanzania |
| 08/2012 | Banro Corporation; Health impact assessment scoping study of the Namoya Gold Project, Democratic Republic of the Congo |
| 06/2012 | Base Titanium Resources; Health impact assessment baseline health study of the Kwale Mineral Sands Project, Kenya |
| 02/2012 | Equatorial Palm Oil plc; Health impact assessment scoping study of the Palm Bay and Butwa Projects, Liberia |
| 10/2011 | RioTinto; Health impact assessment baseline health study of the Simandou Iron Ore Project, Port development area, Guinea |
| 09/2011 | Newcrest Mining Limited; Health impact assessment scoping study and malaria KAP study of the Bonikro Gold Mine, Côte d'Ivoire |
| 12/2010 | Addax Bioenergy Sierra Leone; Health impact assessment baseline health study of the Addax Bioenergy Project, Sierra Leone |
| 08/2010 | Randgold Resources; Health impact assessment baseline health study of the Kibali Gold Project, Democratic Republic of the Congo |

## PUBLICATIONS

**Knoblauch AM**, Divall MJ, Owuor M, Archer C, Nduna K, Ng'uni H, Musunka G, Pascall A, Utzinger J, Winkler MS (**2017**). Selected indicators of women's health and associated determinants in the vicinity of a copper mine development in northwestern Zambia; BMC Women's Health: ***in review***.

**Knoblauch AM**, Divall MJ, Owuor M, Musunka G, Pascall A, Nduna K, Ng'uni H, Utzinger J, Winkler MS (**2017**). Experience and lessons from health impact assessment guiding prevention and control of HIV/AIDS in a copper mine project, northwestern Zambia; Infectious Diseases of Poverty: doi:10.1186/s40249-017-0320-4.

Erismann S, Diagbouga S, Schindler C, Odermatt P, **Knoblauch AM**, Gerold J, Leuenberger A, Shrestha A, Grissoum T, Utzinger J, Cissé G (**2017**). Schoolchildren's Health and Nutritional Status One Year after Complementary School Garden, Nutrition, Water, Sanitation, and Hygiene Interventions: Results from a Cluster-Randomized Controlled Trial in Burkina Faso; American Journal for Tropical Medicine and Hygiene: doi:10.1186/s12889-016-2910-7.

**Knoblauch AM**, Divall MJ, Owuor M, Archer C, Nduna K, Ng'uni H, Musunka G, Pascall A, Utzinger J, Winkler MS (**2017**). Monitoring of selected indicators in children living in a copper mine development area in northwestern Zambia; International Journal of Environmental Research and Public Health: 14, 315; doi:10.3390/ijerph14030315.

Kiefer S, **Knoblauch AM**, Steinmann P, Barth-Jaeggi T, Vahedi M, Maher D, Utzinger J, Wyss K (**2017**). Operantional and implementation research within Global Fund to Fight AIDS, Tuberculosis and Malaria grants: a situation analysis in six countries; Globalization and Health: 13:22; doi 10.11/s12992-017-0245-5.

Erismann S, **Knoblauch AM**, Diagbouga S, Odermatt P, Gerold J, Shrestha A, Grissoum T, Savadogo B, Schindler C, Utzinger J, Cissé G (**2017**). Prevalence of and risk factors for undernutrition among schoolchildren in the Plateau Central and the Centre-Ouest regions in Burkina Faso; Infectious Diseases of Poverty: 6:17.

Pereira CAR, Périssé ARS, **Knoblauch AM**, Utzinger J, de Souza Hacon S, Winkler MS (**2016**). Health impact assessment in Latin American countries: current practice and prospects; Environmental Impact Assessment Review 33: 15-22, in press.

Erismann S, Diagbouga S, Odermatt P, **Knoblauch AM**, Gerold J, Shrestha A, Grissoum T, Kaboré A, Schindler C, Utzinger J, Cissé G (**2016**). Prevalence of intestinal parasitic infections and associated risk factors among schoolchildren in the Plateau Central and the Centre-Ouest regions of Burkina Faso; Parasites & Vectors: 9:544. doi10.1186/s13071-016-1835-4.

**Knoblauch AM**, Archer C, Owuor M, Schmidlin S, Divall MJ, Utzinger J, Winkler MS (2016). Schistosomiasis and soil-transmitted helminth infections in school children in north-eastern Democratic Republic of the Congo (**2016**); Transactions of the Royal Society of Tropical Medicine and Hygiene: 110: 424–426.

Erismann S, Shrestha A, Diagbouga S, **Knoblauch AM**, Gerold J, Herz R, Sharma S, Schindler C, Odermatt P, Drescher A, Yang R, Utzinger J, Cissé G (**2016**) Complementary school garden, nutrition, water, sanitation and hygiene interventions to improve children's nutrition and health status in Burkina Faso and Nepal: a study protocol. BMC Public Health: 16:244.

**Knoblauch AM**, Bratschi MW, Zuske MK, Althaus D, Stephan R, Hächler H, Baumgartner A, Prager R, Rabsch W, Altpeter E, Jost M, Mäusezahl M, Hatz C, Kiefer S (**2015**). Cross-border outbreak of *Salmonella enterica ssp. enterica* serovar Bovismorbificans: Multiple approach investigation in Germany and Switzerland. Swiss Med Wkly: 2015;145:w141182.

**Knoblauch AM**, Hodges MH, Bah MS, Kamara HI, Kargbo A, Paye J, Turay H, Nyorkor ED, Divall MJ, Zhang Y, Utzinger J, Winkler MS (**2014**). Changing patterns of health in communities impacted by a bioenergy project in Northern Sierra Leone; International Journal of Environmental Research and Public Health: 11, 12997-13016; doi:10.3390/ijerph111121997.

**Knoblauch AM**, Winkler MS, Archer C, Divall MJ, Owuor M, Yapo RM, Pokou AY, Utzinger J (**2014**). The epidemiology of malaria and anaemia in the Bonikro mining area, central Côte d'Ivoire; Malaria Journal: 33:194.

Winkler MS, **Knoblauch AM**, Righetti AA, Divall MJ, Koroma MM, Fofanah I, Turay H, Hodges M, Utzinger J (**2013**). Assessing health impacts of a biofuel project in Sierra Leone: findings from a baseline health survey; International Health doi:10.1093/inthealth/ihu031.

Winkler MS, Divall MJ, Krieger GR, Schmidlin S, Magassouba ML, **Knoblauch AM**, Singer BH, Utzinger J (**2011**). Assessing health impacts in complex eco-epidemiological settings in the humid tropics: modular baseline health surveys. Environmental Impact Assessment Review 33: 15-22.

**CONGRESS PARTICIPATION**

| | |
|---|---|
| 06/2010 | International AIDS Conference, Vienna, Austria. *Characteristics and dynamics of condom selling points in Cameroon and the Central African Republic*. Poster Presentation. |
| 04/2015 | Annual Conference of the International Association of Impact Assessment (IAIA), Florence, Italy. *The value of quantitative health* |

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| | *indicators for a biofuel project HIA in Sierra Leone*. Oral presentation. |
| 09/2015 | European Congress on Tropical Medicine and International Health (ECTMIH), Basel, Switzerland. *Health monitoring in a changing social-ecological context of a biofuel project in Sierra Leone*. Oral presentation. |

## ADDITIONAL PROFESSIONAL ACTIVITIES AND SKILLS

| | |
|---|---|
| Extracurricular activities | Student representative (in a consortium of four students) for 150+ PhD students at the Swiss TPH (2015) |
| | Member of the appointment commission for the Eckstein-Geigy-Foundation sponsored professorship at Swiss TPH (2016) |
| Peer review activities | Malaria Journal (March 2015) |
| Memberships | International Association of Impact Assessment (IAIA) |
| Computer skills | MS Office, Stata statistical software, EpiData, Anthro and AnthroPlus softwares, ArcGIS, Open Data Kit (ODK) software for smartphones/tablets |

## APPROVED PROJECTS

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| 2/2017 – 11/2018 | **World Health Organisation (WHO), Interventions for Healthy Environments, Department of Public Health, Environmental and Social Determinants of Health**: **“**Piloting a new WHO framework to support the development of public health strategies on artisanal and small-scale gold mining – including in the context of the Minamata Convention”; Budget: CHF 174,959; Role: Co-applicant, technical expert |
| 8/2016 – 7/2018 | **Swiss Centre for International Health, Swiss TPH:** “Consolidating impact assessment as a service : a cross-departmental initiative of SCIH, EPH and ET”; Budget: CHF 100,000; Role: Co-applicant, technical expert |
| 1/2014 – 6/2016 | **Health Impact Assessment Research Group, Swiss TPH**: “*Assessing and monitoring health impacts of infrastructure projects in sub-Saharan Africa”;* Budget: CHF 300,000 (funded through public-private partnerships); Role: PI |