RESEARCH PROGRAM ON Water, Land and Ecosystems

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Malaria impacts of dams in Africa: Internalizing the externality

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1. Abstract

Malaria transmission – associated with morbidity, mortality and constraining economic development – has been reduced by more than 40% in Africa in the twenty-first century. Large dams, essential to achieving Africa's development goals, have nonetheless created a set of local conditions that have defied the broader twenty-first century progress. Dams typically increase the presence of small pools of water in which mosquitoes breed, resulting in proliferation of the *Anopheles* mosquitoes; the vectors of malaria transmission. Overall, the annual impact of large dams on malaria in Africa is very conservatively estimated at more than 1.1 million cases. In the absence of other changes, this cumulative impact is projected to exceed 2 million cases by the 2050s as a result of climate change and population growth. While there is a clear need to better mitigate these infrastructure-driven malaria cases, several tools and approaches for combatting the disease in the vicinity of reservoirs are currently not widely utilized. Predicting the malaria-enhancing effect of alternative dam options – now possible – can enable selection of disease-conscious development paths. Targeted manipulation of reservoir water levels at critical times also holds potential to reduce malaria transmission. Ultimately, a range of options for reducing the adverse malaria impacts of water resources development – by incorporating this disease externality into water resources planning and management – remain to be put into practice in Africa. This reality is likely resulting in avoidable disease burden.

2. Context and challenge, including key interactions (range and nature) the case study addresses

Dams are key for water security in Africa Rainfall variability disrupts rain-fed agricultural production, contributes to disasters associated with floods and droughts, and hinders economic growth in Africa. Water storage enabled by dams is critical to buffer communities from this variability and establish a platform for sustainable multi-sectoral development. Per capita water withdrawals in sub-Saharan Africa (SSA) are the lowest in the world as is the region's electricity consumption, creating conditions in which the region is vulnerable and growth-constrained. To provide a platform for advancing water security and sustainable development, Africa's heads of state laid out an ambitious, long-term plan for closing the continent's infrastructure gap. In the water and power sectors, the Program for Infrastructure Development in Africa (PIDA) calls for an expansion of hydroelectric power-generating capacity by more than 54,000 megawatts

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(MW) and of water storage capacity by 20,000 cubic kilometers (km^3). Numerous dams are now under construction throughout the continent to close the infrastructure "gap" and accelerate economic development.

Malaria and dams in Africa Malaria is one of the deadliest diseases in Africa and has been described by the World Health Organization (WHO) as one of the three big killers – together with tuberculosis (TB) and acquired immune deficiency syndrome (AIDS) – which collectively result in 6 million deaths per year. Ninety-percent of the malaria burden is concentrated in SSA, where it imposes considerable levels of social disruption and constrains efforts to accelerate critically-needed economic growth. Despite considerable progress toward malaria reduction in Africa in the twenty-first century, evidence is mounting that progress has slowed in recent years. Malaria is a parasite transmitted from person to person by *Anopheles* mosquitoes whose presence is essential to sustaining the disease. Breeding sites for these mosquitoes are typically shallow puddles created naturally, but are also created by human alterations to the environment that lend themselves to water collection. By increasing the area of standing water, dam construction often expands habitat suitable for *Anopheles* mosquito breeding. Further, by creating year-round water storage, dam construction often provides suitable breeding habitat in seasons of the year when natural puddles have dried up and historically malaria was not transmitted. More breeding sites lead to more adult *Anopheles* mosquitoes and, in many cases, more malaria.

The aggregate impact of large dams on malaria in Africa To determine the aggregate effect of large dams on malaria in Africa, 956 dams with georeferenced locations in Africa – representing less than half of the more than 2,000 total large dams in Africa – were drawn from the International Commission on Large Dams (ICOLD) database. The Malaria Atlas Project (MAP) and WorldPop databases were used to determine the population at risk and the number of cases near reservoirs. More than 14 million people live in close proximity (< 5 km) to the reservoirs associated with these dams. Despite conventional control efforts (e.g., insecticide-treated bed nets and indoor residual spraying) that are often applied in at-risk communities around reservoirs, more than 1.1 million additional malaria cases occurred near the dams in 2015. This is 1.1 million cases over and above the number of cases which would have occurred had the reservoirs not been present. The population at risk of malaria around existing reservoirs is projected to increase to 25-26 million due to population growth and climate change, and the number of malaria cases associated with reservoirs is projected to increase to 2.1-2.9 million in the 2050s.

Internalizing the externality: Constructive opportunities for reducing malaria impacts

Growing knowledge on the diversity in the malaria-enhancing effect of dams, and growing understanding of factors that explain such diversity, has given rise to three approaches to mitigate the adverse malaria impacts of dams (Table 1).

Table 1. *Three approaches to mitigate the adverse impacts of dams.*

Approach	Description
Dam placement	***Consider malaria transmission zone and slope of potential dam sites***. While ultimately a dam's disease impacts will need to be balanced against other factors, incorporation of severity of disease impact – as a function of transmission zone, slope and other factors – into planning can enable selection of disease-conscious development paths. Planning based on different dam impacts should account for climate-driven changes in impact.
Dam design	***Consider the nature of shoreline likely to develop at different dam heights***. Dam design (e.g., height) can affect the abundance of breeding sites in reservoirs as a function of the nature of reservoir shoreline that would develop at different dam heights.
Reservoir operations	***Investigate potential to manipulate water levels to minimize malaria***. While trade-offs with other dam objectives need to be considered,

	growing evidence points to the potential for reservoir management in such a way that reduces the abundance of adult mosquitoes.

Dam placement The selection of dam sites is typically based on many, often competing, factors, including the potential for hydropower generation, proximity to demand for irrigation water, and potential unwanted environmental effects. Decision making related to the placement of dams in a river basin may also affect malaria, given the differing impacts of dams on malaria in different locations. As now documented with increasing evidence, water that is impounded in areas of unstable (less intense or seasonal) transmission produces a greater impact than water impounded in areas of stable (more intense or year round) transmission. Further, variation in topography around alternative reservoir sites may render some very conducive to malaria transmission, while others much less so. In basins such as those of East Africa or southern Africa that originate in highland regions of no malaria transmission, flow downstream to midland regions of unstable transmission and continue farther downstream to lowland regions of stable malaria transmission, there would appear clear opportunity to consider geography-specific malaria impacts in selection of dam sites. Incorporation of malaria impacts into water planning should also account for how those impacts may evolve due to climate change, which will facilitate some changes in transmission zones.

Dam design The height of a dam is usually based on factors such as the volume of water that can be stored to mitigate floods and insulate from droughts, the quantity of hydropower that can be generated, and the number of people that would be displaced. The height of a dam also affects the size and shape of the reservoir behind it, which in turn has impacts on suitability for malaria transmission. As mosquitoes typically breed in puddles on the shallow-sloped areas around the reservoir perimeter, identifying how to design a reservoir where water levels are not conducive to puddle formation could play a key role in reducing the abundance of breeding sites. Mapping can be undertaken to identify potential hot spots that would be created by particular dam heights; if such hot spots are in close proximity to a community, they would be particularly dangerous. Although necessary to consider in the context of an integrated decision-making framework, it may be possible to construct dams at heights in which reservoir topography is not conducive to mosquito breeding.

Reservoir operations: ***evidence from Koka and Kariba*** An additional tool to control malaria around reservoirs is through the way in which dams are operated. In the pre-1950s era before the widespread use of Dichlorodiphenyltrichloroethane (DDT) for malaria control, the Tennessee Valley Authority, USA, demonstrated that reservoir water levels can be manipulated to render habitat less favorable for development of *Anopheles* larvae, reducing the prevalence of malaria in surrounding communities. More recently around the Koka Reservoir, Ethiopia, more rapid drawdown rates (e.g., closer to 30 mm/day) at the end of the wet season and beginning of the dry season were found to correlate with reduced larvae abundance in shoreline puddles. Rapid drawdown is postulated to desiccate shoreline breeding sites before larvae develop into adult mosquitoes. As such, more rapid drawdown during the months of greatest malaria transmission is presumed to reduce vector abundance and in turn contribute to malaria control efforts. Around the Kariba Reservoir, adverse malaria impacts were determined on the Zambian side of the reservoir. Using 16 years of data, water levels in the lake were compared with malaria transmission rates in affected communities. Lower water levels (in the order of 2 meters or more below usual) correlated with lower transmission rates, both when climatic variables were and were not considered.

The feasibility of implementing a malaria control parameter The feasibility of implementing water management regimes associated with lower malaria were investigated. This was done by considering the potential impact of the modified management regime on the benefits derived from current uses of the reservoir water such as hydropower, irrigation, flood control, water supply and downstream environmental flows. Around the Koka Reservoir, a computer model was used to simulate lowering the lake by a rate designed to disrupt larval development. In a simulation covering 26 years, application of the malaria control measure increased total average annual electricity generation from 87.6 GWhy to 92.2 GWhy (i.e., a 5.3% increase), but resulted in a small decline in firm power generation (i.e., guaranteed at 99.5% reliability) from 4.16 MW to 4.15 MW (i.e., a 0.2% decrease). Application of the malaria control measure did not impact the ability of the reservoir to meet downstream irrigation demand and reduced the number of days of downstream flooding from 28 to 24. Around the Kariba Reservoir, the implications of maintaining alternative operating policies on annual hydropower and energy production were then investigated. Sixteen alternatives are shown, illustrating options from high malaria-high hydropower to low malaria-low hydropower and to a considerable range in between. All alternatives appear better than historical system performance. Further analysis is needed to understand constraints imposed by the demand for firm hydropower production.

3. How did research efforts deal with the synergies and trade-offs?

At an analytical-level, research efforts dealt with synergies and trade-offs by considering change in malaria cases relative to changes in conventional benefits that are derived from water use, such as hydropower. A Pareto Front, for example, can be determined between number of malaria cases and Megawatts of hydropower production. Results of work around the Kariba Reservoir are shown below (Figure 1).

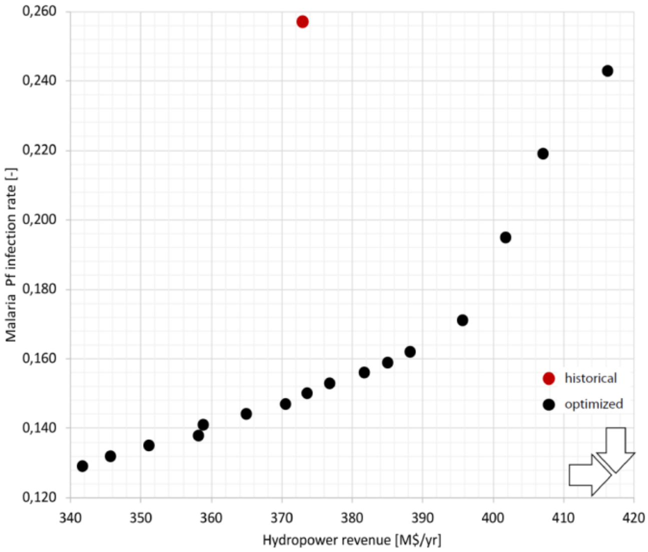

Figure 1. *Trade-off between malaria infection and revenue from hydropower production, Kariba Reservoir*

In terms of theory of change and impact pathways, synergies were often reflected in the regional and international network of partners through which this work has been implemented. There has been a geographically and sectorally diverse set of people involved in this research, which we believe has helped novel approaches to malaria control around reservoirs to resonate more widely as a viable additional option to control. Trade-offs may nonetheless be reflected in the scale of impact pathways. While partnerships are still pursued and realized with particular dam operators and health and water management authorities, emphasis has been increasingly placed on broader (regional) scale. This has partially resulted from a progressively broader focus of the dam-malaria work. Striking the optimal balance in the scale of pathways is likely to require emphasis at both local and regional scales.

To render work intelligible and encourage resonance across sectors, analytical metrics were often conveyed in both health (e.g., epidemiological) terms as well as terms that were more meaningful in the water and energy sectors such as volume of outflow and financial returns on energy production, with assessment of the trade-offs between the two. Metrics to gauge distribution and uptake of knowledge through this research have not been extensively applied as yet. Nonetheless, the level of citation on research articles coupled with levels of international media attention to such articles – from outlets such as British Broadcasting Corporation, Radio France International, South African Broadcasting Corporation, Voice of America – would appear to suggest that international and regional attention to such issues is growing. And such attention can pave the way for change.

4. What kinds of partnerships were critical?

At a broad-level, cross-sectoral partnerships and interaction were critical for this work. It clearly comprises both a health issue (malaria) and a water issue (dam design and reservoir operations). As such, involvement of people in both sectors was very important. Fortunately, at least two of the key professionals driving this work have background in both fields. A positive byproduct of the evolution in graduate curricula over the last couple decades is professionals with a more diverse range of expertise than would have previously been evidenced. This has resulted in pursuit of cross-disciplinary topics such as this.

More specifically, partnerships across applied research institutes like the International Water Management Institute (IWMI) with universities that can contribute the latest approaches is critical. IWMI-WLE possesses links with key water management and dam operating authorities (from the energy sector, in cases) and a range of research expertise and skills. Universities possess more specialized technical expertise in entomology and epidemiology on the one hand, and optimization and water resources modelling on the other.

5. Lessons learnt, including knowledge gaps and good practices in employing these approaches at scale

Additional dam construction is essential to achieving several Sustainable Development Goals (SDGs) in Africa. However, if not undertaken carefully, this may undermine progress toward achieving SDG 3. Due to sectoral disconnects, absence of clear implementation guidelines or other factors, several key opportunities to enhance efforts to mitigate a major unwanted externality of dam development and achieve holistic progress toward SDG realization have not been put into practice in Africa. This omission is resulting in unnecessary disease burden and reflects a fragmented approach to sustainable development, which should be addressed. Ultimately, forgoing viable malaria control tools – namely, water resources planning, dam design and operations – in the face of the pervasive morbidity and mortality associated with water reservoirs calls for a change in practice. The time to convert knowledge into action is overdue.

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