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Dams and malaria in Africa: Time for action

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 adult *Anopheles* mosquitoes; the vectors of malaria transmission. Overall, the annual impact of large dams on malaria in Africa is 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 holds potential to reduce malaria transmission. Ultimately, a range of options for reducing the adverse impacts of water resources development remain to be put into practice in Africa – resulting in avoidable disease burden.

This policy brief was collaboratively undertaken by researchers at IWMI, University of California – Irvine (UCI), and the Politecnico di Milano (POLIMI)

Key messages

- **Contribution of large dams to the malaria burden in Africa.** More than 1.1 million malaria cases each year can be attributed to the presence of large dams in Africa. By the 2050s, this could exceed 2 million cases.
- **Impacts of dams on malaria are variable.** Certain dams significantly increase malaria transmission, while other dams may produce minimal impact on transmission. Local conditions such as climate and topography at a dam site influence the degree to which a dam intensifies malaria.
- **Diversity of dams' impacts presents opportunities.** Expanded understanding of factors that affect the severity of a dam's malaria-enhancing effect can be used to consider impacts at alternative future sites. The slope of a reservoir's seasonally-submerged area, for example, and climate at a reservoir site each influence the degree of malaria increase that a dam will produce. Consideration of differential impacts at different potential dam sites can enable selection of development options with fewer disease externalities.
- **Alternative dam operating regimes hold potential to contribute to reduced disease burden.** Investigations into possible dam operation designed to disrupt *Anopheles* mosquito development around the Koka Reservoir, Ethiopia, suggest there is potential for malaria reduction with minimal disruption to conventional operating objectives (hydropower, irrigation). Around the Kariba Reservoir, shared between Zimbabwe and Zambia, understanding of malaria impacts of water levels may enable consideration of more circumspect management approaches.
- **Failure to pursue implementation of potential malaria control measures contributes to unnecessary disease burden.** Valuable, impactful measures for controlling malaria are currently not being implemented. Given recent progress toward malaria control in Africa, dams increasingly reflect nodes of enhanced transmission that should be better addressed.

Dams, malaria and the Sustainable Development Goals (SDGs)

The United Nations Sustainable Development Goals (SDGs), adopted by more than 193 countries in 2015, are a universal call to action to end poverty, protect the planet and ensure that all people enjoy peace and prosperity. Dams and associated water storage are key to achievement of several SDGs, including SDG 1 (end poverty), SDG 2 (end hunger) and SDG 7 (clean energy). Particularly in areas facing erratic water availability and insufficient food production, dams are key to enabling reliable access to water to enable communities to improve their incomes and achieve food security. However, by imposing additional disease burden in communities that surround them, dams may compromise progress toward achieving SDG 3 (good health and well-being). Ultimately, there is a need to find improved approaches to dam construction and management, so that a win-lose situation across SDGs is averted. It is critical to identify and implement inclusive approaches that foster progress toward achieving the SDGs without undermining progress elsewhere.

The link between dams and malaria in Africa

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) is the lowest in the world (Figure 1) 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 (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.

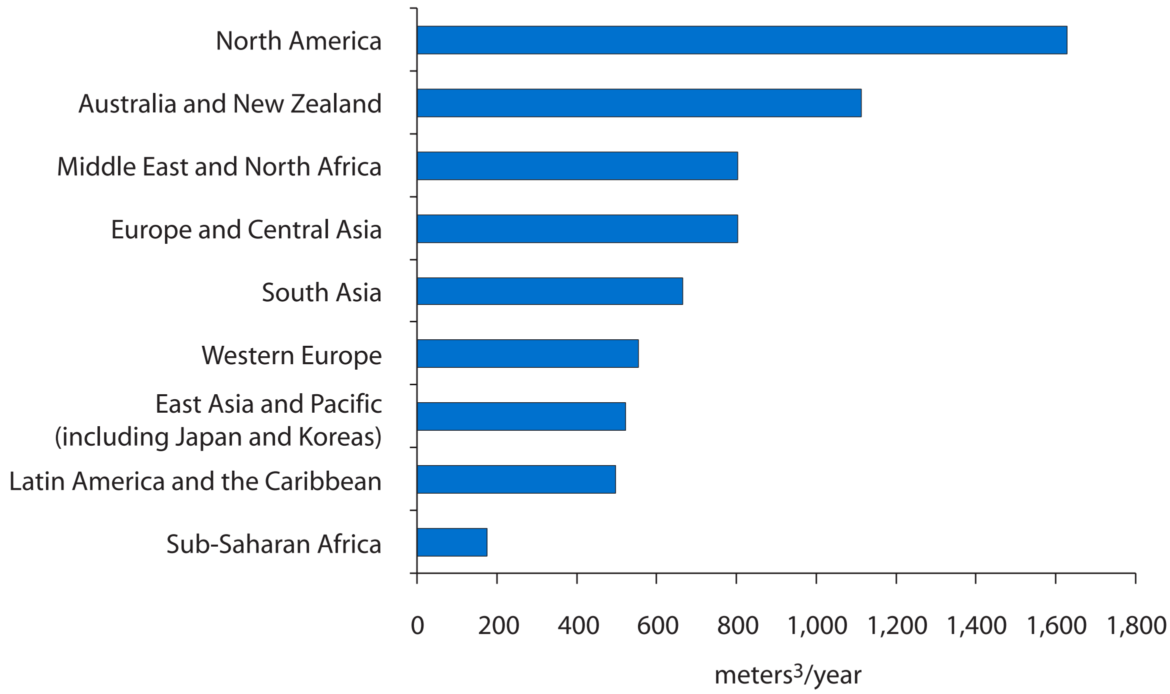

FIGURE 1. Per capita water withdrawals (by region). ***Note:*** **Koreas - South Korea and North Korea (*****source:*** **World Bank - http://siteresources.worldbank.org/INTMENA/Resources/App-all-Scarcity.pdf).**

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 confirmed location 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 (Figure 2). 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 annual 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.

Simple narrative, complicated reality

Dam-malaria impacts do not occur in a vacuum. Expansion of habitat and proliferation of adult *Anopheles* mosquitoes that result from water resources development do not occur in isolation. In areas of unstable transmission (Figure 2), malaria is seasonal. Often, this is because the availability of mosquito breeding habitat in the dry season is a limiting factor for malaria transmission. In geographies of unstable transmission, reservoirs provide year-round breeding sites – even in the dry season – which in turn create year-round malaria transmission. In areas of stable transmission (Figure 2), malaria naturally occurs all year round and water reservoirs simply add to a wide array of existing breeding habitat, available throughout the year. Hence, dams' impacts are often greater in areas of unstable transmission than in areas of stable transmission.

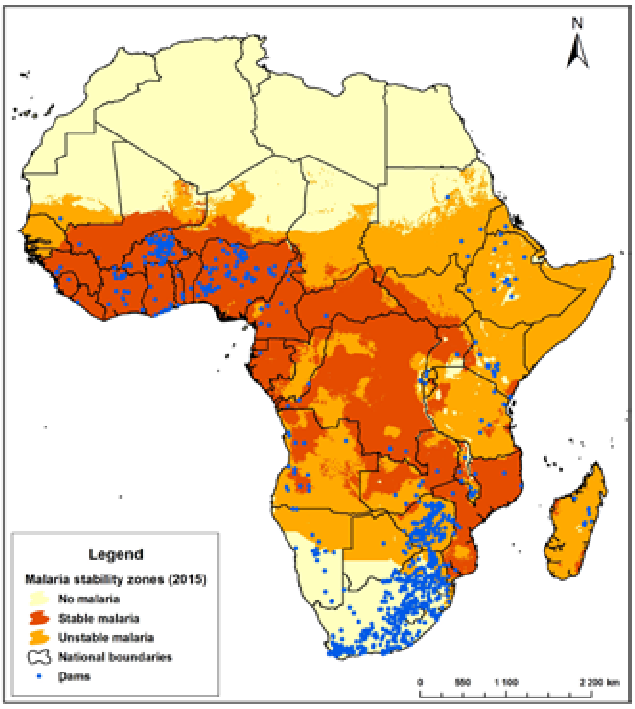

FIGURE 2. Distribution of dams in relation to malaria stability in SSA, circa 2015.

The role of slope. Topography around reservoirs varies considerably, prominently evidenced by difference in the slope of land exposed when the reservoir water level drops (Figure 3). To identify the role of slope in malaria transmission around water reservoirs, a statistical analysis was undertaken to determine the degree to which reservoir slope, rainfall and temperature explained transmission around reservoirs in Africa. Slope was found to be the strongest predictor of malaria transmission around a reservoir. Slope explained approximately 47% of the variations in malaria incidence around large dams in SSA. Gentler, more gradual slopes in the seasonally-submerged areas of reservoirs are associated with much greater malaria transmission (Figure 4).

FIGURE 3a. Steep slope, upstream of Cahora Bassa Dam, Mozambique (*photo:* Richard Beilfuss).

FIGURE 3b. Shallow slope, Koka Reservoir, Ethiopia (*photo:* Jonathan Lautze).

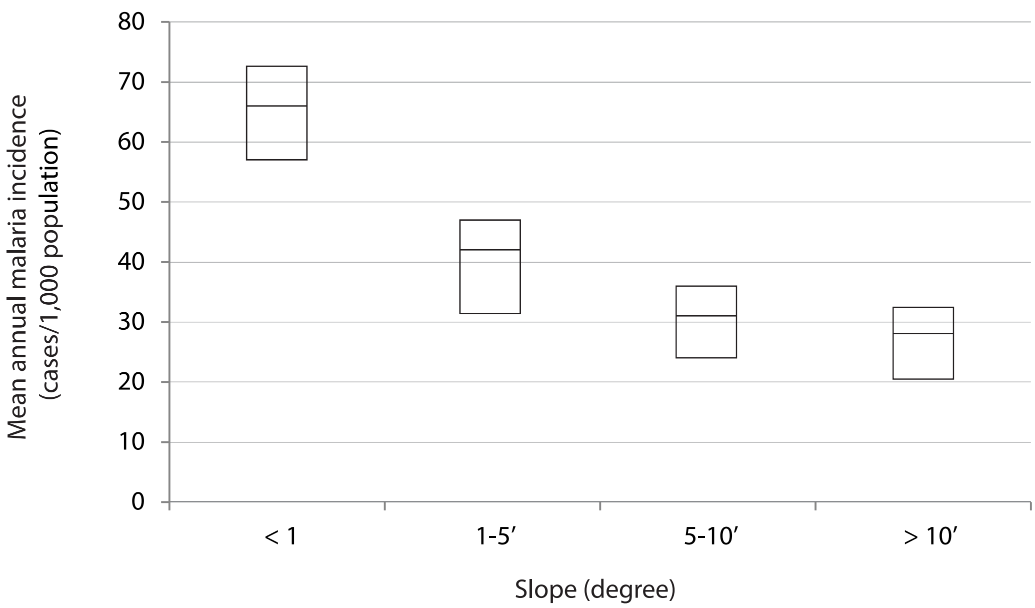

FIGURE 4. Shallower slope, more malaria.
Mean and box plots (representing interquartile range) of malaria incidence at different slope ranges.

Harnessing complication: Towards constructive approaches for engaging with the impact of dams on malaria

The diversity in the malaria-enhancing effect of dams and growing understanding of factors that explain such diversity give rise to three approaches to mitigate the adverse impacts of dams (Table 1).

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 noted above, 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. Certain basins such as those of East Africa or the Limpopo Basin in southern Africa (Figure 5) 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. In the context of diverse malaria transmission intensity within basins, there would appear clear opportunity to consider alternate basin development paths that engender different malaria impacts. Incorporation of malaria 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. Discussed in more detail below, 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. In Damodar Valley, India, a combination of fluctuation and rapid drawdown was utilized. Investigations have now begun into the adaptation of such tools to twenty-first century Africa, with initially promising findings.

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.

Evidence from Koka and Kariba reservoirs

Water levels and malaria. Around the Koka Reservoir, 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 (Figure 6). 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 (on the order of 2 meters or more below usual) correlated with lower transmission rates, both when climatic variables were and were not considered.

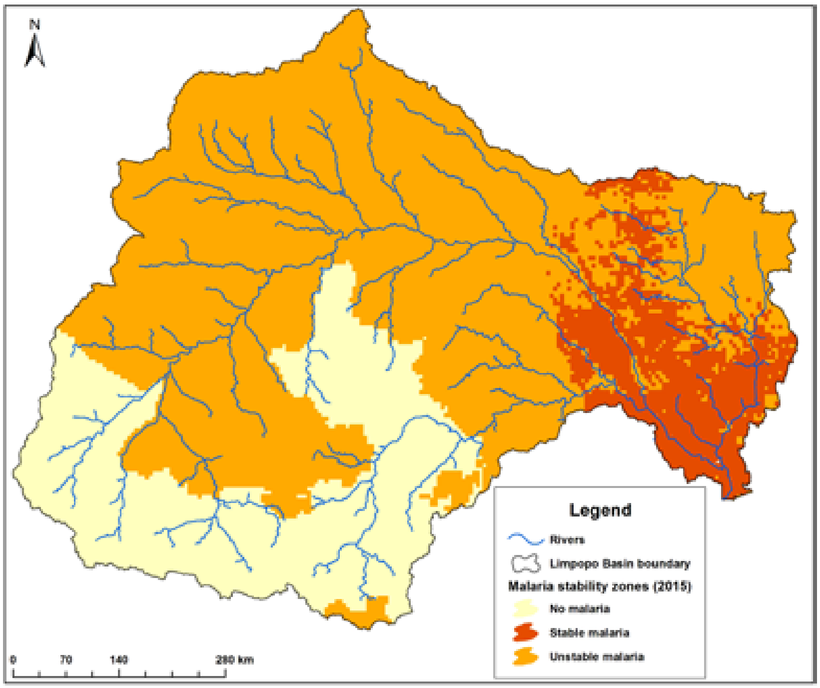

FIGURE 5. Map of the Limpopo River Basin, illustrating diversity in malaria transmission stability.

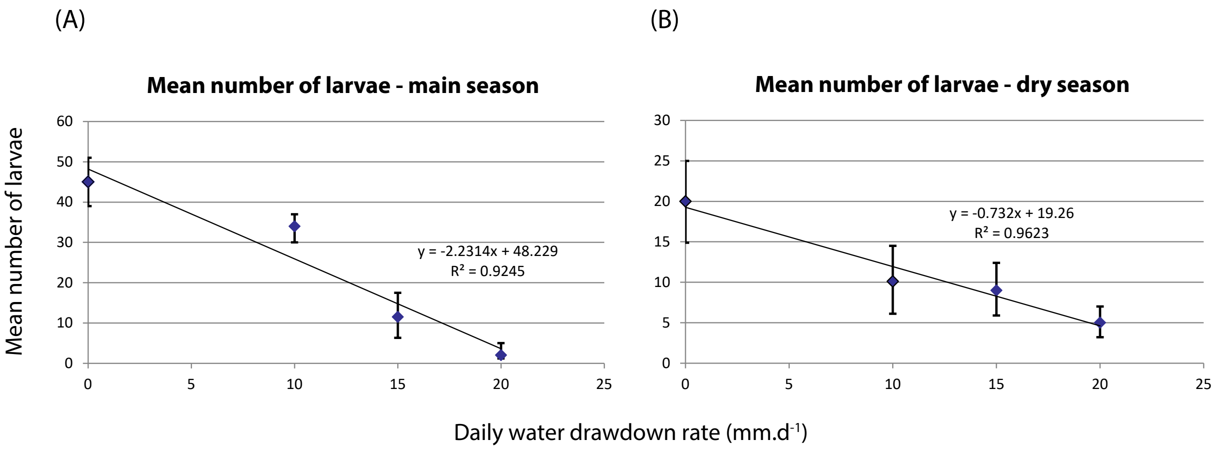

FIGURE 6. *Anopheles* vector larval abundance in experimental dams with different water drawdown rates. (A) *Anopheles* larvae in the main season, and (B) *Anopheles* larvae in the dry season.

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 GWh per year to 92.2 GWh per year (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 (Figure 7). Most alternatives appear better than historical system performance (denoted with a red dot). Further analysis is needed to understand constraints imposed by the demand for firm hydropower production.

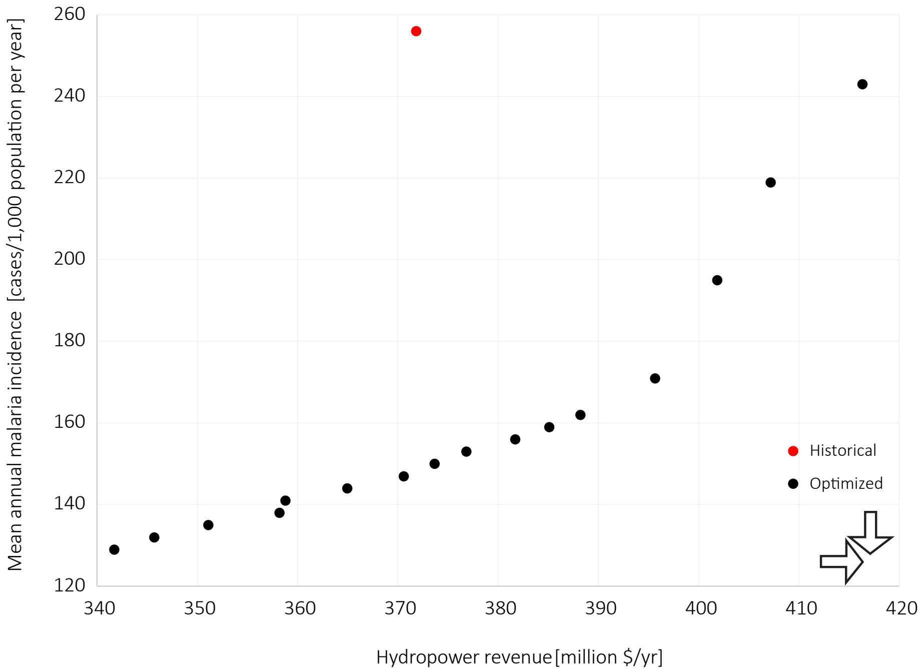

FIGURE 7. Trade-off between malaria infection and revenue from hydropower production.

The bottom line. Additional dam construction is essential to achieving several SDGs in Africa. However, if not undertaken carefully, dams 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.

Source

This Water Policy Brief is largely adapted from the following sources:

Bianchi, P.R.; Gianelli, L.; Castelletti, A.; Lautze, J. 2018. *Water borne disease control via dam operation: Balancing hydropower production and malaria control on the Kariba Lake*. Paper presented at the European Geosciences Union (EGU) General Assembly 2018, Vienna, Austria, April 8-13, 2018.

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Front cover photograph: Kariba Dam between Zimbabwe and Zambia (*photo*: Jonathan Lautze).

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/ mosquito-borne diseases / malaria / water storage / water level / water security / water management / reservoir operation / dam construction / health hazards / Sustainable Development Goals / irrigation / disease transmission / disease control / river basins / slope / Africa / Ethiopia / Zambia / Zimbabwe /

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