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STAGNANT WATER AND WATERBORNE DISEASES: IMPLICATIONS FOR CHILDREN'S HEALTH AND EDUCATION

EBA

Stagnant Water and Waterborne Diseases: Implications for Children’s Health and Education

Steve Berggreen

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to
The Expert Group for Aid Studies (EBA)

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Sammanfattning

Vattenburna sjukdomar orsakar över sex miljarder diarréfall årligen och är en ledande orsak till global barnadödlighet. Den här rapporten sammanfattar ett kapitel i min avhandling (tillsammans med Linn Mattisson) där vi studerar effekten av stillastående vatten på barns hälsa och skolgång i Tanzania. Vi utvecklar ett nytt mått för exponering av stillastående vatten och risk för att insjukna i diarré, benämnt Waterborne Disease Potential (WDP), och uppskattar effekterna på barns hälsa, dödlighet och utbildning. En ökning med 10 procentenheter i WDP ökar förekomsten av diarré med 30 procent, och medför en signifikant ökning av barnadödlighet i urbana hushåll utan tillgång till bra sanitet. Vi finner också att exponering för stillastående vatten har en negativ inverkan på kognitiv förmåga och ökar skolfrånvaron. Klimatförändringarna beräknas dramatiskt öka risken för framtida sjukdomsutbrott, på grund av de kombinerade effekterna av högre temperatur och mer intensiv nederbörd. Våra resultat indikerar att infrastrukturinvesteringar och urban stadsplanering avsevärt kan minska denna exponering. Förbättrad sanitet spelar också en avgörande förebyggande roll. WDP-indexet kan hjälpa till att identifiera var sådana investeringar är mest kostnadseffektiva och vägleda informationskampanjer. Slutligen kan det integreras med väderprognoser för att utveckla varningssystem för riskzoner med stillastående vatten.

Abstract

Waterborne diseases cause over 6 billion diarrheal episodes annually and remain a leading cause of global child mortality. In this development dissertation brief (DDB), I summarize a chapter of my thesis (coauthored with Linn Mattisson), where we study the effect of stagnant water exposure on children's health and schooling in Tanzania. We develop a novel measure of stagnant water exposure, called Waterborne Disease Potential (WDP) index, and estimate its impact on children's health, mortality, and education in Tanzania. A 10-percentage point increase in WDP raises diarrhea incidence by a substantial 30 percent, and significantly increases child mortality among urban households lacking access to improved sanitation. We also find that exposure to stagnant water detrimentally affects cognitive ability and increases school absenteeism. Climate change is projected to dramatically increase the risk of future stagnant water events due to the combined effects of higher temperatures and more intense rainfall. Fortunately, targeted infrastructure investments and zoning regulations can substantially reduce exposure. Improved sanitation also plays a critical preventative role. The WDP index can help identify where such investments are most cost-effective and inform awareness campaigns. Lastly, it can be integrated with weather forecasts to develop short-term early warning systems for stagnant water risks.

Introduction

Waterborne diseases are the second most common type of disease in the world, leading to more than 6 billion diarrheal episodes per year (Murray et al., 2020). Most of this public health burden falls on children in low-income countries (Prüss et al., 2002). Despite persistently high prevalence of waterborne diseases and increasing evidence on long-term effects of childhood health shocks (Currie and Almond, 2011), we have limited knowledge on the consequences of childhood exposure to waterborne diseases and their underlying environmental risk factors.

In this DDB I summarize a chapter of my thesis (Berggreen and Mattisson, 2025), where my coauthor and I evaluate the causal effect of stagnant water – an important environmental risk factor of waterborne diseases – on children's health and education. We focus on Tanzania, where waterborne diseases and cholera outbreaks constitute a major public health challenge (Troeger et al., 2018). We find that exposure to stagnant water increases the incidence of diarrhea in children and negatively impacts both school attendance and academic performance.

Our study addresses two main challenges in estimating the causal effect of stagnant water on socioeconomic outcomes. The primary issue is a lack of data on stagnant water. Previous studies have uncovered positive associations between intense rainfall, floods, high temperatures and waterborne diseases (Levy et al., 2016). Rainfall and floods are believed to trigger waterborne diseases through the pools of stagnant water they leave behind, which facilitate the spread of waterborne pathogens, especially in areas of poor sanitation. A complicating factor of rainfall, however, is that it also affects household income due to effects on agricultural productivity (Maccini and Yang, 2009; Shah and Steinberg, 2017; Mellon, 2022) and may thus confound the relationship between rainfall and child health. Floods, on the other hand, are often reported as rare, binary events, and tend to be hard to quantify in terms of their extent and duration. The Waterborne Disease Potential (WDP) index that we have developed allows us to distinguish between exposure to stagnant water and rainfall and provides a continuous measure of exposure both in terms of the magnitude (i.e. the fraction of land covered by stagnant water), and duration of a stagnant water shock.

The second issue refers to the challenge of causal identification. How can we be sure that we measure the effect of stagnant water on diarrheal disease, and not the effects of other factors? Households who live in areas where stagnant water and waterborne diseases are more common tend to be poorer and less educated. To make sure we estimate a causal effect of stagnant water, rather than a selection effect, we rely on a differences-in-differences strategy. This means that we compare the potential increase in disease symptoms over time in areas exposed to stagnant water shock with the trend observed for a control group of locations that do not experience the same shock. This allows us to estimate the causal effect of a short-term increase in stagnant water on a range of socio-economic outcomes.

This study relates to a number of Sustainable Development Goals (SDGs) enacted by the United Nations (UN) as part of the 2030 Agenda for Sustainable Development. Primarily, it aligns with SDG 3 (Good Health and Well-being), particularly Target 3.9, by demonstrating how stagnant water – a key source of waterborne disease – increases child mortality and morbidity in Tanzania. Our findings highlight sanitation's crucial role in mitigating these impacts and relates to Target 3.9 and 3.2 (ending preventable child deaths).

The study is also intimately linked to SDG 6 (Clean Water and Sanitation). By showing how stagnant water shocks can be mitigated by access to safe water sources and sanitation facilities, it highlights the critical need for safe drinking water (Target 6.1) and improved water quality through pollution reduction

(Target 6.3). The disproportionate impact on urban areas lacking sanitation emphasizes the need for sustainable infrastructure, a core component of SDG 11 (Sustainable Cities and Communities).

Finally, our study relates to SDG 13 (Climate Action). By incorporating climate projections, we illustrate how a changing climate may worsen stagnant water accumulation, exacerbating waterborne disease outbreaks, underscoring the urgency of climate adaptation (Target 13.1).

Context

The context of this study is Tanzania, which is severely affected by waterborne diseases, with prevalence rates of up to 4–6 percent (Global Burden of Disease Collaborative Network, 2021), similar to the situation in many other low-income countries. These diseases are caused by pathogens that are transmitted primarily through water or food, and include bacteria, viruses, and parasites. Some of the more well-known and severe diseases are cholera, typhoid fever, and dysentery, and most often result in gastrointestinal complications, such as diarrhea and abdominal pain.

While Tanzania has made significant progress in reducing child mortality in recent decades, partly due to the introduction of oral rehydration salts (Masanja et al., 2019), the *prevalence* of diarrhea has remained largely unchanged. This is because most medical interventions only address the symptoms of waterborne diseases after infection, and there has been limited progress in improving water and sanitation infrastructure. Over the same period, the rate of improved sanitation has increased from 8 percent to just 15 percent (Masanja et al., 2019). Preventing disease in the first place requires greater investment in both improved sanitation and local environmental conditions.

Adverse health outcomes from diarrheal episodes are also associated with impaired cognitive development (Niehaus et al., 2002; Pinkerton et al., 2016). An independent assessment by the non-governmental organization (NGO) Twaweza highlights that only about 45 percent of children aged 9–13 in Tanzania have achieved basic literacy and numeracy skills (Uwezo, 2011). A 2013 Tanzanian school census found that 3 percent of students dropped out due to illness or the need to care for an ill family member (Unesco, 2014). This aligns with findings in a recent World Bank report, which notes that children in low-income countries are increasingly falling behind their peers in middle- and high-income countries (Filmer et al., 2018). Two key factors contributing to this gap are malnutrition and childhood illness, both of which are closely linked to waterborne diseases.

Focusing on Tanzania provides several methodological advantages. As a large country with significant regional diversity, Tanzania offers an opportunity to explore the substantial variation in waterborne diseases within its borders (Reiner et al., 2020). The WDP index, which varies spatially and reflects local sensitivity to stagnant water exposure, may help explain this variation in disease prevalence. Additionally, Tanzania's diverse climate regimes and ecological zones make the findings more applicable to similar contexts elsewhere. Finally, using nationwide data from a large country with rich survey data improves statistical reliability and allows us to examine rare outcomes, such as child mortality, which would otherwise be challenging due to limited statistical power (Kremer et al., 2023).

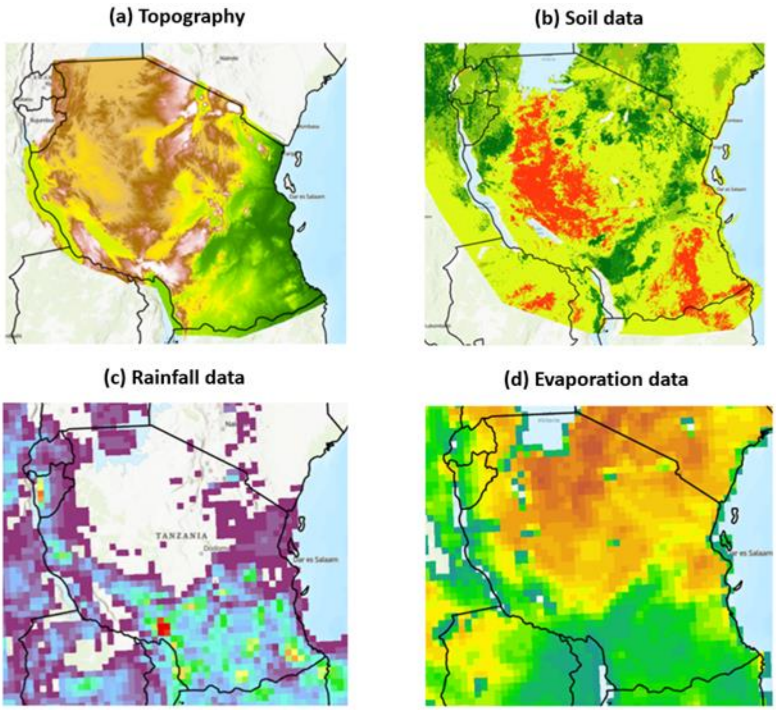
Method

To address the challenge of limited data on stagnant water, we develop a hydrological model specifically designed to simulate stagnant water dynamics over time across an entire country like Tanzania. This model relies on hydrological engineering techniques to model the flow of slow-moving surface water across a grid of 90-meter cells, small enough to accurately capture the extent of surface water during a flood event (Dazzi et al., 2021). The model's inputs, outlined in Figure 1, include: a) topography, which determines the direction of surface water flow; b) soil type, which governs infiltration rates; c) rainfall, and d) evaporation. Rainfall, which varies over time, adds water to the model, where it moves across the landscape shaped by gravity and terrain. The rate of this flow is governed by hydrological equations describing surface water movement. Meanwhile, some of the water is absorbed by the soil through infiltration, while the rest evaporates into the atmosphere, decreasing the surface water in the system. The variations in topography and rainfall lead to differential accumulation of stagnant water, with some areas retaining more water than others based on the local combination of these factors.

The model is run over several years with a 10-minute temporal resolution. To estimate the causal effect of stagnant water over time, we calculate the amount of stagnant water a household was exposed to over the previous 8 weeks. This period encompasses both the incubation and symptomatic phases of waterborne diseases, which can last several weeks (Percival et al., 2014), as well as the time it takes for disease transmission to spread locally. We then compute the average amount of stagnant water at the lowest administrative unit – the ward, typically spanning a few kilometres – over this time frame. To ensure the validity of our stagnant water measure, we validate with satellite data on surface water and survey data on the distance to the nearest surface water source for each household in our sample.

To estimate an unbiased causal effect, we must account for the possibility that households in areas more prone to stagnant water may also be poorer and have worse health, potentially due to lower socio-economic status. To address this potential selection bias, we employ a difference-in-differences identification strategy. This approach compares the change in outcomes over time for locations exposed to a short-term increase in stagnant water with locations that were not exposed. By examining the differences in the changes of outcome variables, such as diarrhea incidence, we can isolate the portion of the increase in diarrhea specifically attributable to stagnant water exposure.

Figure 1: Inputs used in the hydrological model



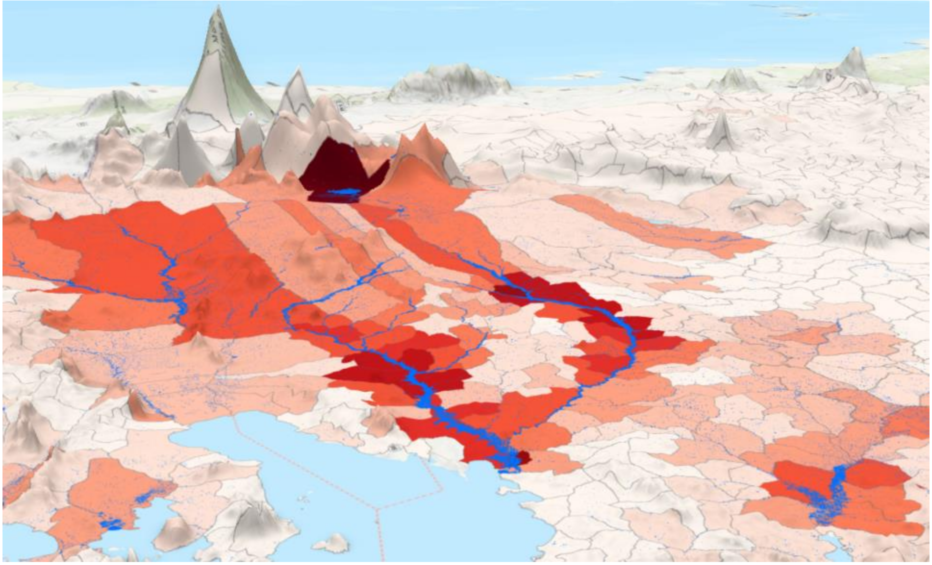
Source: Berggreen and Mattisson (2025).

Additionally, we control for local rainfall, as it may influence both household income and child health – given its importance for agriculture – and also affect the amount of stagnant water in the local area. In general, we find only a weak correlation between local rainfall and stagnant water, because much of the stagnant water results from rainfall in upstream catchments.

Data

The output from the hydrological model is shown in Figure 2 for a cross-section of northern Tanzania, specifically the region between Lake Victoria and Mount Kilimanjaro. Blue cells indicate areas where water remains stagnant over time. The variable of interest – waterborne disease potential (WDP) – is defined as the proportion of the local area, as indicated by borders, covered by stagnant water. Regions exhibiting a higher relative share of stagnant water are depicted with darker shades of red.

Figure 2: Predicted stagnant water occurrence (blue) and corresponding intensity of the WDP index (shades of red) across Northern Tanzania



Source: Berggreen and Mattisson (2025).

We then examine the impact of stagnant water exposure on a range of health and education outcomes.

For child health, we use survey data from the Demographic and Health Surveys (DHS) conducted in 1999, 2010, 2015, and 2022, containing information on nearly 30,000 children under the age of 5 (Boyle et al., 2022). Our primary focus is on symptoms associated with waterborne diseases, such as reported incidents of diarrhea and child body weight, along with symptoms related to other health conditions, including fever and anemia. This allows us to assess whether stagnant water exposure is primarily linked to waterborne diseases or if it also correlates with other health issues. In addition to health symptoms, the DHS data provides valuable information on child mortality and detailed data on sanitation and drinking water conditions, which helps us better understand the interaction of stagnant water shocks with access to water and sanitation quality.

To study the consequences for children's schooling, we use data from the Uwezo survey, carried out by Twaweza over the years 2011, 2013, 2014, 2015, and 2017 (Uwezo, 2011). These survey data contain data on school absence and test score results for more than 400,000 children, aged 6–16.

Importantly, both surveys are georeferenced, which allows us to link the specific location and date of the interview to the output of the hydrological model, in order to assess the WDP index for the 8 weeks preceding the interview.

Results

Implications for child health

We find a highly significant positive effect of exposure to stagnant water on diarrhea incidence. More specifically, our results show that a 10-percentage point increase in the Waterborne Disease Potential (WDP) – meaning that 10 percentage points more of the local area is covered by stagnant water – leads to a 30 percent average increase in diarrhea rates. In contrast, we observe no significant effects on other symptoms, such as fever alone (which may indicate malaria) or long-term malnutrition, conditions that we would not expect to be influenced by short-term exposure to stagnant water.

To better understand the link between stagnant water and child diarrhea, we look at whether children were given plain water and whether they were breastfed. Among children under the age of two, we find almost no increase in diarrhea for children who were breastfed, a practice known to prevent waterborne pathogen exposure (Keskin et al., 2017). Conversely, we find that being given plain water significantly increases diarrhea risk during a stagnant water shock.

In addition to the importance of the rehydration source, we also find that local sanitation plays a critical role in shaping these health outcomes. Specifically, the greatest increases in diarrhea incidence are observed in urban areas lacking access to improved sanitation. Conversely, households with access to improved sanitation show no significant increase in diarrhea from stagnant water shocks. For sanitation to be classified as "improved", it must meet two criteria: it must be a high-quality latrine that is protected from surface flooding and, importantly, it must not be shared with other households. In our sample, many households rely on public sanitation facilities, which can be technically high-quality but are often shared among multiple households. This sharing substantially diminishes the benefits, as we find that shared sanitation facilities do not have the same protective effect against the negative health impacts of stagnant water exposure.

Lastly, the relatively large sample size allows us to look at effects on child mortality. Similar to the effect on diarrhea, we find a significant and large increase in child mortality for urban households lacking access to improved sanitation, but no effect on other groups in our sample. Specifically, we find that the child mortality rate almost doubles during the 8-week window of a stagnant water shock, albeit from a low level at 0.3 percent. In contrast, we find no effect on mortality from a stagnant water shock outside of this window, suggesting that the increase in mortality is contemporaneous with the increase in stagnant water.

Implications for schooling

If exposure to stagnant water increases the risk of disease in young children, we would expect it to also result in higher school absenteeism. Our findings support this expectation: a 10-percentage point increase in the Waterborne Disease Potential (WDP) leads to an increase of more than 5 percentage points in school absence, meaning that approximately 1 in 20 children – or about 2 children per class – are absent from school. Additionally, test scores decrease by around 0.07 standard deviations for every 10-percentage point increase in WDP. This magnitude is comparable to the effects of recent education interventions in Tanzania aimed at improving education quality (Mbiti et al., 2019).

A key strength of the Uwezo survey data is that children are tested in their homes, which allows us to directly capture the impact of school absence on test scores. While the effect we observe may be short-term, it is likely that children face multiple stagnant water shocks during their school years, leading to cumulative effects over time, particularly in areas more prone to stagnant water exposure. Furthermore, even brief school absences of around 10 days have been shown to have significant long-term consequences on educational outcomes (Cattan et al., 2023).

Consistent with our health findings, we observe that the effects are generally more pronounced for urban households, and less so for those with access to improved sanitation, although our data on the specific types of sanitation facilities in these households is somewhat limited.

Alternative explanations

We also consider several alternative explanations for the observed impacts of stagnant water on child health and education. One potential explanation is that the effects are driven by malaria, as mosquitoes breed in stagnant water. However, our analysis suggests that the short-term impacts of stagnant water (within eight weeks) are primarily linked to diarrheal diseases, not fever, which is the primary symptom of malaria. Malaria transmission involves a longer lifecycle for mosquitoes, and our findings indicate a non-linear relationship between stagnant water and malaria, pointing to a "washing out" effect, which is consistent with previous studies (Paaijmans et al., 2010). While areas with persistently high stagnant water levels do exhibit higher malaria prevalence and awareness, short-term fluctuations in stagnant water, as measured by the Waterborne Disease Potential (WDP), do not show a strong correlation with increased fever incidence, unlike the strong effect seen for diarrhea.

We also rule out major flood damage as the primary driver of the observed effects, as our index specifically focuses on stagnant water, not flowing water that may destroy bridges and disrupt other infrastructure. Notably, we observe significant effects even at low levels of stagnant water, and the effects tend to saturate at around 20 percentage points of WDP, suggesting that the effects are not driven by the largest floods, but rather by more marginal and frequent events. In addition, that improved sanitation mitigates most of the negative effect cannot be easily explained by flooding alone. Furthermore, agricultural productivity and child labour changes appear to be unlikely explanations, as the results are not significantly different for farming households or during critical planting seasons. In fact, the effects are more pronounced for urban populations.

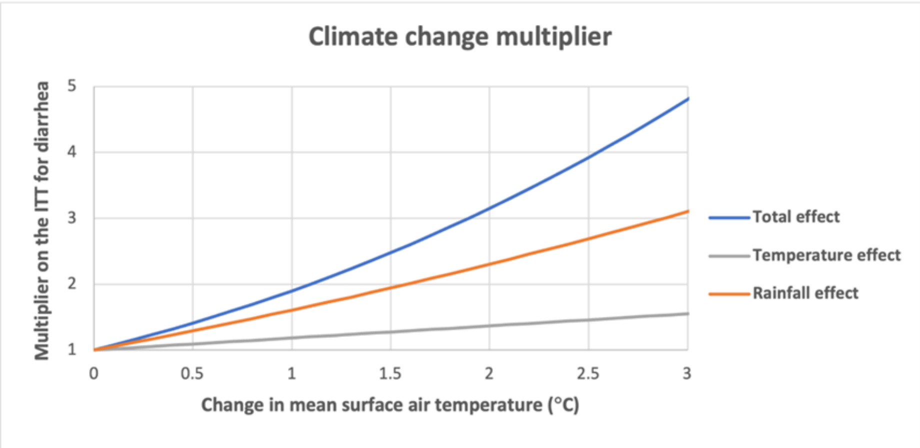
Finally, the short-term nature of stagnant water events, combined with the absence of flood warning systems during the study period, makes it unlikely that anticipation or migration-driven biases are influencing our findings. These considerations reinforce our conclusion that exposure to pathogens in stagnant water – rather than the alternative factors discussed – is the primary driver of the observed negative impacts on child health and education.

Climate change projections

In addition to the importance of sanitation, we find suggestive evidence that temperature plays a moderating role. We find systematically larger effects when weather in the past 8 weeks is warmer, consistent with the robust link between warm weather and WBD (Levy et al., 2018). However, warming caused by climate change may play a more important effect through a second channel. Recent research has found that intense rainfall events – rainfall that is intense enough to cause surface flooding – may increase in frequency by up to 3–4 times due to global warming (Li et al., 2021). This means that warming will lead to multiplicative effects: first, a stagnant water shock when the weather is will lead to greater likelihood of a diarrhea outbreak, and second, that stagnant water shocks will become more common, as intense rainfall events increase in frequency.

Using climate change projections for the change in intense rainfall events from Li et al. (2021) we estimate the future increase in waterborne diseases due to stagnant water. We combine our estimates on how higher temperatures generate more diarrhea outbreaks during a stagnant water shock with the increase in frequency from intense rainfall, which results in a total climate change multiplier shown in Figure 3. To exemplify, we find that 2 degrees of warming leads to more than a threefold increase in the effect of stagnant water on waterborne diseases. This compares favourably to the findings of Moore et al., (2017) who find that the El Niño, which brings both rainfall and warm weather to East Africa, raises cholera risk by about three-fold.

Figure 3: The impact of climate change on the effect of stagnant water on diarrhea



Source: Berggreen and Mattisson (2025).

Importantly, this projection assumes no adaptation response, including immunity, as this risk increases over time. However, since we find that stagnant water has the biggest effect in urban areas lacking improved sanitation, future risk may, if anything, be understated if rapid population growth and urbanization continues without appropriate investment in improved sanitation.

One limitation of this study is that it focuses solely on the short-term effects of a single stagnant water shock. Most children are likely to face repeated shocks, meaning that the long-term effects – even if they partially recover from single shocks – may be underestimated. Future research should consider longer timeframes, such as simulating impacts during critical early life stages, including in utero. Another limitation is that, for computational feasibility, this study concentrates on Tanzania. Expanding the analysis to a global scale could help assess potential variations in effects across different countries, and how to best prioritize preventative interventions. Extending this research to a global scale would require access to large-scale, high-quality survey data on outcomes like child health, as well as control variables such as sanitation quality. So far, much of this data has been made available through the DHS Program by USAID, which is currently on hold due to ongoing funding cuts. To support policy-relevant research on public health, it is essential to resume the collection of representative data from low-income countries. Without this data, the ability to evaluate the global impact of stagnant water exposure and related risks remains limited, which hinders the development of effective and targeted interventions highlighted in this research.

Conclusion and policy implications

This DDB summarizes key findings of my thesis chapter on the role of stagnant water and waterborne diseases (Berggreen and Mattisson, 2025). We find that an increase in local stagnant water over the past 8 weeks leads to an increase in diarrhea and child mortality, especially in urban households without access to improved sanitation. For school-going children, this leads to an increase in school absence and a drop in test scores in affected areas. Also here, most of the adverse effects we identify are concentrated among urban households without access to improved sanitation.

Reduction of stagnant water in urban areas

Fortunately, our findings imply that the right policy decisions may alleviate most of, if not all, the negative consequences from stagnant water. First, stagnant water is determined by topography, and as such is a largely modifiable risk factor. Clearing out areas where stagnant water accumulates has been a longstanding policy to combat malaria (Randell et al., 2010). Since most of the adverse effects are found in urban areas, stagnant water can be reduced by improved infrastructure (e.g. open stormwater channels) and zoning laws (to prevent housing in low-lying areas).

Improve sanitation effectively

Even in the absence of these measures, our findings suggest that sanitation plays a decisive preventative role, but only if it is of sufficiently high quality, and not shared between households. While sanitation investments are typically much costlier than purely alleviating interventions, such as the provisioning of oral rehydration salts, our methodology can be used to target the specific areas most at risk of stagnant water, where sanitation investment would be most cost effective. In our sample, only about 3–5 percent of households live in areas affected by stagnant water shocks.

Measure stagnant water exposure

In addition to preventative measures, the methodology developed in our study can be used to raise awareness and promote local adaptation. For instance, we find that awareness of diarrhea remains low in areas affected by stagnant water shocks. To enhance resilience to the projected increases from climate change, our findings can help guide interventions, such as cost-effective information campaigns. With some adjustments, this approach could be integrated with weather forecasting to provide short-range stagnant water forecasts, enabling households to receive early warnings when stagnant water may accumulate in their neighbourhoods.

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Stagnant water poses serious health-risks to children. Using the Waterborne Disease Potential (WDP) metric, this study shows that increased exposure increases diarrhea cases, child mortality and school absenteeism in Tanzania. The report further points to how strategic infrastructure investments and improved sanitation can reduce these risks and contribute to more sustainable living conditions.

Stillastående vatten utgör en allvarlig hälsorisk för barn. Med hjälp av måttet Waterborne Disease Potential (WDP) visar studien att ökad exponering ökar diarréfall, barnadödlighet och skolfrånvaro i Tanzania. Rapporten pekar vidare på hur strategiska infrastrukturinvesteringar och förbättrad sanitet kan minska dessa risker och bidra till mer hållbara levnadsförhållanden.

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