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When Local Trade-Offs between SDGs Turn Out to Be Wealth-Dependent: Interaction between Expanding Rice Cultivation and Eradicating Malaria in Rwanda

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Abstract: Interactions between SDGs are increasingly mapped and mediating factors that determine whether existing synergies or trade-offs can be identified. However, if and how the wealth status of the concerned population shapes whether SDG interaction constitutes a vicious or virtuous circle is largely overlooked. This article focuses on interaction between SDG2 (nutrition) and SDG3 (health), in particular, the relationship between rice production intensification and the fight against malaria, and thus the role of wealth in explaining the trade-off. This study employed a large-scale survey of rural households (n = 3968) in eastern Rwanda, conducted at a time when a rapid expansion of rice fields co-existed with a strong resurgence of malaria. Logistic regression shows that rice-cultivating households faced significant higher malaria risk, as proxied by fever incidence, confirming the negative externality of agricultural intensification on public health through offering a habitat for vector-borne diseases. Even though rice-cultivating households tend to be higher up the local wealth distribution than those outside the rice sector, its distributional effects are generally biased against the poor. Poorer households outside the rice sector hardly share in the benefits from increased rice production but suffer the consequences in terms of increased malaria risk. The case thus draws attention to the importance of using a distributional lens when analyzing interaction between SDGs locally.

Keywords: SDGs; trade-off; malaria; rice cultivation; paddy paradox; nutrition; Rwanda

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1. Introduction

The Preamble to the 2030 Agenda for Sustainable Development stresses the "integrated and indivisible" nature of the Sustainable Development Goals (SDGs) in a bid to pre-empt tendencies to take a siloed approach towards the different goals on the part of policymakers [1] as well as researchers [2]. To the same aim, one of the targets under SDG17—the global partnership goal—explicitly calls for enhanced policy coherence for sustainable development (target 17.14). In response to this call, attention has been directed to the complex of interactions between the various SDGs, mapping out both synergies and trade-offs. Scholarly work has mostly concentrated on interactions that play out at the (sub-)national level [3,4], but transboundary spillovers have increasingly come under scrutiny as well [5,6]. Analyses of SDG interdependencies have also become more fine-grained in the sense that synergies and trade-offs are identified at the level of sub-goals (targets), either within or across broader goals.

This paper intends to add to our understanding of how interactions at the SDG target level may play out, by zooming in on how stimulating small-scale agriculture (target 2.3), as part of the goal to eradicate hunger (SDG2), links to the fight against communicable diseases (target 3.3), which is a crucial target for achieving healthier lives (SDG3) in a developing country context. Our focus is on one communicable disease in particular, that is, malaria, which remained among the leading causes of both morbidity (ranked 4th) and mortality (ranked 6th) in low-income countries in 2019 according to WHO global health estimates. Rwanda, which serves as our country case study, fits this profile. Malaria features consistently among the top five causes of death and disability for Rwandans in all age categories between 1–50 years. For children under five, however, one of the conditions that trumps malaria in negatively affecting (disability-adjusted) life expectancy is malnutrition, which indicates the country's persistent challenge to eradicate hunger.

The Rwandan government works towards self-sufficiency in staple foods to increase food security, constituting one of the main pillars of its agricultural policy. A drive to boost rice cultivation has been part of this ambition since 2011, when a national rice development strategy (NRDS-I 2011–2018) was formulated. Since irrigated rice fields provide potential breeding grounds for vectors of parasitic diseases like malaria, it is pertinent to explore the set of interactions between targets 2.3 and 3.3, focusing on how the promotion of smallholder rice production and malaria incidence interrelate. We take special interest in the distributional implications of these interactions, providing insight in how the SDG trade-off at hand risks amplifying local inequalities.

In tracing these implications, the paper aims to make a contribution at two different levels. First, our focus on the mediating role of rice farmers' position in the local wealth distribution connects evidence from two strands of studies on malaria. On the one hand, this concerns the literature on the "paddies paradox", a term coined by Ijumba and Lindsay [7] to draw attention to the net positive impact of rice cultivation on malaria reduction that they observed in Tanzania. This seminal contribution sparked a host of studies building (counter) evidence on the paradox since its original formulation in the early 2000s, which will be briefly reviewed in Section 1.3. While these studies—along with those that more broadly consider the relation between wetland/irrigated agriculture and malaria incidence—often allude to wealth differentiation in the interpretation of findings, it is not strongly articulated as a driving force. In contrast, there is a rich body of knowledge on the wealth–malaria nexus, reviewed in Section 1.4, that typically does not probe into the source of wealth, so that a connection to high-risk occupations like rice cultivation is overlooked. The research gap we aim to fill, therefore, is how the wealth dependence of malaria exposure is shaped in cases where wealth is tied up with livelihood activities that inherently affect malaria risk.

Our second contribution is directed at the analysis of SDG interactions more broadly. We aim to illustrate the importance of identifying relevant mediators of SDG interaction—in particular, wealth status—to promote a more evidence-based approach to the normative questions that SDG trade-offs raise for policymakers. Our case serves to show how applying a distributional lens can inform such policy challenges by gaining a better understanding of the heterogeneity of impacts, such as across occupational groups and wealth strata.

In the remainder of this section, we build the analytical framework for the study in two steps. First, the SDG literature is consulted to map the interaction channels between the SDG targets under study in generic terms (see Figure 1). We then introduce the case study in Rwanda and customize the generic framework accordingly, resulting in Figure 2. The paper then proceeds to trace selected channels with survey data collected in Ruhuha, a sub-district where malaria is endemic and rice cultivation is a prominent livelihood activity. The analysis systematically compares households dependent on rice cultivation to those depending on other livelihoods. Apart from malaria incidence, child stunting serves as a second outcome of interest, given the food security rationale behind rice intensification.

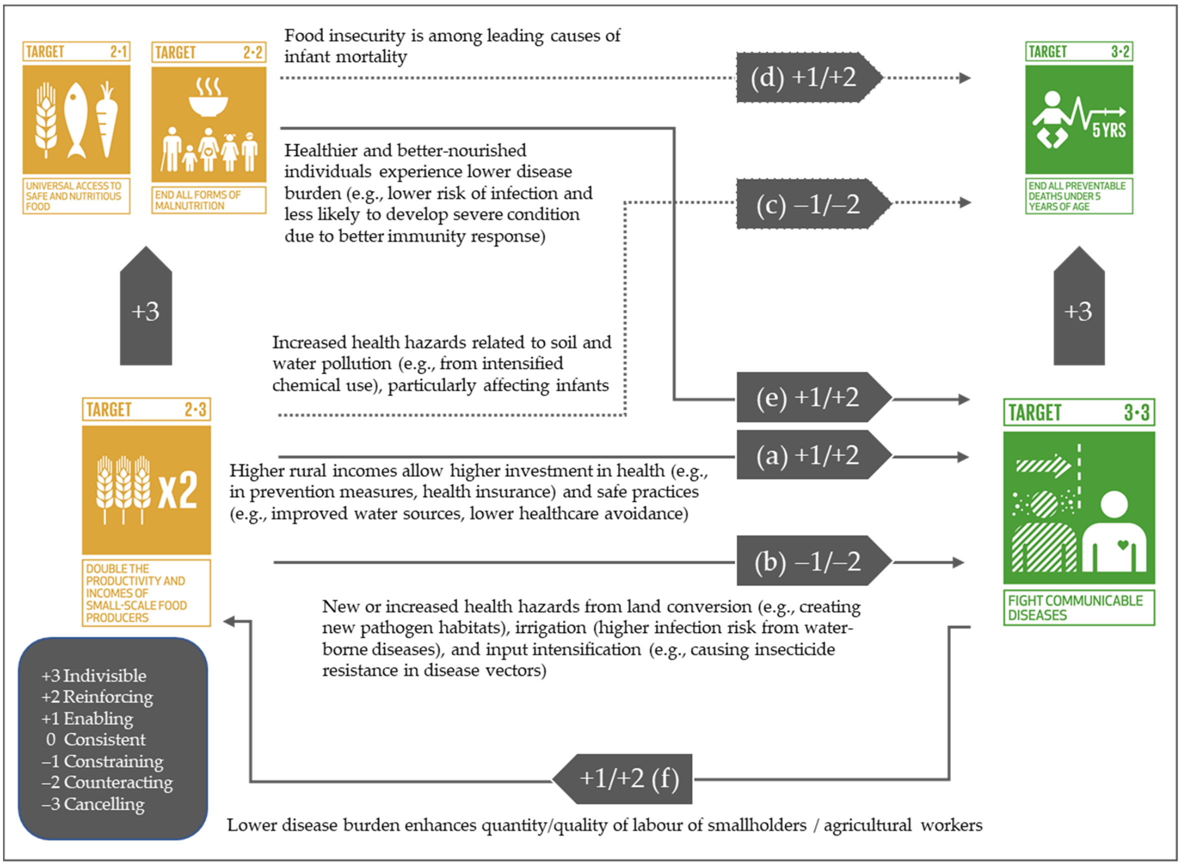

Figure 1. Selected interactions between SDG2 and SDG3 in a developing country context (authors' elaboration based on ICSU 2017).

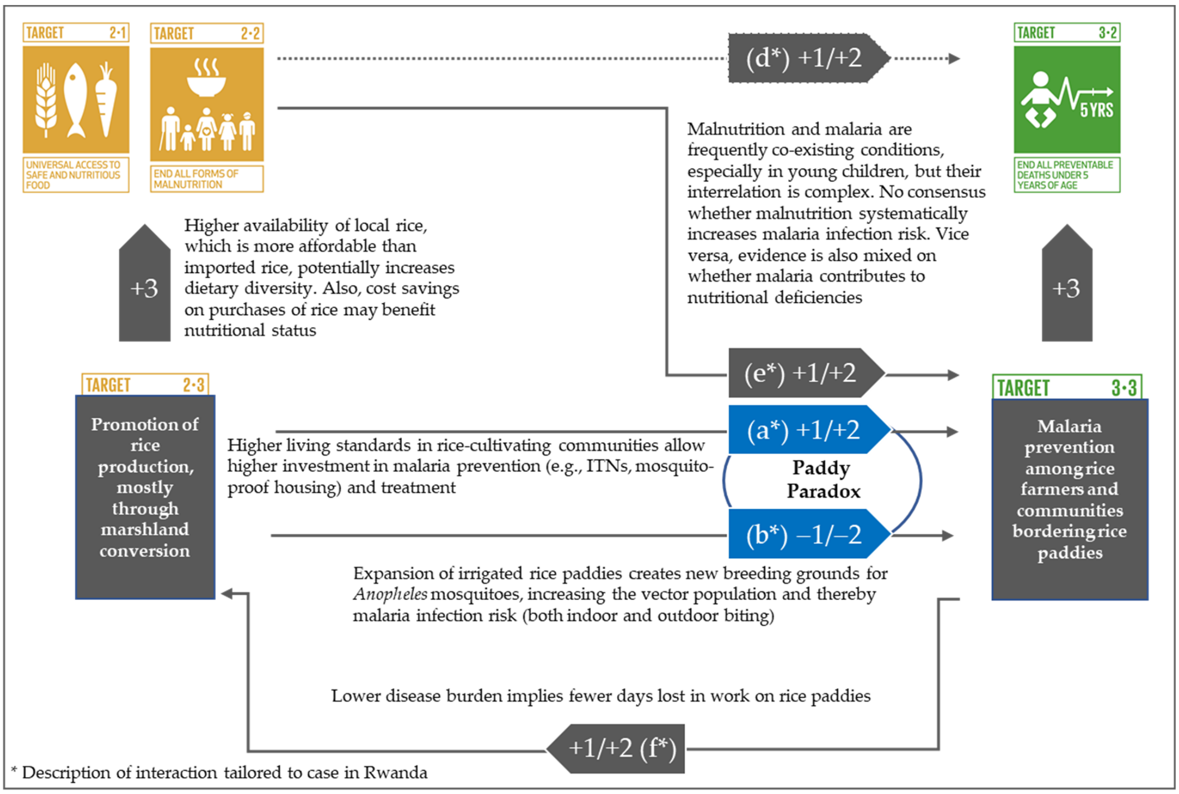

Figure 2. Selected interactions between rice cultivation and malaria prevention (authors' elaboration).

1.1. Agricultural Growth, Food Security, and Communicable Disease

In assessing the type of interdependency between goals, the SDG2–SDG3 pair often comes out as among the most synergetic, regardless of the methodological approach applied [8,9]. Nilsson, Griggs, and Visbeck [1] stress the co-benefits of ending hunger for health promotion in sub-Saharan Africa, and Pradhan et al. [10] identify SDGs 2 and 3 as the top synergy pair among all possible combinations in the Democratic Republic of Congo, one of Rwanda's neighbors. However, unpacking the impact of SDG2 on SDG3 at the target level reveals a more nuanced picture, in which trade-offs come to light as well. The "Guide to SDG Interactions" produced by the International Council for Science (ICSU) in 2017 is most instructive, as it comprehensively traces links between specific targets [11,12].

The ICSU classifies interactions using a 7-point scale, which reflects both direction (positive, neutral, or negative) and intensity [13]. Whether an interaction between targets is uni- or bi-directional is not integrated in the scale; in a bi-directional case the two "arrows" are classified separately. Synergies escalate from "enabling" (+1) to "reinforcing" (+2), to "indivisible" (+3) towards one end of the scale, where indivisibility implies that goals are inextricably (and positively) linked. Concerning trade-offs, the scale moves from a "constraining" (−1) influence, to a "counteracting" (−2) one, and in the worst-case scenario, progress towards one target inevitably "cancels" (−3) another target. The mid-point of the scale is the "consistent" category (0), indicating an absence of significant interaction.

If we take target 2.3 as our starting point, which aims to "double the productivity and income of small-scale food producers", three causal pathways can be identified towards target 3.3 on communicable diseases: two direct links and an indirect one (see Figure 1, which displays a set of causal links between SDG2 and SDG3 coded from (a) to (f), following the order of appearance in the text below). The first direct link concerns an income effect. Better rural incomes would allow households to invest in health prevention, reduce exposure to health hazards, and afford better access to healthcare. The ICSU identifies this as a positive link of moderate strength, as it is believed to be either enabling or reinforcing the fight against communicable diseases (arrow a; +1/+2). However, this fight could be constrained or counteracted by a negative direct link of similar magnitude related to agriculture's footprint, more specifically the risk that land conversion, irrigation, or higher input use induces biohazards (arrow b; −1/−2). The relevance of these respective risks depends on whether agricultural promotion follows an extensification and/or intensification strategy. In the case of malaria, Reid and McKenzie [14] document a particular risk associated with enhanced input-intensity in agriculture: higher pesticide use fosters insecticide resistance in African malaria vectors, reducing the effectiveness of insecticide-treated nets (ITNs) and indoor residual spraying (IRS). Note that exposure to input-intensive agriculture may also negatively impact on health in ways other than through communicable diseases, that is, through water and soil pollution, especially in under-five children (arrow c; −1/−2). For example, Mettetal [15] links increased infant mortality rates in South Africa's former homeland districts to the expansion of irrigated agriculture (1980–2002), leading to increased nitrate concentrations in household water sources from fertilizer use.

The indirect pathway from agriculture promotion to disease burden runs via nutritional outcomes, which are captured under targets 2.1 ("universal access to safe and nutritious food") and 2.2 ("end all forms of malnutrition"). While agricultural production and food security are typically considered "indivisible" (+3), the following qualifier is added by Mollier et al. [12]: "an increase in the agricultural production and affordability of low-nutrient and energy-rich foods can contribute to macro and micronutrient deficiencies" (p. 36). The wealth effect from more productive agriculture could have the similar effect of switching to more high-calorie processed foods following enhanced affordability, compromising nutritional standards. Considering the case of rice, there is some evidence to suggest that, on balance, nutritional outcomes respond positively to higher levels of rice cultivation. For example, in a study on child malnutrition in Ethiopia's Amhara region, Motbainor and Taye [16] reported a lower incidence of wasting (low weight-for-height) among under-five children in communities where a rice-production program was implemented compared to non-intervention communities. Assuming such a positive impact on nutrition, this would not only reduce preventable mortality of children under five years of age (i.e., target 3.2) directly (arrow d; +1/+2) but also indirectly reduce morbidity and mortality from communicable diseases in the wider population, as better-nourished individuals are at lower risk of infection and/or show better immunity response (arrow e; +1/+2). The immunity effect seems most relevant in the case of malaria, as "chronic malnutrition was relatively consistently associated with severity of malaria such as high-density parasitaemia and anaemia" (p. 1), according to a systematic review covering 33 studies that explored the link between malnutrition and malaria [17]. The same meta-analysis could not establish a systematic link between acute malnutrition and malaria infection risk. Understanding the interaction is complicated by potential bi-directionality; a prospective cohort study among young children in Malawi linked malaria infection to a higher risk of stunting, but did not confirm any effect on other nutritional indicators [18]. Since communicable diseases account for a large share of deaths among children between age 1–4 in low-income countries (61 percent in Rwanda in 2019), strong synergy (+3) is assumed within SDG3 between targets 3.2 and 3.3.

Finally, the overview in Figure 1 shows a positive feedback loop from absence of communicable diseases to agricultural productivity (arrow f; +1/+2), as ill health reduces one's abilities to farm. Lukwa et al. [19] reported an average of 4.1 days lost at work due to malaria among farm workers at a banana plantation in Zimbabwe over a five-month observation period. Such work absenteeism can affect agricultural output considerably over a production cycle, as shown among vegetable farmers in Ivory Coast [20]. The study calculated a 47 percent lower yield and 53 percent lower revenues among those who lost more than two working days due to spells of malaria (4.2 days on average) compared to those whose work effort was affected by malaria for no more than two days.

Indirect evidence comes from studies that track changes in agricultural productivity after malaria prevention interventions have been rolled out in farming communities. A randomized controlled trial concerning free distribution of bed-nets to small-scale cotton growers in Zambia resulted in a 25 percent increase in cotton yield in the treatment group within one year [21]. However, a larger-scale randomized free bed-net distribution scheme among Zambian cotton out-growers, as studied by Sedlmayer [22], failed to replicate such significant productivity gains despite sizeable reductions in malaria disease burden. A study offering malaria testing and subsequent ACT-treatment to piece-rate workers on a sugarcane plantation in Nigeria revealed an income increase in the range of 10 percent from its pipeline design. Interestingly, productivity increases were also recorded among workers who tested negative, arguably due to clearing doubts about one's health status [23].

Allowing for a longer timeframe, the negative impact from malaria infection in early childhood on later-in-life productivity should also be factored in. Studies that strategically use the timing of malaria eradication efforts in a given location to compare birth cohorts on economic outcomes consistently find long-run income and employment benefits for those whose time of birth coincided with the roll-out of malaria control, although in some cases these apply to males only [24,25]. Bleakley [26] concludes from analyzing cohort panels in Brazil, Colombia, and Mexico that "being exposed to malaria in childhood depresses labor productivity as an adult" (p. 34). Higher rates of paid employment, suggestive of higher productivity, are also found in a recent study covering 27 sub-Saharan African countries [27]. These longitudinal studies stress the cognitive impairment that malaria infection engenders over time rather than its immediate physical impairment causing work absenteeism.

In order to understand how the different links from Figure 1 translate to our Rwandan case study, we first provide some background on national trends in food insecurity and malaria, as well as on the policies enacted to fight these.

1.2. The Case of Rice and Malaria in Rwanda

Rwanda's SDG agenda is integrated in its National Strategy for Transformation (NST-1), a 7–year program that covers the 2017–2024 period. Increasing agricultural productivity is a key goal in the economic transformation pillar of the NST. A target for increasing productivity in rice is included and is set at 30 percent higher yield by 2024. The fight against malnutrition as well as that against communicable diseases, especially in relation to child health, are assigned priority within the NST's social transformation pillar. The rationale is that malaria and under-nutrition are frequently co-existing conditions among pre-school children in Rwanda [28]. Table 1 (top panel) shows performance trends in nutrition, child health, and malaria burden by comparing values for selected indicators in 2010 (pre-SGD), 2015 (SDG baseline), and 2019, that is, five years into the SDG framework period.

Table 1. Rwanda: selected indicators related to SDG2 and SDG3 (2010, 2015, and 2019).

	SDG(-Related) Indicator	2010 (Pre-SDG)	2015 (Baseline SDG)	2019 (Update)
2.1.1.	Prevalence of undernourishment in total population (%) [29]	31.3	35.3	35.2
2.2.1.	Prevalence of stunting, height for age (% of children under 5) [29]	44.3	36.9	33.1 *
3.2.1.	Under-five mortality rate per 1000 live births [30]	63.5	41.5	34.3
3.3.3.	Malaria incidence per 1000 pop. [31]	107.6	339.1	366.1
	Malaria mortality per 100,000 pop. [31]	31.2	27.5	26.2
	Malaria case fatality rate (per 1000 cases) [31]	2.9	0.8	0.7
2.3.	Indicators on rice paddy cultivation [32]			
	Area harvested (ha)	12,975	30,204	32,896
	Production (tonnes)	67,253	97,435	131,577
	Yield (t/ha)	5.2	3.2	4.0
	Value of production (in 1000 int. $)	26,301	38,104	51,456

* Data point concerns 2020 rather than 2019.

While under-five mortality has shown a consistent downward trend over the last decade, progress towards lower prevalence of stunting among under-five children has slowed since 2015 and has been very marginal in the case of undernourishment in the general population. In fact, the data suggest that a larger share of Rwandans (including adults) were afflicted by under-nutrition in 2019 than in 2010, despite Rwanda's consistent growth in per capita income over this period. The Comprehensive Food Security and Vulnerability Analysis (CFSVA) performed by the World Food Programme in 2018 confirms stagnation, as it classified 18.7 percent of households as food insecure, up from 16.8 percent in 2015. The analysis chiefly attributes this lack of progress to a prolonged drought in 2016, which forced affected rural households into distress sales of productive assets, thereby compromising their food security position in subsequent years [33].

The fight against malaria has witnessed a serious reversal of progress, as malaria infection rates started to shoot back up from 2012 onwards, as documented in Rwanda's 2019 Voluntary National Review Report on SDG progress [34]. Despite increasing case numbers for most of the decade, however, mortality from malaria has significantly declined in the wake of better diagnosis and treatment, most markedly so during the pre-SDG period. Government reports point to various factors that may have played a role in the upsurge in malaria infections, such as climate change and insecticide-resistance, but also mention increased irrigation as a potential driver.

The bottom panel of Table 1 provides testimony to Rwanda's efforts towards achieving higher levels of rice production. It shows that the expansion of rice paddies was more successful than boosting productivity. Despite falling short of the government's ambitious expansion target of 270 percent for 2011–2018, the harvested area increased by 154 percent between 2010 and 2019. In contrast, yield in 2019 remained below the 2010 level, although it was slightly up from 2015. Arouna et al. [35] calculate an average annual yield growth rate of −6.5 percent for Rwanda over the 2012–2018 period, confirming a suppressed trend, whereas the government projected a 30 percent increase. This notwithstanding, area expansion dominated yield reduction, as the production (value) of rice roughly doubled by 2019, which corresponded to an estimated degree of self-sufficiency of 65 percent (up from 59 percent in 2013). Possibly, the area expansion itself may have contributed to lower yields, that is, if learning-by-doing is an important productivity factor, which had to be accumulated in newly created paddy fields and by new entrants to the rice sector.

The analysis above bears out a co-movement of expanding rice cultivation and rising malaria incidence, especially in the period 2010–2015, which allows us to tailor the interactions displayed in Figure 1 to the rice–malaria nexus, resulting in Figure 2. Both figures feature basically the same links, but the corresponding interpretations in Figure 2 are more case-specific (an asterisk has been added to the arrows to indicate specificity for the rice–malaria nexus in Rwanda). However, the negative link from agricultural development to under-five mortality (arrow c) has been omitted from Figure 2, as input intensity is unlikely to have increased dramatically in view of stagnant yields, so that water pollution from pesticide use is not expected to present a major trade-off. Instead, the focus is on the health link that stems from new paddies creating habitats for malaria-transmitting mosquito species (arrow b*) and how this balances out with income effects (a*) and nutrition effects (e*) that may shield against malaria. Depending on the outcome, this feeds back positively or negatively into rice productivity (f*). While the latter is a potentially relevant link, as documented, for instance, for rice farming in Nigeria [36], the cross-sectional nature of our data prevents tracing this feedback mechanism empirically.

1.3. The Paddy Paradox Revisited

The paddy paradox, as originally formulated in the early 2000s, assumes that income (and, by extension, nutrition) effects dominate, such that rice expansion would offer a net protective effect, but later contributions shed a different light on the relative magnitude of these effects. A recent meta-review on the paddy paradox in sub-Saharan Africa by Chan et al. [37], covering 53 studies across 14 countries, reveals that the paradox disappeared from around 2003 onwards. Whereas all of the pre-2003 studies found that rice cultivating communities did not experience excess malaria (and sometimes even experienced lower incidence) compared to non-rice communities, later studies consistently report higher malaria incidence in rice-growing areas. The review calculates that in the current timeframe "malaria transmission in rice villages tends to be about twice as intense as in non-rice villages" (p. 8) [37]. The authors explain the paradox's expiration by the massive scale-up of malaria control measures across sub-Saharan Africa in the early 2000s, coinciding, for example, with the start of the prominent Roll Back Malaria initiative. In addition, general improvements in living standards and rural health services arguably played a role in the broad transition from a high- to low-transmission environment, which consequently stacked the odds against the paradox. Rice cultivation areas become more likely outliers in a low-transmission environment for two reasons, as explained in Wondwosen et al. [38]. First, malaria control methods such as IRS and ITNs mainly target indoor malaria transmission, to which vectors have responded by shifting from indoor to outdoor biting, disproportionally affecting farmers working in irrigated fields. Second, reduced transmission opportunities fail to compensate for the high volume of mosquitoes that rice paddies are able to generate. Both field and lab tests have shown that rice fields exert a particular attraction on gravid malaria mosquitoes—more specifically *Anopheles arabiensis*—as an oviposition site because of the specific odor that is present in the air around rice. The antennas of female anophelines can pick up this complex odor, which lures them even from a long range when searching for a suitable location to lay eggs [38].

The case of Tanzania serves to illustrate the contrast between earlier and later studies. Ijumba et al. [39] studied malaria incidence in the Lower Moshi rice irrigation scheme in the mid-1990s. They set up a comparison with a sugarcane cultivation scheme nearby, which was also irrigated but, unlike rice, never flooded to avoid crop damage. Five cross-sectional surveys were conducted in both locations over the timespan of a year (1994–1995) to track malaria incidence, which revealed malaria infection rates to be more than twice as high in the sugarcane ecosystem than in the rice scheme (40 and 15 percent, respectively). The main explanation that the authors bring to the fore concerns the higher living standard in the rice village, as witnessed by the fact that three-quarters of the villagers lived in metal-roofed houses compared to only half in the sugarcane village. Hence, the data were in clear support of the paradox. However, a decade later (2004–2005), a similar comparison between villages practicing irrigated rice cultivation and a sugarcane village in Mvomero district in east-central Tanzania generated a strikingly different result, as documented in Rumisha et al. [40]. The odds of contracting malaria in the rice area proved almost seven times higher than in the sugarcane community, with corresponding infection rates of 46 and 7 percent, respectively. This increased risk is attributed to living in a watershed area.

Local evidence from Ruhuha shows that our case location fits the picture of higher malaria risk from rice cultivation. Tuyishimire et al. [41] combine a geospatial analysis and malaria diagnostic tests among almost 3500 households in the sub-district in 2013 to find that, when controlling for housing quality and distance to the health center, malaria incidence increases with proximity to irrigated farmland, where rice is the dominant crop. An earlier study in the area found that the largest clusters of malaria positivity rates were located in close proximity of water-based agroecosystems [42]. Consistent with these results, a recent paper by Murindahabi et al. [43], which zooms in on the density of malaria mosquitos in five villages across Ruhuha, is able to explain why certain villages report higher densities at specific times of the year by their distance to irrigated rice schemes and the periodic cycles of rice cultivation (p. 13). Hence, we feel it is safe to start from the assumption that the rice–malaria trade-off is operative in the area of study, which allows us to focus the case study on the differential impact of increased malaria risk across wealth strata.

1.4. Material Protection against Malaria

Material wealth is known to be protective against malaria, as borne out by studies across different regions, including sub-Saharan Africa. For example, a higher wealth index was associated with lower odds of malaria and the highest burden in children under five years living in the poorest rural households in Nigeria [44]. In Tanzania, a higher rank in the wealth hierarchy was associated with lower odds of malaria, although the strength of association proved sensitive to the composition of the wealth index [45]. A statistically significant variation in parasitemia between socio-economic strata was observed in a random sample of 2000 households in Rufiji District, southern Tanzania, where the burden of malaria disproportionally fell on the poorest sections of the population [46]. For Western and Central Africa, it has been found that children in the poorest wealth quartile have experienced a considerably slower decline in prevalence rates, and higher malaria mortality, compared to higher-ranked quartiles over the period 1995–2017 [47].

Various pathways have been identified to explain how wealth protects against malaria. Perhaps the most commonly cited are housing and sanitation conditions, which are directly associated with freedom from material poverty. There is abundant evidence that the type of housing construction matters; improved housing can prevent mosquitoes from freely entering and hiding in a home and hence reduce malaria transmission [48]. Dwellings that are mud-based or have a roof with open eaves significantly contribute to malaria incidence [49]. Non-improved housing significantly predicted malaria infection among children under five years in Nigeria [50]. Houses with open eaves were among the most important risk factors associated with higher malaria infection in the highlands of Western Kenya [51]. In communities of Kanungu district, Uganda, material poverty was associated with increased odds of malaria infection, and open eaves and gaps in housing materials, such as in the case of iron sheet roofing, proved an important risk factor for malaria [52]. A multi-country study confirms that the malaria-reducing potential of modern and improved housing applies across the African continent [53].

Another, more indirect, pathway from wealth to malaria runs through access to prevention and treatment [54]. Economic factors may influence exposure to infection as well as the ability to seek and afford treatment [55]. Lower socioeconomic status significantly contributes to delays in seeking diagnosis and treatment for malaria, as cost is often cited as a key barrier to households accessing such services, and the poor also spend a larger proportion of household income on prevention activities than the non-poor [56]. For example, the poorest households in Bata district, Equatorial Guinea, were almost three times more likely to delay care-seeking for malaria-affected children below 15 years of age than their counterparts with the highest economic status [57]. Wealth proved a far more important predictor for care-seeking behavior than distance to a health center.

Rwanda is no exception to the observed wealth-based differentiation of malaria infection rates. An analysis of 11,202 household members, composed of under-five children and women aged 15–49, from the 2014–2015 Rwanda Demographic and Health Survey revealed that the lowest wealth category was associated with higher malaria prevalence, in addition to non-compliance with ITN usage and living below 1700 m of altitude [58]. A study with similar findings from Rwanda's 2017 Malaria Indicator Survey singled out the quality of housing materials as an important factor in shaping differential infection rates among children across the socioeconomic spectrum [59].

2. Materials and Methods

2.1. Study Setting

We use primary data from a survey conducted in 2013 (June–December), which serves our purpose of capturing a moment in time when rapid rice expansion and an upsurge in malaria coincided (see Table 1), suggestive of a steep trade-off. The survey covered the sub-district (sector) of Ruhuha, which is located within Bugesera district of Rwanda's Eastern Province, at 42 km from Kigali City. Rwanda is subdivided into five provinces, under which there are 30 administrative districts and 416 sectors. Sectors are in turn composed of 2148 sub-sectors (cells) and 14,000 villages. Ruhuha borders Burundi to the south and occupies an area of 54 square kilometers. The elevation ranges from 1300 to 1573 m above sea level. Ruhuha's estimated 26,199 inhabitants are served by one health center located in the most populous village—also named Ruhuha—and hosts a total of 140 community health workers, that is, four per village.

In 2015, Bugesera district featured among the 19 districts, out of a total of 30, that were classified as carrying a high malaria burden [60]. The health center in Ruhuha reported a malaria positivity rate in the range of 20–40 percent in 2013, which is high from a nation-wide perspective, but not extreme for Rwanda's Eastern province, to which Bugesera belongs. The district is also one of the country's main rice production areas. While rice is produced in marshlands and low-lying valleys across the country, promotion of rice in Bugesera by the government was particularly strong, as Bugesera historically faces high levels of food insecurity, which local rice production should redress.

2.2. Data Collection

At the time of the survey, the registered population of Ruhuha was 21,606 individuals across 5100 households [61]. Existing enumeration lists were used to identify all households per village with assistance from local community health workers (CHWs). Close to the survey date, the CHWs notified the households to stay at home at the appointed date if possible. On the survey day, a household was visited by one of the 20 trained Kinyarwanda-speaking interviewers, accompanied by the CHW. The field team member introduced the study and administered the questionnaire to the head of household. In his/her absence, a spouse or other fixed resident of the household acted as the interviewee. Underaged household members were not eligible. Where no adult member was found present in a household, a return visit was scheduled within seven days to maximize study enrolment. In case the household proved non-available during this follow-up visit—or occasionally non-collaborative—the household was omitted from the study. Following this procedure, the survey managed to cover 3968 households in total. The full household rosters with basic demographic data that were elicited from the surveyed households revealed a total of 17,020 individual members within these households. This implies that our survey covered 79 percent of the registered population—or 78 percent of households—in the area.

The surveys were administered face-to-face with the assistance of Android laptops. The questionnaire was prepared in an electronic format, using the Open Data Kit Collect setup [62], allowing the data to be immediately available in digital form (uploaded through an on-site server). Questionnaire items related to family health with a strong focus on malaria, including malaria knowledge, attitudes, and (preventive and curative) practices. Apart from health-related information, a number of questions probed for economic status, access to basic services, and livelihood. The latter allowed us to identify those households whose livelihood depended on rice cultivation, even though they generally tended to other crops as well. Rice was reported as the economically most important crop by 182 households, that is, 4.2 percent of the sample. For comparison, beans and cassava were mentioned as the dominant crop by 77.5 and 69.4 percent of the households, respectively. In the remainder of the study, these 182 rice households are systematically compared to 3786 non-rice households.

In addition to the elicitation of survey questions, blood samples were taken from a subset of household members for microscopic screening on malaria parasitemia in the local health center. In addition, anthropometric measurements were taken from 1761 under-five children from the sampled households, which we use to analyze the incidence of child stunting. Procedures used for blood sample testing and the anthropometric measurements are documented in more detail in Kateera et al. [61].

2.3. Ethical Clearance

Ethical clearance No 385/RNEC/2012 was granted by the Rwanda National Ethics Committee, in addition to the scientific review approval by the National Health Research Committee. Prior to being enrolled, a consent form was read to the primary interviewee and a written consent solicited from him/her. This consent served for all information and procedures carried out on each person in the household, except for persons older than 18 years who opted out of any procedure.

2.4. Data Analysis

IBM SPSS Statistics for Windows 27 (IBM Corp., Armonk, NY, USA) was used for statistical analysis. For the descriptive analysis, differences between rice and non-rice households have been tested by *t*-tests (continuous variables) or chi-square tests (binary proportions). Correlations are tested by Spearman's rho. Two multivariate tests have been performed, concerning binary-dependent variables: (1) fever incidence at household level as proxy for malaria incidence, and (2) stunting prevalence at individual child level, for which logistic regression models have been run. A result is considered significant at 90 percent confidence.

Since the wealth status of households is under scrutiny as a potential mediator in the health impacts from rice cultivation, the construction of wealth categories warrants some attention. Rather than using a principal components analysis to construct a wealth index, we take a more intuitive approach inspired by the Multidimensional Poverty Index (MPI) [63], which focuses on deviations from the minimum standard (deficiencies) and weighs different dimensions of living standards equally. Fourteen indicators were considered in total, clustered around the following aspects: asset ownership (house, land, livestock), basic household amenities (type of sanitation, sources of drinking water, lighting and cooking), housing materials (floor, walls, and roof), financial status (source of income, ability to save, and ability to pay for medical care), and household diet (combination of frequency and type of food items consumed).

On each item, we first identified the "standard", which implied a zero score. Households that fell short of the standard scored a value of −1, while those who lived beyond the standard were assigned a value of +1. A household's overall wealth index score then equaled the sum of scores over all fourteen items. Note that for two indicators, no sub-standard options were identified, because of full compliance with the standard, so that household scores ranged from −12 (most deficient) to +14 (most comfortable). Based on this range, households were classified into wealth categories labelled as "low" ($-12 \leq$ score < 0), "medium" ($0 \leq$ score < 5), or "high" ($5 \leq$ score ≤ 14). The category thresholds are chosen such that the resulting three categories align well with Rwanda's home-grown *Ubudehe* system of wealth classification: low/*umutindi*, medium/*umukene*, and high/*umukungu* [64]. Vignettes of living conditions across these three categories are presented in Table 2.

Table 2. Vignettes of wealth categories in sample (Ruhuha sub-district, Rwanda, 2013).

Low Wealth Status	Medium Wealth Status	High Wealth Status
Household lives in a rented house with a dung floor, walls in mud and poles, and a wooden roof. They do not own livestock nor land and rely on agricultural wage labor. They cannot afford medical treatment nor buy medication when a member falls ill. They lack access to basic public amenities. The main source of drinking water is harvested rainwater. They have no sanitation in the home and use bush toilet instead. In a typical week, they cannot afford to eat tubers, cereals, pulses, or vegetables every day.	Household lives in own house with a clay floor, walls in adobe, and iron sheets as roofing. They own livestock and a piece of land, on which they engage in self-employed agriculture. They spend what they earn and cannot afford to build savings. Hence, there are no reserves to draw from if a member falls ill, but by stretching their means they somehow manage to pay for medical treatment and medication in emergencies. They have access to most basic amenities, often shared with other families. The main source of drinking water is a public well and they use a pit latrine for sanitation. Candles are used as source of lighting. In a typical week, they can eat tubers, cereals, pulses, or vegetables on a daily basis, but they cannot afford to eat meat, fish, or fruits, or drink milk every week. Meals are prepared on stoves fueled by firewood.	Household lives in own house with a concrete floor, walls from concrete blocks, and a tiled roof. They farm on their own land, which generates income that outstrips consumptive needs, allowing them to save some of it every season. If a member falls ill, expenses for medical treatment and medication can be met by dissaving. They have private access to all basic amenities, such as a piped water connection and a flush toilet in the home. The home is electrified, which serves for lighting and cooking. In a typical week, they can afford to eat meat, fish, or fruits, or drink milk at least once.

Regarding the dependent variables, malaria incidence is proxied by self-reported fever over the past 12 months, despite having microscopy results from blood smears for 76 percent of the individuals in the sample. This choice is motivated by the fact that malaria positivity rates at the time of survey are subject to strong seasonal fluctuations in malaria, related to weather patterns and the cultivation cycles of rice. Snapshots may therefore be misguiding in conjunction with the fact that households were surveyed over a number of months, including a two-month rainy season (October–November), which complicates interpretation. Even though fever self-reports are commonly used as proxy [65], it should be acknowledged that these may present an upward bias in malaria incidence [66]. Assuming that this bias is fairly consistent across societal groups, however, it serves its purpose in a comparative analysis. In addition, our data show a significant positive correlation between an individual testing positive for malaria at the time of survey and the likelihood that this person's household self-reported a fever case in the past year (r = 0.03 ***; $p < 0.001$), lending further credence to its relevance.

Finally, stunting prevalence among under-five children (from 6–60 months old) is used as dependent variable in regression. Following WHO guidelines, children are considered stunted if their z-score on height-for-age is below −2, where height is measured in cm and age in months.

3. Results

Before considering whether rice-cultivating households differ from non-rice households in terms of wealth status, malaria infection risk, and child stunting in Sections 3.1–3.3, respectively, first a basic background profile of the two groups is provided. The descriptive overview in Table 3 shows that rice households are neither significantly different from non-rice households in terms of age of head of household and spouse, nor in religious denomination. A narrow majority adheres to a Protestant or Evangelical church in the sample. Since this mimics the religious profile of the general population, there is no indication that rice cultivation is tied up with a specific religious community or faith-based agency. This avoids a potential source of bias in the comparison, as shown in an Ethiopian case where access to a new and profitable livelihood activity induced religious conversion [67]. However, systematic differences show up in household composition. Rice-growing households are less likely to be single-headed, either through separation or widowhood, and, in connection, less likely to be female-headed. In addition, rice households tend to be larger in size. Another noteworthy observation is that rice households have a significantly stronger education profile, at least on the modest criterion of having received any schooling. This applies to both heads of household and their spouses.

Rice and non-rice households are roughly equally spread over Ruhuha's five sub-sectors, comprising Kindama, Gikundamvura, Gatanga, Bihari, and Ruhuha center itself. Sub-sector dummies are included in the regression analyses to pick up location-specific effects. In case these prove to have significant explanatory power, we can exclude the possibility that this is driven by a strong concentration of rice-farming households in particular sub-sectors.

Table 3. Sample Description, by Rice-Cultivation Status.

	Rice	Non-Rice	Difference
Demographics			
Mean age head of household	41.5	43.0	=[t = −1.43]
Mean age spouse	36.9	35.5	=[t = 1.54]
Head of household without schooling (%)	27.5	36.1	<[X^2 = 4.96 **]
Spouse without schooling (%)	22.5	30.1	<[X^2 = 3.71 *]
Protestant/Evangelical head of household (%)	52.2	55.2	=[X^2 = 0.54]
Head of household separated or widowed (%)	13.8	26.8	<[X^2 = 19.65 ***]
Female-headed household (%)	14.4	27.4	<[X^2 = 13.17 ***]
Mean household size (no.)	5.2	4.3	>[t = 6.36 ***]
Location (sub-sector)			
Ruhuha (%)	18.7	16.1	
Kindama (%)	25.3	27.5	
Gikundamvura (%)	17.0	18.4	0 [X^2 = 1.80]
Gatanga (%)	23.1	20.8	
Bihari (%)	15.9	17.2	
Livelihood			
Head of household is farmer (%)	90.6	82.6	>[X^2 = 6.89 ***]
Spouse is farmer (%)	96.5	90.3	>[X^2 = 5.99 **]
Household owns land	97.3	80.5	>[X^2 = 32.13 ***]
Mean wealth index (min. score: −12; max. score 14)	3.38	1.36	>[t = 9.36 ***]

Table 3. *Cont.*

	Rice	Non-Rice	Difference
Health/malaria			
ITN ownership (%) (household level)	97.8	92.7	>[X^2 = 6.96 ***]
Health insurance coverage (%) (household level)	79.1	65.7	>[X^2 = 14.02 ***]
Fever during past year (%) (household level)	70.3	56.1	>[X^2 = 14.27 ***]
Household in which $\geq$ 1 individual tested positive on malaria at time of survey (%) ^	13.8	13.1	0 [X^2 = 0.07]
No. of households	182	3786	
No. of individuals	912	16,108	

^ 76% of individuals in sample were tested for malaria parasitemia; infants up to six months were excluded. *, **, and *** denote significance at 10, 5, and 1 per cent, respectively.

3.1. Rice Farming and Wealth Status

Livelihoods in Ruhuha are strongly agriculture-based. More than 80 percent of household heads self-identified as farmer in the survey, and this increases to 90 percent for spouses, confirming the important role of women in local agriculture. Not surprisingly, rice households reported almost universally to be engaged in farming, and spousal engagement again exceeded that of the household head. Nearly all own land, albeit often on government lease. Data obtained from local rice cooperatives show that the cultivation area of individual households is typically around 0.1 ha, with paddy sizes up to 0.3 ha for the largest farmers. While our data do not contain direct information on the profitability of rice relative to the return on other agricultural activities, rice households have significantly higher wealth scores than non-rice households (see Table 3). We need to be cautious in assuming a causal link, as it cannot be ascertained in our cross-sectional data to what extent these assets have been accumulated in the process of rice cultivation or were already present upon entering the rice sector.

The stronger wealth position of rice famers is also reflected in Figure 3, which shows the distribution of rice and non-rice households across the categories of low, medium, and high wealth. Their respective shares in the low wealth category are most dissimilar; almost one in three non-rice households classified as such, as compared to fewer than one in ten rice households. These shares are consequently lop-sided for the high wealth group, although somewhat less extreme; one in three rice households featured a high wealth status, against only one in five non-rice families. Given the protective effects from wealth documented in Section 1.4, one would expect rice households to experience fewer malaria cases.

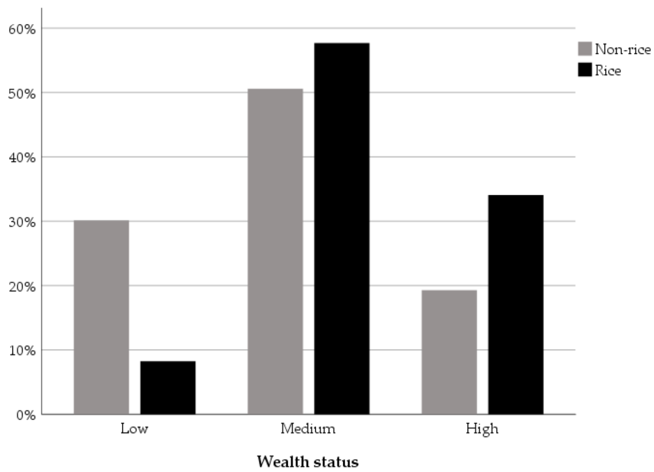

Figure 3. Wealth distribution of rice vs. non-rice households.

3.2. Rice Farming, Fever Incidence, and Wealth Mediation

Confirming one of the pathways through which wealth affects malaria, viz. better access to preventive measures and healthcare, rice households are significantly more likely to own at least one ITN, even though bed-net ownership is above 90 percent among non-rice households as well (see Table 3). Rice families are also more likely covered by health insurance, either community-based or private insurance. This notwithstanding, rice households systematically report more fever than non-rice households overall: 70 versus 56 percent.

Figure 4 de-aggregates this disparity by wealth category, which reveals that excess fever for rice households appears across the wealth distribution, although it should be noted that there are relatively few observations for rice households in the low wealth category. Interestingly, the disparity is widest (more than 30 percentage points) for families in the wealthiest category. A tentative explanation emerges if we assume that rice profitability is in fact the main driver of wealth in the rice group. Higher wealth might imply stronger engagement with rice cultivation and thereby more intensive exposure to malaria vectors, such as when multiple household members perform labor in or around the paddy fields. Wealth generation and increased infection risk would thus correlate in this case, undermining the paddy paradox hypothesis.

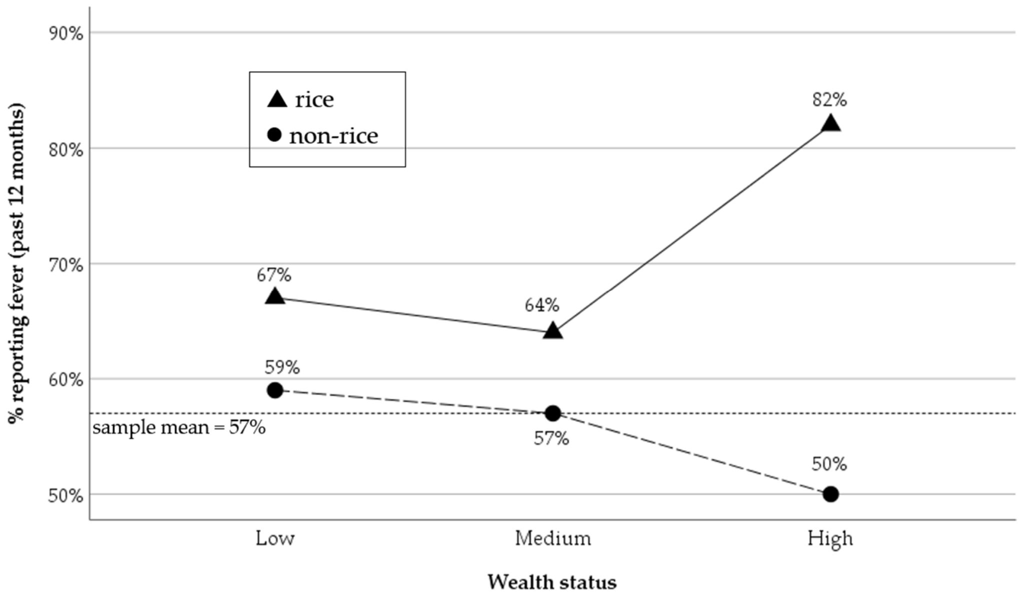

Figure 4. Fever incidence by wealth status: rice vs. non-rice households.

Another relevant observation from Figure 4 concerns the trend in fever incidence of non-rice households, which falls marginally from low to medium wealth, but markedly declines when moving from medium to high wealth. In the high wealth category fever incidence is 7 percentage points below the overall sample mean, where the latter coincides with the incidence level of the medium wealth group. Hence, the protective effects from wealth seem to be operative in the local population (rice farmers excluded).

The above observations are corroborated in a multivariate logistic regression, which controls for household composition and locational variation. The purpose of the model is to isolate the effect of rice farmer status rather than to build a "best-fit" model concerning fever incidence for the entire sample. The results in Table 4 confirm that a rice-based livelihood pushes up fever incidence significantly (see positive coefficient in first row). Controlled for wealth, rice households are 1.6 times as likely to report fever compared to non-rice households.

Table 4. Logistic regression: the impact of a rice-based livelihood on fever incidence (as a proxy for malaria incidence) in household, controlled for wealth status.

	Coeff. (St. Dev.)	**Wald (*p*-Value)**	**Odds Ratio**
Rice-cultivating household	0.482 (0.172)	7.86 *** (0.005)	1.62
Wealth category (omitted: medium wealth status)			
Low wealth status	0.166 (0.079)	4.42 ** (0.036)	1.18
High wealth status	−0.261 (0.089)	8.62 *** (0.003)	0.77
Household composition			
No of members in household	0.227 (0.019)	136.78 *** (0.000)	1.26
No of children in household	0.135 (0.077)	3.06 * (0.080)	1.15
Any child born in past 5 years	0.084 (0.126)	0.44 (0.507)	1.09
Sub-sector (omitted category: Ruhuha)			
Bihari	0.102 (0.117)	0.75 (0.386)	1.11
Gatanga	0.308 (0.113)	7.43 *** (0.006)	1.36
Gikundamvura	−0.131 (0.115)	1.30 (0.254)	0.88
Kindama	−0.336 (0.104)	10.32 *** (0.001)	0.72
Obs.	n = 3968		
Overall model test	X^2 = 317.21 *** ($p < 0.01$)		

*, **, and *** denote significance at 10, 5, and 1 percent, respectively.

When considering the impact of belonging to a given wealth category, the mediating role of wealth in shaping malaria incidence is borne out. In reference to the medium wealth category, those in the lower category report a significantly higher rate of febrile illness. In contrast, families in the higher wealth category report lower fever than those in the medium wealth group. Note that the corresponding coefficients in Table 4 basically reflect the impact of wealth on the non-rice population, as the small group of rice farmers, for whom wealth mediation runs in the opposite direction, carries only marginal weight in the overall regression.

With respect to the remaining control variables, household size raises fever incidence at the household level, as expected. The number of children in the household, but not those under five years of age, reinforces this effect, in alignment with the observation by Habyarimana and Ramroop [60] that malaria infection rates in Rwanda are highest in the group aged between five and nine years. Location-wise, residence in Kindama sub-district reduced the odds of fever, while living in Gatanga increased it. It is tempting to connect this to rice cultivation, as Gatanga is squeezed between two large marshlands (Nyaburiba and Kibaza) where rice is cultivated, but other studies have shown that malaria transmission risk can vary widely over small areas, even between neighbouring villages [68], which potentially invalidates inferences from sub-sector geography.

3.3. Nutritional Benefits Associated with Rice Farming

Turning our attention to the link from rice cultivation to nutrition and child health (arrow d* in Figure 2), the focus is on child stunting, as Rwanda has one of the world's highest rates of stunting prevalence [69]. For a total of 1761 children up to age five, z-scores on height-for-age were calculated. The aim is to test whether children in rice households (n = 82) enjoy a nutritional advantage, controlled for the higher wealth status with which rice production is associated. Improved food security may, for instance, stem from the fact that local rice cooperatives typically stipulate that 80 percent of rice is sold, while 20 percent is retained by the farmer groups for home consumption [70]. Table 5 reports on the logistic regression on z-scores, to which a limited set of child and parent characteristics have been added as explanatory variables alongside locational dummies.

Table 5. Logistic regression: the impact of a rice-based livelihood on stunting of under-five children, controlled for wealth status.

	Coeff. (St. Dev.)	Wald (p-Value)	Odds Ratio
Rice-cultivating household	0.974 (0.542)	3.22 * (0.073)	2.65
Rice-cultivating household * age of child (months)	−0.038 (0.016)	5.36 ** (0.021)	0.96
Wealth category (omitted: medium wealth status)			
Low wealth status	0.243 (0.113)	4.59 ** (0.032)	1.28
High wealth status	−0.003 (0.135)	0.00 (0.984)	1.00
Child characteristics			
Gender (1 = female; 0 = male)	−0.120 (0.098)	1.49 (0.222)	0.89
Age (in months)	−0.001 (0.003)	0.13 (0.721)	1.00
Parent characteristics			
Age of household head	0.000 (0.004)	0.01 (0.914)	1.00
Female-headed household	0.419 (0.138)	9.28 *** (0.002)	1.52
Household head has not gone to school	0.193 (0.110)	3.06 * (0.080)	1.21
Sub-sector (omitted category: Ruhuha)			
Bihari	−0.285 (0.176)	2.61 (0.106)	0.75
Gatanga	0.071 (0.155)	0.21 (0.650)	1.07
Gikundamvura	−0.235 (0.165)	2.03 (0.154)	0.79
Kindama	−0.135 (0.158)	0.73 (0.394)	0.87
Obs.	n = 1761		
Overall model test	X^2 = 38.83 *** ($p < 0.01$)		

*, **, and *** denote significance at 10, 5, and 1 percent, respectively.

In order to appreciate the impact of rice cultivation status per se (ignoring wealth effects), the analysis reveals that a child's age is crucial. The main effect of rice in Table 5 is positive and significant, but the interaction term with child age (in months) has a significant negative sign. This suggests that the nutritional advantage for children in rice households takes time to materialize and that they even start out at a disadvantage. We revert to this unexpected finding below.

As anticipated, stunting prevalence varies with wealth status in Table 5. Children in households with low wealth status are almost 1.3 times as likely to be stunted as those in medium-wealth households. However, no further improvement is observed when comparing the medium- and high-wealth groups. Other control variables also point in the expected direction, which is reassuring, given the limited sample size. In line with Weatherspoon et al.'s [69] study on stunting in Rwandan under-fives, male children are more likely to be stunted, although this gender difference does not reach significance in our sample. Moreover, our analysis replicates their finding that the education level of the head of household is a relevant predictor of stunting. Children from heads of household that have not gone to school are significantly more likely to be stunted in our sample. A result that stands out concerns the increased odds of stunting when born into a female-headed household, which is 1.5 times the odds for those in male-headed households. This aligns well with results obtained in the CFSVA 2018 study [33], in which 23 percent of female-headed households were found to be food insecure, compared to only 17 percent of male-headed ones. The report explains that female household heads are mostly widows, who are more likely to be landless or suffer from weak land tenure, so that they are more dependent on sharecropping, agricultural day labor, other precarious livelihoods, or external support. Finally, different from the regression on fever in Table 4, none of the sub-sector dummies proves significant in Table 5.

Returning to the effect of prime interest, viz. the age-mediated impact from rice cultivation status, it is informative to plot stunting prevalence across age (in years) for rice and non-rice children, as shown in Figure 5. Children of rice-growing parents face an initial disadvantage, but there is a turning point around two years of age, from which stunting prevalence drops markedly below that of non-rice children. While data limitations do not allow us to pinpoint the exact mechanisms responsible for the observed pattern, the literature on early childhood development offers some tentative insights. First, it should be noted that the dynamics in Figure 5 are at odds with a strict interpretation of the "first 1000 days" as the unique window of opportunity for influencing developmental outcomes. The pattern rather suggests that height-for-age responds to changing conditions even after the age of two, that is, that catch-up growth is possible, as evidenced in a large cohort study across four developing countries by Crookston et al. [71]. The finding that child growth trajectories are not "fixed" early on is relevant, as the nutritional advantage of rice availability at home may have a slow onset, following from infants being breastfed and/or receiving formulas rather than rice-based meals.

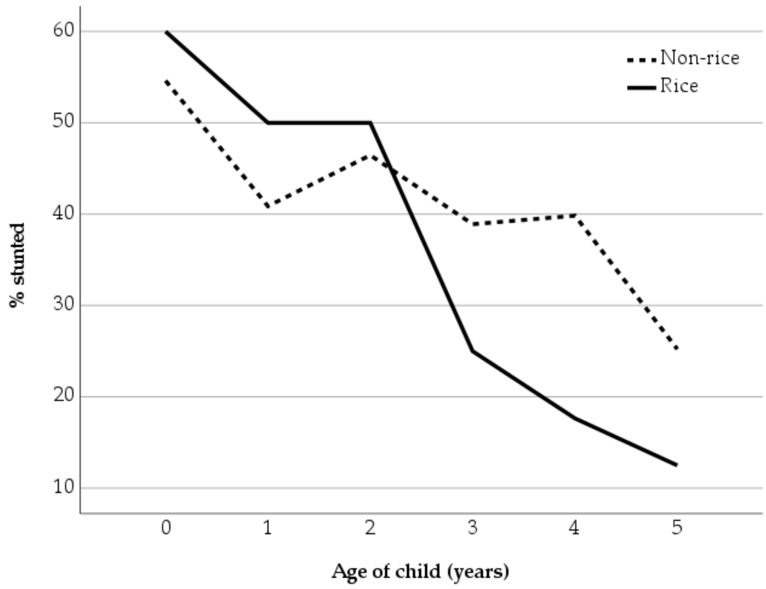

Figure 5. Stunting prevalence across age (in years), by rice cultivation status of household.

To explain the initial disadvantage of children in rice-farming households, the literature suggests a link to the analysis on malaria incidence in Section 3.2. If pregnant mothers in rice households are more likely to suffer from malaria, this may in turn negatively affect fetal growth [72]. Intriguingly, higher incidence of placental or postnatal malaria among children in rice-growing families may even explain the reversal in Figure 5 according to recent research on immunity formation in early childhood. Fink, Venkataramani, and Zanolini [73] use the interruption of a malaria control program in Zambia to find that "cohorts with higher exposure to malaria infection risk in the first two years of life were substantially less likely to be anemic and to suffer from fever—two key symptoms of malaria—at ages 3–5 than cohorts with lower early exposure in similar disease environments" (p. 3), which would in turn benefit the physical growth of pre-schoolers. This scenario underlines the complexity of the interaction between nutrition, malaria, and (child) health, such that a claim that pre-school children in rice households benefit nutritionally from their parents' rice-based livelihood should be made cautiously.

4. Discussion

Our results first of all align with Chan et al.'s [37] observation that the paddy paradox no longer applies. The rice-cultivating share of the local population reports more fever, suggesting that higher wealth fails to shield them from exposure to malaria vectors. Since higher-quality housing should offer protection against mosquito bites indoors, this might indicate a scenario where outdoor biting in and around paddies is the dominant malaria transmission mechanism. In terms of the scheme in Figure 2, arrow b* dominates a* + e* (the latter two cannot easily be distinguished in our empirical set-up). We do find evidence of a nutritional benefit on children (2–5 years), confirming the presence of arrow d*, but this does not directly translate into lower fever incidence at the household level.

This outcome for rice cultivators does not bode well for households outside the rice sector (95.8 percent of the population). Given the evidence reviewed in Section 1.3 that physical proximity to irrigated rice fields increases malaria risk locally, those residing in communities within close range of irrigated rice schemes seem bound to face a higher risk of contracting malaria. As shown in Figure 4, this impact is not wealth-neutral under the assumption that wealth among the non-rice population does not vary systematically with distance to marshlands. Those who belong to the lowest wealth category are most at risk, and even those with medium wealth are at higher risk than households in the high wealth category. Hence, wealth mediates health impacts in this case, resulting in a biased impact against the bottom part of the local wealth distribution. This mediation effect might be self-reinforcing, as the economic cost associated with malaria episodes likely entrenches wealth inequalities (within the non-rice population) further.

The observed mediation of impact by wealth status is unlikely to be unique to the type of SDG interdependency under study. Distributional analysis warrants more attention than currently reflected in most empirical contributions on SDG interaction. Typically, claims on distributional consequences are formulated at a fairly aggregate level, indicating for example that "farmers" or "the rural poor" in developing countries are most vulnerable to negative impacts. Unpacking such broad social categories is pertinent, however, as illustrated by the work of Hutton et al. [3], which addresses trade-offs between SDG2 and environmental goals, most notably SDG13 (climate action) and SDG15 (life on land), in coastal Bangladesh. Using a model that takes account of both climatological (e.g., sea-level rise) and ecological (e.g., land salinization) effects from "progressive" agricultural policies, simulations are run separately for distinct livelihood groups. Comparative results among large landowners, small farmers, and agricultural workers reveal that local inequalities are set to deepen, as smallholders and the landless are disproportionally affected by ecological degradation and climate-related disasters.

Prospects of rising local inequality can equally emerge from policies that bank on SDG synergy. Chapman and Darby [74] consider the case of heightening dykes in Vietnam's Mekong delta, which serves the twin purpose of climate adaptation (SDG13) and food security (SDG2), as higher dykes allow for a shift from double- to triple-cropping rice cultivation. Distributional analysis indicates, however, that this shift "may actively increase the efficiency gap, and hence wealth gap, between the wealthiest farmers and the rest of agricultural society" and "can force a greater debt burden on poorer farmers" (p. 336). This perverse impact results from dykes preventing fluvial sediment deposition in rice paddies, which requires farmers to replenish soil nutrients by applying (expensive) artificial fertilizer.

Mapping the distributional consequences of SDG interaction may require going beyond wealth categories, depending on the context. Two examples that are situated within the nexus of agricultural intensification and health may serve as illustrations.

Bhumiratana et al. [75] examine the expansion and intensification of rubber plantations in a bid to upgrade rural livelihoods in Thailand, which—similar to paddy expansion—increases exposure to malaria. The risk of contracting malaria, however, differs between local Thai rubber tappers and foreign migrant tappers. Migrant worker health tends to be more affected for several reasons; weak immunity against malaria due to absence of malaria in their home country, more indoor biting in precarious non-permanent housing, and more outdoor biting as a result of different working hours than local tappers (more hours during nightfall when biting risk is highest). Hence, migrant status presents a relevant differentiation variable in this particular case.

A second example concerns (non-parasitic) health problems related to agricultural intensification, in particular exposure to toxic agrochemicals, which can lead to neurological, respiratory, and immunologic problems, among others [76]. Mrema et al. [77] explore the link between intensification of horticulture and pesticide exposure in Tanzania. While acknowledging that the wealth status of a household engaged in horticulture is an important mediator in terms of, for example, level of access to personal protective equipment (PPE), the main focus is on differential impacts for men and women. Women are arguably more at risk because of, among other factors, weak power to negotiate PPE use (when available) in the household, a tendency to change heavy professional spraying gear for unsafe improvised devices, weaker literacy skills to understand safety instructions, re-use of empty pesticide containers for household purposes, and more frequent contact with contaminated water (e.g., laundry). Gender disaggregation gains additional urgency from an intergenerational perspective, as evidence is building that prenatal pesticide exposure negatively impacts on child health [78]. In sum, in-depth contextual consideration of trade-offs may reveal mediating variables that would not surface in a wealth stratification exercise, but significantly affect local inequalities.

5. Conclusions

This paper analyzed the impact of a specific trade-off between SDG2 and SDG3, that is, the impact of the expansion of rice cultivation on public health in Rwanda, through a distributional lens. Comparing impacts across wealth strata reveals that the negative externality of increased malaria exposure falls disproportionally on the poorest section of the non-rice producing local population in Ruhuha. An important qualifier is that exposure is highest among rice-farming households themselves, who are typically located at the higher end of the local income distribution. However, this is unlikely to undo the overall inequality-enhancing nature of the trade-off, as rice farmers make up a relatively small portion of the population (less than five percent), and additionally, they appear to reap nutritional benefits from increased rice production. After overcoming an initial disadvantage, under-five children in rice-cultivating households outperform their counterparts in non-rice households on height-for-age. Overall, therefore, the wealth dependence of malaria incidence likely becomes more entrenched, despite the anomaly that the rice-farming group presents.

It should be noted that the regression analyses informing these results face some limitations, in particular the risk of omitted-variable bias. Both the incidence of malaria and child stunting are outcomes of a highly complex set of factors, while our data only cover the most straightforward ones. In the case of malaria incidence, for instance, we lack information on the adaptive behavior of vectors in the case study area as well as the geographical risk factors other than rice paddies that residents face close to their homestead. When explaining stunting rates, our analysis could have been more precisely fitted, for example, using anthropometric information on the children's mothers to isolate genetic effects. Notwithstanding these and other omissions, we feel the results effectively substantiate, in line with previous studies, the public health risk that rice intensification poses and, more innovatively, indicate the prospects for the distribution of such risks.

The broader goal of our study was to showcase the importance of being attentive to mediators of SDG interaction such as wealth status. From a policy-making perspective, a distributional analysis may assist decision-makers in screening out SDG-promoting policies that compromise criteria of social justice. It may identify those categories of the local population that warrant compensation or mitigation measures to prevent further widening of existing welfare gaps. In the case of, for instance, stimulating rice production, policymakers might pay special attention to the poorer strata of non-rice growers, in order to avoid immediate negative effects on their health and productivity, but also to prevent the attrition of human capital and labor market prospects for the next generation.

We acknowledge that the distributional calculus involved is not straightforward. Even if the data allow for inequalities to be expressed in a common metric across distinct SDG outcomes—for instance, concentration indices have been calculated to gauge the wealth gradients associated with interventions targeting malaria [79] and food insecurity [80]—these cannot meaningfully be aggregated, given that the outcome metrics as such are distinct. This non-additivity across SDG targets implies that the assessment of a trade-off ultimately rests on a societal valuation process of the respective outcomes at stake, and thus requires resolution in the political domain.

Moreover, distributional calculus might produce ambiguous results, depending on the level or scale at which interaction is analyzed. Even if a policy does not trigger a trade-off with SDG10 (reduce inequality) in the aggregate, a more fine-grained, localized inquiry can still bring out distributional effects that are deemed socially undesirable. For instance, if a policy brings higher net benefits—or lower net costs, depending on the SDG interaction at hand—to rural residents than to urban ones, overall inequality may decline country-wide, but impacts could nevertheless prove highly heterogeneous across rural categories. Our common pledge to "leave no one behind" in the SDG preamble therefore puts a responsibility on scholars and policymakers to keep an eye out for problematic distributional impacts. Timely and adequate anticipation on such impacts is required, even if it adds to the inherent complexities of SDG interactions.

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References

1. Nilsson, M.; Griggs, D.; Visbeck, M. Policy: Map the interactions between Sustainable Development Goals. *Nature* **2016**, *534*, 320–322. [CrossRef] [PubMed]
2. Breuer, A.; Janetschek, H.; Malerba, D. Translating Sustainable Development Goal (SDG) interdependencies into policy advice. *Sustainability* **2019**, *11*, 2092. [CrossRef]
3. Hutton, C.W.; Nicholls, R.J.; Lázár, A.N.; Chapman, A.; Schaafsma, M.; Salehin, M. Potential trade-offs between the sustainable development goals in coastal Bangladesh. *Sustainability* **2018**, *10*, 1108. [CrossRef]
4. Mainali, B.; Luukkanen, J.; Silveira, S.; Kaivo-Oja, J. Evaluating synergies and trade-offs among Sustainable Development Goals (SDGs): Explorative analyses of development paths in South Asia and Sub-Saharan Africa. *Sustainability* **2018**, *10*, 815. [CrossRef]
5. Koch, D.-J. Measuring long-term trends in policy coherence for development. *Dev. Policy Rev.* **2017**, *36*, 87–110. [CrossRef]
6. Zhao, Z.; Cai, M.; Wang, F.; Winkler, J.A.; Connor, T.; Chung, M.G.; Zhang, J.; Yang, H.; Xu, Z.; Tang, Y.; et al. Synergies and tradeoffs among Sustainable Development Goals across boundaries in a metacoupled world. *Sci. Total Environ.* **2021**, *751*, 141749. [CrossRef]
7. Ijumba, J.N.; Lindsay, S.W. Impact of irrigation on malaria in Africa: Paddies paradox. *Med. Vet. Entomol.* **2001**, *15*, 1–11. [CrossRef]
8. Independent Group of Scientists appointed by the Secretary-General. In *Global Sustainable Development Report 2019: The Future is Now—Science for Achieving Sustainable Development*; United Nations: New York, NY, USA, 2019; Available online: https://sustainabledevelopment.un.org/content/documents/24797GSDR_report_2019.pdf (accessed on 29 June 2021).
9. Fonseca, L.M.; Domingues, J.P.; Dima, A.M. Mapping the sustainable development goals relationships. *Sustainability* **2020**, *12*, 3359. [CrossRef]
10. Pradhan, P.; Costa, L.; Rybski, D.; Lucht, W.; Kropp, J.P. A systematic study of Sustainable Development Goal (SDG) interactions. *Earth's Future* **2017**, *5*, 1169–1179. [CrossRef]
11. International Council for Science. *A Guide to SDG Interactions: From Science to Implementation*; ICSU: Paris, France, 2017; Available online: https://council.science/wp-content/uploads/2017/05/SDGs-Guide-to-Interactions.pdf (accessed on 29 June 2021).
12. Mollier, L.; Seyler, F.; Chotte, J.L.; Ringler, C. SDG 2: End Hunger, achieve food security and improved nutrition and promote sustainable agriculture. In *A Guide to SDG Interactions: From Science to Implementation*; Griggs, D., Nilsson, M., Stevance, A., McCollum, D., Eds.; International Council for Science (ICSU): Paris, France, 2017; pp. 31–75.
13. Nilsson, M.; Griggs, D.; Visbeck, M.; Ringler, C.; McCollum, D. Introduction: A framework for understanding sustainable development goal interactions. In *A Guide to SDG Interactions: From Science to Implementation*; Griggs, D., Nilsson, M., Stevance, A., McCollum, D., Eds.; International Council for Science (ICSU): Paris, France, 2017; pp. 18–30.
14. Reid, M.C.; McKenzie, F.E. The contribution of agricultural insecticide use to increasing insecticide resistance in African malaria vectors. *Malar. J.* **2016**, *15*, 107. [CrossRef]
15. Mettetal, E. Irrigation dams, water and infant mortality: Evidence from South Africa. *J. Dev. Econ.* **2019**, *138*, 17–40. [CrossRef]
16. Motbainor, A.; Taye, A. Wasting in under five children is significantly varied between rice producing and non-producing households of Libokemkem district, Amhara region, Ethiopia. *BMC Pediatr.* **2019**, *19*, 300. [CrossRef] [PubMed]
17. Das, D.; Grais, R.F.; Okiro, E.A.; Stepniewska, K.; Mansoor, R.; van der Kam, S.; Terlouw, D.J.; Tarning, J.; Barnes, K.I.; Guerin, P.J. Complex and vicious interactions between malaria and malnutrition: A systematic review. *BMC Med.* **2018**, *16*, 186. [CrossRef] [PubMed]
18. Bendabenda, J.; Patson, N.; Hallamaa, L.; Mbotwa, J.; Mangani, C.; Phuka, J.; Prado, E.L.; Cheung, J.B.; Ashorn, U.; Dewey, K.G.; et al. The association of malaria morbidity with linear growth, hemoglobin, iron status, and development in young Malawian children: A prospective cohort study. *BMC Pediatr.* **2018**, *18*, 396. [CrossRef]
19. Lukwa, A.T.; Mawoyo, R.; Zablon, K.N.; Siya, A.; Alaba, O. Effect of malaria on productivity in a workplace: The case of a banana plantation in Zimbabwe. *Malar. J.* **2019**, *18*, 390. [CrossRef]
20. Girardin, O.; Dao, D.; Koudou, B.G.; Essé, C.; Cissé, G.; Yao, T.; N'Goran, E.K.; Tschannen, A.B.; Bordmann, G.; Lehmann, B.; et al. Opportunities and limiting factors of intensive vegetable farming in malaria endemic Côte d'Ivoire. *Acta Trop.* **2004**, *89*, 109–123. [CrossRef]
21. Fink, G.; Masiye, F. Health and agricultural productivity: Evidence from Zambia. *J. Health Econ.* **2015**, *42*, 151–164. [CrossRef]
22. Sedlmayr, R. If it pays, it stays: Can agribusiness internalize the benefits of malaria control? *World Bank Econ. Rev.* **2018**, *32*, 410–427. [CrossRef]
23. Dillon, A.; Friedman, J.; Serneels, P. Health information, treatment, and worker productivity. *J. Eur. Econ. Assoc.* **2021**, *19*, 1077–1115. [CrossRef]
24. Cutler, D.; Fung, W.; Kremer, M.; Singhal, M.; Vogl, T. Early-life malaria exposure and adult outcomes: Evidence from malaria eradication in India. *Am. Econ. J. Appl. Econ.* **2010**, *2*, 72–94. [CrossRef]
25. Venkataramani, A.S. Early life exposure to malaria and cognition in adulthood: Evidence from Mexico. *J. Health Econ.* **2012**, *31*, 767–780. [CrossRef] [PubMed]
26. Bleakley, H. Malaria eradication in the Americas: A retrospective analysis of childhood exposure. *Am. Econ. J. Appl. Econ.* **2010**, *2*, 1–45. [CrossRef] [PubMed]
27. Kuecken, M.; Thuilliez, J.; Valfort, M.-A. Disease and human capital accumulation: Evidence from the Roll Back Malaria partnership in Africa. *Econ. J.* **2021**, *131*, 2171–2202. [CrossRef]

28. Kateera, F.; Mens, P.F.; Hakizimana, E.; Ingabire, C.M.; Muragijemariya, L.; Karinda, P.; Grobusch, M.P.; Mutesa, L.; van Vugt, M. Malaria parasite carriage and risk determinants in a rural population: A malariometric survey in Rwanda. *Malar. J.* **2015**, *14*, 16. [CrossRef] [PubMed]
29. World Health Organization. The Global Health Observatory: Joint Child Malnutrition Estimates. Available online: https://www.who.int/data/gho/data/themes/topics/joint-child-malnutrition-estimates-unicef-who-wb (accessed on 19 October 2021).
30. UN Inter-Agency Group for Child Mortality Estimation. Available online: https://childmortality.org/data (accessed on 1 November 2021).
31. World Health Organization. World Malaria Report 2020. Available online: https://www.who.int/publications/i/item/9789240015791 (accessed on 19 October 2021).
32. Food and Agriculture Organization. FAOSTAT: Food and Agriculture Data. Available online: https://www.fao.org/faostat/en/#data (accessed on 2 November 2021).
33. Paridaens, A.-M.; Jayasinghe, S. *Rwanda: Comprehensive Food Security and Vulnerability Analysis 2018*; World Food Programme: Kigali, Rwanda, 2018; Available online: https://www.wfp.org/publications/rwanda-comprehensive-food-security-vulnerability-analysis-december-2018 (accessed on 6 July 2021).
34. Republic of Rwanda. 2019 Rwanda Voluntary National Review (VNR) Report. Available online: https://sustainabledevelopment.un.org/content/documents/23432Rwanda_2019_VNR_Final_Draft___17_06_2019.pdf (accessed on 29 June 2019).
35. Arouna, A.; Fatognon, I.A.; Saito, K.; Futakuchi, K. Moving toward rice self-sufficiency in sub-Saharan Africa by 2030: Lessons learned from 10 years of the Coalition for African Rice Development. *World Dev. Perspect.* **2021**, *21*, 100291. [CrossRef]
36. Awoniyi, S.O.M.; Apata, T.G.; Igbalajobi, A.O.; Fakayode, S.B.; Sanusi, R.A.; Olorunfemi, B.J.; Ogunjimi, S.I. Malaria and agriculture: Evidence of relationship and labour/ income loss among rural rice-farming households in Nigeria. *Res. Crop.* **2018**, *19*, 353–364. [CrossRef]
37. Chan, K.; Tusting, L.S.; Bottomley, C.; Saito, K.; Djouaka, R.; Lines, J. Rice and malaria in Africa: A systematic review and meta-analysis. *Lancet* **2021**. [CrossRef]
38. Wondwosen, B.; Birgersson, G.; Seyoum, E.; Tekie, H.; Torto, B.; Fillinger, U.; Hill, S.R.; Ignell, R. Rice volatiles lure gravid malaria mosquitoes, Anopheles arabiensis. *Sci. Rep.* **2016**, *6*, 37930. [CrossRef]
39. Ijumba, J.N.; Shenton, F.C.; Clarke, S.E.; Mosha, F.W.; Lindsay, S.W. Irrigated crop production is associated with less malaria than traditional agricultural practices in Tanzania. *Trans. R. Soc. Trop. Med. Hyg.* **2002**, *96*, 476–480. [CrossRef]
40. Rumisha, S.F.; Shayo, E.H.; Mboera, L.E.G. Spatio-temporal prevalence of malaria and anaemia in relation to agro-ecosystems in Mvomero district, Tanzania. *Malar. J.* **2019**, *18*, 228. [CrossRef]
41. Tuyishimire, J.; Kateera, F.; Mugisha, J.; Amer, S.; Mens, P. Spatial modelling of malaria risk factors in Ruhuha sector in the east of Rwanda. *Rwanda J.* **2016**, *1*, 1–17. [CrossRef]
42. Rulisa, S.; Kateera, F.; Bizimana, J.P.; Agaba, S.; Dukuzumuremyi, J.; Baas, L.; Harelimana, J.D.; Mens, P.F.; Boer, K.R.; de Vries, P.J. Malaria prevalence, spatial clustering and risk factors in a low endemic area of Eastern Rwanda: A cross sectional study. *PLoS ONE* **2013**, *8*, e69443. [CrossRef] [PubMed]
43. Murindahabi, M.M.; Hoseni, A.; Vreugdenhil, L.C.C.; van Vliet, A.J.H.; Umupfasoni, J.; Mutabazi, A.; Hakizimana, E.; Poortvliet, P.M.; Mutesa, L.; Takken, W.; et al. Citizen science for monitoring the spatial and temporal dynamics of malaria vectors in relation to environmental risk factors in Ruhuha, Rwanda. *Malar. J.* **2021**, *20*, 453. [CrossRef]
44. Oguoma, V.M.; Anyasodor, A.E.; Adeleye, A.O.; Eneanya, O.A.; Mbanefo, E.C. Multilevel modelling of the risk of malaria among children aged under five years in Nigeria. *Trans. R. Soc. Trop. Med. Hyg.* **2021**, *115*, 482–494. [CrossRef] [PubMed]
45. Homenauth, E.; Kajeguka, D.; Kulkarni, M.A. Principal component analysis of socioeconomic factors and their association with malaria and arbovirus risk in Tanzania: A sensitivity analysis. *J. Epidemiol. Community Health* **2017**, *71*, 1046–1051. [CrossRef]
46. Khatib, R.A.; Chaki, P.P.; Wang, D.-Q.; Mlacha, Y.P.; Mihayo, M.G.; Gavana, T.; Xiao, N.; Zhou, X.-N.; Abdullah, S. Epidemiological characterization of malaria in rural southern Tanzania following China-Tanzania pilot joint malaria control baseline survey. *Malar. J.* **2018**, *17*, 292. [CrossRef]
47. Weber, A.C.; Bogler, L.; Vollmer, S.; Simen-Kapeu, A.; Ekpini, E.R.; Zagre, N.M. The wealth gradient in diarrhoea, acute respiratory infections, and malaria in childhood over time: A descriptive analysis using DHS and MICS from Western and Central Africa between 1995 and 2017. *J. Glob. Health* **2021**, *11*, 13009. [CrossRef]
48. Bousema, T.; Drakeley, C.; Gesase, S.; Hashim, R.; Magesa, S.; Mosha, F.; Otieno, S.; Carneiro, I.; Cox, J.; Msuya, E.; et al. Identification of hot spots of malaria transmission for targeted malaria control. *J. Infect. Dis.* **2010**, *201*, 1764–1774. [CrossRef]
49. Deressa, W.; Ali, A.; Berhane, Y. Household and socioeconomic factors associated with childhood febrile illnesses and treatment seeking behaviour in an area of epidemic malaria in rural Ethiopia. *Trans. R. Soc. Trop. Med. Hyg.* **2007**, *101*, 939–947. [CrossRef]
50. Morakinyo, O.M.; Balogun, F.M.; Fagbamigbe, A.F. Housing type and risk of malaria among under-five children in Nigeria: Evidence from the malaria indicator survey. *Malar. J.* **2018**, *17*, 311. [CrossRef]
51. Essendi, W.M.; Vardo-Zalik, A.M.; Lo, E.; Machani, M.G.; Zhou, G.; Githeko, A.K.; Yan, G.; Afrane, Y.A. Epidemiological risk factors for clinical malaria infection in the highlands of Western Kenya. *Malar. J.* **2019**, *18*, 211. [CrossRef] [PubMed]
52. Donnelly, B.; Berrang-Ford, L.; Labbé, J.; Twesigomwe, S.; Lwasa, S.; Namanya, D.B.; Harper, S.L.; Kulkarni, M.; Ross, N.A.; IHACC Research Team; et al. Plasmodium falciparum malaria parasitaemia among indigenous Batwa and non-indigenous communities of Kanungu district, Uganda. *Malar. J.* **2016**, *15*, 254. [CrossRef] [PubMed]

53. Tusting, L.S.; Bottomley, C.; Gibson, H.; Kleinschmidt, I.; Tatem, A.J.; Lindsay, S.W.; Gething, P.W. Housing improvements and malaria risk in sub-Saharan Africa: A multi-country analysis of survey data. *PLoS Med.* **2017**, *14*, e1002234. [CrossRef] [PubMed]
54. Dickinson, K.L.; Randell, H.F.; Kramer, R.A.; Shayo, E.H. Socio-economic status and malaria-related outcomes in Mvomero District, Tanzania. *Glob. Public Health* **2012**, *7*, 384–399. [CrossRef] [PubMed]
55. Novignon, J.; Nonvignon, J. Socioeconomic status and the prevalence of fever in children under age five: Evidence from four sub-Saharan African countries. *BMC Res. Notes* **2012**, *5*, 380. [CrossRef] [PubMed]
56. Wiseman, V.; Mcelroy, B.; Conteh, L.; Stevens, W. Malaria prevention in The Gambia: Patterns of expenditure and determinants of demand at the household level. *Trop. Med. Int. Health* **2006**, *11*, 419–431. [CrossRef]
57. Romay-Barja, M.; Cano, J.; Ncogo, P.; Nseng, G.; Santana-Morales, M.A.; Valladares, B.; Riloha, M.; Benito, A. Determinants of delay in malaria care-seeking behaviour for children 15 years and under in Bata district, Equatorial Guinea. *Malar. J.* **2016**, *15*, 187. [CrossRef]
58. Hartung, C.; Anokwa, Y.; Brunette, W.; Lerel, A.; Tseng, C.; Boriello, G. Open Data Kit: Tools to Build Information Services for Developing Regions. Information and Communication Technologies and Development (ICTD). 2010. London, UK. Available online: http://opendatakit.org/wp-content/uploads/2010/10/ODKPaper-ICTD-2010.pdf (accessed on 11 December 2021).
59. Rudasingwa, G.; Cho, S.-I. Determinants of the persistence of malaria in Rwanda. *Malar. J.* **2020**, *19*, 36. [CrossRef]
60. Habyarimana, F.; Ramroop, S. Prevalence and risk factors associated with malaria among children aged six months to 14 years old in Rwanda: Evidence from 2017 Rwanda malaria indicator survey. *Int. J. Environ. Res. Public Health* **2020**, *17*, 7975. [CrossRef]
61. United States Agency for International Development. *Rwanda: Malaria Operational Plan FY 2016 (President's Malaria Initiative)*; Penny Hill Press: Damascus, MD, USA, 2016.
62. Kateera, F.; Ingabire, C.M.; Hakizimana, E.; Karinda, P.; Mens, P.F.; Grobusch, M.P.; Mutesa, L.; van Vugt, M. Malaria, anaemia and under-nutrition: Three frequently co-existing conditions among preschool children in rural Rwanda. *Malar. J.* **2015**, *14*, 440. [CrossRef]
63. Alkire, S.; Santos, M.E. Measuring acute poverty in the developing world: Robustness and scope of the multidimensional poverty index. *World Dev.* **2014**, *59*, 251–274. [CrossRef]
64. Sabates-Wheeler, R.; Yates, S.; Wylde, E.; Gatsinzi, J. Challenges of measuring graduation in Rwanda. *IDS Bull.* **2015**, *46*, 103–114. [CrossRef]
65. Owoeye, D.O.; Akinyemi, J.O.; Yusuf, O.B. Decomposition of changes in malaria prevalence amongst under-five children in Nigeria. *MalariaWorld J.* **2018**, *9*, 1–6.
66. Stoler, J.; Awandare, G.A. Febrile illness diagnostics and the malaria-industrial complex: A socio-environmental perspective. *BMC Infect. Dis.* **2016**, *16*, 683. [CrossRef] [PubMed]
67. Alemu, S.H.; van Kempen, L.; Ruben, R. The long shadow of faith-based social networks on agricultural performance: Evidence from Ethiopian apple growers. *Eur. J. Dev. Res.* **2018**, *30*, 297–319. [CrossRef]
68. Yé, Y.; Kyobutungi, C.; Louis, V.R.; Sauerborn, R. Micro-epidemiology of Plasmodium falciparum malaria: Is there any difference in transmission risk between neighbouring villages? *Malar. J.* **2007**, *6*, 46. [CrossRef]
69. Weatherspoon, D.D.; Miller, S.; Ngabitsinze, J.C.; Weatherspoon, L.J.; Oehmke, J.F. Stunting, food security, markets and food policy in Rwanda. *BMC Public Health* **2019**, *19*, 882. [CrossRef]
70. Rulisa, A.; van Kempen, L.; Mutesa, L.; Hakizimana, E.; Ingabire, C.M.; Kateera, F.; Koenraadt, C.J.M.; van Vugt, M.; van den Borne, B. Willingness to contribute to bio-larviciding in the fight against malaria: A contingent valuation study among rice farmers in Rwanda. *Int. J. Environ. Res. Public Health* **2021**, *18*, 11575. [CrossRef]
71. Crookston, B.T.; Schott, W.; Cueto, S.; Dearden, K.A.; Engle, P.; Georgiadis, A.; Lundeen, E.A.; Penny, M.E.; Stein, A.D.; Behrman, J.R. Postinfancy growth, schooling, and cognitive achievement: Young lives. *Am. J. Clin. Nutr.* **2013**, *98*, 1555–1563. [CrossRef]
72. Unger, H.W.; Ashorn, P.; Cates, J.E.; Dewey, K.G.; Rogerson, S.J. Undernutrition and malaria in pregnancy—A dangerous dyad? *BMC Med.* **2016**, *14*, 142. [CrossRef]
73. Fink, G.; Venkataramani, A.S.; Zanolini, A. Early life adversity, biological adaptation, and human capital: Evidence from an interrupted malaria control program in Zambia. *J. Health Econ.* **2021**, *80*, 102532. [CrossRef] [PubMed]
74. Chapman, A.; Darby, S. Evaluating sustainable adaptation strategies for vulnerable mega-deltas using system dynamics modelling: Rice agriculture in the Mekong Delta's an Giang Province, Vietnam. *Sci. Total Environ.* **2016**, *559*, 326–338. [CrossRef] [PubMed]
75. Bhumiratana, A.; Intarapuk, A.; Sorosjinda-Nunthawarasilp, P.; Maneekan, P.; Koyadun, S. Border malaria associated with multidrug resistance on Thailand-Myanmar and Thailand-Cambodia borders: Transmission dynamic, vulnerability, and surveillance. *Biomed Res. Int.* **2013**, *2013*, 363417. [CrossRef]
76. Sheahan, M.; Barrett, C.B.; Goldvale, C. *The Unintended Consequences of Agricultural Input Intensification: Human Health Implications of Agro-Chemical Use in Sub-Saharan Africa*; African Development Bank Working Paper 234; African Development Bank: Abidjan, Côte d'Ivoire, 2016.
77. Mrema, E.J.; Ngowi, A.V.; Kishinhi, S.S.; Mamuya, S.H. Pesticide exposure and health problems among female horticulture workers in Tanzania. *Environ. Health Insights* **2017**, *11*, 1178630217715237. [CrossRef]
78. Mora, A.M.; Hoppin, J.A.; Córdoba, L.; Cano, J.C.; Soto-Martínez, M.; Eskenazi, B.; Lindh, C.H.; van Wendel de Joode, B. Prenatal pesticide exposure and respiratory health outcomes in the first year of life: Results from the infants' Environmental Health (ISA) study. *Int. J. Hyg. Environ. Health* **2020**, *225*, 113474. [CrossRef]

79. Galactionova, K.; Smith, T.A.; de Savigny, D.; Penny, M.A. State of inequality in malaria intervention coverage in sub-Saharan African countries. *BMC Med.* **2017**, *15*, 185. [CrossRef] [PubMed]
80. Makate, C.; Makate, M.; Mango, N. Wealth-related inequalities in adoption of drought-tolerant maize and conservation agriculture in Zimbabwe. *Food Secur.* **2019**, *11*, 881–896. [CrossRef]