The effect of an integrated multisector model for achieving the Millennium Development Goals and improving child survival in rural sub-Saharan Africa: a non-randomised controlled assessment

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Summary

Background **Simultaneously addressing multiple Millennium Development Goals (MDGs) has the potential to complement essential health interventions to accelerate gains in child survival. The Millennium Villages project is an integrated multisector approach to rural development operating across diverse sub-Saharan African sites. Our aim was to assess the effects of the project on MDG-related outcomes including child mortality 3 years after implementation and compare these changes to local comparison data.**

Methods **Village sites averaging 35 000 people were selected from rural areas across diverse agroecological zones with high baseline levels of poverty and undernutrition. Starting in 2006, simultaneous investments were made in agriculture, the environment, business development, education, infrastructure, and health in partnership with communities and local governments at an annual projected cost of US$120 per person. We assessed MDG-related progress by monitoring changes 3 years after implementation across Millenium Village sites in nine countries. The primary outcome was the mortality rate of children younger than 5 years of age. To assess plausibility and attribution, we compared changes to reference data gathered from matched randomly selected comparison sites for the mortality rate of children younger than 5 years of age. Analyses were done on a per-protocol basis. This trial is registered with ClinicalTrials.gov, number NCT01125618.**

Findings **Baseline levels of MDG-related spending averaged $27 per head, increasing to $116 by year 3 of which $25 was spent on health. After 3 years, reductions in poverty, food insecurity, stunting, and malaria parasitaemia were reported across nine Millennium Village sites. Access to improved water and sanitation increased, along with coverage for many maternal-child health interventions. Mortality rates in children younger than 5 years of age decreased by 22% in Millennium Village sites relative to baseline (absolute decrease 25 deaths per 1000 livebirths, p=0·015) and 32% relative to matched comparison sites (30 deaths per 1000 livebirths, p=0·033).**

Interpretation **An integrated multisector approach for addressing the MDGs can produce rapid declines in child mortality in the first 3 years of a long-term effort in rural sub-Saharan Africa.**

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Introduction

At the UN Millennium Summit in September, 2000, world leaders adopted the Millennium Declaration, committing their nations to a new global partnership to reduce extreme poverty and address a series of time-bound health and development targets.[1] Among these Millennium Development Goals (MDG) was a pledge to reduce child mortality by two-thirds between 1990 and 2015.

Despite the priority placed on child mortality within the MDG framework, an estimated 7·6 million children die every year.[2] While important gains have been made in several settings,[3] progress in sub-Saharan Africa has been slow with mortality rates 20 times higher than industrialised countries and about an eighth of children dying before the age of 5 years.[2]

Over two-thirds of child deaths are preventable through the delivery of effective and low-cost health interventions.[4] The integrated delivery of these interventions has been suggested to be among the most effective strategies for improving child survival.[5,6] Although several large-scale health-sector initiatives to support these efforts have been introduced in sub-Saharan Africa,[7–9] many important challenges remain. Weak and deeply underfinanced health systems,[10] frequent shortages of medicine and health workers, absence of a supportive policy environment,[8] an over-emphasis on facility-based service provision,[7] and access barriers such as user-fees remain crucial obstacles to achieving universal coverage.[11] While coverage is improving for interventions such as vitamin A or

immunisations that can be delivered through single contacts with health services, persistent challenges remain in areas requiring ongoing engagement with well-functioning systems, or where behavioural and social changes influence uptake—such as appropriate infant feeding or modern contraceptive use.[12,13]

Equally important, however, has been the uneven progress in addressing wider social and economic targets articulated in the MDG framework.[14] Poverty and food insecurity, low levels of education, the absence of basic infrastructure, and persistent gender inequalities continue to undermine gains in child survival.[5,15] While addressing these simultaneous and overlapping vulnerabilities has theoretical appeal, the design and testing of programmes that work across sectors to achieve the MDGs has thus far been limited.

The Millennium Villages project is a 10-year initiative supporting the integrated delivery of a package of scientifically proven interventions with the central aim of achieving the MDGs across diverse sub-Saharan African sites.[16,17] Local partnerships between the project, communities, and governments coordinate activities across many sectors including health, agriculture, the environment, business development, education, and infrastructure. Sites are based in rural areas where MDG-related progress has been insufficient, representing a range of agroecological zones with corresponding challenges to income, food production, disease ecology, infrastructure, and health-system development.[16] Project spending is informed by estimates from the UN Millennium Project suggesting the MDGs can be achieved with sustained annual investments of about US$120 per person ($140, 2008) across all sectors and $40 for health ($47, 2008).[18] We aimed to assess progress towards the MDGs and child survival over the project's first 3 years and compare these changes to local trends.

Methods

Study design and setting

This study was done between 2006 and 2010 in Millennium Village sites in nine sub-Saharan African countries (figure 1). Sites represent contiguous villages, with populations averaging 35 000 people, and were selected on the basis of several criteria. First, all villages were so-called hunger hot-spots with at least 20% of children younger than 5 years of age malnourished.[19] Second, sites were chosen to represent the agroecological zones characterising more than 90% of farming systems on the continent.[20] Third, the project was undertaken in countries where national governments are committed to partnering with the initiative and with the MDGs more broadly.

A core set of interventions for achieving the MDGs have been identified by the UN Millennium Project.[18] These interventions were adapted and flexibly implemented in response to local conditions after consultation with governments and local communities.[16,17] The main components of the Millennium Village model and the sequence of interventions are shown in figure 2.

In the health sector, basic services were often unavailable at baseline, requiring major investments in infrastructure and staffing. Governments were core partners and remained responsible for employing local professional staff and managing facilities and supply chains. To reduce access barriers, free primary health care was made available at nearly all sites as even modest co-payments can restrict access among the poorest.[21] An evidence-based package of maternal–child health interventions was introduced in line with national and WHO guidelines.

In agriculture, improved seeds and fertilisers were subsidised to support high-yielding crop varieties alongside farmer training on best agronomic practices. Interventions in education included upgrading buildings and classrooms, making learning materials available, recruiting qualified teachers, and providing school meals. Finally, these efforts were combined with investments in basic infrastructure to enhance access to improved drinking water and sanitation, upgrade local roads, promote partnerships to expand mobile-phone coverage, and improve facility access to grid and solar electricity.

The study design was approved by ethical review committees at Columbia University, New York, USA, and by all governments of host countries. Community consent was obtained before every survey round and individual informed consent was obtained for all interviews and when biological specimens were collected.

Procedures

To assess MDG-related spending, we examined the financial records of the Milliennium Villages project, interviewed district government representatives, valued in-kind contributions of materials and human resources from external partners, and estimated material and labour contributions from local communities. Non-amortised costs were generated by sector and stakeholder at baseline and for the first 3 years of the project in eight of the nine countries. We reported baseline spending relative to year 3, which approximates an annual steady-state given low levels of disbursement in the first project year. Costs were reported in 2008 US dollars and prices for in-kind contributions were documented with standard imputation methods for multicentre interventions.[22]

To measure progress towards child mortality and MDG-related outcomes, assessment rounds were done at baseline (2006–07) and after 3 years (2009–10). Within each site, intervention delivery commenced with about 1000 households before subsequent expansion to a wider area, representing the target population for longitudinal assessment.

A population census was undertaken at baseline to establish sampling frames, after which 300 households were selected at random and proportionally sampled from strata defined by subvillage, wealth category, and sex of the household head. Sample size was determined

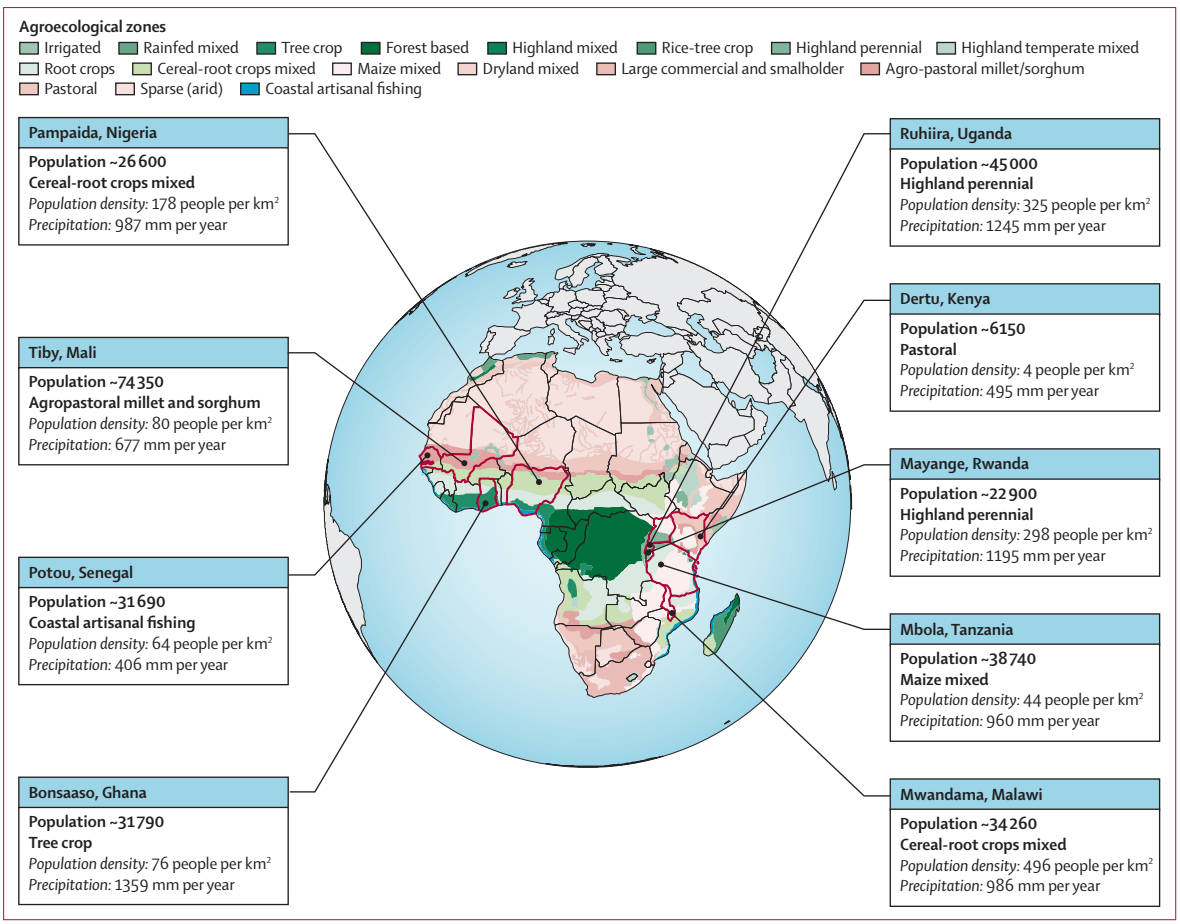

Figure 1: **African Millennium Village project study sites**

on the basis of the ability to detect changes across a range of MDG outcomes, including a 40% reduction in mortality rate in children younger than 5 years of age assuming an intracluster correlation coefficient of 0·02 and 200 births per site. Assessments were done during preharvest periods. To maintain the sample size, households lost to attrition were replaced with households from the same baseline strata.

Local comparison village sites were introduced in the third study year to enhance the plausibility that recorded changes were the result of intervention exposure.[23] Sites were selected at random from up to three candidates matched on village-level parameters with the potential to influence child mortality and MDG outcomes. Efforts were made to ensure adequate distance between Millennium Village sites and comparison sites to minimise spillover effects (average distance 40 km). The same sampling strategy was used for the comparison villages, which were assessed on all outcomes at entry into the study.

At each assessment round a household survey was administered to gather information on demographic characteristics, education, employment, bednet usage, land ownership, agriculture, food security, assets, and access to basic services including water, sanitation, energy, transport, and communication. An adult survey was administered to all individuals aged 15–49 years to examine health-related MDGs, nutrition, and common causes of child mortality. A section on women's reproductive history provides dates of birth for all children and the survival status of each, which is used to calculate the mortality rate in children younger than 5 years of age. Indicator definitions were derived from standard MDG assessment guidelines.[24]

To assess malaria parasitaemia, thick and thin peripheral blood smears were collected from eligible participants. Smears were read by experienced microscopists in local laboratories at baseline and in a research laboratory in Addis Ababa, Ethiopia, in year 3, using best-practice techniques.[25]

Anthropometric data for children younger than 5 years of age were assessed using standard protocols.[26] Recumbent length of children (0–24 months) was read twice to the nearest 0·1 cm on wooden length boards or mats with sliding head blocks (Shorr Productions, Woonsocket, RI, USA). Anthropometric indices were calculated using

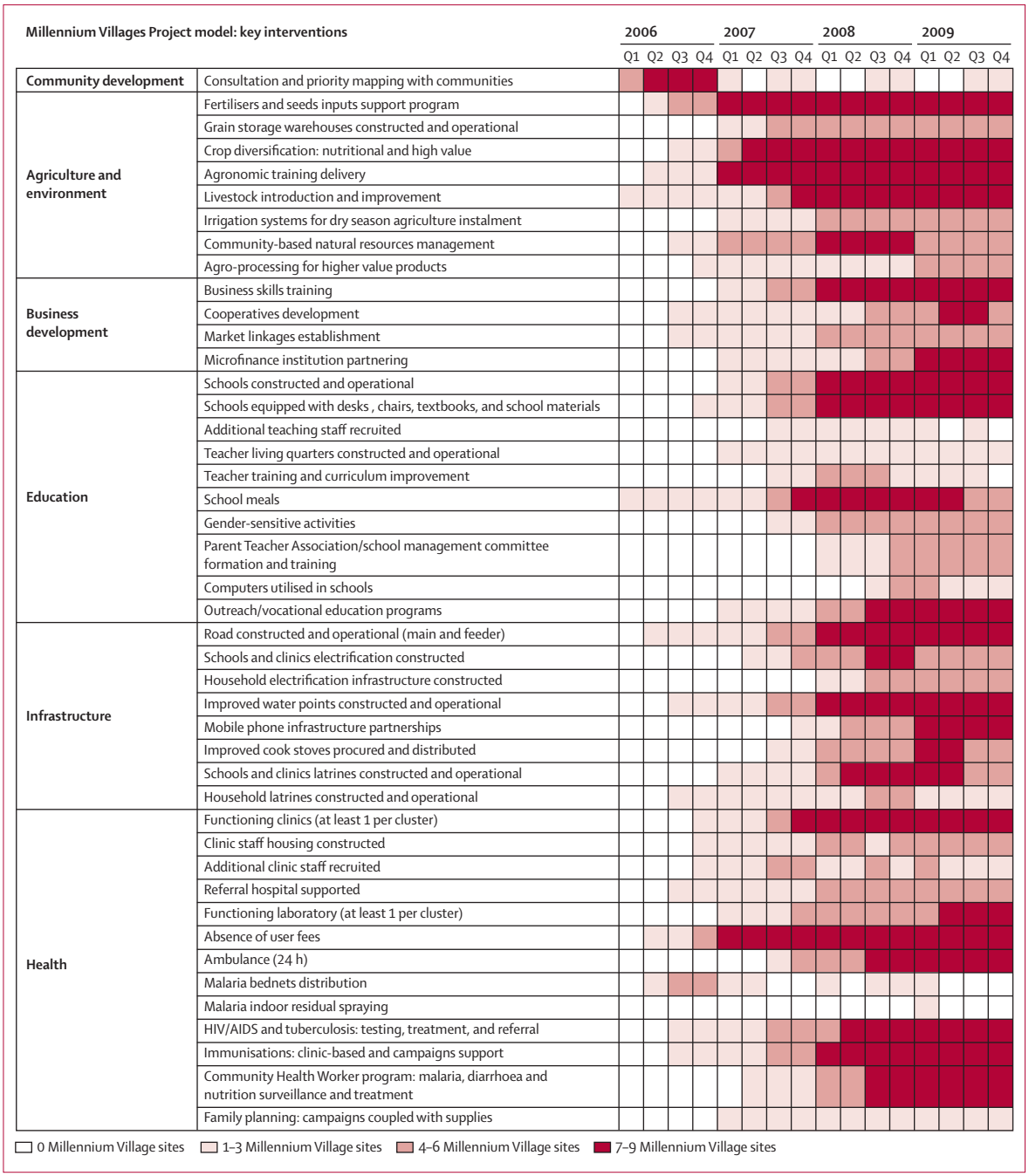

Figure 2: **Millennium Villages project: intervention activity time line (nine sites)**

growth references with extreme *Z*-scores excluded.[27] At year 3, greater efforts were made to ensure all children aged younger than 5 years from sampled households were assessed, resulting in an increase in sample size for anthropometric indicators.

Survey data were gathered by enumerators who underwent 3 weeks of field training. At each site, the same teams oversaw data collection at baseline and year 3, as well as the enumeration of Millennium Village and comparison village sites. Masking of enumerators to the intervention was not feasible. Survey data were double entered using CSPro (version 3.3) and cleaned for structural and logical errors in both CSPro and Stata (version 10).

The primary study outcome, child mortality, is expressed as the mortality rate in children younger than 5 years of age—defined as the probability of a child born in a specified year dying before reaching the age of 5 years subject to current age-specific mortality rates. A range of secondary

outcomes were prespecified on the basis of effect pathways outlined in the study protocol (appendix p 1).

Birth-related outcomes were derived from the reproductive histories of female respondents at year 3. Birth histories were used to retrospectively calculate birth-related outcomes for the period before and after the start of the intervention in Millennium Village and comparison village sites. For the mortality rate in children younger than 5 years of age, the preintervention period includes the 5-year period before programme implementation, whereas the postintervention period spanned the first 3 years of the project. For pregnancy-related outcomes, the postintervention period included births in the third year of implementation. All postintervention child-related outcomes were age-constrained and non-overlapping with the preintervention period. Finally, survey methods enumerated up to three births for skilled birth attendance but only the most recent birth for antenatal and postnatal outcomes, resulting in variability for these denominators.

Household wealth was estimated through an asset index whereby the first principal component was extracted from eight indicators of whether or not a household owns a given asset at the time of data collection (year 3) and 3 years before (baseline).

All other outcomes were presented for baseline and year 3 in the Millennium Village sites, and for year 3 in the comparison village sites. Some outcomes—such as the nutrition indicators—are defined for age-specific groups (ie, children younger than 2 years of age) to capture the effect of the intervention on children conceived or born since the start of the intervention.

In Millennium Village sites, progress towards the MDGs was assessed on the basis of changes from baseline to 3 years after programme initiation. To assess changes relative to comparison village sites, various strategies were used. For birth-related outcomes, a difference-in-differences approach was used to assess whether changes over time in Millenium Village sites were significantly greater than comparison village sites. For all other outcomes, when comparison village baseline levels were unavailable, effects were assessed by comparing year 3 outcomes between Millennium Village and comparison village sites.

A multilevel regression model was used to account for the clustering of observations within sites, and to adjust for between-group and between-period differences in the recorded characteristics of households and individuals. The analysis adjusted for differences in the sex of the household head, whether the household's main livelihood strategy was farming, and whether the household head had schooling. For birth-related outcomes, estimates were also adjusted for the mother's age at birth, birth order of the child, and child sex; for child outcomes, we also controlled for child sex and age. To maximise the number of observations in the analysis, missing values for covariates were imputed using the dummy variable approach,[28] with the percentage of cases with missing data not exceeding 11%. The analyses are also adjusted for site pairing to account for the study design. Logistic regression was used for binary outcomes. Two indicators—the mortality rate in children younger than 5 years of age and the survival rate to the last grade of primary education—were estimated using a discrete time survival analysis, on the basis of probabilities of event occurrence (death or promotion to the next grade) for different time categories.[29] Significance was assessed using a *T* test. Cases with missing data on the outcome measure were excluded from the analysis.

All analyses were done on a per-protocol basis. The outcome of antimalarial treatment for children younger than 5 years of age was excluded because new WHO guidelines for rapid testing and treatment at the household level invalidate questions used to construct this indicator.[30] Questions on exclusive breastfeeding, the introduction of complementary feeding, and appropriate pneumonia treatment were not captured in our year 3 assessments. Analysis of malaria parasitaemia excluded one site (Rwanda) because of missing data. Reports adhered to the guidelines for *Transparent Reporting of Evaluations with Nonrandomized Designs (TREND)*.[31] Statistical analyses were done with SAS (version 9.2). Additional details on statistical models are shown in appendix pp 9–18.

The study protocol is registered with ClinicalTrials.gov, number NCT01125618.

See Online for appendix

Role of the funding source

The sponsor of the study had no role in study design, data collection, data analysis, data interpretation, or writing of the report. PMP had full access to all the data

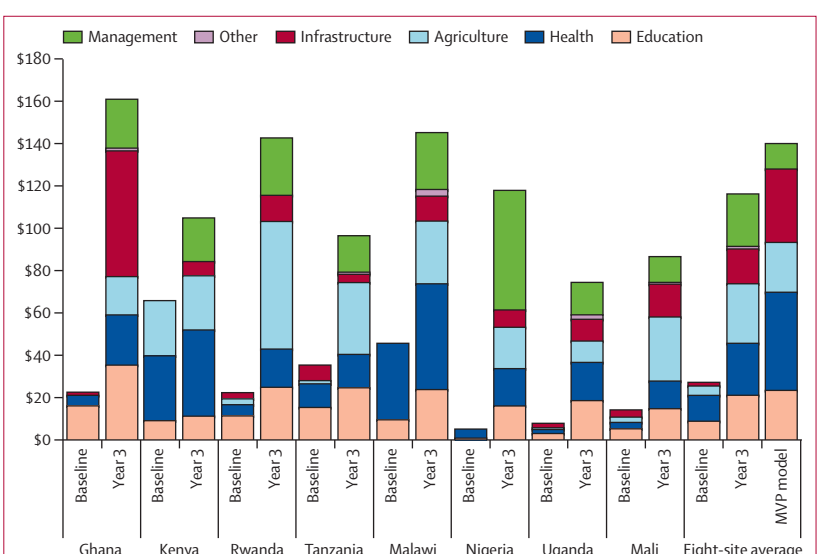

***Figure 3*: Non-amortised spending on Millennium Development Goals per head by sector, constant 2008 US dollars (eight sites, all stakeholders)**
MVP=Millennium Villages project.

	Millennium Village sites (N=9)	Comparison village sites (N=9)
Village characteristics (at Year 0)		
Land area (km²)	133·2 (102·2 to 164·1)	128·2 (97·2 to 159·1)
Number of sites with electricity	0·0%*	0·0%*
Number of sites with cellular coverage	78% (39 to 95)	78% (39 to 95)
Distance to nearest main town (km)	11·9 (8 to 15·8)	12·6 (8·7 to 16·5)
Distance from centre of village to nearest paved road (km)	14·8 (0·8 to 28·7)	14·5 (0·5 to 28·4)
Number of months road not accessible to vehicles	2·3 (2·0 to 2·7)	2·5 (2·2 to 2·8)
Distance to clinic (km)	5·6 (1·8 to 9·5)	10·2 (6·3 to 14·1)
Number of NGOs or partners per site	1·3 (0·8 to 1·9)	1·4 (0·9 to 2)
Number of facilities per 10 000 people		
Markets	0·7 (–0·4 to 1·7)	1·4 (0·4 to 2·5)
Primary schools	5·6 (–0·4 to 11·5)	8·6 (2·6 to 14·5)
Secondary schools	0·0*	0·0*
Clinics	0·7 (–0·8 to 2·1)	1·3 (–0·1 to 2·7)
Number of sites that have no irrigation of cultivatable land	33·3% (10·0 to 69·1)	33·3% (10·0 to 69·1)
Religion (% of population that is Christian)	47% (32·7 to 61·4)	38% (23·4 to 52·1)
Characteristics of households (at year 3)		
Household head has no primary education	87·1% (83·1 to 90·3)	87·9% (84·1 to 90·9)
Household head is a woman	14·3% (10·2 to 19·7)	11·3% (7·9 to 16)
Household head's main livelihood strategy is farming	81·9% (77·2 to 85·9)	85·1% (80·9 to 88·5)
Household size	7·1 (5·7 to 8·6)	5·9 (4·5 to 7·3)
Dependency ratio	138·2 (132·6 to 143·7)	131·9 (126·3 to 137·4)
Age of adult female household members	33·0 (32·3 to 33·8)	31·9 (31·1 to 32·7)
Baseline outcomes (at year 0)		
Asset-based wealth index	41·0 (38·3 to 43·7)	39·0 (36·4 to 41·7)
Skilled birth attendance	32·6% (26·6 to 39·1)	25·9% (20·7 to 31·8)
Access to antenatal care	45·3% (29 to 62·8)	46·0% (29·5 to 63·4)
Mortality rate in children younger 5 years of age	113 (99 to 128)	90 (77 to 103)

Data are mean (95% CI). Information on village infrastructure is from the village matching checklist. The characteristics of households are from the year-3 household survey. Baseline outcomes are calculated on the basis of reproductive and pregnancy histories collected from women at year 3. The asset-based wealth index is scaled to have a mean of 50 (SD 25). *Interval has zero width because there is no variance in this characteristic across sites.

Table 1: **Characteristics of Millennium Villages and comparison villages**

in the study and had final responsibility for the decision to submit for publication.

Results

One site (Ikaram, Nigeria) in the study was lost to evaluation after being absorbed by a separate government programme (the Nigerian Conditional Grants Scheme), with nine of the original ten site pairs included in the final analysis. Response rates at year 3 were comparable between intervention and comparison sites although more adult women were interviewed in comparison sites (2592 [78%] of 3310 in Millennium Villages *vs* 2825 [87%] of 3244 in comparison villages).

Baseline levels of government, non-governmental organisation, and community spending on MDG-related activities were estimated at $27 per head (figure 3). Average annual spending per head at project year 3 was about $116, of which $25 was spent on health—somewhat below original projections and in-line with the $43 average heath expenditure per head for countries included in this study (appendix p 2). Half of spending was derived from the project, with the remainder from local governments (30%), non-project stakeholders (14%), and local communities (6%). Major activities in each sector are summarised in figure 2.

No significant differences in baseline characteristics between Millennium Villages and comparison villages were reported for village, household, or individual characteristics (table 1). The mortality rates in children younger than 5 years of age before the intervention were higher in the Millennium Villages than in the comparison villages (p=0·020; table 1). Site level differences are shown in appendix p 3.

Within the intervention sites, 2627 (97%) households were successfully interviewed at baseline. Between baseline and year 3, 306 (12%) households were lost to follow up and replaced with 298 households from the same baseline strata. An additional 77 households were replaced at random to retain a sample of about 300 households per Millennium Village site. In total, 2617 (97%) of households were successfully interviewed at year 3 (appendix p 8).

At follow-up, adjusted point estimates of effect for 15 of 17 indicators changed in the postulated direction with significant differences for 13 outcomes (table 2). Reductions in household poverty, food insecurity, and stunting were reported. For child health services, improvements were made in access to measles immunisation, postnatal checks for neonates, and diarrhoea prevalence decreased. Large increases in coverage with skilled birth attendance and access to improved water and sanitation were reported. For MDG 6, levels of antenatal HIV testing and bednet use improved, and prevalence of *Plasmodium falciparum* was reduced from 19% to 3%. After 3 years, the mortality rate in children younger than 5 years of age was reduced by 25 deaths per 1000 livebirths, or 22% relative to baseline (p=0·015). No changes were reported in access to antenatal care, or rates of wasting in children and underweight children younger than 2 years of age. Site-specific data shows mortality reductions in eight of nine sites (appendix p 7). For site specific changes in secondary outcomes, the most consistent improvements were reported for economic and nutritional outcomes, skilled birth attendance, bednet use, malaria, and access to improved water and sanitation (appendix p 6). As a sensitivity analysis, households lost to attrition in year 3 were dropped from the longitudinal assessment; this does not appreciably affect estimates of change over time with the exception of the stunting outcome. Unadjusted results were similar in magnitude to adjusted results (appendix pp 4–5).

Study outcomes in comparison villages were assessed at year 3 for 2703 (94%) of eligible households. The

	Observational unit	Millennium Village sites (N=9)				Comparison village sites (N=9)				Millennium Villages *vs* comparison villages in year 3	
		Year 0 (number)	Year 3 (number)	Absolute change (95% CI)	p value	Year 0 (number)	Year 3 (number)	Absolute change (95% CI)	p value	Absolute difference (95% CI)	p value
MDG 1: poverty and nutrition											
Asset-based wealth index	Household*	41·0% (2617)	60·3% (2617)	19·3 (18·1 to 20·5)	<0·0001	39·0% (2699)	59·5% (2699)	20·5 (19·3 to 21·6)	<0·0001	–1·2% (–2·8 to 0·4)†	0·140
Food insecurity	Household‡	68·8% (2627)	40·1% (2617)	–28·7% (–31·7 to –25·6)	<0·0001	..	58·0% (2703)	..	..	–17·9% (–36·4 to 0·6)§	0·057
Wasting	Children younger than 2 years of age‡	6·4% (271)	5·5% (644)	–0·9% (–4·1 to 2·4)	0·591	..	6·7% (776)	..	..	–1·2% (–6·5 to 4·2)§	0·630
Underweight	Children younger than 2 years of age‡	13·1% (279)	14·3% (660)	1·2% (–4·2 to 6·6)	0·669	..	16·1% (803)	..	..	–1·8% (–8·9 to 5·4)§	0·584
Stunting	Children younger than 2 years of age‡	36·0% (255)	28·2% (709)	–7·9% (–15·6 to –0·2)	0·045	..	35·7% (784)	..	..	–7·5% (–20·0 to 5·0)§	0·205
MDG 2: primary education											
Primary education survival rate	Children ever enrolled in primary school	..	39·7% (3049)	..	..	..	51·3% (2450)	..	..	–11·6% (–27·1 to 3·9)§	0·140
MDG 4: child health											
Diarrhoea prevalence	Children younger than 5 years of age‡	19·5% (1572)	16·4% (2115)	–3·1% (–5·7 to –0·5)	0·018	..	15·6% (2094)	..	..	0·8% (–9·4 to 11·0)§	0·868
Diarrhoea treatment	Children younger than 5 years of age‡	59·1% (385)	60·6% (431)	1·5% (–6·3 to 9·4)	0·700	..	51·1% (412)	..	..	9·5% (–0·9 to 20·0)§	0·067
Measles immunisation	Children 1 year of age‡	72·9% (280)	92·0% (351)	19·1% (12·7 to 25·6)	<0·0001	..	92·2% (396)	..	..	–0·2% (–9·7 to 9·3)§	0·970
Postnatal check	Births*	6·9% (194)	14·3% (460)	7·4% (1·9 to 12·9)	0·010	7·5% (191)	12·7% (444)	5·2% (–0·2 to 10·5)	0·057	2·2% (–6·2 to 10·6)†	0·598
MDG 5: maternal health											
Access to antenatal care	Births*	45·3% (194)	41·5% (460)	–3·8% (–13·3 to 5·6)	0·422	46·0% (191)	40·3% (443)	–5·7% (–15·2 to 3·7)	0·230	1·9% (–11·3 to 15·1)†	0.773
Skilled birth attendance	Births*	32·6% (685)	57·2% (483)	24·7% (18 to 31·4)	<0·0001	25·9% (693)	38·6% (472)	12·7% (6·6 to 18·7)	<0·0001	12% (1·1 to 22·9)†	0·032
MDG 6: HIV, tuberculosis, and malaria											
Antenatal HIV testing	Births*	28·8% (189)	70·1% (453)	41·3% (29·6 to 52·9)	<0·0001	24·0% (187)	53·1% (439)	29·1% (18 to 40·3)	<0·0001	12·1% (–5·6 to 29·9)†	0·175
Bednet use	Children younger than 5 years of age‡	7·6% (3330)	43·2% (3018)	35·6% (33·2 to 38·1)	<0·0001	..	6·5% (2629)	..	..	36·7% (24·0 to 49·4)§	0·0002
Malaria prevalence	Children younger than 5 years of age‡	18·8% (1014)	2·7% (1652)	–16·1% (–18·7 to –13·6)	<0·0001	..	7·4% (1780)	..	..	–4·7% (–8·8 to –0·72)§	0·027
MDG 7: environmental health											
Access to improved water	Household‡	12·7% (2624)	77·4% (2617)	64·6% (60·7 to 68·6)	<0·0001	..	37·8% (2703)	..	..	39·5% (–5·7 to 84·7)§	0·078
Access to improved sanitation	Household‡	1·9% (2557)	28·6% (2617)	26·8% (24·6 to 29·0)	<0·0001	..	15·8% (2703)	..	..	12·9% (1·3 to 24·5)§	0·033
Mortality rate in children younger than 5 years of age (deaths per 1000 births)	Children younger than 5 years of age*	113·3 (5336)	88·7 (4905)	–24·6 (–44·5 to –4·8)	0·015	90·3 (4093)	96·2 (3933)	5·9 (–13·8 to 25·7)	0·556	–30·5 (–58·5 to –2·5)†	0·033

The asset index is scaled to have a mean of 50 (SD 25). Malaria results are based on eight of nine site pairs; one pair of sites is excluded because data were unavailable. Estimates are regression-adjusted for household and respondent characteristics. Rounding could have caused slight discrepancies in calculating differences. *Year-0 value is based on recall items in the year 3 survey (eg, women's reproductive histories). †Difference between Millennium Village and comparison village sites in year 3, minus the preintervention difference between groups for the relevant indicator in year 0 (ie, Millennium Village–comparison village difference in year 3 adjusted for baseline difference). ‡Year-0 value is from the baseline survey administered at the Millennium Village sites. §Difference between Millennium Village and comparison village sites in year 3.

Table 2: **Study outcomes in Millennium Village intervention sites and comparison village sites**

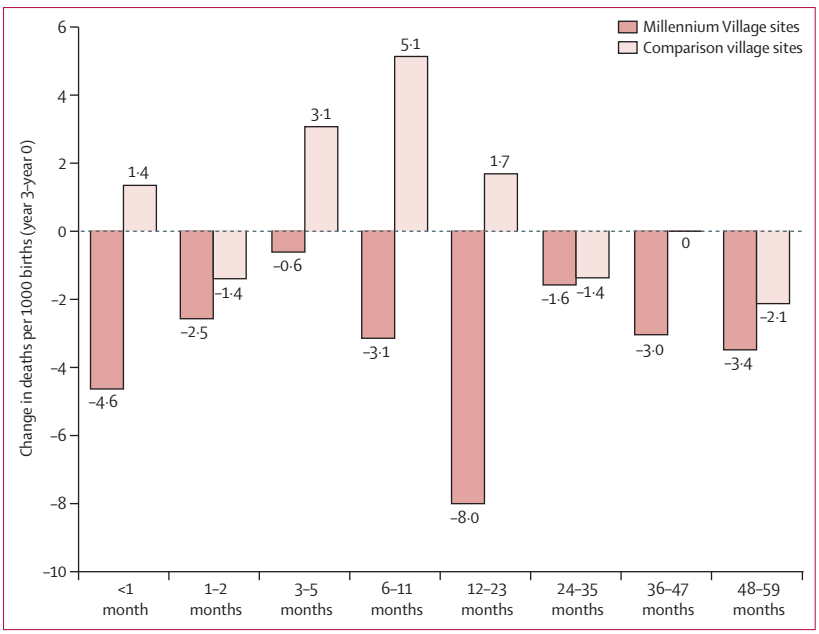

Figure 4: **Absolute change in the mortality rate of children younger than 5 years of age from baseline to year 3, by age category**

intracluster correlation was 0·03 for the mortality rate in children younger than 5 years of age, and ranged from 0·01 to 0·49 for other outcomes. For 14 of 18 outcomes, changes occurred in the predicted direction. No significant differences were recorded when comparing poverty, anthropometric outcomes, diarrhoea prevalence, measles immunisation, newborn care, antenatal care, or HIV testing in pregnancy between Millennium Village and comparison clusters.

Relative to comparison villages, significantly higher levels of food security, skilled birth attendance, bednet use, and access to improved sanitation were observed. Malaria parasitaemia was lower in Millennium Village sites. Changes in access to improved water and diarrhoea treatment approached threshold levels (p=0·06–0·10). Relative to comparison sites, mortality rates in children younger than 5 years of age were reduced by 30 deaths per 1000 livebirths, or a 32% relative difference (p=0·033). Site-specific data showed reductions in all Millennium Village sites relative to comparisons sites (appendix p 7).

Although our assessment was not powered to assess changes in neonatal and infant mortality, the greatest reductions were seen in the first month of life, as well as during the 6–23 month age periods (figure 4).

Discussion

This assessment focused on key drivers of child mortality, where progress in sub-Saharan Africa has been slow, and where cross-MDG synergy is crucial. Average levels of MDG-related spending were just $27 per person at baseline, increasing to $116 per person across all sectors by year 3, of which $25 was spent in the health sector, which is in-line with current levels of per-head health expenditure for countries included in this assessment (appendix p 2). 3 years after project initiation, rural sites across nine sub-Saharan African countries had positive shifts in a range of MDG-related outcomes including poverty, food security, and chronic undernutrition; and better coverage with maternal–child health interventions, lower malaria parasitaemia, and improved access to water and sanitation. Finally, child mortality was reduced relative to baseline levels and relative to matched comparison sites (table 2).

As a complex intervention operating across many sectors, definitive statements about the specific mechanisms of mortality reductions are not possible. However, the project placed a strong initial health sector emphasis on so-called quick wins including optimisation of immunisation coverage and bednet distribution to all sleeping sites—with concurrent reductions in malaria parasitaemia. Early efforts to enhance health staffing and facility infrastructure, reduce access barriers such as user-fees, and increase cross-sectoral investments to improve roads, emergency transport, and mobile communication played potentially important parts in improving access to skilled birth attendance. Although our assessment was insufficiently powered to detect changes in newborn mortality, reductions in child deaths in the first month of life are encouraging. In the agricultural sector, the early introduction of fertiliser and improved seeds resulted in a two to three-times increase in staple crop yields,[32] potentially contributing to gains in food security and lower levels in childhood stunting in Millennium Village sites.[33] Finally, major improvements in access to safe water and sanitation might have generated additional synergies.

Health-sector challenges existed in the project's first 3 years including procurement and supply chain management, improving health-worker performance, and establishing community health-worker programmes. The presence of these challenges was reflected by the absence of major shifts in health-sector outcomes that characterise the continuum-of-care, including diarrhoea case management, antenatal care, and postnatal checks with skilled providers. These factors probably did not make a substantial contribution to mortality reductions in the early phase of this 10-year project. In view of the relatively low starting point for many sites, additional time will likely be needed to optimise systems and fully extend the reach of services to vulnerable households.

For our assessment, we used longitudinal data from project sites in a range of real-world settings to assess changes in intervention coverage and MDG-related outcomes. As random site selection across multiple countries was not feasible, we used a pair-matched design to better understand causality and attribution. We opted for this design recognising that in the context

of continent-wide MDG scale-up, many of the same interventions introduced by the project were simultaneously being implemented by government and NGO partners, which could potentially result in understated intervention effects.[34] Notably, the consistency of findings across diverse implementation contexts could serve to enhance generalisability, as factors such as climate, governance, and economic shifts, which carry the potential to influence MDG-related outcomes, are likely to vary between settings.

The study also had several limitations that are important to underscore. First, with relatively few sites, statistical thresholds were difficult to achieve in the absence of large and consistent effect sizes. Second, the use of historical data from year 3 to calculate preintervention baselines for some indicators could have led to recall bias and underreporting. As the study was undertaken similarly in intervention and comparison groups, this bias would be evenly distributed and result in conservative estimates of programme effects. Third, for a subset of the indicators, regression-to-the mean cannot be ruled out as a factor explaining estimated gains in the Millennium Village sites. This explanation would, however, not influence the estimates of the mortality rate in children younger than 5 years of age, which were based on one round of data collection. Fourth, sampled households were drawn from an initial cluster of 1000 households within each site. While the nature and intensity of the interventions were similar across the site, this sample might not be representative in all cases. Fifth, while political commitment and community ownership were important prerequisites for participation in the programme, we suggest that any large scale development programme is unlikely to succeed in their absence. Finally, spill-over effects between intervention and comparison sites cannot be ruled out, which again would understate intervention effects.

In summary, early results from the Millennium Villages provides encouraging evidence that accelerated progress towards the MDGs with reductions in child mortality can be achieved for a modest cost even in remote rural areas of sub-Saharan Africa (panel). While persistent challenges to child survival remain in much of the region, we suggest that integrated approaches that deliver health-sector inputs alongside broader investments in agriculture, nutrition, environment, and basic infrastructure hold great potential. Finally, as a complex initiative with many simultaneous interventions operating across a range of deeply challenging environments, considerable opportunities for learning remain. Further research to assess the long-term effects of the programme and improve understanding of barriers, facilitators, and synergies to implementation, and the development of methods and systems to scale-up these lessons will be crucial for achieving the MDGs as 2015 approaches.

Panel: Research in context

Systematic review

We searched PubMed and Google scholar for reports published in English between Jan 1, 2001, and Jan 1, 2011, with the search terms "child mortality" and "Africa". We identified no previous reviews or assessments of integrated initiatives that aimed to achieve the full range of MDGs, or of programmes to reduce child mortality by combining health and non-health sector inputs, especially in the African context. There is, however, extensive evidence from systematic reviews supporting the efficacy of a range of discrete, low-cost health and nutrition interventions for improving child survival in low-income settings.[4,35] Additional reviews have examined the effectiveness of systems to integrate and deliver these interventions at the primary care and household level.[6,36] While strategies such as those including community health workers hold great promise, few studies have reported outcomes across the continuum of care or have assessed programmes that work on a large scale. Finally, although a few assessments have attempted to address access barriers and sociocultural factors that influence demand for services, the reduction of user-fees, mass-media campaigns, conditional cash transfers, and community mobilisation have been linked to improvements in child-health outcomes in some settings.[6,36,37]

Interpretation

Our analysis suggests that the integrated delivery of interventions across many sectors is feasible for a modest cost, that substantial progress towards the Millennium Development Goals (MDGs) can be achieved in a relatively short 3-year period, and that the combination of interventions can lead to reductions in child mortality at a pace sufficient to achieve MDG 4 in areas of rural sub-Saharan Africa. Although health-sector interventions such as immunisation and malaria control were potentially important drivers, efforts outside the health sector (agricultural inputs to improve food security and nutrition; interventions to reduce access barriers such as the elimination of user fees and the upgrading of roads, transport, and communication; and basic improvements in water and sanitation) probably contributed to the reported improvement in child survival.

Contributors

CAP and PMP were responsible for study design and interpretation of data. PMP drafted the report. MM and BN contributed to study design and were responsible for data collection and interpretation. M-AS did the statistical analysis. UKH was responsible for implementation research. LM was responsible for economic costing data. CAP coordinated the design and assessment of agricultural interventions. SES, YBA and PS were responsible for the design of the package of health interventions and their implementation. AN and BB were responsible for project implementation and oversight in west and east Africa, respectively. JWM led the management team of the project and contributed to the scientific design. AT oversaw the assessment and implementation of malaria interventions and analysis of malaria specimens. JDS was responsible for the overall project conception, design, and study oversight. All authors contributed to the editing of this report and approved the final version.

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Conflicts of interest

We declare that we have no conflicts of interest.

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