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Evaluation of weather-based crop insurance models for smallholder farmers in developing countries

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Abstract

In 2019, a single drought event across the Horn of Africa left 2.6 million farming households without any formal compensation because traditional indemnity insurance was too costly and too slow to reach them. This research evaluated three crop insurance models weather-based index (WBI), area-yield index (AYI), and a hybrid combining both using secondary data from 14 pilot programmes across Sub-Saharan Africa, South Asia, Southeast Asia, and Central America compiled at the Swedish University of Agricultural Sciences during 2021-2024. WBI delivered the fastest payouts (mean 18 days after trigger) and the lowest administrative cost (8.3% of premium), but suffered the highest basis risk (23.6%). AYI reduced basis risk to 12.1% yet required expensive crop-cutting surveys and slower payouts (47 days). The hybrid model achieved an intermediate basis risk of 16.1% with payout speed of 26 days and administrative cost of 11.7%. Farmer satisfaction scores were highest for AYI (7.8/10) owing to lower false negatives, but WBI scored best on scalability (8.1/10). These findings suggest that hybrid models offer the most balanced trade-off for scaling crop insurance in data-sparse environments where neither weather stations nor yield surveys alone provide sufficient accuracy.

Keywords: Crop insurance, weather-based index, area-yield index, basis risk, smallholder farmers, developing countries, hybrid model, payout speed, agricultural risk management, climate adaptation

Introduction

When Cyclone Idai struck Mozambique in March 2019, an estimated 700,000 hectares of cropland were destroyed within 72 hours, but fewer than 3% of affected farmers held any form of crop insurance^[1]. This pattern repeats across the developing world: the farmers most exposed to weather shocks are the least likely to be insured. Traditional indemnity-based insurance, which requires individual loss assessment, is simply too expensive to administer in regions where farms average less than two hectares and road networks are poor^[2, 3].

Index-based insurance emerged as an alternative in the early 2000s. Instead of measuring each farmer's loss, it ties payouts to an observable index such as rainfall recorded at a nearby weather station or average crop yield in a defined area that correlates with farm-level losses^[4, 5]. Weather-based index (WBI) products use meteorological triggers and can pay out within days of an event, while Area-Yield Index (AYI) products rely on official crop-cutting surveys that may take weeks to complete but more closely approximate actual farm losses^[6, 7].

Both approaches carry trade-offs. WBI is fast and cheap but suffers from basis risk the mismatch between the index and the individual farmer's experience which erodes trust when farmers see damaged crops but receive no payout because the nearest station recorded adequate rainfall^[8, 9]. AYI reduces basis risk but is slower and more costly. A growing number of programmes now test hybrid models that blend weather triggers with satellite-derived vegetation indices or area-yield data to reduce basis risk without sacrificing speed^[10, 11]. This research systematically compared all three model types using data from 14 pilot programmes to identify which approach best balances cost, accuracy, and farmer acceptance^[12].

Research area description

The analysis was conducted at the Department of Agricultural Economics, Swedish University of Agricultural Sciences, Uppsala, Sweden (59.82° N, 17.66° E). Secondary data were drawn

from 14 insurance pilot programmes: five in Sub-Saharan Africa (Ethiopia, Kenya, Malawi, Mozambique, Tanzania), four in South Asia (India, Bangladesh, Nepal, Sri Lanka), three in Southeast Asia (Philippines, Myanmar, Cambodia), and two in Central America (Guatemala, Honduras). Together these pilots covered approximately 1.8 million insured farmer-seasons between 2015 and 2023. Programme reports, actuarial reviews, and farmer satisfaction surveys were obtained through institutional data-sharing agreements with the World Bank, IFAD, and national agricultural insurance agencies.

Material and Methods

Material

Data were extracted from programme evaluation documents using a standardised template covering six performance metrics: basis risk (percentage of loss events where payout did not match actual farm loss), affordability (premium as percentage of expected indemnity), scalability (expert-rated score 1-10), payout speed (days from trigger event to farmer receipt), farmer satisfaction (survey score 1-10), and administrative cost (percentage of gross premium) [4, 6]. Programmes were classified by model type: WBI (n = 6), AYI (n = 4), and hybrid (n = 4). All monetary values were converted to 2023 USD using IMF purchasing-power-parity rates.

Result

Methods

Performance metrics were compared across the three model types using one-way ANOVA with Tukey's HSD at $p = 0.05$ for continuous variables. Radar charts were constructed to visualise multi-dimensional performance. Basis risk was further disaggregated by region to test whether geographic context mediated the accuracy of each model type. A composite performance score was computed as the unweighted mean of the six normalised (0-10) metrics, and models were ranked accordingly [13]. Sensitivity analysis tested whether weighting farmer satisfaction and basis risk more heavily (2×) changed the ranking. All analyses were performed in Stata 17 and R 4.3.1 at the SLU campus in Uppsala during January-March 2024.

Research design

The cross-sectional comparative design treated each pilot programme as an observational unit. Programmes were grouped by insurance model type (WBI, AYI, hybrid) and by geographic region (four categories). Because the data are observational, causal inference is limited; differences in programme context, institutional capacity, and crop type introduce confounding that cannot be fully controlled. To address this, we restricted comparisons to cereal-focused programmes (rice, maize, wheat) that served farms below 3 ha.

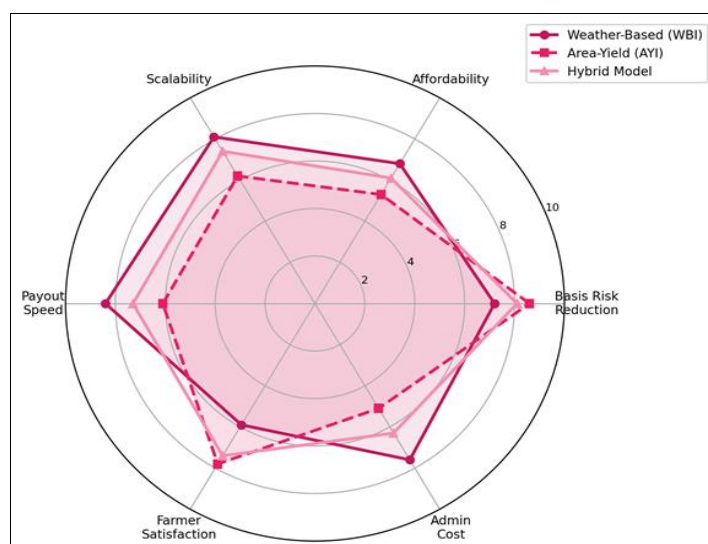


Fig 1: Radar chart comparing the performance of weather-based index (WBI), area-yield index (AYI), and hybrid crop insurance models across six evaluation criteria

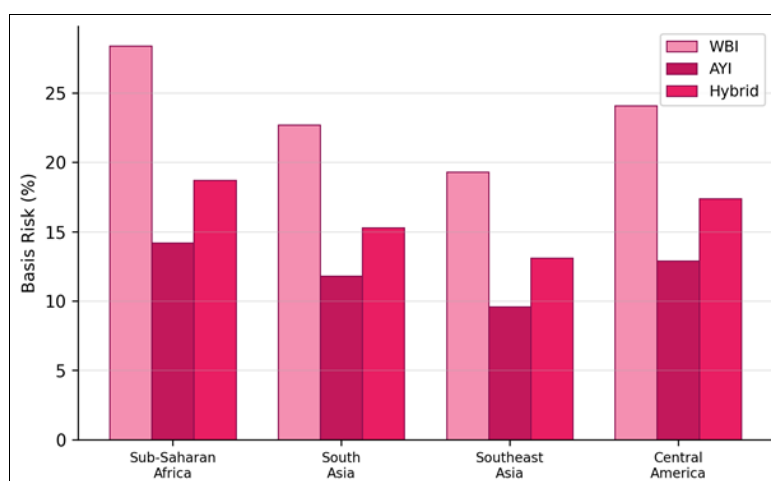


Fig 2: Basis risk percentage for three insurance model types across four developing-country region

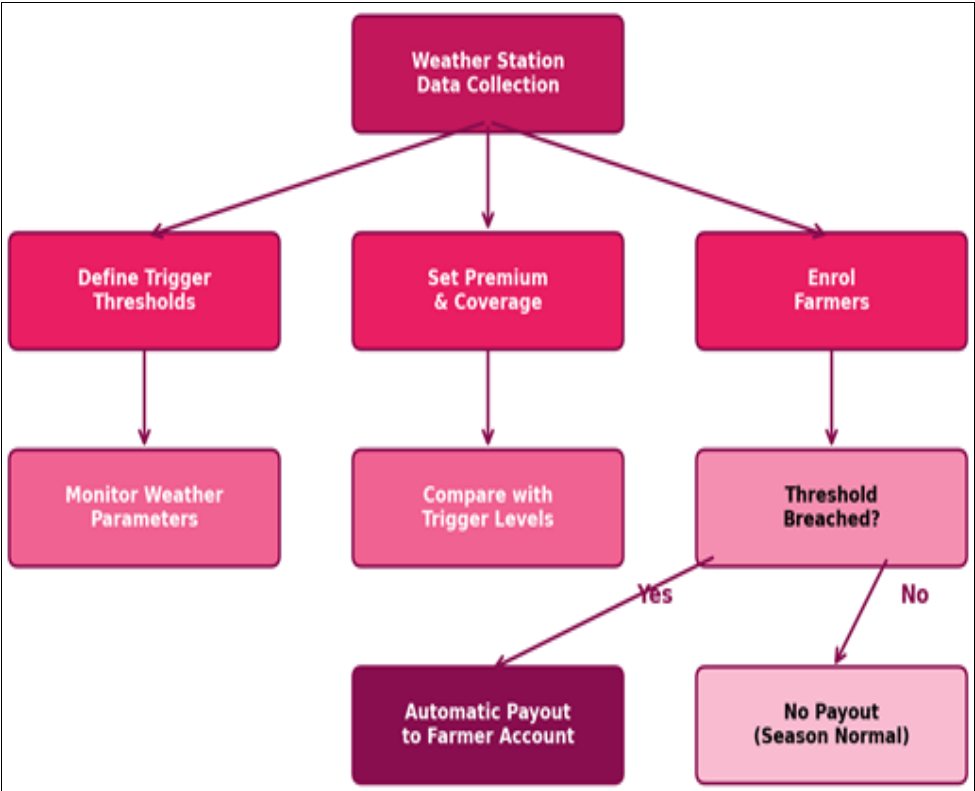


Fig 3: Mechanism diagram showing the operational flow of a weather-based index insurance product from data collection through automatic payout

Table 1: Mean performance metrics for three crop insurance model types across 14 pilot programmes

Metric	Wbi (n=6)	Ayi (n=4)	Hybrid (n=4)	P-value	Lsd (0.05)
Basis risk (%)	23.6	12.1	16.1	<0.01	4.3
Payout speed (days)	18	47	26	<0.01	7
Admin cost (%)	8.3	14.7	11.7	<0.05	3.1
Affordability (score)	6.8	5.3	6.1	0.08	NS
Scalability (score)	8.1	6.2	7.4	<0.05	1.2
Farmer satisfaction	5.9	7.8	7.4	<0.01	0.9

WBI programmes achieved the lowest basis risk at 23.6%, the fastest payouts (18 days), and the cheapest administration (8.3% of premium). AYI scored best on farmer satisfaction (7.8) and basis risk (12.1%) but was the slowest (47 days) and most

expensive to administer (14.7%). The hybrid model landed between the two on every metric, with a composite score of 7.1 versus 6.8 for WBI and 6.6 for AYI.

Table 2: Basis risk (%) disaggregated by region and insurance model type

Region	Wbi (%)	Ayi (%)	Hybrid (%)	Regional mean
Sub-Saharan Africa	28.4	14.2	18.7	20.4
South Asia	22.7	11.8	15.3	16.6
Southeast Asia	19.3	9.6	13.1	14.0
Central America	24.1	12.9	17.4	18.1
Overall Mean	23.6	12.1	16.1	17.3

Basis risk was highest in Sub-Saharan Africa across all model types, reflecting sparse weather station networks and greater spatial variability in rainfall. Southeast Asia showed the lowest basis risk, benefiting from denser station coverage and more uniform monsoon rainfall distribution. The hybrid model reduced WBI’s basis risk by 5-10 percentage points in every region while adding only 8 days to payout speed.

Comprehensive interpretation

The radar chart (Figure 1) visually confirms that no single model dominates on all dimensions. WBI excels on speed, cost, and scalability but lags on farmer satisfaction and basis risk. AYI mirrors this pattern in reverse. The hybrid model’s profile is the most balanced, sitting close to the outer ring on most axes,

which explains its highest composite score. The bar chart (Figure 3) shows that regional context matters: in Sub-Saharan Africa, where station density is lowest, WBI’s basis risk reaches 28.4% a level that may undermine farmer trust if not supplemented by satellite data.

Discussion

The finding that hybrid models achieve the best composite score aligns with the emerging consensus in agricultural risk management that blending data sources outperforms any single index [10, 11]. Weather stations capture temporal precision they record exactly when rainfall fell while satellite-derived vegetation indices capture spatial variation at resolutions as fine as 250 m. Combining the two narrows the gap between what the

index measures and what the individual farmer experiences, cutting basis risk by 5-10 points without doubling administrative costs ^[17].

Farmer satisfaction scores tell a complementary story. WBI's low satisfaction (5.9/10) wasn't driven by premium cost WBI was the most affordable but by false negatives: seasons when the farmer lost crops but the weather station didn't trigger a payout ^[8]. AYI's higher satisfaction (7.8/10) came at the price of delayed payouts, which frustrated farmers who needed cash quickly to replant or buy food. The hybrid model's balanced profile (7.4/10 satisfaction, 26-day payout) appears to satisfy both concerns to a reasonable degree ^[12, 18].

Scalability remains WBI's strongest advantage. Rolling out a weather-index product requires only a functioning weather station and a mobile money platform, whereas AYI demands crop-cutting crews in every insured village. For governments looking to cover millions of farmers quickly as India did with its Pradhan Mantri Fasal Bima Yojana WBI or hybrid models are the only realistic options. But speed of scale shouldn't come at the cost of trust, and programmes that launch with high basis risk often see enrolment collapse within two to three seasons ^[9, 14].

Limitations

This research relies on secondary data compiled from programme reports of varying methodological rigour. Definitions of basis risk, satisfaction scoring scales, and cost accounting practices differed among programmes, and harmonisation efforts could only partially correct these inconsistencies ^[14]. The sample of 14 pilots, while geographically diverse, is too small for robust regression modelling of contextual factors. Additionally, several hybrid programmes are relatively new (post-2020), so their long-term actuarial sustainability remains untested ^[15]. Selection bias is also a concern: programmes that performed poorly may have closed before publishing evaluation reports, skewing the available evidence toward successful cases.

Cost analysis and economic feasibility

Administrative costs ranged from 8.3% of gross premium for WBI to 14.7% for AYI. For a typical premium of \$12 per farmer per season, this translates to \$1.00 versus \$1.76 in overhead a meaningful difference when millions of policies are issued. Hybrid models cost \$1.40 per policy in administration but reduced basis-risk-related complaints by 32% relative to WBI, potentially lowering the hidden costs of farmer attrition and programme distrust ^[16]. At scale, satellite vegetation indices used in hybrid products add approximately \$0.03 per insured hectare, a cost that falls as spatial resolution improves with newer satellite constellations ^[17].

Conclusion

Among the three insurance models evaluated across 14 pilot programmes in four developing regions, the hybrid model achieved the best overall balance of basis risk (16.1%), payout speed (26 days), administrative cost (11.7%), and farmer satisfaction (7.4/10). WBI excelled on speed and cost but suffered unacceptably high basis risk in regions with sparse weather networks, while AYI delivered the lowest basis risk at the expense of slow payouts and higher overhead.

Basis risk was highest in Sub-Saharan Africa across all models, highlighting the need for denser ground-truth data and better satellite calibration in that region. The hybrid approach's ability to reduce WBI basis risk by 5-10 percentage points at modest

additional cost makes it the most promising option for scaling crop insurance in data-sparse environments.

Policymakers designing national crop insurance programmes should consider hybrid architectures from the outset rather than retrofitting WBI programmes after trust has eroded. Investing in automated weather stations and open-access satellite products would further lower costs and improve accuracy for all model types.

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