



# EXPANDING INSURANCE COVERAGE: HYBRID INDEX SOLUTION FOR SMALL FARMERS



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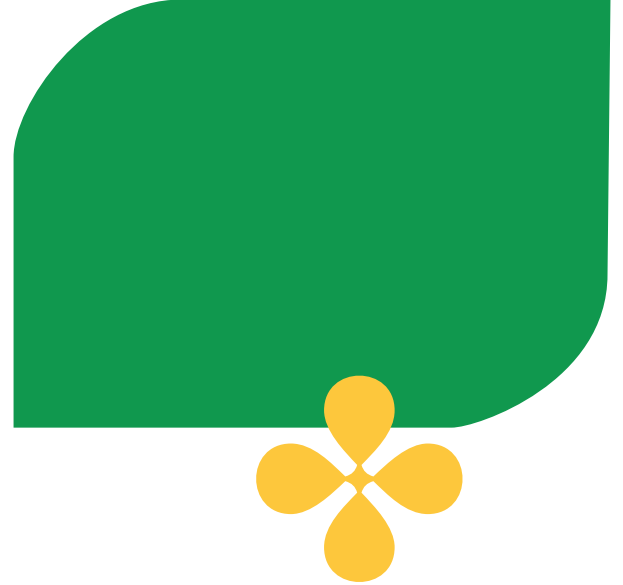
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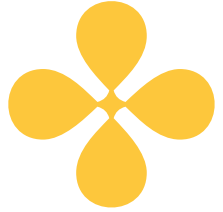
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# EXECUTIVE SUMMARY

Agriculture is significantly influenced by weather-related factors thus it particularly impacts farmers in developing nations who often lack effective risk management tools. Even though agricultural index insurance has offered solutions to cover the unexpected risks from weather conditions, traditional insurance challenges persist, such as missed payouts in satellite index systems and the high costs associated with yield assessments in Area Yield insurance indices. In response to these challenges, we have developed a strategy that aims to mitigate potential basis risk in satellite-based indices and reduce costs associated with area yield-based indices. The strategy leverages innovative triggers combining satellite data with local insights for more accurate yield assessments. By doing so, we aim to bridge the coverage gap for smallholder farmers, thereby reducing the risk of missed payouts and empowering farmers to secure their livelihoods effectively. Our research underscores the importance of striking a balance between accuracy and cost-effectiveness to facilitate the widespread expansion of index insurance. Furthermore, our findings highlight the complementary strengths of satellite data and local extension experts in assessing areas that require higher-average area yield index payouts. While satellite data may offer broader coverage, local extension experts excel in evaluating severity for the areas that need the most amount of payment, emphasizing the need for a collaborative approach that harnesses the strengths of both methods.



# I. INTRODUCTION

Agriculture, being a globally high-risk sector, is particularly vulnerable to the impacts of weather-related factors. Farmers, especially in developing nations, often lack effective risk management tools to cope with these challenges. In recent years, innovations in agricultural index insurance have provided potential solutions to the traditional limitations of conventional insurance products. However, these innovations also come with their own set of challenges. For instance, satellite index systems have been criticized for their tendency to miss payouts, while the high costs associated with yield assessments in Area Yield insurance indices present additional hurdles.

Addressing these challenges requires a multifaceted approach. One key aspect is the analysis of cross-sectional data and yield assessments to mitigate basis risk, which is the risk that the index does not accurately reflect the individual farmer's losses. Additionally, examining different trigger mechanisms for yield measurements can help tailor insurance products to better suit the needs of farmers. Another important consideration is evaluating the trade-off between site visit frequency and payout expansion. Finding the right balance is crucial to ensure that insurance products are both affordable and effective in providing the necessary protection to farmers.

To evaluate this, we focus on Zambia. In Zambia, the government has implemented a unique approach to agricultural insurance by bundling it with the Farm Input Subsidy Programme (FISP). This initiative, introduced in the 2018–19 season, aims to protect farmers' input costs against poor seed germination caused by drought or excessive rainfall. The impact of this bundled insurance was notable in the 2019–20 season when approximately 874,000 farmers received insurance payments due to low rainfall at the start of the growing season. These payments enabled farmers to swiftly purchase new inputs and replant their crops, mitigating the potential losses they would have faced otherwise.

By 2023, the program had expanded significantly, with over 1,000,000 farmers enrolled. The insurance premium, though pre-financed by the FISP, is ultimately paid by the farmer as a mandatory cash contribution to access the input package. This innovative approach not only provides financial protection to farmers but also ensures that they actively participate in the risk management process, enhancing the sustainability and effectiveness of the program.



## MAIN QUESTIONS AND OBJECTIVES OF THE STUDY

Based on the limitations of index insurance due to the occurrence of basis risk, this report seeks to address the following questions:

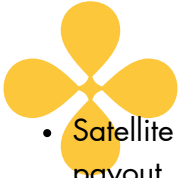
1. How can satellite data be effectively combined with local insights to improve the accuracy of yield assessments for index insurance?
2. How does the use of innovative triggers impact the accuracy of payouts compared to conventional methods?
3. What is the cost-effectiveness of this approach compared to traditional area yield-based indices?

This Columbia Capstone team explored these key questions to develop a strategy to improve agricultural insurance for smallholder farmers, particularly addressing basis risk and high costs. Combining satellite data with local insights is a promising approach to enhance the accuracy of yield assessments and reduce the likelihood of missed payouts. Achieving a balance between accuracy and cost-effectiveness is key to making index insurance more accessible and beneficial for farmers.

## SUMMARY OF KEY FINDINGS

- Analysis of the 2022 PULA yield assessment data shows significant area yield discrepancies across various provinces in Zambia, highlighting the need for improved assessment methods.
- Three strategies were considered for targeting area yield payouts, including comprehensive area yield assessment, assessments in areas near satellite index triggers, and assessments based on local extension expert evaluations of the season's conditions.
- The analysis suggests that comprehensive sampling can capture the "true" loss of area yield by 60%, with average insurance coverage to farmers of 43% of the sum insured. Utilizing local extension experts to identify bad seasons could capture the "true" loss by 35.71% to 57.14%, with an average of 43% to 51%.
- If we utilize a satellite index focusing on the edge areas with a 30% threshold, we could capture a "true" loss of 64.29% for "normalize to much worse" conditions and 60.71% for "normalize to much worse and slightly worse" conditions, with an average of 32% and 38% respectively.



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- Satellite index triggers are more efficient at the margins, particularly when assessing yields near payout thresholds. However, local extension experts demonstrate superior capability in identifying specific areas that necessitate higher-than-average area yield index payouts.
  - We assumed sampling costs 10% of the premium, this equates to 20 ZMW (0.8 USD) per farmer. Using the satellite index and focusing on areas described by local extension experts as 'much worse' and 'slightly worse' conditions can significantly reduce sampling costs to 24% or 5 ZMW per farmer, compared to comprehensive sampling (100% cost). This strategy also results in lower additional payout costs compared to relying solely on local extension experts.
  - Focusing on districts described by local extension experts as in 'much worse' condition (12% of total districts) further reduces sampling costs to 2 ZMW per farmer. This strategy, while cost-effective, also requires careful consideration of the potential impact on the accuracy and coverage of insurance payouts.

## 2. DATA SOURCES

- Our capstone focused on complementary index insurances which are satellite indices and area yield indices. The satellite indexes are publicly available and target the two main agricultural risks—drought and excess rainfall—by being calibrated to each district's specific rainfall patterns and cropping schedules. This index is designed to provide the best possible protection for each district while ensuring standardization and uniformity across districts. For area yield payouts, data from the 2022 Pula Insurance Company's yield assessments and historical yield data from the Zambian government are utilized. The design of the index and the details on how the Pula's area yield data has been used can be found on the following links: <https://fist.iri.columbia.edu/publications/docs/zambiaFISPindexdesign2021/>, [https://fist.iri.columbia.edu/publications/docs/zambia\\_fisp\\_yieldaudit\\_2023/](https://fist.iri.columbia.edu/publications/docs/zambia_fisp_yieldaudit_2023/).
- This project focuses on regions that experience "true" yield losses according to area yield data but do not receive payouts from satellite indices. The accompanying district-level audit map visualizes this discrepancy. It includes data on the audit status of satellite and area yield indices, as well as feedback from local extension experts. From Figure 1 and Table 1, Areas highlighted in light green (audit status=2) indicate area yield losses that are not covered by the satellite index, revealing a coverage gap between the satellite index and the area yield index. This gap suggests that existing insurance mechanisms may not accurately reflect the actual agricultural conditions or meet the farmers' needs.

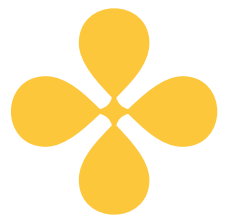
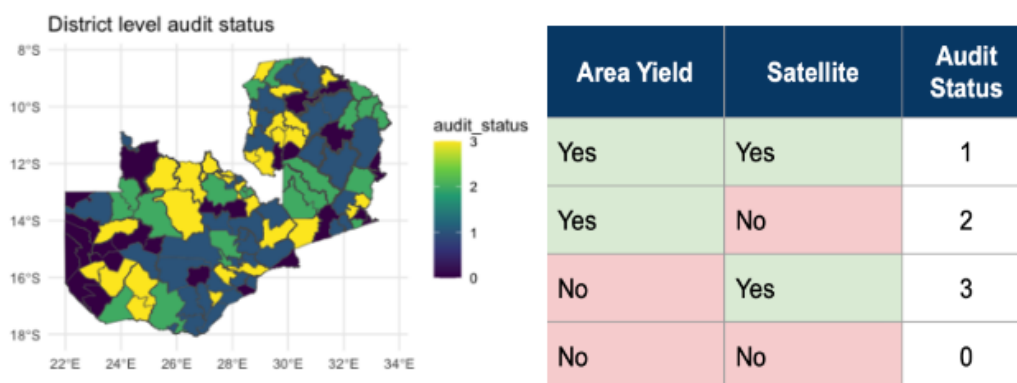


Figure 1 and Table 1 illustrate the status of satellite and area yield index insurance

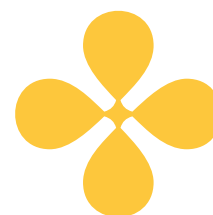


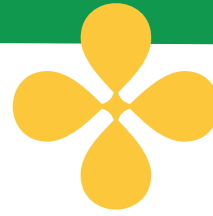
Source: International Research Institute for Climate and Society Staff

To address this issue, assessing the area yield in regions not covered by the satellite index can help bridge the coverage gap. Integrating area yield assessments only where they are valuable for triggering payouts will enhance the accuracy of risk assessments and ensure more farmers receive adequate protection against yield losses.

## CAVEAT AND AREA YIELD VARIATION

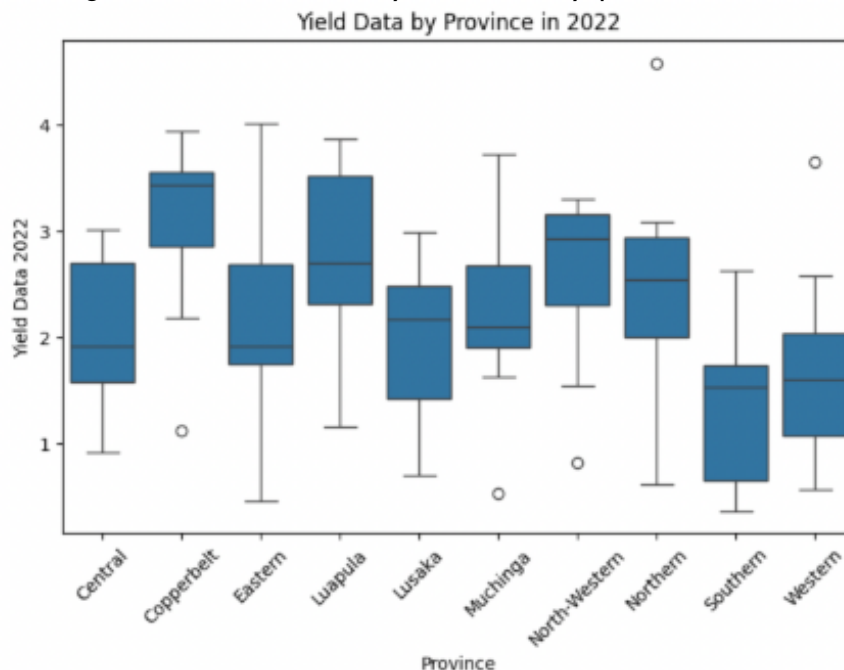
- This report assumes the area yield method to be "the truth" for analysis purposes. Nonetheless, it is important to recognize that this might not accurately reflect real-world conditions. Indeed, evidence indicates that satellite-based methods could offer yield measurements that are equally or more accurate than traditional ground-based approaches, including farmer reporting and sub-plot crop cutting.
- In the paper "Eyes in the Sky, Boots on the Ground: Assessing Satellite- and Ground-Based Approaches to Crop Yield Measurement and Analysis", Lobell et al. evaluate traditional ground-based yield measurements and satellite-based measurements for estimating crop yields and their responsiveness to inputs, focusing on maize data from Eastern Uganda. Notably, the study found satellite-based yield measures explain as much or more variation in yields based on (gold-standard) full-plot crop cuts as ground-based yield measures. There are large discrepancies among the ground-based measures, especially among yields reported by farmers and those determined through sub-plot or full-plot crop cutting.





- Moreover, the correlation between maize yield and various production factors, such as fertilizer use and soil quality, is consistent whether assessed through crop cut- and satellite-based yield measures. The latter yields more significant results due to the ability to analyze larger datasets. This suggests that satellite methods can offer comparable accuracy to traditional methods and the added benefits of broader geographic coverage and lower cost at scale.
- Overall, the findings indicate that satellite data, with its continual improvements in spatial, temporal, and spectral resolution, offers a compelling tool for accurately monitoring agricultural productivity, particularly in regions where traditional, labor-intensive ground-based measurements are logistically challenging.
- For farmers, yield samples may display as much noise, if not more, as measurements taken from satellites. The data on area yields shows considerable differences from one location to another; even two samples within the same administrative district can yield substantially divergent results. This variability is further demonstrated by the accompanying boxplot (Figure 2), which uses the 2022 PULA yield assessment data to illustrate the range of area yield discrepancies across various provinces in Zambia.

Figure 2 illustrates the yield data by province in 2022



Source: International Research Institute for Climate and Society Staff

### 3. STRATEGIES FOR TARGETING AREA YIELD PAYOUTS

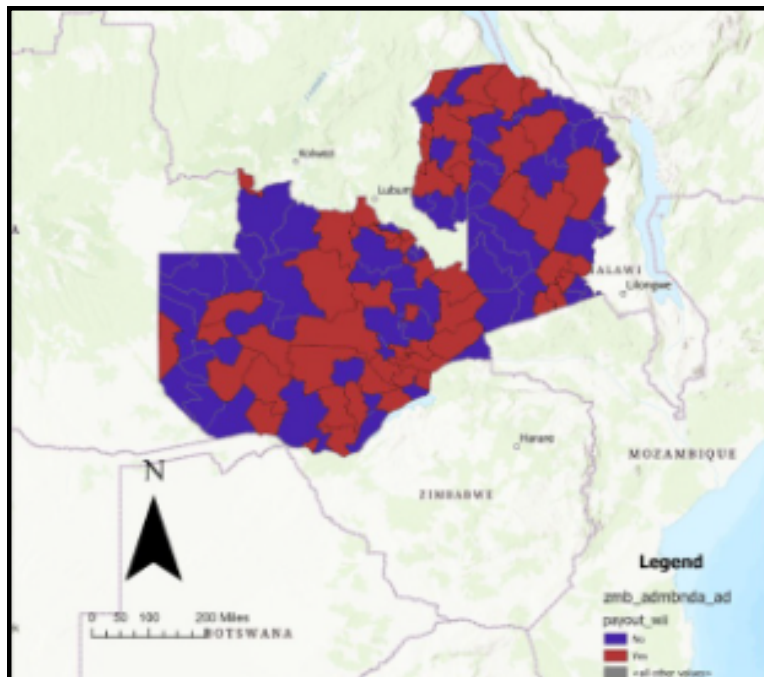
In our work, we considered payout from area yield assessment as the “truth”. To determine the places that would receive a payout, we have to identify the places where assessments should be performed. To identify those areas, we considered three different strategies:

1. Conduct a comprehensive area yield assessment, which means that we assess the crops everywhere.

2. Conduct area yield assessments only in the areas that did not trigger a payout from the satellite index but came close to triggering.

For this strategy, we are looking at the satellite index on the edge. In that case, we ignore the places that already received a payout from the satellite index and focus on the ones that did not. Among the places that did not receive a payout from the satellite index, we would conduct an area yield assessment in the places in which the index is at most 20% above the threshold for triggering a payout.

Figure 3 Districts that would have received payouts based on Satellite Index Insurance in 2022



Source: International Research Institute for Climate and Society Staff, illustrated by capstone

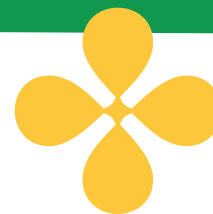


Figure 3 illustrates that 57 districts out of 115 would have received a payout in 2022 based on Satellite Index Insurance. In this strategy, we would ignore those districts and conduct an area yield assessment in the districts that came close to triggering the satellite index payout among the 58 other districts. This strategy has some advantages as well as inconveniences. Using the satellite index to trigger area yield payout can provide a broader coverage more efficiently and more rapidly, and it is also less susceptible to subjective interpretation. However, it provides limited new information on what is going on on the ground.

3. Conduct area yield assessments in the areas that did not trigger a payout from the satellite index but were described by the local extension experts as a bad season. In our dataset, the local extension experts were asked this question:

*"How would you assess the area yield of this season in comparison to the average of the last five years?"* And they have five possible answers that they can choose from to answer this question: *"Much Worse", "Slightly Worse", "Average", "Slightly Better", and "Much Better"*.

In that case, we would only conduct an area yield assessment on the places that were described as much worse by the extension experts. Because, from their perspective, those are the areas that should get a payout. This method has some advantages over using the satellite on the edge because it provides new information and provides real-time insights into what is going on the ground. Furthermore, the local extension experts are more able to handle complex cases due to their proximity to the farmers. However, this method also has its inconveniences.



It can be more resource and time-intensive since you have to survey all the experts. Additionally, it is subject to more subjectivity and bias because what is considered a "much worse" season can vary widely from one expert to another. Lastly, the local extension experts are subject to moral hazard, knowing their answer may trigger a payout, they may be more inclined to describe the season as much worse than the last five years.

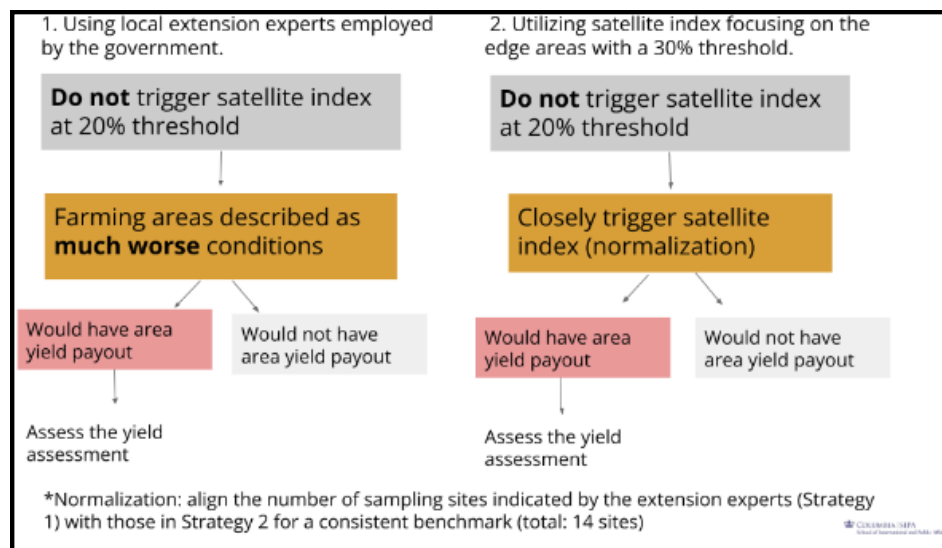
As we mentioned before, both methods have their advantages and disadvantages. Therefore we had to compare their results and determine which one performed better and under what conditions. To compare the results of both methods (Using the local extension expert versus using the satellite index on the edge), we consider the area yield result to be the truth. Therefore if a place received a payout based on the stylized model of the area yield payout, then we consider it a "true positive". On the other hand, if a place did not receive an area yield payout then we consider that it did not need it and it would be a "false positive".

Using the stylized model of the area yield payout, we first looked at the places that did not trigger a satellite index payout but were described as much worse by the extension experts. For all those places, we looked at what would happen if we went and conducted an area yield assessment in those places:

- The places that would have received a payout based on the area yield would be our “true positive”. In other words, they would be the missed payouts that would be caught by the area yield assessments.
- The places that would not have received a payout would be the “false positive”, in other words, the wasted samples.

Then we did the same process again, this time we looked at the places that did not trigger a payout from the satellite index but came close to triggering it. The entire process is summarized in the figure 4.

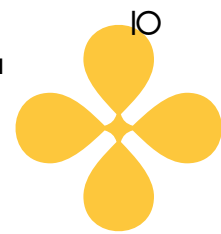
**Figure 4 Data Analysis Diagram**



Source: Capstone team

## 4. CROSS-SECTIONAL ANALYSIS: FINDINGS

In this study, we have established a nuanced understanding of the relationship between different assessments and insurance payouts, deriving from the comparative effectiveness of satellite indices and local extension expert evaluations. Our analysis reveals that by comprehensively sampling all areas not included in the satellite index payouts, it is possible to capture the “true” loss of area yield by 60%, with average insurance coverage to farmers of 43% of the sum insured. If we use local extension experts employed by the government, especially for “much worse” conditions and “slightly worse and much worse” conditions, we could picture the “true” loss of area yield by 35.71% and 57.14%, with an average of 43% and 51% respectively.



**Table 2 summarizes the findings for each strategy in detecting area yield payouts and occurrences of additional average payouts.**

Thresholds	Triggers of Yield Assessment				
	1. Local Extension Experts		2. Satellite Index		Comprehensive Sample in All Place did not get satellite index payout
	Much Worse	Much Worse and Slightly Worse	Normalize to Much Worse	Normalize to Much Worse and Slightly Worse	
(A) Additional Samples Required	14	28	14	28	50
(B) Identified Missed Payouts	5	16	9	17	30
Identified Rate (A/B)	35.71%	57.14%	64.29%	60.71%	60.00%
Average Area Yield Index Payment	43%	51%	32%	38%	43%

Source: Capstone team calculation

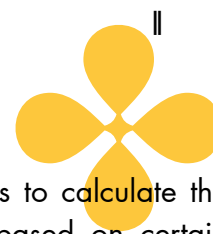
If we utilize a satellite index focusing on the edge areas with a 30% threshold, we could capture a “true” loss of 64.29% for “normalize to much worse” conditions and 60.71% for “normalize to much worse and slightly worse” conditions, with an average of 32% and 38% respectively.

In terms of feedback trigger efficiency, we have identified a notable variation in the accuracy of feedback from extension experts, which tends to decrease in years with more severe yield years. Specifically, in years categorized as “much worse, (35.7%)” the accuracy of local expert feedback is significantly reduced compared to years with less severe conditions (57.14%). The efficiency of satellite index triggers is more pronounced at the margins, particularly when assessing yields near payout thresholds. However, expanding these margins invariably compromises targeting accuracy, as evidenced by identified missed payouts of 64.29% and 60.71%.

Nevertheless, local extension experts demonstrate superior capability in identifying specific areas that necessitate higher-than-average area yield index payouts (can detect an average of up to 51% of the sum insured to farmers), compared to satellite data. This expertise is crucial in assessing the severity of yield loss, which may not be as adequately captured by satellite indices. Based on the satellite indices, it would detect an average area yield index payment of 32% for “normalize to much worse” and 38% for “normalize to much worse and slightly worse” conditions, presenting a much less average payment.

In conclusion, while satellite indices offer broad coverage and are effective in identifying a large number of areas for potential payouts, local extension experts provide invaluable insights into the severity of conditions and the specific needs of individual areas. Both tools have their strengths and limitations, suggesting that an integrated approach, utilizing both satellite data and local expert assessments, could offer a more effective and nuanced method for managing agricultural risks and enhancing the reliability of yield predictions and insurance payouts.

# 5. SAMPLING COSTS AND ADDITIONAL PAYOUTS



Based on our analysis of each strategy, we aim to extrapolate our findings to calculate the comparative costs of sampling and additional payouts. Our calculations are based on certain assumptions. Firstly, we consider the cost of sampling for the entire country (115 districts) under the "If Yield" sampling method to be 100% of the sampling cost. Assuming comprehensive sampling costs 10% of the premium, this equates to 20 ZMW (0.8 USD) per farmer. The sampling cost can vary depending on the level of detail provided by local extension experts in different areas as summarized in Figure 5. The additional cost of payout is determined by multiplying the average payout with the maximum liabilities per farmer in each district.

Under the "If Yield" sampling method for the entire country, the additional cost of payout is calculated to be 1823 ZMW. Conversely, utilizing the satellite index and collecting yields in only 1 district with no payouts (out of 58 districts) reduces the sampling cost to 50% or 10 ZMW per farmer. However, it's important to note that in a good year, comprehensive sampling would still be necessary everywhere. The additional cost of payout under this strategy is 1917 ZMW.

Further refining the approach, if we use the satellite index and collect yields in districts described by local extension experts as much worse and slightly worse conditions, the sampling cost is reduced to 24% or 5 ZMW per farmer. The additional cost of payout is calculated to be 2285 ZMW for the case of relying on local extension experts, whereas it is 1700 ZMW when using the satellite index for areas on the edge.

Finally, focusing on districts described by local extension experts as in much worse condition, which constitutes 12% (14/115) of the total districts, the sampling cost is reduced to 2 ZMW per farmer. The additional cost of payout is 1935 ZMW for the case of local extension experts, while it is 1460 ZMW when relying on the satellite index for areas on the edge. In summary, given the same cost of sampling, adopting the local extension expert strategy can potentially identify more areas in need of insurance payments compared to relying solely on the satellite index.

**Figure 5 Summarizes the cost of sampling and additional payouts**

An Estimated Cost of Sampling (ZMW/per farmer)			Additional Cost of Payouts (ZMW/per farmer)	
0	Comprehensive collect yields everywhere	100% of Cost	1,823	
1	Satellite index and collect yields in only districts with no payouts (58 districts)	58/115= 50% or 10 ZMW per farmer Note: In a good year, need to sampling everywhere.	1,917	
			Local Extension Expert	Satellite on edge Normalization
2	Satellite index and collect yields in districts that local extension expert described as <u>much worse and slightly worse condition</u>	28/115 = 24% or 5 ZMW per farmer	2,285	1,700
3	Satellite index and collect yields in districts that local extension expert described as <u>much worse condition</u>	14/115 = 12% or 2 ZMW per farmer	1,935	1,460

Source: Capstone team calculation

## 6. CONCLUSION, LIMITATIONS, AND NEXT STEPS



Satellite indices offer extensive coverage and effectively identify numerous areas eligible for payouts, while local extension experts offer crucial insights into the severity and the unique needs of each area. However, The analysis in this research is constrained by several limitations. Firstly, our investigation is based solely on the cross-sectional data from 2022, which may not fully capture long-term trends or variations. Additionally, in years where no payouts occurred, conducting a comprehensive survey across all regions would be necessary to gain a complete understanding, introducing potential biases or gaps in the analysis. Moving forward, future research should broaden its scope to include historical trends in satellite payouts, weather patterns, and area yield payouts to provide a more comprehensive and nuanced analysis.

Another limitation to consider is the potential for moral hazard among local extension experts, which could lead to an increase in area yield assessments. This behavior could impact the accuracy of assessments and the effectiveness of insurance payouts. Moreover, future studies need to evaluate the statistical significance of differences in sampling efficiency between different strategies to ensure robust and reliable results.

## FUTURE STEPS

Looking ahead, several proactive steps can be taken to address these limitations and enhance the efficacy of the analysis. One approach is to implement a tiered insurance system that combines satellite data with local expert assessments. This tiered approach could involve using satellite data for large-scale initial assessments (Tier 1) to trigger payouts for severe cases with high confidence. In contrast, local experts could be deployed for areas flagged by the satellite index or for situations requiring a more nuanced evaluation (Tier 2), ensuring accurate assessments and avoiding unnecessary payouts for borderline cases.

Furthermore, designing incentives based on accuracy rates can help mitigate the moral hazard associated with local extension expert feedback. By aligning incentives with accurate assessments, the system can encourage more responsible behavior among experts, ultimately improving the overall quality of assessments and the effectiveness of insurance payouts.

Finally, leveraging a novel dataset that includes 40 years of historical data on yields, satellite indexes, and farmer focus groups presents an exciting opportunity for future research. This dataset can provide valuable insights into long-term trends, patterns, and dynamics, enriching the analysis and leading to more informed decisions in agricultural insurance and risk management strategies.

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