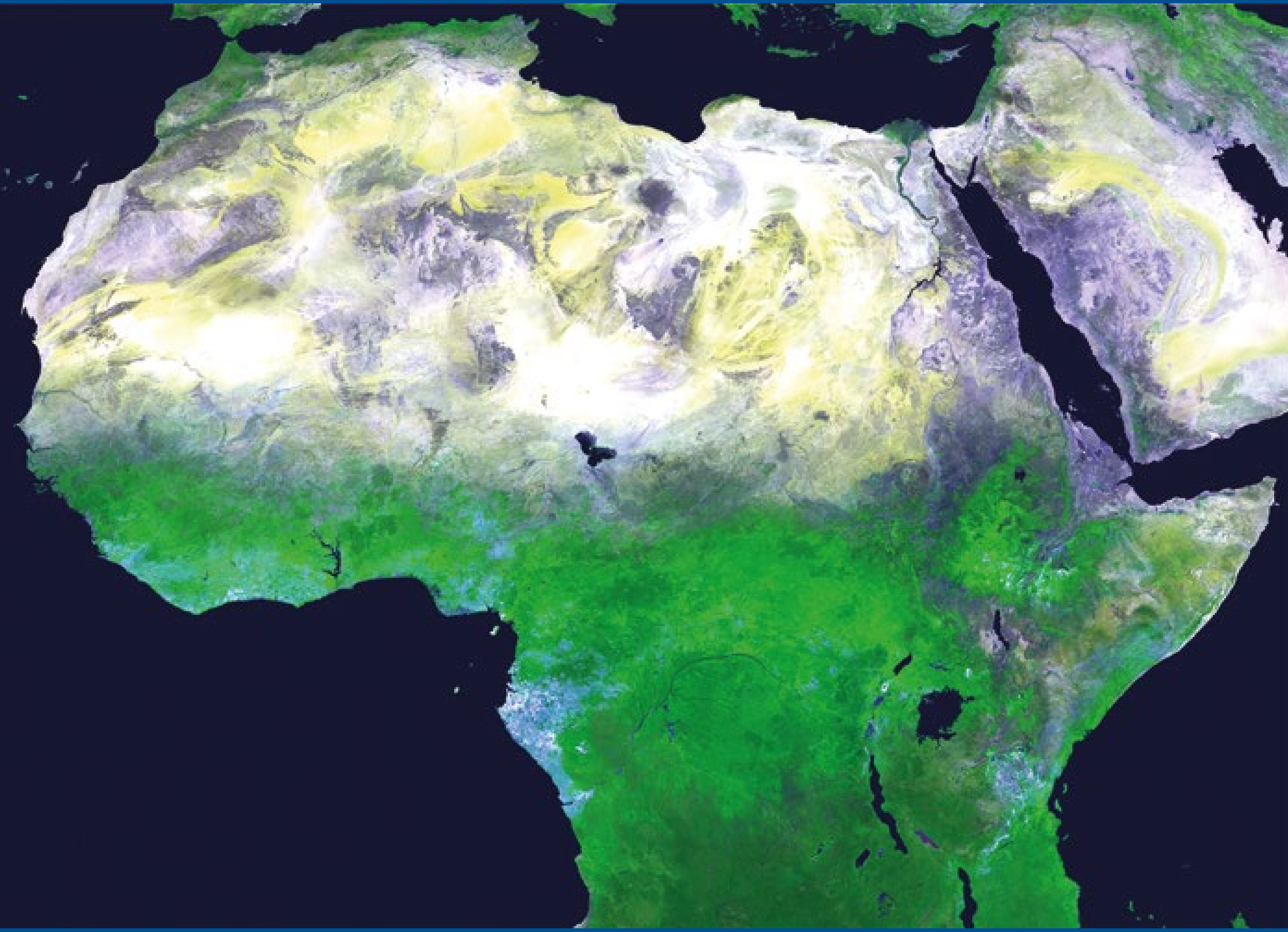

Remote sensing for index insurance

An overview of findings and lessons learned for smallholder agriculture

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Acronyms

AYII	area yield index insurance
EARS	Environmental Analysis and Remote Sensing
ELC	expected loss cost
ERS	European Remote Sensing satellite
ET	evapotranspiration
fAPAR	fraction of Absorbed Photosynthetically Active Radiation
FEWS NET	Famine Early Warning Systems Network
IRI	International Research Institute for Climate and Society (Earth Institute, Columbia University)
ITC	Faculty of Geo-Information Science and Earth Observation, (University of Twente)
NDVI	Normalized Difference Vegetation Index
RFE	rainfall estimate
ROI	region of interest
RSSP	remote sensing service provider
SAR	Synthetic Aperture Radar
SoS	start of season
UAI	unit area of insurance
VITO	Vlaamse Instelling voor Technologisch Onderzoek (Flemish Institute for Technological Research)
WII	weather index insurance

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1. Introduction

Index insurance is a type of agricultural insurance that can serve agricultural development and risk management by protecting assets and encouraging productive investments. Yet it faces operational and technical challenges to reach scale and sustainability. Data are a key challenge – in terms of, for example, availability, accessibility, quantity and quality – and were the focus of the project "Improving Agricultural Risk Management in Sub-Saharan Africa: Remote Sensing for Index Insurance." The project was designed to contribute to scalable and sustainable approaches to index insurance, and specifically to evaluate the feasibility of remote sensing for index insurance that would benefit smallholder farmers. Although research and development focused on Senegal, the findings are intended to inform the entire sector. The project was implemented by the Weather Risk Management Facility (WRMF) of the International Fund for Agricultural Development (IFAD) and the World Food Programme (WFP) from 2012 to 2016 with financial support from the Agence Française de Développement and an additional contribution from the Belgian Federal Science Policy Office.

This publication outlines the project, and it aims to give people working in the insurance community, agricultural development and government an overview of remote sensing opportunities and challenges for index insurance, together with recommendations on where further work and investment is needed. The paper provides the context of index insurance for smallholder agriculture (Section 2), delving deeper into data requirements (Section 3). It lays out the key project steps (Section 4), along with the remote sensing approaches (Section 5) and methodologies (Section 6) explored by the project. It ends with overall findings (Section 7) and recommendations (Section 8). For full information on the project methodologies, as well as detailed results and outcomes of the performance assessments and evaluation exercises, please refer to *Remote Sensing for Index Insurance: Findings and Lessons Learned for Smallholder Agriculture* (IFAD-WFP, 2017).

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2. Insurance for smallholder agriculture: the need, the opportunities and the challenges

Climate uncertainty traps smallholder farming households in poverty and food insecurity. Without reliable tools to protect against climate-related production risks, smallholders forgo opportunities to become more productive: they focus on more resilient but less profitable production activities and do not invest in better quality inputs and technology. This situation is exacerbated by financial service providers who fear offering financial products and services, by input suppliers who limit their outreach, and by external shocks that threaten the sustainability of well-meant donor and government interventions (IFAD, 2015).

Agricultural insurance

Agricultural insurance can offer part of the solution, helping to protect assets and encourage productive investments in smallholder agriculture, unlock access to credit, increase resilience of rural households and businesses, and improve food security. This publication focuses on index insurance for crops (see Box 1). To overcome the limitations of ground-based data, index insurance developers are turning to remote sensing approaches such as satellite data. However, despite the significant experience developed in drought insurance for pasture, applications for smallholders' cropping activities are relatively new, and remote sensing data are not yet being used to their full potential for index insurance.

In indemnity insurance, compensation is based on measured loss or damage and, therefore, it requires an insurer to make individual farm visits to set up coverage and to assess loss. This overhead makes it costly and difficult to administer efficiently and effectively for smallholders, and it leaves open the problems of moral hazard and adverse selection. The most widespread indemnity insurance product (multi-peril crop insurance) is based on measurement of shortfalls of actual yield at the individual farm level compared with expected yield.

Box 1. Types of agricultural insurance

Indemnity products
- Named peril crop insurance (e.g. hail)
- Multi-peril crop insurance (MPCI) (yield guarantee)
- Accident and mortality livestock insurance

Index-based products
- Weather index insurance (WII) using ground-based or remotely sensed measures of weather variables
- Area yield index insurance (AYII) using ground measurement
- Index insurance using remote sensing to monitor cropping or pasture conditions

In contrast, index insurance payments are based on an indirect indicator, such as lack of rainfall, intended to be a proxy for loss or damage. The index is built on historical data, and it uses current season data to verify when a payment is triggered. Generally, all farmers within a given area purchase the same policy, for the same price, and receive the same payouts when the index triggers.

The reduced administrative costs and the simplified and automated claims processes make index insurance more accessible for smallholder agriculture. The standardized nature of the product also means that it can be bundled with other services, such as credit or inputs, and delivered through aggregators. It protects against systemic risks,[1] such as widespread drought, which are typically difficult to recover from quickly without external help or appropriate financial tools in place. Because the index insurance products are built on existing data, they are based on objective and transparent information, which means some of the risk can be transferred to national or international markets.

Challenges facing index insurance

The main challenges for index insurance fall into two categories: (i) delivery challenges; and (ii) technical product challenges.

Delivering at scale and at a low cost, building insurance awareness and understanding among clients and partners, and bringing added value for clients and partners are all key issues to be overcome. Clients and partners can be smallholder farmers, value chain actors, microfinance institutions or governments; and the added value might be achieved through either bundling

[1] Systemic risks – also known as covariate risks – affect many people in the same area and at the same time, be it in a local area, across a region or throughout a whole country.

index insurance with other products or benefiting farmers indirectly by covering the business risks faced by financial institutions or those that arise within the value chain.

Technical product challenges include basis risk (see Box 2), development costs and product replication. Data are also a key challenge, and were the focus of the project (see Section 3).

Box 2. Basis risk

Basis risk is a key constraint for index insurance. In its widest sense, basis risk is the difference between the loss experienced by the farmer and the payout triggered. Index insurance products need to demonstrate product quality through their ability to match losses with payouts.

Identifying the differences between losses and payouts can be complex. Such differences depend on the cover intended by each index insurance methodology. For example, index insurance products can be crop-specific or reflect more general crop losses, but a weather index insurance contract would not cover losses due to pests and disease. These differences also emphasize the importance of clarity in the wording of the insurance policy and of educational outreach when index insurance is sold.

A key dimension of index insurance is the distinction between average losses experienced in the coverage area as a whole and losses experienced by individual farmers. Potential causes of basis risk can include the distance from the point of measurement of the indexed variable, and the geography or size of the area covered (spatial basis risk), or the precise timing of the start of the crop season (temporal basis risk).

If parameters such as triggers and exits are incorrectly calibrated, or the relationship between the index measurement and the crop yield is not clear, basis risk may be attributed to product design (product basis risk).

In remote sensing-based index insurance, the extent of basis risk can be influenced by the spatial resolution of the satellite images. Index measurements may be in the form of single pixels or groups of pixels which are aggregated to form the unit area of insurance (UAI). The UAI is the area set by the insurer under which all policyholders are grouped, paying the same premium and having the same payout rates related to their sums insured. Understanding the extent of variation in crop yields at the level of the individual farmer, the village and the larger aggregated area is important in implementing index insurance. Similarly, understanding the actual causes of crop loss is extremely important in interpreting potential basis risk.

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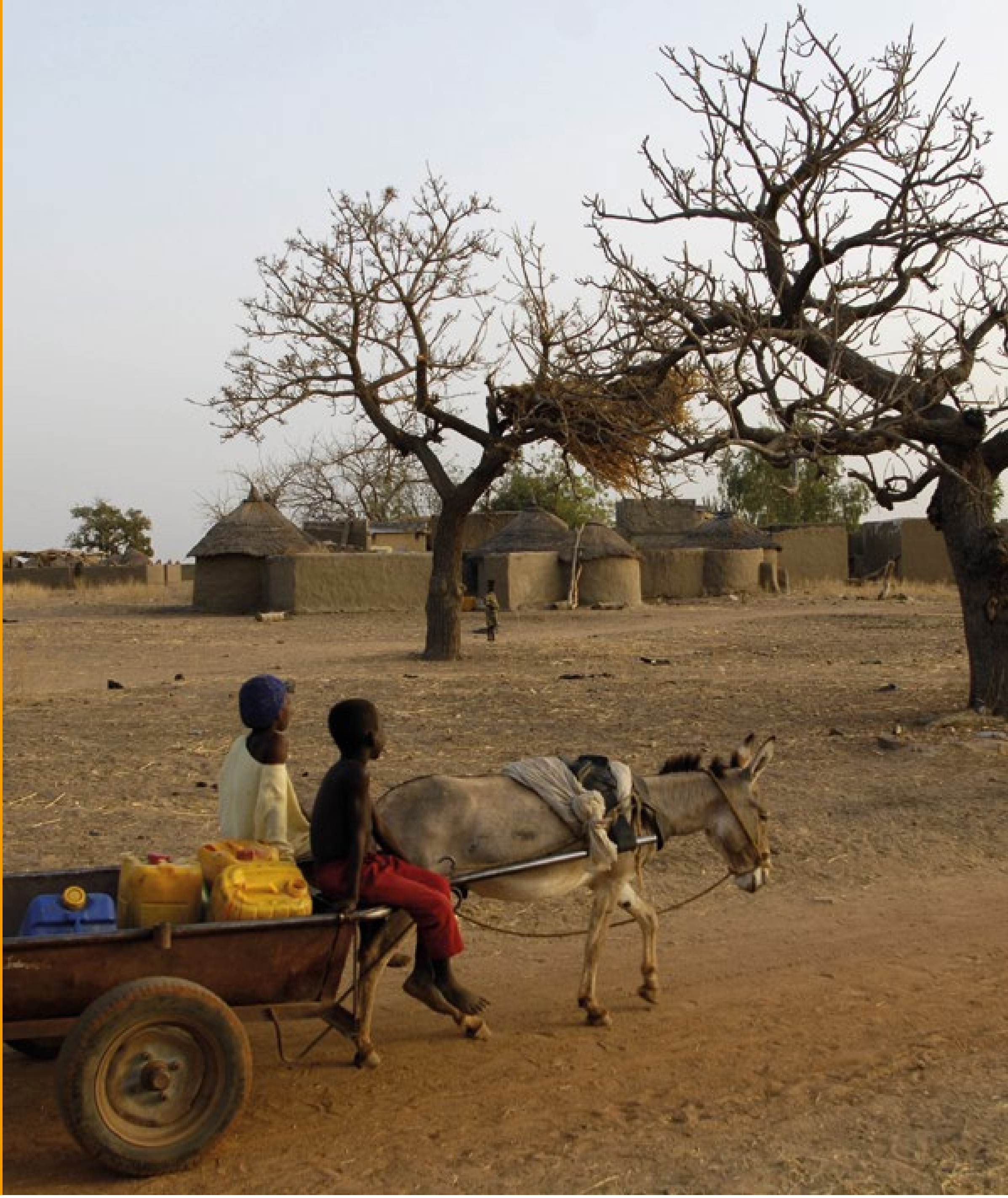

3. Data for index insurance

Numerous studies have shown that limitations in on-the-ground data infrastructure are a challenge to the scaling up of index insurance (IFAD-WFP, 2010; European Commission Joint Research Centre, 2013; Hellmuth et al., 2009; World Bank CRMG, 2008; MicroSave, 2013). As a result of these limitations, designing index insurance that highly correlates with the losses its policies intend to cover is more complex.

Ground data needs for index-based insurance

Weather index insurance (WII) and area yield index insurance (AYII) are the most common forms of index insurance. Both WII and AYII require ground data for designing the index and operating the contract. WII based on ground measurements relies on both historical and current weather data, and some agricultural data, to design and calibrate products. AYII relies on historical yield data for design and pricing, and it relies on current yield data to provide compensation when yield losses occur.

Designing and underwriting the contract

Historical weather data requirements. Historical weather data are used as the basis for data analysis in the design and pricing of WII. Generally, to meet commercial insurer and reinsurer requirements, significant historical data are needed (ideally, 20 to 30 years of daily observations), and missing or out-of-range values should represent only a small percentage of the total dataset.[2] Of the utmost importance is the quality and reliability of the dataset. Data can be used from weather stations managed by the national meteorological service or, in some cases, a reliable private provider, but they should meet international standards such as those set by the World Meteorological Organization. The density of weather stations needed depends on the weather risk being insured, the homogeneity of topography of the insured area, and the distribution of the farming population. For index insurance purposes, stations may be needed from 5 km up to 25 km away from insured farms. Data collection and recording procedures should be secure and trustworthy to reduce the risk of tampering

[2] Indicatively, "small" means below 3 per cent, but references to the required length of the time series and amount of missing data should not be considered as binding rules. Reinsurers may agree to use datasets that are shorter or have a higher percentage of missing data.

with measurements, and data collection methodologies should be consistent. For the same reason, while manual weather stations could be acceptable in some cases, data from automated weather stations are preferred as they are less vulnerable to fraud or error.

Weather data are not usually required for AYII, unless specific add-on provisions are embedded in the yield index cover, such as a sowing failure cover based on lack of rainfall.

Agricultural data requirements. Agricultural information is important for both WII and AYII products. For WII, it complements the contract design process; for AYII, it is the base for structuring the insurance coverage. The most relevant information to be collected is yield data, which should be as disaggregated as possible in the insured areas, and, if available, official loss or damage data. Consistency of data collection methods is important as is following minimum required standards. This information should be supplemented with a clear description of the agricultural production characteristics in the areas.[3]

Operating the contract

Ongoing weather data requirements. Once contracts are in operation, it is necessary to have ongoing access to the data to determine whether a payment is due. For weather data, it is normally the role of the national meteorological service to provide these data and maintain the stations. Data need to be appropriately collected, maintained and stored. Data should be reported as frequently as possible (ideally on a daily basis) and made available to insurers and other involved actors to allow them to determine when a payout should be made and to identify any problems in a timely manner (e.g. problems with data transmission or availability). An independent source of data should be available for verification, if needed (e.g. surrounding weather stations, the World Meteorological Organization Global Telecommunication System).

Ongoing agricultural data requirements. Yield data are needed at a level of disaggregation appropriate to the area covered by the contract. To match the timelines required by the insurance transactions, data should be reported in a timely manner.

[3] This would include intensity of production, cropping patterns and varieties, soil types and water balance.

Challenges with data

Limited availability, accessibility, quantity and poor quality of data on the ground are some of the main technical constraints preventing the scaling up and sustainability of index insurance. Without sufficient, quality data it is either impossible to design products for some areas and countries, or it can lead to an unreliable product that does not compensate when it should.

Weather data. Weather data that meet all the necessary requirements are rarely available in developing countries, and are especially scarce in those areas needing coverage. The completeness of the historical dataset is highly variable for different areas, particularly for daily data. Similarly, the density of weather stations forming the national network varies considerably from country to country. Even if the perfect datasets exist, they are not necessarily accessible or available for commercial purposes. Apart from the cost of obtaining the data, successful design and operationalization requires reaching a good understanding with national meteorological services that manage and provide the data. Installing new weather stations just for the purposes of index insurance would be an issue of volume needed to cover often dispersed populations, across heterogeneous areas, as well as costly long-term maintenance. Furthermore, no historical record would be available. In certain circumstances, artificial datasets can be calculated in areas where new stations are installed to partly overcome this problem; however, it is not a viable solution in all cases.

Yield data. Good quality yield data of sufficient time series at the required disaggregated level are frequently unavailable. For WII, the lack of quality yield data has an impact on contract development. For AYII, yield data are essential since the data are needed both to structure the insurance coverage and to determine compensation. In practice, local staff of ministries of agriculture or national statistical departments collect yield data; however, it is often the case that yield data are unreliable or not available at the appropriate level of disaggregation, or reporting is slow after harvest, which delays payouts. Index insurance schemes that require a reliable and ongoing flow of quality yield data may need to set up dedicated yield collection methodologies and procedures, but it is not always economically or technically possible to do so.

Remotely sensed data

With the challenges of ground-based data, the sector has begun to turn to satellite data either as a possible supplement to ground-based data indices or to create remote sensing index insurance products.

Remotely sensed indices do not take direct measurement on the ground. Instead, satellites collect different types of datasets based on specific biophysical dynamics, such as cloud temperature to estimate rainfall, evaporation and transpiration of water from the soil/plant system (evapotranspiration), soil moisture content or vegetation greenness (see Section 5). These data are typically calibrated with some ground information to create indices. The index is designed to proxy yield loss based on the parameters used.

For more than 20 years, agricultural monitoring has been one of the primary operational applications of earth observation. These applications have remained primarily in the public sector, but over the past decade, the interest from the private sector has been steadily growing.

Remote sensing can significantly contribute to providing a timely and accurate picture of crop growth and development as it can gather information over large areas with a high revisit frequency. Moreover, the availability of remote sensing data archives allows users to compare climate and vegetation over time and analyse trends.

There are two main types of remote sensing systems that can be used – "passive" sensors and "active" sensors. Passive sensors measure either sunlight being reflected or radiation being emitted from the earth's surface. Like our eyes, these sensors operate largely within the optical spectrum, producing images that are recognizable and easily interpreted. Passive sensors, however, do not provide information if there is cloud coverage.

Active sensors are independent from the sun's illumination because they have their own energy source (usually microwave) directed towards the earth's surface. Radio detection and ranging (RADAR), for example, sends microwave radiation, which is bounced off the earth's surface and recorded again by the sensor. The amount of energy received by the sensor is determined by, among other variables, the surface roughness and moisture content, and can be interpreted accordingly. RADAR images are more difficult to interpret, but the key advantage of active sensors is that images can be acquired at any time of the day or night and in cloudy weather conditions.

Different types of information products are derived from these remote sensing systems. Some of the most widely used remotely sensed products for agricultural monitoring are rainfall estimates, soil moisture, evapotranspiration and vegetation indices. Satellite-based rainfall or soil moisture estimates may provide information on the climatic conditions that influence crop growth. Evapotranspiration compares the crop's water demand with the available soil moisture. Vegetation indices such as the Normalized Difference Vegetation Index (NDVI) or the fraction of Absorbed Photosynthetically Active Radiation (fAPAR) make it possible to follow crop growth and development during the season. Vegetation indices can also be used to distinguish between different land cover types or, in some cases, even different crop types. Identifying land cover, and possibly crop types, is important in creating masks that act as inputs to remote sensing interpretation.[4]

Directly or indirectly, each of these products provides indications on crop health and productivity, and they can aid in identifying crops affected by weather-related damage (e.g. lack of rainfall or flooding) or by pests or diseases.

Remotely sensed data have several advantages over ground-based data; for instance, they:

- are spatially continuous across large areas of the earth
- may have extended historical records
- can be available in near real-time
- can be freely accessible and available in their unprocessed version
- can generate a large spectrum of indices that detect biophysical changes in plant growth, such as soil moisture, rainfall, temperature and vegetation greenness and, therefore, they can calculate yield loss due to risks beyond rainfall
- are difficult for the parties involved in the insurance transaction to influence.

Because of these advantages, remote sensing-based index insurance could help with scalability and sustainability issues. However, remotely sensed data are not yet being used to their full potential for index insurance.

One bottleneck is that there is a lack of reliable information on remote sensing for index insurance, including different methodology options and their possible combinations; what works best in which areas and for which types of crops; and whether and how remote sensing solutions can be used more for index insurance. These are some of the challenges that the project sought to address.

[4] A crop mask is based on coarse resolution data, and it expresses a percentage of a crop represented in a pixel. It thus leads to better exploitation of mixed pixels in coarse resolution imagery and is increasingly used in regional and global crop monitoring systems.

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4. Project overview

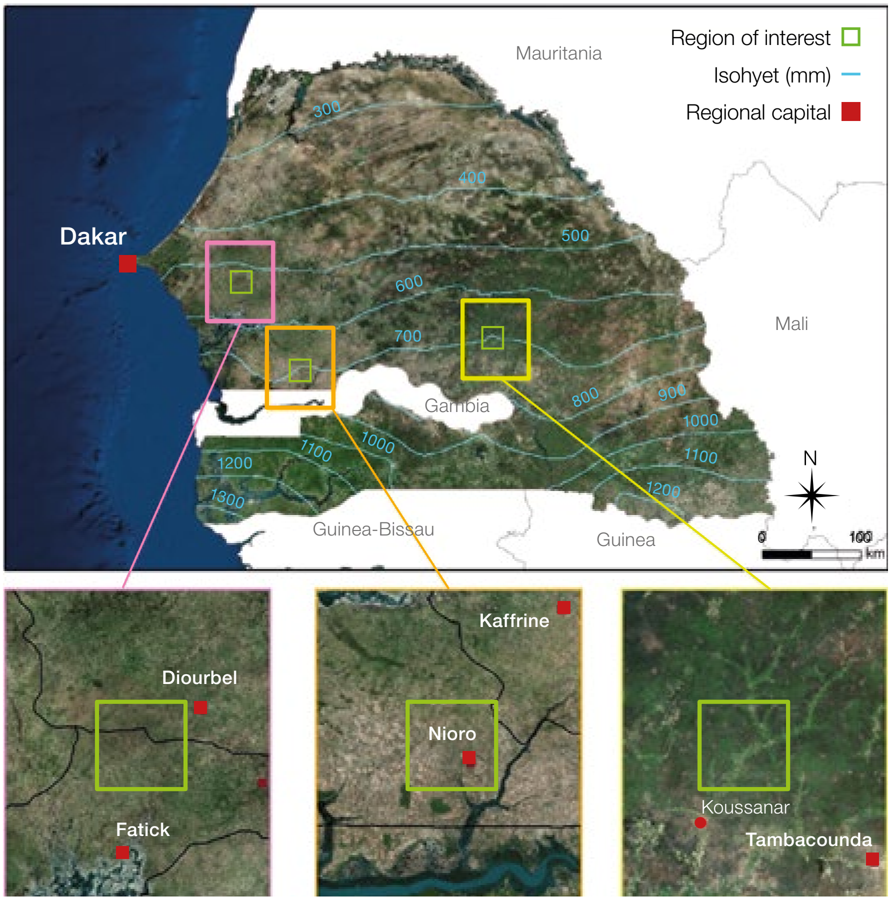
The project "Improving Agricultural Risk Management in Sub-Saharan Africa: Remote Sensing for Index Insurance" began with extensive research of the sector. This research formed the basis for identifying the most promising remote sensing approaches for use in index insurance: rainfall estimates, soil moisture estimates, evapotranspiration estimates, vegetation indices and Synthetic Aperture Radar (SAR) data.

Following this effort, seven remote sensing service providers (RSSPs) with experience in the different approaches were selected for participation in the project: Environmental Analysis and Remote Sensing (EARS), Famine Early Warning Systems Network (FEWS NET), GeoVille, International Research Institute for Climate and Society (IRI), Faculty of Geo-Information Science and Earth Observation (ITC) at the University of Twente, sarmap, and the Flemish Institute for Technological Research (VITO), which also acted as the project's technical coordinator.

The RSSPs used different methodologies to develop index structures. These aimed to cover losses of maize, groundnut and millet in Senegal within three typical smallholder farming areas of 20 km x 20 km, known as regions of interest (ROIs) (see Figure 1).[5] Senegal was chosen as a good country in which to test the remote sensing indices because of the variability of its weather and climate patterns and its favourable operational conditions, which were conducive to carrying out the project. However, the findings are intended to inform the sector more broadly on the use of remote sensing for index insurance.

[5] One area, Diourbel, did not include maize because it is not grown there.

Figure 1. Project regions of interest in Diourbel, Nioro and Koussanar



The structures designed were not commercialized as insurance contracts, but their performance was assessed over two seasons against ground data collected in each ROI for the project. The methodologies were evaluated by a multidisciplinary evaluation committee to produce findings and recommendations on the performance of the different indices to depict yield loss accurately due to weather and other perils (depending on the remote sensing approach), and on the operational feasibility of mainstreaming remote sensing in index insurance operations. The project focused on index insurance for smallholders at the micro level (see Box 3).

Box 3. Index insurance levels

Indices could be used in operational insurance schemes delivered at the micro level or, in more aggregated forms, at the meso level. Even if index insurance is distributed through aggregators, it is classified as a micro-level index insurance when the policyholder is the farmer. This means the smallholder is directly covered and would see a direct benefit from the insurance coverage even if the insurance product itself might be bundled with other financial and non-financial services. This structure is the most common internationally, and it is different from meso- and macro-level index insurance.

Meso-level index insurance – where an entity such as a microfinance institution is the policyholder and is responsible for decisions on distribution of payouts – is of much interest, but there are currently very few operational examples. African Risk Capacity (ARC), where the government is the policyholder, is an example of macro-level index insurance. Both meso and macro schemes can have indirect or direct benefits for a smallholder farmer, depending on the design.*

*The different index insurance levels are further outlined in IFAD-WFP, 2011.

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5. Remote sensing approaches for index insurance

The most promising remote sensing approaches for index insurance, as identified at the beginning of the project, included rainfall estimates, soil moisture estimates, evapotranspiration estimates, vegetation indices and SAR data. Using different methodologies, index insurance structures and associated products were developed and assessed for the project based on each of the selected approaches outlined in this section.[6]

Rainfall estimates

Despite the fact that rain gauges provide highly accurate local information, they are often too scarce and unevenly distributed to achieve accurate analysis of rainfall patterns in space and time.[7] While building out a dense network is expensive and requires ongoing funding for maintenance, satellite-based rainfall estimates (RFEs) may offer a solution to overcome this problem. Most RFE products are available on a daily basis and provide a time series of more than 30 years. The spatial resolution varies from roughly 4 km to 25 km. However, it is important to recognize that satellites do have their own shortcomings, such as not being able to measure precipitation directly.

The main strengths of satellite RFEs are that they provide good spatial coverage, including remote areas, and that they can be freely available. Applications include drought monitoring and early warning, flood modelling, wetland monitoring and irrigation management. RFE-based index insurance products are comprehensible and relatively easy to explain to smallholder farmers as they are closely related to measured rainfall. Another advantage is the availability of a long RFE time series going back up to 35 years.

However, the rainfall estimated from satellite products is derived from the detection and measurement of clouds, and can thus be inaccurate for a single pixel on a specific day. Excess cloud cover often makes it more complicated

[6] Except for SAR data, which were used for testing mapping.

[7] Washington et al., 2006: In Africa, the density of weather stations is only about 15 per cent of that recommended by the World Meteorological Organization.

for satellites to track a specific weather system. Rainfall, especially in Africa, is extremely variable, and a single event might cover only a few kilometres. Additionally, satellite RFEs will generally record fewer high rainfall events and more low rainfall events than raw gauge data, and they tend to underestimate extreme rainfall compared with gauges. Ten-day or monthly RFEs are more accurate than daily RFEs because there is significant uncertainty in an individual rainfall estimate, which is true of both gauge or satellite sources.

RFEs are used in operational index insurance schemes, particularly those designed by IRI in Africa. RFEs are only suited for insurance against drought-related damage to crops. There is no direct link between RFE and crop yield, and distribution of rainfall timing in the growing season is very relevant; hence, appropriate modelling is required to determine whether a suitable relationship can be identified. Another drawback is the coarse spatial resolution of the RFE products (5 km to 25 km) and the fact that the performance of different RFE products varies over space and time.

Soil moisture estimates

Moisture in the soil determines crop growth and agricultural production. Observations from both active and passive microwave satellites can be used to map soil moisture in the upper soil layer (< 5 cm) (Srivastava et al., 2016). Most soil moisture products are available on a daily basis. The spatial resolution of the global products ranges from 1 km to 50 km. However the 1 km Sentinel-1 soil moisture product was not available at the time of the project. Due to the natural variability in rainfall, topography, soil characteristics and vegetation properties, soil moisture may vary considerably from one location to another and from one moment to another in the season. Due to this natural variability in soil moisture content and local variability in the performance of the satellite-based soil moisture algorithms, the quality of the global soil moisture products (especially the older ones) may be quite variable (Dorigo et al., 2015).

Soil moisture, as measured by remote sensing techniques, represents only the first few centimetres of the soil. However, for agricultural monitoring, a representation of root-zone soil moisture is more important. Therefore, the Soil Water Index was developed by the Vienna University of Technology (TU Wien) (Wagner, 1998) in the late 1990s to represent the soil moisture content in the first metre of the soil. A revised version of the product is made available in near real-time by the Copernicus Global Land Service.

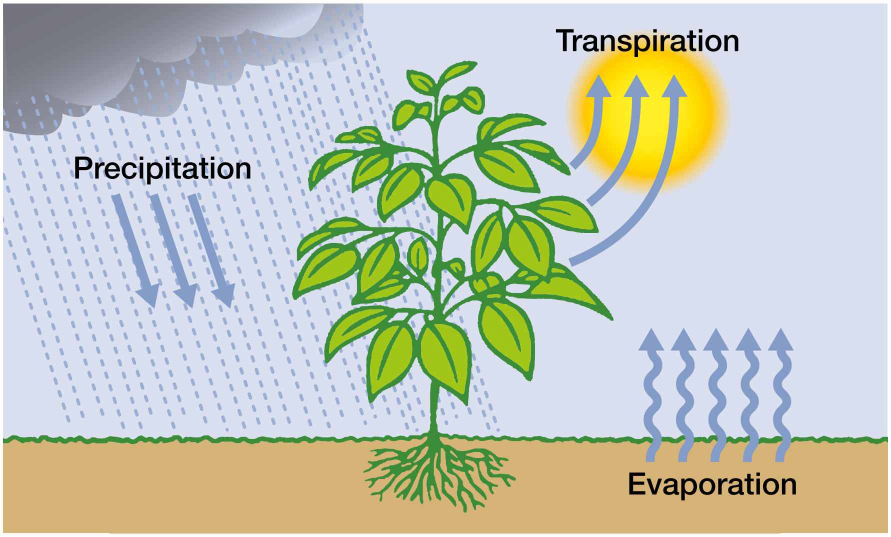
Satellite-based soil moisture data support the monitoring of droughts, floods and wetlands, and they are frequently used as input for water and irrigation management. Thanks to the availability of long time series, soil moisture data are also often used for climate studies.

Soil moisture data are not yet used in operational index insurance schemes, although they could have potential. Soil moisture-based index insurance products are comprehensible, and they may be relatively easy to explain to smallholder farmers. Another advantage for building insurance products is the availability of a long time series of data. However, just like RFEs, soil moisture products are only suited for insurance against drought-related damage to crops. It is assumed that lower soil water content leads to a reduction in vegetation activity and hence reduced crop yields. Other drawbacks include the coarse spatial resolution and the variable accuracy of the global soil moisture products.

Evapotranspiration estimates

Evapotranspiration (ET) is the sum of evaporation and plant transpiration from the earth's land and ocean surfaces to the atmosphere (see Figure 2). Evaporation accounts for the movement of water to the air from sources such as the soil, canopy interception and waterbodies.

Figure 2. Evapotranspiration



Source: www.salinitymanagement.org.

Evapotranspiration can be calculated in different ways: as actual ET (ETa), which is the amount of water that evaporates from the surface and is transpired by plants if the total amount of water is limited; or as relative ET (ETr) to provide an indication of plant-available water in the root zone, which can be considered as a measure of actual plant water use.

Evapotranspiration products are usually made available on an 8- to 10-day basis. The spatial resolution varies from roughly 1 km to 3 km. Depending on the satellite observations used, the time series can go back up to 35 years.

Evapotranspiration is a good indicator for agricultural drought. The Food and Agriculture Organization of the United Nations (FAO) addressed the relationship between crop yield and water use in the late 1970s, proposing a simple equation where relative yield reduction is related to the corresponding relative reduction in evapotranspiration (Steduto et al., 2012).

Evapotranspiration is a key variable that plays a strategic role in the fields of water resource management, agriculture, ecology and climate change. ET products generated by FEWS NET are used for African agricultural drought monitoring and food security status assessment.

Since 2011, EARS has developed and provided crop-specific insurance products based on evapotranspiration for maize, wheat, rice, beans and cotton in Benin, Burkina Faso, Kenya, Mali, Rwanda and Tanzania.

Vegetation indices

Optical satellite data from sensors such as SPOT-VGT, Proba-V, NOAA/METOP-AVHRR and MODIS have been used for many years by the public sector to monitor and map vegetation anomalies over large areas and to assess major damages caused by extreme climatic conditions. Thanks to their frequent availability, these images are useful for monitoring crop growth and development. One drawback is their rather coarse spatial resolution with pixel sizes varying between 250 m and 1 km. Increasingly, high-resolution images (10-20 m) are becoming available, but the time series, which are currently less than 10 years old, are still too limited for high-resolution agricultural monitoring. Crop monitoring with optical satellite images can be hampered by persistent cloud cover, though special techniques such as profile smoothing or data fusion may offer a solution to overcome this problem.

The best-known vegetation index is NDVI. NDVI is a good indicator of the amount and the condition of vegetation. More advanced indicators include fAPAR and the Leaf Area Index (LAI). Compared with NDVI, these model-based, biophysical variables often show a better correlation with crop yield and primary production. Due to its sensitivity to vegetation stress, fAPAR is one of the drought indicators often used by the Joint Research Centre's European Drought Observatory.

Insurance programmes based on vegetation indices are implemented on a sizeable scale in Canada, Ethiopia, India, Kenya, Spain and the United States. In most cases, these are grassland or livestock products insuring against drought, although similar products for crops are also being developed in Ethiopia with the support of ITC.

As it is a good indicator of vegetation vigour (or health) and yield, NDVI is suitable for index-based insurance to provide cover against drought or other perils that are impacting crop yield (e.g. those pests or diseases that have a visible impact on plant health). The relationship between NDVI and crop yields, however, is highly variable, depending on crops and regions. It also assumes that sufficiently long time series of accurate and preferably fine-scale yield data are available for calibration, which, in practice, may be problematic, especially in developing countries.

Synthetic Aperture Radar data

Synthetic Aperture Radar (SAR) data are frequently used for crop mapping, but they can also be used for monitoring crop growth and development. SAR systems can penetrate clouds, which is an advantage when monitoring crops in areas that are frequently covered by clouds. SAR images provide information on a crop's structure, unlike optical images, which provide information on its health. By taking advantage of the particular sensitivity of SAR-to-surface roughness and moisture content, additional information about soil preparation can be discovered. For example, by monitoring changes in surface roughness, soil tillage and/or crop-specific field activities can be detected. SAR data are frequently used to monitor rice in Cambodia, India, Indonesia, Thailand, the Philippines and Viet Nam. Insurance products using SAR were developed for South-East Asia in collaboration with sarmap as part of the RIICE project (see www.riice.org).

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6. Overview of the methodologies

The remote sensing service providers EARS, FEWS NET, GeoVille, IRI, ITC, sarmap[8] and VITO each used a different methodology to develop index insurance structures and associated products based on the remote sensing approaches identified and outlined in Section 5: rainfall estimates, soil moisture, vegetation indices, evapotranspiration and SAR.

Index insurance structures

Six RSSPs developed indices to be used for insuring against the impact of drought, or drought and other perils, on the yields of the selected crops in the chosen cropping areas in Senegal. The project requested each RSSP to:

- analyse the risk profile of each of the three regions of interest (ROIs) in Senegal
- develop remote sensing indices for covering the selected crops against drought, or drought and other perils (depending on the capability of the methodology)
- use the indices developed to create insurance structures to test in two crop seasons (for background, Box 4 gives an overview of the basic rules for converting an index into an insurance structure)
- analyse the possibility of segmenting the ROIs in UAIs – different areas under which all policyholders are grouped.

[8] In the project, sarmap was asked to concentrate on developing maps and start of season indicators.

Considering the project's overall goal to contribute to scalable and sustainable approaches to index insurance and to evaluate the feasibility of remote sensing for index insurance to benefit smallholder farmers, the methodologies were evaluated on:

- the performance of the different indices to accurately depict yield loss at the village level due to weather and other perils
- the operational feasibility and implementation needed to mainstream remote sensing in index insurance operations.

The performance assessment of the index structures developed by the RSSPs consisted of two parts: historical performance and product testing. Historical performance analysis aimed to show how well the methodologies were able to replicate the loss of crops over past years in specified areas. Product testing gauged how well the methodologies were able to "predict" losses, analysing and assessing their performance during the two test seasons compared against data specifically collected by the project.

The operational applicability assessed the general features of the methodologies. The applicability of different methodologies for index insurance for smallholders was evaluated based on the following criteria:

- availability and source of base data and supplementary data/information
- cost and sustainability of data acquisition, data processing and product development
- ownership and transparency of methodologies
- general performance and suitability.[9]

[9] The specific outcomes of the performance assessment, its evaluation, and the evaluation on operational applicability can be found in IFAD-WFP, 2017. Overall conclusions and recommendations are included in this publication.

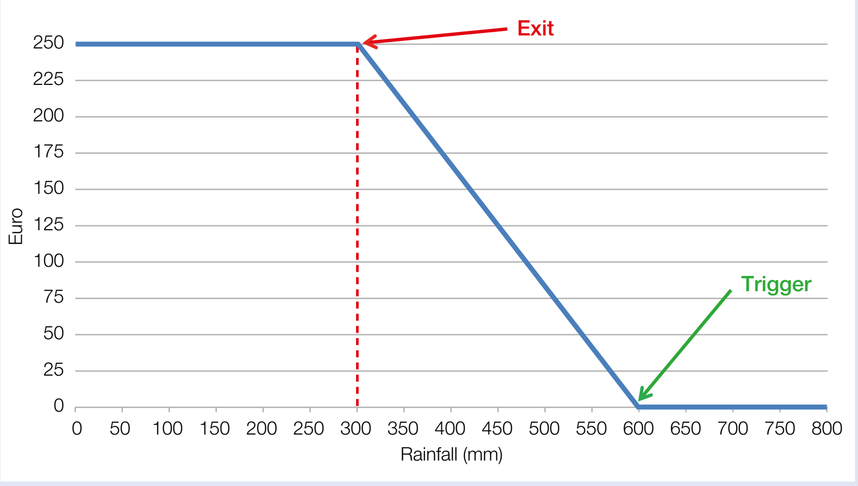
Box 4. Setting index insurance parameters

The objective of index insurance product design is to develop an index that effectively captures the relationship between the indexed variable and the potential crop loss, and to then define the structure that is most effective in providing payouts when losses are experienced, reducing basis risk as far as possible.

To convert an index into an insurance structure, it is necessary to set the rules that regulate the provision of payouts. This means defining:

- the maximum payout: highest payout that the contract can provide
- the trigger (or strike): threshold above or below which payouts are due
- the exit (or limit): threshold above or below which no additional incremental payout will be applied
- the tick (or tick size): incremental payout value per unit deviation from the trigger.

Example of index insurance payout structure



This figure presents an example of the definition of such parameters for a simple rainfall-deficit index insurance structure:

- the maximum payout is set at €250
- payouts are provided any time the cumulative precipitation falls below 600 mm (trigger = 600 mm)
- the maximum payout is provided for rainfall levels of 300 mm or below (exit = 300 mm)
- given a maximum payout of €250, a trigger of 600 mm and an exit of 300 mm, the monetary value of each deficit mm of rainfall below the trigger is: €250/(600 – 300 mm) or €0.8333 per mm (tick = €0.8333 per mm).

Official yield statistics, including underlying field data, from 2001 to 2012 and qualitative information sets were made available to the RSSPs to facilitate the design and the calibration of the index insurance structures. To harmonize the products for evaluation and make them more comparable, all RSSPs then adjusted the parameters of their products to have a fixed expected loss cost (ELC) per crop (see Box 5). These "fixed ELC products" were the basis for assessment and evaluation of performance.

Box 5. Expected loss cost

The expected loss cost (ELC), also known as the pure risk premium, can be calculated by taking the average of the potential historical payouts that would have been provided by the contract structure in the observed period. The ELC is a key component of the final premium that is charged to the insured party. It is, therefore, an important variable to be considered in the evaluation of the feasibility of an insurance proposition.* Index insurance structures developed through different methodologies can be more comparable if carried out for products that have similar premium costs (i.e. all things being equal, an insurance product with a higher ELC would be more expensive as it would provide larger and more frequent payouts).

* The final commercial premium has to be loaded to include uncertainty in the data, the cost of reinsurance, insurer's margins (including distribution and overhead costs), and any other cost of doing business.

There are many ways to structure index insurance products since the design depends on the variable to be indexed, on the object of the coverage and on various operating conditions. The design options presented in Table 1 have a critical influence on the nature of the insurance product to be offered, and they were part of the design options for the products developed by the RSSPs.

Table 1: Product design options for crop index insurance

Product parameter	Options	Explanation
Indexed variable (based on remote sensing)	Input-based (e.g. rainfall) Output-based (e.g. yield or yield proxy)	In remote sensing-based index insurance, the index focuses on either the input or the output side of the crop production process. Input-based methodologies – such as rainfall estimates and soil moisture – look strictly at the impact of drought on crop production and focus on an input variable (rainfall); other sources of production risk (e.g. pests and diseases) are not considered. Output-based methodologies – such as vegetation or evapotranspiration indices – look at variables connected to output (amount of vegetation, evapotranspiration, etc.), and therefore are likely to match more closely with yield variations generated by drought and by other sources of risk.*
Triggering measurement for indexed variable	Cumulative Average Maximum Minimum	How the trigger point is determined can be defined in different ways. The measure of the observed variable can be cumulative (e.g. sum of millimetres of rainfall over a defined period); an average over a period of time (e.g. average temperature); or a maximum or minimum value to be reached in order to generate a payout (e.g. high or low temperatures).
Period covered by index	Entire life cycle of crop Fractions of crop life cycle	The insurance product can cover the entire crop calendar, from sowing to harvest, or just concentrate on specific portions of the crop life that are exposed to specific types of risks (flowering, maturity, etc.).
Start of coverage period	Fixed Dynamic	The possibility of developing a dynamic start of the crop season is particularly relevant where the start of certain agricultural activities and planting is strictly linked with the occurrence of determined environmental conditions. For some types of insurance products, if the coverage period and the crop calendar are not synchronized, the likelihood of an increase in basis risk is very high. More information on identifying start of season dates is found in Box 6.

Product parameter	Options	Explanation
Number of phases into which covered period is divided	Typically 1-3 phases	Together with the dynamic start provision, a contract feature that accounts for the progression of the index variable in the different parts of the crop calendar may improve the performance of the insurance structure. The crop life cycle can be segmented into different phases, each with its own index and defined period, which avoids the overall cumulative value of the index hiding damages resulting from events in a specific phase of crop development. The actual structure of a phase contract is crop/variety- and location-dependent.
Payout structure	Incremental Lump sum (single value payout)	The payout triggered by an index structure can be incremental, as in the case presented in Box 4 where the damage is considered to be progressively more severe as the deviation from the trigger increases; or it can provide a lump sum payment in case an all-or-nothing type of event is covered, such as cases in which reaching a particularly sensitive threshold (e.g. a critical temperature) generates a total loss.

* Since the causes of loss recorded in the project analyses were mainly related to rainfall deficit, the performance assessment of input-based methodologies is unlikely to have been negatively affected by the occurrence of loss events different from rainfall deficit.

The remote sensing service providers EARS, FEWS NET, GeoVille, IRI, ITC and VITO used different methodologies to derive the indices and selected product design options to design the contract structures:

- **EARS methodology**. Relative evapotranspiration, calculated from Meteosat data via the Energy and Water Balance Monitoring System (EWBMS), is used to develop the insurance product. The strike and exits of the insurance product are defined based on the relative evapotranspiration and the start of the growing season.
- **GeoVille methodology**. The GeoVille insurance product is based on soil moisture estimates derived from the European Remote Sensing satellite (ERS) and the Advanced Scatterometer (ASCAT) microwave observations. The payouts are based on the soil moisture deficit (the difference between the long-term average and the respective year's soil moisture conditions) for the specific crop life cycle range, which is the period that is determinative for crop yield.

- **FEWS NET methodology**. MODIS Land Surface Temperature 8-day composites are used as a principal input to a simplified surface energy balance model that estimates actual evapotranspiration (ETa) at the land surface. This information is aggregated over the FAO-based cropping calendar for Senegal for the different crops (maize, millet and groundnuts). Vulnerability functions are defined based on drought risk profiles of the crops. These vulnerability models calibrated per crop over the different ROIs form the basis of the insurance contracts.
- **IRI methodology**. The IRI index design process is based on measuring rainfall during key periods in the growing season. Remotely sensed rainfall estimates are analysed over different periods to best represent the adverse years in Senegal. The index is based on the amount of rainfall in a specific period of the growing season for the different ROIs.
- **ITC methodology**. Based upon the historical SPOT-VEGETATION NDVI data, three crop maps (for millet, maize and groundnuts) are generated for Senegal. At the village level, these maps are used to extract temporal NDVI profiles for the different crops. The (detrended) NDVI values, accounting for a variable start of the growing season, are then used together with village yield values to develop crop-specific yield models for Senegal. The yield estimates per pixel, aggregated afterwards at the ROI level, are used to define the insurance coverage.
- **VITO methodology**. Region- and crop-specific yield models are set up based on combinations of vegetation indices (fAPAR derived from SPOT-VEGETATION/Proba-V data) and rainfall estimates aggregated over critical periods during the growing season. Yield statistics are used to calibrate these models. The yield estimates generated by the models form the basis of the insurance contracts.

The methodologies used and contract structures generated formed the basis of performance assessment and evaluation. Most of the indices developed are crop-specific, divided into fractions of crop life cycle (vegetative, flowering, yield formation) and calibrated using historical yield statistics (department- and village-level).[10] All products adopt a cumulative measurement for triggering a payout and have an incremental payout structure (i.e. the larger the deviation from the trigger, the larger the payout). The different remote sensing methodologies and product design options are outlined in Table 2.

[10] The department is an administrative area and is the official data collection unit of the *Direction de l'Analyse de la Prévision des Statistiques* of the Ministry of Agriculture in Senegal, which is responsible for collecting agricultural statistics. The project also acquired the field-level crop yield data that form the basis of the department statistics.

Table 2. Overview of remote sensing methodologies and product design options

Remote sensing service providers	Overview of remote sensing methodologies			
	Type of remote sensing product/approach	**Remote sensing data used (including spatial resolution)**	**Type of index (input- or output-based)**	**Index target**
EARS	Relative evapotranspiration (ETr) Start of season based on ETr	MSG-based ETr (3 km × 3 km)	Estimation of yield deficit (output-based)	Crop-specific
GeoVille	Radar-based estimation of soil moisture Start of season detection based on Soil Water Index	ERS (25 km x 25 km) resolution and METOP ASCAT (25 km x 25 km)	Soil moisture deficit (input-based)	Generic
FEWS NET	Actual evapotranspiration (ETa)	MODIS-based ET (1 km × 1 km)	Estimation of yield deficit (output-based)	Crop-specific
IRI	Rainfall estimates (RFE)	NOAA-based RFE ARC2 (10 km × 10 km)	Rainfall deficit (input-based)	Generic
ITC	Vegetation indices (NDVI)	SPOT-VGT/Proba-V NDVI (1 km × 1 km)	Estimation of yield deficit (output-based)	Crop-specific
VITO	Vegetation indices (fAPAR) Start of season estimation based on rainfall estimates	SPOT-VGT/Proba-V fAPAR (1 km × 1 km) and TAMSAT rainfall estimates (4 km × 4 km)	Estimation of yield deficit (output-based)	Crop-specific

Note: ARC2 = Africa Rainfall Climatology version 2; ASCAT = Advanced Scatterometer; EARS = Environmental Analysis and Remote Sensing; ERS = European Remote Sensing satellite; ETr = relative evapotranspiration; fAPAR = fraction of Absorbed Photosynthetically Active Radiation; FEWS NET = Famine Early Warning Systems Network; IRI = International Research Institute for Climate and Society, Columbia University; ITC = Faculty of Geo-Information Science and Earth Observation, University of Twente; METOP = Meteorological Operational Satellite; MODIS = moderate-resolution imaging spectroradiometer; MSG = Meteosat Second Generation; NDVI = Normalized Difference Vegetation Index; NOAA = National Oceanic and Atmospheric Administration; PROBA-V = Project for On-Board Autonomy – Vegetation (satellite); SPOT-VGT = Satellite Pour l'Observation de la Terre Vegetation; TAMSAT = Tropical Applications of Meteorology using SATellite Data and Ground-based Observations; VITO = Vlaamse Instelling voor Technologisch Onderzoek (Flemish Institute for Technological Research).

Product design options		
Period covered	**Number of phases**	**Start of coverage period**
Entire crop life	One or three phases	Dynamic
Growing phase	One	Dynamic
Entire crop life	One	Fixed
Two fixed windows at beginning and end of crop cycle with an interval in the central part of the covered period	Two	Fixed
Entire crop life	One	Dynamic
Entire crop life	One	Dynamic

Box 6. Identifying start of season

The start of season (SoS) date is an important parameter that is frequently adopted in the design of index insurance for crops. SoS can be identified with the time of sowing or with the time of plant emergence. Index contracts can include specific provisions aimed at synchronizing the insurance coverage with the actual crop calendar (e.g. the contract coverage can be bound to start when precipitation reaches a specific rainfall threshold per day or per dekad – a 10-day period). The remote sensing service providers EARS, GeoVille, sarmap and VITO tested methodologies based on different approaches to determine whether they were able to capture the SoS date correctly.

Field explorations indicate that, due to changes in climate patterns and to potential issues in the supply of inputs, the sowing windows tend to be less predictable than in the past. Therefore, adopting input-based remote sensing approaches that actually monitor the situation on the ground may yield more accurate results than establishing the SoS based on output-based remote sensing approaches in specific time periods.

Unit areas of insurance

In designing index insurance, one fundamental issue is the identification of the unit area of insurance (UAI). The UAI is the geographical area within which the specific index is applied and where policyholders pay the same rates of insurance premium and are entitled to receive the same unitary payouts.

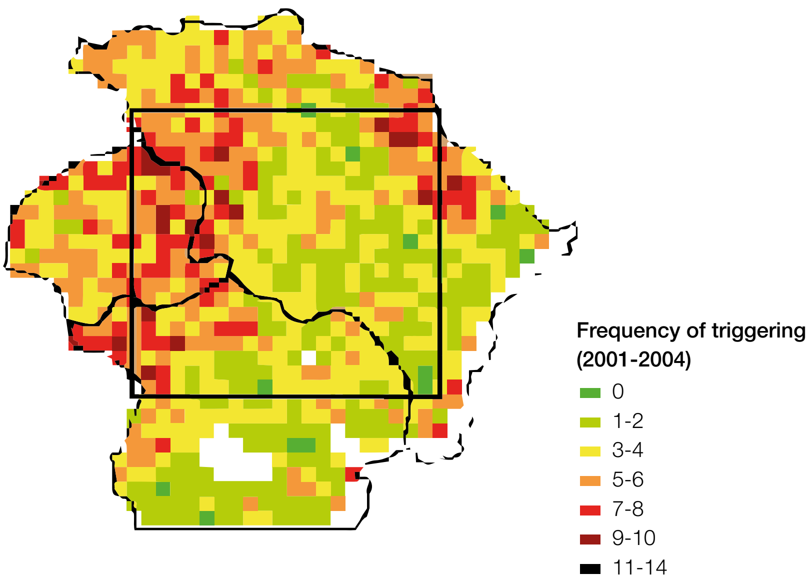
When developing indices based on ground station weather data, the area to be covered by a specific index is delimited based on the characteristics of local weather patterns. In these cases, the UAI is usually represented by circles of different radii, typically from 5 km to 20 km, depending on the climatological features of the area.[11] With remote sensing, the spatial building block is the pixel, so UAIs can be developed as an aggregation of pixels, depending on the resolution of the remote sensing methodology. While high-resolution data may be extremely effective in mapping, zoning and classifying the risk profile in full detail, the final indices developed for insurance applications need to spatially cover a significant portion of the selected areas that will be defined as the UAI. The identification of UAIs that are too small would conflict with the principles of index insurance.[12]

[11] Depending on the orography – elevated terrain – of the area, the UAI can also take different shapes.

[12] This condition is by no means implying that operating insurance on smaller areas is not possible or not advisable, but only that this would make the products closer to individual farmer crop insurance contracts, which were not the specific focus of the project. At the same time, it is also worth recalling that basis risk may increase as the size of the UAI increases.

In the project, the RSSPs were asked to analyse whether they would segment each of the ROIs into more than one UAI (see an example in Figure 3) based on the spatial homogeneity of the areas examined.

Figure 3. Payout frequency map



Note: The figure shows the payout frequency map for groundnut in Nioro for the regions of interest (ROIs) (square in black line) developed by VITO, one of the remote sensing service providers. It indicates how many times the index triggered at pixel level in the period 2001-2014, and it seems to suggest that the left section of the ROI has a more pronounced risk profile. Accordingly, the ROI could be segmented into different unit areas of insurance.

Crop maps and masks

Satellite images are frequently used to map cultivated areas (cropland) or to map specific crop types.

Cropland or crop-type maps are images whereby a class (either cropland or a specific crop) is attributed to each pixel. Such maps can be used to locate specific crops or cropland. Highly detailed cropland maps can be used to unmix the signal of less detailed satellite images. The maps can also be converted to masks whereby a single class is extracted from the map. Such masks can be used to perform class-specific analyses (e.g. crop-specific monitoring or insurance product development).

One RSSP, sarmap, was specifically requested to develop maps based on SAR data[13] for the different ROIs in Senegal. The goal of this exercise was to analyse whether, within the ROIs:

- the cultivated areas could be mapped
- different crop types could be mapped
- how these maps could be used to improve the insurance products (e.g. developing crop-specific products, definition of UAI).

During their development of indices and structures, some of the other RSSPs also developed and/or used maps and masks. In contrast to sarmap's, theirs were based on optical satellite data. ITC produced three maps that indicate the respective growing areas for millet, groundnut and maize. These were also used to generate the crop-specific NDVI data used as input for model development. FEWS NET also used the maps produced by ITC for deriving crop-wise drought vulnerability and payoff functions. VITO applied a cropland mask to limit the analysis to cropland areas.

13 sarmap used COSMO-SkyMed data (3 m × 3 m) from the Italian Space Agency and Sentinel-1A images (20 m × 20 m).

The effect of integrating cropland or crop-type information in index structures was not a specific focus of the performance analysis or evaluation of the project. However, the overall product performance analysis did point towards the integration of crop-type maps, and to a lesser extent cropland maps, having a positive influence on the performance of the insurance products, particularly in regard to crop-specific indices. This effect might be due to the fact that some of the products performed better in areas where one crop is dominant, which creates a clearer remote sensing signal versus those signals from mixed crop zones where performance was poorer.

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7. Findings

Overall findings were drawn from the results of the detailed assessment and evaluation exercises, which were designed by the project to assess the feasibility of remote sensing for index insurance. The project findings are divided into three areas:

- performance of remote sensing methodologies applied in the project
- technical features of index insurance structures based on remote sensing data
- operational applicability of index insurance schemes based on remote sensing data.

Performance of remote sensing methodologies

The project conducted two stages of performance assessment of the remote sensing methodologies: (i) historical performance analysis; and (ii) product testing. Analysis of the historical performance of index insurance products was made using historical yield datasets. The product tests took place over two seasons during the project, where performance was analysed using yield data collected for the project. The overall findings drawn from the performance assessment are as follows.

1. The lack of appropriate yield data and ground information is one of the primary challenges in designing and testing index insurance

With the focus on satellite data, there is a tendency to overlook the critical role of appropriate ground data, particularly yield data, needed to design, calibrate and validate indices. Drawing reliable and significant conclusions on the use of different remote sensing products for index insurance requires a significant amount of good quality historical yield data and ground information at levels of spatial aggregation matching the requirements of the methodologies adopted. In developing countries, suitable datasets are often not available. This finding was highlighted by challenges in the availability of appropriate yield data experienced in the project – and, in particular, the yield benchmarks used for index design, calibration and product testing – which were not of the ideal aggregation level with respect to the selected ROIs. As a result, despite the accuracy of the methodological procedures adopted, the project results are characterized by a degree of uncertainty due to the lack of ideal sets of yield data.

2. Product design has a critical influence on performance

Product design significantly influences the capabilities of the remote sensing methodologies to capture productivity losses. Some of the RSSPs modified their design between the tests in year one and two, which significantly improved the performance of their structures. Further product design improvements could be expected in operational schemes where an RSSP might have the opportunity for additional field explorations and interactions with local experts.

3. Project analyses show that, overall, the historical performance of the index insurance structures is suboptimal

Although historical performance is not a guarantee of future behaviour, the analysis of historical performance can provide clues on how the indices relate to crop variability. The main findings of the historical performance analysis are:

- (i) Despite the relevant differences between the products of the various RSSPs, the ability of the remote sensing index structures to track the historical loss patterns of the crops in the test areas is suboptimal.
- (ii) The significant limitations in the available yield benchmarks make it difficult to generate definitive and objective statements, and the modest performance of the index structures may, in part, be attributed to the nature and the aggregation of the yield data.

It is important to note that these findings cannot be generalized, since they apply only to the cases explored in the project, and that more relevant indications on the performance of the index structures are provided by the product testing analysis.[14]

4. Crop maps and masks can improve performance

Some of the RSSPs adopted or developed maps and masks with the objective of identifying land use and exploring the possibility of differentiating between various crops. In addition, one of the RSSPs was specifically requested to carry out dedicated explorations on the use of SAR data for mapping land use and crops. The rationale behind the focus on mapping is that some of the project methodologies could generate more effective results if they were able to segment areas to be monitored, particularly those that estimate the field performance of crops, such as approaches based on vegetation indices and evapotranspiration.

[14] A full breakdown of different results from the product testing and the historical performance analysis can be found in IFAD-WFP, 2017.

Combining crop mapping or masking with another remote sensing methodology might enable the development of more crop-specific index structures. The crop-specific insurance products that are available today integrate information on cultivated areas or typical growing areas for a certain crop, but only to a limited extent. Currently, no information is available on the exact location of the insured crops. A major contribution to the improvement of the insurance structures could come from annually updated crop-specific maps. However, it would also add complexity to the data processing carried out by the RSSPs to create the index insurance contract structures.

5. Methodologies based on vegetation indices seemed to track loss histories more accurately. The use of crop maps and masks and the combination of remote sensing approaches may have contributed to the relatively better performance

The two methodologies based on vegetation indices used crop maps or masks to discriminate which parts of the ROIs were to be monitored in the index structure. Doing so may have had a relevant impact on their performance. In addition, one such methodology adopted a hybrid approach, combining a vegetation index with rainfall estimates. It is unclear whether the improved performance is mainly due to the actual response of the vegetation indices and the fact that they operate at higher resolutions than the input-based methodologies, or whether the use of crop maps or masks and the synergy between different remote sensing approaches play a relevant role. It would, therefore, need future research.

6. Product tests indicate that the index structures developed would not have tracked yield variability to a satisfactory level

Data and information collected on the ground in 2013 and 2014 provided a useful but limited testing opportunity since they had not been used for product design. They can, therefore, be considered for an independent "predictive" test. However, there were a high number of mismatches between index-triggered payouts and when a payout should have been expected.

These mismatches were particularly pertinent for the year 2014, which the on-the-ground monitoring reports indicate as a loss year and, therefore, one of the years in which the index structures would need to perform accurately.[15]

[15] However, it is also true that the interpretation of the testing analysis is complicated by the potential source of noise embedded in the yield references.

7. Performance of the remote sensing methodologies developed for the project varies across different crops and areas

The index insurance structures perform differently for the different selected crops and in different test sites. These indications reinforce the notion that the evaluation findings for such a complex testing activity are hard to generalize and are largely dependent on the specific operating conditions. Setting up similar tests in other areas and in other environments may further enhance the understanding of the specific potential of each of the tools examined.

8. Remote sensing methodologies can be usefully adopted for identifying key stages of the crop life such as the start of season (SoS) or the end of season (EoS) date

Index contracts can include specific provisions aimed at synchronizing the contract with the actual crop calendar so that the coverage starts when the crop enters the required growth stage. The project compared the SoS estimates derived by remote sensing with the field observations compiled by the monitoring institution and demonstrated the ability of some of the methodologies to detect the actual start of the growing season. Remote sensing technology could also be used to detect SoS in contract structures based on data measured on the ground.

Technical features of insurance structures

Beyond the performance of the specific methodologies, the project generated overall findings on the technical features of index insurance structures based on remote sensing data.

1. Yield variability between individual farmers in the ROIs can create challenges in operating index insurance

Yield and yield loss constituted the benchmark for measuring performance of the indices designed. Since farmers in the ROIs generally adopt low levels of farm inputs (such as fertilizer) and do not farm intensively, yield variability is high. For the same reasons, the yield gap between actual yields achieved and potential yields with improved seeds and inputs is significant. In addition to yield differences attributed to farming practices, localized rainfall patterns can be markedly different, and yield shortfalls can also be caused by other risks such as pests, disease and floods.

2. Input-based and output-based methodologies offer different options for index insurance

Depending on the aim of the insurance policy, a decision needs to be taken on whether to use input- or output-based indices. Input-based indices, such as those using rainfall estimates and soil moisture, focus on the variables that influence production. They measure factors that act as determinants of crop growth and, ultimately, yields. Output-based indices, such as those based on evapotranspiration or vegetation indices, attempt to directly track changes in productivity. They work by receiving information from the actual ground conditions, such as crop vigour or transpiration. Output-based measurements reflect the average measurement over pixels where there could be a wide mix of crop types and other land cover typical of smallholder agriculture. In contrast, the data used in input-based methodologies are much less dependent on the actual ground conditions. In index insurance, input-based indices would be expected to proxy the expected yield loss due to drought (e.g. rainfall or soil moisture-based indices), while output-based indices (e.g. evapotranspiration or vegetation-based indices) would be expected to proxy yield loss caused by a wider range of perils.

3. Smallholder farms create a complex ground signal for interpreting output-based remote sensing methodologies

Larger-scale commercial farms (with large fields and continuous cropping areas) produce better remote sensing signals that more uniformly reflect the growth situation of a specific crop type. In contrast, smallholder farms have small field sizes, diversified crop types, different proportions of crop and other land cover, and yields vary widely among farmers and among villages. This situation creates a complex ground signal for output-based remote sensing interpretation, which measures the average value for the pixel.

4. The methodologies cannot discriminate between yield performance of different crop types in highly mixed cropping areas at a local (village) level

The development of crop-specific index insurance products requires more detailed information. For example, it requires knowledge of the exact location of the target crop type so that the satellite signal can be unmixed to obtain information for a single crop type. Such information is not usually available. Consequently, insurance products based on low-to-medium resolution indices generally perform better in homogeneous areas or in areas where different crops show similar reactions to drought, but their performance may not be as good in more complex environments. To address this element, dominant crop types have been estimated within some methodologies. In addition, index parameters (including inception dates and insurance windows) also require knowledge of SoS dates, crop types and crop maturity lengths. This requires knowledge of local farming practices, normal soil water balance, crop varieties and soil moisture holding capacities during the product design phase. Further, since mixed cropping and small field sizes predominate in smallholder farming, signals received by sensors are an average for several crops, even for higher resolution remote sensing. Thus, it may become difficult to design products that are specific to certain crop types, which is why some of the project indices were developed to be generic and not crop-specific.

5. A key dimension in operating index insurance is the accurate definition of the unit areas of insurance (UAIs)

Appropriate segmentation of the geographical areas covered by insurance contracts is extremely important; remote sensing methodologies can actually provide useful insights for the definition of spatially homogeneous areas that could benefit index insurance based on remotely sensed as well as ground data. Different methodologies will operate on various resolution scales, providing results of different accuracy, with potentially better risk profiling results the higher the resolution and the longer the time series available. The explorations carried out by the RSSPs provided interesting indications on risk distribution patterns within the ROIs, but they also highlighted the need to carry out more specific and dedicated activities to develop modelling approaches for risk segmentation.

6. There are key operational considerations in determining the appropriate size of unit areas of insurance (UAIs)

For example, registering farmers for insurance requires all clients to be allocated to a specific UAI. Doing so may not be practical at a high resolution because it implies a significant workload in geo-referencing individual clients. In addition, defining UAIs based on one or a few "high-resolution" pixels (i.e. smaller pixels), where values are sensitive and may differ from surrounding pixels, may actually increase the chance of anomalous payouts. In empirical terms, areas somewhere between 3 km x 3 km and 10 km x 10 km seem to be realistic. Where methodologies allow for higher resolution, appropriate aggregation of pixels should be used to determine suitable UAIs.

7. Basis risk remains the main concern to both insurers and insured farmers

The potential for basis risk is strongly influenced by the size of the UAI, by the uniformity of local yield losses experienced in a loss event, and by the ability of the methodologies to detect such yield losses. Index insurance products based on remote sensing technology (as with station-based WII and AYII) are best calibrated to provide payments in the most serious loss years, when crop yield loss can be expected to be very widespread and affects all farmers within the defined UAIs. Although remote sensing data are available over very wide areas surrounding the insured areas, it is the index performance within the specific UAI that dictates whether a farmer has suffered from basis risk. Insurance payouts that do not correspond to the true losses experienced by the farmer and are intended to be covered by the policy carry the danger of client dissatisfaction and reputational risk for the insurer and for all stakeholders. It is also a primary concern of the insurance regulator who protects consumer interests.

Operational applicability of schemes based on remote sensing

Ultimately, the use of remote sensing for index insurance will also depend on how easily such products can be incorporated into insurance schemes, given the current environment. With this in mind, the operational applicability of different methodologies for index insurance for smallholders was evaluated based on the following criteria:

- availability and source of base data and supplementary data/information
- cost and sustainability of data acquisition, data processing and product development
- ownership and transparency
- general performance and suitability.

Some broad findings from this evaluation on the programming features of index insurance schemes based on remote sensing data are outlined below.

1. Each of the methodologies tested fulfils the criteria of operational feasibility for insurance purposes

Each methodology could support index insurance contracts that are marketable to farmers and underwritten by insurance companies. As with any index insurance product, contract development would require normal operational and technical planning processes to be undertaken, such as identification of the target clients, definition of UAIs, analysis of pricing and payout options, and distribution and payout planning. None of the methodologies has barriers to implementation from an operational standpoint. Some of the approaches are currently used in index insurance, such as rainfall estimates, evapotranspiration and vegetation. Operationally, the same principles of index insurance apply to all methodologies, particularly decisions on grouping farmers into UAIs for registration, premium payment and payouts.

2. Two models currently exist for operationalizing remote sensing-based index insurance schemes: external service provision and transfer of capacity

End-users of insurance programmes based on remote sensing indices could be divided between: (i) insurers and their clients directly seeking remote sensing services in the market; and (ii) wider development initiatives normally driven by governments, international organizations and donors looking to develop in-country markets as part of financial inclusion, agricultural development, agricultural risk management, social protection, or climate change adaptation approaches.

Private-sector initiatives would tend to identify providers able to supply a complete package of products and services, allowing development and sale of index insurance products. Government and development initiatives are generally promoting the development of national capacity for index insurance involving public-private partnerships. In the latter case, the development of national capacity and capacity transfer assumes major importance. An early decision is needed to determine whether, based on timeline and strategy, index design and support should be fully or partially outsourced (for either the short or the long term), and/or whether technical capacity should be developed within the insurer and/or within technical institutions in-country, for both design and maintenance of index insurance products.

3. Availability of expertise and dedicated service providers is a key challenge

The technical competence needed to design insurance indices is high. Organizations would need to hire technicians spanning the fields of remote sensing, agriculture and insurance. It seems likely that ongoing support from international specialists would be needed, not least since there is so much development in remote sensing (e.g. in increased resolution and in skilled agricultural interpretation).

In scoping the market to set up the project, it was evident that there were few technical service providers with the relevant expertise and/or with an existing model able to support operations. Much development of remote sensing for agricultural development and risk management has been carried out by research or international organizations. However, they are not currently structured to provide sustained commercial services to meet the requirements and timelines of insurers, or may not have the expertise required for services to support index insurance. The availability and cost of expertise and of firms and organizations able to process remote sensing data, to design and calibrate indices, and to handle the organizational and technical planning of remote sensing index insurance is a significant constraint. Remote sensing technical service providers have only recently started to identify market opportunities.

4. Knowledge of land use, local farming practices, agronomy and agro-meteorology is necessary

Agriculture, soils and climate can bring about complex combinations in smallholder farming areas that affect agricultural production and the yields actually achieved by smallholder farmers. Additional local knowledge and data from the ground are therefore essential to inform the analysis developed by remote sensing methodologies for index insurance.

5. Remote sensing data are increasingly available, but there are constraints on supplementary data in terms of availability and cost

Access and cost no longer constitute a constraint for remote sensing data, whereas for supplementary data (e.g. yield data, meteorological data) this is more often problematic.[16] In addition, the increasing number of satellites in orbit and the various space agencies' policy of free data access are noteworthy.

[16] SAR data were not used for designing indices, but only for mapping purposes, and were less available at the time of the project. However, SAR is becoming more easily accessible and will be available at no cost with the launch of the European Space Agency's Sentinel-1 satellites.

Access to and cost of supplementary data, such as yield information, is a much more significant issue. While remote sensing methodologies are of particular interest in overcoming some constraints of ground data (especially yield data and meteorological data), supplementary data are still needed for validation and calibration. Time series of yield data are rarely available at a disaggregated level (e.g. village, subdistrict), and they are difficult to interpret due to high individual farmer yield differences in smallholder agriculture. Daily meteorological data are dependent on past station density and length of operation of stations. Collection of reliable rainfall data is a demanding task; and when historical data exist, their accessibility and affordability are frequently problematic. The availability and cost of supplementary data is therefore as important as the remote sensing data itself. Confidence in the quality of all micro-level index methodologies in the project is dependent on available supplementary data.

6. The insurance regulatory authorities need to be involved and have, generally, been supportive of initiatives for remote sensing index insurance provided that consumer interests are properly protected

Remote sensing applications for index insurance have, so far, been acceptable to regulatory authorities. The project confirmed that all the processing algorithms were available for audit in the event of a dispute, even when they were proprietary. However, regulators will find it more challenging to verify and approve products that are more complex to understand or that lack transparency, and they may require external support. All specific products must be approved for the specific programmes where they will be introduced; and each specific situation, with its specific methodologies, needs to be confirmed with the regulatory authorities in the country involved. Regulatory authorities are likely to be concerned with the protection of consumers and the independent confirmation of index outcomes.

7. Consumer education will be a key component for success

Although project activities did not include a retail component, it was assumed that it might be difficult to explain index insurance based on remote sensing to smallholder farmers. In reality, experience has shown that farmers will accept indices that are technically complex if they can rely on trusted organizations or key farmers in rural areas. However, the ultimate test of farmers' trust remains the ability of the index to provide appropriate payouts that match losses.

Educational campaigns are essential so that there is consumer awareness of how the index operates and consumers can understand what is and is not covered by the insurance policy. It is equally important that others in the insurance distribution chain understand the index and the principles of index insurance.

8. Access to reinsurance has generally ceased to be a limiting factor in starting index insurance programmes

There is an active international reinsurance market willing and able to provide reinsurance financial capacity, although technical support is rarely available. The interest of reinsurers is high, and there do not appear to be any technical or operational constraints to supporting any of the different methodologies tested in this project. Reinsurers' support will consider product design and data quality, as well as the business opportunity, insurer client assessment and other factors such as potential premium volume, reputational risk or portfolio diversification. A reinsurer's commitment to corporate social responsibility may also play a role in their involvement in index insurance schemes.

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8. Recommendations

Remote sensing is a powerful tool that could expand and improve index insurance and allow scaling up. To support this happening, governments, donors and the wider insurance community should consider the following recommendations.

I. Additional research and development activities should be supported to further improve the potential of remote sensing for index insurance.

The development community should support additional research and development activities, combined with dedicated monitoring and evaluation frameworks, to develop approaches that provide an acceptable performance level. Spatially diversifying the scope of testing and evaluation activities is also important since the performance of remote sensing-based methodologies varies across crops and areas.

II. Further investment should be made in ground data collection protocols, capacity and systems.

Ground data collection remains important for the development of the index insurance sector. In many developing countries, yield statistics are of low quality, with high frequencies of missing data and short time series, and at a level of aggregation that makes validation and calibration of micro-level index insurance problematic. The introduction of remote sensing in index insurance still requires that there is continuing ground data, including yield and meteorological data, but also good information on farming systems and practices, soil types and land cover. Investment in such systems would not only bring benefit to agricultural development in general, but would also positively impact the development and sustainability of index insurance.

III. Different tools and available data sources should be combined to develop suitable index insurance products.

Combining different remote sensing approaches, adopting dedicated mapping tools and integrating them with ground-level sources of data and information can improve the quality of index insurance structures. Currently, at both the national and the international level, remote sensing data are collected, stored and managed separately from ground data, and there is little or no coordination between them in terms of responsibilities, expertise and systems. Any initiative to support the development of systems that make ground and remote sensing data sources available and accessible would significantly benefit the development of more comprehensive index insurance products.

IV. Future initiatives should focus on developing appropriate methodologies for segmenting UAIs to improve the performance of index insurance products.

The definition of appropriate UAIs is key to the successful implementation of index insurance and should be based on operational considerations (minimum size requirements to avoid asymmetric information, and realistic administrative and logistical frameworks); and also on the identification of areas that are homogeneous with respect to the risks to be covered in the insurance policies. Remote sensing could be used to develop dedicated risk profiling activities for the definition of appropriate UAIs given the broad spatial coverage and long time series that satellite data can provide. Given the technical complexity and the cost implications of such activities, there seems to be a role for governments and donors in supporting the development of these tasks.

V. Index insurance schemes based on remotely sensed data should carefully plan for measures aimed at mitigating the occurrence of basis risk events.

Historical performance analysis and product testing activities of the project indicate that for the smallholder areas studied there were mismatches between losses incurred and payouts intended by the insurance scheme. As with other index insurance products, consumer education is essential, and schemes should plan how possible basis risk events are to be managed or compensated for.

VI. The capacity of private and public remote sensing institutions should be built in order to fill current gaps in expertise and ensure future sustainability.

All remote sensing methodologies require highly technical skills to design, maintain and update the indices. Currently, operational schemes for remote sensing index insurance in developing countries have relied on external service provision, and they have often been facilitated by development agencies and donors. Capacity-building applies both to firms specializing in remote sensing in the private sector and to national institutions as part of a public-private partnership.

For private-sector providers, investment decisions are likely to be driven by commercial opportunity, which will depend on the scaling-up potential. For national capacity, governments and donors are likely to dictate decisions, which would be linked to the willingness of national insurers and stakeholders to join such an initiative.

The project experience showed that index design is highly intensive in the initial phases, particularly since skilled processing and programming of large volumes of remote sensing data is required in order to structure products for different locations and, therefore, higher initial investment could translate to a decreased intensity of work in subsequent years. Even after the implementation of remote sensing index insurance with some national institutions, it is likely that, for all methodologies, continued technical support will be required from specialist remote sensing institutions to build additional skills for maintenance and revisions. Scaling up of remote sensing index insurance, and/or sharing resources with other applications of remote sensing such as early warning systems, would bring down the unit cost to the national institutions and the cost of ongoing external support.

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