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Evaluating the use of remote sensing data in the U.S. Agency for International Development Famine Early Warning Systems Network

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Abstract. The U.S. Agency for International Development (USAID)'s Famine Early Warning System Network (FEWS NET) provides monitoring and early warning support to decision makers responsible for responding to food insecurity emergencies on three continents. FEWS NET uses satellite remote sensing and ground observations of rainfall and vegetation in order to provide information on drought, floods, and other extreme weather events to decision makers. Previous research has presented results from a professional review questionnaire with FEWS NET expert end-users whose focus was to elicit Earth observation requirements. The review provided FEWS NET operational requirements and assessed the usefulness of additional remote sensing data. We analyzed 1342 food security update reports from FEWS NET. The reports consider the biophysical, socioeconomic, and contextual influences on the food security in 17 countries in Africa from 2000 to 2009. The objective was to evaluate the use of remote sensing information in comparison with other important factors in the evaluation of food security crises. The results show that all 17 countries use rainfall information, agricultural production statistics, food prices, and food access parameters in their analysis of food security problems. The reports display large-scale patterns that are strongly related to history of the FEWS NET program in each country. We found that rainfall data were used 84% of the time, remote sensing of vegetation 28% of the time, and gridded crop models 10% of the time, reflecting the length of use of each product in the regions. More investment is needed in training personnel on remote sensing products to improve use of data products throughout the FEWS NET system. [DOI: 10.1117/1.JRS.6.063511]

Keywords: drought monitoring; food security; imaging systems; remote sensing; satellites.

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1 Introduction

The Famine Early Warning Systems Network (FEWS NET), funded by the U.S. Agency for International Development (USAID), works to improve global food security through the provision of actionable and early information to policy makers of populations at risk of malnourishment. Food security, which occurs when all people at all times have access to sufficient, safe, and nutritious food to maintain a healthy and active life,[1] is a critical concern in the largely subsistence farming economies of sub-Saharan Africa. Rural populations, which rely on rain-fed agriculture and pastoralism for their livelihoods, are particularly susceptible to shifts in climate conditions.[2] Monitoring growing conditions using remote sensing information is currently part of early warning that can mitigate or even prevent the loss of lives and livelihoods associated with food security crises.[3,4]

This paper extends research published by Ross et al. (2008) that focused on eliciting FEWS NET's data requirements.[5] Using a professional review questionnaire with FEWS NET expert end-users, the study provided FEWS NET operational requirements and assessed the usefulness

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of additional remote sensing data for the system. Here, we examine FEWS NET's food security reports themselves to determine how remote sensing information is used in the system.

Communication of information about food security crises in FEWS NET occurs through a system of reports that are written each month in the country office by the country FEWS NET Representative and then sent to a central office in Washington, D.C. for posting on an internet database (www.fews.net). These reports provide critical information upon which USAID makes decisions about where to send assistance and in what form. To identify the onset of food security crises, FEWS NET analysts use a "convergence of evidence" approach to combine biophysical and climate information with local and regional socioeconomic household livelihood analysis. Specifically, in-country analysts construct an assessment of food availability using production statistics as well as rainfall, temperature, and vegetation data derived from local measurements and from remote sensing to identify abnormally wet and dry periods.[6] The analysts also evaluate market conditions, threats to pastoral resources, availability of wild food, and, ultimately, the agricultural economy as a whole to understand what impact these growing conditions may have on overall food security. Contextual livelihood information is then used to understand how these market and environmental conditions will impact specific groups in each community in the country.[4]

Here, we evaluate 1342 monthly food security update reports that were produced by FEWS NET's 17 African field offices for a 10-year period from 2000 to 2009 (Table 1). The focus of this study is to evaluate the how food security analysts use satellite data as measures of environmental variability in the primary reporting mechanism of FEWS NET and its monthly country food security update. By examining the actual reports, we can increase our understanding of how physical science data are used within the FEWS NET system. We quantified the utilization of data types across 14 categories, containing a total of 72 keywords (Table 2). We analyzed the reporting of data spatially by region (Table 3, Fig. 1) and temporally over the course of the decade (Figs. 2 and 3). We then compared the frequency of data usage during growing and dry seasons (Figs. 4 and 5) and in the context of agricultural production surplus and deficits (Fig. 4).

2 Remote Sensing Data Products Used by FEWS NET

Remote sensing provides evidence that is believable, understandable, and factual for decision makers at a variety of levels.[23] Food security problems usually occur in remote, agricultural regions with poorly developed governance and statistics-gathering infrastructure. Monitoring food production in these areas has required that FEWS NET invest in remote measures that do not rely on reporting of yield and area planted information of the sort that would be used, for example, in the United States.

Table 1 Overview of food security reporting by country.

Country	Region	Percent reporting	Percent of 120 months with positive agricultural production
Burkina Faso	West	50%	43%
Chad	West	60%	50%
Mali	West	54%	43%
Mauritania	West	42%	48%
Niger	West	57%	50%
Nigeria	West	19%	43%
Djibouti	East	40%	0%
Ethiopia	East	83%	42%
Kenya	East	82%	50%
Somalia	East	71%	60%
Sudan	East	76%	60%
Tanzania	East	80%	56%
Uganda	East	78%	53%
Malawi	South	83%	50%
Mozambique	South	82%	57%
Zambia	South	82%	36%
Zimbabwe	South	68%	24%

Table 2 Categories and constituent keywords assessed for utility

Category	Keywords	Description
NDVI	NDVI, NDVI Figure in Update Report	The Normalized Difference Vegetation Index, *NDVI*, is highly correlated with photosynthetic biomass productivity.[7,8]
RFE	RFE, RFE Figure in Update Report	The satellite-derived and rain gauge-coupled Rainfall Estimates, *RFE*, provide a valuable indicator of water supply problems.[9,10]
WRSI	WRSI, WRSI Figure in Update Report	The Water Requirement Satisfaction Index*WRSI*, merges the satellite-derived rainfall quantities with the evapotranspiration levels of specific plants to estimate crop yield.[11,12]
Rainfall	Drought, Dryness, Precipitation, Rain, Rainfall	*Rainfall* includes both remote sensing and general precipitation observations.
Livestock	Camels, Cattle, Goat, Herd, Livestock, Pastoralists, Sheep, Transhumant	*Livestock* encompasses information on the health of animals and the pastoralists who depend on the animals for their livelihoods.
Production	Bananas, Barley, Beans, Cassava, Coffee, Cowpeas, Farm, Maize, Millet, Plantains, Potatoes, Production, Sorghum, Teff, Wheat, Yams	*Production* focuses on cereal yields and includes common grain stocks and the farmers who depend on these crops for their livelihoods.[13]
Prices	Deficit, Prices, Nominal, Surplus	*Prices* reflect market mechanisms of supply and demand along with the influence of inflation or deflation.
Food Access	Access, Food Access	*Food Access* is a direct determinant of food security and is a product of livelihood factors along with physical infrastructure (e.g. roads) and social barriers (e.g. language, gender).[14]
Terms of Trade	Purchasing Power, Terms of Trade	*Terms of Trade* represents the relative prices of commodities exchanged at markets and reflects the social welfare of the traders.[15]
Pests	Banana Bacterial Wilt, Beetle, Foot and Mouth Disease, Locust, Pests	Fungal, bacterial, and animal *Pests* can strongly affect the yield of nutritious biomass available to subsistence farmers.[16–18]
Civil Insecurity	Civil Insecurity, Civil Security, Conflict, Fighting, Political Instability, Political Tension	*Civil Insecurity* can challenge food security by limiting the access of subsistence farmers to markets and endangering workers during crop production.[19]
Disease	Diarrhea, Diarrhoea, Disease, Fever, Outbreak, Malaria, Meningitis, Mortality	*Disease* can reduce production by hindering the viability of individual workers and also by occupying the time of caregivers.
Refugee	IDP, Internally Displaced, Migration, Refugee	Internally displaced persons and refugees, collected under the term *Refugee*, decrease the labor forces and increase the demand on food markets.[20,21])
Malnourishment	Malnourished, Malnourishment, Malnutrition, Nutrition	As a cause of food insecurity, *Malnourishment* can limit the working capacity of a labor force, and as a consequence, *Malnourishment* reflects the prevalence of the food security crises.[22]

FEWS NET was formed in 1986 as an inter-agency partnership between USAID and partners in the National Aeronautics and Space Administration (NASA), the National Oceanic and Atmospheric Administration (NOAA), and the U.S. Geological Survey (USGS).[6] NOAA provides rainfall expertise; the USGS mapping, modeling, and data processing expertise; and NASA access to and information about a wide variety of satellite remote sensing data. Here we review the technology that is produced and operationally used by FEWS NET in order to understand its impact on food security analysis.

Table 3 Percent of total reports per region that cite term from Table 2.

	West Africa	East Africa	Southern Africa
NDVI	36%	46%	3%
RFE	74%	99%	81%
WRSI	17%	10%	6%
Rainfall	100%	100%	100%
Livestock	96%	98%	55%
Production	100%	100%	100%
Pests	37%	16%	14%
Prices	100%	99%	99%
Food access	88%	91%	89%
Terms of trade	66%	45%	26%
Civil insecurity	23%	61%	2%
Disease	63%	85%	53%
Refugee	60%	65%	3%
Malnourishment	43%	64%	32%

Starting in 1988, FEWS NET used vegetation data derived from the NOAA series of satellites carrying the advanced very high resolution radiometer (AVHRR) to estimate interannual variations in food production.[24] Although the data that come from this sensor are too coarse to determine how a particular crop or community's fields were doing, it can provide an overview of how the growing season is progressing over a region. Vegetation estimates do not allow specific estimation of crop yields, as the information from both agriculture and fallow vegetation and trees are combined together into a single observation.However, by comparing a given period of the current year with those from previous years when conditions were known, or with the mean of all previous years, a reasonably reliable estimate of the quality of the growing season and ultimate yield can be developed. Thus, using satellite remote sensing FEWS NET can determine if the cropping season in an area will be better or worse than last year or from the average.[25]

In addition to AVHRR data, vegetation data from the MODerate Resolution Imaging Spectroradiometer (MODIS)[26] and SPOT-Vegetation[27] sensors have moved center-stage since

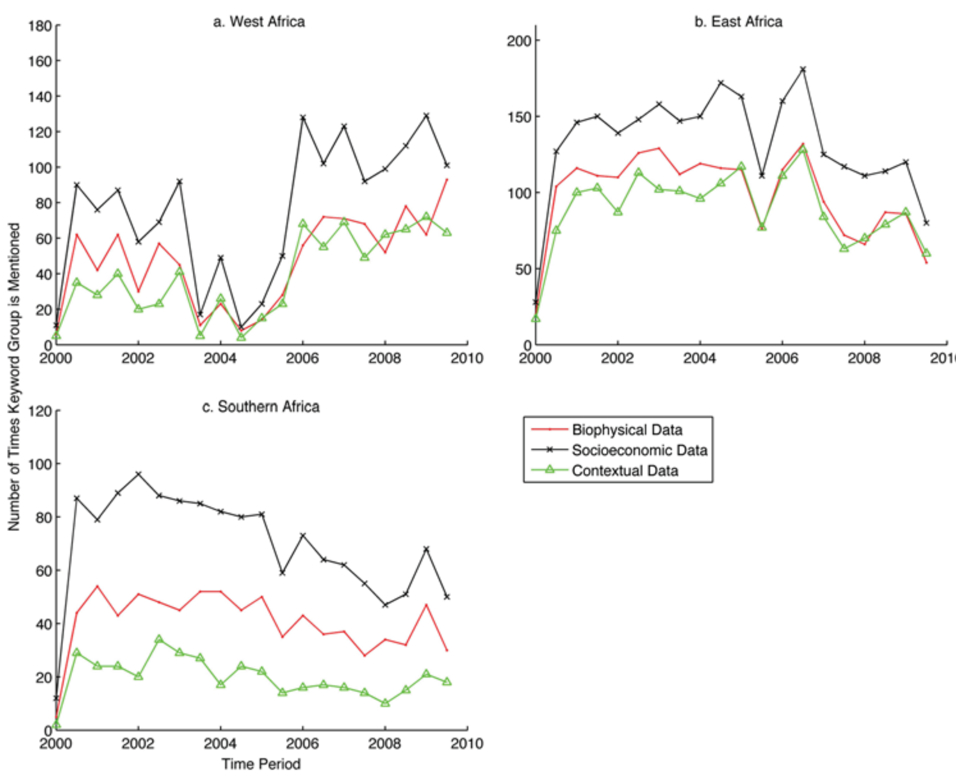

Fig. 1 Timeseries of reporting of each data type by region, 2000 to 2009. Y-axis maximum reflects the maximum possible reporting of each data.

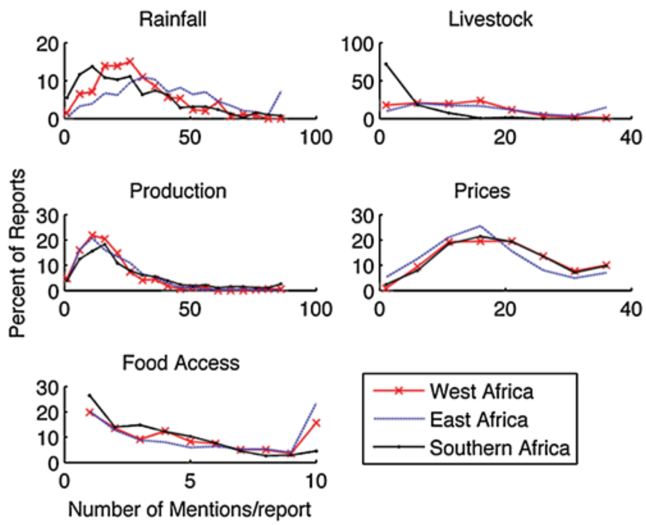

Fig. 2 Frequency of mention of consistently reported categories by percent of reports in each region. Axes scaled to data.

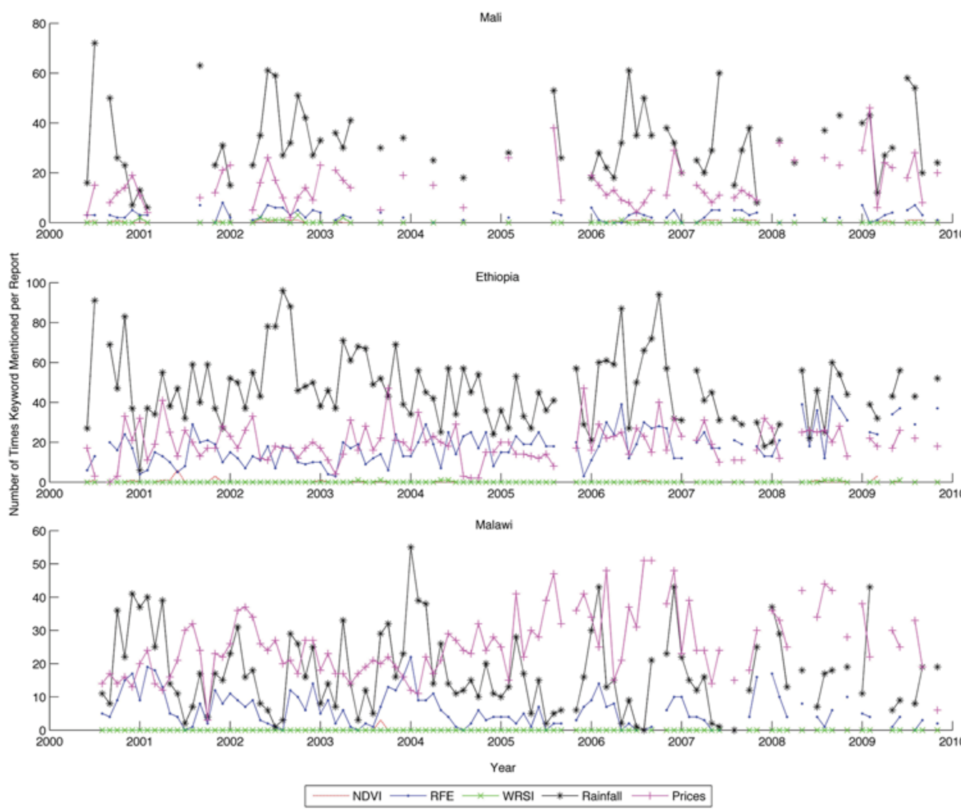

Fig. 3 Timeseries overview of the absolute number of mentions of "Rainfall" and "Prices" in Malawi, Ethiopia, and Mali, 2000 to 2009.

2000, with their higher resolution, improved calibration and processing, and new observational datasets. The most notable of these new datasets are the 250-m normalized difference vegetation index (NDVI)[28] and the land surface temperature (LST) product from the MODIS sensor.[29] New operational 250-m 10-day NDVI datasets derived from MODIS reflectance products are now (since 2011) being produced by the USGS. These products enable FEWS NET to be in control of dataset specifications.

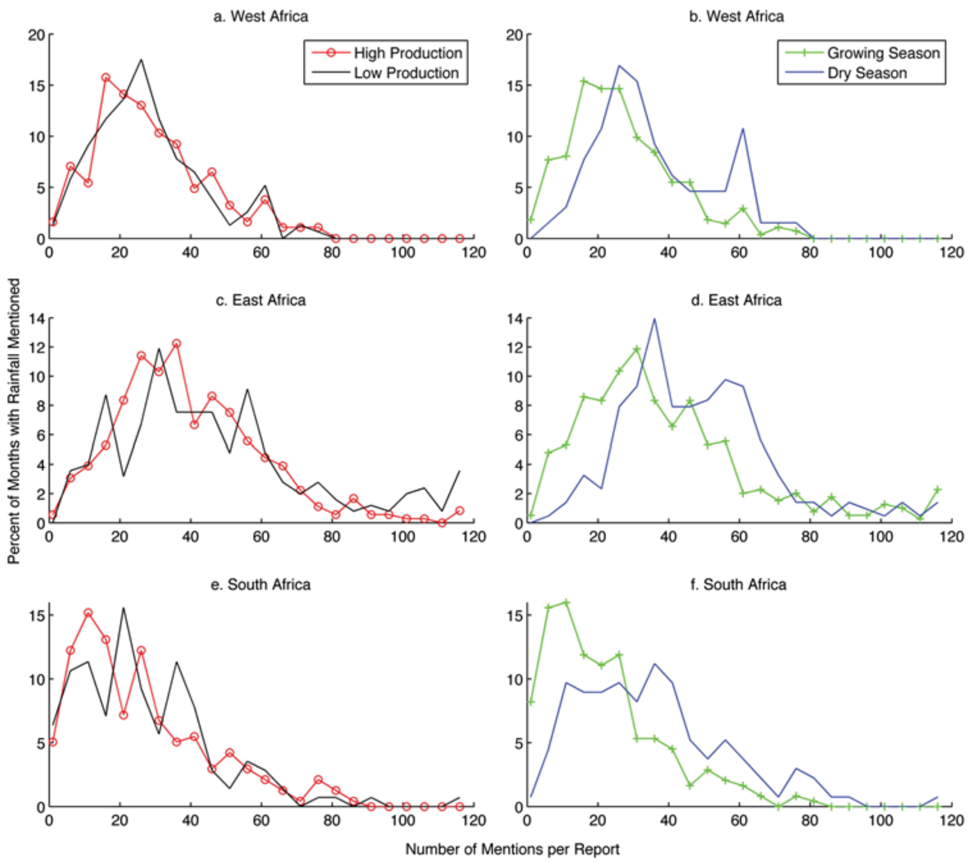

Fig. 4 Comparative mention of "rainfall" by region in reports from high-production versus low-production agricultural years and growing seasons versus dry seasons.

NOAA provides rainfall estimation (RFE) imagery based on multiple satellite inputs and operational daily rainfall observations. Used by the FEWS NET system since 1991, the RFE is an automated, satellite-derived rainfall product that uses MeteoSAT infrared data, rain gauge reports from the United Nation's global telecommunications system (GTS), and microwave satellite observations within an algorithm to provide daily rainfall estimates in millimeters at an approximate spatial resolution of 10 km.[9] The main use of these data in FEWS NET is to identify droughts as well as excessive rainfall, and to provide input for hydrological and agrometeorological models that enable analysts to evaluate much more directly food crop health than simply vegetation index or rainfall.

The spatially explicit water requirement satisfaction index (WRSI) is a crop model used by FEWS NET since 2005, and is an indicator of crop performance based on the availability of water to the crop during a growing season.[11,12] Using the RFE as input, WRSI measures the reduction in yield per unit area due to water deficiencies at specific stages of crop development. It does not attempt to measure any other kind of yield reduction, of which there are many, including pests, disease, and inadequate availability of nitrogen and phosphorus, among others. FEWS NET has operational programs that calculate the WRSI for maize (corn), millet, sorghum, and rangeland grasses in Africa and Central America.

3 Data

Our primary source of information for this research consisted of 1342 monthly FEWS NET update reports from 17 countries in three regions of Africa (Table 1 and Fig. 6). These reports were written by FEWS NET country representatives in each country during the period directly before each report date and sent to the Head Office in Washington, D.C.

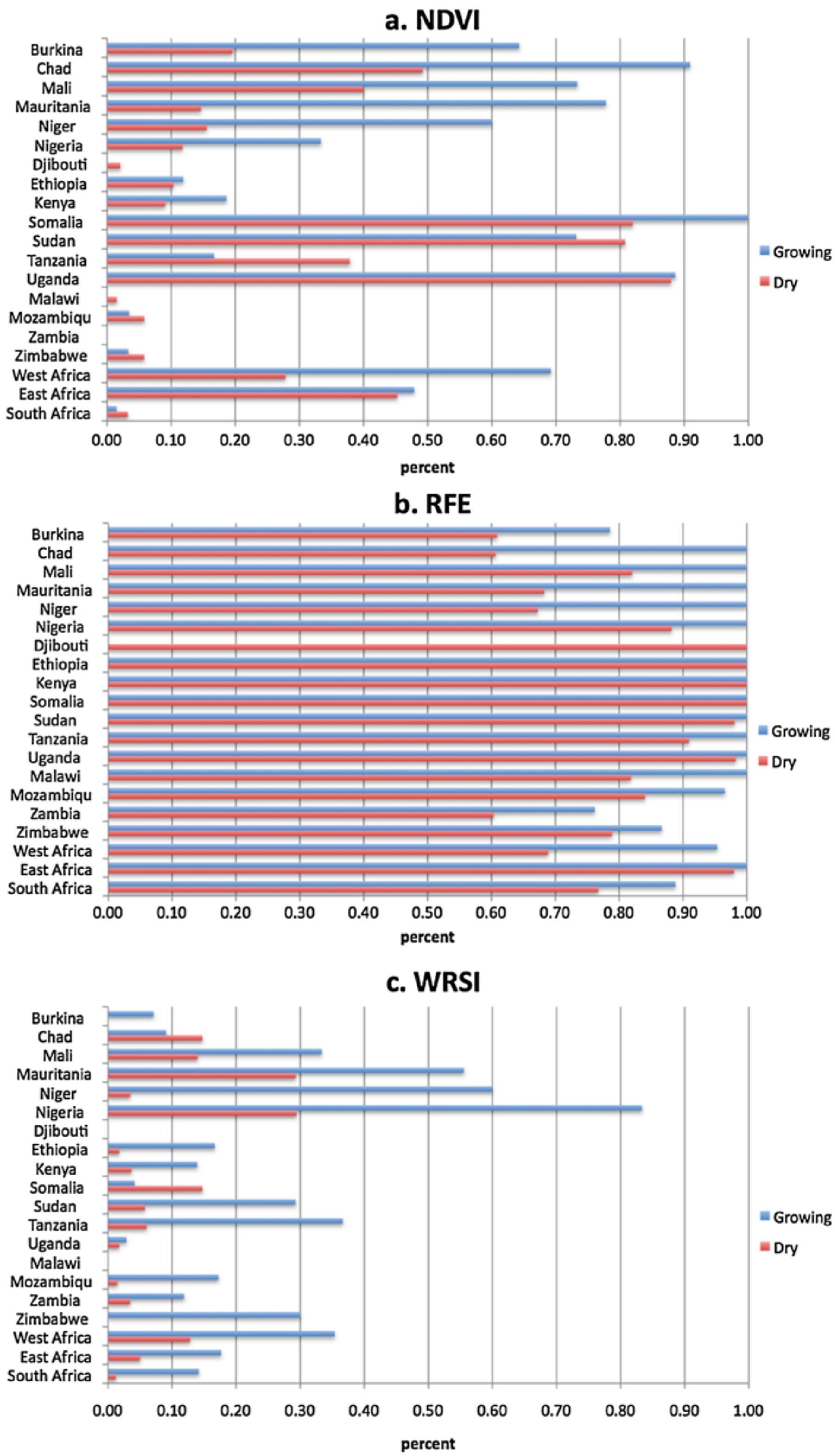

Fig. 5 Bar graphs for reporting of satellite-derived data in growing and dry seasons and in high and low agricultural production years, by country.

The reports represent analysis, information, and description of ongoing problems without benefit of revision or amendment in hindsight. Once received by the Washington, D.C. head office, the reports are posted online and hard copies are distributed widely within the affected country and in USAID within one month of the report date. We analyzed all available

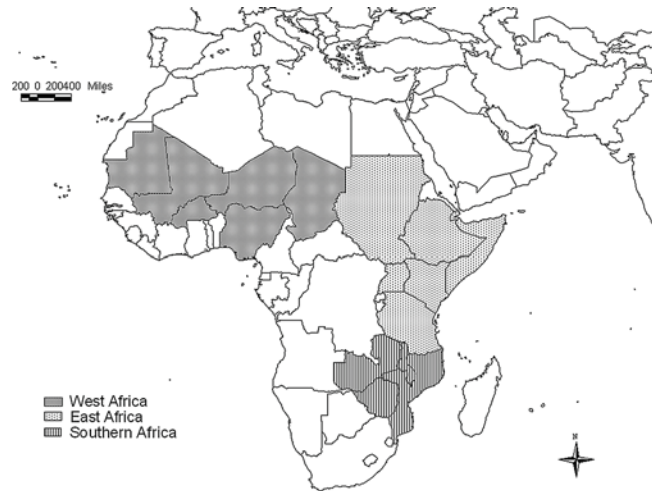

Fig. 6 Map of the 17 countries analyzed, designated by region.

English-language reports posted on the FEWS NET website from January 2000 to December 2009.

We use the locally determined growing and dry seasons as specified in each FEWS NET country in the "Seasonal Calendar and Critical Events Timeline" section (www.fews.net). This information provides the growing period, harvest, and dry periods for each country by month. We hand-coded this information for each country for the 10 years of the analysis.

To estimate the high and low agricultural production periods in each of the 17 countries, we used annual production statistics from the Foreign Agricultural Service (FAS) production, supply, and distribution (PSD) online data for cereal and pulse commodities published in the World Agricultural Supply and Demand Estimates (WASDE) Report and listed in Table 4. The production data were obtained from agricultural attachés, FAS commodity analysts, and United States Department of Agriculture (USDA) Economic Research Service (ERS) commodity analysts. The variability of food production data during the period of 2000 through 2009 was measured using the coefficient of variation to determine the extent of the agricultural production deficits. Reports were grouped by country and agricultural years and categorized as production surplus or production deficit conditions.

4 Methodology

To analyze the data, we used a computer program to count the number of instances of each keyword in each document. The program reported zero if the word was not mentioned in the document. We began with 72 keywords and aggregated them by synonymy and parallelism to the 14 categories listed in Table 2. We categorized the data inputs into three broad divisions: biophysical, socioeconomic, and contextual.

The biophysical division focuses on the environmental influences on food security in the categories of NDVI, RFE, WRSI, and rainfall. The socioeconomic indicators include livestock, production, prices, food access, and terms of trade. The contextual livelihood parameters measured in this study are pests, civil insecurity, disease, refugee, and malnourishment. These keywords were chosen as being important for food security assessment in the broader literature,[30,31] and are critical in the ability of FEWS NET to understand the impact of production declines.

We confirmed the use of satellite remote sensing images in all 1342 reports through visual inspection of report figures. If a satellite-derived image of vegetation, rainfall, or WRSI crop model output was present in the report, the time period for that country was given a one, if not, it was given a zero.

We then created a matrix with all possible months from January 2000 to December 2009 (120 months), 14 keywords, and 17 countries. If an update report mentioned a keyword, we put the number of times the keyword was mentioned in the appropriate month-location. If it did not

Table 4 Profiles of 17 FEWS NET-monitored countries in Africa

Country	Average. population[a] (2000 to 2009) (in millions)	GDP[b] (2009 est.) (in billions)	Global Hunger Index[c] (2009)	Total amount of aid provided to each country from 2000 to 2008[d]
Burkina Faso	13.6	$18.79	20.4	$351,490
Chad	9.83	$16.26	31.3	$436,304
Mali	11.7	$15.52	19.5	$234,552
Mauritania	2.95	$6.568	15	$466,586
Niger	13.0	$10.45	28.8	$557,249
Nigeria	139.4	$357.2	18.4	$48,604
Djibouti	0.80	$2.011	22.9	$118,235
Ethiopia	73.9	$76.74	30.8	$9,273,218
Kenya	35.5	$63.73	20.2	$2,158,084
Somalia	8.26	$5.731	..	$908,358
Sudan	38.4	$92.81	19.6	$3,879,814
Tanzania	38.7	$57.89	21.1	$951,577
Uganda	28.4	$43.22	14.8	$1,713,648
Malawi	13.5	$12.81	18.5	$1,034,766
Mozambique	20.6	$20.17	25.3	$1,530,294
Zambia	11.6	$18.50	25.7	$738,585
Zimbabwe	12.5	$0.332	21	$1,648,236

[a]PopSTAT, "Annual Time Series" <http://faostat.fao.org/site/550/default.aspx#ancor>. Accessed 19 Aug 2010.
[b]CIA World Factbook, <https://www.cia.gov/library/publications/the-world-factbook/>. Accessed 20 Aug 2010.
[c]*2009 Global Hunger Index The Challenge of Hunger:Focus on Financial Crisis and Gender Inequality* Klaus von Grebmer, Bella Nestorova, Agnes Quisumbing, Rebecca Fertziger, Heidi Fritschel, Rajul Pandya-Lorch, Yisehac Yohannes, International Food Policy Research Institute, <http://www.ifpri.org/publication/2009-global-hunger-index>. Accessed 20 Aug 2010.
[d]From Interfais, World Food Program database of food aid deliveries in metric tons, accessed 29 Aug 2010.

mention the word, a zero was placed there. If no report was generated that month, a "missing data" term was put in that month-country-keyword location.[32]

Drawing from 10 years of food security update reports, we compared the reporting of the types of data to the seasonal environmental variability and the annual agricultural production declines. These are measured using the FAS commodity production data. We categorize each year as a net positive or negative production year based on the 10-year mean, and analyze the contents of the report given this information. The percent of positive anomaly years are listed in Table 1.

5 Results

The analysis shows that FEWS NET has a consistent approach to reporting across all 17 countries on the topics of rainfall, agricultural production, and food prices. There are significant differences, however, in the use of remote sensing and other technical information between eastern, western, and southern regions. The West African analysts use vegetation data more than rainfall, and Southern African analysts use rainfall data almost exclusively, using very little vegetation data. Significantly more discussion of biophysical information was seen during the growing season than during the dry season across all regions. In contrast, there is little discrepancy between the use of satellite products during periods of agricultural production deficits as opposed to periods of adequate or surplus agricultural production.

Analyzing the reports by region for the presence of each category across all time periods, we found the highest levels of reporting of parameters that directly influence food supply and access. Rainfall information, agricultural production, food prices, and food access parameters are discussed consistently with reporting greater than 85% of the time for all regions. Table 4 shows that livestock data are reported with greater than 95% consistency in West and East Africa, but are only mentioned in 55% of the Southern Africa reports. In addition, satellite-derived RFE data are incorporated with greater than 98% consistency in East African reports. Overall, East Africa has the most consistent levels of reporting of metrics across all 14 categories, and Southern Africa has the least consistent reporting of these data.

When we examine the magnitude of mentions per region, we similarly find the highest level of reporting for parameters that directly influence food security. Figure 2 shows that greater than 95% of all reports mention "prices," "production," and "rainfall" more than one time per report. Food access keywords are mentioned at least 40% of the time for all three regions. By comparing these consistently and frequently reported parameters, we find very similar distributions in the magnitude of mention of the market categories of "prices," "production," and "food access" across all three regions (Fig. 2). In contrast, the peak quantity of usage of the "rainfall" keywords varies significantly by region, with East Africa discussing rainfall the most and Southern Africa discussing rainfall the least. This suggests that while agroclimatic conditions are important to the assessment of food security in general, the magnitude of reporting of rainfall data may reflect more general environmental differences specific to each region. The distribution of "livestock" magnitudes of mention in Fig. 2 also varies by region, with over 80% of the reports from West and East Africa containing multiple mentions and only 25% of Southern African reports.

We were interested in broadening our examination of the reports beyond the remote sensing information, to see if other important analytical terms for food security had trends similar to those of the remote sensing. Figure 1 reports the absolute number of terms through time for the broad groupings of environmental, socioeconomic, and contextual keywords. The figure shows the number of times each category of keywords is mentioned per group of countries per month, with 180, 210, and 120 possible mentions per West, East, and Southern Africa, respectively. As expected, the reports show that socioeconomic parameters are utilized with greater frequency than biophysical and contextual data sources for all three regions. Since food security is caused by broader economic and political contexts, these factors are likely to be more important than environmental conditions.

While the presence of "rainfall" keywords was nearly ubiquitous in the reports, the frequency of mention of "rainfall" demonstrated marked annual oscillations (Fig. 3). The timeseries plot for the magnitude of "rainfall" mentioned in Malawi, Ethiopia, and Mali follows a cyclical frequency of reporting in which the peak coincides with the respective growing seasons of January through April, June through October, and August through September. In contrast, the oscillations in the mentions of "prices" do not seem to be as variable as "rainfall." The breaks in the lines reflect the absence of update reports for the corresponding months.

Figure 3 also shows the frequency of use of satellite data per report in the three countries' reporting. NDVI and WRSI are mentioned only a few times in each country, but the RFE data is used extensively in all three countries. No obvious trend through time is present, however, in these countries. There has not been a significant change in the use of remote sensing information in the food security reporting during the past 10 years. Particularly in that the WRSI was introduced to the broader FEWS NET audience in 2003, Fig. 3 shows that it has not become more used during the period of analysis.

The seasonality of "rainfall" mention is made more obvious when we divide the reports by those written during the growing season and dry season for all countries (Fig. 4). The regional histograms clearly show a rightward shift between the number of mentions of "rainfall" during the growing periods as compared to the dry periods. In contrast, the histograms for the usage of "rainfall" did not respond as dramatically to high and low agricultural production years. The exception occurs in East Africa, where there exists a notably high proportion of greater than 100 mentions per report of "rainfall" during dry seasons. Overall, these data suggest that the reporting of environmental conditions is responsive to seasonal variability.

5.1 *Use of Remote Sensing Data*

As the reporting of "rainfall" reflects seasonal and regional variations of discussions of rainfall broadly, we sought to understand if the utilization of satellite-derived remote sensing information about environmental conditions was similarly responsive. Figure 5 shows both the country-level and regional reporting of NDVI, RFE, and WRSI.

Overall, satellite remote sensing of vegetation (NDVI) was used 28% of the time, rainfall imagery (RFE) 84%, and gridded crop models (WRSI) 10%. As demonstrated in Table 3, NDVI data are included in 46% of East African reports and are nearly absent (with only

3%) of Southern African reports. RFE is reported in 99% of reports from East Africa and least reported in West Africa, where it is present in only 74%. WRSI data are utilized in 17% of West African reports, but only 6% of Southern African reports.

East Africa most frequently uses satellite-derived biophysical data to assess food security. However, studying the data by country reveals that the distribution within each East African country is the most disparate among the regions (Fig. 5). Specifically, we find that NDVI data are highly incorporated into reports from the East African countries of Somalia, Sudan, and Uganda, but are rarely used or absent in reports from Djibouti, Ethiopia, Kenya, and Tanzania.The data for RFE, however, are much more broadly used across all countries.

Despite regional distinction in the frequency of reporting, satellite-derived data from all three regions are sensitive to seasonal variation. FEWS NET analysts report NDVI, RFE, and WRSI data with a notably higher frequency during the growing seasons over the dry seasons. The discrepancy in reporting rates is most pronounced in the seasonal utilization of remote sensing data for the countries of West Africa (Fig. 5). In contrast, there is little response in the utilization of remote sensing data to agricultural production deficits.

6 Discussion

FEWS NET must balance multiple influences on food supply, such as changes in precipitation patterns and changes in agricultural productivity, with long-term systemic patterns of food access, including chronic poverty and insufficient public infrastructure and services, in the relevant political and economic contexts.[33] Effective early warning for food security crises requires that the FEWS NET analysts are asking the right questions, using the most appropriate datasets for the biophysical hazard, within the appropriate time frames. Remote sensing information enables earlier warning of weather-related production declines,[34] and can be a critical tool for areas that have a weak in-country presence.

The need for accurate, efficient, and actionable food security assessments remains important, particularly as economic and environmental pressures on developing countries are changing (Table 2). Over the next two decades, shifting precipitation patterns, rising temperatures, and more extreme weather events associated with climate change are projected to reduce the agricultural yields of corn, wheat, rice, and other primary crops.[35,36] With the predicted increase in demand for food assistance, there will be an ever-greater need for rapid and targeted responses to food security crises that are driven by drought.[37] Biophysical data, coupled with contextual information, has the potential to accelerate response when there is a consensus that assistance is required.[34] As USAID expands its financial commitment to an improved resilience to climate change in Africa, remote sensing data is a valuable and underutilized tool for projecting future environmental conditions and agricultural production.

Results from the professional review conducted in 2007 showed that there was a need to have higher-resolution information about climate hazards (at the community or village level) and sub-daily data to capture rapid changes such as "floods".[38] Higher-resolution information, particularly for smaller countries with small field size, is of great interest to the FEWS NET community. In this analysis we do not explore resolution and temporal requirements, but the ability of FEWS NET to use the data already at its disposal. NDVI, for example, is available now at a much higher resolution than rainfall data, but it is used only very little in the actual food security assessments in many countries.

Our analysis shows that the gridded crop model WRSI, which incorporates rainfall estimates from the current growing season to forecast a spatially specific projected crop yield at the end of the season, has been incorporated into less than 15% of African FEWS NET update reports in the last decade. Not only does WRSI provide a projection of food supply to policy makers *early*, it also provides a directive of the location and the extent of the problem that can enable a more efficient response. While gridded crop models have the potential to provide decision makers both within the USAID and local governances with actionable and defendable data to inform budgetary and policy mandates, realizing this potential will require additional training and efforts to make the data more usable to non-scientists.

Similarly, while the general concepts of “food access” and “prices” were prevalent within the reports, there was limited reporting of primary determinants of market accessibility, such as measures of household purchasing power and terms of trade. To provide more specific and actionable information, future analysts should incorporate an analysis and description of the impact of a changing price regime, the likelihood of the regime changing, and the consequences of higher (or lower) prices for food security. Moving simple presentation of data into analysis, which can be understood and acted upon by policy makers in Washington, D.C., is challenging and requires continuous interaction between the food security analyst and stakeholders who read the reports.

To provide actionable early warning information, FEWS NET analysts need not only to improve the specificity of their analysis of food supply and food access, but also to assess food security in the broader context of long-term nutrition patterns. “Malnourishment” was discussed in fewer than half of the food security assessment reports for Africa over the last decade. This was because little quantitative information on nutrition is usually available, and it is a lagging indicator of food security as it is the consequence rather than the cause of hunger. Thus, increasing the information available regarding nutrition analysis is important for diagnosing the impact of crises when they occur.

Overall, we find that the indicators of food security assessed by FEWS NET analysts are consistent with food security assessments; however, the reports tend to be more responsive than predictive. To expand the *early warning* utility of remote sensing data, datasets such as the MODIS land surface temperature and atmospheric infrared sounder (AIRS) precipitable water are being introduced to FEWS NET through a new online tool called the Early Warning Explorer (EWX). This tool provides interactive time series, normalized anomaly maps, and linked windows for easily viewing satellite remote sensing for improved data delivery to FEWS NET representatives in the field. New datasets will also be useful, particularly that of soil moisture from the Soil Moisture Active Passive (SMAP) mission to be launched in 2014.[39,40] This information will provide direct observation of poor growing conditions that is independent of rainfall and vegetation measurements, and will enable a much earlier indication of dry growing conditions and possible harm to agriculture. Improving the way that food security analysts learn about and use these new types of data, however, should be implemented if investments in new technologies are to result in improved outcomes and more timely humanitarian response.

In addition to new datasets, improving the way remote sensing is described and the comprehensibility of maps of remote sensing information in food security assessments would further increase its utility to a wide-ranging audience of policy-makers, economists, scientists, and nonprofit administrators in both the United States and the targeted country. To achieve these goals, increased training of the FEWS NET representatives will be necessary to improve the accessibility of remote sensing–based information about the weather and climate.

6.1 *Demand-driven Reporting*

Food security update reports lie at the confluence between the observations of the in-field analysts and the demands of the governmental decision makers. In this study, we find a demand-driven utilization of data in the food security assessments that reflects the seasonal environmental variability observed by the analysts and the budgetary demands of the policy makers.

The discrepancy in reporting of biophysical data between the growing and dry seasons presents a logical demand-driven reporting of data. During the dry seasons, vulnerable communities rely on the harvest from the previous agricultural year. Biophysical data is a relevant metric during growing season that can provide insight to predict future food supply in the next harvest; thus, discussion of remote sensing information during the growing season is expected. In contrast, this study found that FEWS NET analysts’ utilization of biophysical data is not responsive to agricultural production deficits. This is because both high and low levels of food production are important for food security conditions.

While the update reports are largely shaped by the tangible seasonal observations of the environment by analysts in the field, the reporting patterns are also driven by the fiscal allocations of food assistance. Overall, this study demonstrates the most active reporting for all metrics is in East Africa, which has also received the highest gross food assistance over the last decade and has the largest number of food-insecure people. Clear variations in the level of reporting were seen due to a reduction in funding of FEWS NET during times of government uncertainty or political change in the United States (Fig. 1). Remote sensing information can be a critical tool during times of fiscal uncertainty, as they provide inexpensive, early, and ongoing coverage even when funding for direct monitoring and response is reduced.

7 Conclusions

Analysis of FEWS NET's reports demonstrate the ongoing importance of remote sensing information to food security monitoring. The most important factor in use of the data was the familiarity with remote sensing information by the FEWS NET representatives responsible for reporting, and the history of the country's FEWS NET office. This conclusion should lead to further investigation of the familiarity of the representatives with remote sensing technology and its use in agricultural monitoring.

In this paper, we analyzed rainfall, vegetation, and crop model use in 17 FEWS NET countries and found underutilization of crop models, a critical tool for understanding the impact of weather on agricultural conditions. The most important factor in use of the data was the familiarity to remote sensing information of the FEWS NET representatives responsible for reporting, and the history of the country's FEWS NET office. As the demand for early warning information grows to new countries in different ecosystems such as those in Asia and South America, there is likely to be an increased need for the effective utilization of remote sensing, market, and livelihood data, which can be achieved only through effective training and movement of personnel and therefore expertise from one region to another to increase institutional knowledge of all available tools.

Although remote sensing information provides the earliest possible warning of a harvest failure in a particular region,[34] response to the failure is determined by the political and economic context in which the failure occurs. Because food security crises are slow-fuse events that take years to unfold, only through constant monitoring of the food security situation can the humanitarian response be both timely and properly scoped.[41] Food aid when it is not needed can be nearly as harmful to farmers as food aid provided too late during a crisis. The analysis conducted here shows that the focus of FEWS NET reporting remains on the many factors that cause food security crises beyond the biophysical that remote sensing information provides.

In this meta-analysis, we reviewed the reporting patterns for 14 unique indicators of food security in 1342 food security assessments from the 17 African FEWS NET–monitored countries. Our results indicate that FEWS NET analysts most consistently utilize socioeconomic parameters when assessing food security. The efficacy of the early warning information could be improved by expanding the use of specific and predictive remote sensing models. Overall, this study demonstrates demand-driven variability in the monitoring and reporting of food security indicators that is reflective of environmental variability and irrespective of agricultural production variations. Understanding these historical trends in data usage by country will better inform early warning food security analysis in the future.

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