# Developing a Malaria Early Warning System for Ethiopia

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## Abstract:
Malaria is the number one health problem in Ethiopia, with an estimated 65% of the 70 million people exposed to Malaria. Satellite-derived rainfall data were used to investigate the relationships between rainfall magnitude and temporal distribution with malaria transmission rates. Preliminary data analysis of clinical malaria data from 11 districts in Ethiopia showed a strong seasonal pattern of malaria transmission rate, which is related to the seasonal pattern of rainfall with a lag time varying from a few weeks at the beginning of the rainy season to more than a month at the end of the rainy season. The presence of a lag-time between peak malaria transmission and seasonal rainfall distribution is very important for forecasting malaria outbreak using observed weather data. This study presents a draft concept idea in the establishment of a malaria early warning system that uses satellite derived rainfall and the participation of local community volunteers.

## Background:
Malaria is reported to be the number one health problem in Ethiopia, with an estimated more than 65% of the 70 million people exposed to Malaria. Each year more than 5 million malaria cases are estimated to occur in the country. The Ethiopian Ministry of Health (MoH) emphasized the need to mapping malaria transmission pattern and intensity in Ethiopia. It was revealed that the existing knowledge and distribution of malaria transmission in Ethiopia has not been updated since it was first established by an Italian investigator four decades ago. For example, it was known that malaria transmission only occurred in areas below 2,000 m above sea level, now the limit has moved up to 2,500 m. Although elevation is important, factors such as rainfall, temperature and humidity levels play an important role in determining its intensity (Malakooti, 1998).

Ministry of Health of Ethiopia has summarized the impact of malaria in Ethiopia in the following paragraph: *"The socioeconomic burden resulting from malaria is immense: 1) the high morbidity and mortality rate in the adult population significantly reduces production activities; 2) the prevalence of malaria in many productive parts of the country prevents the movement and settlement of people in resource-rich low-lying river* *valleys; on the flip side, the concentration of population in non-malaria risk highland areas has resulted in a massive environmental and ecological degradation and loss of productivity, exposing a large population of the country to repeated droughts, famine and overall abject poverty; 3) the increased school absenteeism during malaria epidemics significantly reduces learning capacity of students; 4) coping up with malaria epidemics overwhelms the capacity of the health services in Ethiopia, and thus substantially increases public health expenditures."*

Thus, malaria in Ethiopia, is not only a health issue, it is also a food-security and environmental issue. Several studies have been made to connect malaria epidemics and weather variables. Rainfall, temperature, humidity, soil moisture etc are known to affect the transmission rate of malaria. What is missing now is an early warning system that will help the local health offices to plan better for epidemic situations.

USGS/ Famine Early Warning System Network (FEWS NET) has identified a local collaborating organization that is interested in developing and implementing a procedure (pilot project) that will link local volunteers (organized from village-to-district -to-regional offices) and satellite-data driven malaria early warning models. The proposed project involves the training of district health officers in the usage of satellite derived rainfall to forecast the likelihood of a malaria epidemic for a district with a lead time of up to a month or two depending of site and season specific criteria. High-school volunteers will send back weekly updates on model performance along with malaria transmission and control measures. This manuscript presents a concept proposal to establish and implement a Malaria Early Warning System (MEWS) based on a preliminary study conducted using data from the northwest Ethiopia.

USGS/FEWS NET has access to daily rainfall, temperature and relative humidity datasets that can be used to monitor and forecast malaria outbreak ahead of a potential malaria epidemic situation. Simon Hay et al (2003), in a retrospective study, reported that satellite derived rainfall data (RFE) (Xie and Arkin, 1997) was able to provide a timely and reliable warning for the 2002 malaria epidemic in the highlands of Kenya while the monthly surveillance of malaria out-patients gave no effective alarm. Currently, USGS/FEWS NET in collaboration with the International Research Institute produces 10-day rainfall (RFE) anomaly maps that are indicative of malaria outbreak potentials in malaria epidemic sites all over Africa (http://igskmncnwb015.cr.usgs.gov/adds/). Testing and validation of existing products and future products is in the interest of USGS/FEWS NET and the local community at the village level. Realizing the impact of malaria on food security, USGS/FEWS NET plans to develop and implement an operational Malaria Early Warning System (MEWS) that is mainly operated by the local partners in Ethiopia in collaboration with USGS/FEWS NET.

The main objective of this study is to develop a simple malaria outbreak monitoring and forecasting model in selected districts (woredas) in Ethiopia and propose an implementation strategy for operational applications.

## METHODS

There are two basic data sources for this study: 1) clinical malaria data from 11 districts (Figure 1) in northwest Ethiopia (1997/1998 - 2001/2002), and 2) satellite rainfall estimate (RFE) for Africa (1997/98 – 2002/03). The malaria clinical data were obtained from Anti-malaria Association, a local NGO in Ethiopia.

The northwestern Ethiopia can be characterized by high plateaus dissected by deep river gorgeous of the Blue Nile River and its tributaries. The rainfall pattern of the region is generally unimodal with the rainy season spanning between May and September. However, a significant amount of the rain falls in two months time between July and August. Temperature of the region is generally mild in the highland plateaus and warmer in the lowland valleys. The monthly average temperature is the highest in the dry months of March and April and lowest during the rainy season in July and August.

Satellite rainfall data (RFE) is available in girded format for each 10 km by 10 km pixel on a daily time step, covering the entire continent of Africa. The malaria clinical data were organized by districts called “woreda”. An average woreda roughly occupies an area of 40 km by 40 km. Furthermore, the clinical values are reported in a weekly time step. In addition, historical (1954 – 2000) air temperature data were used to characterize the seasonal temperature patterns of the region.

District boundaries were used to create district average rainfall estimates (RFE). The daily RFE values were aggregated to a dekadal (10-day) time step for this study. The dekadal rainfall data were further accumulated on a moving 3-month time period. The three-month moving aggregation was chosen after initial data exploration with varying aggregation periods (1 to 3 month) showed that the 3-month time period provided more consistent results across the different districts. Clinical malaria data were aggregated at monthly time step. Temporal patterns of the cumulative rainfall and monthly clinical data were investigated to identify the relationships between seasonal rainfall distribution (magnitude and timing) and malaria transmission rates.

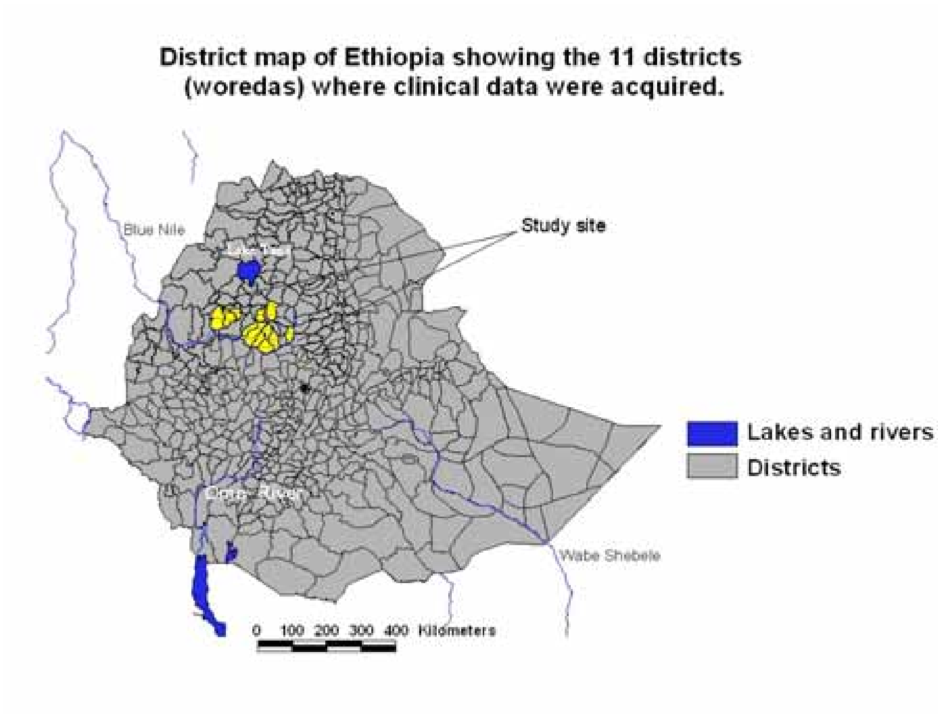



Figure 1: District map of Ethiopia showing "woreda" district boundaries and highlighting the 11 study districts in yellow (light colors).

## RESULTS AND DISCUSSION

Preliminary data analysis of 11-woreda clinical malaria data shows a strong seasonal pattern of malaria transmission rate being related to the seasonal pattern of rainfall. In most of the 11 woredas, the malaria transmission rate peaks in May/June at the beginning of the "kiremet" rainy season and in October/November after the "kiremet" rains have stopped in mid September.

Figure 2 shows a typical seasonal malaria transmission pattern exhibited in most of the 11 districts. In addition to the seasonal pattern of malaria cases rates the Figure 2 also highlights the two malaria epidemic years (1998/99 and1999/00) in Hulet Eju Enesie district (woreda). The 1998/99 malaria case rate coincides with the highest cumulative rainfall in the same time period (1998/99-2001/00) (Figure 3). The 3-month cumulative rainfall shown in Figure 3 is significant in two ways: first, the total amount of the rainfall in a three month period is very high, reaching as much as 800 mm in some years. This also corresponds to a high volume of runoff generated in the region (Senay and Verdin, 2003), creating a conducive environment for mosquito habitat by creating temporary water pools and expanded wetlands; secondly, Figure 3 indicates the presence of a large year-to-year variability of seasonal rainfall, making it possible for malaria epidemic to occur in some years. On the other hand, such a high degree of rainfall variability allows the use of rainfall to forecast malaria epidemic years.

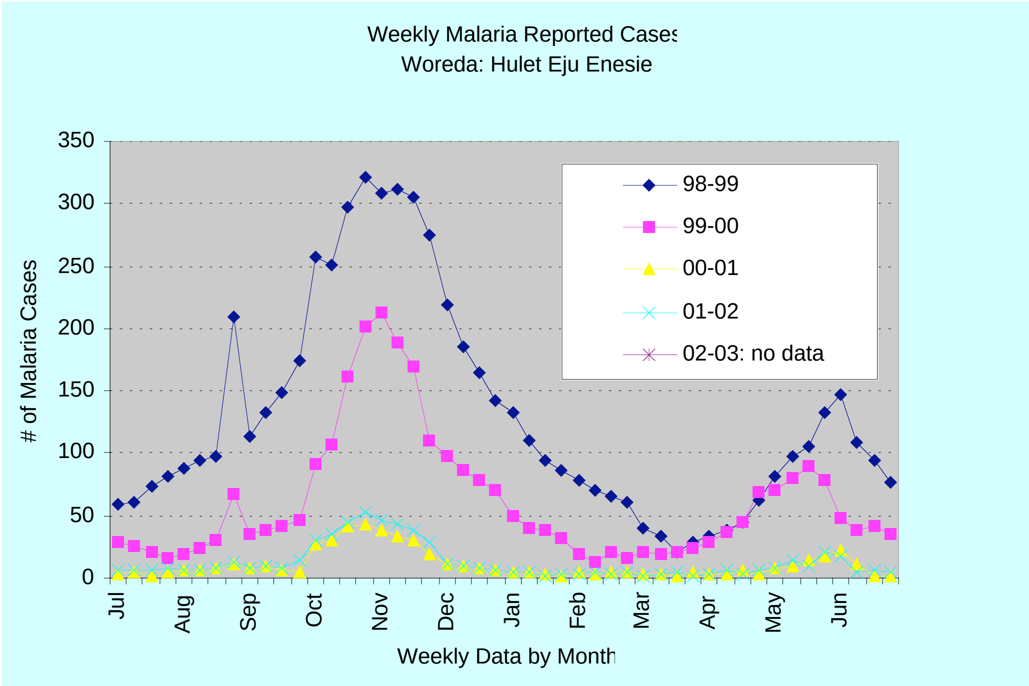



Figure 2: Weekly malaria cases reported at Hulet Eju Enesie (woreda) health care facility (1998/99-2001/02)

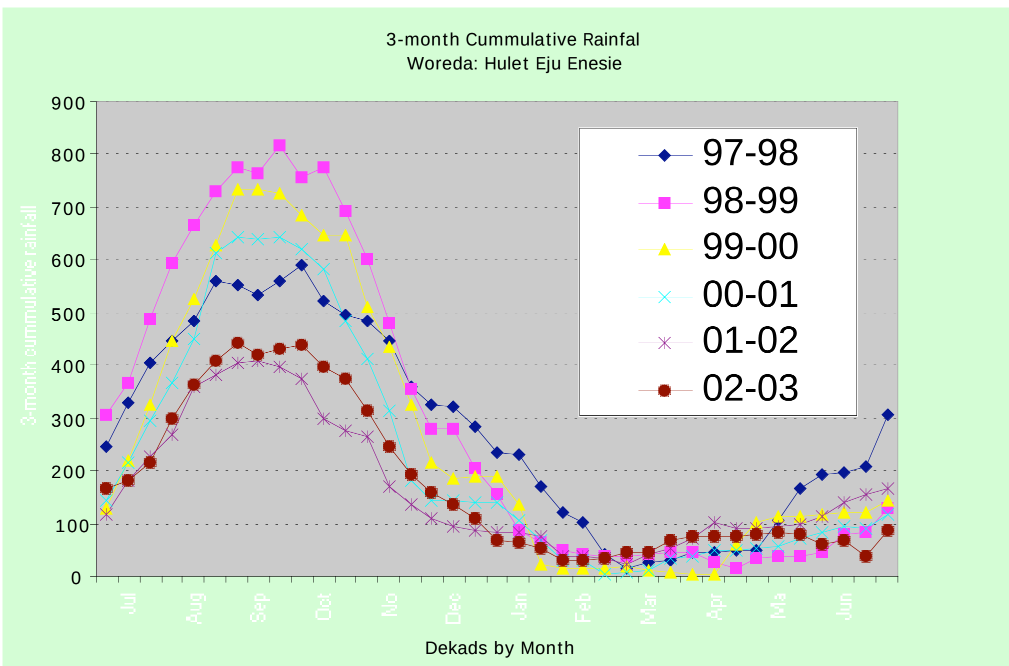



Figure 3: Three-month cumulative rainfall plots for Hulet Eju Enesie woreda. From 1997/98 through 2002/03.

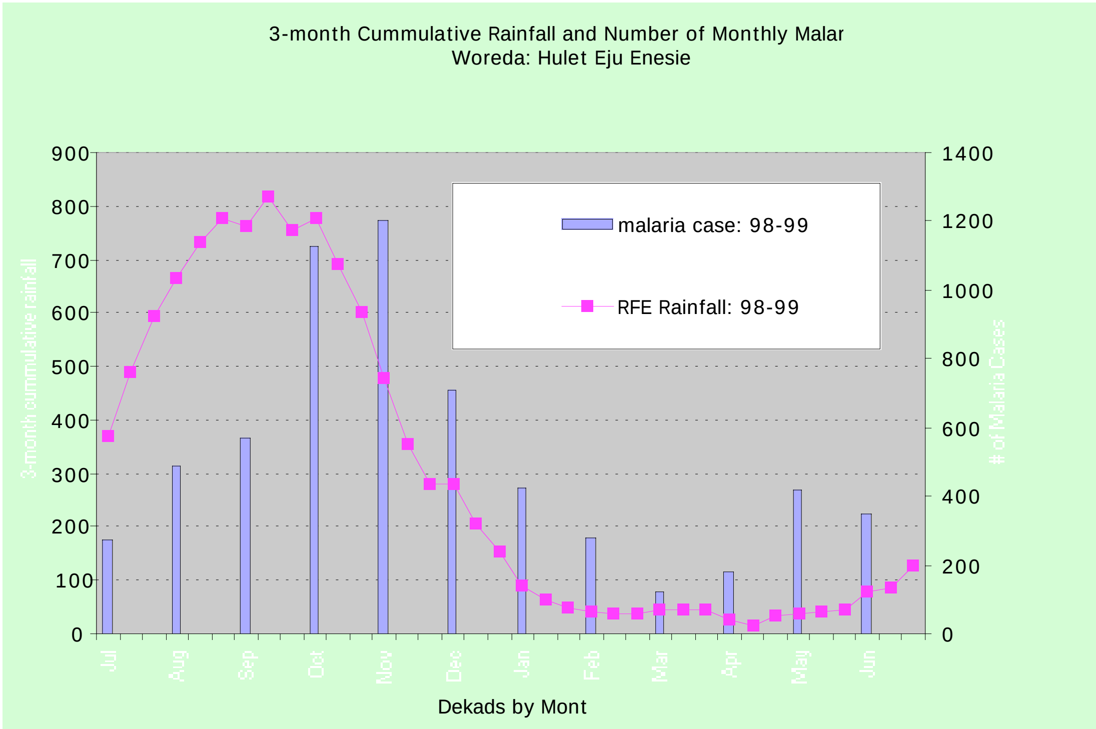



Figure 4: Temporal patterns showing lagged-peak malaria cases with respect to 3-month cumulative dekadal rainfall amounts.

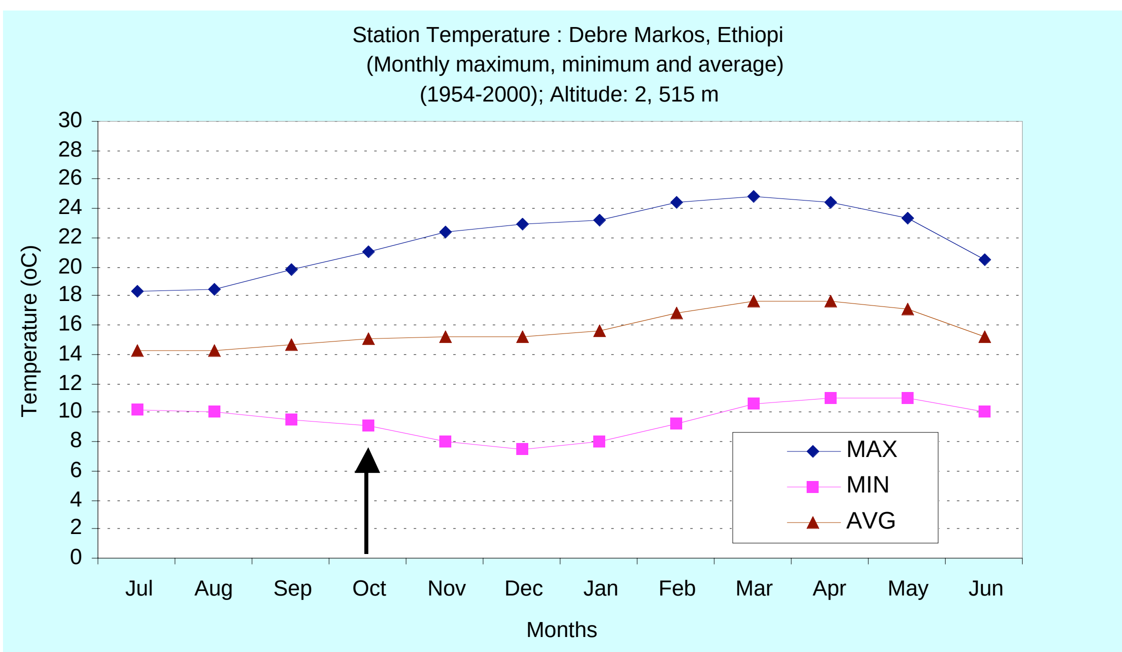



Figure 5: Monthly temperature pattern for a station in northwestern Ethiopia.
The station represents temperature patterns in cool-highland areas where new malaria epidemics have been reported in altitudes above 2,000 m.

Figure 4 shows the temporal patterns of malaria case rates and cumulative rainfall for the peak malaria transmission year of 1998/99 in the same graph. Note that at the beginning of the rainy season in May, the response of malaria case is immediate. This appears to be the result of two factors: 1) intermittent rainfall (rainfall followed by dry periods) and relatively high temperature in May. Figure 5 shows that March, April and May tend to have the highest average temperature in the region. On the other hand, the peak malaria case lags the 3-month cumulative rainfall by about a month at the end of the rainy season. Again, the explanation for this is tied to the high rainfall and its continuous nature combined with low temperature in the main rainy season between June and September for this woreda (Figure 5). Once the main rainy season declines in intensity and frequency in September, the increasing average daily temperature and progressive dryness beginning mid-September creates a conducive environment for mosquito breeding in areas where water has been accumulating from the main season. The lag time between the end of the main rainy season and peak malaria transmission can be explained by the inherent lag time in mosquito breeding and parasite life cycle inside the mosquito, which are dependent on air temperature and humidity (Zucker, 1996, Malakooti et al, 1998). In addition, the appearance of a malaria patient to the clinic will play role in the observed lag time.

This study shows the potential of using satellite derived rainfall data to develop an early warning system for detecting rainfall seasons that may cause malaria epidemic situations. For developing an effective malaria early warning system the relationships between malaria epidemic and rainfall timing and magnitude need to be investigated for each geographic unit and season.

Considering the large hydro-climatic variations in Ethiopia that is induced by complex terrain and proximity to the equator, the relationship between malaria transmission and the rainfall is further complicated by other important factors such as temperature, humidity and the movement of people between lowland and highland areas (Malaria Control Program, 1983)

However, with the promising relationships observed between seasonal rainfall totals and malaria epidemics, we are recommending the establishment of a guideline for forecasting epidemics situations using the following steps.

1) For districts where there are concurrent malaria and rainfall data, the relationships between rainfall and the timing and magnitude of malaria epidemic will be determined using historical data.

2) For districts that do not have clinical malaria data, the relationship between rainfall and malaria transmission will be inferred from a similar hydro-climatic districts in the region.

3) At the district level, the following two data sets will be established using historical data: 1) the average cumulative seasonal rainfall distribution beginning with an appropriate "malaria year" counting system that is

specific to the district, 2) a similar rainfall distribution for the most severe year.

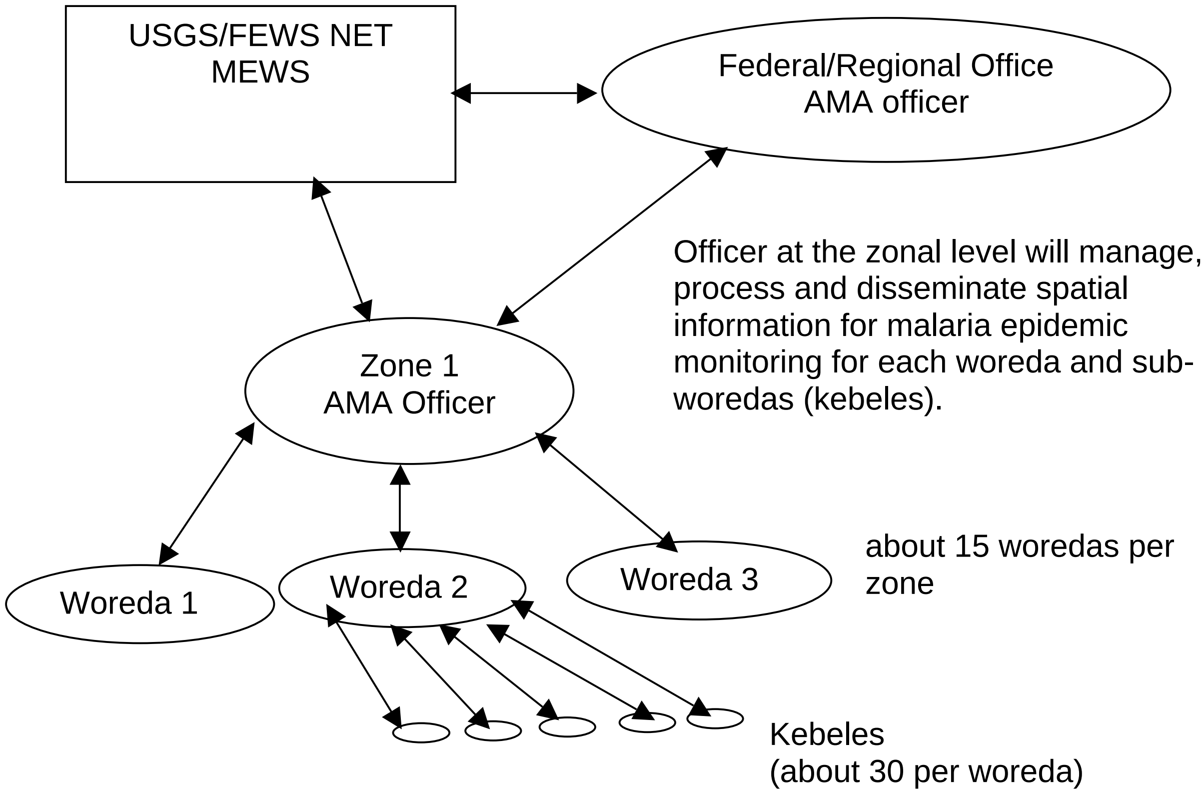
4) As a monitoring and forecasting tool, the current season cumulative rainfall will be updated every week and superimposed on the historical average and epidemic malaria-year rainfall patterns from step 4.

5) The relationship between the current year's (or a year of interest) cumulative rainfall progression and the historical data will be rated to provide qualitative indicators for taking appropriate actions by the community. Community actions that will be triggered by such kind of alarms include the initiation of awareness campaign for the general public and the mobilization of community volunteers for the treatment and/or draining of pools.

## Implementing the Malaria Early Warning System (MEWS)

Our partner organization in Ethiopia is a local non-governmental organization (NGO) called Anti-malaria Association (AMA). AMA having realized the severity of malaria was established in the wake of the 1998 malaria epidemic. AMA is a non-profit making organization with the objective of supporting the government's effort by developing community participation in preventing and controlling malaria, HIV and other communicable diseases. It works closely with the government and other NGOs. The organization is administered by volunteer board members and more than 2,000 active members who participate on its daily activities throughout 34 woredas and 920 kebeles in the region. Its major funding comes from membership fees, various international and local organizations.

The following chart shows a schematic representation of the intended communication link between USGS/FEWS NET and community volunteers down to the kebele level. The smallest administrative units are called "kebeles". Several kebeles (around 30) constitute a woreda. The aggregate of woredas makeup the zones which in turn makeup the regions; there exist 9 regions and over 547 woredas in Ethiopia.




Communication and data transfer between the various institutions will be conducted in the following way: USGS/FEWS NET will send daily rainfall data to partners in Ethiopia using E-mail and/or FTP (file transfer protocol) to the regional and zonal offices; on the other hand, printed materials will be used to distribute malaria alert information between zones and woredas and between woredas and kebeles. Local communities will take appropriate corrective actions according to the directives attached to the alert levels in terms of community cleanup and water management. The importance of surface water management for malaria outbreak in Ethiopia has been pointed out by Ghebreyesus et al (1999) in their investigation on the relationship between farm ponds and malaria transmission.

The Anti-Malaria Association (AMA) has recognized the following as some of the reasons that aggravate malaria epidemic situations.

- Lack of skilled Health Workers at grass root level to predict epidemics
- Absence of early preparedness for malaria epidemics
- Absence of active and sustainable surveillance system
- Inefficient implementation of epidemic control measures

Thus, a malaria early warning system will play a crucial role in mobilizing scarce resources in an efficient manner. The task of more than 2,000 community volunteers includes weekly monitoring and draining of small pool of water that may become a breeding ground for the vector and the application of insecticides.

The malaria early warning system (MEWS) will coordinate community volunteers from high-school students and community health officers who can provide guidance and document relevant activities and also provide feedback all the way back to USGS/FEWS NET for model validation purposes in the accuracy and usefulness of the MEWS product.

The concept proposal envisages a capacity building and training program for AMA officers at zonal centers so that they will be able to receive/download 10-day rainfall images from USGS data archives and process the data to produce seasonal cumulative rainfall charts along with malaria epidemic indicators for each of the woredas in the zone (about 15 woredas per zone). Zonal officers will produce paper maps for distribution to woreda and kebele volunteers, who, in return, will collect and send back malaria incidence and environmental information to the zonal officer. The pilot project intends to equip the zonal centers with a standard computing and printing resources. In addition, volunteers will need to be provided with weekly transport and meal allowances for collecting and reporting field information.

In summary, while raw rainfall data are supplied by USGS/FEWS NET, local partners are responsible for the monitoring of the seasons progress in relation to epidemic years and to communicate the warning system with the local community using printed media. With feedback obtained from the local field officers, the accuracy of the alert system will be validated and enhanced.

## CONCLUSIONS

This study investigated the relationships between clinical malaria data and cumulative rainfall patterns using district data from northwestern Ethiopia. The study showed a strong seasonal pattern of malaria transmission rate being related to the seasonal pattern of rainfall with a lag time varying from a few weeks to a couple of months.

The presence of a lag-time between peak malaria transmission and seasonal rainfall events is very important for forecasting malaria outbreak using observed weather data. However, the magnitude of the lag-time appears to depend on the season and location. This requires a site and season specific formulation of the relationship between weather variables and malaria transmission rates. Based on such relationships, an operational malaria outbreak forecast model could be produced in advance for a given area whose specific lag time may vary from a few weeks to months according to the region and season.

With the promising relationships observed between seasonal rainfall totals and malaria epidemics, this study drafted a concept proposal on the establishment of a FEWS NET malaria early warning system (MEWS) for forecasting malaria epidemics situations in collaboration with a local NGO in Ethiopia.

## ACKNOWLEDGEMENT

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