# Grant agreement no. 243964

# QWeCI

# Quantifying Weather and Climate Impacts on Health in Developing Countries

# 7.c – Third Periodic Report

Start date of project: 1st February 2010 Duration: 42 months

**Lead contractor:** UNILIV
**Coordinator of deliverable:** UNILIV
**Evolution of deliverable**

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|---|---|
| **Due date :** | M44 |
| **Date of first draft :** | 20th September 2013 |
| **Start of review :** | 30th September 2013 |
| **Deliverable accepted :** | 10th October 2013 |

| Project co-funded by the European Commission within the Seventh Framework Programme (2007-2013) | | |
|---|---|---|
| Dissemination Level | | |
| PU | Public | |
| PP | Restricted to other programme participants (including the Commission Services) | PP |
| RE | Restricted to a group specified by the consortium (including the Commission Services) | |
| CO | Confidential, only for members of the consortium (including the Commission Services) | |

# PROJECT PERIODIC REPORT

**Grant Agreement number:** 243964

**Project acronym:** QWeCI

**Project title:** Quantifying Weather and Climate Impacts on Health in Developing Countries

**Funding Scheme:** FP7

**Date of latest version of Annex I against which the assessment will be made:**

**Periodic report:** 3rd

**Period covered:** from 1 August 2012 to 31 July 2013

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[1] Usually the contact person of the coordinator as specified in Art. 8.1. of the Grant Agreement .
[2] The home page of the website should contain the generic European flag and the FP7 logo which are available in electronic format at the Europa website (logo of the European flag: http://europa.eu/abc/symbols/emblem/index_en.htm logo of the 7th FP: http://ec.europa.eu/research/fp7/index_en.cfm?pg=logos). The area of activity of the project should also be mentioned.

## *Declaration by the scientific representative of the project coordinator*

I, as scientific representative of the coordinator of this project and in line with the obligations as stated in Article II.2.3 of the Grant Agreement declare that:

- The attached periodic report represents an accurate description of the work carried out in this project for this reporting period;
- The project (tick as appropriate) [3]:

  ☐ has fully achieved its objectives and technical goals for the period;

  X has achieved most of its objectives and technical goals for the period with relatively minor deviations.

  ☐ has failed to achieve critical objectives and/or is not at all on schedule.

- The public website, if applicable

  X is up to date

  ☐ is not up to date

- To my best knowledge, the financial statements which are being submitted as part of this report are in line with the actual work carried out and are consistent with the report on the resources used for the project (section 3.4) and if applicable with the certificate on financial statement.
- All beneficiaries, in particular non-profit public bodies, secondary and higher education establishments, research organisations and SMEs, have declared to have verified their legal status. Any changes have been reported under section 3.2.3 (Project Management) in accordance with Article II.3.f of the Grant Agreement.

Name of scientific representative of the Coordinator: ...Professor Andrew Paul Morse.....................

Date: ...8th../..October.../..2013...

For most of the projects, the signature of this declaration could be done directly via the IT reporting tool through an adapted IT mechanism.

[3] If either of these boxes below is ticked, the report should reflect these and any remedial actions taken.

# QWeCI Third Periodic Report Main Section – September 2013

## *3.1 Publishable summary*

### Overview

This project brings together and refines the best available knowledge of vector-borne diseases (VBD), climate variability and climate change trends, disease dependence on climate, factors governing infection rates in humans and animals, and the needs of end-user health professionals. The result is a valuable predictive tool that anticipates disease outbreaks and optimises the ability of health professionals and decision-makers to manage some of the most important diseases affecting human populations and livestock.

Vector-borne diseases are the cause of major loss of life, hardship and economic stress in many African countries. Seasonal and interannual climate variability is a primary control of vector and pathogen survival and vector breeding success, leading to disease emergence and spread. A perfect storm of environmental drivers, as well as extreme events that cause floods and droughts are key factors in the dynamics of epidemics. Infection rates depend on vector and pathogen abundance, proximity to human or animal hosts, and on environmental variables including temperature, vegetation and the availability of standing water, which supports aquatic stages of vector life cycles. Climate variability alters temperature and precipitation which, by increasing the area, depth, number and duration of breeding ponds, directly influences vector survival rates and abundance.

The overall objective of QWeCI was to combine state-of-the-art climate model outputs, weather-dependent infection control data for key infectious diseases in African, and local knowledge about population behaviour, disease, vectors and transmission patterns. These would generate maps showing areas of infection risk appropriate to the decision-making of health professionals on the ground and the policy-making of governments of susceptible countries.

Knowledge of how current and future climate is likely to influence infection patterns will have profound implications for planning and disease prevention and control, and be a valuable tool for health professionals and government bodies in countries susceptible to VBD impacts.

### Databases and Reviews

A database of all human and animal pathogens (the ENHanCEd Infectious Disease Database, EID2 http://www.zoonosis.ac.uk/EID2/) has been completed as a part of the NERC ENHanCE and FP7 QWeCI projects. Pathogen entries within the EID2 are labelled with information on their source (i.e. host), where they are found (at the country-level) and when they were isolated. This information is linked to map systems and enables us to study pathogens that are present in the target region for the QWeCI project, Africa. The capability to spatially map disease or pathogen data has been built into the EID2 database at the same spatial resolution as fields of climate data and some host population data.

The modelling exercises that have been undertaken within this work have demonstrated the utility of the EID2 as a source of presence/absence information for pathogens in Africa and other parts of the world. The techniques developed and the modelled outputs for specific diseases/pathogens from EID2 could prove to be of great use within the disease modelling community in the future.

The QWeCI atmospheric database (http://qweci.uni-koeln.de) has bought together a unique set of meteorological data that have been used to support the project. The database has data already in the public domain and new data sets; including historical station time series from Ghana, weather reports from Africa, satellite-derived rainfall estimates, automated weather station data and mosquito breeding site measurements from the Kumasi and wider Ghana region, as well as surface variables from atmospheric reanalyses. The database is also linked to the AMMA database.

A review document has been written on climate and disease interactions based on currently active research finding. Activity characterizing the climatic features that might impact on RVF risk over Senegal and Mauritania has been undertaken. The literature suggests that dry spells followed by large flooding events at the end of the rainy season (Sep-Oct) preceded the major RVF outbreaks that occurred in Senegal and Mauritania. This was also the case for the 2012 outbreak that occurred in southern Mauritania. The relationship between rainfall, temperature and malaria transmission in rural, peri-urban and urban areas of Kumasi (Ghana) has been investigated. A complex statistical analysis focusing on the relationship between rainfall and temperature and malaria in the Limpopo province of South Africa has also been carried out. These investigations in different regions in Africa have lead to several journal papers. The relative importance of climate on malaria transmission with respect to other socio-economic factors has been assessed for Malawi. The relationship between environmental factors and RVF risk in Kenya and Senegal has been investigated. Information about livestock properties in Kenya has been gathered through a participatory survey involving Somali pastoralists in Kenya.

### Climate Model Analysis and Processing and Impact Model Development and Testing

The development and validation of disease models for the regions of interest has been a major focus in QWeCI. A user-friendly interface to the Liverpool Malaria Model was developed through the Disease Model Cradle (DMC) and is available from the project website (http://www.liv.ac.uk/qweci/project_outputs/), it was shared amongst the project partners via two training workshops held in 2011 and the software has allowed users to test the LMM and explore parameter settings for their region. The UoC web portal has provided further a user-friendly interface to LMM. The work package has seen development by project partners of a rich variety of new malaria and Rift Valley fever models, incorporating dynamic, semi-dynamic and statistical approaches. The models have been tested against observations and different modelling approaches have also been compared. The modelling effort and the on-going collaborations built within QWeCI will continue beyond the end of the project.

The production of the regional seasonal predictions required by users of the data in the project, utilises a multi-downscaling multi-model unified approach in order to calibrate different downscaling techniques and to obtain local downscaled values from state-of-the-art global predictions (ECMWF operational products and the multi-model FP6 ENSEMBLES hindcasts, which has been validated for the African domain) for the QWeCI countries.

New areas of research have been opened up by QWeCI in describing the characteristics of African temperature and precipitation in interannual and decadal time scales and assess and improve the state-of-the-art forecast quality with dynamical and statistical models. This has lead to a number of high-level publications from the project. The partners have addressed for the first time the problem of interannual prediction of the West African monsoon using the most recent experiments available. Not surprisingly, much more work remains to be done to determine the usefulness of such a novel tool as climate prediction beyond the seasonal time scale. The problem of the prediction of the precipitation variability over West and Southern Africa at seasonal time scales has been revisited, but this time, and following the requests of the project addressing the distribution of the precipitation within the season (intraseasonal variability).

At the heart of the QWeCI modelling effort has been the integration of climate and disease models on monthly to seasonal timescales, and extending this integration to experimental decadal climate predictions. We also employed an ensemble of climate models driven by different anthropogenic emission scenarios to assess the impact of climate change on future malaria transmission risk. A further objective was to work on the initial development of a multi-agent-based modelling system for Senegal.

A prototype integrated operational malaria forecasting system has been set up at ECMWF. The VECTRI and LMM models have been installed and run at ECMWF. If made public this system could provide dynamic, state-of-the-art ensemble malaria forecasts across Africa. The skill of predicting malaria using the ECMWF System-4 seasonal forecasts has been assessed for Senegal, Ghana and South Africa and Sahel, the Gulf of Guinea, Malawi and Botswana, where the System-4 forecast show significant improvement against those from earlier forecasting systems utilised in FP5 DEMETER and FP6 ENSEMBLES. A pilot integrated multi-agent system has been developed in Senegal for Rift Valley fever and it is intended to be used as part of a risk evaluation and early warning system.

After limited skill was found in the ENSEMBLES decadal hindcasts the decision was made to focus on decadal to centennial timescales and use a multi-scenario multi-model ensemble of global climate model projections from the CMIP5 archive and regional climate model projections for Africa from CORDEX (linking to our sister project FP7 HEALTHY FUTURES). The super-ensemble of climate forecasts/scenarios were integrated with five different malaria models, including two from QWeCI with high level publications submitted. This work will have a high impact and will be disseminated through the IPCC WGI.

### Field Studies and their Integration

Further elements and updates were made to the information systems hosted in Cologne. The Liverpool Malaria Model libraries and the same for the VECTRI model were supplied and are running and being used by African partners. In Senegal work was undertaken to further developed and supplied standing water-monitoring tool (for mosquito breeding habitat) that is now also included in the information system. In addition to the Open GIS application had been provided by

CSE. In Kenya an operational system for RVF model was developed and a further RVF model was developed in Senegal.

The impact of climate variability on malaria incidence and prevalence in urban, peri-urban and rural settings in the forest zone of the Ashanti region in Ghana has been studied. The research allowed the identification and mapping of malaria risk areas, which are possibly related to socio-economic and environmental conditions that enhance malaria transmission. Stakeholders in the health sector comprising the Ministry of Health, Ghana Health Service, Health Administrators, Medical Doctors, and other Health Personnel, have been educated about the project and they found the results very useful in formulating policies related to malaria control measures in Ghana. The field programme in Senegal major component of the QWeCI project and as pilot project and it is mainly focused on field activities with a strong section of field data collection, covering various sectors: climate, hydrology, water quality, vegetation, land use and land cover changes, veterinary (vegetation abundance, serosurvey, ruminants holdings), malaria incidence, entomological, viral surveys and social pastoral practices investigations. The area of investigation is the Barkedji Health and Environment Observatory. Three scientific research teams and two stakeholders/end users were involved in the Barkedji field experiment site. Major findings for this reported period focus on the intra-seasonal rainfall with an upgraded rain gauge network, and with observations and models of the temporal and spatial dynamics of the ponds. These ponds provide habitat and breeding sites for both malaria and RVF vectors and we now start to understand their dynamics in relation with land cover and land use information. We expect that these findings will help in developing and refining health early warning systems for RVF and malaria in Senegal, but also will help end users with their localised health forecasts.

In Malawi the focus is on implementing hardware modifications and software requirements to enable medical data collection from Zomba and Mangochi districts' health centres and to be able to log the details in a Ministry of Health central database using long – range WiFi technology. The work involved the installation, maintenance and performance measurement of wireless communicating nodes from Blantyre all the way to Mangochi. Additionally, this included the setting up of a database for logging medical data instances from remote rural health centres. The same system was used to demonstrate the transmission of seasonal malaria forecasts to the health districts.

QWeCI has brought together scientists from different disciplines, including those involved with public health and animal health, the QWeCI project has contributed to a better understanding of linkages and mechanisms between disease emergence, transmission and spread, and climate/environment variability and changes.

### Integrating Activities

The QWeCI project has fostered synergy and encouraged capacity building through exchange of knowledge within the consortium. This was readily achieved given the unexpectedly large number of inter-consortium extended visits that occurred. The role initially allocated to focus groups, of divulging knowledge acquired during extended visits, was actively and effectively supplemented by teleconferencing. The number of scientific exchanges exceeded the number planned by a significant amount, and pleasingly a large proportion of these scientific exchanges involved direct interaction between European and African partners. The exchanges were instrumental in fostering synergy among QWeCI partner institutes and were the principal medium of inter-consortium capacity building. The exchanges and collaborative relationships are expected to continue well after the project end especially through the sandwich PhD programme STEP, and the ICTP associate programme.

The project provided platforms for the transfer of knowledge and for the dissemination of scientific results both within and beyond the consortium membership. Intra-consortium communication of results is achieved via the newsletters, website and the scientific presentation modules in symposia and workshops; while scientific outreach is accomplished through the circulation of the brochure, stakeholder modules in workshops and symposia.

Finally, the assessment of the products and their potential impacts in the three pilot projects in Ghana, Senegal and Malawi, this report itself shows the successes of each pilot project, and the key actions that were required in order to deliver this success, and the difficulties that were encountered that were not envisaged at the project outset. A critical component in this endeavour has been to draw on the collaborative relationships that have been built through the project, in particular between European and Africa partners, evidenced from the frequent extended visits and scientific exchanges and workshops and the General Assemblies that have taken place throughout the project.

### Management

The management of the project has been a key integrating ingredient as well as ensuring and advising with EU project officer support the compliance with the contracts and financial arrangements. It has provided a homely hub for the project with many new friendships and professional working relationships initiated through teleconference and exchanges organised by the management team. The support of the Annual Assembles, together with the support of the local organisers of workshops and the development of the final project meeting were all essential elements to the success of the QWeCI project. Finally, the useful newsletters, information emails and website and Twitter feed have left an impression on a wider community in Europe, Africa and worldwide.

### Summary

The project has developed a major meteorological database and information system as well as adding to an existing pathogens database QWeCI has seen development by project partners of a rich variety of new malaria and Rift Valley fever models, incorporating dynamic, semi-dynamic and statistical approaches. The models have been tested against observations and different modelling approaches have also been compared. At the heart of the QWeCI modelling effort has been the integration of climate and disease models on monthly to seasonal timescales, and extending this integration to experimental decadal climate predictions.

QWeCI has addressed new and emerging areas of research in investigating the African climate from seasonal to interannual and decadal time scales and assess and has contributed to improve the state-of-the-art forecast quality for the climate and infectious diseases especially malaria. QWeCI brought together scientists from a range of disciplines and has contributed to a better understanding of linkages and mechanisms between disease and the variability of the climate and environment.

The focus on three countries in Africa with different field projects in each has helped to further develop and integrate the emerging African environmental science base working on and leading investigations with European partners within the QweCI project. There were a large number of inter-consortium extended visits that occurred.  A large proportion of these scientific exchanges involved direct interaction between European and African partners.

The success of the QWeCI is evidenced by the individual successes of the pilot projects and their integration and use of products developed in other sections of the project.

## *3.2 Core of the report for the period: Project objectives, work progress and achievements, project management*

### 3.2.1 Project Objectives for the period

**1.1 – Disease database**

- To map known pathogen-climate relationships for use as a visualization tool for possible areas of risk.

- To develop and display via a website mapped outputs from the whole project e.g. current climate sensitivities of disease and projection of future distributions; for regions in Africa and for selected diseases pan-African plots will be produced.

**1.2 – Atmospheric database**

- Activity to update and extend the existing QWeCI atmospheric database.

**1.3 – Climate-disease associations**

- Define selected animal and human disease targets of importance to Africa and summarize present knowledge concerning their climate drivers.

- Using published literature, summarize present knowledge concerning their climate drivers and assess the state of knowledge of climate-disease incidence associations.

- Test the validity of a proportion of published climate –disease associations, using data collected from the pilot project target countries.

- Document these associations and present climate-disease vulnerability in a review document for planners.

**2.1 – Development of dynamic disease models**

- To develop more complex models with more complex transmission cycles e.g. Rift Valley Fever, tick-borne diseases etc; but falling back to simpler semi-dynamic modelling approaches where data sets allow the testing and the development of these modelling systems.

- To run the existing dynamic malaria model to test and validate against data sets provided through the project, to confirm it can be run in different countries and to test parameter settings.

- To use data from the project and other sources; to develop parameter settings for the model for set diseases; and to develop and test more complex dynamic or semi-dynamic approaches.

- In regions where significant disease data exist the dynamic model [LMM] will be run against other modelling approaches.

### 3.1 – Calibrated seamless seasonal atmospheric forecasts

The activities ended in M30. Therefore the have been the dissemination of results and the collaboration with other tasks of the project in order to provide them with the necessary regional seasonal predictions.

### 3.2 – Seamless decadal predictions and projections

This WP was expected to finish its activity in M30, when the objectives were already achieved. However, the partners kept working on the problem initially formulated and interacting with the partners involved in other WPs to ensure an optimal use of the interannual-to-decadal predictions was made.

### 4.1 – Seamless climate-disease model integrations

- To integrate a dynamic disease model within a up to seasonal time scales within a seamless ensemble prediction system using monthly and seasonal hindcasts.

- To move the integrated modelling system into the experimental decadal ensemble prediction system hindcasts and projections.

### 5.1 - Development of integrated information and decision support systems

- Development of a multi-agency system based on the monthly to seasonal and decadal climate disease simulations.

- Definition of a Monitoring Tool (MT) for Standing Water in Senegal based on remotely sensed data sources.

- Development of a Disease Operation System that targets on the epidemiology of malaria and Rift Valley Fever (RVF) in Senegal.

- Construction of a MT of Near-Real Time Disease Incidence in Health Clinics.

### 5.2 – Ghana pilot project: peri-urban malaria

- Entomological survey of malaria transmission in rural, peri-urban and urban settings in the study area.

- Characterization of mosquito larval and adult habitats, and water temperature in the different study areas.

- Analysis and mapping of possible malaria risk areas using GPS.

- Assessment of the impact of climate variability (rainfall patterns, temperature and relative humidity) on the incidence of malaria in the target groups and different settings based on statistical methods.

- Validation of the Liverpool Malaria Model (LMM) and improvement of the LMM with WP2.1.

- Development of Decision Support System (in collaboration with WP5.1) that serves as an early warning system and that assesses the effectiveness of intervention and control measures.

**5.3 – Senegal pilot project: RVF and malaria**

- Characterize the impacts of the intra-seasonal variability in the West African monsoon on malaria and RVF (detection and forecast dry spell and extreme events, climate model downscaling).

- Examine the impact of rainfall, hydrology pond dynamics and land use on malaria and RVF vector populations.

- Validate the dynamic malaria and a new model for RVF in Senegal with a focus on the role of climate and hydrologic parameters at different timescales (rainfall estimation by satellite or directly infrared brightness temperature at different thresholds will also be tested).

- Validate hazard, vulnerability and risk maps.

- Establish a regional set of tools for these two diseases (RVF and malaria) using weather and climate forecasts for predicting timing and Health Early Warning System (HEWS).

**5.4 – Malawi pilot project: disease risk dissemination by long-range WiFi technology**

- Determine forecast format suited to end-user needs in Zomba and Mangochi clinics.

- Disseminate malaria forecasts using the low-cost long-range WiFi network in place and provide training on their use.

- Monitor the use of these forecasts and determine potential improvements

**6.1 – Targeted training and exchange visits**

- Foster inter-consortium communication and exchange of capacity.

- Coordinate and track consortium partner-to-partner knowledge exchange.

- Identify potential for the advancement of core consortium objectives through exchange activities.

**6.2 – Workshops and dissemination**

- A follow up workshop hosted by UCAD was planned by M30.

- A Symposium was to be held in Pretoria (relocated to Rwanda) by the project end.

- Increased dissemination activity in the form of conference attendance and publications was expected, as the science work of the first period of QWeCI is written up and disseminated.

**6.3 – Pilot projects: impacts and recommendations**

A critical component in this endeavour has been to draw on the collaborative relationships that have been built through the project, in particular between European and Africa partners, evidenced from the frequent extended visits and scientific exchanges and workshops and the General Assemblies that have taken place throughout the project.

### 3.2.2 Work progress and achievements during the period

**1.1 – Disease database**

Since the start of the QWeCI project much of the underlying work within WP1.1 has been undertaken and completed in line with the original objectives, description of work and deliverables.

Tasks 1.1a and 1.1b:
Much of the underlying work within the pathogen database work package (WP1.1) has been undertaken and completed using semi-automated methods developed by the University of Liverpool. Having demonstrated the database to project participants, data entry into the ENHanCEd Infectious Diseases database (EID2) has been finalised, fulfilling the first two objectives of the work package, and making the fourth redundant. The completion of UNILIV M1.1.a has been undertaken.

Task 1.1c:
For the report on the current climate controls of selected infectious diseases in Africa (D1.1.a), semi-automated literature searches were employed to identify papers which may contain evidence for the effects of climate drivers upon an agreed short-list of diseases. Some changes to previously used climate terms which were to be utilised for the literature searches using the EID2 were agreed. As information on the vectors of these diseases to the species level had not been provided by some project partners, it was decided that a MeSH term for 'Africa' would be included within literature searches for climate terms and pathogen/vector names. This should omit for instance, a large body of literature linking climate with tick species in North America. Work-package partners (UP, KNUST, CSE) were provided with links to identified papers; they wrote a review for each disease on the effects of climate upon disease dynamics. Their results combined with an introduction and methodology section to complete the third objective of the work package, and provide deliverable D1.1a, thus completing task 1.1c.

Task 1.1d:
The capability to spatially map disease or pathogen data has been built into the EID2 database at the same spatial resolution as fields of climate data and some host population data. Exports of information for *Plasmodium falciparum*, Rift Valley Fever, and the tick-borne pathogen *Babesia bigemina* have allowed predictive presence/absence spatial distribution modelling of these diseases/pathogens with different extents of presence across the African continent to be undertaken. Two types of modelling exercise were developed at different spatial scales: (1) at the country-level predicting distribution around the globe and (2) at a 0.25 degree square resolution predicting distribution on the African continent.

Country-level modelling used generalized linear modelling (GLM) and multivariate adaptive regression spline (MARS) techniques. The results indicate that no added skill was attained with the use of the more sophisticated MARS technique. Model skill was poor in the case of *B. bigemina* infection. Models for *P. falciparum* and particularly Rift Valley Fever attained moderate/good skill, indicating the potential usefulness of the models developed. Regarding variable importance, the results indicate that at the country-level, diseases can be modelled using bioclimatic variables as predictors, with little or no added benefit from the inclusion of host density predictors. The exploitation of the data stored in EID2 has enabled a straightforward development of the models presented, leaving the door opened to further advances in disease distribution modelling using this database.

The 0.25 degree square resolution modelling predicting the distribution of pathogens/diseases across the African continent used a bespoke multi-objective evolutionary expectation-maximisation (EM-) algorithm technique applied to generalised additive modelling (GAM) with a binomial logistic error distribution. Parameters have been investigated to use within EM-GAM modelling. The best models incorporated a refined variable which takes into account surveillance effort for a pathogen and within a country (estimated using EID2 data), adjusting the final output when absences in a pathogen have been reported in the presence data. EM-GAM modelling outputs could be used in the future as a comparator for disease model outputs, developed using other methodologies; as such, the technique and modelled outputs for specific diseases/pathogens from EID2 could prove to be of great use within the disease modelling community. The development of this technique was reported as M1.1b within D1.1b.

1.1e:
The web interface of the EID2 has been completed, and the database is publically available (after user registration) on the world-wide web. The database allows interrogators to look at information in the context of the evidence available within the literature about both disease or pathogen spatial distribution and information on their climate drivers, thus completing the objectives of the work package.

### 1.2 – Atmospheric database

During the last 12 month of the QWeCI project, WP1.2 included and updated atmospheric data sets into the QWeCI atmospheric database (http://qweci.uni-koeln.de go to "Atmospheric database"). WP1.2 constructed the version 1.1 of the QWeCI atmospheric database. Included was the Kumasi Mosquito Breeding Site Measurements (KuMosqSite) data set. Further updates were made to the data sets in terms of Historical Meteorological time series from Ghana (GMet). Moreover, the Ghana Precipitation Time Series (GhanaPTiS) data set is almost ready to be included into the database.

### 1.3 – Climate-disease associations

Significant progress has been made on developing a simple climate risk model for RVF in West Africa, especially for Senegal and Mauritania (UNILIV, CSE and IPD). We found a similar climatic profile (dry spell followed by large precipitation) that was preceding the RVF outbreak that occurred in late 2012 in southern Mauritania. Results are being updated and a publication should be re-submitted soon (Aug-Sep 2013). We have continued to develop links within region climate disease relationships e.g. Lowe (ICTP now IC3) with UNIMA and the Ministry of Health in Malawi on malaria. The relationship between climate variables and malaria morbidity in Limpopo has been assessed. Malaria data from the National Control Malaria Programme has been used and correlated with climate variables for Senegal (D5.3.c). All studies focusing on the link between climate and malaria in different urban settings of Ghana have now been published.

### 2.1 – Development of dynamic disease models

- The Liverpool Malaria Model has undergone further parameter calibration, development/extensions and has been tested against observations collected in the project and against other models/mapped products.

- Development of the new malaria model VECTRI has continued and the model has been published and validated against various sources of observations.

- The EpiCS generic disease modelling library has been developed, tested and used to create and new dynamic Rift Valley fever model (LRVF).

- Development and testing of numerous new statistical and dynamic RVF and malaria models has been carried out by project partners, as reported in Deliverable 2.1b which has now been compiled.

ILRI has continued to develop a dynamic model for RVF. This activity is a joint effort between QWeCI and Healthy Futures project. The model is made up of a vector component (Figure 1) and a host component (Figure 2) that are joined using a parameter that captures the degree of vector:host interaction.

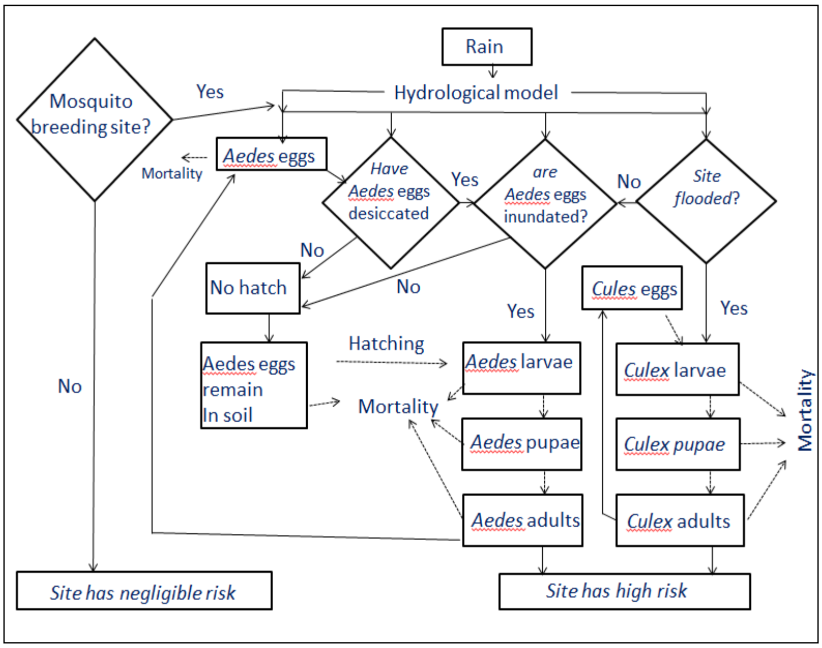


Figure 1. The vector component of the RVF dynamic model

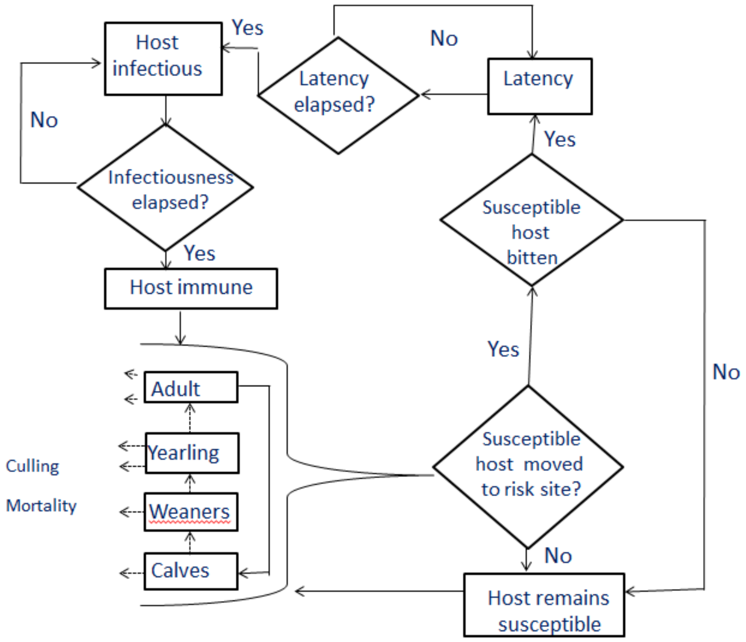


Figure 2. The host component of the RVF dynamic model

The QWeCI project will specifically contribute to the refinement of the vector component of the model using experiences and expertise gained while developing the Liverpool Malaria Model. At the moment, the vector component of this RVF model is still in development and has not yet allowed ways of incorporating effects of temperature and humidity on population dynamics of mosquito populations.

### 3.1 – Calibrated seamless seasonal atmospheric forecasts

Collaborations with other tasks of the project have been undertaken in order to provide them with the necessary regional seasonal predictions. In particular, the monthly to seasonal ECMWF seamless forecasting system has been used to provide the driving model outputs (mainly precipitation and temperature) to force the two dynamical malaria models available into the QWeCI project.

On the other hand, the simulation and analysis of the RegCM4 regional runs (driven both by ERA-interim and the ECMWF ensemble system during the period 1991-2002) have been finished. Post-processing of the resulting data is completed for the South African domain, and the resulting monthly mean files of surface variables (containing precipitation, 2m air temperature, etc) at 25km are stored at http://clima-dods.ictp.trieste.it/data/d10/QWeCI/ so that they can be accessed by the QWeCI project partners. Similarly monthly mean output for the West Africa domain will be processed and made available to the QWeCI Partners.

Moreover, during this reporting period, a pending deliverable was submitted and different dissemination activities were undertaken (see Appendix 1 for detailed partners' reports).

### 3.2 – Seamless decadal predictions and projections

All the results obtained have been made available to the consortium on time. The second deliverable (D3.2b) has been completed. The partners addressed in detail the problem of interannual prediction of the West African monsoon using the most recent experiments available, in particular those that are operational and can be used regularly in the impact models. This activity was part of tasks 3.2b and 3.2c Much more work remains to be done to determine the usefulness of such a novel tool as climate prediction beyond the seasonal time scale, but it is extremely important to note that the African continent has been one of the first land areas for which the skill of the new decadal predictions has been assessed. Feedback from the potential users of this information has been sought to modify the approach to address more specific requirements.

**4.1 – Seamless climate-disease model integrations**

- A prototype malaria early warning system has been set up at ECMWF incorporating two malaria models (one currently online).

- Tier-2 assessment of the ECMWF System-4 forecasts has been completed for the regions of interest.

- Two QWeCI malaria models have been integrated with regional and global climate model output and used to produce multi-model ensemble projections of future malaria distributions.

**5.1 - Development of integrated information and decision support systems**

During the last 12 months of the QWeCI project WP5.1 constructed a multi-agency system in terms of the dissemination of scientific results of the QWeCI project. Included into the multi-agency system is a health early warning system, an information system regarding the monitoring of ponds in the Sahel, a disease operation system for Senegal, and a monitoring tool of near-real time disease incidence in Malawi health clinics. The health early warning system itself comprises four different tools: (i) the pilot system of the multi-agency system, that is the online version of the Liverpool Malaria Model, (ii) the online version of VECTRI (vector-borne disease community model of the International Centre for Theoretical Physics, Trieste, (iii) a demonstrative malaria early warning system for Kumasi, and (iv) prototype operational seamless monthly-to-seasonal malaria forecasts. Regarding the disease operation system two different tools were generated: (i) an information system with regard to a review of malaria and Rift Valley fever control measures and (ii) a Rift Valley fever vector model.

ILRI has completed analysing historical data on RVF epidemics in Kenya collected by the Department of Veterinary Services over the period the period 1951 – 2010. Logistic regression models were fitted to the data to determine factors associated with outbreaks. The analysis used a division as the unit of analysis and the infection status of each division was defined on a monthly time scale and used as a dependent variable. Predictors investigated and sources of the data used are shown in Table 1. Both univariable and multivariable analyses were conducted. Spatial autocorrelation was accounted for using spatial multiple membership model that utilizes Markov Chain Monte Carlo techniques. Functional relationships between the continuous and the outcome variables were assessed to ensure that the linearity assumption was met.

Table 1. Predictor variables used in the analysis of historical data on RVF epidemics in Kenya

| Variable | Source | Description |
|---|---|---|
| Livelihood zones | FEWS NET | Livelihood practices (2006) |
| Land cover | FAO | Global land cover data (GLC) (2000) |
| Precipitation | ECMWF | Monthly minimum, maximum and average for the period: 1979 - 2010 |
| NDVI | Spot Vegetation | Monthly average, minimum, maximum values from: 1999 - 2010 |
| Human population | Kenya National Bureau of Statistics | Human and household census for 1960, 1970, 1980, 1990, 1999 |
| Elevation | CSI SRTM | |
| Soil types | FAO | FAO's Harmonized World Soil Database (HWSD), 2008 |
| Number of previous events | Historical data from CDC | The number of times a division has reported RVF outbreaks between 1912 - 1998 |

Descriptive analyses indicate that a total of 91 divisions in 42 districts (of the original 69 districts in place by 1999) reported RVF outbreaks at least once over the period. The mean interval between outbreaks was determined to be about 43 months. The final model obtained from the analysis is shown in Figure 3. Factors that are associated with RVF outbreaks are:

- Soil type – solonertz (soil 1), vertisols (soil 2) and luvisols (soil 3) are significantly associated with the disease probably because they have poor draining properties and so they are likely to retain water for a long time leading to flooding during the rainy season. During inter-epidemic periods, these soils are also likely to retain high moisture content hence allowing eggs of the floodwater *Aedes* mosquitoes believed to harbor the virus to survive for a prolonged period of time. The reference is all other soil types (based on FAO classification - Table 1)
- Altitude – low areas have higher risks of RVF outbreaks than higher areas. This factor could be a proxy for ecological conditions that would support the prevalence and persistence of RVF vectors. This variable is categorized into 3:
    - Elevation 1 (elev3_1) for altitudes ranging from 0 to 1000
    - Elevation 2 (elev3_2) for altitudes greater than 1000 and less or equal to 2000
    - Elevation 3 (elev3_3) for altitudes greater than 2000
- Rainfall (raintot) –rainfall is significantly associated with RVF. This is a factor that has been reported my many authors. Rainfall associated with El Nino weather patterns is particularly important in this regard because it will cause flooding in high risk areas, leading to amplification of mosquito populations. This analysis however finds a non-linear relationship between rainfall and RVF risk. Rainfall has therefore been fitted as a quadratic term – raintot and rainssquare
- Maximum NDVI – thick vegetation cover are used as vectors as habitats. Like rainfall, NDVI

is fitted as a quadratic term since it does not meet the linearity assumption, i.e., ndvimax and ndsquare

- The number of times an area had experienced an outbreak. This is presented as a categorical variable
    - Casenocat_1 – less than 2 outbreaks
    - Casenocat_2 – 2 – 5 outbreaks
    - Casenocat_3 – greater than 5

Outbreaks were classified as being new if no cases occurred in the preceding 6 month period.

Equations

$$\text{case}_i \sim \text{Binomial}(\text{denom}_i, \pi_i)$$

$$\begin{aligned}\text{logit}(\pi_i) = {} & \beta_{0i}\text{cons}_i + 0.840(0.517)\text{soil\_1}_i + 1.538(0.599)\text{soil\_2}_i + 0.861(0.627)\text{soil\_3}_i + \\ & 1.515(0.570)\text{elev3\_1}_i + \text{-}2.132(0.618)\text{elev3\_3}_i + 1.028(0.115)\text{raintot}_i + \text{-}0.035(0.006)\text{rainsquare}_i + \\ & \text{-}10.935(1.663)\text{ndvimax}_i + 16.818(1.522)\text{ndsquare}_i + 3.858(0.621)\text{casenocat\_2}_i + \\ & 4.093(0.705)\text{casenocat\_3}_i\end{aligned}$$

$$\beta_{0i} = \text{-}14.678(1.209) + u^{(3)}_{0,livehoods(i)} + \sum_{j \in neigh1(i)} w^{(2)}_{i,j} u^{(2)}_{0j}$$

$$\left[u^{(3)}_{0,livehoods(i)}\right] \sim \text{N}(0,\ \Omega^{(3)}_u) \ : \ \Omega^{(3)}_u = \left[4.115(2.666)\right]$$

$$\left[u^{(2)}_{0,neigh1(i)}\right] \sim \text{N}(0,\ \Omega^{(2)}_u) \ : \ \Omega^{(2)}_u = \left[11.995(5.252)\right]$$

$$\text{var}(\text{case}_i|\pi_i) = \pi_i(1 - \pi_i)/\text{denom}_i$$

*Deviance(MCMC)* = 1520.294(71919 of 72720 cases in use)

Figure 3. Final regression model generated from MLwiN ver. 2.27 indicating the variables that significantly predict RVF outbreaks in Kenya

The model was has been validated with spatial data from Tanzania and used to predict potential RVF hotspots in East Africa. Figure 4 shows predicted hotspots generated from the model for the eastern Africa region.

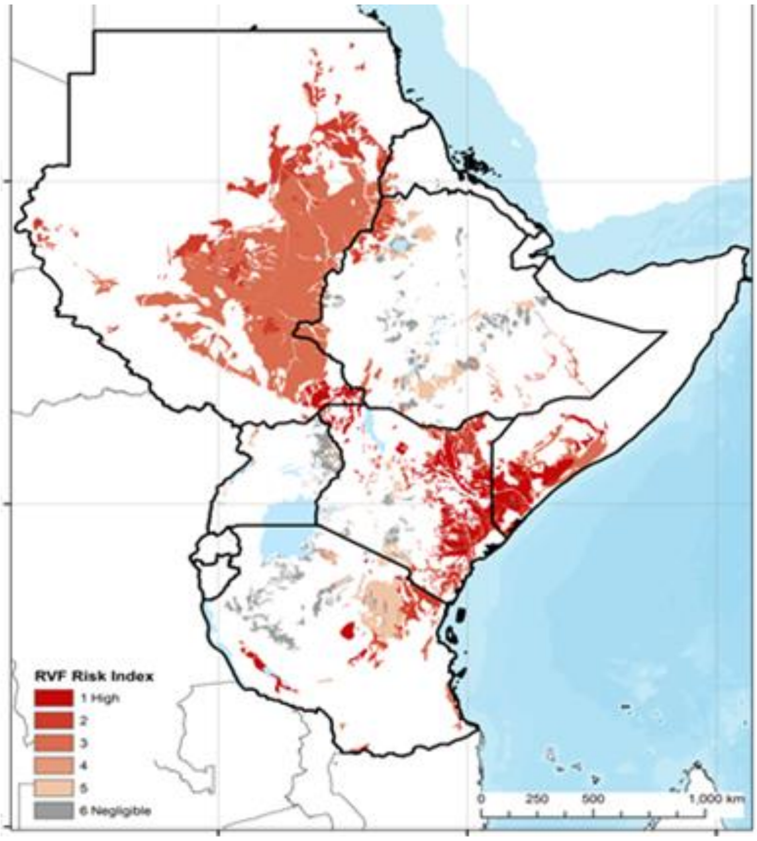


Figure 4. Map of eastern Africa region showing the distribution of predicted RVF hotspots

A journal publication is being developed to present these findings.

**5.2 – Ghana pilot project: peri-urban malaria**

Progress has been made in the following areas:-

- Investigation of malaria transmission patterns in peri-urban and urban areas in Kumasi and its surrounding villages, in and far remote rural communities, all in the forest belt of the Ashanti Region, Ghana.

- Malaria risk areas have been identified and mapped in the study areas; possible related socio-economic and environmental conditions that enhance malaria transmission to be known.

- A pilot run showed how a skilful prediction of malaria transmission on seasonal time scales using the LMM in an ensemble prediction mode will allow for the development of an early warning system (EWS) for the Kumasi and surrounding areas.

The research results are very useful to stakeholders of the Health Ministry, Ghana Health Service and other Health Personnel in general in formulating policies relating to malaria control measures in Ghana; these policies will help bring about a decline of malaria cases with time and thus increase productivity, as more people will become healthy with time. This will contribute positively to socio-economic development.

### 5.3 – Senegal pilot project: RVF and malaria

Main findings help us to publish some results in peer review journals, where PhD students have done several efforts. For example: thanks to Ibrahima Diouf work's, we have a better understanding and validation of LMM in Senegal (http://www.sciencedirect.com/science/article/pii/S1631069113000735). In the same way, Ismaïla Diallo evaluates the performance of a set of regional climate models (RCMs) in simulating the mean climatology and the interannual variability of rainfall over the Sahel (http://www.hindawi.com/journals/ijgp/2012/972896/; http://www.jle.com/e-docs/00/04/89/80/vers_alt/VersionPDF.pdf). More recently, a paper coming from IPD and CSE, and dealing with "*Spatio-temporal analysis of host preferences and feeding patterns of malaria vectors in the sylvo-pastoral area of Senegal: impact of landscape classes*" has been submitted to Parasite and Vectors (http://www.parasitesandvectors.com/imedia/9433696321043643_article.pdf).

Major results have been also presented in Kigali (*4th Annual East Africa Health and Scientific Conference & International Health Exhibition 27-29 March 2013, hosted in Kigali, Rwanda*) and during the QWeCI Closing meeting in Barcelona. The main week point was the Open GIS software where strong bugs have been identified; the problem has been resolved just at the end of July and now CSE finalized the tutorial and by the end of year additional GIS layers will be added.

ILRI:

A total of 993 samples from Senegal were obtained and biobanked with full meta data. These included 464 samples from cattle, 308 from goats and 221 from sheep from a total of 96 households. Locations where the samples were collected from are shown in Figure 5.

Isolation of RNA on additional 80 samples has been done, cDNA synthesized and screening for viruses using specific primers performed. All were negative. Libraries from cDNA have been prepared awaiting sequencing on Roche 454.

The RNA, cDNA and libraries are stored in liquid nitrogen and are available for further analysis. Sequence data from the first 100 samples can be made available.

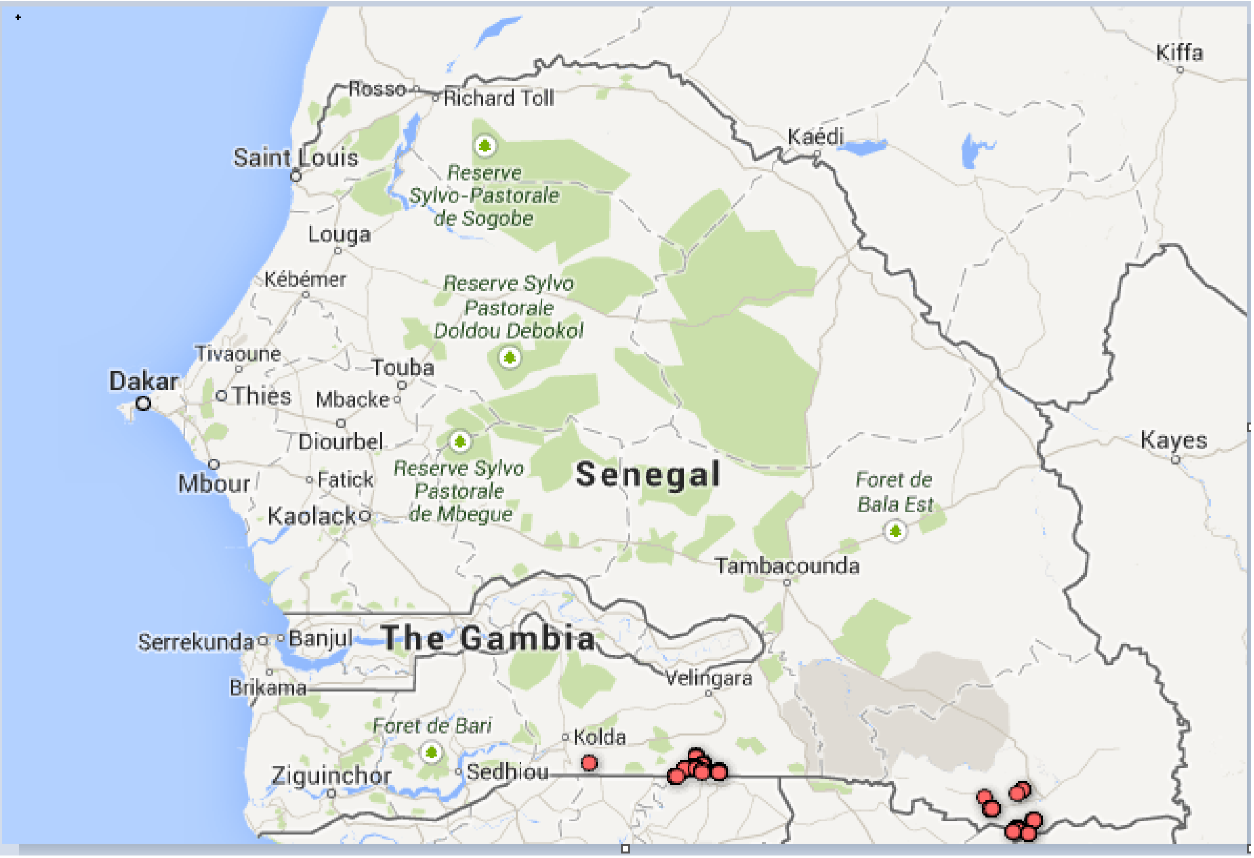


Figure 5. A map showing locations where biological samples were collected from in Senegal

Objective: 1. Metagenomic screening of pathogens. (Aimed at identifying pathogen signatures to be later targeted in all samples)

One hundred serum samples sequenced earlier had no virus presence confirmed. Nucleic acids has been extracted from additional 80 serum samples and libraries prepared for sequencing on Roche 454 platform.

Objective: 2. Screening for known viruses.

First set of 100 samples screened for known arboviruses. No positives obtained. Screening of the additional 80 samples with specific primers on going.

### 5.4 – Malawi pilot project: disease risk dissemination by long-range WiFi technology

Work was undertaken to restore the WiFi backbone from Blantyre to Mangochi through Mpingwe and Zomba, covering about 162 km, as outlined in the QWeCI DoW, the site survey regarding potential clinics that could be served by the Mangochi tower that identified the highest priority clinic, St Martin's, which was linked to the backbone in 2011, and upgraded in a second ICTP visit in 2013 to improve the link quality and reliability as reported in D5.4g and M5.4a/b.

The success of connecting the St Martin's clinic to the network and the Malawi Ministry of Health database via the new web-based health information system DHIS2, developed by UNIMA, has started an upsurge in interest in this technology in Malawi and elsewhere in southern Afreica.

The radio link between the College of Medicine in Blantyre and St. Martins Hospital, extending over 200 km, is an example of the use of low cost WiFi technology to give internet access to institutes far from any fibre optic connections.

**6.1 – Targeted training and exchange visits**

During the strategizing stages of the DoW, a minimum of nine extended visits were expected to take place during the 42 months of the QWeCI project, three per year in the first three years, with no fixed upper limit. The visits were to play an essential role in the capacity building, activity coordination and dissemination of results within the project. In the end, the particular structure of the QWeCI partnership, as collaboration between diverse scientific communities in different continents together with the presence of three specific pilot projects requiring communication and synergy between these communities, has resulted in a great number of extended visits being planned and carried out with seven visits taking place during the first 12 months alone, as reported in the 18M workpackage report. This high rate of scientific visiting and exchange has continued throughout the project to its completion.

In addition to small cluster groups of exchanges, which usually involved scientists of one organisation visiting one other, there were also a number of opportunities to organise extended visits associated with side events at ICTP training schools. Thus both the major training events conducted on the theme of “climate and health” at ICTP (5-16$^{th}$ September 2011 and 15th April to 10 May 2013) had a major involvement of QWeCI partners, with the QWeCI partner meeting organised in conjunction with the first school (which was QWeCI co-sponsored) to facilitate partner travel.

**6.2 – Workshops and dissemination**

- The UCAD workshop went ahead in late 2012 as planned.
- QWeCI jointly held a symposium with sister project HF as a session at the EAC organised conference on health in Rwanda (Kigali, 27–29 March 2013).
- Considerable conference, workshop and publication activity occurred.

**6.3 – Pilot projects: impacts and recommendations**

The progress of the three pilot projects has been continuously monitored throughout the project by the UNILIV project office. In addition, the arrangement of the project was such that the partners in each pilot region had strong ties with a number of European partners in pilot “clusters” (e.g. Senegal with UNILIV, Malawi with ICTP/IC3, Ghana with UoC/ICTP) which facilitated the ease of overview of the pilot projects.

Not all pilot projects have progressed smoothly during the project period, with administrative, technical and political issues arising in addition to scientific developments that lead to some delays in the project achieving its objectives successfully. This workpackage strives to document these issues and the ways in which they were addressed, and provide advice to guide the development of future similar projects.

The roadmap and skeleton for the report was laid out at a series of side-meetings during the final

QWeCI meeting in Barcelona 2013. The meetings were led by UNILIV and ICTP, and involved partners from each of the three pilot regions in turn. Notes and ideas were taken during these meetings to provide input for the report, since it was felt that discussing the issues in person facilitated exchange concerning problematic aspects of the project progress. Where necessary, further teleconferences were organised after the Barcelona meeting to garner further feedback and information for the report.

The report is expected to be completed on time at the end of the QWeCI project period. It should be noted that the regular exchange visits and telecons that have occurred throughout the project duration (see WP 6.1) have also greatly facilitated the delivery of this report, since problems were raised and addressed in a timely manner as a result.

### 3.2.3 Project management during the period

- Consortium management tasks and achievements;
  - Overall co-ordination of the QWeCI project.
    - Management of all internal 6-monthly reporting by partner and work package.
    - Management of third FP7 periodic reporting.
    - Management of final FP7 reporting.
    - Follow up on completion of milestones and deliverables.
    - Coordination of project meetings.
    - Budget overview and analysis.
    - Weekly updates to project partners and researchers.
  - Monitor the implementation of the scientific/technical plan, financial plan and dissemination plan.
  - Delivery of QWeCI aims, objectives and outcomes.
    - Management of all internal 6-monthly reporting by partner and work package.
    - Management of third FP7 periodic reporting.
    - Management of final FP7 reporting.
    - Follow up on completion of milestones and deliverables.
  - Effective communication with the EC and external partners, including stakeholders.
    - Regular communication with EC project coordinator to communicate project status and address any questions.
    - Dissemination of external newsletters to external partners, project stakeholders and interested parties, every six months.
    - Maintenance of QWeCI website with updated news and documentation.
  - Effective communication between work packages and partners.
    - Facilitation of regular, as well as ad hoc, teleconferences between partners and work packages, to discuss progress, questions, issues, deviations, and resolutions.
    - Dissemination of meeting and teleconference minutes to all relevant partners.
    - Dissemination of internal 6-monthly work package reports to all partners.
    - Frequent exchange visits between partners, in line with WP 6.1.
  - Consistent and effective and efficient decision-making.
  - Project Office accessible to partners, researchers, stakeholders and the EC three days a week for all queries and enquiries. Whilst staffing changes in the project office have resulted in changes in accessibility, the project office has remained consistent in its support to partners, researchers and stakeholders. Access to the Project Office has been extended from 1 August 2013 – 30 September 2013 in order to assist partners and researchers in effective completion of third periodic and final FP7 reporting.

- List of project meetings, dates and venues;
  - Third QWeCI Annual Project Meeting: 23rd – 25th October 2012, ILRI (Nairobi, Kenya).
  - Symposium hosted jointly by Healthy Futures and QWeCI at the Fourth Annual East Africa Health &Scientific Conference: 27th – 29th March 2013 (Kigali, Rwanda).
  - School on Modelling Tools and Capacity Building in Climate and Public Health: 15th – 26th April 2013, ICTP (Trieste, Italy).

- Final Project Meeting: 1th – 18$^{th}$ May 2013, IC3 (Barcelona, Spain).

- Project planning and status;
  - On a six monthly basis, internal reports are generated and all partners submit a progress report and identify areas in need of development and attention.
  - Partners communicate and collaborate through informal teleconferences and plan delivery of results within relevant work packages.

- Development of the Project website;
  - Regular updates to news page with recent developments, published papers, newsletters, other related EU funded projects etc.
  - Project outputs (with a public dissemination level) can now be downloaded from the project website.
  - Changes and updates made to partner profiles at the request of the partner.

### 3.2.4 Deviations

2.1
The adjustment of original objectives resulting in the development of DMC and the delay in the development of the generic modelling library towards the end of the project has meant that the new dynamic RVF model (derived from LMM) has not been validated within the project timescale. The work continues within FP7 HEALTHY FUTURES. However, development and testing of three other new RVF models has been carried out within the work package and is reported in Deliverable 2.1.b.

4.1
Due to the revision of the original WP2.1 objectives, only malaria models have been coupled with seasonal hindcasts to assess skill.

6.1
UNILIV tried to arrange an exchange for John Gachohi from IRLI to visit UNILIV during May 2013 but his visa request was turned down even though he had recently travelled in Europe. UNILIV were re-trying his application for a visit in July before the end of the project. This was not possible and the visit eventually went ahead in late August/early September 2013 when the QWeCI sister FP7 project Healthy Futures funded the visit (ILRI and UNILIV) are partners in both projects.

### 3.2.4 Proposed corrections - are these done by now?

4.1
The software tools developed in WP 2.1 will enable forecasts of RVF and other similar vector borne disease to be assessed once the disease models have been validated. Further development and testing of dynamic Rift Valley fever models will be continued in FP7 Healthy Futures starting with East Africa, as the very episodic nature of RVF in Senegal makes the testing of the model difficult.

## 3.3 Deliverables and Milestones tables

| TABLE 1. DELIVERABLES | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Del. no.** | **Deliverable name** | **Version** | **WP no.** | **Lead beneficiary** | **Nature** | **Dissemination level[4]** | **Delivery date from Annex I (proj month)** | **Actual / Forecast delivery date dd/mm/yyyy** | **Status Not submitted/ Submitted** | **Contractual Yes/No** | **Comments** |
| 5.3.b | Entomological profile of the Barkedji Environment and health Observatory for malaria and RVF vectors. | 1.0 | 5 | IPD | Report | PU | 24 | 28/06/2013 | Submitted | | |
| 2.1.b | Report on the performance of the dynamic and semi- | 1.0 | 2 | UNILIV | Report | PU | 28 | 02/08/2013 | Submitted | | |

[4] **PU** = Public
**PP** = Restricted to other programme participants (including the Commission Services).
**RE** = Restricted to a group specified by the consortium (including the Commission Services).
**CO** = Confidential, only for members of the consortium (including the Commission Services).
**Make sure that you are using the correct following label when your project has classified deliverables.**
**EU restricted** = Classified with the mention of the classification level restricted "EU Restricted"
**EU confidential** = Classified with the mention of the classification level confidential " EU Confidential "
**EU secret** = Classified with the mention of the classification level secret "EU Secret "

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|---|---|---|---|---|---|---|---|---|---|---|---|
| | dynamical modelling approaches for selected diseases for regions in Africa. | | | | | | | | | | |
| 5.3.d | Vulnerability and risk cartography of malaria and RVF at the Barkedji Observatory. | 1.0 | 5 | CSE | Report | PU | 28 | 28/06/2013 | Submitted | | |
| 3.2.b | Report on the advantages in terms of forecast quality of the combination of dynamic and statistical models of interannual and decadal variability for Africa. | 1.0 | 3 | IC3 | Report | PU | 29 | 28/06/2013 | Submitted | | |
| 4.1.b | Report on decadal ensemble prediction system integration with a dynamic disease model. | 1.0 | 4 | UNILIV | Report | PP | 30 | 28/06/2013 | Submitted | | |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 5.2.b | Report on the correlation between malaria observations and meteorological / ecological and environmental variables and correlation between water temperature and meteorological variables. | 1.0 | 5 | UOC | Report | PU | 30 | 28/06/2013 | Submitted | | |
| 6.2.d | Report on the follow-up workshop. | 1.0 | 6 | ICTP | Report | PP | 30 | 02/08/2013 | Submitted | | |
| 7.b | Second periodic report | 1.0 | 7 | UNILIV | Report | PP | 32 | 19/10/2013 | Submitted | | |
| 5.2.c | Report on the validation and improvements of the LMM and malaria seasonal forecasts based on LMM. | 1.0 | 5 | UOC | Report | | 33 | 04/10/2013 | Submitted | | |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 5.4.g | Report concerning end-user experience and feedback from first season of use; other potential sites for wireless network in Malawi, and other potential countries that could benefit from such a system. | 1.0 | 5 | UNIMA | Report | | 33 | 27/09/2013 | Submitted | | |
| 5.1.b | Multi agency system | 1.0 | 5 | UOC | Report | PU | 36 | 02/08/2013 | Submitted | | |
| 5.1.c | Health Early Warning System | 1.0 | 5 | UOC | Report | | 36 | 27/09/2013 | Submitted | | |
| 5.1.e | Disease Operation System | 1.0 | 5 | IPD | Report | PU | 36 | 03/09/2013 | Submitted | | |
| 5.1.f | MT of Near-Real Time Disease Incidence in Health Clinics | 1.0 | 5 | UNIMA | Report | | 36 | 19/09/2013 | Submitted | | |
| 5.2.d | DSS and malaria early warning system for the Kumasi area with WP5.1 | 1.0 | 5 | KNUST | Report | PU | 36 | 03/09/2013 | Submitted | | |
| 6.2.e | Twice annual newsletter | 1.0 | 6 | UNILIV | Report | PU | 36 | 28/06/2013 | Submitted | | |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1.1.b | Report on current climate sensitivities of disease and projections of future distributions including a mapped output on the project website | 1.0 | 1 | UNILIV | Report | PU | 38 | 02/08/2013 | Submitted | | |
| 5.3.e | GIS HEWS - Development of decision support systems for end users in conjunction with WP5.1 | 1.0 | 5 | CSE | Report | PU | 38 | 03/09/2013 | Submitted | | |
| 6.3.a | Final Pilot Project Report: summarising the success and failures in each pilot project and making recommendations for improvements and future pilot projects | 1.0 | 6 | UNILIV | Report | PP | 38 | 11/10/2013 | Submitted | | |
| 6.2.f | Non-technical summary of the project overview for end-users (including policy makers and NGOs) | 1.0 | 6 | ICTP | Report | | 40 | 04/10/2013 | Submitted | | |

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|---|---|---|---|---|---|---|---|---|---|---|---|
| 6.2.e | Twice annual newsletter | 1.0 | 6 | UNILIV | Report | PU | 42 | 11/10/2013 | Submitted | | |
| 7.c | Third periodic report | 1.0 | 7 | UNILIV | Report | PP | 44 | 29/10/2013 | Submitted | | |
| 7.d | Final report including plan for use and dissemination of foreground and report on societal implications | 1.0 | 7 | UNILIV | Report | PP | 44 | 30/10/2013 | Submitted | | |

| TABLE 2. MILESTONES | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Milestone no.** | **Milestone name** | **Work packag e no** | **Lead beneficiary** | **Delivery date from Annex I dd/mm/yyyy** | **Achieved Yes/No** | **Actual / Forecast achievement date dd/mm/yyyy** | **Comments** |
| 1.1.b | Completion of disease-climate relationships from pilot projects | 1 | UNILIV | 31/07/2012 | Yes | 25/04/2013 | |
| 5.2.b | Malaria seasonal forecast | 5 | KNUST, UOC | 31/07/2012 | Yes | 21/09/2012 | |
| 5.4.b | First use of long-distance wireless technology for disease forecast dissemination to rural clinics. | 5 | ICTP, UNIMA | 31/07/2012 | Yes | 25/07/2013 | |
| 5.3.e | GIS HEWS conceptual model | 5 | CSE | 31/10/2012 | Yes | 14/12/2012 | |
| 5.1.b | Final versions (including documentatio n) of all SDSS, IS and MT | 5 | UOC | 31/01/2013 | Yes | 20/06/2013 | |
| 6.2.b | Completion of the Pretoria Symposium | 6 | UNILIV | 31/01/2013 | Yes | 23/04/013 | |
| 7.b | Final Project Symposium | 7 | ICTP, UNILIV | 31/05/2013 | Yes | 21/06/2013 | |

## *3.4 Financial Statements*

Form Cs electronically submitted to the European Commission.

Paper copies of the financial statements have been sent to the European Commission via courier.

# Appendix I to QWeCI Third Periodic Report Main

## Detailed Summary of Progress

1.1
A database of all human and animal pathogens (the ENHanCEd Infectious Disease Database, EID2) has been completed as a part of the ENHanCE (www.liv.ac.uk/enhance) and QWeCI projects. Pathogen entries within the EID2 are labelled with information on their source (i.e. host), where they are found (at the country-level) and when they were isolated. This information is linked to map systems and enables us to study pathogens that are present in the target region for the QWeCI project, Africa. The capability to spatially map disease or pathogen data has been built into the EID2 database at the same spatial resolution as fields of climate data and some host population data. Exports of information for Plasmodium falciparum, Rift Valley Fever, and the tick-borne pathogen Babesia bigemina have allowed predictive presence/absence spatial distribution modelling of these diseases/pathogens to be undertaken; they all have different extents of presence across the African continent. Two types of modelling exercise were developed at different spatial scales: (1) at the country-level predicting distribution around the globe and (2) at a 0.25 degree square resolution predicting distribution on the African continent.

Country-level modelling used generalized linear modelling (GLM) and multivariate adaptive regression spline (MARS) techniques. Models were evaluated using a k-fold cross-validation procedure (k=5) in terms of their predictive skill as given by the ROC skill area metric (RSA). The independent contribution of the different variables was also assessed in the context of GLM modelling using a technique involving hierarchical partitioning in order to gain an insight into the importance of the climatic/human/animal factors in explaining disease occurrence. Our results indicate that no added skill was attained with the use of the more sophisticated MARS technique. Model skill was poor in the case of B. bigemina infection. Models for P. falciparum and particularly Rift Valley Fever attained moderate/good skill, indicating the potential usefulness of the models developed. Regarding variable importance, the results indicate that at the country-level, diseases can be modelled using bioclimatic variables as predictors, with little or no added benefit from the inclusion of host density predictors. The exploitation of the data stored in EID2 has enabled a straightforward development of the models presented, leaving the door opened to further advances in disease distribution modelling using this database.

The presence or absence of pathogens was modelled at a 0.25 degree square resolution using an expectation-maximisation (EM-) algorithm technique which was applied to generalised additive modelling (GAM) with a binomial logistic error distribution. Within the modelling exercise, the effects of (1) using different numbers of iterations within the EM-GAM modelling, and (2) the use of different Pi values (examining the effect of changing the prior probability of a detected absence actually being a presence within the data) were explored. A further Pi value (3) which estimated (using a combined assessment from data from EID2) the surveillance effort for a pathogen in different countries and of the general surveillance of all pathogens in one country relative to other countries was also examined. Model outputs suggested that (1) models converged after 20 iterations; (2) the Pi value to use within modelling cannot be estimated using the data; and (3) a model which incorporates surveillance adjusted Pi values should be utilised as the best Pi estimate for EM-GAM modelling.

The modelling exercises that have been undertaken within this work have demonstrated the utility of the EID2 as a source of presence/absence information for pathogens around the world. The use of the EM-GAM technique could provide national and global modelled outputs which could be used as a comparator for disease model outputs, developed using other methodologies. As such, the technique and modelled outputs for specific diseases/pathogens from EID2 could prove to be of great use within the disease modelling community in the future. Future work using this technique will need to include testing the accuracy of the outputs of EM-GAM modelling exercises, by comparing outputs with test data for diseases/pathogens; either from previous modelling exercise outputs describing the presence of pathogens, or real-world data.

1.2
The following data sets were either prepared, included or updated for the QWeCI atmospheric database:

- **Ghana Precipitation Time Series (GhanaPTiS)**

UoC collected daily rainfall data from Ghana. The GhanaPTiS data set includes daily precipitation time series from 191 rainfall stations in Ghana. Comprised are rainfall observations between 1990 and 2010. The overall data availability during this period is about 47%. Some of the station time series reveal no data gaps, whereas other stations include only measurements from few years. Most of the stations are located in the denser populated southern part of the country. The data was provided by the Ghana Meteorological Agency (GMet).

The metadata for this data set was compiled. At present, the geographical position of some of the rainfall station is unknown. It is unclear if these stations are located to the West or East of the Greenwich meridian.

- **Kumasi Mosquito Breeding Site Measurements (KuMosqSite)**

During the visit between 14 and 20 November 2012 of Volker Ermert at ICTP, metadata regarding the Kumasi mosquito breeding site measurements was drafted. The metadata was proofread and complemented. Exemplary figures were generated and the data files were collected. The data set and the metadata is now available online (http://www.qweci.uni-koeln.de go to "Atmospheric database" and choose "KuMosqSite" data set). Available is the metadata for the public. At the current stage, the pond data is restricted for the QWeCI partners. Ernest Ohene Asare is drafting an article preliminary entitled as "Simple pond parametrization for a malaria transmission model", which applies the KuMosqSite data set.**Historical Meteorological time series from Ghana (GMet)**

The GMet data set was updated in terms of daily rainfall amounts and daily minimum and maximum temperatures. The data set now comprises time series from the 22 synoptic weather stations of Ghana between 1944 and 2011.

The overall data availability is about 71%. Most of the rainfall time series indicate a data availability of more than 80%, whereas the availability of the temperature time series is in general between 40 and 90%. The data set covers the whole of Ghana; however, most stations are located in the denser populated southern part of the country. Single rainfall and minimum and maximum temperature time series of the stations were illustrated.

A quantitative quality check of the data was performed on a monthly scale. It was found that the data seems to be reliable in most cases. For the comparison also other data sources were used, as well as data from neighbouring stations. It was partially unclear, if the GMet data set is valid. In particular, the station AKATSI shows many deviations in comparison with monthly rainfall reports. In the GMet data the 1998 values are also found in 1988. Regarding AKIMODA false "0" values were found in December 1987 and September 1988. False "0" values were also found for BOLE in October 1951, TAKORADI in July 1984, ADA in September 1975, and WENCHI in April 2007. The GMet data and the comparison helped to detect some errors in the database and to correct the data.

Furthermore, the data set was qualitatively checked by the visually inspection of the illustrated time series. Corrected were, for example, temperatures values in Fahrenheit instead of Celsius. Deleted were unrealistic high or low temperature values. All the performed corrections were noted down such that the corrections can be reversed.

1.3

All milestones and deliverables have been completed for this work package.

**Task 1.3a: Document climate drivers of priority infectious diseases, in an African context, from published studies**

Information based on the existing literature has been gathered from a number of partners (UNILIV, KNUST, UP..) for malaria, Rift Valley Fever (RVF), tick and flea borne diseases and to less extent for other significant infectious diseases (West Nile, other water borne diseases) in an African context. This information was compiled by UNILIV in the accepted (M16) deliverable D1.3.a "Review document for governmental and NGO planners concerning state-of-the-art knowledge concerning climate driver impact on target disease incidence and present climate vulnerabilities for endemic and epidemic incidence according to these relationships" which is publicly available online on the QWeCI website.

Another review paper concerning the link existing between RVF and climate in Africa is still in progress (CSE, Ndione et al., 2013). Note that all QWeCI partners are still actively sharing recent scientific papers about climate and vector-borne diseases in Africa.

**Task 1.3b: Test published climate-disease associations with new datasets from WP1.1 and WP1.2 in the pilot countries**

Based on the work of Ndione et al., 2008, (CSE) and Mondet et al., 2005; the RVF climatic risk has been mapped over West Africa by Caminade et al., 2011 (UNILIV). The method is based on the detection of dry spells (lasting for 6 days minimum) which are followed by a huge rainfall event (above 20mm) during the late rainy season (Sept-Oct). This climatic feature has been observed during the four major RVF outbreaks that occurred over northern Senegal and has also been recently tested for Mauritania for four major outbreaks (1998, 2003, 2010 and 2012). We used TRMM satellite data (version 7) from WP1.2 to carry out this analysis. The impact of climate change on future malaria risk has been estimated by Ermert et al., 2011 (UOC and UNILIV in connection with WP2.1). A simulated decrease in rainfall over the northern edge of Senegal leads to a southward shift of the simulated malaria epidemic belt; simulated future malaria prevalence slightly increases over Ghana and Malawi due to the temperature increase. The link between climate variables and risks of RVF, malaria and babesiosis in Africa has been investigated in conjunction with WP1.1 (see Deliverable D1.1.b for further details). For example, the importance of bioclimatic variables was confirmed by the relative importance of some bioclimatic variables compared to population-related ones. In the case of *B. bigemina*, the most important variables were the precipitation of driest month and temperature seasonality. The deliverable D1.3.b "Scientific publication validating existing published climate-driver disease (principally malaria and Rift Valley Fever) incidence relationships in pilot project target countries and appropriate modifications to these relationships in a future climate" related to this task has been accepted on M28.

**Task 1.3c: From the above analysis, identify most important and multivariate key statistics of these variables for the key identified diseases i.e. mean, max, variance and critical thresholds.**

A dry spell (lasting for 6 days minimum) which is followed by a large rainfall event (above 20mm) during the late rainy season (Sept-Oct) has been identified to be a key climatic factor in driving the four main RVF outbreaks that occurred in Senegal and the four main RVF outbreaks that occurred in Mauritania (UNILIV, CSE, IPD).

Climate data (rainfall and temperature from WP1.2) and other socio-economic data (demography, urbanization...) have been utilized to build a malaria statistical model for Malawi at the district level (using malaria standardized morbidity ratio) at the monthly time scale. This work is lead by R. Lowe (now in IC3, former ICTP member) in collaboration with the Ministry of Health, Malawi, which helped in providing the health and socio-economic data for Malawi.

**Task 1.3.d: Prior to the work with the dynamical models in WP 2.1 we propose to build and use statistical models of increasing complexity to simulate in each region the dynamics of malaria, RVF etc. as a function of the different climate drivers. Analysis of the temporal dependence and validation of the diseases on the drivers (GCVs, Akaike‟s, etc..) and a dimensional space study will be undertaken.**

Statistical models of increasing complexity have been developed to simulate malaria risk, as a function of different climate drivers, in one of the QWeCI pilot sites: Malawi (IC3-ICTP, UNIMA). Malaria transmission is influenced by variations in meteorological conditions which impact the biology of the mosquito and the availability of breeding sites, but also socio-economic conditions such as levels of urbanisation, poverty and education, which influence human vulnerability and vector habitat. The many potential drivers of malaria, both extrinsic, such as climate, and intrinsic, such as population immunity are often difficult to disentangle. This presents a challenge for modelling of malaria risk in space and time. Using an age-stratified spatio-temporal dataset of malaria cases from July 2004 – June 2011, a spatio-temporal modelling framework has been developed to explore variations in malaria risk in the 28 districts of Malawi. District level data is tested in the model to account for confounding factors, including the proportion of the population living in urban areas; residing in traditional housing; with no toilet facilities; who do not attend school, etc, the number of health facilities per population and yearly estimates of insecticide-treated mosquito net distribution. Climatic and topographic variations are included by using an interpolation method to relate gridded products (e.g. CPC FEWS-Net rainfall estimates based on satellite and rain gauge data and ERA-Interim Reanalysis temperature data) to administrative districts. Figure 2 shows the relationships between malaria standardised morbidity ratios (SMR, the ratio of observed to expected malaria cases), climate variables are the most significant time lags (precipitation 1 month lag, temperature 3 months lag) and the relationship between precipitation and temperature. The solid line shows the linear model fit and the dashed curve shows the local polynomial regression fit. Using the exploratory variable outlined above, a generalised linear model framework was used to test and select spatial and temporal variables, factors, interactions and polynomial terms. Stepwise model selection was performed using Akaike Information Criterion (AIC). Categorical variables of importance were age group (over and under five years), region (north, central, south), zone (lowland, lake shore, highland and combinations), annual cycle. Important climate information was temperature (lag 3 months), precipitation (lagged 1 month with a quadratic association, see Fig. 3), interaction between temperature and precipitation (see Fig, 2). Non-climate information included altitude, longitude and latitude (quadratic relationships), demographic information: urbanisation, population density, housing conditions: one room for sleeping, no toilet facilitates, health facilities per population and education level. Figure 3 shows a summary of the model fit, divided into five years and over age group (top panel) and under five years age group (lower panel). The scatter plots and time series show the relation between model fit and observed malaria SMR for the whole of Malawi for the 84 month time period. Observed and fitted values appear to agree quite well. The annual cycle in malaria is well captured. Although the model does not well represent inter-annual variation in malaria, the temporally varying climate information does explain some of this variability. Over all, the model explains 41% of the variation in malaria risk. The maps show the root mean squared error

(RMSE) of the difference between model fit and observed SMR over the time period in each of the 28 districts, highlighting districts where the model performs less well. These districts will be investigated further. The model framework will be extended to include random effects to capture the unobserved and unexplained variation in malaria risk. The feasibility of using dynamical disease model output to drive statistical models is investigated.

Climate-disease relationships have been analysed from country-based information provided by University of Liverpool to CSIC. In particular, statistical modelling tools for presence-only data have been tested. The world occurrence of three diseases —Rift Valley fever, Babesia bigemina and Plasmodium falciparum infections— has been modelled at the country level using two presence/absence algorithms: generalized linear models (GLM) and multivariate adaptive regression splines (MARS). Models have been evaluated using a k-fold cross-validation procedure (k=5) in terms of their predictive skill as given by the ROC skill area metric (RSA). The independent contribution of the different variables was also assessed in the context of GLM modelling using a technique of hierarchical partitioning in order to gain an insight into the importance of the climatic/human/animal factors in explaining disease occurrence (for further details see D1.1.b).

Binary data for RVF outbreaks in animals has been collated. Statistical models that accommodate binary data and confounding factors have been developed to investigate the role of climate in driving RVF outbreaks over Kenya (see D2.1.b for further details).

Diouf (UCAD) also worked on using climate data in order to model the hydrological dynamics of the ponds in the northern region of Senegal (Barkedji ponds). This is carried out in order to study RVF risk over the Ferlo region in Senegal. The link between malaria cases and climate for various eco-zones of Senegal has been investigated by UCAD in the delayed deliverable D5.3.c.

**Task 1.3e: Document the relationships found in Tasks 1.3 a to d and the present climate disease vulnerability in a review document for planners**

A review document for planners has been compiled by UNILIV with inputs from all partners in the accepted (M16) deliverable D1.3.a "Review document for governmental and NGO planners concerning state-of-the-art knowledge concerning climate driver impact on target disease incidence and present climate vulnerabilities for endemic and epidemic incidence according to these relationships" which is available online on the QWeCI website. As this deliverable was due on M12, this does not necessarily include all the work that was carried out within this WP1.3 during the present reporting period (this document has not been updated since). The significant results are still communicated to core stakeholders through Task1.3.f.and through open access scientific publications.

**Task 1.3f: Engage core stakeholder groups in each region through the organization of a series of small workshops. This will also act as an introduction to the project for stakeholders.**

A workshop with stakeholders was organised by CSE in Dakar in November 2011. Morse and Heath (UNILIV) contributed to the workshop. This was well attended by national, regional and local representatives from Senegal. Almost 40 delegates attended from local, regional and national groups. The village leader from the Barkedji also attended and said how important the research was for his village.

2.1 Detailed summary of progress:

*Task 2.1a: Evaluate current dynamic Liverpool Malaria Model (LMM)*

UCAD have used the DMC-LMM package to develop their own parameter settings based on local data and have also used the UoC portal to carry out testing of LMM2004 and LMM2010 using both reanalysis data and station data for Senegal.

Extensions to the original LMM (2004 and 2010) versions have also been developed and tested. UoC coupled the LMM2010 with an infection model to simulate the parasite infection rate in children. The integrated model was driven by the 0.5° resolution REMO regional climate model, and the resulting simulations compared to maps of malaria endemicity from the Malaria Atlas Project (MAP). UNILIV tested LMM2004 parameter settings and the impact of two new model components to improve model response at the start of the season, compared to observations of malaria for Senegal and South Africa.

*Task 2.1b: Generalize the current dynamic Liverpool Malaria Model for any simple single vector, single host vector borne disease and Task 2.1c To develop the malaria model - for two or multi-host diseases.*

These tasks were modified earlier in the project since it was felt that users would benefit more from an easy-to-use interface to the model rather than the opportunity to configure any model structure. As a result the development of the Disease Model Cradle, DMC, replaced the development of a generic model. However, in the last year of the project, model development at UNILIV has resulted in the creation of a generalised disease modelling library, the EPICS toolkit (EPIdemiological modelling toolkit for Climate Sensitive disease), a C/C++ library which allows expert users to build models for any multiple host, multiple vector disease. The EpiCS toolkit has been used to rebuild LMM and tested against existing versions of the mode, and to build a prototype dynamic two vector, single host RVF model, LRVF, which has not yet been tested against observations. Development of the LRVF model will now continue beyond the end of QWeCI as part of the HEALTHY FUTURES EU FP7 project.

This work package has also seen the development of numerous new dynamic and statistical disease models by different project partners:

- A new dynamic malaria model, VECTRI, published in malaria journal in February 2013. *(ICTP/UoC)*
- A statistical model for RVF vector abundance in Senegal. *(IPD)*

- A statistical model linking rainfall, RVF vectors, and RVF-infected livestock. *(CSE-UCAD)*.
- A spatio-temporal statistical malaria model for Malawi which includes the effects of climate and socio-economic parameters. *(IC3/UNIMA/ICTP/Ministry of Health, Malawi)*
- A dynamical stochastic differential equation model validated against observed data in Senegal. *(IC3)*
- An RVF mixed statistical model for Kenya *(ILRI)*
- A climate envelope model for malaria in Limpopo province, South Africa *(UP)*.

These new models are described in further details in the report for Deliverable 2.1b.

*Task 2.1d: Test new generalized model with Rift Valley Fever and malaria data (and possibly tick borne diseases) from database and Task 2.1e For regions where there are sufficient disease data, recovered by this project, other modelling approaches e.g. statistical models will be compared with the performance of the dynamical modelling approaches.*

With such a diverse range of models developed on different platforms and with different data interfaces, performance assessment of the new models has focused on individual model validation against observations, rather than on intercomparison. These validation studies are reported in Deliverable 2.1b.

An intercomparison of different modelling approaches was carried out in QWeCI through UNILIV and ICTP who compared five malaria models (MARA, LMM, UMEA, MIASMA and VECTRI) for current and future climate scenarios. The results, reported in Deliverable D4.1b, will be included in the next IPCC report and the PNAS publication of the study is currently under review (with positive feedbacks from the reviewers).

The report for Deliverable 2.1b was delayed in order to allow the different partners to finish model development and validate their various modelling approaches. The report has now been compiled and is ready for submission at month 42.

3.1

WP3.1 included four different tasks with the final goal of producing downscaled/calibrated regional seasonal predictions to be used by other tasks of the project. **Task 3.1.a** aimed at the development of seamless calibrated products for disease-related variables combining ECMWF monthly and seasonal forecasting products. As a result of the activities in this task, a seamless weekly-updated operational forecasting system has been developed at ECMWF by appending the first 25 days of the monthly system (VarEPS-monthly) with month 2 to 4 of the seasonal forecasting system (SYSTEM-4). Different calibration procedures were tested for precipitation and temperatre in order to avoid discontinuity between the two systems. **Task 3.2.b** aimed at the development and assessment of statistical downscaling approaches (analogs, weather types, neural networks) in terms of health-relevant climate/weather variables. The activities in this task have been targeted to the QWeCI countries (Senegal, Ghana and Malawi), using the best available observations in each case. As a result of these activities a throughout assessment of the analog, linear regression, and Generalized Linear

Models (GLMs) was performed using the 40 years hindcast from the ENSEMBLES multi-model seasonal forecasting system, analyzing different combinations of potential predictors over different geographical domains around the target area. As a result, a complete assessment of the added value of these techniques for the different locations considered is reported considering a period larger than twenty years in all cases. The results from this task have been included in the QWeCI statistical downscaling portal, which allows accessing the downscaled series produced and also testing new configurations/datasets. In **Task 3.1c**, the possible gain of seasonal forecasts with dynamical downscaling methods was tested considering two different regional climate models (WRF and RegCM4) for west and southern Africa. To this aim both reanalysis- and seasonal forecast-driven simulations have been performed and tested, with promising results over the southern Africa domain. 25km simulations for the period 1991-2002 driven by both for ERA-Interim and ECMWF seasonal forecasting system for the RegCM4 model are available from http://clima-dods.ictp.trieste.it/data/d10/QWeCI/

Finally, **Task 3.1d** aimed at the production of regional seasonal predictions as a multi-model multi-downscaling unified approach and estimation of the associated uncertainty. The different products developed within WP3.1 have been finally assembled in this task, providing other WPs with the health-relevant weather variables at the appropriate scale they need. In particular, the calibrated operational seamless predictions are made available trough an ftp repository to be used as driving fields for the malaria models. A web-site for the visualisation of the products has also been opened. The multi-model downscaled predictions from the ENSEMBLES Stream2 hindcast are available through the QWeCI statistical downscaling portal.

Overall, as a result of the activities performed within this WP, the following significant results can be highlighted:

- Developed a monthly to seasonal seamless operational forecasting system which is weekly updated, with a corresponding 18-years hindcasts.
- Extensive validation of different statistical downscaling techniques in different African regions considering both "perfect" forcing conditions (ERA-Interim) and a multi-model hindcast. Results are acceptable for temperature (with inter-seasonal correlations in the range 0.6-0.8 for different seasons/stations in Ghana and Malawi), but are poor in general for precipitation.
- Dynamical downscaling (with regional climate models) has been tested with promising results over the western and southern Africa domain. The regional model is not only able to reduce the wet bias of the driving GCM over most part of the domain but also enhances the temporal correlation between the forecast and observation over most part of the domain.

Finally, collaborations with other tasks of the project have been established in order to use the forecasting systems to provide the driving model outputs (mainly precipitation and temperature) to force the two dynamical malaria models available into the QWeCI project. In particular, the monthly to seasonal ECMWF seamless forecasting system has been used for this purpose.

3.2
The milestone and deliverables already available serve as reference documents for the health partners to determine what inputs could be relevant to their health models. The results described up to now have focused on problems identified by the partners as key for the modelling of those physical processes leading to increased risk of outbreaks.
The results are also highly relevant for the wider scientific community and have lead to several publications.

4.1
All milestones and deliverables have been completed for this work package.

**Task 4.1a: Modelling System development to modify the input output routines from the dynamic Liverpool Malaria Model to work with different ensemble model output**
LMM and VECTRI have been installed at ECMWF and the I/O routines (shell scripts) rewritten to run on the automated SMS scheduling system which is used for operational model runs. Sample plots from the integrated system are shown in Figure 1.

LMM has been run on the UNILIV archive of ensembles climate model output:

- SYSTEM-4 seasonal ensemble forecasts
- GCM data from the CMIP5 archive
- RCM data from CORDEX

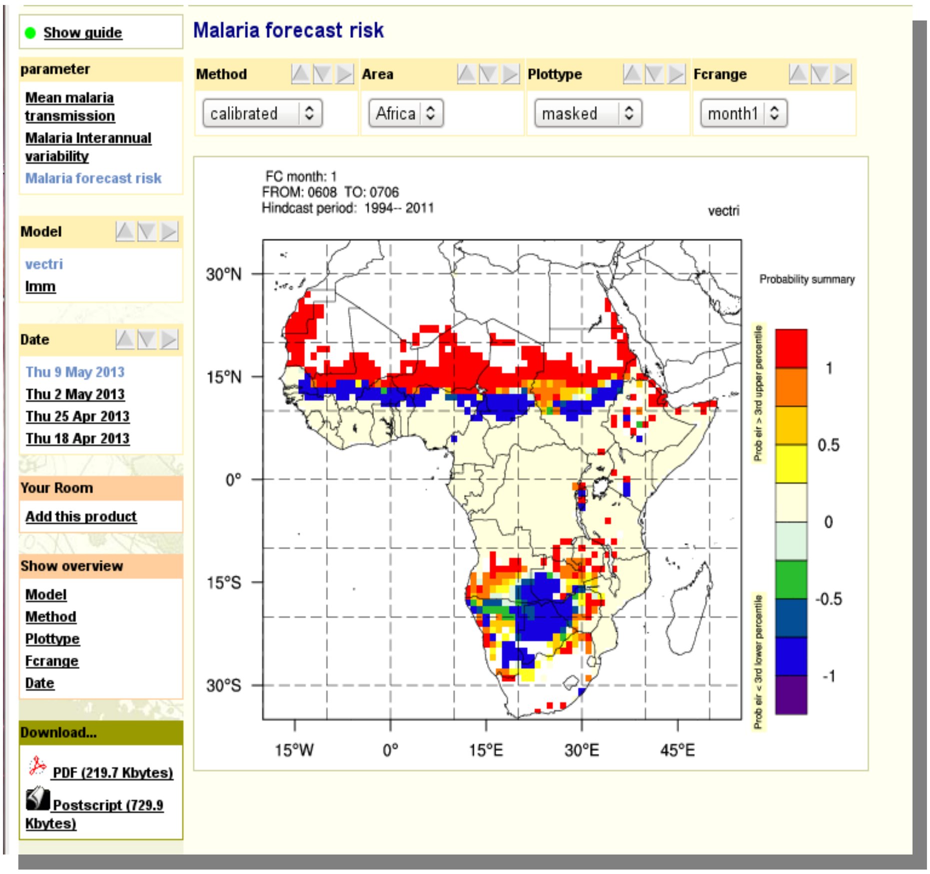



**Figure A1**. Sample output from the integrated operational malaria forecasting system showing malaria risk forecast using the VECTRI model.

**Task 4.1b: Force malaria specific dynamic models (fully and semi dynamic) with bias corrected monthly and seasonal hindcasts – to develop a seamless system – using verification against control (reanalysis data sets) runs for disease model outcomes**

The LMM has been run with uncorrected and bias-corrected (temperature) System-4 hindcasts, and verification at tier-2, against the ERA-Interim reanalysis is now complete. This work was reported in the M4.1a report and in more depth in Macleod (2013, PhD thesis). A summary of results is given in Table 1.

**Table A1** Summary of tier-2 malaria forecast skill using LMM driven by System-4

| Region/Target | Summary |
|---|---|
| Sahel: Sep/Nov | • Some significant ROC AUC at the epidemic fringe in the Western Sahel for forecasts initialized July, below significance outside this region.<br>• No skill for forecasts initialized May or June<br>• Temperature bias correction does not increase ROC AUC. |
| Gulf of Guinea: Sep-Nov | • ROC AUC below significance over entire region for all start dates.<br>• Temperature bias correction gives no improvement. |
| Malawi: Mar-May | • Skill over the north west for start dates in October, November and December; no significant scores outside this region.<br>• Temperature bias correction does not improve forecasts |

**Task 4.1c: Evaluate skill of malaria and RVF (and tick borne diseases depending on completion of Task 2.1C ) seasonal hindcasts using disease databases**

Due to the revision of the original WP2.1 objectives, only malaria has been considered. The skill of the System-4 forecasts when used to drive LMM has now been evaluated for Botswana against a published malaria index and the forecasts show a good improvement in skill compared to DEMETER and ENSEMBLES (See Table 2). A paper concerning these results, together with an evaluation of the potential improvement in using the seamless monthly-seasonal forecasts over System-4, is currently in preparation. The very periodic nature of RVF in Senegal makes the full testing of a dynamic RVF model problematic. The work continues in development in East Africa in FP7 Healthy Futures and can then be reapplied to West Africa.

**Table A2.** Tier-3 skill (ROCSS) for LMM prediction of low (LT) and high (UT) malaria events in Botswana relative to Botswana Malaria Index (Thomson et al, 2005).

Results show that System-4-driven forecasts for high events are early as high as that for the reanalysis-driven runs.

| Model | LT | UT |
|---|---|---|
| DEMETER multimodel | **0.84** | 0.67 |
| ENSEMBLES multimodel | **0.85** | 0.69 |
| DEMETER-ECMWF | 0.67 | 0.44 |
| ENSEMBLES-ECMWF | **0.81** | 0.59 |
| SYSTEM-4 | **0.77** | **0.89** |
| ERA-Interim | 0.72 | **0.91** |

**Task 4.1d: Force malaria and RVF specific dynamic models with bias corrected decadal hindcasts and projections.**

After limited skill was found in the ENSEMBLES decadal hindcasts (now published in Macleod et al., 2012), the decision was made to focus on decadal to centennial timescales and use a multi-scenario multi-model ensemble of global climate model projections from the CMIP5 archive and regional climate model projections for Africa from CORDEX. The super-ensemble of climate forecasts/scenarios were integrated with five different malaria models, including VECTRI and a steady state version of LMM. The ensemble approach allowed different sources of uncertainty (scenario/climate model/disease model) to be compared. The main results have been summarized in a peer reviewed paper (Kovats et al., 2013) which has been successfully submitted (January 2013) to the Proceedings of the National Academy of Science (PNAS) in a special issue. This work will have a high impact and will be disseminated through the IPCC WGI. The results focusing on Africa have been reported in Deliverable 4.1.b, which is the basis for a publication currently in preparation.

**Task 4.1e. The initial development of an integrated multi-agency system in Senegal**
UCAD have worked on this task through Ms Fanta Bouba's PhD research: "Decision support system on environment-health interactions: case of the Rift Valley Fever (RVF) in Barkedji": including participation in the Doctoriales IDP (International Doctoral Program) at Paris (France) on complex systems (8-26 October 2012) and training on ETL Tools for Spatial Decision Support System (7-9 November 2012), and publication of a paper :Multidimensional data model on Rift Valley Fever in Ferlo" at CNRIA 2012.

Cheikh Ahmed Tidiane Cisse's PhD research "A meta-model based on agent vector-borne diseases" has also contributed to this task, including presentations at the Conference on Mathematical Modelling and Computing Complex Systems (23-25 October 2012 and at LIP6

5.1

***Task 5.1c: Formation of a Health Early Warning System (UoC, UNILIV, KNUST, UNIMA, ICTP, CSIC)***

As is stated in the DoW, the formation of a Health Early Warning System (HEWS) strongly depends on the performance of seasonal health forecasts from WP4.1. When the DoW was constructed, the WP5.1 perspective expected the existence of operational seamless health forecasts. According to milestone M4.1.a a seamless monthly-to-seasonal ensemble prediction system should have been integrated at M18 (July 2011). However, WP4.1 intended only to provide hindcasts and not predictions for the future. Note that hindcasts are useless when disease forecasts are needed that look into the future. The same issue is also found in other work packages. Disease forecasts for the future are required by WP5.2 and WP5.4. Also the Tasks 5.1c, 5.2g and 5.4f,g,h intend to use forecasts and not hindcasts.

In order to cope this issue, UoC set up a meeting in April 2012 at the European Geophysical Union (EGU) General Assembly. At this meeting, it was decided that the new malaria model VECTRI would be implemented by the project partners ICTP and ECMWF. In summer 2012, VECTRI was finally integrated onto the ECMWF forecasting system and uses a calibrated seamless monthly-to-seasonal weather forecast from the ECMWF. The malaria forecasts are generated on a weekly basis (every Thursday) with a lead time of 120 days (i.e. four months) and are available at the ECMWF web portal:

http://nwmstest.ecmwf.int/products/forecasts/d/inspect/catalog/research/qweci/

Available are precipitation and temperature maps from the calibrated and non-calibrated monthly-to-seasonal weather forecasts. This data is used for the malaria forecasts in terms of the Entomological Inoculation Rate (i.e. the number of infectious mosquito bits per human) and the parasite ratio (i.e. the proportion of the population that is infected by the malaria parasite). Maps are provided for the hindcast period and a probability map represents the probability that transmission is below, normal, or above the average value.

It is foreseen that malaria forecasts could also generated by different published parameter sets of the Liverpool Malaria Model (LMM). Therefore, the user will be able to compare the output of at least three different malaria model sets. This will enable an uncertainty analysis of the malaria forecasts. The multi agency system, in which the Health Early Warning System is embedded, includes a web link to the seamless malaria forecasts of the ECMWF.

In order to show the feasibility of local malaria forecast, the Health Early Warning System includes further a demonstrative malaria seamless monthly-to-seasonal malaria forecasts for the Kumasi region (see Task 5.2.e). Illustrated were the seamless malaria forecasts from January 2013. The results of this example malaria forecast are included into the multi agency system. In contrast to the forecasts from the ECMWF, the local forecasts mainly focus on the generation of time series of key malaria variables. In January 2013, the lead time of 120 days includes the start of the malaria season, for which the forecast is provided by VECTRI and the LMM.

***Task 5.1d: Definition of a Monitoring Tool (MT) for Standing Water (CSE, UoC)***

This task is led by CSE. UoC included an Information System (IS) for standing water in Senegal into the web-based Java framework. CSE provided information to UoC with regard to pond measurements from 2011 in the Barkedji region of Senegal. Transferred were photos from July and August 2010 from the Kangaledji, Ngao, Niakha and Furdu ponds. Also a topographic map of the ponds was produced by CSE. Images were also provided from some of the installed weather stations. Precipitation is available from the 2011 rainy season from twelve locations in the Barkedji area. The observed heights of the water level of the Kangaledji, Ngao, Niakha and Furdu ponds were furthermore provided to UoC. Passed were also equations in terms of the relationship between the water level and the covered area and water volume of the ponds.

The aforementioned images, data, and equations were used to construct an information system with regard to pond characteristics in the Barkedji region of Senegal. The water volume of the ponds is associated with the attendance of people and livestock at the ponds. The ponds are potential breeding sites for mosquitoes and the availability of breeding habitats depends on the size of the ponds.

In addition to pond water level field data collection during the rainy season, CSE provided spatio-temporal breeding sites mapping based on SPOt-5 satellite data (figure A2 below).

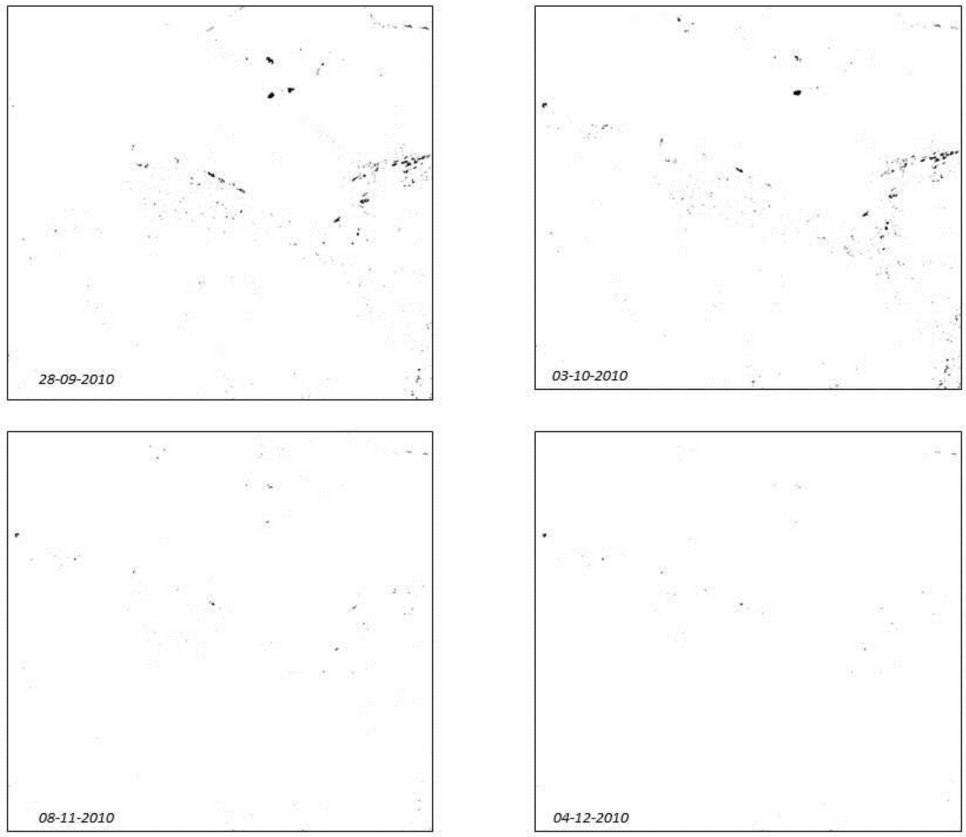



Figure A2: Water bodies mapping on 28/09/2010 (481.62 ha for 425 ponds), 03/10/2010 (462.08 ha for 460 ponds), 08/11/2010 (79.95 ha for 104 ponds) and 04/12/2010 (40.25 ha for 53 ponds).

### *Task 5.1.e: Disease Operation System M36 (IPD, UoC)*

The construction of the Disease Operation System is led by IPD and is associated with D5.1.e (M36). UoC included an information system in terms of malaria and Rift Valley fever control measures developed for Senegal and with regard to a Rift Valley fever vector model into the web-based Java framework.

IPD reviewed the strategies developed for malaria and Rift Valley fever and current methods of control developed in Senegal. The large distribution of *Insecticide Treated Nets* (ITNs), the introduction of *Rapid Diagnostic Test* (RDT), the treatment using *Artemisinin-based Combination Therapies* (ACTs), and *Indoor Residual Spraying* (IRS) have generated a considerable decrease of malaria cases. It was found that in the context of an increased epidemic risk of malaria a functional system of monitoring, early detection and response of malaria cases is required.

Concerning the Rift Valley fever disease, a statistical model using the relationship between environmental variables and the number of mosquito vectors was developed by IPD. Mosquito collections from 2005 were used from the Barkedji area to calibrate the parameters of the model. The Rift Valley fever vector model was passed to UoC, where simulations were performed for the year 2005. It was not possible to include the Rift Valley fever vector model into the web-based Java framework due to the WinBUGS software that is used by the model. The Java framework is set up within the Linux operating system.

Another problem would also prevent to run the model in the framework. The model simulations required about 10 minutes, which is not acceptable from the user's point of view.

Instead of running the model on the framework, the example model results for 2005 are interactively presented within an information system. Time series can be generated for different biotopes. Vector distribution maps of the area can be produced for fortnightly periods of 2005.

***Task 5.1.f: MT of Near-Real Time Disease Incidence in Health Clinics M36 (UNIMA, ICTP, UoC, UNILIV)***

This task was undertaken only by UNIMA and is associated with D5.1.f (M36). No further involvement of the other partners was required. However, the multi agency system provides a web link to the Health Information Systems Program (HISP) of Malawi.

5.2

Trend of malaria cases with rainfall in a rural community

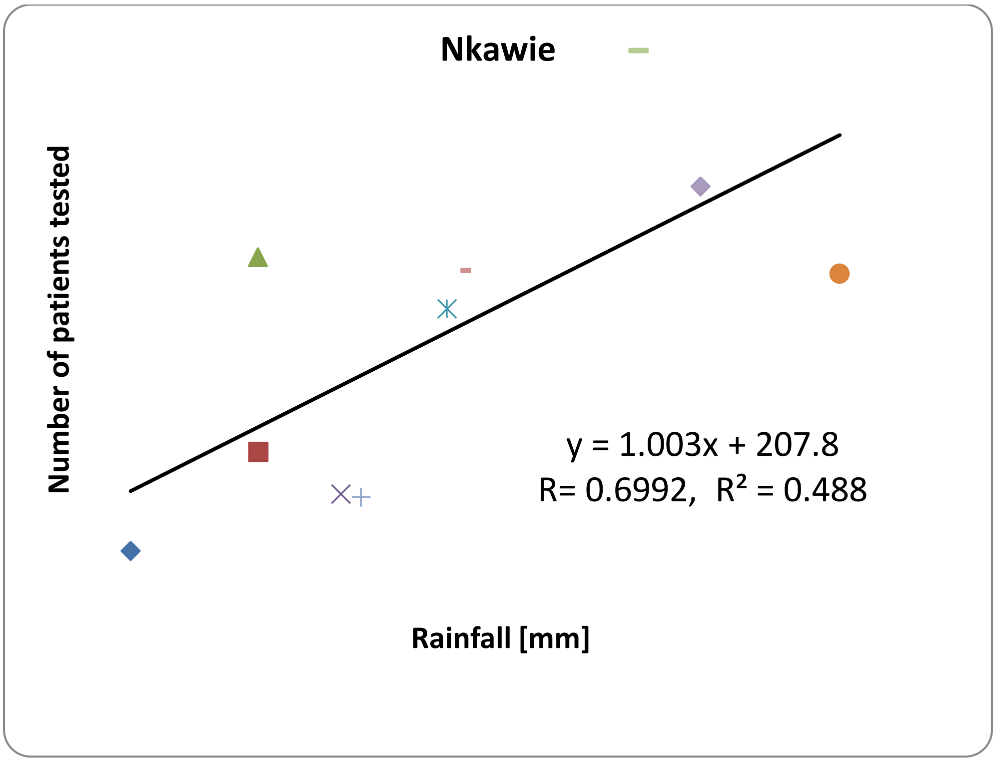



Fig. A3. Trend of malaria cases with increasing rainfall in a rural community, Nkwawie

The results show that in general there is an increase of malaria cases with increase in rainfall over the study period

**Factors affecting mosquitoes breeding include:**

a. Rainfall intensity (both positive and negative feedback)
b. Availability of water in the puddle for completion of sub adult mosquito maturation cycle (about 7 - 10 days ).
c. Relative humidity > 60 percent (Pampana, 1969)
d. Longer stay of water in the puddle (hydrology of site)

**Summary of Results**

- It was observed that rainfall frequency can limit the presence of breeding sites that dry up within four (4) days since mosquitoes larvae require a minimum of seven (7) days for adults to emerge.
- It was observed that mosquitoes prefer pools that are open to sunlight with or without vegetation for their breeding.
- The presence of mosquitoes larvae was also observed in stagnant water within human dwellings except those under shaded places.

The observed temperatures were found to be within the temperatures required for the breeding and survival of anopheles mosquitoes. This implies that the sites could serve as breeding sites for mosquitoes.

**Some Results of Entomological Studies**

Entomological survey was carried out in the communities of the health facilities or study sites for the period March to May, 2012. Pyrethrum Spray Catch method is being used to carry out in the mornings between 5.30 a.m and 10 a.m in bedrooms of residents in the study catchment areas. In each month, a total of ten bedrooms per study site were sprayed and mosquitoes collected for examination and analysis.

In the rural catchment areas, between 2 to 37 mosquitoes per room were collected from the bedrooms of residents, in the peri-urban, between 1 to 30 mosquitoes per room and 3 to 29 were collected per room from urban catchment areas.

All mosquitoes collected were morphologically identified under stereomicroscope and examined for the presence of blood and degrees of blood meal digestion. Three genera were identified: *Anopheles, Culex* and *Mansonia.* The *Anopheles* was further identified into species, *gambiae* and *funestus.* Over 75% of the mosquitoes have taken blood meal and over 80% was human blood. The *Anopheles genus* was the pre-dominant in all the study sites with little variations at the different study sites. For the anopheline mosquitoes collected, only some were dissected and examined for the presence of sporozoites.

The results are shown below.

**Mosquitoes Sepecies Identified**

| | Mosquitoes Species | Number |
|---|---|---|
| Agogo Hospital (Rural) | Gambaie | 73 |
| | Funestus | 48 |
| | Mansonella | 2 |
| | Culex | 33 |
| | Total: | 156 |
| Nkawie (Rural) | Gambaie | 63 |
| | Funestus | 4 |
| | Mansonella | 10 |
| | Culex | 47 |
| | Total: | 124 |
| Manhyia (Urban) | Gambaie | 60 |
| | Funestus | 0 |
| | Mansonella | 24 |
| | Culex | 32 |
| | Total: | 116 |

**Circumsporozoite Rate**

| | |
|---|---|
| Agogo (Rural) | 6.7 |
| Nkwawie (Rural) | 6.2 |
| Manhyia (Urban) | 6 |

**Human Bite Rate**

| | | |
|---|---|---|
| Agogo (Rural) | B/N | 1.9 |
| Nkwawie (Rural) | B/N | 1.5 |
| Manhyia (Urban) | B/N | 1.3 |

**Entomological Innoculation Rate**

| | | |
|---|---|---|
| Agogo (Rural) | Ib/p/day | 1.3 |
| | ib/p/yr | 464.6 |

| | | |
|---|---|---|
| Nkawie (Rural) | Ib/p/day | 0.93 |
| | Ib/p/yr | 339.5 |
| Manhyia (Urban) | Ib/p/day | 0.78 |
| | Ib/p/yr | 284.7 |

UOC:

**- Quality check of rainfall and temperature time series from Ghana**

The provided rainfall and temperature time series from 22 synoptic weather stations were quality checked. Several issues were detected due to, for example, missing data that was not flagged missing or rainfall, which was reported in inch instead of mm. For this reason, KNUST checked again the time series and provided a new data set, in which the issues in terms of precipitation were solved.

There seemed to be erroneous temperature values included in the data. For example, the minimum temperature was lower than 10°C in the 1950s, 1960s, and parts of the 1970s for Navrongo. These are unrealistic minimum temperatures for Ghana. KNUST found that the unrealistic minimum temperatures were reported in tenths of Fahrenheit. After the conversion of these values into degrees of Celsius, realistic minimum temperatures were computed. The remaining issues are the following:

*Data gaps*

Many data gaps remain in the temperature and precipitation time series. For example, many months are completely missing. Note that the Liverpool Malaria Model requires complete rainfall and temperature time series as its data input.

During a visit in May 2012 Robert Schuster (UoC) visited KNUST and maintained the Owabi AWS as well as the weighing rain gauges in the Kumasi area. Several problems were found in terms of the AWS:

- Termites needed to be eliminated in the battery box of the AWS.
- New temperature and humidity sensors were installed. Note that the ventilation of the temperature and humidity sensors is currently not working.
- The AWS is covered with a greenish layer that might be a result of an algae contamination.
- The upward shortwave radiation measurement suffers from the end of March 2012 from technical problems (defective contact).

Also an issue was found at the weighing rain gauge of the Kumasi airport weather station. Unrealistic rainfall peaks of 400 mm were found. These peaks were caused when the rain bucket was filled with water. Usually, the measurement stops when the shell of the rain gauge is removed. However, a spider blocked the switch of the box, which resulted in continuous measurements.

Furthermore, data was collected from KNUST for the production of deliverables D5.2.b and D5.2.d. Gathered were the following data sets:

a) ***Mosquito breeding site characteristics*** (water temperatures, water level, pond volume) regarding measurements between June 2010 and August 2010 funded by ICTP

b) ***Malaria cases*** from up to four hospitals in the Kumasi area between 2010 and April 2012

c) ***Mosquito spray catches*** at an urban, peri-urban, and rural site in the Kumasi area for December 2010, July 2011 and October 2011 (10 rooms were sprayed per month per study site)

d) ***Rainfall amounts*** from May 2010 to April 2012

e) **Temperature observations** from the AWS in Owabi (partly not ventilated sensors)

The following strategy was defined by UoC and a response is awaited from KNUST in terms of the production of deliverable D5.2.b (Report on the correlation between malaria observations and meteorological/ecological and environmental variables and correlation between water temperature and meteorological variables):

1) ***Correlation between malaria cases and meteorological variables***

   KNUST could correlate the rainfall and temperature data with malaria cases. Such analyses were already performed by KNUST for the AMMA project.

2) ***Correlation between malaria transmission and meteorological variables***

   Mosquito spray catches were only performed for three months between December 2010 and October 2011. This means that the intra-seasonal variation of malaria transmission cannot be studied in the area of Kumasi. For this reason also the correlation between malaria transmission and meteorological variables is not possible and will be dropped. The malaria observations provide a snap shot of the transmission of malaria at the three study sites.

   The representativeness of the derived entomological inoculation rates is questionable since only 10 rooms were sprayed per study area and per month. Collected were about 900 adult mosquitoes. For example, a comparable study in Barkedji/Senegal performed biweekly adult mosquito captures between June to December 1994 and from July 1995 to March 1996. Performed were human night bait collections (8 human-nights were undertaken every 2 weeks) and pyrethrum spray collections in the early morning inside 16 bedrooms (>32 rooms per month) in different parts of the village. Altogether, they collected 26,973 Anopheles mosquitoes, which is a much larger sample than that of the QWeCI field study in Kumasi.

3) ***Correlation between water temperature and meteorological variables***

   Correlated can be, for example, daily mean temperatures with the observed water temperatures to see if there is a close relationship between the two variables. There might be also a strong influence of rainfall events on the water volume and depths of puddles.

KNUST needs to define which analyses they like to undertake. Note that it will not be possible to provide correlations between malaria observations and ecological variables and other environmental variables than temperature and rainfall values.

**Contribution from UoC**

***Task 5.2d: Correlation of meteorological and malaria data as well as with water temperatures***

This task is associated with D5.2.b. KNUST was undertaking the correlation of meteorological and malaria observations and UoC correlated the water temperatures from temporary breeding sites with meteorological observations.

Correlation between water temperatures and potential mosquito habitats measured at different times within a day at a peri-urban area of Kumasi (Ghana) and meteorological air temperatures (daily minimum, maximum and mean) from Kumasi airport synoptic station and Owabi automated weather station were assessed. Persistence of temporary breeding habitats was strongly influenced by precipitation. Almost half of the ponds dried out in August 2011 when less rainfall was observed. Pond water temperatures decreased from June to August of about 4°C and the daily water temperatures ranged between about 22 and 36°C. Highest water temperatures were measured during noon (12:00-13:30 UTC). A strong correlation between maximum air temperatures and midday water temperatures were identified with a linear correlation coefficient of about 0.74. The results show the possibility of predicting water temperatures using air temperatures.

***Task 5.2e: Validation of the LMM by EIR data***

The validation of the Liverpool Malaria Model (LMM) was planned in this task and should have been undertaken by UoC. However, sufficient entomological and parasitological malaria data is not available from the Kumasi area.

The QWeCI project was not allowed to use standard bite catches due to ethical issues. During four three monthly periods KNUST undertook spray catches in ten rooms, respectively. This amount of data did not allow the calculation of monthly Entomological Inoculation Rates ($EIR_m$; i.e. the number of infectious mosquito bites per person per month). Moreover, the number of rooms per study site was not sufficient meaning that Entomological Inoculation Rates (EIR) values could not be computed for urban, peri-urban and rural areas within the Kumasi region.

Regarding parasitological malaria data, the QWeCI project was not allowed to undertake representative parasite surveys within Kumasi. The QWeCI project was only permitted to gather confirmed malaria cases from hospitals of the Kumasi metropolis. Note that the LMM output cannot be compared to malaria cases from hospitals. The LMM simulates the parasite ratio, which comprises asymptomatic and symptomatic malaria cases. The model is not able to distinguish symptomatic malaria cases and those that are admitted to hospital.

Instead of the validation of the LMM, both VECTRI and LMM simulations were performed and compared for Kumasi. The malaria models were driven by observed data from the Kumasi airport and with data from the Tropical Rainfall Measuring Mission (TRMM) and other satellite daily precipitation estimate (version 7). The comparison with observed precipitation reveals similar rainfall amounts of the TRMM and other precipitation estimate.

VECTRI was driven with an urban, peri-urban and rural population density, respectively. As expected, the VECTRI simulations lead to too much higher transmission values in rural than in urban locations.

The output of the model was qualitatively compared to the malaria cases from Hospital. The malaria cases showed a small interannual variability, whereas the models reveal a strong interannual variability in the malaria transmission. In general, both malaria models reveal the same annual cycle in malaria transmission. During the dry season no or very low transmission is simulated in the models. The simulated malaria transmission is bimodal. The first transmission peak follows the stronger first rainy season of the year and is simulated for June/July. The second peak is predicted for October/November after the shorter second rainy season of the Guinea Coast. In comparison to the LMM, VECTRI reveals a much lower interannual and spatial variability with regard to the $EIR_m$ values.

***Task 5.2f: LMM seasonal forecasts for the Kumasi region***

The set up of the QWeCI project led to misunderstandings. WP5.1 and WP5.2 expected the existence of a seamless monthly-and-seasonal malaria forecasting system from WP4.1 (see M4.1.a: Pilot integration of the existing dynamic malaria model with a seamless monthly and seasonal ensemble prediction system M18). At the time of the DOW compilation, it was expected that operational EPS seasonal forecasts would have been generated by WP4.1. However, WP4.1 was only generating seasonal hindcasts and not operational malaria forecasts.

For this reason within this task, the possibility of seasonal forecasts for the Kumasi region was only demonstrated for one single seasonal ensemble forecast from the end of January 2013. The LMM was initiated by the ERA-Interim data (ERA: ECMWF Reanalysis) and operational forecasts of the ECMWF and in the following the model was forced by the 120-day seamless monthly-to-seasonal forecasts from the ECMWF (originating from WP3.1). The seamless forecasts were compared with the baseline period, when the LMM was driven by ERA-Interim. This skill of the forecast could be evaluated by KNUST and the result and the format of the provided forecast products could be discussed with stakeholders in the follow-up of the QWeCI project.

Note also that the QWeCI partners ECMWF, ICTP and UNILIV set up VECTRI and the LMM at the ECMWF server. Prototype malaria forecasts are now produced for the African continent every week providing seamless monthly-to-seasonal malaria forecasts with a lead-time of four months:

http://nwmstest.ecmwf.int/products/forecasts/d/inspect/catalog/research/qweci/

Therefore, operational prototype malaria forecast are available for the Kumasi region. In contrast to the demonstrative Kumasi malaria forecast, only maps are produced for Africa, where a small grid box represents the Kumasi metropolis. UoC produced by contrast time series of some key malaria variables like EIR and the parasite ratio. Note again that the LMM and VECTRI are not able to reproduce clinical malaria cases.

***Task 5.2g: Malaria Early Warning System for Kumasi***

**Executive Summary**

The report presents a malaria early warning study carried out over the Rural, Peri-urban and Urban communities within the Kumasi metropolis, using Ghana Meteorological Agency's synoptic station data as model input and reported malaria cases in some selected hospitals within the study areas. Two independent models (Liverpool Malaria Model and VECTRI model) were employed for this study. In addition, the correlation between climate variables (rainfall, temperature and relative humidity) and reported outpatient malaria cases in Rural, Peri-urban and Urban communities in the Kumasi Metropolis for the entire study period were reported. Poor positive correlations were found with rainfall and negative correlations were seen with temperature. The model results revealed higher malaria prevalence in the rainy season (from May to October) with peaks in June and July for the first (major) rainy season and October and November for the minor rainy season. The seasonality shown is evidence of strong climatic influence on malaria transmission in the study area.

**Correlation of climate data with malaria hospital data**

Rainfall and malaria transmission do not peak at the same time as there is always a time lag between them. The time variation is due to the time required for mosquitoes to complete their life cycle and the parasite to fully develop in the human host. Therefore poor positive correlation in the range of 0.25 – 31 were seen for these study cases. It was observed that the rainfall and malaria recorded cases do not peak simultaneously. Thus, increasing rainfall amounts are therefore not leading to an increase in malaria transmission even under the consideration of time lags. This could point to the fact that, some productive breeding habitats are permanent and semi-permanent.

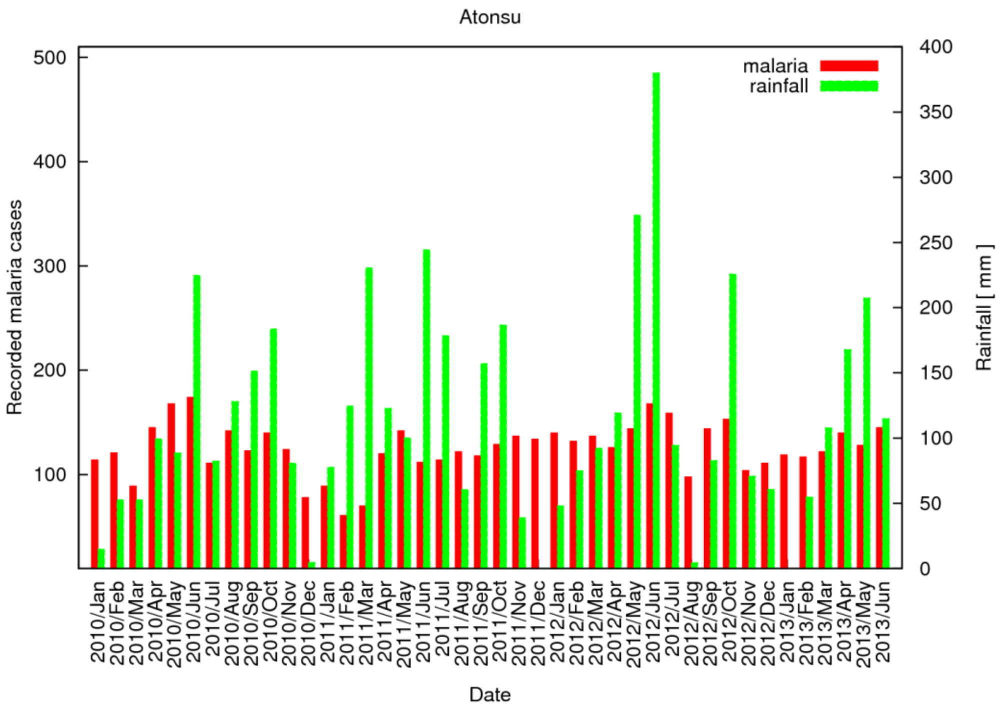


Figure A4: Confirmed monthly malaria  cases reported at Atonsu Hospital (Urban) over the study period (red) and corresponding monthly rainfall (green)

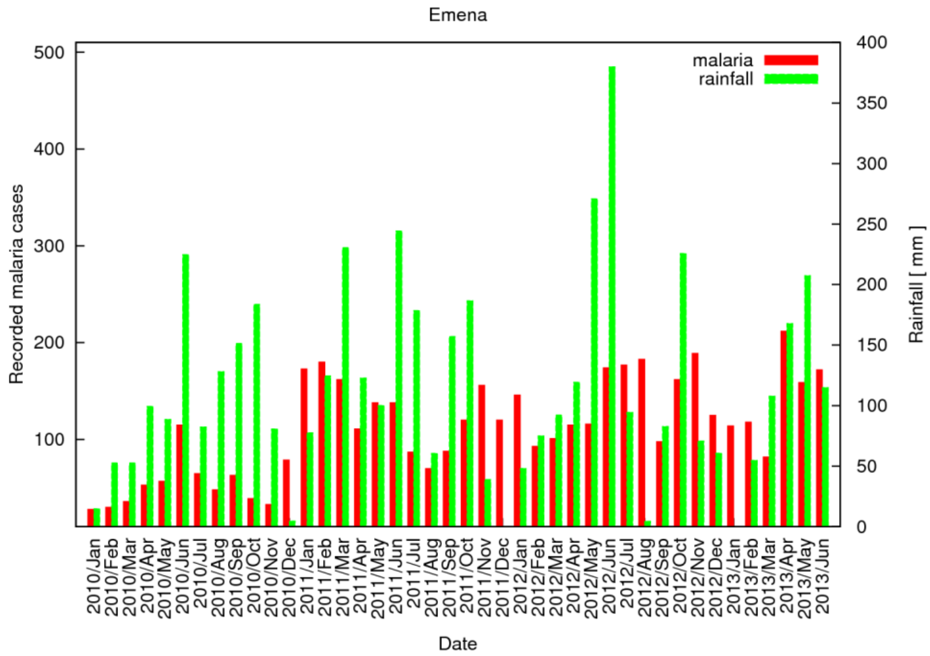



Figure A5. Confirmed monthly malaria cases reported at Emena Hospital (peri-urban) over the study period (red) and corresponding monthly rainfall (green)

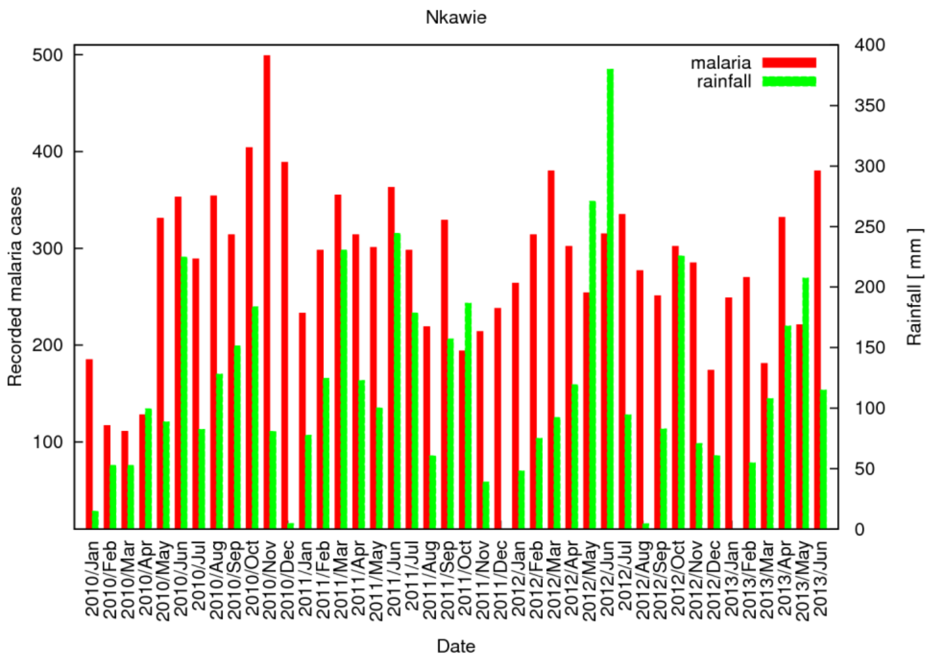



Figure A6 Confirmed monthly malaria cases reported at Nkawie Hospital (rural) over the study period (red) and corresponding monthly rainfall (green)

Temporary shallow waters are the preferred breeding habitats for *Anopheles gambiae.* These breeding habitats are most productive when there are many rainy days in the month. The critical factors for malaria forecast therefore are the onset and frequency of rainfall since these determine the stability of habitat to complete aquatic stage life cycle. In general, malaria prevalence rate is high after the onset of rain (from May to October). This is because at the start of the rainy season, rainfall provides additional breeding habitats. This leads to an increase in the *Anopheles gambiae* mosquito population and hence increases the malaria prevalence.

The average monthly temperature for Kumasi is in the range of 25–28°C, which is a favourable temperature for both breeding and survival of mosquitoes. Relative humidity affects malaria transmission by influencing the life span and flight range of Anopheline mosquitoes. The vector has a shorter life span when the relative humidity is below 60%, which may not allow complete development of the parasite within the vector. Results from the monthly data show that throughout the year, relative humidity is greater than 70% in Kumasi and therefore there can be a complete development of the malaria parasite within the vector to increase the probability of infectious bites. This further explains the reason for higher malaria transmission during the rainy season in Kumasi. The limiting factors however are the availability of breeding habitats, which are provided by rainfall, drainage and sewage systems and other environmental factors.

A correlation plot of the temperature with outpatient malaria cases recorded at Nkawie a rural hospital and Emena Peri-urban hospital are shown in Figure 2.4. In general, a negative correlation was observed with temperature with correlation coefficient -0.26 to -0.18.

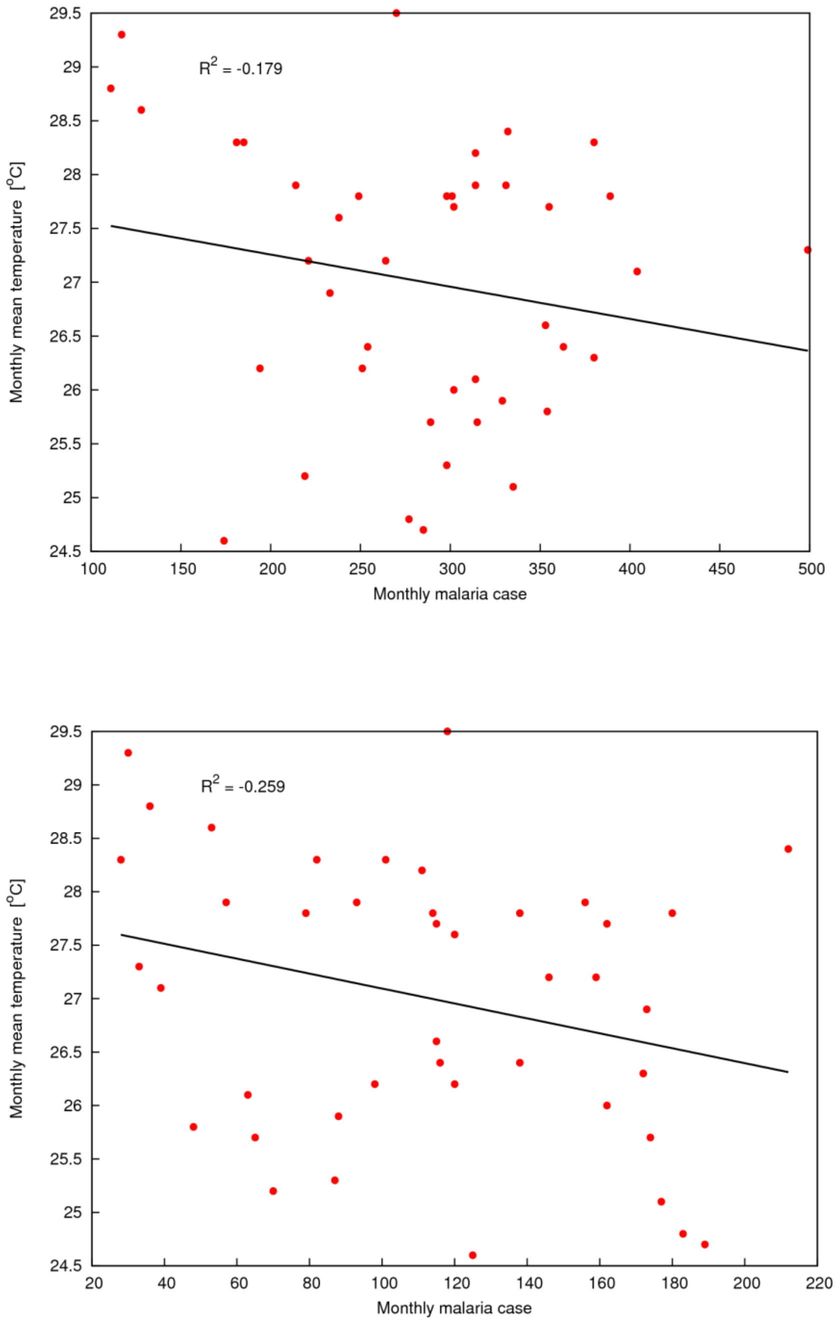



Figure A7*:* Scatter plot for temperature as a function of outpatient malaria cases for Nkawie.

**Malaria-vector Model**

The Liverpool Malaria Model (LMM) and the VECTRI malaria model, are mathematical-biological models of malaria parasite dynamics driven by daily temperature and precipitation data (Hoshen and Morse, 2004). Extensive details on parameter setting and definitions are described in the 2011 parameter setting LMM version which was used for this study (Ermert et al., 2011a,b). The details on VECTRI malaria model are described in Tompkins and Ermert (2013).

In this study, temperature and precipitation measurements were taken from GMet synoptic station at Kumasi airport. Entomological malaria field studies frequently sample biting mosquitoes on humans (Le Go et al., 1997). Standard measurements include the Human Biting Rate (HBR), which is the number of mosquito bites per human per time. However, it is known that only female mosquitoes with sporozoites in their salivary glands are able to infect humans [(Ermert et al., 2011b) and references therein]. This fraction of the biting females is called Circumsporozoite Protein Rate (CSPR) (Awolola et al., 2002). By multiplying HBR with CSPR results in the Entomological Inoculation Rate (EIR), which is deemed as the number of infectious mosquito bites per human per time. Only months revealing infectious mosquito bites (EIR values above zero) are usually used to define the malaria season at a certain location. By contrast, parasitological malaria studies usually measure the asexual parasite ratio (PR) representing the proportion of the survey population, which is positive for the malaria parasite. Extensive literature has been reviewed on all these parameters in Ermert (2010). Other parameters such as entomological and parasitological variables are taken into account in the model; these are: the annual Human Biting Rate (HBRa), the annual Entomological Inoculation Rate (EIRa), the annual mean Circumsporozoite Protein Rate (CSPRa), the length, onset, and end of the malaria season, the length of the main malaria season (MSeas); i.e. the number of months in which 75 % of EIRa is recorded (Hay et al., 2002), the month of maximum transmission (XSeas; i.e. the month with the largest entomological inoculation rate, the annual mean, maximum, and minimum of the asexual parasite ratio (PRa, PRmax; a, and PRmin, a, respectively). The output results of all these parameters from LLM are reported in this study. This new version of the LLM described in Ermert et al. (2011b,a) provide 12 to 15 days life cycle of mosquitoes comprising the egg, larval, pupal, and adult stages. The egg, larval, and pupal stages are entirely aquatic and, therefore, mostly depend on weather conditions. Besides climatic conditions, competition due to over-crowding, water quality, food supply, cannibalism, predators, parasites, as well as pathogens are limiting factors for aquatic stages of mosquitoes (Ermert et al., 2011a,b). In addition to all these in the LLM, the VECTRI model takes into account the surface hydrology (relative small breeding pond size) climate and population density(Tompkins and Ermert 2013).

The model results shown in Figures 3.1 and 3.2 revealed higher malaria prevalence in the rainy season (from May to October) with peak in June, July for the first season and October - November for the minor rainy season. The seasonality shown is evidence of strong climatic influence on malaria transmission in the study areas. The box-and-whisker plot shown in Figure 3.3 indicate relatively high monthly EIR values (greater than 50) for the peak malaria transmission seasons and relatively low EIR values for the dry season (December to March).

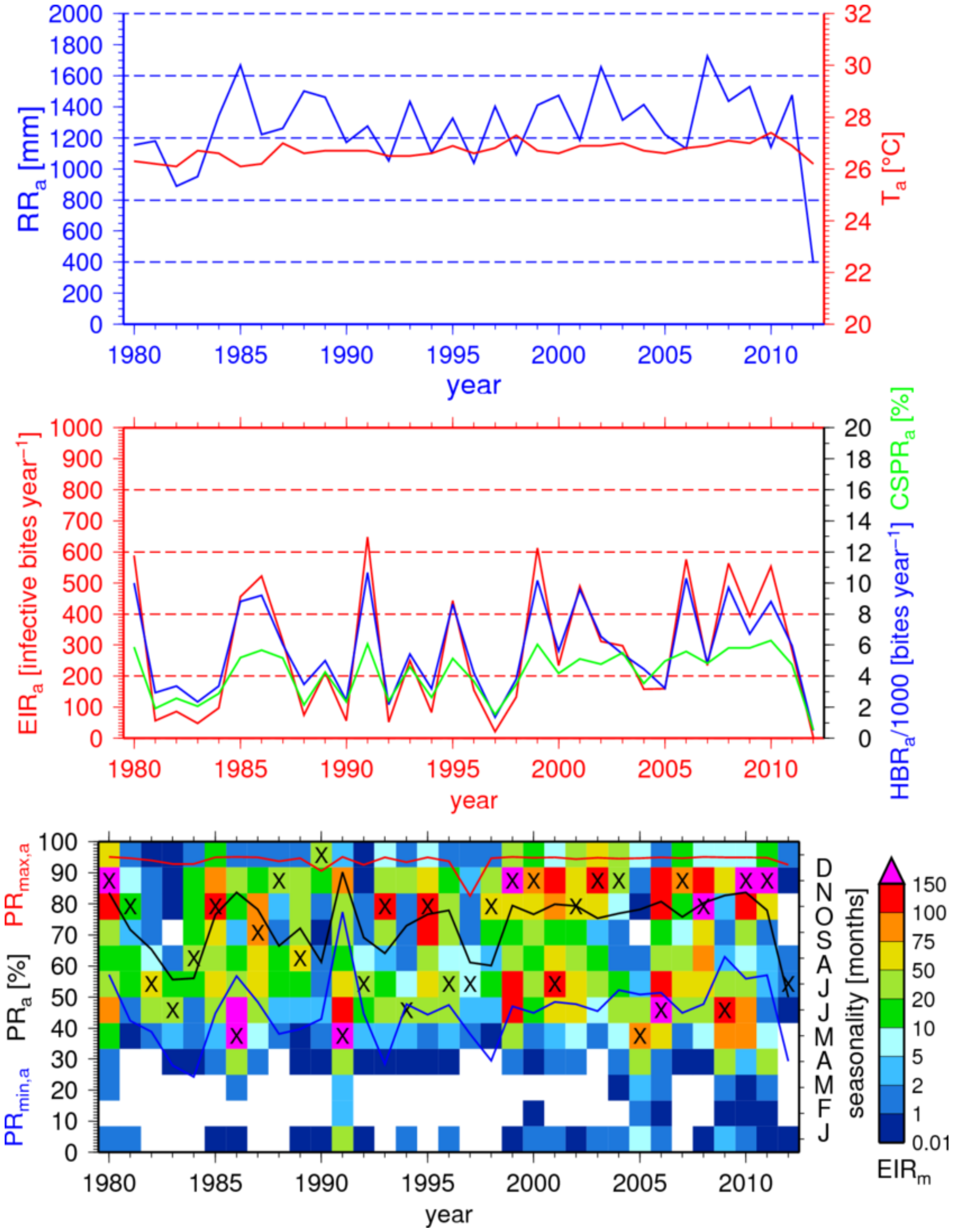
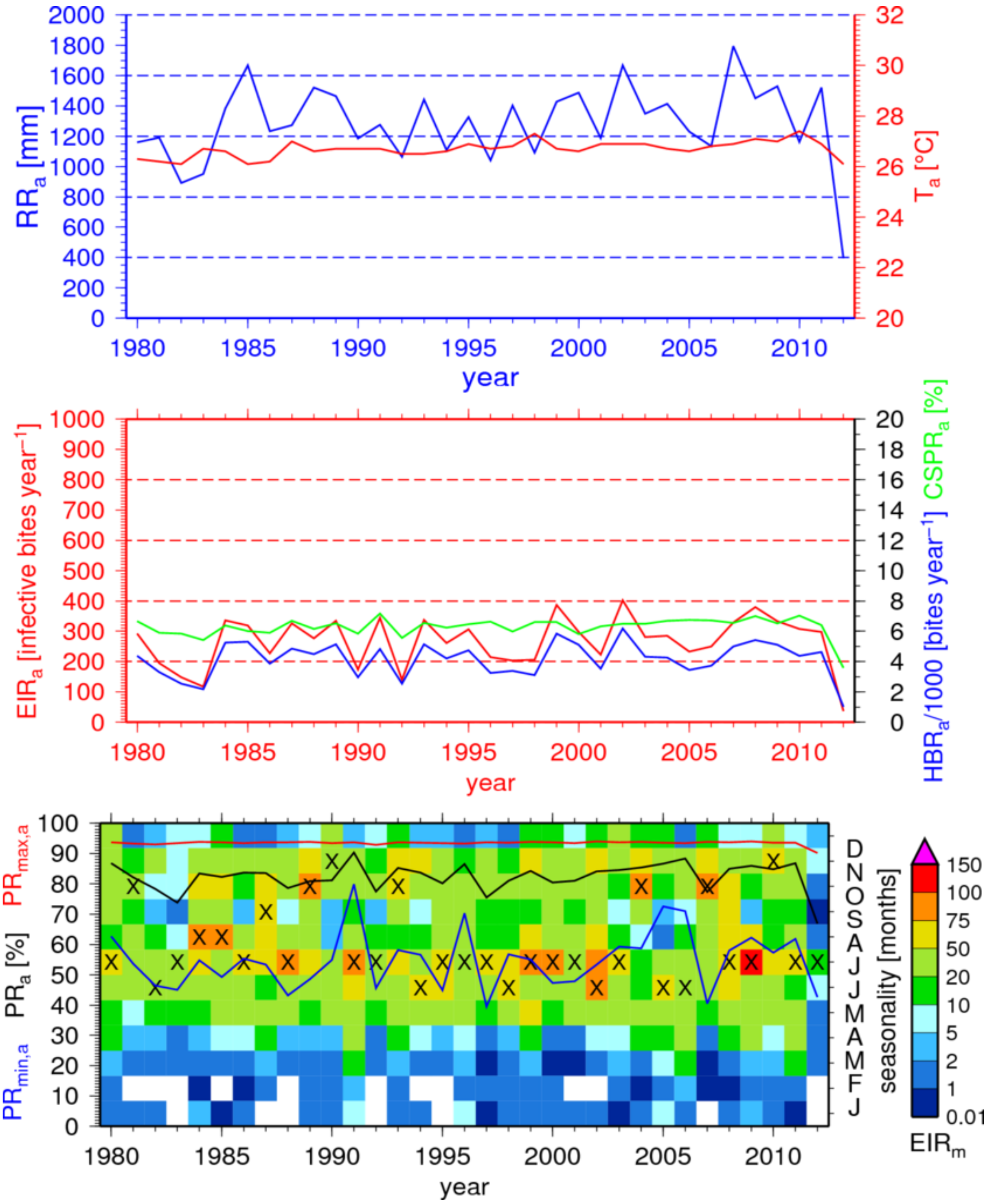


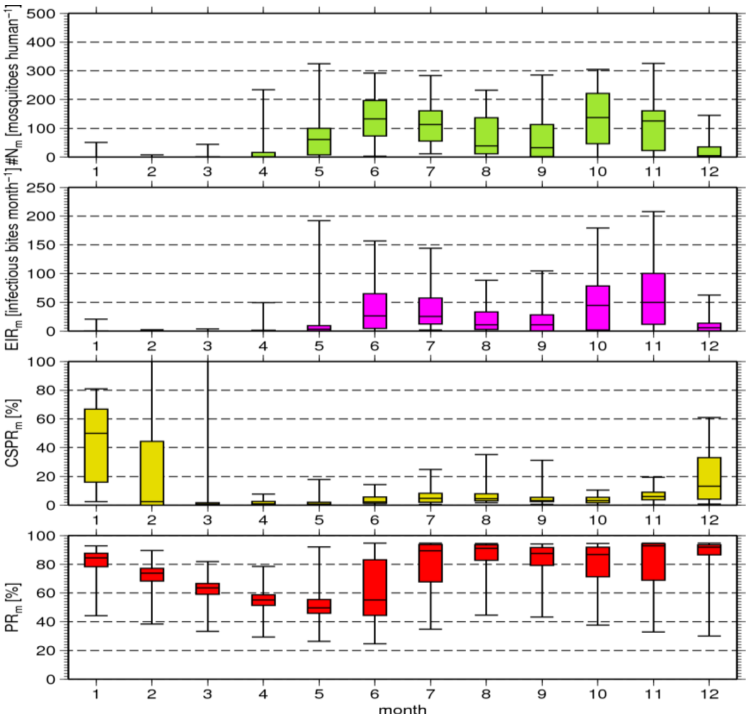

Figure A8: The inter-annual variability of rainfall and temperature as well as the simulated inter-annual malaria transmission and asexual parasite ratio between 1980 and 2012 for kumasi using LLM. The top panel annual rainfall (RRa; in mm; blue line) and annual mean temperature (Ta; in °C; red line). Middle: Annual

Entomological Inoculation Rate (EIRa; red line), annual Human Biting Rate (HBRa; blue line; right scale divided by 1000), and annual CircumSporozoite Protein Rate (CSPRa; in %; green line). Bottom panel: Annual mean parasite ratio (PRa; in %; black line), the annual minimum (PRmin,a; in %; blue line) and annual maximum (PRmax,a; in %; red line) of the parasite. The malaria seasonality (right scale; in month). The monthly Entomological Inoculation Rate (coloured squares) of month when the monthly Entomological Inoculation Rate reaches at least 0.01 infectious mosquito bites per human per month. The month with the maximum transmission is marked via an "X".



RRa [mm]
Ta [°C]
year
EIRa [infective bites year−1]
HBRa/1000 [bites year−1]
CSPRa [%]
year
PRmax,a
PRa [%]
PRmin,a
D
N
O
S
A
J
J
M
A
M
F
J
seasonality [months]
150
100
75
50
20
10
5
2
1
0.01
EIRm
year

Figure A9: Result from VECTRI malaria-model but  same plot as Figure 1.5



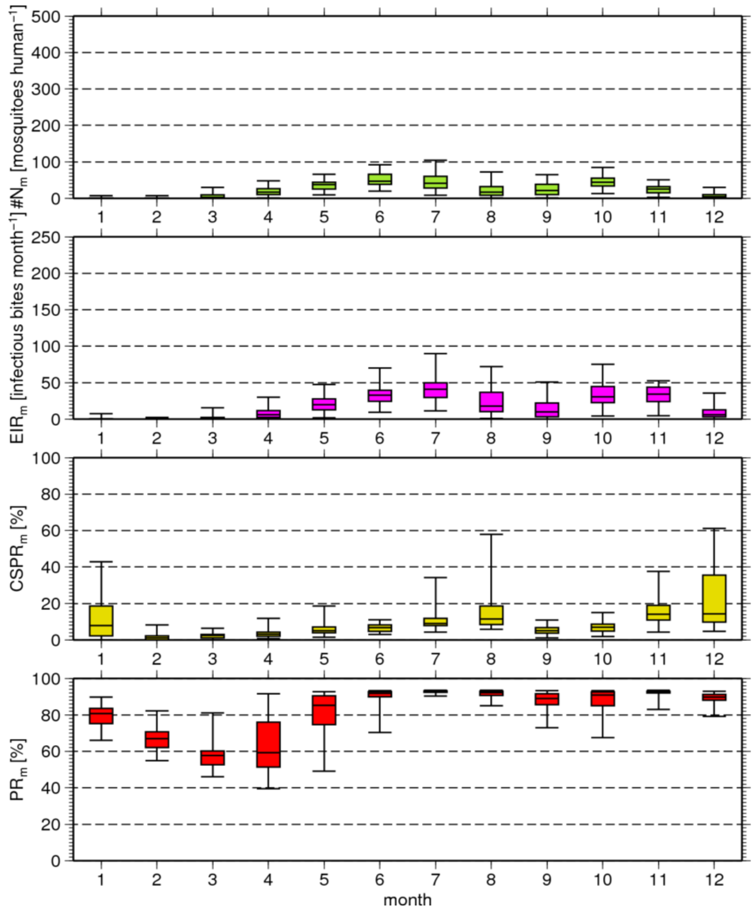



Figure A10: Box-and-whisker plot with regard to simulated monthly entomological and parasitological values for 1980 – 2012 from LLM (top) bottom (Vectri). Illustrated are the box-and-whisker plots of the simulated number of mosquitoes per humans (Nm; green box-and-whisker plots), the monthly Entomological Inoculation Rate (EIRm; i.e. the number of infectious mosquito bites per human per month; ma-genta box-and-whisker plots), the monthly CircumSporozoite Protein Rate (CSPRa; fraction of infectious mosquito bites; in %; yellow box-and-whisker plots), and the monthly averaged asexual parasite ratio (PRm; in %; red box-and-whisker plots).

## Summary

Malaria early warning study has been carried out over the Rural, Peri-urban and Urban communities within the Kumasi metropolis. Liverpool Malaria Model and VECTRI model were employed for the study. The model results revealed higher malaria prevalence in from May to November with peaks in June, July for the major rainy season and October - November for the minor rainy season. The seasonality shown are evidence of strong climatic influence on malaria transmission in the study areas. The study reveals relatively high monthly EIR values for the peak malaria transmission seasons and relatively low EIR values for the month of December to March.

In addition, the correlation between climate variables (rainfall, temperature and relative humidity) and the outpatient malaria cases in rural, peri-urban and urban communities in the Kumasi Metropolis for the entire study period were reported. Poor positive correlations were found with rainfall and negative correlations were seen with temperature.

This study will serve as a first step of developing Malaria Early Warning System (MEWS) for the study area. Currently a downscaling of a regional climate model (ERA-interim) to be used to prepare temperature and rainfall data for the past, present and future malaria seasonal forecast. This climate data generation is been done using the downscaling scheme described in Gutierrez et al. (2004); Brands et al. (2011). The climate data generated would be us as input data to run the LLM and VECTRI models and the results will be prepare for publication.

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Tompkins A. M. and Ermert V., 2013. A regional-scale high resolution dynamical malaria model that accounts for population density, climate and surface hydrology, Malaria Journal 12(1):65.

This task was led by KNUST, who undertook a stakeholder dialogue in terms of the malaria early warning system. At the end of the QWeCI project, UoC included a prototype seamless monthly-to-seasonal malaria forecasts for Kumasi for demonstration purposes into the web-based Java framework of WP5.1 (see Task D5.1c and D5.2.c). This example forecast (see Task 5.2.f) demonstrates the general feasibility of malaria forecasts for the Kumasi region. What is possible for the Kumasi metropolis can of course also be attained for other endemic and epidemic malaria areas.

**Statement on the use of resources**

Within the QWeCI project, UoC consumed 4.5 of the 4 planned person-month for WP 5.2. We originally did not plan to generate the demonstrative forecast for Kumasi within WP5.2. UoC expected that WP4.1 would produce such forecasts, which was a misunderstanding during the setup of the project.

5.3

By bringing together scientists from different disciplines, including those involved with public health and animal health, the QWeCI project has contribute to a better understanding of linkages and mechanisms between disease emergence, transmission and spread, and climate/environment variability and changes.

The WP 5.3 is a major component of QWeCI project and as pilot project it is mainly focused on field activities with a strong section of field data collection, covering various sectors: climate, hydrology, water quality, vegetation, land use and land cover changes, veterinary (herbs concentration, serosurvey, ruminants parks), malaria incidence, entomological, viral surveys and social pastoral practices investigations. The area of investigation is the Barkedji Health and Environment Observatory (figure 1). Three scientific research teams (*Institut Pasteur de Dakar* (IPD), *Laboratoire de Physique de l'Atmosphère et de l'Océan Siméon Fongang* (LPAO-SF) in UCAD and *Centre de Suivi Ecologique* (CSE)) and two stakeholders/end users, PNLP (*Programme National de Lutte contre le Paludisme,* National Malaria Control Programme) and DIREL (*Direction de l'Elevage*, National Livestock Service), are involved in the Barkedji field experiment site. CSE, UCAD and IPD worked closely on the field site and ensure that the various observations are integrated. CSE was focused on land use and land cover change monitoring processing and integration of remote sensing data sets, water pond's quality. UCAD had the responsibility for climate and hydrology field measurements and analysis. IPD had undertaken the entomological field survey, with PNLP (for malaria) and DIREL (for RVF), the two national stakeholders/end users that had contributed to the development and implementation of decision support systems; and had in charge the health data sets.

Major findings for this reported period are dealing with the intra-seasonal rainfall variability in the fact that we increase and improve raingauge network, ponds temporal and spatial dynamics, both malaria and RVF vectors dynamics, in relation with land cover and land use information including *composition and biodiversity of anopheline fauna, malaria vectors biting rates and cycles, parity rates, circumsporozoite infection and entomological infection rates, tropic preferences, RVF Mosquito mean densities, population dynamics and host attractiveness*. We expect that these findings will help in adjusting health early warning systems regarding RVF and malaria in Senegal, but also will help end users in health forecast, but more interactions are needed in validation.

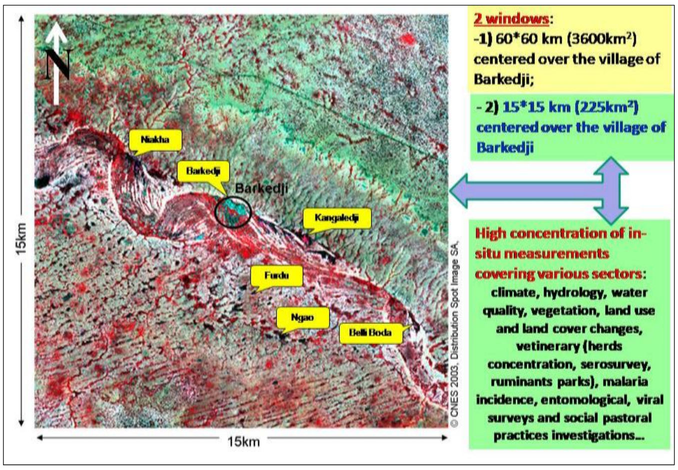


*Figure A11: Overview of Barkedji Health and Environment Observatory*

5.4

In summary, as outlined in earlier deliverables and this milestone report, despite technical and political problems impeding progress, the pilot project in Malawi concerning the Wireless infrastructure has proceeded well. The following steps have been concluded successfully:

- The backbone connection from Blantyre-Zomba-Mangochi has been restored
- A local site survey for local clinics has been conducted
- The top priority local rural clinic has been connected to the wireless backbone.

- The clinic now has the potential to connect to the new DHIS2 health system logging facility and can thus already log their disease incidence to the central database in Blantyre/Lilongwe in near real-time.
- Maintenance work has been carried out to improve the link performance
- The link has been used to transmit preliminary forecast products to the local clinic.
- Software to monitor the link quality to the clinic is now in place

Again it is emphasized that there are not yet country-specific forecasting products available, only pan-Africa products for forecasting, but the visit demonstrated the potential of the QWeCI portal for disseminating forecast information at the local level. The next steps that will be taken to ensure the further development and lasting legacy of the work that has taken place during QWeCI will entail:

- **near-term**: A further visit to Lilongwe Ministry of Health and St. Martin's clinic by ICTP researchers is planned for late October/early November 2013 (after the end of QWeCI) to demonstrate further the system and conduct a workshop to improve the format of the products to maximize their use and usefulness to in-country stake-holders and end-users.
- **medium-term**: ICTP plan a workshop on the theme climate and health in the region in 2015/2016. ICTP has organised frequent training schools/workshop concerning solely or containing components on the theme "climate and health" (ICTP, 2011 & 2013, Arusha, 2012, Nairobi, 2011, Addis, 2009, 2011, 2013). This would be a continuation of these successful events and would help to maintain links in-region.
- **medium to long-term**: the main contact on the QWeCI project at the ministry of health will apply for the associate programme at ICTP funding a 2 month exchange visit every second year over the next 6 year period, 2014-2019.

ICTP's long-term commitment to Malawi, with the collaboration already ongoing for more than 8 years, will ensure that these efforts to roll out the research outcomes arising within the QWeCI research project endure long past the project end in an ongoing effort.

6.1

In summary, the scientific exchange and capacity building that has taken place within the project far exceeded expectations, and will leave a lasting legacy of QWeCI beyond the project end, taken on by exchange programmes of the key QWeCI European partners and other potential future projects.

6.2

Symposium in Rwanda.

The final QWeCI workshop was originally planned to take place at the University of Pretoria in South Africa. However, in the early stages of the project the main researcher at the partner institute changed employers and was as a consequence, the partner organization placed a reduced role in the project. As a result, at an early stage it was decided to look for an alternative venue to hold the final QWeCI symposium. The QWeCI management team decided that the East African Community (EAC) “health and Science” conference in Kigali, Rwanda on 27-29 March 2013 would be ideal due to the large audience that would be attracted to the event and the overlap in interests.

The symposium was held successfully and was detailed in the deliverable **D6.2.d – Completion of Pretoria workshop**

## 3. Publications and workshops

The last phase of the project has see a high rate of activity in terms of conference attendance and publications from QWeCI scientists as the science development occurring during the opening phases of the project have matured into written scientific documents. These conference attendance and publication are summarized in the tables below. There are a considerable additional number of publications currently in review associated with the project which, if accepted, will appear in the period after the project end. These will appear on the Liverpool QWeCI site while it is still actively maintained:

http://www.liv.ac.uk/media/livacuk/qweci/Publications,list,at,portal,July,24th,2013,for,website.xlsx

Tables A3: presentations and dissemination activities:

| Name | Institute | Venue | Dates | Theme | Activity |
|---|---|---|---|---|---|
| Volker Ermert | UoC | EGU | 22-28 April 2012 | EGU General Assembly | Provided a presentation at the CL2.5 (Climate and infectious disease interactions) session; WP5.1 issues were discussed with ECMWF, ICTP, and UNILIV |
| Rachel Lowe | IC3 | ICTP | 29 June 2012 | AMMA conference July 2012 | presentation of results |
| Luís Ricardo Lage Rodrigues | | | 25-01/09-10/2012 | MedCLIVAR 2012 conference, Madrid | Presentation of results. |
| Isabel Andreu-Burillo, | | ISMAR | 16-17/04/2013, | EC Earth meeting, Lisbon | Presentation of results. |
| Francisco Doblas-Reyes | | ISMAR | 16-17/04/2013, | EC Earth meeting, Lisbon | Presentation of results. |
| Isabel Andreu-Burillo, | | Météo-France | 13-16/04/2013, | s2d meeting | Presentation of results. |
| Francisco Doblas-Reyes | | Météo-France | 13-16/04/2013, | s2d meeting | Presentation of results. |
| Volker Ermert | UoC | Basel, Switzerland | 1-12 October 2012 | Challenges in malaria research | Presentation of results<br><br>http://www.malariajournal.com/content/11/S1/P133 |
| Adrian Tompkins | ICTP | EGU | 8-12 April 2013 | EGU general assembly | Presentation of QWeCI results – oral presentation<br><br>meetingorganizer.copernicus.org/EGU2013/EGU2013-1956.pdf |
| Adrian Tompkins<br>Andrew Morse<br>Francesca Di Giuseppe | ICTP<br>UNILIV<br><br>ECMWF | Kigali, Rwanda | 28-30 March 2013 | EAC 4th Annual East African Community Health & Scientific Conference | Presentation of QWeCI results |
| Adrian Tompkins | ICTP | Potsdam, Germany | 27-30 May, | IMPACTS WORLD 2013 conference | Presentation of QWeCI results |

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| Cyril Caminade | UNILIV | | 2013 | | |
| Rachel Lowe | | International Centre for Theoretical Physics (ICTP), Trieste, Italy, | 29 April-10 May 2013 | Workshop on Mathematical models of Climate Variability, Environmental Change and Infectious Diseases, | Lecturer |
| Rachel Lowe | | ICTP | 15 April-26 April 2013 | Spring School on Modelling Tools and Capacity Building in Climate and Public Health | Lecturer and Organiser |
| Rachel Lowe | | , 23-24 May 2013, Barcelona, Spain. Lecture:. | | II Conference on Emerging Diseases: viral diseases transmitted by mosquitoes | Presentation: Impact of climate variability and change on mosquito-borne arboviruses' |

Table A4: dissemination activities conducted by Senegalese groups:

| | | |
|---|---|---|
| ***2013. *Quinzaine Internationale des Sciences et des Technologies*** | Abidjan (Côte d'Ivoire) 1-15 avril 2013 | Oral presentation (***keynote address***): **Ndione J-A.**, Lacaux J-P, Dia I., Caminade C., Diallo M., Ba Y., Vignolles C., Morse A.P., Tourre Yves M., Faye A., Ba T., Dème A., Bah A., Gaye A. Th. 2013. ***Climate change and RVF emergence in Senegal: the contribution of tele-epidemiology, lessons learned and perspectives*** |
| **2013. 4th Annual East Africa Health and Scientific Conference & International Health Exhibition** | 27-29 March 2013, Kigali (Rwanda) | Oral presentation: **Ndione J-A.**, Lacaux J-P, Dia I., Caminade C., Diallo M., Ba Y., Vignolles C., Morse A.P., Tourre Yves M., Faye A., Ba T., Dème A., Bah A., Gaye A. Th. 2013. Rainfall and RVF emergence in Senegal: beyond twenty years of investigations, lessons learned and perspectives |
| **2012. Symposium international « Population, développement et changement climatique »** | 12 -14 December 2012, Dakar (Senegal) | Oral presentation: **Ndione J-A.,** J-P., Tourre Y., Vignolles C., Lafaye M., Faye A., Ba T., Sall B., Ndiaye El H. Y., Ba Y., Dia I., Diallo M., Gaye A. Th., 2012. Surveiller, prévoir et prévenir les épidémies dans un contexte de changement climatique : apport de la télé- |

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| | | épidémiologie dans l'étude de la fièvre de la vallée du Rift (FVR) à Barkédji (Ferlo, Sénégal)<br><br>Oral presentation: **Ndione J-A.**, Caminade C., Jones A., Morse A.P., Duchemin J-B., 2012. *Malaria risk and climate change over West Africa: lessons learned from AMMA project* |
| **2012. Colloque international Science, Enseignement et Technologie pour le développement de l'Afrique** | 30 octobre-01 November 2012, Dakar (Senegal) | Oral presentation: **Ndione J-A.**, Lacaux J-P., Tourre Y., Vignolles C., Caminade C., Jones A., Morse A.P., Dia I., Diallo M., Ba Y., Kébé C.M.F., Gaye A.Th., Duchemin J-B., 2012. *Mapping Rift Valley Fever and Malaria risk over West Africa using climatic and remote sensing indicators: lessons learned from AMMA project* |
| **2012. *Information days on the new FP7 calls for proposals*** | 8 -10 October 2012, Dakar (Senegal) | Oral presentation: **Ndione J-A.**, 2012. ***African researchers involvement in european projects: lessons learned*** |
| **2012. DAAD-UNESCO Conference on sustainable water management in Africa Countries** | 1-3 October 2012, Kisumu (Kenya) | Oral presentation (Keynote): **Ndione J-A.**, 2012. *Water and health: an emerging and challenging issue for developing countries in Africa*. |
| ***Bridging health and climate knowledge in West Africa*** | May 26 - June 01st 2012, Ouagadougou (Burkina Faso) | Oral presentation: **Ndione J.-A.**, Caminade C., Morse A.P., Faye O., Ba Y., Dia I., Diallo M., 2012.*The QWeCI project: forecasting disease outbreaks. Rift Valley Fever example* |

*** Invited by the Ministry of Research of republic of Côte d'Ivoire, Dr Jacques-André NDIONE was a Member of International Scientific Committee.**

Table A5: Publications in press or appeared associated with QWeCI:

| D.O.I. | Title | Author(s) | Title of the periodical or the series |
|---|---|---|---|
| 10.1007/s00382-012-1313-4 | Decadal prediction skill in a multi-model ensemble | van Oldenborgh, G.J. F.J. Doblas-Reyes B. Wouters W. Hazeleger | Climate Dynamics |
| 10.1186/1475-2875-10-35 | Development of a new version of the Liverpool | Ermert V Fink AH Jones AE Morse AP | Malaria Journal |

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|---|---|---|---|
| | Malaria Model. I. Refining the parameter settings and mathematical formulation of basic processes based on a literature review | | |
| 10.1029/2010JD015394 | Decadal climate prediction with the ECMWF coupled forecast system: Impact of ocean observations | F. J. Doblas-Reyes M.A. Balmaseda A. Weisheimer T.N. Palmer | Journal of Geophysical Research |
| | The Impact of Regional Climate Change on Malaria Risk due to Greenhouse Forcing and Land-Use Changes in Tropical Africa | Ermert V Fink AH Morse AP Paeth H | Environmental Health Perspectives |
| 10.1038/nclimate1863 | Retrospective prediction of the global warming slowdown in the past decade | Guemas V. Doblas-Reyes F. J. Andreu-Burillo I. Asif M. | Nature Climate Change |
| 10.1007/s00382-012-1413-1 | On the assessment of near-surface global temperature and North Atlantic multi-decadal variability in the | García-Serrano, J. and F.J. Doblas-Reyes | Climate Dynamics |

| | | | |
|---|---|---|---|
| | ENSEMBLES decadal hindcast | | |
| 10.1186/1475-2875-10-62 | Development of a new version of the Liverpool Malaria Model. II. Calibration and validation for West Africa | Ermert V Fink AH Jones AE Morse AP | Malaria Journal |
| 10.1007/s00382-011-1285-9 | Sensitivity of decadal predictions to the initial atmospheric and oceanic perturbations | Du, H. F.J. Doblas-Reyes J. García-Serrano V. Guemas Y. Soufflet B. Wouters | Climate Dynamics |
| doi:10.1007/s00382-012-1600-0 | Real-time multi-model decadal climate predictions | Smith D.M. A.A. Scaife G.J. Boer M. Caian F.J. Doblas-Reyes V. Guémas E. Hawkins W. Hazeleger L. Hermanson C.K. Ho M. Ishii V. Kharin M. Kimoto B. Kirtman J. Lean D. Matei W.J. Merryfield W.A. Müller H. Pohlmann A. Rosati B. Wouters K. Wyser | Climate Dynamics |
| 10.1038/nclimate1834 | Malaria epidemics and the influence of the tropical | Cash, B.A. X. Rodó J. Ballester M.J. | Nature Climate Change |

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|---|---|---|---|
| | South Atlantic on the Indian monsoon | Bouma R. Dhiman M. Pascual | |
| 10.1029/2012GL053283 | Understanding Atlantic multi-decadal variability predictions skill | García-Serrano, J.F.J. Doblas-ReyesC.A.S. Coelho | Geophysical Research Letters |
| 10.1029/2011GL049278 | Ultra-low clouds over the southern West African monsoon region | Knippertz P Fink AH Schuster R Trentmann J Schrage JM Yorke C | Geophysical Research Letters |
| 10.1029/2012JD018004 | Identifying the causes of the poor decadal climate prediction skill over the North Pacific | Guemas, V. F.J. Doblas-Reyes F. Lienert Y. Soufflet H. Du | Journal of Geophysical Research |
| 10.1002/grl.50355 | Multiyear climate predictions using two initialization strategies | W. Hazeleger V. Guémas B. Wouters S. Corti I. Andreu-Burillo F. J. Doblas-Reyes K. Wyser M. Caian | Geophysical Research Letters |
| 10.1002/qj.2019 | A rainfall calibration methodology for impacts modelling based on spatial mapping | Francesca Di Giuseppe F Molteni A M Tompkins | Quarterly Journal of the Royal Meteorological Society |
| 10.1088/1748-9326/7/4/044012 | Useful decadal climate prediction at regional scales? A look at the ENSEMBLES stream 2 decadal hindcasts | Macleod, D. A. Caminade, C. Morse, A. P. | Environmental Research Letters |

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|---|---|---|---|
| 10.1029/2011JD016997 | Dynamical downscaling of ECMWF Ensemble seasonal forecasts over East Africa with RegCM3 | Diro, G. T. Tompkins, A. M. Bi, X. | Journal of Geophysical Research |
| 10.1186/1475-2875-12-65 | A regional-scale, high resolution dynamical malaria model that accounts for population density, climate and surface hydrology | Adrian M Tompkins Volker Ermert | Malaria Journal |
| 10.1186/1475-2875-11-S1-P133 | Development of dynamical weather-disease models to project and forecast malaria in Africa | Ermert V Fink AH Morse AP Jones AE Paeth H Di Giuseppe F Tompkins AM | Malaria Journal |
| | The real time correction of ERA-Interim rainfall | Francesca Di Giuseppe E. Dutra F. Molteni | Geophysical Research Letters |
| 10.1007/s10584-013-0744-1 | Climate Change and Infectious diseases: Can we meet the needs for better prediction? | Rodó, X. M. Pascual F. J. Doblas-Reyes A. Gershunov D.A. Stone F. Giorgi P. J. Hudson J. Kinter M.-À. Rodríguez-Arias N.Ch. Stenseth D. Alonso J. Garcia A. P. Dobson | Climatic Change |

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|---|---|---|---|
| 10.1002/grl.50557 | Dependence of the climate prediction skill on spatio-temporal scales: internal versus radiatively-forced contributions | D. Volpi F. J. Doblas-Reyes J. García-Serrano V. Guemas | Geophysical Research Letters |
| 10.1002/jgrd.50465 | Decadal prediction of the West African monsoon | García-Serrano, J. F.J. Doblas-Reyes R. J. Haarsma I. Polo | Journal of Geophysical Research |
| doi.org/10.1016/j.crvi.2013.04.001, | Climate and health: Observation and modeling of malaria in the Ferlo (Senegal) | Diouf, I. Deme, A. Ndione, J-A. Gaye, A. T. Rodríguez-Fonseca, B. Cissé, M. | Comptes Rendus - Biologies |
| 10.1175/JCLI-D-12-00049.1. | The Indian Ocean: the region of highest skill worldwide in decadal climate prediction | Guemas, V. Corti S. J. García-Serrano F.J. Doblas-Reyes M. Balmaseda | Journal of Climate |
| 10.1038/ncomms2704 | Initialized near-term regional climate change prediction | F. J. Doblas-Reyes I. Andreu-Burillo Y. Chikamoto J.García-Serrano V. Guemas M. Kimoto T. Mochizuki L. R. Rodrigues G. J. van Oldenborgh | Nature Communications |
| doi.org/10.1175/JCLI-D-12-00083.1 | Initialized near-term | Brands, S.Manzana | Journal of Climate |

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|---|---|---|---|
| | regional climate change prediction Seasonal Predictability of Wintertime Precipitation in Europe Using the Snow Advance Index | s, R.Gutiérrez , J. M. | |
| http://onlinelibrary.wiley.com/doi/10.1029/2012GL054040/full | Skill of ENSEMBLES seasonal re-forecasts for epidemic malaria prediction in West Africa. | Jones, AE and Morse, AP | Geophysical Research Letters |

Table A6: Papers in press:

| | | | |
|---|---|---|---|
| 10.1007/s10584-013-0851-z. | Revisiting the potential effects of climate change on malaria transmission in Africa using regionalised climate projections | Ermert, V., A. H. Fink, and H. Paeth, | Climatic Change |
| n/a | the world as we know it: Hotspots of global climate change impacts | Franziska Piontek et al. (incl. Caminade, Morse, Tompkins, Colon-Gonzalez) | PNAS |