Malaria in Somalia: 
Assembling the evidence and modeling risks 

Report prepared for the Malaria Working Group 
of the 
Somalia Aid Coordinating Body 

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13 March 2006
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1. Ecological position and dominant vector species

In the North of Somalia, a low-lying coastline borders the Gulf of Aden, beyond which, running parallel to the Coast, a series of dry hills, the Haud, at 500 to 2,000 meters altitude, form a skeletal framework for the country: they descend thereafter to the south-east as they join the Ethiopian Ogaden (Figure 1). In the East and the South, the plateau ends in arid steppes, from under 200 meters in altitude down to the Indian Ocean. The plains drain into the Juba River in the south and Shabelle River in the centre, which disappears into a swamp before reaching the coast (Figure 1).

Most of Somalia receives less than 500 mm of rain annually, and a large area encompassing the northeast and much of northern Somalia receives as little as 50 to 150 mm. Certain higher areas in the north, however, record more than 500 mm a year, as do some coastal sites. The southwest receives 330 to 500 mm.

Mean daily maximum temperatures throughout the country range from 30°C to 40°C, except at higher elevations and along the Indian Ocean coast. Mean daily minimum temperatures vary from 20°C to more than 30°C. Northern Somalia experiences the greatest temperature extremes, with readings ranging from below freezing in the highlands in December to more than 45°C in July in the coastal plain skirting the Gulf of Aden. The north's relative humidity ranges from about 40% in mid-afternoon to 85% at night, varying somewhat with the season.

Temperatures in the south are less extreme, ranging from about 20°C to 40°C. The hottest months are February through April. Coastal readings are usually five to ten degrees cooler than those inland. The coastal zone’s relative humidity usually remains about 70% even during the dry seasons.

*Anopheles arabiensis* is the main and often, the only vector in the country (Maffi, 1958; 1960; Maffi & Colluzi, 1960; Mouchet et al., 2004) and typical of the dominant vector species composition across the Horn and Sahelian belt of Africa. The presence of *An. merus* in Mogadishu has not been confirmed (Mouchet et al., 2004). *An. funestus* and *An. nili* have also been reported in the South (Maffi, 1960). In the North East *An. pharoensis* and *An. d’thali* have been described (Figure 2: Choumara, 1961). The characteristic habitation of *An. arabiensis* is temporary water pools in arid areas and has a preference for bovine blood meals and thus predominantly feeds outside. The Haud plateau, which reaches 2000m, is dry; since the end of the war, cisterns – water tanks – have been trucked and distributed throughout the Haud creating breeding sites for *An. Arabiensis*.

*Figure 1: Main topography of Somalia*
2. Historical and contemporary descriptions of malaria risk

2.1 Northern Somalia 1946 & 1960

Wilson (1949) undertook a malaria reconnaissance of the then British Somaliland between May and June 1946 as part of the British Army’s Malaria Service. He provides a topographical description of the malaria ecology of the region (Figure 3) based largely on rainfall patterns. He describes *An. gambiae* larval (later confirmed by Maffi (1958) as *An. arabiensis*) and adult distributions similar to those described by Glasgow & MacInnes (1943) – breeding was found in rain-pans, pools and alongside running rivers of the northern foothills. They also undertook a series of opportunistic village-based parasitological and spleen surveys in the three principal zones shown in Figure 3. The overall *Plasmodium falciparum* parasitological index among 600 people surveyed was 11.3%; *P. malariae* 1.3% and *P. vivax* 0.3%. Table 1 provides the information according to zones shown in Figure 2.
Wilson concludes "The only truly endemic portion on British Somaliland consists of small foci around the sandy stream beds in the northern foothills. From these foci there may, provided the season is conducive to such an event, be an epidemic spread. This spread will depend more upon whether the availability of grazing will tempt the guardians of the grazing herds to remain longer in the area than upon the extent of anopheline breeding places created. The results of such epidemics may be seen in the high central plateau, but the comparative lack of surface water (in spite of the higher rainfall) and the prevailing cold nights are believed to be the factors that limit transmission sufficiently to give the low endemic indices found, and to make any epidemic occurrence unlikely, if not extremely improbable".
The northern areas were also studied by Choumara (1961) and described as a hypo-endemic region but he also notes that heterogeneity is marked and hard to predict. Of significance were pools of water that formed in the rainy season which produce seasonal “micro-epidemics”. In 1951, one such epidemic resulted in 7,500 cases with a 1-2% mortality rate.

2.2 The Lower Shabelle Region areas during the 1980's

There have been remarkably few studies between the 1940’s and 1990’s of malaria infection or vector composition in the Southern and Central areas of Somalia and particularly around the densely populated areas of presumed risk around the Juba and Shabelle rivers. Two villages in the Lower Shabele Region were studied by Warsame et al. (1987; 1989) – Sigaale and Malable in September 1985 and July 1986 respectively. Blood smear *P. falciparum* parasite prevalence was 22% in Sigaale and 15% in Malable. This area is traditionally regarded as mesoendemic but with a marked over-distribution of risk. A study of geohelminths among nomads and semi-nomads in Merin Gutai (Barawe District, 130 km South-East of Mogadishu) & Bulo Mereeta (Marka district, 100 km South of Mogadishu), both in the Lower Shabele region, in September 1985 showed neither population were infected with malaria parasites (Ilardi et al., 1987). The area is therefore still prone to epidemics and in 1986 a 20-fold increase in clinical episodes was recorded at Balcad, 40 km North of Mogadishu, beside the Shabelle River (Warsame et al., 1995). The marked heterogeniety of endemicity in the Lower Shabele region creates very different patterns of herd immunity and Balcad was thought to have had a low level of endemicity and premunition compounded by the emergence of drug resistance and favorable climatic conditions in 1986.

2.3 The Lysenko map of malaria risk 1968

The global distribution of malaria endemicity was last mapped over 40 years ago through a synthesis of historical records, documents and maps of a variety of indices, including records of disease and vector presence, spleen and parasite rates, prevalence of sickle cell trait, sporozoite rates, biting rates, and other malariometric parameters (Lysenko & Semashko, 1968). These data were then interpolated globally at the peak of malaria’s assumed historical distribution in 1900, using a combination of expert opinion, global elevation, temperature and rainfall isohyets (Lysenko & Beljaev, 1969). In 2006, the “Lysenko” map represents our only source of information on the spatial limits of various categorical descriptions of *P. falciparum* transmission intensity at a global scale and has recently been resurrected as a framework to understand the changing global limits of malaria transmission and populations at risk of malaria this century (Hay et al. 2004).

The distribution of historical risk compiled by Lysenko and colleagues for Somalia is shown in Figure 4. Its course definition of risk is a result of almost no empirically driven descriptions of endemicity up to 1968 but nevertheless represents a reasonable “expert” opinion on the distribution of malaria risks ranging from hyperendemic around the two major river courses to pockets of mesoendemicity and large areas of hypoendemic transmission. According to the Lysenko map nowhere was classified as holoendemic and no area regarded at no risk.
2.4 The MARA Fuzzy Climate Suitability Map

The Mapping Malaria Risk in Africa (MARA) project attempted a modeled description of malaria risk using climatic conditions for stable *P. falciparum* transmission (Craig *et al.*, 1998) producing values that range from unsuitable (0) to completely suitable (1). The Fuzzy Climate Suitability (FCS) index is defined by a series of curves

\[
y = \cos^2 \left( \frac{(x - U)(S - U)}{(S - U) \pi} \right)
\]

where \(x\) is a climate parameter, \(U\) is the value of \(x\) when conditions are unsuitable, and \(S\) is the value of \(x\) when conditions are suitable. When \(S\) is greater than \(U\) the suitability \((1-y)\) increases with \(x\); when \(S\) is less than \(U\) the suitability \(y\) decreases as \(x\) increases. The model defines monthly increasing curve \((S=22^\circ C, \)

---

Figure 4: the historical expert opinion distribution of malaria risk in Somalia – The Lysenko Map: Areas shaded dark green represent hyperendemic transmission supporting parasite rates in childhood of between 50 and 75%; areas shown as middle green represent mesoendemcity (childhood parasite rates 10-49%); and areas of light green are hypoendemic supporting parasite rates less than 10% and a tendency to unstable transmission.
U=18°C) and decreasing curve (S=22°C, U=32°C) for mean diurnal air temperature, a monthly increasing curve (S=80 mm, U=0 mm) for rainfall, and a single increasing curve (S=6°C, U=4°C) for annual minimum temperature. Because no other endemicity-specific malaria map currently exists for Africa this model has become the most widely used malaria suitability transmission and has become the de facto standard for defining populations at risk (PAR) for malaria morbidity and mortality estimates in Africa (Snow et al., 1999). However these maps, despite being widely used, have rarely been tested against empirical data on risk (Omumbo et al., 2004) and have several limitations being based entirely on climate (Hay et al., 2005).

Figure 5 shows the MARA FCS map for Somalia suggesting that the likelihood of stable P. falciparum transmission is almost negligible across the entire country with a marginally higher likelihood in areas located in the North West of the country in the higher reaches of the Haud. This is clearly erroneous and the sources of error might lie in the use of synoptic interpolated climate data from neighboring countries or the model was developed primarily with An. gambiae SS as its template and the bionomics and sporogony in An. arabiensis might be different in this region of Africa.

*Figure 5 The MARA FCS predictions of stable P. falciparum transmission ranging from very unlikely (light blue) to likely (dark blue)*
2.5 National Malaria Survey 2002

A cross-sectional point-prevalence study was completed in three locations in Somalia during the peak transmission period (May-July) during 2002 (Burns, 2002). Sample populations were selected in the three zones: zone 1 (Awdal, W. Galbeed, Togdheer, Sanaag, Sool, Bari, Nugaal and Mudug districts); zone 2 (Galgaduug, Gedo, Bay, Bakool and Hiraan districts); and zone 3 (Middle & Lower Juba, Middle & Lower Shabelle districts). Due to security restrictions in zone 3 sampling was biased to the only two Bantu villages (Jamaame), living in close proximity to the river Juba where safe access was guaranteed. Thick and thin blood smears were obtained on all participants offering informed consent within each village sample in addition to a simultaneous test for *P. falciparum* antigen using the Rapid Immunodiagnostic Test (RDT), Paracheck®.

Results indicated that there were huge transmission heterogeneities throughout the country ranging from stable to unstable conditions. At district level point-prevalence’s from Hargeisa-Gebiley (North West), Baidoa (Central) and Jamaame (Southern) districts were 0% (0/203), 2% (5/251) and 32.2% (29/90) respectively.

*Plasmodium falciparum* was the only species identified from all positive samples. The author of the report states that the “The finding above is not consistent with the suggestion that areas in Zone 2 (Central) could be classified as having mesoendemic pattern of transmission. Further localized studies, with consideration for geographical location, climate specificity, and occupation must be considered especially in Zone 2 to further delineate the transmission pattern. This is especially important in these areas where constant population movement, conflict, and health care infrastructure remains fragile and will form the pre-conditions for a proper response to malaria epidemics if they occur.” Unfortunately disaggregated data from this survey is not available for further analysis as it can no longer be retrieved from the consultant.

2.6 National Malaria Survey 2005 (WHO-MERLIN, 2005)

A cross-sectional point prevalence survey was conducted between January and February 2005 covering three zones of Somalia (WHO-Merlin, 2005): North–West zone, Central zone and the Southern zone. The final sample included 11 473 subjects of all age groups in 351 villages located in 57/88 selected districts. The survey in the North–East zone (Puntland) was postponed to May-June 2005, this survey was successfully completed on 2675 individuals from 29 villages in eight districts (WHO, 2005). Sampling was undertaken in a stratified manner within each zone down to household level. Blood slides and RDTs (Parasight–F) were used to determine parasite prevalence. However, there were notable difficulties with the implementation of the survey in the Southern, North Western and Central Zones. Many of the questionnaires were returned with incomplete information and some had to be discarded due to gross deficiency in the data collected. Quality assurance of survey methods and blood slide reading was absent and the final report questions the utility of the smear readings (a total slide positivity of 0.1% was reported for all three zones covered in January-February 2005). However, the results of the RDT assessments were felt to be more reliable (total positivity rates of 12.3%). The results of the RDT examinations by zone are shown in Table 2

<table>
<thead>
<tr>
<th>Table 2: Parasitological summary of four Geographical Zones* 2005 (WHO-MERLIN, 2005; WHO, 2005)</th>
</tr>
</thead>
<tbody>
<tr>
<td>North-West</td>
</tr>
<tr>
<td>% Pf RDT positive No. Examine with RDT all ages</td>
</tr>
<tr>
<td>% Pf RDT positive No. Examine with RDT 2-10 years</td>
</tr>
</tbody>
</table>

* These zones do not bear any relationship to malaria risk but have been created for administrative purposes.
2.7 Summary of previous descriptions of malaria risk in Somalia

Malaria risk in Somalia has either been described by broad generalizations of endemicity based largely on expert-opinion augmented with very little data (Lysenko & Beljaev, 1969; Kassatasky, 1998; Mouchet et al., 2004) or aggregated empirical survey data at zonal levels (Burns, 2002: WHO-MERLIN, 2005; WHO, 2005). The consensus of these descriptions is that malaria is absent or hypo-endemic in the North and Central regions and tending to mesoendemic in the South. However, these aggregated data and expert-opinions do not adequately reflect the heterogeneity of risks within the four major zones of the country. The implications of assuming a single homogeneous risk among zones is best demonstrated by the variations in risk in the Lower Shabele region, a “mesoendemic” area that experienced localised epidemics in the mid-1980’s. Climate-based models of risk, not driven by data, are not accurate descriptives of malaria risk in Somalia (Figure 5) and even a simple comparison with the zonal estimates of parasite prevalence (Table 2) show the limitations of the MARA model in this part of Africa. Fortunately disaggregated village data are available for further analysis from the 2005 national survey. These data form the basis of a higher resolution P. falciparum prevalence mapping exercise described below.

3. Mapping malaria prevalence in Somalia 2005

3.1 Reconstructing the village-based parasite prevalence data

Raw survey data were obtained in Access and SPSS formats from MERLIN in Nairobi and the WHO office in Hargeissa. These were exported to Microsoft Excel. Individual identifiers were removed and data were transformed into village numbers of people seen, RDT negative and RDT positive test results. There were a substantial number of blank fields in the RDT test results and these tended to apply to entire communities (43). Where only 1-10 people were examined per village these were immediately excluded as too small a sample population for reliable PR determination.

Each village name was organised within a database of Zone, Region and District. Names were compared with a digital place name directory generated by SWALIM (John Cody, personal communication) and FSAU (Thomas Gabrielle, personal communication). GPS coordinates were extracted for name matches. For those not matched Encarta (Microsoft Encarta 2006 Reference Library, Microsoft Corporation, USA) and GoogleEarth (2005, Google, USA) were used to identify matching place names within district boundaries defined by SALB (http://www3.who.int/whosis/gis/salb/salb_MDATA.htm). Finally two additional sources were used to locate those still not positioned: hard copy reports with maps located at the KEMRI/Wellcome Trust Programme in Nairobi and a digital database of health facilities generated by DIMU/UNDP. For those communities located in the greater Mogadishu area that were not possible to geo-locate a best guess suburb was selected as the most appropriate set of coordinates using SALB. Matching names to spatial coordinates was a non-trivial process that required extreme caution given the variations in place name spelling and similarities in place names. Triangulation of various sources of data increased the skill in this exercise but would be unnecessary if future surveys were accompanied by a GPS coordinate locator in the database.

Villages were then ordered according to the total numbers of people of all age groups examined using an RDT and for which a result was available. We elected to select only individual communities that had at least 50 subjects examined. This is a rule applied to a larger global malaria prevalence mapping exercise (the Malaria Atlas Project: http://www.map.ox.ac) and relates to the lower confidence in the precision of estimates from hypoendemic areas. Several smaller village settlements were within a 3 km radius and a maximum of three were combined as clusters of villages representing the same infection risk with the centroid position representing the cluster were amalgamated. Village points were displayed in ARCGIS overlaid on the 8x8 km grid square resolution used to extract attribute data such as the NDVI. Two villages falling within the same grid square were identified and the largest sample was selected as representative of that grid square.

We have adopted a classification of malaria endemicity proposed by Metselaar & van Thiel (1959). Their classification is based on parasite rates among children aged 2-10 years but in areas of low transmission
intensity, such as Somalia in 2005, can be applied to all age-groups. We have selected three *P. falciparum* endemocities:

**Unstable risk:** Or rather reported zero prevalence – given that malaria risk could occur nominally in most of Somalia a zero prevalence reported during the 2005 surveys could be >0% owing to the sample size of the study population being too small or the timing of the survey was coincidental with a period of no risk. Zero prevalence should therefore be considered as a combination of true no risk and marginal risk subject to sampling and survey timing errors.

**Hypoendemic malaria:** Community parasite prevalence greater than zero but less than 10%. These areas are classically those where there is little transmission and the effects, during the average year, upon the general population are intermittent. These communities can be regarded as unstable and should possibly be viewed coincidentally with those as reporting zero prevalence.

**Mesoendemic malaria:** Community parasite prevalence greater than or equal 10% but less that 50%. Typically found among rural communities in sub-tropical zones when wide geographical variations in transmission risk exist. Metselaar & van Thiel (1959) also suggest that these areas can be regarded as unstable malaria in a few instances although epidemics are much less severe than in hypoendemic areas.

Unlike the Lysenko map shown in Figure 4 there were no reports of parasite prevalence in excess of 50% and thus definable hyper- or holoendemic transmission conditions reported during the 2005 survey.

Of the circa 360 villages, 43 surveys points had surveys done but no data reported, 259 had sample sizes less than 50 (but some were latter grouped in clusters). The final database contained 58 geo-located single communities and 33 clusters of three or less villages within a 3 km radius. Each village sample had at least 50 people (range 50-200) examined by RDT. The total number of people examined across the 91 communities was 7,227. Data are summarized in Table 3. The distribution of survey communities included in the GIS analysis is shown in Figure 6.

*Table 3: Summary of village estimates of *P. falciparum* parasite prevalence (PR) included in the analysis [min-max values]*

<table>
<thead>
<tr>
<th></th>
<th>North West</th>
<th>North East</th>
<th>Central</th>
<th>South</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>PR 0%</td>
<td>10 (76.9%)</td>
<td>4 (21.1%)</td>
<td>13 (41.9%)</td>
<td>6 (21.4%)</td>
<td>33 (36.3%)</td>
</tr>
<tr>
<td>PR &gt;0 - &lt; 10%</td>
<td>2 (1.5%)</td>
<td>11 (57.9%)</td>
<td>10 (32.3%)</td>
<td>8 (28.6%)</td>
<td>31 (34.1%)</td>
</tr>
<tr>
<td>PR &gt;= 10% &lt; 50%</td>
<td>1 (0.8%)</td>
<td>4 (21.1%)</td>
<td>8 (25.8%)</td>
<td>14 (50.0%)</td>
<td>27 (29.7%)</td>
</tr>
<tr>
<td>Total [range of PR values]</td>
<td>13 [0-16%]</td>
<td>19 [0-38%]</td>
<td>31 [0-26%]</td>
<td>28 [0-48%]</td>
<td>91</td>
</tr>
</tbody>
</table>

The fidelity of the final database of parasite prevalence (PR) remains unknown: who was selected for examination, reasons for not seeing sampled household members, reasons for no test results on interviewed members were not provided in the database. In addition, there were significant omissions from the national sample owing to missing data. The random distribution of community points is poorer in some areas than others – for example data for the North West zone was more incomplete than the South Zone. Nevertheless a general crude picture emerges consistent with previous zonal reports summarised in section 2: the highest recorded PR data were found along the rivers and low or zero prevalence was recorded in the central regions. There were however three extreme outliers in the Bari region (Rako, 38%) and the Bay region (the combined villages of Balourarue & Mowkubow, 48%, and the combined villages of Burogaras & Duro Emed, 47%). These were located away from perennial rivers in notably dry areas.
Figure 6: Distribution of survey data included in spatial analysis. Grey is reported zero prevalence; pink is hypoendemic PR estimates >0% and < 10%; and red is mesoendemic >= 10% and < 50%. Size of points related to sample size.
3.2 Assembling the physical and remotely sensed attribute data

There are a number of well defined biological drivers for malaria transmission. These include temperature, rainfall, proximity to permanent and temporary breeding sites and urbanization. Most centre on the ability of the dominant vector species to breed in sufficient numbers to produce adults that can subsequently survive long enough for the parasite to develop in the vector between human blood meals. We assembled direct and indirect measures of potential transmission modifiers for Somalia and extracted individual measures for each of the survey locations described above using Idrisi 14.02 Kilimanjaro (1987-2004, Clark Labs, Clark University, USA) & ArcGIS 9.1 (1999-2005, Environmental Systems Research Institute Inc., USA).

3.2.1 Urbanization

Urbanization reduces the diversity of anopheline species in an environment, their numbers, their survival, their infection rates with \( P. falciparum \) and the frequency with which they bite people. The most common explanation is the lower vector densities resulting from a paucity of clean freshwater breeding sites (Lindsay et al., 1990). As has been eloquently detailed (Trape & Zoulani, 1987), however, the process of urbanization effects changes in malarialometric indices not only by eliminating open spaces for breeding, but also by increasing pollution of the remaining breeding sites, limiting the dispersion opportunities for adult mosquitoes. With higher human densities, \textit{per capita} exposure also decreases.

There is little consensus among international agencies on what constitutes urban areas or how to describe the process of urbanization (Vlahov & Galea 2002; Tatem & Hay, 2004). Of the 228 countries for which the United Nations Population Division (UNPD) has data (UN, 2002), 108 use administrative definitions (e.g. living in a city), 51 use size and density (e.g. number of people per square kilometer), 39 use functional characteristics (e.g. majority of economic activity non-agricultural), 22 have no definition whatsoever and 8 define all or none of their populations as urban. The role of urbanization and malaria and quantifying any relationships obviously depend heavily on how urban populations are categorized in space.

The urban extents developed as part of the Global Rural-Urban Mapping Project (GRUMP) (Balk et al., 2006) aims to circumvent some of these ambiguities. The GRUMP urban layer was developed at a 1 x 1 km spatial resolution using data on night-time lights and Landsat satellite sensor imagery in combination with other geographic data (Digital Chart of the World populated places, Tactical Pilotage Charts produced by the Australian Defense Imagery and Geo-Spatial Organization, and national census data). These data were extracted for Somalia and despite a standardized approach for global applications only seven Somali communities were defined as urban reflecting probably the inadequacy of night time lights in this region, poor and old (pre-war) census data and a paucity of other pilotage data.

The population databases described below (section 3.2.5) were provided with fields describing the settlement types. Each village selected as part of the parasite prevalence mapping was coded as \textit{urban} if the SWALIM/FSAU database defined the community as “district town”, “major town”, “regional capital”. All communities identified as “settlement” were coded as \textit{rural}. In Somalia the UN states that the urban is classified as towns with populations of more than 5000 people – this criteria was therefore used to validate the urban rural distinctions used in the parasite prevalence database – all those defined as urban did have populations in excess of 5000 people and none of those classified as rural had populations above 5000 people.

Among the 14 urban communities within the database 7 (50%) were reported as having a zero parasite rate [all 5/5 Mogadishu communities reported zero prevalence], the remaining 7 had parasite rates recorded between 1 and 16%. The samples were too few to draw any conclusions about the effects of urbanization on parasite prevalence but where possible data were examined for other drivers of risk with and without inclusion of urban samples.
3.2.2 Normalized Difference Vegetation Index (NDVI)

As of January 1, 2001, Rainfall Estimates (RFE) version 2.0 has been implemented by National Oceanic and Atmospheric Administration’s (NOAA) Climate Prediction Center. This used an interpolation method to combine Meteosat and Global Telecommunication System (GTS) data, and included cold cloud information for the dekadal estimates. World Meteorological Organization (WMO) GTS data from ~1000 stations provide station rain gauge totals, and are taken to be the true rainfall within 15-km radii of each station. The accuracy of RFE, therefore, depends greatly on the reliable GTS data. In the case of Somalia, there are no sufficient GTS stations while Ethiopia, which is the neighboring country with the most reliable data, has refused to release this for development of RFE (John Cody, Personal Communication). In the absence of reliable RFE for Somalia, Normalized Difference Vegetation Index (NDVI) was used in this malaria mapping exercise.

NDVI provides a measure of the amount and intensity of vegetation at the land surface. The magnitude of NDVI is related to the level of photosynthetic activity in the observed vegetation. In general, higher values of NDVI indicate greater intensity and amounts of vegetation. NDVI is derived from data collected by NOAA satellites, and processed by the Global Inventory Monitoring and Modeling Studies group (GIMMS) at the National Aeronautical and Space Administration (NASA) (Tucker et al. 2005). NDVI is calculated from two channels of the AVHRR sensor, the near-infrared (NIR) and visible (VIS) wavelengths, using the following algorithm:

\[
NDVI = \frac{NIR - VIS}{NIR + VIS}
\]

NDVI is a ratio (hence no units) that varies between -1 and +1. Values of NDVI for vegetated land generally range from about 0.1 to 0.7, with values greater than 0.5 indicating dense vegetation. Negative values are indicative of water.

NDVI data for Somalia were obtained from the Famine Early Warning System (FEWS) Africa Data Dissemination Service (ADDS) archives. Since the late 1980’s, FEWS has used the Advanced Very High Resolution Radiometer (AVHRR) satellite sensor data to produce dekadal (10-day), 8 km resolution composite NDVI images of Africa, and has built an archive of these data from mid 1981 to present (http://earlywarning.usgs.gov/adds).

No correction has been applied for atmospheric effects due to water vapor, Rayleigh scattering or stratospheric ozone. Maximum value compositing has been used, with a forward binning procedure method implemented. Artifacts in NDVI due to satellite drift have been corrected using the empirical mode decomposition (EMD). The correction is especially important in tropical regions (Pinzon et al., 2004). NDVI was archived as byte data files. NDVI values near large water bodies, particularly if they are very moist or covered by water are often attenuated. Land surfaces along oceans and other large water-bodies are therefore assigned lower NDVI than their actual vegetation would represent. Data were therefore re-sampled for these areas of uncertainty. For the parasite prevalence data this was particularly important for the multipoint area of Buufow, El Munge and Jimey along the coast that was re-assigned a more reliable NDVI value closest to the correct pixel.

The raw NDVI data ranged from 0-250 values with 253 and 255 representing bad pixels and water bodies respectively. Once the raw data was imported into Idrisi, it was rescaled from -1 to 1. To recover the -1 to 1 range of NDVI, the following formula was used: \(NDVI = \frac{\text{raw}}{250}\). After conversion, water pixels have a value of 1.0200, and 1.0160 are masked pixels, and missing pixels are 1.0120. To derive an average annual NDVI map, all three re-scaled NDVI dekadal data in each month of the 24 (1982-2005) years were compared and the maximum NDVI value was selected to represent the monthly NDVI for the given year. Values for individual months were summed for each of the 12 months over the 24 years. In addition the NDVI values for the months of the survey in a particular village and the preceding month were extracted. A series of 1x1 km spatial resolution NOAA-AVHRR data are available at the “Global Land 1-KM AVHRR Project” homepage on the United States Geological Survey (USGS), EROS Data Center, web [URL: http://edcdaac.usgs.gov]. The data set was generated to obtain a standard year of observations for the global land cover mapping project by the International Geosphere Biosphere Programme– Data and
Information System (IGBP-DIS). The 1x1 km NOAA-AVHRR data are available by dekad (10 day unit) from April to December 1992 (9 months, 27 dekads, 162 files); January–September 1993 (9 months, 27 dekads, 162 files); February–December 1995 (11 months, 33 dekads, 198 files) and January–April 1996 (2 months, 6 dekads, 36 files). The 8x8km and 1x1km distribution of the average annual NDVI values for Somalia are shown in Figures 7a and 7b respectively. These were obtained from Hay et al. (2006).

Figure 7 A map of Somalia showing annual average a) maximum 8x8 km NDVI values and b) maximum 1x1km NDVI values

The relationship between parasite prevalence classes and median (and interquartile ranges) annual 8x8 km 24-year average NDVI, month of survey NDVI and lags of one and two months prior to the survey are shown in Figures 8a-d. These figures have excluded the three outlying communities described above, all with extremely low NDVI values and reported high (mesoendemic) parasite prevalence values. Correction for urbanization had no major effects on the median, mean or ranges of NDVI values. Moreover, using the 1x1 km resolution NDVI values from EROS did not significantly improve the discrimination between malaria risk classes. Overall the data shown in Figures 8a-d are inconclusive – with large ranges of NDVI values within each of the malaria risk classes. There was a tendency toward lower NDVI values in the unstable, zero prevalence class compared to other classes but easiest to distinguish only with mesoendemic classifications of risk.

30/33 (91%) of communities included in the analysis that reported a parasite prevalence of 0% were located in an 8x8km pixel with average NDVI value less than or equal to 0.300. Where a parasite prevalence was record of between 0.01% and < 10% 21/31 (68%) were in areas with an NDVI value of <= 0.300; and of those communities reporting mesoendemic transmission 11/27 (37%) were in areas with an NDVI value <= 0.300. Whilst a cut-off of 0.3 does not exclude stable transmission, with several outliers within this range of
NDVI, this is consistent with previous work. In Kenya we have shown that a minimum threshold NDVI of between 0.3 and 0.4 was required to support transmission prior to seasonal changes in severe clinical malaria presentation at three hospital settings and subsequently used to map malaria seasonal risks across Kenya (Hay et al., 1998).

Figure 8: Box and whisker plots of NDVI versus parasite rate. a) NDVI annual is the average maximum NDVI for any given year derived from monthly NDVI averages for 24 years (1982-2005). b) NDVI survey month shows NDVI values of the month PR survey was done (70 points in January and 18 points in July). c) NDVI one month-lag was derived from December 2004 and June 2005 for January and July 2005 surveys respectively d) NDVI two-month lag was computed from November 2004 and May 2005 for January and July 2005 surveys respectively. Line and point represent the median values, the length of the box shows the interquartile range (IQR), the upper cap of the whiskers is drawn at the largest observation that is less than or equal to the 75th percentile + 1.5*IQR. The lower cap is drawn at the smallest observation that is greater than or equal to the 25th percentile - 1.5*IQR. The outliers are shown separately. Parasite prevalence classes: 0= zero, unstable transmission; 1= hypoendemic, >0-<10% parasite prevalence; 2= mesoendemic, >=10%<50% parasite prevalence.
3.2.3 Permanent and seasonal water-bodies

Construction of dams, formation of reservoirs and irrigation systems and agricultural practices provide important influences on human settlement, land-use and disease risk. The relationship between the amount of rainfall and the development of breeding sites is dependent on several factors such as the slope of the land; run-off and soil type and the suitability of these breeding sites will further be affected by the availability of shade, vegetation, predators and level of salinity.

Two significant studies have been undertaken in areas where the dominant vector species is An. arabiensis on the relationship between malaria risk and distance to breeding sites. First, in Dakar, Senegal, in the late 1980's Jean-Francois Trape and colleagues studied An. arabiensis vector densities in urban households along a 910 meter transect away from a permanent marsh (Figure 9).

Figure 9: Average number of An. arabiensis per 100 rooms on the Y axis in the dry season (light blue) and wet season (dark blue) per meters away from a permanent marsh (x-axis) (Trape et al., 1992).

Within a kilometer there is a marked gradient in vector density in an area of otherwise negligible malaria risk of urban Dakar. Malaria exposure among children aged 8-11 years, as judged by IFAT antibody tests, followed a similar risk pattern to the vector gradient shown in Figure 9 declining steeply from 83% positivity closest to the marsh to 27% furthest away from the marsh (Trape et al., 1992).

The second important study was undertaken in Tigray, northern Ethiopia in 1997 (Ghebreyesus et al., 1999; 2003). The authors studied the incidence of clinical malaria attacks among children less than 10 years of age in relation to distance from micro-dams. They classified villages into those within the maximal flight path of Anopheles, 3 km (Gilles, 2002) [Case villages] and villages between 8-10 km [Control villages]. The incidence of clinical malaria was 2.5 times higher among case villages (17.9%) close to dams compared to control villages 8-10 km away (7.2%) within the altitude range of 1800-1900 meters.

Both the Dakar and Tigrayean studies were undertaken in areas of exceptionally low transmission intensity and where An. arabiensis was the only vector. Their observations therefore have relevance to the malaria conditions in Somalia.

Data were obtained for Somalia on the major perennial rivers and permanent water bodies; seasonal rivers and streams, dams, berkads (a manmade cistern to store run off water -typically sunk into the ground and made of stonework plastered watertight) and springs (isha or laas). Three principal data sources were used and amalgamated: FAO Africover (http://www.africover.org); SWALIM (http://www.faoswalim.org); and the
Regional Centre for Mapping Resources for Development (RCMRD) under contract from Chemonics International for FEWSMET/USGS. All these datasets were produced by visual interpretation of LANDSAT TM satellite images (bands 2, 3, 4). Africover images were acquired mainly in 1999 while the SWALIM data were digitised from 2000/2001 imagery. The geographic projection shapefiles were re-projected using Albers Equal Area Conical projection with parameters similar to those used in the NDVI. Data was coded into 3 layers: 1) Perennial rivers and permanent large water bodies; 2) Seasonal dams and berkads; and 3) Seasonal rivers, streams and springs. Wells were not included as it is uncertain whether An. arabiensis breed in completely shaded wells and whether all the wells were identified in the GIS data provided. The spatial resolution of these three classes of local breeding sites is shown in Figure 10.

Figure 10: Distribution of permanent water bodies (dark blue); Seasonal rivers, streams and springs (light green) and Seasonal dams and berkads (pink).
Communities where parasite prevalence was recorded were classified as to whether they were within the 3 km flight path of *An. arabiensis* or beyond 3 km. Finer resolution of the classifications within 3 km or over 8 km were not possible owing to the distribution of the finite number of prevalence data points between more infinite distance classifications. We again removed the three outlier communities described earlier and examined the median and interquartile range of parasite prevalence in communities located within 3 km and beyond 3 km of permanent water bodies (Figure 11a); seasonal dams and *berkads* and seasonal rivers and streams (Figure 11b). Only two communities were classified as being within 3km of a seasonal dam or *berkad* and thus no meaningful conclusions can be drawn from these observations. This is more likely to reflect the incompleteness of spatial data related to these drivers of local vector density and parasite prevalence and would be improved with higher spatial capture of these features in the future. Examination of median distances to water bodies by malaria risk class was distorted by exceptionally long nearest distances of those communities located a great distance from any spatially positioned water source shown in Figure 6. Exclusion of urban settlements from this analysis did not significantly affect the discriminatory value of the parasite prevalence and distance criteria.

*Figure 11: Box and whisker plot of parasite rate versus a) distance (km) of parasite survey villages to permanent rivers and other water features; b) seasonal rivers, streams and springs. The length of the box shows the interquartile range (IQR), the upper cap of the whiskers is drawn at the largest observation that is less than or equal to the 75th percentile + 1.5*IQR. The lower cap is drawn at the smallest observation that is greater than or equal to the 25th percentile - 1.5IQR. The others are outliers.*

The distance criteria for permanent and seasonal water bodies were inconclusive with wide overlapping estimates of parasite prevalence within and over 3km. However, a trend is seen in favor of higher parasite prevalence among those communities located within 3km of a permanent water source, notably the larger Juba and Shabele rivers, compared to those greater than 3km. Two of 33 (6.1%) communities reporting a parasite prevalence of zero were within 3km of a permanent water body compared to 10/31 (32.3%) classified as hypoendemic and 7/24 (29.2%) classified as mesoendemic class. The indeterminate nature of seasonal rivers and springs again does not necessarily reflect no effects on transmission in the areas they are most prolific but probably a poor spatial capture of these attribute data and lack of reasonable knowledge of availability of water in these sources during the times of the surveys.

### 3.2.4 Elevation exclusions

Altitude is inversely related to temperate and in general a 0.5-0.6°C drop in temperature occurs for every 100-metre increase in altitude (Cox et al., 1999). Malaria transmission is dependent on the presence of suitable numbers of parasitised vectors and susceptible hosts. *Anopheles* are generally not found at altitudes over 2500 meters above sea level (Service & Townson, 2002). As altitude increases, transmission periods become shorter and a more seasonal transmission profile tending towards ‘epidemics’ may be experienced. This altitude/temperature criterion, however, is very variable and is influenced by latitude, air
saturation and distance from large water bodies (Cox et al., 1999). In their review of parasitological and Ministry of Health data on epidemic reports, Cox and colleagues concluded, for Ethiopia (sharing a same dominant vector species as Somalia) that transmission was rare or unstable above 2000 meters. We have therefore adopted this as a mask layer for the Somali mapping exercise and consider the variation in parasite prevalence below this limit.

The US Shuttle Radar Topography Mission (SRTM), a joint project between the National Geospatial-Intelligence Agency (NGA) and the National Aeronautics and Space Administration (NASA) was launched in February 2000 to produce digital topographic data for 80% of the Earth's land surface (all land areas between 60° north and 56° south latitude), with data points located every 1-arc-second (approximately 30 meters) on a latitude/longitude grid (http://srtm.usgs.gov/mission/missionsummary.html). The absolute vertical accuracy of the elevation data is 16 meters (at 90% confidence). A 90m ArcGrid copy of the SRTM DEM for Somalia was obtained from SWALIM and classified into 250 m intervals.

3.2.5 Population density exclusions

Clearly transmission between human hosts is dependent upon human population density. In previous malaria mapping exercises it has been assumed that where population density is less than 1 person per km$^2$ this represents an exclusion of risk (Guerra et al., 2006). In Somalia populations are migratory and it may be difficult to strictly apply the rule of 1x1 km population exclusions. What might be more appropriate is a wider classification of no recorded population with a 5x5km grid.

Data on settlements was originally obtained from the DIMU of UNDP Somalia and received by the KEMRI/Wellcome Trust through SWALIM (John Cody, Personal Communication). The settlement database contained 4522 settlement names and coordinates that had been developed from a) Somalia topographic maps at a scale of 1: 100,000 produced by stereo photography using aerial photography 1974 and printed in 1976 by Bureau of Cartography, Ministry of Defense, Somalia Democratic government. The maps have been updated by the Canadian Forces Mapping and Charting Establishment from reprographic material of native Somalia mapping by the British Director of Military Survey; b) other settlements were recorded and entered into the database from a gazetteer database developed by the USA Defense Mapping Agency and the United Nations Department of Security (UNDOS); c) finally additional data were compiled from population surveys carried out between 1997/98 of N.W Somalia- Middle and lower Shabele. The data file contained information on estimated population size from two sources a) estimated populations sizes from pre-war hut and house numbers and b) surveyed population size from more contemporary AID agency census exercises. The database contained 1198 (26.5%) settlements with no population size estimate from either source. To augment the population estimates for established settlements we then used a database of community names and estimated populations developed principally in 2004 to assist the Polio vaccination campaign mounted by the WHO. Data were provided by WHO for 17 regions (i.e. not the whole country). The population total estimates in this file were rounded to best guess 100's and were not as apparently precise as the SWALIM database for estimated population size. Nevertheless unique matching of names of the 1198 settlements with no recorded population identified a population estimate from the polio database for an additional 160 communities, leaving 1038 (23%) without an estimate of population. As such it was not possible to develop a population density interpolated map for Somalia at a sufficiently high spatial resolution.

Instead we have reverted to using the presence or absence of a settlement within 5km grid square as a marker of population distribution in accordance with risk. Figure 12. shows the “populated”. i.e. where a settlement is recorded in red and areas masked as white having no recorded settlement.
Figure 12: Population settlements recorded within a 5km grid (red) or not (white)
3.2.6 Assembling endemicity and mask criteria for a proximate malaria map for Somalia.

The univariate analyses presented in sections 3.2.2-3.2.3 above suggest that traditional methods of discriminant analysis, Bayesian modelling or supervised classification within a GIS platform for malaria risk mapping would not be possible for the 91 data points obtained during the 2005 national survey. The number of surveys located in urban settings or close to mapped berkads did not support analysis of these drivers of malaria risk. The completeness of GIS data on presence and quality of potential seasonal or man-made breeding sites was inadequate for an efficient analysis of these determinants of exposure to infected An. arabiensis.

Despite these caveats it is worth noting two key drivers of malaria risk, the ability to distinguish communities with no one reported as positive for malaria infection from those communities with infected residents: a) an annualised NDVI estimate of less than or equal to 0.3; and b) living greater than a 3km vector flight range of a permanent water body. With these two drivers it is possible to resample attribute data around a set of semi-evidence based rules. Here we have made the following assumptions to apply to the re-sampled 8x8 km assembled NDVI, water bodies, elevation and population data.

**Mask:** Malaria does not exist >= 2000 meters or in 5km gridded areas with no recorded human settlement

**Unstable malaria:** Areas with an annualised 1x1 km NDVI value less than or equal to 0.3 and greater than 3km from a permanent water body.

**Hypoendemic malaria:** Areas greater than 3km from a permanent water body but an NDVI value > 0.3 OR areas less than 3 km of a permanent water body with an NDVI value <= 0.3.

**Mesoendemic malaria:** Areas less than or equal to 3km of a permanent water body and an NDVI value > 0.3

The spatial and population settlement distributions are shown in Figures 13a and 13b respectively.
Figure 13a: The re-sampled 8x8km NVI estimates $\leq 0.3$ and 3 km distances to water sources (white area in north is 2000m exclusion) without population density exclusions. Orange = unstable transmission risk; green = hypoendemic risk; and red = mesoendemic risk.
Figure 13b: The re-sampled 8x8km NVI estimates $\leq 0.3$ and $3$ km distances to water sources (white area in north is $2000$m exclusion) without population density exclusions with population density exclusions (i.e. settlements within a $5x5$ km grid square). Orange = unstable transmission risk; green = hypoendemic risk; and red = mesoendemic risk.
Using NDVI and distance to permanent water body criterion 28/33 (85%) of the communities reporting zero prevalence were identified as being in the unstable risk areas shown in Figures 13a and 13b. However, these criterion performed badly in being able to distinguish areas of hypoendemic (8/31, 26%, correctly identified) and mesoendemic (7/27, 26%, correctly identified) malaria risk. A combination of unstable and hypoendemic risk areas as a single entity of combined low/unstable risk the two criterion would have been able to correctly identify 57/64 (89%) of the true estimates of risk. However, areas of moderate parasite transmission described as mesoendemic were hard to classify based on these two criteria alone and there were a significant 11/27 (41%) of mesoendemic communities living greater than 3 km from permanent water bodies or in NDVI classified dry areas.

4. Summary & Conclusions

The dependent parasite prevalence data exhibited a marked heterogeneity within major discriminating independent features of transmission risk. This observation may be a genuine finding, and consistent with what we expect of historical descriptions and the over-distribution of risk among communities exposed to lower annual entomological inoculation rates (EIR). Recent mathematical modelling exercises of parasite prevalence and entomological challenge have shown that 80% of all new infections are provided by only 20% of an at-risk population (Smith \textit{et al.}, 2005) and as the basic reproduction rate of infection is lowered spatial heterogeneity becomes a dominant feature of transmission (Smith \textit{et al.}, in prep.). Within Somalia this is not a new observation, both Wilson (1949) and Choumara (1961), made a point of emphasizing the marketed heterogeneity of transmission in the areas they studied in the Northern reaches. Such localized features of risk would be hard to model and map at a country or regional level – but they do have important implications for disease control and management.

Conversely our inability to model and map malaria endemicity may have been because the prevalence data were inadequate for this exercise. There is a suggestion from the original reports that the 2005 national survey was less than perfect in its conduct and quality assurance. The data points used in this analysis are not randomly sampled from the universe of villages in a given ecological setting. Within the 380 villages sampled we could maximally utilize only 91 (24%) due to either appropriate sample size or actual availability of data. Within the selected villages there is no indication of sampling efficiency and reasons for non-response.

Finally the poor final model skill is likely to result from an incomplete series of other attribute data such as berkads, seasonal breeding sites and the lack of adequate descriptions and numbers of urban communities. In a country where the predominant vector is \textit{An. arabiensis} and subject to opportunistic seasonal breeding and feeding these localised features of malaria transmission are extremely important.

5. Implications of malaria endemicity for control options in Somalia

Case-management and presumptive treatment: It would be dangerous to assume gross generalizations about zonal risks of malaria in Somalia. The data presented show marked heterogeneity. Whilst we can assume that on average transmission intensity is low and unstable across large areas of the central and northern parts of the country – localized high transmission – probably temporally related do occur. The extent and magnitude of these localized high transmission conditions might be hard to map and model. Their impact on disease risks remains unknown but one could probably assume that they pose an important clinical burden on all age groups traditionally used to low parasite exposure and thus have a poorly developed functional immune response.

Under such conditions it would seem prudent to ensure adequate diagnostic support through RDTs and ensure all positives are treated with an ACT. It might additionally be interesting to undertake a small trial of mass treating asymptomatic family, household or community members of index cases presenting with parasitologically confirmed fevers – this targeted presumptive treatment with artemisinins might have a dramatic effect upon localized transmission.

At present the modeling exercises – although less than perfect – do reflect a general position that there are very few areas in Somalia where the adoption of presumptive treatment without diagnostics should be
adopted. It would be important to further test this policy implication with data on the proportions of fevers parasite positive through RDT measures at clinics. These could be mapped and modeled at a national scale and is an exercise worth mounting in the immediate future.

**Larval control:** The northern areas of the country offer challenges for control. It seems entirely reasonable to assume that insecticide-treated nets will be used by large numbers of people only minimally at risk of bites from infected adult vectors. If there were more confirmatory epidemiological data on transmission and vectors in the north these data might suggest a more cost-effective means of vector control targeting larval development. Attempts to biologically control *An. arbienesis* in man-made breeding sites in the North using *Oreochromus spilurus* fish have been somewhat successful and could have eliminated malaria in this particular region (Alio et al., 1985). This report is hard to interpret but it would seem that a paired village design and the introduction of *Oreochromis spilurus spilurus* (Tilapia) into berkads in the Togdheer region (near Burao Town) did successfully reduce adult vectors and the parasite prevalence in the experimental villages compared to control villages. A considerably smaller study in Kalabeydh village in northern Somalia showed similar effects on larval density reduction using Tilapia in 2002 (Mohamed, 2003). Neither of these studies were properly community randomized controlled trials and would need to be undertaken again at scale, with parasitological and clinical outcomes and with a comparative cost-effectiveness element against ITN. These trials would need to be developed coincidently with better mapping skills and predictions of where to target this control methodology.

**Zooprophylaxis:** Several successes have been reported of using alternate blood meal sources as a way to control adult vectors. *An. arbienesis* will feed on cattle and studies in Kenya, Ethiopia and Pakistan (Hewitt & Rowland, 1999; Rowland et al., 2001) have used pyrethroid impregnated cattle as a means to reduce vector densities – pyrethroids do not have a large repellency effect and thus are thought not to divert feeding to human hosts. The effects of similar approaches with camel herds and the feeding preferences of *An. arbienesis* in areas of dense camel populations are unknown.

**Insecticide treatment of temporary living quarters and materials of nomadic people:** The Samburu in Kenya have been part of a novel approach to treating *shukas* (wraps) with permethrin (MacIntyre et al., 2003). Among refugees located in camps tarpaulins have been treated with insecticides. These less traditional methods of personal protection have met with varying degrees of success and might merit further investigation amongst special groups in Somalia.

**6. Future work**

6.1. **National sample surveys versus sentinel sites:**

National sample surveys are important tools to establish baseline indicators of malaria control, such as ITN use, access to medicines and use of other preventative strategies by the community. These data are best presented as aggregate estimates at low spatial resolutions. To this end the 2002 and 2005 national survey data in Somalia have been successful. However, where malaria infection prevalence is over-dispersed, difficult to collect data and assure quality, the national sample survey approach may not be the optimal design to understand localised patterns of malaria transmission and epidemiology.

The determinants of malaria risk, the implicated vector populations and their behaviour and the epidemiology of disease risks are essential components to developing an effective malaria control strategy. Optimally these investigations would take place under well controlled survey conditions among entire well characterised communities, not randomly selected households within a community, with sample sizes large enough to provide meaningful epidemiological data.

Given the diversity of malaria risks in Somalia sampling of communities for further, more intensive malarialymetry should be guided by the very provisional mapping exercises described above against a better understanding of the representations of these sentinel sites per national population-weighted-risk.
It is recommended that a series of four sentinel locations be identified in each of the main ecological settings shown in Figure 13 with at least 30 contiguous communities that would form the basis of more detailed:

a) Investigation of the proportion of symptomatic and asymptomatic infection prevalence among communities by age
b) Entomological investigations of dominant vector species and their feeding and larval ecology
c) The incidence of clinical incidence of disease under different transmission, health service and preventative use scenarios.

These studies would then inform the Somali National Control Programme on the likely effectiveness of alternative and existing vector control strategies and diagnostic case-management strategies. These sites might also then serve as areas to test novel intervention strategies through controlled trials.

6.2 Developing and exploiting existing GIS data

Somalia is comparatively rich in its GIS data. Somalia’s digital spatial data on road networks and health service distributions is substantially better than Kenya’s. With respect to developing health-service use and access maps to identify areas of vulnerability Somalia has excellent possibilities. For malaria mapping there remain several spatial features that require improvement and expansion of mapping coverage, notably: berkads, seasonal rivers and dams and other possible vector breeding sites. The use of IKONOS imagery at high spatial resolution could be used to train topographical descriptions of malaria risk. For example, at a resolution of 1m, the IKONOS imagery can be used to control for the differences in NDVI indices along the coastline and major water bodies to ascertain whether these differences are real or they are interference of reflectance due to moist or water laden vegetation.

Perhaps of greatest importance is the assembly of the national health facility database and the population settlement database. These are of generic importance to health service planning and both human settlement maps and health service provision maps require additional work for them to be of any utility in Somalia.

One immediate use of these data is to form a GIS platform to display current and reliable data on RDT positivity among febrile presentations by age to refine the proposed IMCI presumptive case-management strategy.
7. References


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## 9. Abbreviations

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<th>Abbreviation</th>
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<tr>
<td>ADDS</td>
<td>Africa Data Dissemination Service</td>
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<td>DIMU</td>
<td>Data &amp; Information Management Unit</td>
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<td>FAO</td>
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<td>Food Security Analysis Unit</td>
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<td>Global Telecommunication System</td>
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<td>Kenya Medical Research Institute</td>
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<td>Immunofluorescent Antibody Test</td>
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<td>NDVI</td>
<td>Normalized Differential Vegetation Index</td>
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