Prospective Study of the Impact of Climate Change on Vector-Borne Diseases: A Generic Research Protocol

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- Dr G S Sonal, Joint Director, National Vector Borne Disease Control Programme, Delhi
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Contents

Acronyms

ELISA	enzyme linked immuno sorbent assay
GCM	global climate model/ general circulation model
GHG	green house gas
GIS	geographical information system
HadCM3	Hadley climate model
IITM	Indian Institute of Tropical Meteorology
IPCC	Inter-governmental Panel on Climate Change
MARA	mapping malaria risk in Africa
MIASMA	modeling framework for the health impact assessment of man-induced atmospheric changes
NVBDCP	national vector-borne disease control programme
PHC	primary health centre
PRECIS	providing regional climate for impact studies
RH	relative humidity
SRES	special reports on emission scenarios
TW	transmission window
UNFCCC	United Nations Framework Convention on Climate Change
VBD	vector-borne disease
V&A	vulnerability and adaptation
WHO	World Health Organization

1. Introduction

The outcome of retrospective study on impact of climate change elicits some climatic factors associated with incidence of (Vector-borne Diseases). Validation of identified indicators is necessary to ascertain their role in disease transmission. There is also a need for finding early evidence of climate change affecting the transmission dynamics of diseases and the future scenario of spatial or temporal distribution of VBDs. The countries which do not have meteorological stations and lack a surveillance mechanism for VBD should initiate generating baseline data on VBDs of public health importance. Therefore, prospective studies are warranted by generating meteorological and biological data in hot spot areas for developing baseline data so as to provide a framework for assessment of impact of climate change on VBDs and for developing a preparedness plan to address the negative impacts.

2. Objectives

(1) To validate the role of meteorological factors in disease occurrence.

(2) To assess the impact of climate change on VBDs in view of the projected rise in temperature.

(3) To find early evidence of impact of climate change on VBDs.

3. Significance of the study

- The countries which do not have any information on disease surveillance, vector prevalence and a system of data generation on daily temperature, rainfall and RH will have baseline data.
- A surveillance system will be in place.

- The baseline data so generated will form the basis of impact assessment of climate change on VBDs.
- Researchers, public health managers and policy makers will have a better understanding of the role of climate variability and change on VBDs so as to develop preparedness plans to address the negative impacts.
- Data so generated will form the basis of disease modeling.

4. Review of models developed on impact assessments

The biology of disease vectors and epidemiology of vector-borne diseases have been studied extensively throughout the globe. However, with the emerging threat of climate change, a number of studies have been undertaken using various methods to develop suitable models of their choice. These models are usually not comparable with each other due to different methodologies used, varying climate scenarios and differences in biological requirements for development of parasites and vectors. At present, no single method can be recommended as each approach has advantages limitations. The various models for impact assessment studies are listed in Annexure I and can be grouped into three categories which are reviewed below:

4.1 Biological Models:

Under this approach, data generated under laboratory conditions on the effect of temperature and rainfall/RH on the development of disease pathogen and vector are used to determine the relationship between climatic parameters and biological aspects of disease pathogen and vector. This approach is also termed as process-based modeling. Based on the minimum and upper threshold of required temperature and rainfall/RH, transmission windows (the minimum and upper threshold of temperature, rainfall/RH required for transmission) of disease are generated. Factors affecting vectorial capacity (calculated using daily survival of mosquito vectors, human biting rate, and sporozoite rate, duration of gonotrophic cycle and sporogony) are also taken into consideration for developing transmission model. A comparison between the vectorial capacity of a

vector population in the current scenario (Garrett-Jones, 1969; Dye, 1986) with the projected rise in climate scenario provide an aggregate measure of how climate variability or change can bring about proportional changes in transmission intensity. Such models have the following limitations:

Limitations

- The minimum or maximum thresholds of temperature derived for development of parasite/vector are based on laboratory experiments. Ground conditions may be quite different from laboratory-based findings as the mosquito vectors find micro-niches for their survival and transmission of disease.
- Integration of other determinants of disease like socio-economics, developmental aspects, population growth and intervention measures etc. are not considered in this approach.

Advantages of this approach are:

This approach is more realistic as it elicits the impact of climatic factors on disease incidence as reflected by field conditions and directly corroborated by the monthly fluctuations in disease incidence and geographic distribution. However, it has the following limitations:

Limitations:

- Availability of data on distribution of vector and disease are a prerequisite.
- Quality of the diagnosis of disease, surveillance, data management and resolution of data collecting units may affect the analysis (In India, sub-centre –wise epidemiological data of malaria among population of 5000 in plains and 3000 in hilly forested areas, is available).
- There is no possibility of including other determinants of disease like, intervention measures undertaken, population growth or socio-economic conditions etc.

4.2 Combined biological and statistical models

This approach is a combination of biological and statistical methods including other determinants like population and socio-economic data. The

climatic cut-offs as determined by using laboratory data on vector and parasite survival are validated based on field observations. Overlaying of population data on climate suitability/unsuitability maps can provide an estimate of population at risk during different months of a year. Several models have been developed using a combination or integrated approach for assessing the impact of climate on malaria and dengue (**Annexure I**). The work by Craig et al (1999) using the MARA model (Mapping Malaria Risk in Africa), Tanser et al (2003) further enhancing the scope of MARA, and the MIASMA model (Martens ,1998) are detailed below:

MARA Model*:* Craig et al (1999) described a simple numerical approach to define distribution model of malaria transmission, based upon the relationship between temperature and biological aspects of parasite and vector development (duration of sporogony, percentage of vectors surviving sporogony, daily vector survival and larval duration at different temperatures) and effect of rainfall on transmission. Temperature and rainfall cut-offs between no malaria, epidemic-prone, seasonal malaria (less than six month transmission) and stable malaria were determined based on some selected sites in sub-Saharan Africa. The minimum value of suitability based on temperature and rainfall was calculated using 18^0C temperature as the lower threshold and 32^0C to 40^0C as the upper threshold, and rainfall of 80 mm per month for at least five months in a year for stable malaria. These suitable conditions have to occur for a minimum duration of three months for continuity of transmission. If temperature and rainfall are suitable for less than three months in a year in any area, transmission of malaria cannot be maintained. Such areas are considered 'not suitable'. Areas with 3-6 months of continuous transmission were also placed under unstable malaria category but, areas with 7-12 months of suitability of transmission were placed under stable malaria category. The maps showing climate suitability for malaria transmission using suitability index from 0 to 1 (where 0 means no transmission, and 1 means stable transmission were generated (Figure 1). The MARA LITe tool has developed the facility of getting an information database on time series data points, prevalence of malaria and population at risk up to district level (www.mara.org.za/lite/information.htm).

The model compares well with contemporary field data and historical expert opinion maps with some small-scale anomalies. The model provides a numerical basis for further refinement, and has scope of adding other datasets like population for estimation of population at risk due to the impact of climate change on transmission.

If the current scenarios of temperature and rainfall are replaced with projected ones, the impact of climate change on a spatial and temporal increase in malaria may be assessed.

Advantages

- It does not rely only on laboratory-based thresholds of climatic parameters and avoids using coarse data of disease distribution maps to define the statistical relationship.
- Persons at risk due to climatic factors are known.
- This model has been validated independently in Africa.

Limitations:

- Basically, the effect of temperature on pathogen and vector is derived based on laboratory conditions, which may be different from the field situation.
- Field studies are required for validation of transmission windows and climatic cut- offs in different paradigms.

Using basically MARA model for studying the effect of climate change on malaria transmission in Africa, Tanser et al (2003) estimated an overall potential increase of 16%-28% in person-months by 2100 (Figure 2). The model used Gridded temperature, precipitation, GCM climate scenarios (HadCM3), and population data and produced a spatiotemporally validated model of *P falciparum* transmission using datasets of 3791 parasite surveys.

MIASMA Model: This model is basically a biophysical model which has been used for assessment in malaria, dengue and schistosomiasis globally. This model links GCM-based climate scenarios with an impact module for calculation of transmission potential of malaria vector population and population at risk (Martens, 1998; Martens et al., 1999). In the process of transmission of infectious diseases, basic reproduction rate (R_0) which is closely related with vectorial capacity, is very crucial and can be defined as the average number of secondary infections produced when a single infected individual is introduced into a potential host population in which each member is susceptible. If R_0 is >1, the disease will proliferate indefinitely; if R_0 is <1, the disease will die out. Output from MIASMA malaria model indicates the number of months per year when climate conditions are suitable for falciparum transmission and where there is

competent mosquito vector, months of potential transmission under current climate (1961-1990) and months of potential transmission under a GHG-only climate scenario (HadCM2 ensemble mean) in the 2080s (IPCC, 2001). Inputs required for this model are given in Table 1. (For details please see **Annexure I).**

Table 1: *Main Inputs required for MIASMA Model*

IPCC scenarios	GCM Scenarios	Mosquito population	Human population
• User scenario-Change Temperature • Population	• Monthly projections of temperature and precipitation • Baseline • Projected for 2030/2050/2080	• Parasite development • (P vivax/P falciparum) in mosquito • Minimum temperature • Degree days for pathogen • Mosquito survival probability • Mosquito feeding probability • Transmission potential	• Susceptible • Infected • Immune

For details please refer to CD (**Annexure II**)

Advantages

The limitations of biological and statistical models are overcome by validation through field observations and addition of population data in the format of GCM-based climate scenarios (Leishout et al 2004). A compact disc of this Model is available (**Annexure II)**.

Limitations

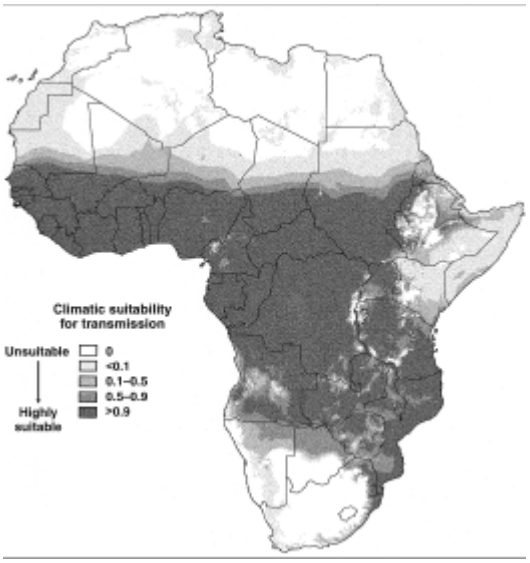
- Climate thresholds for mosquito and parasite effects in the model are defined through laboratory data and only a small number of field studies. This may affect the accuracy of the estimate. It is, therefore, desirable that climatic thresholds of

vector and parasite (s) at different temperatures, rainfall and RH should be determined and verified in different paradigms of disease in the field.

- The role of intervention measures is not included in the assessment.

Figure: 1 Fuzzy model for sub-Saharan Africa, showing the suitability of temperature and rainfall conditions for malaria transmission for any three consecutive months in North Africa and any five consecutive months in the rest of Africa (see text).

Figure 1: *Fuzzy model for Sub-Saharan Africa*

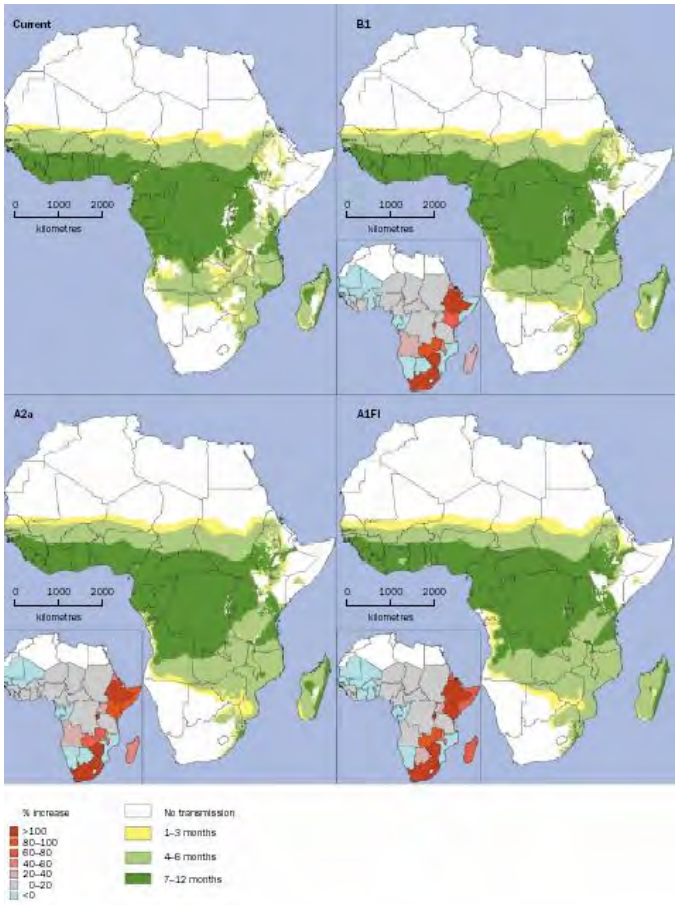


A value of 1 means that conditions in the average year are suitable, hence one could expect to find endemic malaria transmission (seasonal or perennial); a value of 0 means conditions are unsuitable in the average year, hence transmission should be absent or occur in rare epidemic episodes. Fractions from 0 to 1 indicate increasingly suitable climate, hence increased risk of regular transmission (Source: Craig et al 1999).

Figure: 2 Estimated numbers of months suitable for *Plasmodium falciparum* malaria transmission, and change in person-months of exposure by country at present and by 2100 using three HadCM3 scenarios (B1, A2a, and A1FI).

The scenarios project overall potential increases in person-months exposure by 2100 to be 16% (B1), 23% (A2a), and 28% (A1FI), respectively (constant population assumed) (Source: Tanser et al 2003).

Figure 2: *Plasmodium falciparum malaria transmission*



A simple biological model based on suitability of three classes of temperature and RH using IS92a, HadCM2 scenario has been developed in India (Bhattacharya et al 2006) which provides insight only for spatial extension of malaria.

5. Prospective study

To validate the role of meteorological factors in disease occurrence and early evidence of climate change.

Study site and study population:

The study should be undertaken in two paradigms i.e. hilly and urban areas. The ideal study site under in the hilly area should be an area at the fringe of disease transmission where some areas are not endemic due to limitation of climatic conditions. In a district[1], three sites at increasing altitudes should be selected for the prospective study. Three sites at ascending altitude should be identified in a district from Maps of India (www.mapsofindia.com) or from global elevation datasets (http://www.vterrain.org/Elevation/global.html). One sub-centre (having a population of about 3000 in hilly/tribal area or 5000 in the plains) from each level of altitude should be selected for generation of data.

If there is not much difference in altitude within a district, alternately two primary health centres (one with high and the other with low incidence of disease) should be selected. In each PHC, two sub-centres should be selected for generation of entomological and pathogenic data.

Duration of study: Four years (three years for data generation and the fourth year for development of the impact assessment model).

Data collection:

Parasitological data: Schools up to the eighth class (having children below 14 years) in each category of sub-centre should serve as sentinel sites for monitoring of disease incidence. Blood on Whatman filter paper No 3 should be collected from fever cases each month. The level of antibodies against a particular disease may be monitored monthly following ELISA (Roy et al, 1994). In order to cross-check the validity of disease data collected through the surveillance mechanism of the health system, fortnightly data on disease incidence from a population of about 1000 in each sub-centre should be generated by collecting blood slides for microscopic examination in case of malaria or through rapid diagnostic kits for dengue and leishmaniasis etc. This emphasis will be on finding indigenous cases in

infants/children. Formats for recording data on fever survey and compilation by each sub-centre are given in **Annexure III.** If available, the epidemiological data of the past 10-20 years and entomological data on vector density of a particular VBD in respect of three selected sites should be procured from district malaria officer/primary health centre so as to compare the change in vector population and disease distribution.

Entomological data: Fortnightly entomological data on density of adult mosquitoes/vectors in study villages in three categories of sub-centres should be generated following the WHO manual (1975 part II). Five sentinel sites ideal for the resting place of mosquitoes in each village of selected sub-centres should be identified for collection of adult disease vectors for monitoring of man-hour density. The format is given in **Annexure III**.

Meteorological data: Based on the relationship between climatic parameters and VBD incidence, temperature, rainfall and relative humidity (RH) have been found of the most relevance. In a country like India, data on temperature and RH is available usually at district level and that too not for all the districts. However, daily data on rainfall is available at sub-district level also. For the prospective study temperature and RH data loggers should be installed at each sub-centre. The frequency of data collection may be on a **** hour or daily basis. Data can be downloaded at six-monthly intervals so as to compute monthly minimum-maximum temperatures and RH. Data on daily rainfall may be collected by installing a rain gauge in each sub-centre.

A system of generating disease, vector, climatic and non- climatic data may be established for VBD of public health importance as given in Annex IV.

LCD Temperature and Humidity Data Logger

Processing of data

Data on adult insect vectors collected from different sentinel sites as well as villages will be computed to calculate monthly man hour density following the WHO manual (1975, I and II).

Data generated on surveillance of school children will be computed to derive monthly prevalence of disease in the study population. Fortnightly data generated on fever surveys in selected population of 1000 in each sub-centre, will be averaged to monthly. In order to cross-check the data generated by surveillance workers from same-study villages, the discrepancy rate will be derived by cross-checking the blood slides/positivity of collected from sub-centre/PHC.

Daily meteorological data of temperature will be averaged to monthly minimum and maximum, average monthly temperature and monthly RH and rainfall.

Analysis: To establish the role of climatic factors with disease incidence, the relationship between temperature, RH and rainfall will be determined to ascertain the significance of climatic factors in disease incidence.

Monthly data on temperature, RH and rainfall generated for three years will be compared with retrospective data (if available) to find-out-month to month increase in climatic parameters.

Data on antibody level against a particular disease at three sites will reflect the prevalence of a particular VBD vis-a-vis altitude. Monthly positivity of cases of a particular VBD will be compared with earlier records to find evidence of occurrence of cases temporally and spatially. If earlier epidemiological data are not available, comparison should be made between prevalence data generated during the first and third year of study. In case of malaria, results examination of blood slides will reveal the species and stage of parasite, positivity of infants/children below 5 years will elicit the indigenous transmission. The presence of disease in hitherto free areas or temporal extension would provide early evidence of the impact of climate change on disease occurrence.

Monthly entomological data on man-hour density of disease vectors will be compared within three selected sites and between the first and third year of study to find out the role of altitude and climatic parameters. If previous records of density of disease vectors are available it would be worth comparing the same with current density in time and space.

The role of non-climatic factors like socio-economic conditions and developmental activities in the area should also be kept in view to ascertain the attribution of climatic factors in disease transmission and spread.

Assessment of impact of climate change on VBDs in view of projected climate scenario:

With the increased level of awareness about the potential impact of climate change in different sectors, after 1990 a lot of work has been undertaken on vulnerability assessment and adaptation, most of which has been undertaken at the global scale (Jetton and Tekken, 1994; Jetton and Flocks ,1997; Sutherst, 1998; Sutherst et al 1998; Martens ,1998; Patz et al 1998; Martens et al 1999; Kovats et al 2000; Reiter et al 2001;Hales et al 2002; Patz et al 2005; McMichael et al 2006). IPCC and WHO have also documented the work undertaken and methodologies for impact assessments (Mc Michael et al 1996; Kovats et al 2003; IPCC, 2007). In

India also preliminary studies have been undertaken on climate change and malaria (Dhiman et al 2003 and Bhattacharya et al 2006). As the vulnerability depends upon a number of determinants namely the individual behaviour, populations and regions, local environmental conditions, degree of exposure, types of housing and economic conditions and health facilities available, global level assessments are not applicable to country or sub-country level due to lack of relevant information such as population, socio-economics and local coping capacity etc. (A review of the models/tools used by various workers all over the world reveals that components of all the approaches are needed for impact assessment) (Martens, 1998; Chan et al 1999; Craig et al 1999; Martens et al 2002; Tanser et al 2003; Campbell-Lendrum and Woodruff, 2007).

In order to have uniformity, exchange of information and international collaboration, it is prudent to use common generic protocols to assess the impact of climate change on VBDs at multi-country level. Now a days, with the advent of Geographical Information System(GIS), data sets are available in grid format and maps of disease, vector distribution and vulnerability can be generated with little modest infrastructure and training. The requirements of various data sets and step by step generic procedure to conduct the impact assessment are described below:

Unit of study: The study unit for undertaking impact assessment will vary according to availability of data at country level and with respect to objectives. Initially the study should be undertaken at country level. After identification of hotspots of vulnerable areas and depending on the availability of data on disease burden, vector distribution, population and socio-economics in the country, in-depth studies may be undertaken in a district[1] with a population of about 0.5 million.

The data requirement for assessment of impact of climate change is detailed below:

[1]A district is regarded as an administrative sub-division in a province or state in a country. However, this would vary from country to country depending on the size and population. In this context, country-specific sub-divisions should be adhered to.

Biological data

Data on development of parasites/viruses of VBDs in vectors so as to determine minimum required temperature for disease transmission and upper threshold beyond which transmission is not possible. Such data are available in respect of some pathogens/vectors particularly for malaria and dengue (Table 2), but for diseases like leishmaniasis, Japanese encephalitis and filariasis such data should be generated by infecting the vectors through artificial feeding (Adak et al. 2005) under laboratory conditions at different temperatures and determine the lower and upper thresholds of temperature.

Table 2: *Temperature thresholds (^{0}C) for pathogens and vectors of major vector-borne diseases*

Disease	Pathogen	Minimum Temperature	Maximum temperature	Vector	Minimum temperature for vector
Malaria	*Plasmodium falciparum*	16–19	33–39	*Anopheles*	8–10 (biological activity)
	Plasmodium vivax	14.5–15	33–39	*Anopheles*	8–10 (biological activity)
Dengue	Dengue virus	11.9	not known	Aedes	6–10
Chagas disease	*Trypanosoma cruzi*	18	38	Triatomine bugs	2–6 (survival) 20 (biological activity)
Schistosomiasis	Cercaria	14.2	>37	Snails (*Bulinus* and others)	5(biological activity) 25±2(optimum range)
Lyme disease	*Borrelia burdorferi*	Not yet determined	Not yet determined	Ixodes tick	5–8

Source: IPCC, 2001; Max T for vectors is not certain

As there may be more than one vector species of a disease as in malaria, biological data should be generated for major species so as to have species-specific assessment.

Data on the effect of rainfall on vector abundance should be generated in areas where temperature is not limiting for disease transmission (Craig et al 1999). It will be essential for determining the minimum required rainfall for ensuing/continuity of transmission. Determination of the lower and upper limits of RH in disease transmission would also be worth studying.

Countries with laboratories for vector-borne diseases may generate biological data and other inputs on disease vectors and pathogen required for MIASMA model (Table 1). Data on Degree days[2] as determined for *P vivax* and *P falciparum* malaria parasites should be determined for other pathogens. Daily survival probability of vector species following the standard methods (WHO, 1975; Martens, 1997). Man biting rate of vector species may be determined by using human blood index (Beier and Koros, 1991). The number of mosquito vectors biting per man per night may be determined using the WHO standard methods (WHO, 1975). Mosquito feeding probability at different temperatures. Infection rate in different vector species may be determined using analogy from standard technique (Wirtz et al., 1987). To determine susceptible and immune population, data on immunity level of the population in different paradigms, may be generated using well tested immunological tools like Enzyme Linked Immuno Sorbent Assay and Indirect Fluorescence Antibody Test (Roy et al 1994). Epidemic potential of disease pathogen (the critical density of mosquitoes per human: derived from the concept of vectorial capacity; defined in MIASMA Model).

For further details of methodology for generation of above mentioned biological data, WHO manuals (WHO 1975, Part I and II) may be referred.

Baseline and projected climate scenarios:

A large number of climate change experiments using general circulation models (GCM) have been completed in recent years based on the changes in green house gas concentrations, sulphate and aerosol changes. Of various scenarios developed by six modeling teams in different parts of the world, six groups of scenarios are drawn from A1, B1, A2 and B2 families of

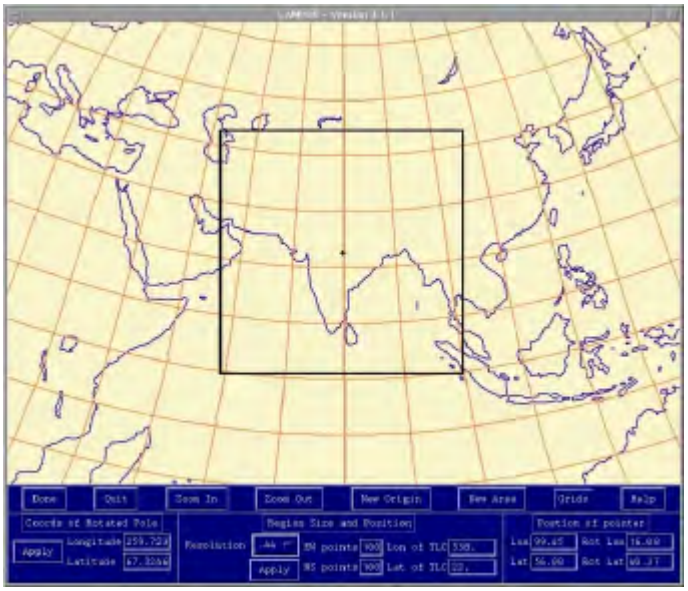
[2]Degree days: Temperature of the day minus 14.5^{0}C for *P.vivax* or 16^{0}C for *P. falciparum.* When the sum of difference on different days will be 104/111, those days will be required to complete one sporogonic cycle (after Moshkovsky and Rashina (1951) and Organov-Rayevsky (1947) as cited in WHO (1975).

scenarios which are A1F1, A1T, A1B, A2, B1 and B2 (IPCC, 2000). These scenarios represent different demographic, social, economic, technological and environmental developments. B1 is the lowest green house emission, A2 is medium and A1F1 is a high emission model. In 1992, there were IS92 scenarios of which IS92a has been widely adopted as the standard scenario for use in impact assessments.

HadCM3 model developed by the Hadley Centre for Climate Prediction and Research, U.K. is widely used globally and has a spatial resolution of 2.5 degree X 3.75 degree (latitude/longitude) with a surface spatial resolution of about 278 x 417 Km. Based on the changes in green house gas emissions, the projections are from 1990 to 2100 with a 30-year interval i.e. 2020, 2050, 2080 and 2100. The baseline climate is a 30-year average computed from 1961 to 1990 (New et al 1999). There is free license for using data for research projects only. The available data formats are GRIB (in Binary format, WMO Standard) and GZIP (compressed ASCII format). ASCII data may be converted into point data using appropriate software.

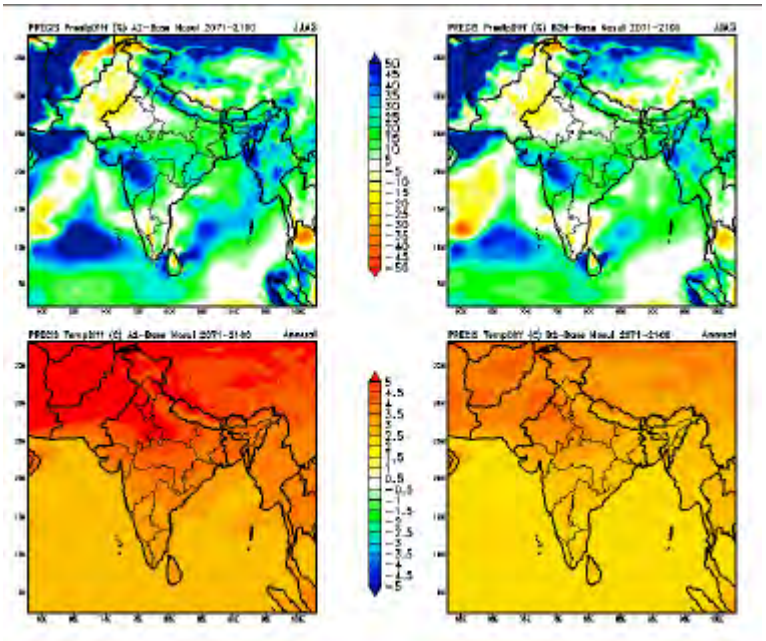
Global models are not useful for impact assessments at regional level for which Regional Climate Models have been developed. PRECIS (Providing Regional Climates for Impact Studies), a Regional Climate Model, basically derived from HadCM3 model for temperature, rainfall and RH etc. at the resolution of 50x50 Km has been developed, for use in climate change impact assessment studies within India and adjoining countries. Baseline and projected scenario of this model are available from IITM, Pune for all South-East Asian countries except DPR Korea, Timor-Leste and parts of Indonesia and Thailand (Figure 3 and 4), the details of which are given in **Annexure V.**

Figure 3. ***Coverage by PRECIS runs at IITM, Pune***



The generic study at multi-country level may be undertaken in different phases depending on the availability of disease burden and vector data in the country, efficiency of the surveillance system for disease and vectors, meteorological infrastructure and the degree of refinement required. A review of the models/tools used by various workers all over the world reveals that components of all the approaches are needed for impact assessment. Now-a-days, with the advent of Geographical Information System(GIS), data sets are available in grid format and maps of disease, vector distribution and vulnerability can be generated with little modest infrastructure and training. The requirements of various data sets and step by step generic procedure to conduct the impact assessment are described below:

Figure 4 ***Projected changes in summer monsoon precipitation and surface air temperature by 2100 under A2 and B2 scenarios of PRECIS model derived from HadCM3.***



(Source: Kumar et al (2006)

Population data: Gridded maps of current population distribution, and projections up to the year 2015, can be obtained at a relatively high resolution, with 0.5 degree latitude and longitude grid cells (approximately 55 km^2) from the Centre for International Earth Science Information Network (CIESIN). Projections of future population size and current demographic structure are also available at national level, either from national census agencies (e.g. in India, projections are available from the Registrar General, with population projections for India and states from 1996 - 2016, http://www.censusindia,gov.in/data_products) or from summaries developed by international agencies, such as the UN Population Division, World Population Projects Database http://esa.un.org/unpp/. Population projections will decrease in reliability if the area of grid cells and length of time from the present increases. Depending on the study boundaries, population data may be available for city areas or sub-national geographical regions.

Socio-economic scenarios: This information, along with climate scenarios is important for characterizing the vulnerability and adaptive capacity of social and economic systems in relation to climate change in different regions. A section of the Data Distribution Centre of IPCC provides access to baseline and projected scenario data related to population, economic development, technology and natural resources for use in climate impact assessments (www.ipcc.data.org./social.com.data and http://sedac.cesin.columbia.edu/ddc/sres/index/html). Socio-economic data from IPCC Data Distribution Centre are available for two emissions scenarios i.e. the IS92 and SRES scenarios, prepared for the IPCC second and third Assessment Reports respectively describing the current scenario and projections up to 2100. The data available from IPCC are at coarse resolution. For country or sub-country level impact assessment, datasets at higher resolution will have to be accessed. Downscaling of data to finer resolution has been described by Gaffin et al (2003). However, use of socio-economic projections beyond 30 years is not desirable in impact assessments owing to rapid changes in developmental activities.

Though it is difficult to integrate socio-economic data with available models (Leishout et al 2004), these may be used for planning preparedness in the vulnerable areas (Tol and Daulatabadi, 2001; Arnell et al 2004).

Steps for conducting a generic study: After the data sets have been accessed, an assessment of the impact of climate change on vector-borne diseases can be made using the generic steps described below:

Step 1 Determination of climatic cut-offs for disease transmission
Ideal sites representing perennial transmission, seasonal transmission, epidemic-prone and 'no transmission' in the country should be selected to analyse retrospective epidemiological data of disease, temperature and rainfall so as to determine the limits of temperature and rainfall for perennial, seasonal, epidemic-prone and no transmission areas (cut-off limit). Craig et al. (1999) determined climatic cut-offs of temperature and rainfall for malaria transmission in Africa as follows:

- In areas where rainfall is high all year a constant temperature of 22^0 C is sufficient for perennial transmission while 18^0 C all year is too cold but epidemic prone but with 15^0 C no transmission occurs.
- Areas with seven months temperature of above 22^0C allow seasonal transmission while six months above 18^0 C does not.
- Five months above 80 mm rain is sufficient but five months rain above 60 mm is not.

- Rain above 80mm for one month is not sufficient for a transmission season but rain for three months above 80 mm is.

The climatic cut-offs for different VBDs may be determined based on epidemiological data of disease incidence, temperature and rainfall.

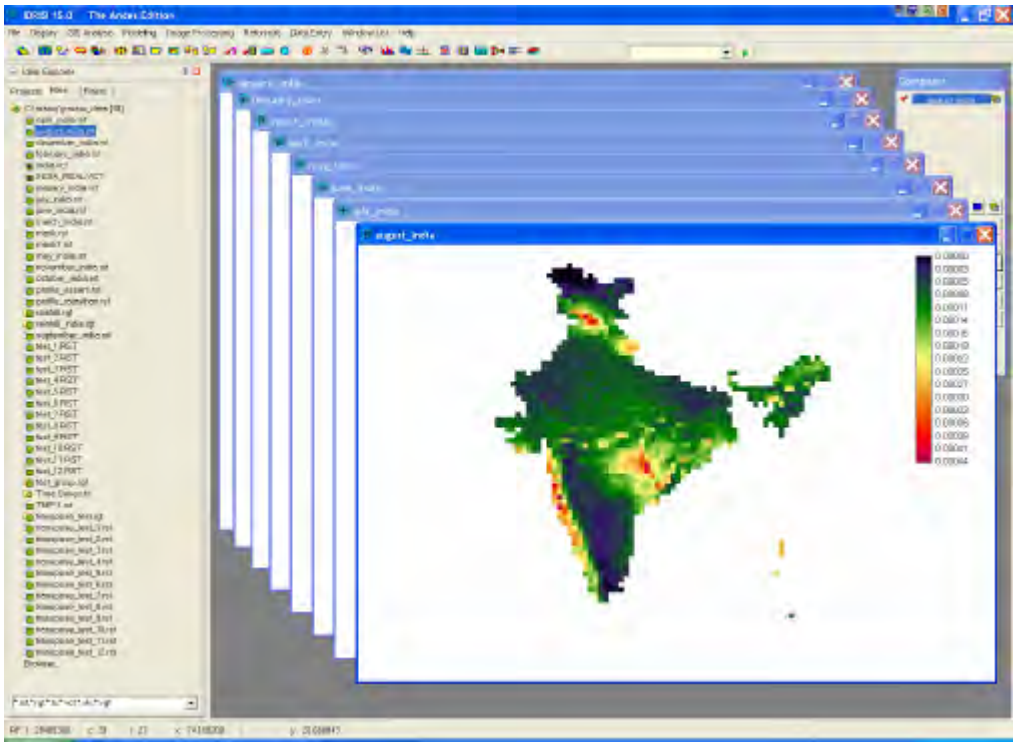
Step 2: **Identification of transmission windows of disease:** Monthly gridded data of A2 (high emission) and B2 (low emission) scenarios of PRECIS model on temperature and rainfall for the baseline years (1961-1990) are imported into GIS format (Figure 5). For *P vivax* the lower limit of required temperature is 16^0C while for *P falciparum* it *is* 18^0C. Therefore, 19^0C is taken as the minimum temperature required for development of both the parasites in the mosquito vector. The upper limit should be taken as 33^0C as the maximum limit of development of *P vivax* and *P falciparum* is 33^0-39^0C (Table 2)) and there is high mortality in vectors from 32^0-40^0C (Craig et al 1999). The threshold of rainfall determined in African conditions (80 mm per month for at least five months in stable malarious area) may not be suitable outside Africa. Therefore, the cut-off of rainfall should be determined by selecting the site from perennial, seasonal, epidemic-prone and 'no transmission' areas where temperature is not a limiting factor. The criteria for determining transmission windows (TW) for malaria are given in Table 3. Monthly temperature and rainfall grids are overlaid using GIS software. Keeping in view the lower and upper limits of required temperature and rainfall, TWs are determined grid-by-grid for every month. In view of the relapse phenomenon in *P vivax* parasite, it is better to give emphasis on assessing the impact on *P falciparum*. Grid cells fulfilling the minimum required climatic conditions for transmission for a particular VBD are identified. Based on the TWs in different months, current spatial and temporal suitability maps of transmission of disease can be prepared (Figures 1 and 2). For example in malaria, if TWs are not suitable for a continuous three months in a grid, such grids are identified as 'no transmission', TWs suitable for 3-6 months as seasonal and 7-12 months suitability as stable malarious as devised by Craig et al (1999).

Table: 3 ***Criteria used for determining transmission windows of malaria***

Meteorological parameter	Minimum threshold
Minimum temperature required for development of parasite and vector survival	19^0 C (for both *P falciparum* and *P vivax*); $>33^0$ C for upper limit
Average rainfall in a month for creating source for vector breeding	=40 mm*

* 80 mm rainfall has been considered optimum in studies undertaken in Africa (Tanser et al 2003). However, it needs to be determined for countries in the SEA Region. In Bikaner (India), malaria outbreak occurred with =40 mm rainfall in two consecutive months at the threshold of transmission season.

Figure 5 ***Monthly rainfall data files from PRECIS model in GIS format***



Step 3: Validation of TWs: The identification of TWs based on temperature and rainfall may not be realistic in field conditions as disease vectors find micro-niches for their resting places. In Rajasthan (India), indigenous transmission of malaria was found to occur in May when temperature is unsuitable for transmission (Batra et al 1999). Therefore, TWs determined from biological data should be verified in field conditions by parasitological surveys for finding the evidence of indigenous transmission and entomological survey for any shift in resting habitats of disease vectors in the particular month which defy the logic of minimum/maximum required conditions for transmission. After validation of TWs, current spatial and temporal suitability maps of disease transmission may be generated (Figures 5 and 6).

Step 4: TWs under projected climate scenario: By replacing the baseline temperature and rainfall by the projected scenarios (PRECIS model

scenarios derived from HadCM3 model) the TWs under climate change may be identified. A2 and B2 scenarios may be used for the years 2080 and 2100. The difference in opening of TWs in hitherto transmission-free areas and increase/decrease in months suitable for disease transmission in already endemic areas will determine the spatial and temporal change in disease distribution under the climate change scenario.

Step 5: Estimating population at risk in current and projected climate change: Overlaying of monthly current and projected population data on the grid cells of TWs under current and projected scenarios will provide the population at risk per month. As the population of all the 12 months will remain the same, person per month at risk of disease may be determined (Tanser et al 2003). The difference in population at risk under current and projected climate scenarios will elicit the additional population at risk of disease due to climate change.

Step 6: Identification of negative impacts of climate change: Extension in spatial or temporal distribution of any disease due to projected climate scenario in areas hitherto free from that particular disease will indicate the new areas coming in the fold of transmission. The increase in the number of suitable months of transmission will indicate an increase in the intensity of transmission which may be from seasonal to perennial. Any increase in population at risk will quantify the additional population at risk in particular months.

A generic framework for assessing the impact of climate change on vector-borne diseases using the PRECIS model of climate scenario, biological attributes of parasites and vectors and population data has been prepared (Fig. 6).

Impact assessment on dengue and other VBDs: Depending on the national priority, each country should prioritize diseases for impact assessment. The methodology for assessing the impact of climate change in other VBDs should essentially remain similar to mosquito vector borne diseases with minor modifications. Dengue and leishmaniasis are the other VBDs in the South-east Asia which deserve impact assessment. The impact of climatic parameters on pathogen and vectors has not been studied in detail as in malaria. However, biological (Jetten and focks 1997) and statistical models (Hales et al 2002) have been developed for dengue. There is a need to generate data from field sites for validation of biological models. The relationship between temperature, rainfall and RH has to be established in a multicentric mode and the impact on indicators like house index, container index and Breteau index for breeding of Aedes mosquito may be established.

In leishmaniasis also, data on the minimum and maximum limits of temperature for parasite development in the sand-fly vector and gonotrophic cycle and vector survival are limited. With the generation of more data on distribution of leishmaniasis vis-a-vis temperature, rainfall and RH, distribution maps of the disease may be developed under the current climate scenario.

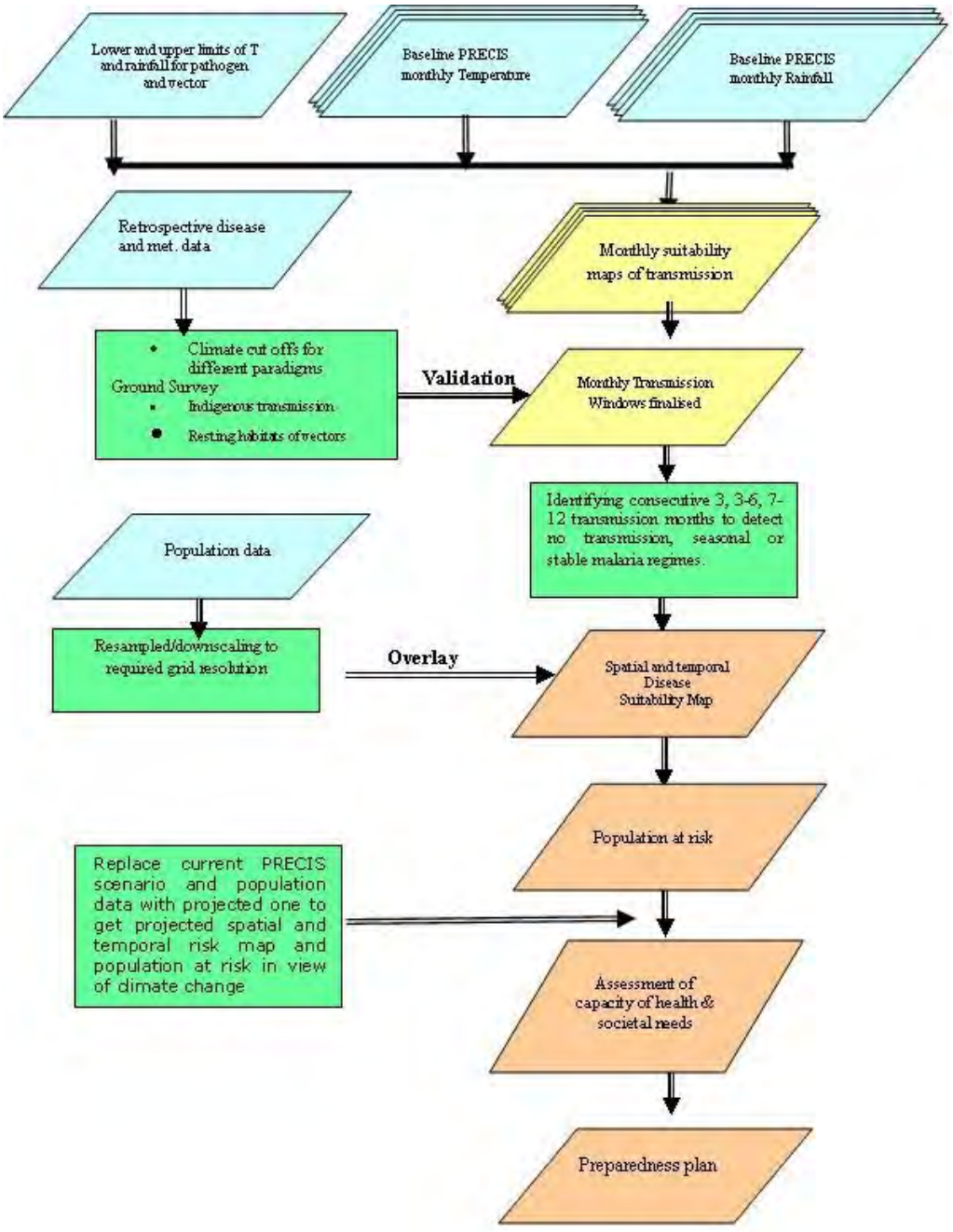
Depending on the availability of data as required for malaria modeling, impact assessments for other VBDs may be made by replacing the lower limits of temperature, rainfall/RH for pathogen and vector in the generic framework. By replacing the current scenario with projected ones, spatial or temporal change due to climate change can be determined.

The way ahead: Almost all the models developed so far are at global level and have the following limitations of non-incorporation of non-climatic factors like socio-economic conditions, land use changes, intervention methods used and development of resistance in vectors and parasites. There is no scope of consideration of immunity due to projected increase in transmission.

A data base for reliable epidemiological, meteorological and biological data should be established. If countries are able to generate biological data as per requirement of MIASMA Model, use of MIASMA model for malaria and dengue would be worth attempting. Independent validation of the models should be a continuous process for refinement of assessments.

Monitoring of land use features particularly vegetation cover and water bodies related with disease endemicity is also an important data set for assessing increased/decreased risk of vector-borne diseases. For example, in Orissa (India), there are two vectors of malaria i.e. a*n. culicifacies* in riverine plain areas and *An. fluviatilis* in foothills and forested areas (Nanda et al 2000). With the projected climate change, the vector in foothills and forested areas may find microclimate and therefore, may not be affected as compared to *An. culicifcaies.* Therefore, for in-depth assessment at district level it would be worth while to generate data on temperature and rainfall at multilocations for determining TWs at finer resolutions. Overlaying maps of land use features generated through satellite images (Dhiman et al 2007) with appropriate resolution on projected TWs would help in identifying the microclimatic conditions in limited foci. The work undertaken by Matola et al (1987) in Tanzania is worth referring to.

Figure 6: ***Generic framework for assessment of impact of climate change on vector-borne diseases***



In view of lacunae in existing models, framework for realistic estimation of future burden of vector-borne diseases following integrated assessment modeling has been proposed by Chan et al (1999) and Martens et al (2002).

Socio-economic changes have been found equally or more important than climate change for some factors (Holman et al 2005), therefore, the effect of changing socio-economic conditions on the impact of climate change should also be studied on the lines of Berkhout et al (2002) and Arnell et al (2004) which will be possible with the availability of finer resolution data at national and state levels compatible with regional climate models.

6. Budget (tentative)

Budget Item	Year 1 US$	Year 2 US$	Year 3 US$	Year 4 US$	Total US$
17.1 Personnel*					
(A) Professional Scientific Staff (Salary As Per Country Norms) (B) Technical (C) Other Staff					
17.2 [1]Equipment					
(A) Major	40499	-	-	-	40499
(B) Minor	4055	-	-	-	4055
Operational Expenses					
(A) Laboratory/ Office Expenses	15500	14000	12500	12500	54500
(B) Clinical Expenses	3000	3000	1000	1000	8000
(C) Field Expenses	9500	27500	23850	-	60850
(D) Data Analysis	-	520	1040	1040	2600
(E) Training	7000				7000
Others (miscellaneous 10% of total)					
Grand **Total**					

- *Scientific and technical personnel(full time research scientist, project associate, lab technician, data entry operator, field worker, driver, lab assistant, field lab attendant)
- [1] Equipment: Environmental chamber ,ELISA reader,ArcInfo GIS software, statistical package, desktop computer, laptop, Temperature/RH Hobo-4,

multichannel pipette -2 sets, pipettement-5 sets, artifical blood feeding apparatus, holding cages for insects and dawn and dusk machine for insecatry).

This is essential for major equipment and individual items of operational expenses costing more than US$ 500

Sub-title	Amount (USD)	Budget Justification
Item requested		
Major Equipments	40499	Major equipment The environmental chamber requested under this head is essential for undertaking laboratory experiments to determine the temperature thresholds of pathogen and vector development. GIS software is essential for handling different data sets, overlaying, analysis and generation of maps. An ELISA reader would be required for confirmation of infected vectors with pathogens and detection of antigen in vector species for providing evidence of indigenous transmission of disease in field conditions. Statistical package will be required for data analysis for establishing climate –disease relationship, laboratory-based experiments and KABP study. Desktop computer and laptop computers would be a basic facility for handling data related with the project independently even in field conditions. The equipment available with the host institute can not be spared.
Minor equipments	4055	Minor equipment costing $ 4055 will be required for routine laboratory activities.

Sub-title	Amount (USD)	Budget Justification
Staff (scientific, technical and others)	Salary as per country norms	Professional scientific staff like one research scientist and one project associate have been requested for the project as the project involves laboratory experiments, field work, handling of data sets and analysis on GIS software. As the work demands high scientific skill, the scientific staff requested is fully justified. Technical staff requested for the project are the bare minimum for the maintenance of the entomological and parasitological laboratory, and field work.
Operational expenses (Lab/office)	42000	Laboratory operational expenses for chemicals, glassware, and other consumables like lancets, stains, microslides for parasitological lab., cages, maintenance of insectary, animal facility for feeding of insects for experimental use etc. will be required for undertaking lab work. Carrying out parasitological and entomological surveys would also entail operational expenses. For office use, stationery like A4 size paper, photographic paper, cartridges for computers, printers and GIS outputs etc. will be required. The expenditure of 42,000 $ is fully justified. Information retrieval will be an important component of the project for procuring epidemiological data, meteorological data, photocopying of old data from libraries, honorarium to concerned persons etc, therefore, an amount of US $ 4500 has been asked

Sub-title	Amount (USD)	Budget Justification
		for under this head.
Operational expenses (Clinical)	7000	During field work, rapid diagnostic kits would be required for immediate confirmation of diagnosis of malaria, dengue and leishmaniasis, cost of drugs, over-time payment to persons involved. An expenditure of US $ 7000 is justified.
Operational expenses (field work)	60850	The project involves field work for determining climatic cut-offs of temperature and rainfall, validation of transmission windows through field surveys and generation of data on assessment of capacity of the health system and society through field work requiring field visits @ 10 days per month for two years. Therefore, hiring of vehicle and payment of petrol, travel allowance for investigators, subsistence allowance and means of communication to the staff would involve an expenditure of US$ 60850, which is justified.
Data analysis	1560	The project involves generation of lab and field data for establishing climate-disease relationship, analysis on GIS and SPSS softwares. The work may demand consultation of experts for data analysis for which an expenditure of 1560 $ has been earmarked.
Miscellaneous expenses (10% of the total budget)	Will be decided after finalizing budget	Provision of miscellaneous expenses to meet escalation in budget (5% of the total budget) and for meeting any unforeseen expenses (5% of the total budget) has been made.

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Annex 1

Models used for assessing impact of climate change on vector-borne diseases

Model Name	Approach	Disease	Reference
Biological	Temperature effects on parasite and vector	Malaria	Garrett-Jones (1964); Martens et al. (1995)
Empirical/ statistical	Distribution of disease and climatic parameters	Malaria	Rogers and Randolph (2000)
MARA (Mapping Risk of Malaria in Africa)	Combination of biological and statistical approach	Malaria	Craig et al. (1999)
Spatiotemporally validated model(basically MARA model with additional inputs)	GCM-based scenarios, biological attributes of parasite vector and population data	Malaria	Tanser et al. (2003)
MIASMA (Modeling Framework for the Health Impact Assessment of Man-Induced Atmospheric Changes)	GCM-based climate models, biological attributes of parasite vector and population data	Malaria, dengue and schistosomiasis	Martens, et al. 1997; Martens (1998)
CLIMEX	Distribution, abundance, and phenology of the malaria mosquito	Vector-borne disease risk (malaria)	Sutherst et al. (2004)
CIMSiM and DENSiM	Weather and habitat-driven entomological dynamic simulation model	Dengue	Focks et al. (1995)

Annex 2

MIASMA (modeling framework for the health impact assessment of man-induced atmospheric changes)

MIASMA is a Windows-based application that models several health impacts of global atmospheric change and includes simulation for several modules including vector-borne diseases, including malaria, dengue fever, and schistosomiasis and other human health aspects. The models are driven by population and climate/atmospheric scenarios, applied across baseline data on disease incidence, prevalence and climate conditions etc.

MIASMA can be used to link GCM output of climate change or scenarios of stratospheric ozone depletion to any of the human health outcomes mentioned above. Applicability of this model is limited only by the scope of available data.

Scope Health; regional and global analysis.

Key output for vector-borne disease modules: cases and fatalities from malaria, and incident cases for dengue fever and schistosomiasis.

Key input, Climate input is module or disease specific. For thermal stress, maximum and minimum temperatures are required. For skin cancer, the column loss of the stratospheric ozone over the site is required to determine the level of UV-B radiation potentially reaching the ground. Requires maximum and minimum temperature and rainfall. Vector-borne diseases also require other baseline data, determinable by local experts. For example, for malaria it would help to know the level of partial immunity in the human population and the extent of drug resistant malaria in the region.

Ease of use, after a short training, developing computer simulations should not be difficult.

Training required, requires familiarity with computer modeling; some mathematical skills may be beneficial.

Training Available: Dr Pim Martens (see contacts below).

Computer requirements: Pentium PC, 16 MB RAM, Windows 95 or NT4 or higher. For hard drive installation: 20 MB free disk space. A monitor resolution of 1074 x 768 is recommended. To view the documentation and help files, either Netscape Navigator (version 4 or higher) or Microsoft Internet Explorer (version 4 or higher) is recommended.

Documentation Martens, P. 1998. *Health and Climate Change: Modeling the Impacts of Global Warming and Ozone Depletion*. Earthscan Publications, London.

Dr. Pim Martens, e-mail: p.martens@icis.unimaas.nl.

Cost Low cost (price of shipping CD-ROM and documentation).

Adapted from**: http://unfccc.int/files/adaptation/methodologies_for/vulnerability_and_adaptation**

Annex 3

Format for recording information of fever survey in malaria

Name of Village----------PHC----------District----------

Name of person	Father/husband's name	Age & sex	History of fever	Drugs taken	Positivity PV/Pf/Mix

Format of monthly compilation of fever survey data generated at Sub centre

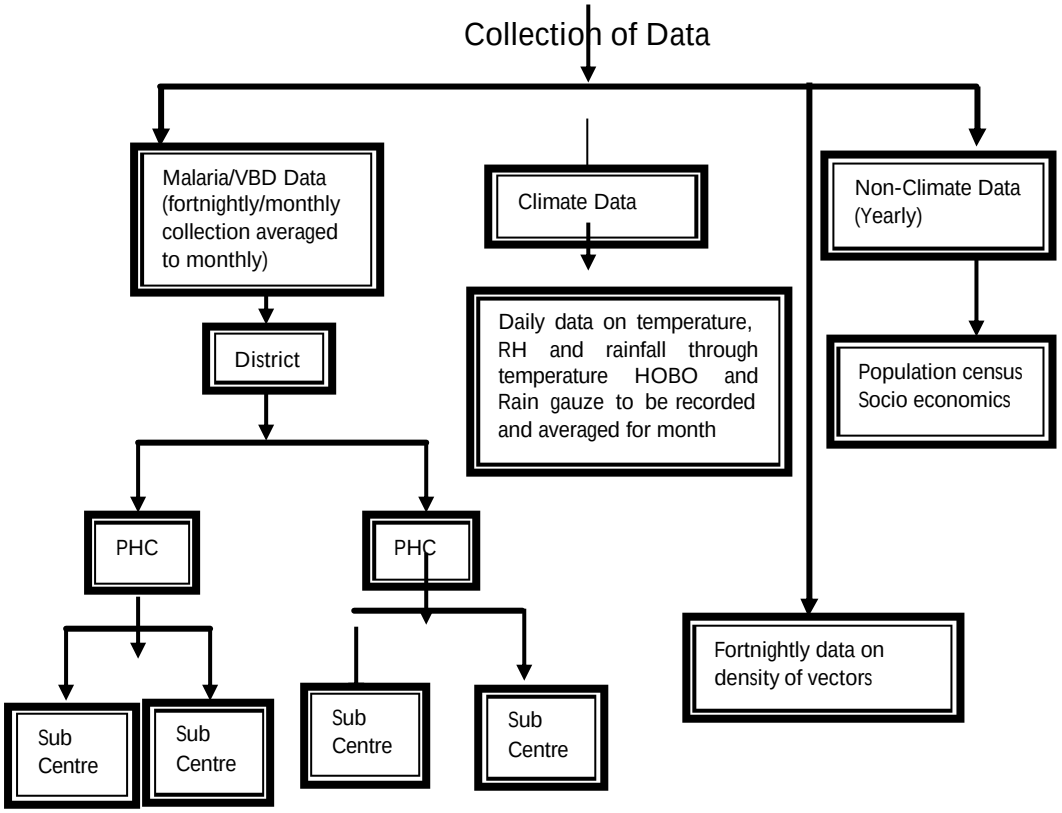
Name of sub centre	Population	Blood slides collected	Positive				Age –wise Break up of positive cases(years)				
			Pv	Pf	Mix	Total	<1	2-5	6-14	15-24	25+

Format of recording fortnightly data on Man-Hour-Density of vector species

Vector Species	No. Collected from									Time spent (hour)	Man-hour density
	Cattle shed			Human dwelling			Mixed dwelling				
	Unfed	Fed	Gravid	Unfed	Fed	Gravid	Unfed	Fed	Gravid		

Annex 4

System for generation of parasitological, climatic and non- climatic data



Annex 5

Regional climate model PRECIS (Providing Regional Climate for Impact Studies)

The regional Climate model PRECIS (Providing Regional Climate for Impact Studies) developed by the Hadley Centre for Climate Prediction and Research, U.K. has been used to generate the high resolution Climate Change scenarios for the Indian region towards the end of present century (2071-2100) (Kumar et al. 2006). The model simulations were carried out at the Indian Institute of Tropical Meteorology (IITM), Pune with the horizontal resolution of 50 km x 50 km for the South Asian domain (0-40 ^{0}N and 56^0 -100^{0}E) which includes India, Bhutan, Nepal, Bangladesh and Sri Lanka etc. (Fig 3). These future projections are made using IPCC-SRES A2/B2 GHG emission scenarios for a future time slice of 2071-2100 with the baseline corresponding to 1961-1990. Currently efforts are on at IITM to generate climate scenarios for the period 1961-2100 using IPCC SRES A1B GHG emission scenarios While formulating policy initiatives for adaptation or mitigation of climate change, the projected changes should be used as some plausible future rather than viewing them as things certain to happen.

Many diseases related to environmental factors have recently emerged worldwide and are of serious concern. To find early evidence of impact of climate change on vector-borne disease required studies. The outcome of retrospective studies elicits some climatic factors associated with increased incidence of vector-borne diseases. Validation of identified indicators is necessary to ascertain their role in disease transmission. Prospective studies may help for developing preparedness plan to address the negative impacts. The various models for impact assessment studies can be considered the countries to assess the scenarios.

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