blossom period. Considering the economic impact of poor pollination of commercial crops like mango, the technology developed is a step forward in the direction of augmenting pollinator populations and enhancing the fruit set in farmers' fields. Since mango orchards are located away from human habitats and are subjected to pesticide sprayings during post-flowering period, the probability of released flies posing health problems could be ruled out. However, follow-up studies after release need to be conducted before continuing the releases in the next cropping season. Other crops of its use include vegetables under protected conditions where pollination is a limiting factor. Producing sterile adults through irradiation of pupae is an option in the future to avoid further breeding of the released flies. This technology also has applicability in medical as well as forensic research where laboratory rearing of *C. megacephala* is involved.

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Prevention of malaria through forecast-based precision vector sanitation and exposure advisory: a conceptual and feasibility analysis

Response to outbreaks of malaria is still mostly reactive, based on general schedule or post-outbreak decision. However, abundance of mosquito vector that leads to outbreaks of malaria can vary significantly depending upon the environmental conditions, making a general schedule less effective. Further, exposure of the [incidental] human host to bites also determines the intensity of the epidemic. Identification of potential sites and time of vector genesis can, therefore, enable proactive vector sanitation and reduction of encounters between mosquito and human through exposure advisories. Validated quantitative relations between weather variables and malaria vector, along with recent advances in meteorological monitoring and mesoscale weather forecasting, integrating other critical components like GIS and communication now make such a platform feasible. Such an approach and methodology would lead to a paradigm shift through ensuring wellness rather than treatment; the applicability of the approach to some other diseases is discussed.

Malaria still presents a major health risk and a considerable burden to the healthcare system worldwide[1,2], with greater challenge for areas remote from healthcare infrastructure[3]. The challenges are getting bigger due to enhanced resistance of many mosquito species[3–5]. A shift of paradigm from treatment to ensuring wellness through proactive vector sanitation and exposure advisory is possible through an integration of recent developments in modelling, weather forecasting and communication technologies. The dependence of malaria vector on weather variables has been known for a long time[4–7]. Several studies have demonstrated the conceptual basis for and the feasibility of estimating malaria vector load based on weather variables[8–10]. The first part of the proposed methodology is to use very high resolution (<1 km) forecasts of variables like temperature, humidity and rainfall at daily or shorter timescales and combine them with weather-based vector genesis model to identify potential areas of vector genesis to enable proactive vector sanitation. Severity of malaria also depends on the number of bites and thus host–vector encounter. The second aspect of proactive mitigation is to reduce the host–vector encounter cross-sections through exposure advisories, ensuring avoidance rather than medication after manifestation. This can be achieved using forecasts of vector genesis coupled with data on local lifestyle and land use with GIS and modern communication tools. Such a procedure can ensure wellness and considerably reduce the burden on the healthcare system.

There have been studies on the potential applications of seasonal prediction of disease risk with climate models[11]; however, such forecasts cannot enable precision action in terms of time and space. A typical seasonal prediction would represent fields averaged over many hundreds of square kilometres, averaged over time. However, vector controls are effective only if they are carried out at the time of maximum exposure rather than at the time of detection of infection. It has been emphasized that the malaria vector depends on daily variables of the weather variables and the micro-climate of a region[12–14]. It is also necessary that the genesis locations and onset of malaria vector, and hence of the weather variables are at sufficiently high spatio-temporal resolution to be effective for application in disease control[15]. One of the challenges is thus to generate such forecasts with acceptable uncertainties. However, while meteorological forecasts still have large errors, and may not be of sufficient accuracy for certain applications, they can be effectively used for forecasting vector genesis, allowing targeted campaign for vector sanitation at specific locations. More importantly, because vector genesis depends on a range of a weather variable (like temperature), the forecasts even with their unavoidable errors have applicability for such cases. Similarly, although malaria depends on the local characteristics and land use[16], it is possible to incorporate these features in high-resolution forecast configurations.

Several works have shown the potential of weather-driven models of mosquito genesis[8–10]. It has been shown, for example, that malaria over Arunachal Pradesh, a region endemic to the disease, can be well simulated for each of the 12 districts with an epidemiology model combining weather-driven vector genesis, exposure and transmission[10]. Although no single weather variable like temperature can reproduce the observed epidemiology, a combination of temperature, rainfall and humidity in the model provides an accurate description. Similarly, atmospheric mesoscale models can now generate forecasts at horizontal resolution of a few hundred metres or less; there has been significant improvement in skill due to incorporation of processes and techniques like model configuration[17], data assimilation[18] and debiasing[19]. While a forecast model needs calibration and validation over a specific region, the basic algorithm is easily applicable to any region. For a given geographical region, the parameters can be recalibrated periodically. Such

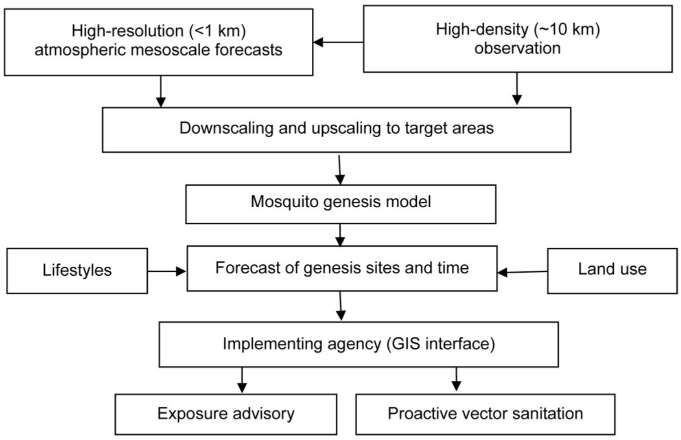

Figure 1. Schematic diagram of forecast platform for exposure advisory and proactive vector sanitation for malaria prevention.

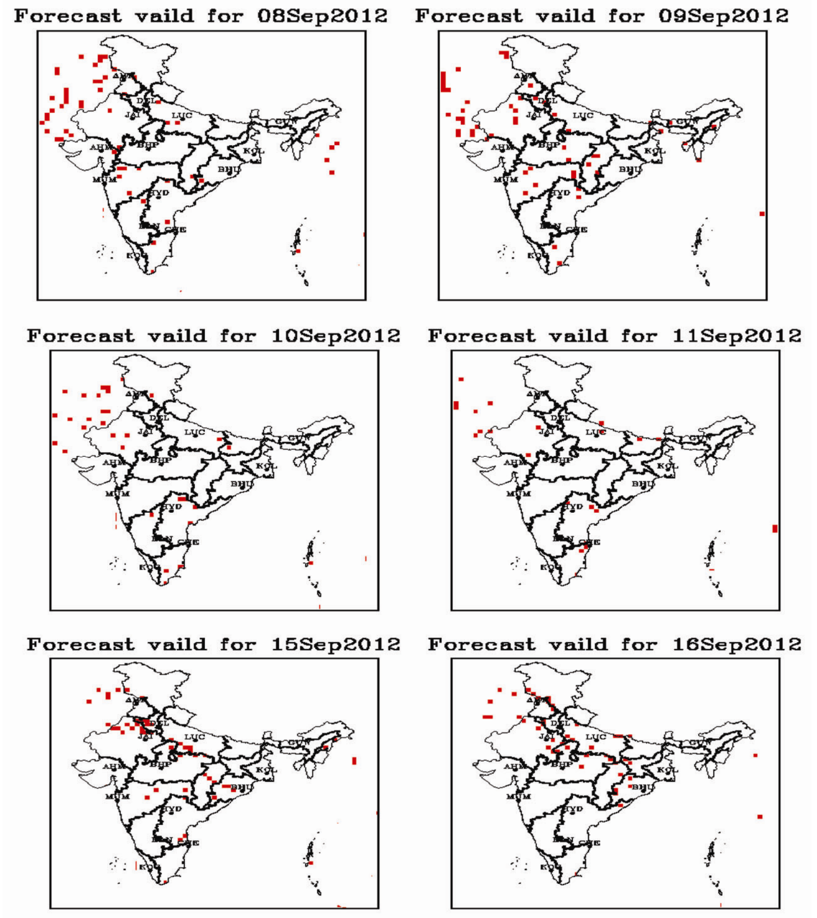

Figure 2. Distribution of mosquito genesis sites averaged over one year over based on mesoscale forecasts. Spatial distribution of potential mosquito genesis over India during 8–16 September 2012 based on vector genesis model driven by mesoscale weather forecasts. The forecasts show potential vector genesis over areas known to be endemic to malaria, with appreciable day to day variability.

forecasts, along with data on local land use and habitat such as through GIS, can be integrated for proactive vector sanitation and the issue of exposure advisories.

The main components of such a forecast platform are schematically presented in Figure 1; all these components are now available and well tested. The challenge is more on integration of all the relevant components, followed by necessary optimization and calibration and validation for a given region. As a preliminary proof of concept, we carried out simulation of genesis over India for a few days spread over a period using an optimized mesoscale model[17–19] and a model of vector genesis[10]; the simulations showed consistent and significant day-to-day variability, with peaks over some of the expected locations; samples of such forecasts for different days of September 2012 are shown in Figure 2. While these results do not represent a strict validation, they show the basic capability.

Such a platform is implementable with current technology, with the important components tested and calibrated for a given region. For example, the first requirement, a vector genesis model driven by weather variables, has been developed, calibrated and validated for a given region[10]. A primary requirement is monitoring of the parameters for genesis at sufficiently high spatial and temporal resolution, followed by validated high-resolution forecasts. An important aspect is the dissemination of information, and ensuring acceptability among the end-users, not necessarily conversant with the concepts and the techniques, through appropriate communication tools. Another challenge is the outreach of the mitigation measures to people living in remote areas away from adequate medical facilities; thus integration of modern information and communication technologies is necessary for effective advisories.

In terms of actual implementation, a forecasting agency can generate locations and timing of vector abundance using high-density monitoring and high-resolution forecasts of weather variables. Vector sanitation programmes as well as exposure advisories based on these data can be generated at the required intervals and communicated to implementing agencies like the Public Health Centres for proactive vector sanitation of the susceptible areas with risk (closeness to human habitats). The dissemination of the advisories can be through various communication channels in local language. As an additional benefit accumulation of such sustained monitoring and forecasting over a long period at daily scale will provide more reliable estimates of impact of regional climate change on malaria[20]. At the same time, such a programme can provide enhanced preparedness in the case of increase in malaria due to factors like climate change[21] and resistance to insecticides[22] over some regions. At the same time, quantitative delineation of the impacts of increasing human population on exposure and change in climate on mosquito genesis that have been carried out over India can help in better policy planning for malaria control.

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