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Burden of disease and climate interactions: An illustrative study of Surat City, India

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Working Paper 373

Burden of Disease and Climate Interactions: An Illustrative Study of Surat City, India

Amrita Goldar

Meenu Tewari

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April 2019



INDIAN COUNCIL FOR RESEARCH ON INTERNATIONAL ECONOMIC RELATIONS

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Abstract

The rising burden of disease counts as one of the most salient concerns of a warming climate. These risks are especially serious in populous, rapidly growing urban landscapes of low-income, tropical countries. Surat, located on the banks of the River Tapi, has temperature and humidity patterns that can be climatologically described as ideal mosquitogenic conditions. Its flat terrain, long history of riverine flooding, and routine water logging during monsoons makes it especially prone to endemic vector borne diseases and morbidity during the peak rainy season. In the past, a large share of malarial cases within India, and Gujarat state in particular, were reported from Surat. In recent times however, government interventions with respect to the introduction of numerous public health initiatives has led to a plateauing of the number of cases reported. This deceleration in cases reported has occurred despite an increase in population over time and expansion of city limits in 2006.

Climate change induced probable increases in temperatures and rainfall would arguably add to the aggregate malarial risk within the city. This paper attempts to develop an urban climate impact assessment model with a focus on public health. Using past data on disease cases, climate trajectories (temperature, precipitation) malarial risk is projected. This health risk is then monetized to help establish the burden of malaria to be faced by the city from an economic point of view. If viewed from a different angle, this estimated monetized value of health risk is also the disease burden that could be avoided due to possible health interventions (adaptation strategies). To compare against these, health intervention costs of a public programme undertaken by the government and households at a micro disease-treatment level is undertaken as an illustrative example of how the costs of prevention may compare to the benefits of prevented disease to assess the economic benefits of adaptation. We find that in a conservative estimate, against an investment of Rs. 8 million in programme and prevention costs, Surat saved Rs. 11.1 million in economic costs (loss of work-days, reduced income and productivity, and treatment costs, suggesting that there is an immediate economic case for adaptation in the face of a warming climate.

Key words: *Public Health, Climate Governance, Economic Modelling*

JEL classification: *I18, C53, Q54*

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Burden of Disease and Climate Interactions: An Illustrative Study of Surat City, India¹

Amrita Goldar,² Meenu Tewari³ and Flavy Sen⁴

1. Introduction

Malaria is a leading source of morbidity and mortality in India. An estimated 1.5 million confirmed cases are reported annually by the National Vector Borne Disease Control Programme (NVBDCP), and more than two-thirds of the Indian population lives in malaria-prone zones, with the highest number of cases reported from the states of Orissa, Gujarat, Jharkhand, West Bengal, North Eastern States, Chhattisgarh, and Madhya Pradesh (Kumar, et al., 2007; Sarika and Chugh, 2011).⁵

Malaria is curable if effective treatment is started early. Delay in treatment may lead to serious consequences including death. Prompt and effective treatment is also important for controlling the transmission of malaria. Estimates show that out of 4.2 million disability adjusted life years lost due to vector borne diseases, malaria alone accounts for an estimated 1.85 million years of loss per annum in India (Peters, 2001; Kumar, et al., 2007; Sarika and Chugh, 2011). The groups most vulnerable to risk of death due to malaria are children under five years of age, pregnant women and those with compromised immunity (Sarika and Chugh, 2011). However the largest risk of mobility and economic loss due to ill health and lost wages is often borne by low income communities, migrants and others living in flood prone areas inadequately served by basic sewerage and solid waste management services. This paper contributes to the available literature on climate adaptation and vector borne disease by estimating the costs and benefits of action by urban local governments due to climate induced malaria incidence. Focusing on the case of Surat, we estimate the costs incurred by households (prevention costs) and government (health department) programme costs, and weigh them against benefits in terms of avoided morbidity and its valuation.

The rest of the paper is organized as follows. Section 2 presents a summary of the literature on climate adaptation and vector borne diseases to show how limited the existing work on the quantification of adaptation interventions still is. Section 3 introduces disease statistics in Surat. Section 4 presents climate normals and projections for Surat. Section 5 forecasts

¹ We are grateful to the Rockefeller Foundation for generous funding for the field work associated with this study. This study is part of ICRIER's CAC 312, 2012 grant. We thank Ketan Shah and Ted Mansfield, both former graduate students at the University of North Carolina at Chapel Hill, for very useful feedback on an earlier draft of the paper.

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⁵ In India, the epidemiology of malaria is complex because of geo-ecological diversity, multiethnicity, and wide distribution of nine anopheline vectors transmitting three Plasmodial species: *P. falciparum*, *P. vivax*, and *P. malariae*. Of these malaria vectors, *An. stephensi* is largely responsible for malaria in urban and industrial areas while *An. culicifacies* is the vector of rural and peri-urban malaria in peninsular India. *An. culicifacies* complex is responsible for 60-70% malaria cases occurring annually in India. In terms of plasmodial species, a large part of total malaria cases (40-50%) are due to *Plasmodium falciparum* (Kumar, et al. 2007; Sarika and Chugh, 2011).

malarial incidence in Surat given climate projections. Section 5 estimates the cost effectiveness of adaptation interventions in Surat, and section 6 concludes.

2. Climate Adaptation and Vector Borne Disease: A Summary of the Existing Literature⁶

Previous studies on climate change adaptation and vector-borne disease have largely focused on the costs imposed by increased disease incidence under a changing climate (mainly emphasizing treatment costs). Although preventive adaptations, such as vaccine development and vector surveillance, are noted as possible adaptation strategies in recent reviews, few quantitative assessments exist of such interventions. For this paper, we were able to identify only six studies that considered vector-borne disease incidence in the context of climate change adaptation. Of these, two studies estimate malaria treatment costs using a simple projection model (Ramakrishnan, 2011; Ebi, 2008); one demonstrates the application of a more advanced model to provide decision support for a malaria warning system (MacLeod et al., 2015); one provides a framework for modeling malaria risk at an urban scale (Garg et al., 2009). Two additional studies apply ecological niche models to model vector distributions and, in turn, human exposure to disease risk (Gonzalez et al., 2010; Beebe et al., 2009).

Ramakrishnan (2011) and Ebi (2008) use a dose-response relationship linking CO₂ concentrations and the relative risk of malaria incidence developed by the World Health Organization to estimate adaptation costs associated with future incidence of malaria. Using variations in this relationship associated with different emissions scenarios, both of these papers project spikes in malarial outcomes in the future using baseline malaria incidence. Ramakrishnan estimates a 1–2% increase in India by 2030 relative to malaria incidence in 2006, contingent on the assumed emissions scenario. Ebi employs the same method at a global scale, estimating a 5% increase by 2030 relative to baseline incidence. Ebi and Ramakrishnan then both estimate the treatment costs associated with excess malaria cases attributable to climate change. These costs may be considered a reactive adaptation to climate change (i.e., an effort to remain at “status quo” despite increased malaria incidence in the future). While these studies provide some perspective on the future costs of malaria in a changing climate, the relative risk relationship linking CO₂ to malaria directly limits this framework’s ability to consider costs and benefits of disease burden mitigation beyond emissions reduction scenarios that slow the growth of CO₂ concentrations in the future. Overall, the method employed in Ramakrishnan and Ebi has its limits for assessing the benefits of climate change adaptation in the context of vector-borne diseases.

To offer improved malaria forecasting models, some researchers, such as MacLeod et al. (2015) link downscaled climate models (i.e., local future temperature and precipitation estimates) to malaria models that forecast incidence based on these climate drivers. While this approach offers a more nuanced method to project future malaria incidence at smaller scales, this framework is still limited in its ability to consider adaptation actions. Without a model that first links climate drivers to mosquito populations and then mosquito populations

⁶ We thank Ted Mansfield for helping us compile this literature.

to malaria incidence, it is not possible to directly estimate the impact of adaptive interventions on disease outcomes such as, say, urban drainage improvements that reduce the frequency of standing water on malaria incidence. Similarly, the efficacy of interventions that influence the mosquito to human transmission pathway, such as provision of bednets, will be difficult to estimate in a future climate when mosquito populations may also be affected by climate drivers. Still, McLeod's approach has merits and can be instructive illustrators of outcomes in given scenarios.

A framework for improving projections of malaria incidence and adaptation benefits is developed by Garg et al. (2009) in a case study of malaria risk in India . The authors acknowledge the complexity of vector-borne disease transmission in urban areas and attempt to include a more nuanced causal understanding of transmission in a straightforward generalized model. Specifically, Garg et al. (2009) conceptually link changing climatic conditions at the local scale (e.g., temperature and precipitation) and secondary variables (e.g., standing water and vegetation growth) and consider potential mediators of risk, such as economic development and planned adaptation in their projection model to present a “stylized interaction” of these three variables. They use these interactions to illustrate how different adaption scenarios (e.g., investing in preventive adaptation measures such as improved urban drainage or education campaigns) may be compared. However, they do not attempt to fit the proposed model to any observed data or estimate costs and benefits.

A promising future direction for urban-scale models of vector-borne disease incidence may be explicit modeling of vector populations based on climate drivers, which could then be linked to human exposure to estimate disease incidence using a two-stage model. Gonzalez et al. (2010) develop an ecological niche model that uses a combination of climate variables (e.g., temperature and precipitation) and physical variables (e.g., elevation and slope) to estimate the distribution of vector species in North America under a changing climate. The authors then overlay future population distributions and future vector distribution estimates to produce a preliminary estimation of human health risks. Similarly, Beebe et al. (2009) use ecological niche models to analyze how some adaptations may have negative health impacts by inadvertently increasing vector populations. Most of these models however, are at the national scales and are not yet downscaled to urban scenarios. Calibration of such a downscaled model may be difficult, and data availability at the urban scale may present a barrier. As such, none of them estimate actual economic costs and benefits.

Overall, existing studies of climate change adaptation in the context of vector-borne disease often employ modeling techniques that lack the specificity required to accurately model the health benefits of climate change adaptations. While existing studies fall short of effectively estimating the benefits of climate change adaptation on vector-borne disease incidence, emerging methodological approaches provide a promising framework for doing so in future studies.

Keeping in mind the caveats about the limits of data availability and the complications of downscaling global models to urban scales, we turn to a simpler monetization of Surat's efforts to use a number of public health initiatives to successfully control the rise of vector

borne diseases, particularly malaria, in the face of a history of flooding and water logging that has been aggravated by climate changes. Our goal is to assess programme costs and compare them with benefits accrued to examine whether an immediate economic case for adaptation exists.

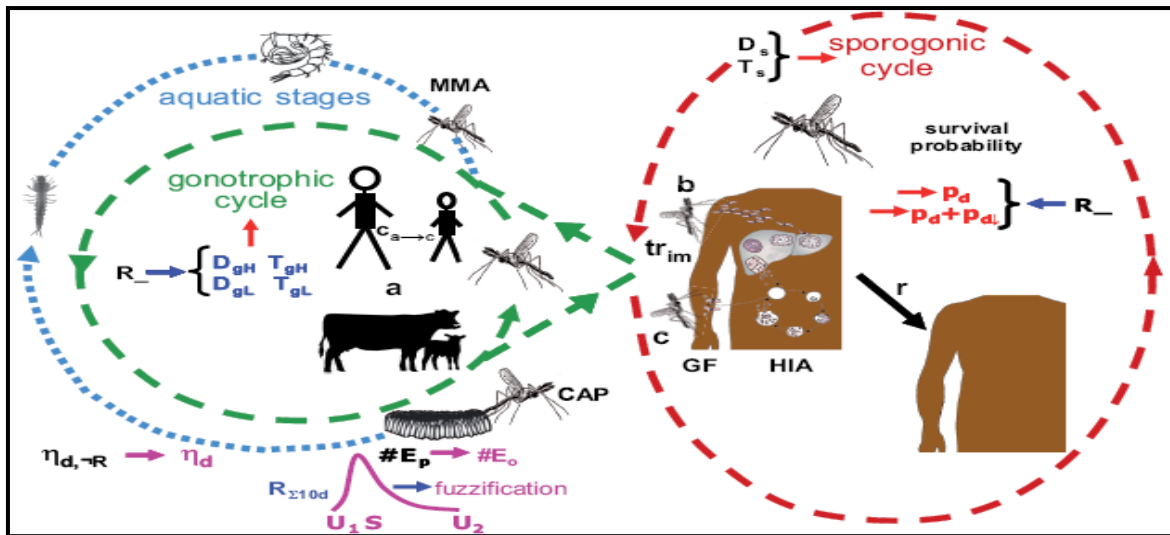
3. Disease Incidence and Climate Interactions

Since Mosquito breeding, survival and their disease transmission efficiency is influenced by local climate patterns (rain, temperature and humidity), most vector born diseases have a strong seasonal trend. A similar pattern is observable in Surat's case as well. It is this predictability of disease onset with respect to seasonal patterns which provides an opportunity to researchers to forecast disease incidences and help in building better preparedness for high disease transmission seasons as well as climate resilience in general.

Climate induced changes in temperature and precipitation have large impacts on the rates of vector and water borne disease incidence. In the case of malaria, temperature drives both the development rate of the malaria parasite within the mosquito (the sporogonic cycle) and the biting-laying cycle of the mosquito itself (the gonotrophic cycle). The sporogonic development rate is arguably the most important of these constraints for rainy season temperatures and is generally taken to be linearly proportional to the number of "degree-days" above a threshold temperature. In general, Sporogonic cycles take about 9 to 10 days at temperatures of 28°C, but note that temperatures higher than 30°C and below 16°C have negative impact on parasite development. A similar relationship governs the rate of progression of the gonotrophic cycle. Temperature affects the mosquito bionomics through decreasing the time taken for the development of parasite eggs in the midgut of the mosquito (temperature rises from 21°C to 27°C). The interval between mosquitoes' blood meals decrease with temperature rise which shortens the incubation periods of the plasmodium parasites in the mosquitoes and the number of times eggs are laid by the mosquitoes (Craig, et.al. 1999; Snow, et.al. 1999; Hoshen and Morse, 2004; Jones and Morse 2010; Ermert, et.al. 2011; Ermert, et.al. 2012; Tomkins & Ermert 2013).

Precipitation contributes to the growth of the modeled mosquito population via the availability of breeding sites. The survival of mosquito larvae also depends on rainfall. It should however be noted that the development of the disease in the human host population is not directly climate driven, and infected humans remain in a latent incubation period of 15 days before becoming able to transmit malaria gametocytes to mosquitoes (Ermert, et.al. 2012; Tomkins & Ermert 2013).

Figure 1: Diagrammatic Representation of Malaria Transmission

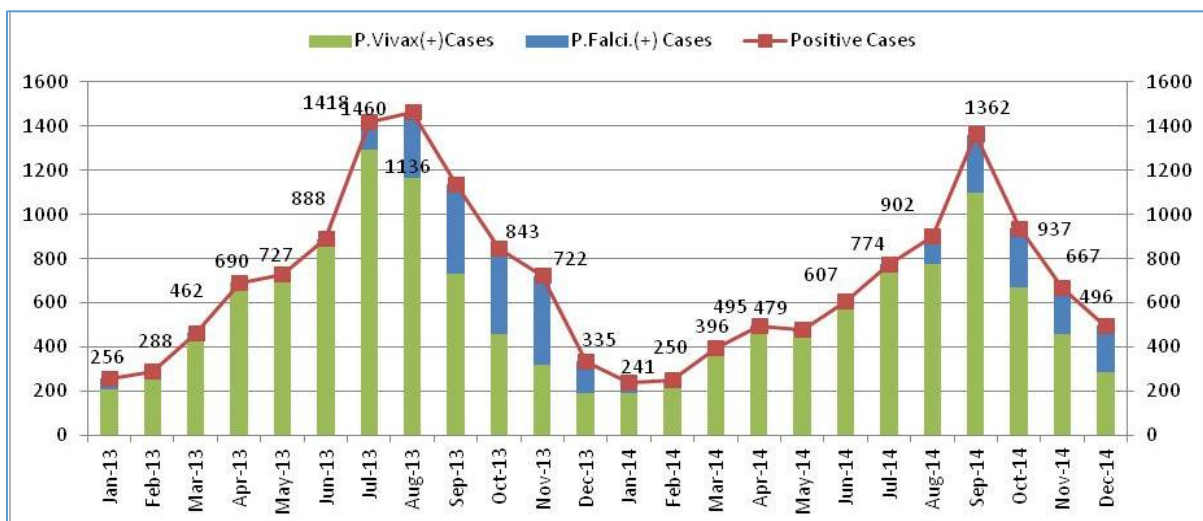


Source: Ermert et al. (2011)

Disease Statistics for Surat

The first step in investigating urban disease patterns is to look at the city’s history of cases and the seasonality, spatial location, details of disease spread specific to that location. While looking at disease patterns we found that although Malaria is endemic in Surat city with cases of malaria, filariasis and leptospirosis related morbidity reported throughout the year, there is a clear seasonality to the spread of disease during the three-four months of monsoon season with a peak between August–November reaching base in December. Falciparum malaria cases show rise from July with a peak October and reach at base from February – June. (Figures 2 and 3).

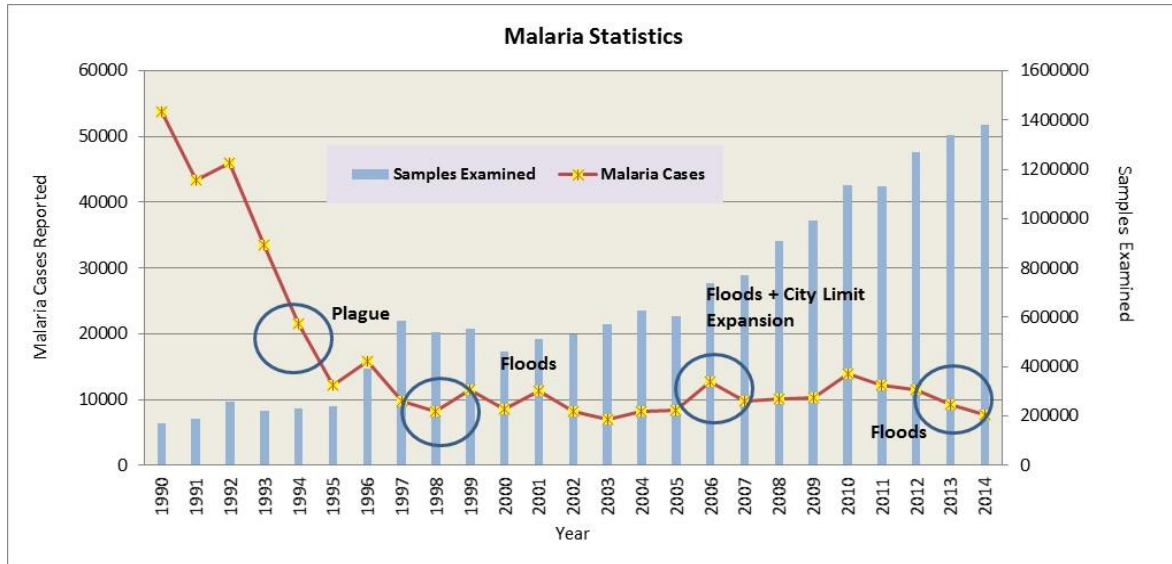
Figure 2: Malaria Cases in Surat



Data Source: Disease Statistics, SMC Website

In the past, a large share of malarial cases within India, and Gujarat state in particular, were reported from Surat. In recent times however, government interventions with respect to public health programmes has led to a plateauing of the number of cases reported. This deceleration in cases reported has occurred despite the increase in city limits in 2006. Figure 4 shows the event history for the city with important natural disasters highlighted. Also shown are the increases in samples taken as well as the number of malaria positive cases found among those tested.

Figure 3: History of Malaria Cases in Surat Juxtaposed with Event History



Data Source: Disease Statistics, Surat Municipal Corporation Website

Even within city parameters there can be significant geographical variation in malaria cases. The city’s East zone has the highest number of malaria cases followed by Central, South west and South East zones. The North and West zones are relatively less prone to malaria. Location-wise, there are concentrated pockets of cases reported in the South west (Athwa zone) and Central (Old city zone) areas where reported cases are nearly double their contribution to the total population. Large slums are located in the East and South east zones of the city these areas also contribute significantly to the incidence of Malaria in Surat city.

The incidence and spread of disease is influenced by a number of factors: the socio-economic status of households, migration status, quality of the built and natural environment, households’ access to basic sanitation and urban services, and the reach and access of health care services. Nearly half of Surat’s workforce is of migrant status. Many of them especially those in the construction textile industry are seasonal migrants, and live in congested housing of poor quality and in locations that are low-lying, prone to flooding and sites at high risk of mosquito breeding infestation. Comparison of SPR among migrants and overall SPR of the city in the last decade reveals that the transmission rate remained high among migrants for all years. Estimates made by the SMC show that the scale of construction activity is one of the contributing factors to the magnitude of malarial morbidity in various zones.

4. Climate Normals and Future Projections

Surat has a Tropical Monsoon climate. Temperatures in Surat range from 37 to 44 degrees Celsius in Summer with winter temperatures approximately at 22 degrees Celsius. Monsoon begins in June and lasts till the end of September, with the average temperature staying around 28 degrees Celsius during those months. Average annual rainfall is around 1143 mm (TARU, 2010). Topologically, the city's landscape slopes gradually from Northeast to Southwest, but Surat is situated on the banks of the Tapi River and is just 16 Km away from the estuary where the Tapi flows into the Arabian Sea. The city thus faces the risks of both sea level rise and flooding.

We used NCEP-NOAA⁷ data (1977-2007) for past climate patterns for various cities to draw climate normals for the city, including maximum and minimum temperatures (in °Celsius), total precipitation (in mm), number of rainy and heavy rain days in a month (in days), and the dry spell periods.

Data from the University of Cape Town climate information portal was used to make climate projections for Surat. Using an empirical downscaling technique called Self Organising Maps Downscaling (SOMD), the website presents downscaled climate projections for select stations. The technique uses five different climate models (Table 1) and provides five sets of station-specific forecasts. The portal provides results for climate parameters for 2 SRES⁸ scenarios- A2 and B1⁹. There are two timeframes of forecasts as well, i.e. 2045-65 and 2081-2100. The following results depict data for the A2 SRES scenario with a projection timeframe of 2046-65.

Both of these sets of data have been used in this paper for fitting the time series model (past climate values) and forecasting disease incidence in the future (climate projections).

⁷ National Centers for Environmental Prediction- National Oceanic and Atmospheric Prediction

⁸ Because projections of climate change depend heavily upon future human activity, climate models are run against scenarios. The **Special Report on Emissions Scenarios** (SRES) is a report by the Intergovernmental Panel on Climate Change (IPCC) that was published in 2000. The greenhouse gas emissions scenarios described in the Report have been used to make projections of possible future climate change.

⁹ The A2 family of scenarios is characterized by (a) A world of independently operating, self-reliant nations, (b) continuously increasing population, (c) regionally-oriented economic development. The B1 scenarios are of a world more integrated, and more ecologically friendly. The B1 scenarios are characterized by: (1) rapid growth and movement towards a service and information economy, (2) reductions in material intensity and the introduction of clean and resource efficient technologies (3) emphasis on global solutions to economic, social and environmental stability.

Table 1: Climate Models with Results Available

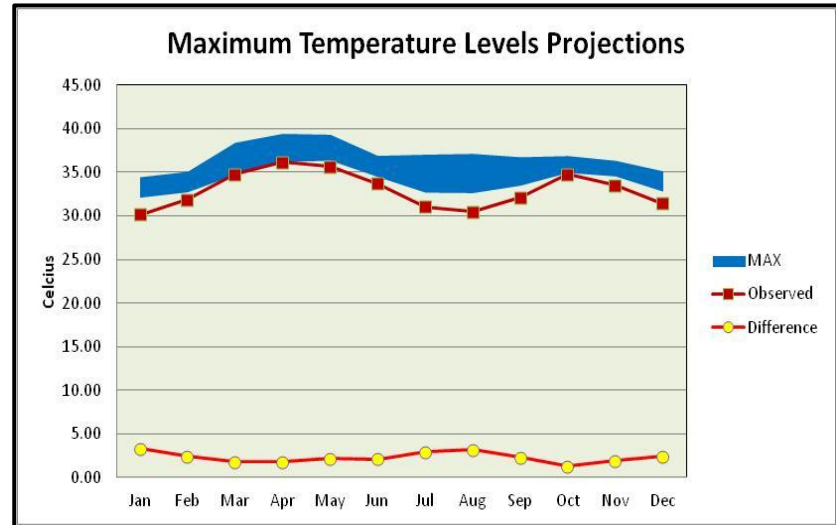
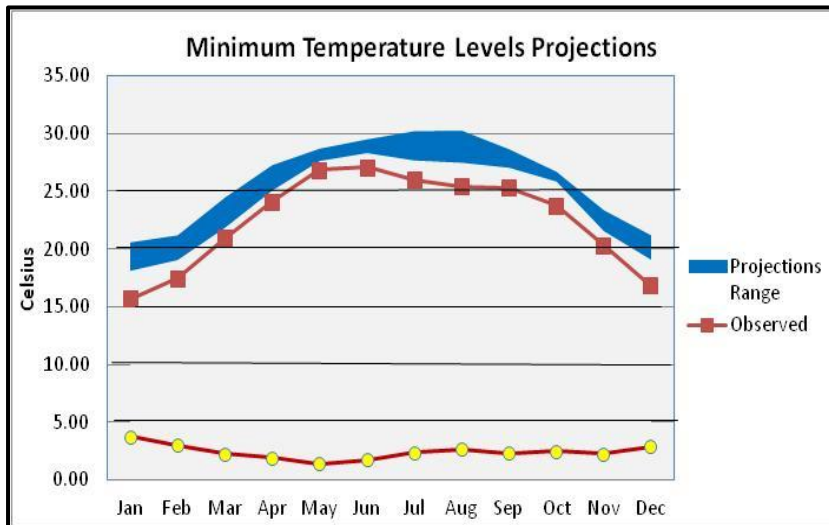
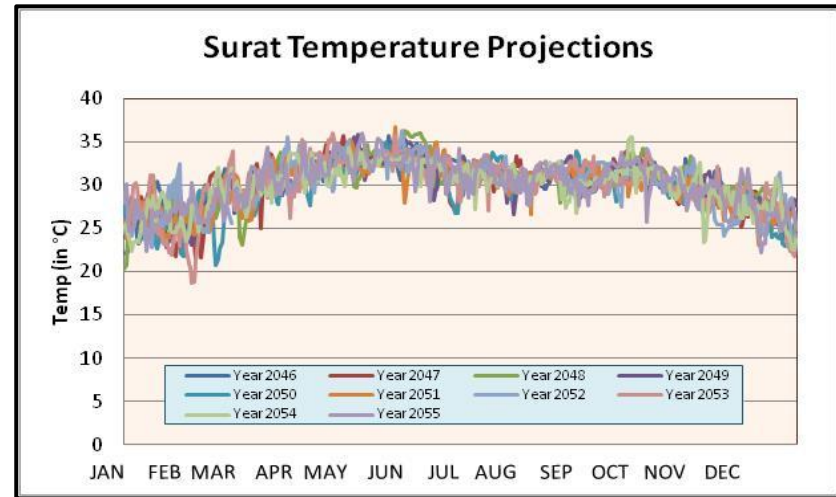
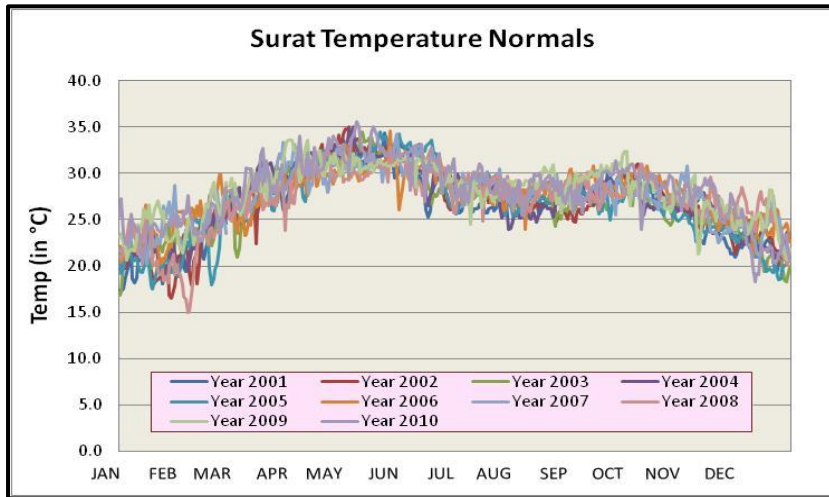
Acronym	Model	Source
ECHAM	MPI ECHAM5	Max Planck Institut für Meteorologie
CGCM	CCCMA CGCM3.1	Canadian Centre for Climate Modelling and Analysis
CNRM	CNRM CM3	aMétéo-France/Centre National de Recherches Météorologiques model
GFDL	GFDL CM	Geophysical Fluid Dynamics Laboratory
MIUB	MIUB ECHO-G	Meteorological Institute University of Bonn

Regional climate models (CSAG 2010) show that monthly average maximum temperatures in Surat are likely to increase by 0.5° C per decade and between 2070-2100 the maximum temperature may increase by around 4°. Figure 5 illustrates the model predicted maximum temperature anomalies. Anomalies illustrate the difference between the predicted values (from various climate models) and the historic observed data. The models predict a possible increase of around 4 to 5 degrees during the winter months. This implies that there is a possibility that in the future there could be shorter winters with the average temperature being well above current normals.

With respect to minimum temperatures, the models predict an increase of around 5 degrees in the winter months and around 3 to 4 degrees during the monsoon and summer season (Figures 6-7). An increase in minimum temperature may aid the disease causing pathogens to survive during winter giving rise to the possibility of increase in the health related issues.

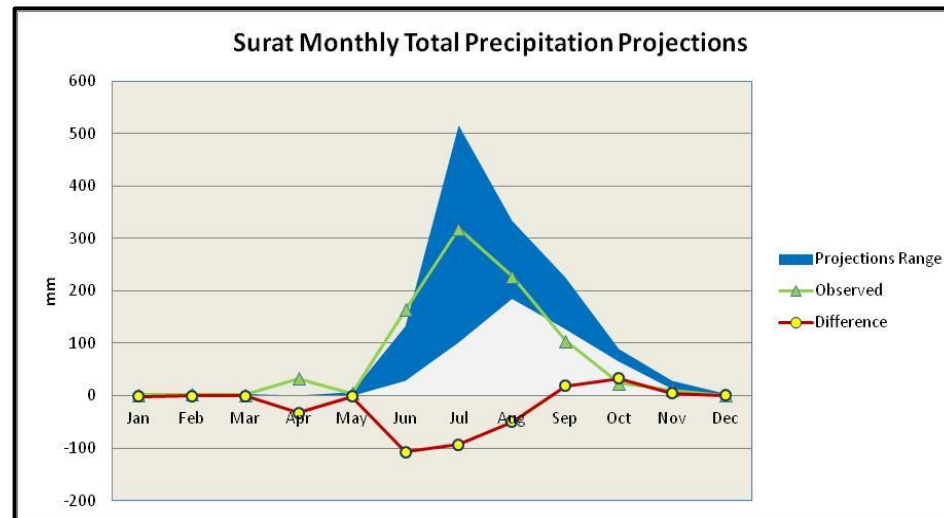
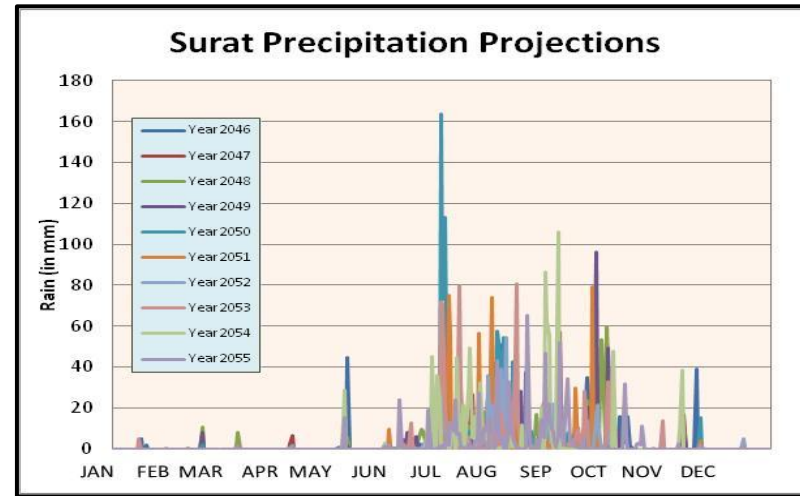
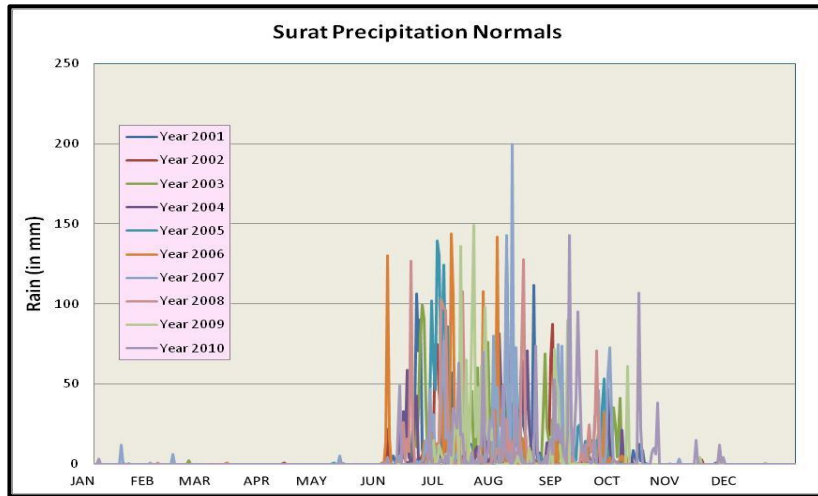
Surat currently receives annual rainfall ranging from 950-1200mm. Figure 7 below shows the typical monthly precipitation patterns for the city (2001-2010). Precipitation projections for 2046-55 are plotted in Figure 6. Figure 9 depicts the results for total monthly anomalies of precipitation as shown by various models. There is a wide variance in the precipitation projections amongst various models. However, a broad average of these 6 models predicts a fall in total precipitation. A comparison based on monthly variation (Figure 8) shows that a large part of the fall in precipitation would occur in the months of June and July. Greater, more intense precipitation levels would be witnessed in the months of September and October, increasing the risk of flooding, water logging and hence increase in the risk of spikes in vector borne diseases.

Figure 4-7: Surat Temperature Normals and Projections



Data Source: Climate Information Portal, Climate Systems Analysis Group (CGAG)

Figure 8-10: Surat Precipitation Normals and Projections



Data Source: Climate Information Portal, Climate Systems Analysis Group (CGAG)

5. Malaria Forecasts for Surat

Coauthor Goldar used the multiplicative seasonal Auto-regressive Integrated Moving Average (ARIMA) to forecast plausible Malaria incidence in Surat going forward. A single equation ARIMA model states how any value in a single time series is linearly related to its own past values through combining two processes: the autoregressive (AR) process which expresses Y_t as a function of its past values, and the moving average (MA) process which expresses Y_t as a function of past values of the error term e :

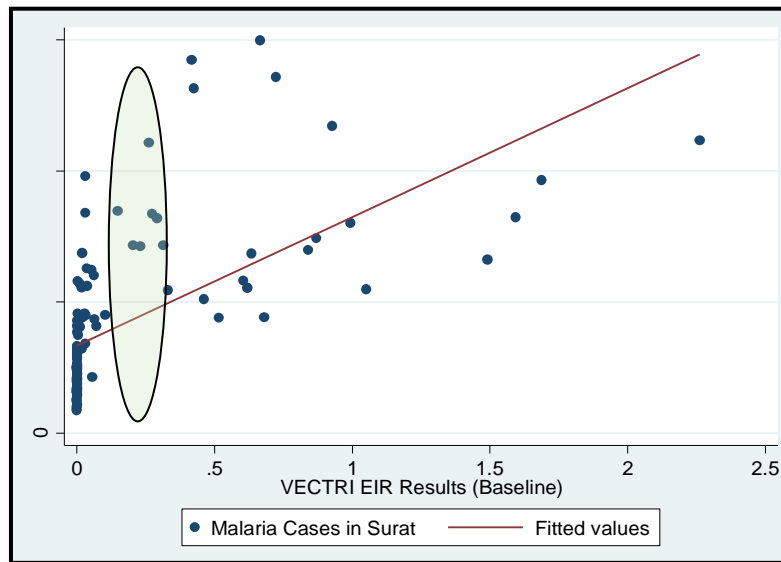
$$Y_t = \varphi_1 Y_{t-1} + \varphi_2 Y_{t-2} + \dots + \varphi_p Y_{t-p} - e_t - \theta_1 e_{t-1} - \theta_2 e_{t-2} - \dots - \theta_q e_{t-q}$$

where the φ s and θ s are the coefficients of the AR and MA processes, respectively, and p and q are the number of past values of Y_t and the error term used, respectively. To incorporate the role of climate in the forecasting process, three climate variables namely, maximum and minimum temperature and precipitation patterns are included as explanatory variables as well.

In earlier versions of this paper, we had used an epidemiological malaria model (VECTRI) forecasting disease patterns. The model incorporated a malaria transmission model as well as a dynamic mosquito population growth model. Despite the theoretical merit of this model, the figures from this model were underestimating disease levels in the city. This was due to the fact that the VECTRI model is not able to model the role of artificially created pools of water storage or stagnation. For most Indian cities (including Surat), disease occurrence has strong linkages with anthropological factors, i.e. pools of stagnant water lying in construction sites, indoor water storage facilities, and so on, that provide artificially created breeding grounds for mosquitoes. Shown in Figure 11 are cases where despite having low EIRs¹⁰, the city reported malaria cases. The usage of past diseases values such as the AR term in the time series model mentioned above, controls for the existence of these anthropogenic factors and gives better fits and modeling results.

¹⁰ Entomological Inoculation Rate (EIR) is the number of infective bites per person per unit time. This measure represents the degree of risks of malaria to a person.

Figure 11: Scatter Diagram for Surat’s Malaria Cases Reported and VECTRI Model’s EIR Results¹¹



Source: Authors’ Calculations

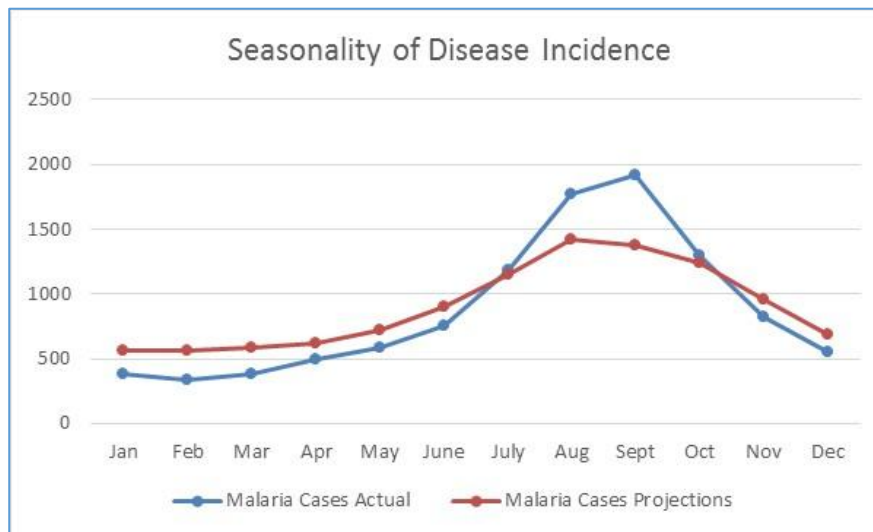
Using the time series forecasting methodology, we find ARIMA (2,0,0) to best represent the Surat Malaria incidence data (see Appendix 1 for more details). The modeling results show a strong positive relation between precipitation and minimum temperature and malaria incidence in the time period 1995-2012. The negative impact of maximum temperature on disease is relatively weaker. Past disease values were found to be strongest explanatory variables.

Assuming this relation between climate variables to continue in the future and the vagaries introduced by future climate change (2045-65) to occur immediately; it is possible to construct a hypothetical worst case scenario. In such a scenario, the existing causal relationships between climate and disease would continue but the impact would be heightened because of the assumed heat and precipitation changes occurring sooner. This scenario thus assumes that future impact of climate change on disease can be immediately witnessed in the city.

Details about the estimation procedure, results and model fits, diagnostic checks, are in Annexure 1. Figure 12 below shows the variation in average year disease profile for past years (actual data) and forecasted values for the future.

¹¹ VECTRI is the *vector*-borne disease community model of the International Centre for Theoretical Physics (*Trieste*)

Figure 12: Seasonality of Disease Incidence



Source: Authors' Calculations

The seasonality of disease patterns shown in Figure 12 highlights the parallel shift upwards for certain months in terms of cases due to higher temperature levels, etc. The results show that while the peaks of disease incidence in the projected period occur during the months of August and September, there are higher cases reported in the off-peak spring and autumn months as well. The model results clearly show that public health issues would continue to be an issue of high concern for the city public health officials and general population in the future as well.

Following from this exploration of the trajectory of disease incidence as might occur in Surat in the future, the following section tries to estimate the impact it would have on the city's competitiveness. The next few sections of this paper look at the costs and benefits of health sector interventions in the situation of higher disease incidence.

6. Cost Effectiveness of Interventions

Ill-health can contribute to losses in individual utility or social welfare both directly and indirectly by reducing the enjoyment or utility associated with the consumption of goods and services unrelated to health, or by compromising other economic objectives such as producing income (workdays lost). Illness leads to increased household expenditures on health services and goods, and may also reduce time spent producing income by caregivers, which further reduces their capacity to consume goods and services on the market. Since the consumption of health goods and services in general does not yield utility or welfare directly, people with low incomes may defer or prefer not to incur these expenses in terms of money and time lost. Microeconomic impacts of ill-health include the change in income and/or expenditure which induces households to reduce their consumption of non-health goods and services. It may also induce them to liquidate household savings or assets in the case of emergencies. In addition to the above, the opportunity cost of illness also includes a reduction

in non-market activities such as giving up unpaid housework or leisure time to look after a sick household member.

Traditional approaches to cost-of-illness (COI) estimations use the following formula for quantification:

$$\text{COI} = \text{Private Medical Costs} + \text{Non Private Medical Costs} + \text{Labor Loss} + \text{Risk related behavior modification} + \text{Investment Loss} + \text{Non Economic Personal Burden}$$

The first two terms, private medical costs and non-private medical costs, are together part of the treatment cost of illness. In this model, labour loss is part of the indirect cost of illness and includes the number of workdays and thus wages lost by an ailing person. Risk related behavior modification refers to the effects caused by modification of social and economic decisions in response to the risk of contracting the illness in highly endemic areas. This includes changes in decision making in such diverse areas as crop choice, trade, investment, and fertility that are all affected by the risk of the disease. The term investment loss refers to the effects of the disease on the long-term economic growth process through its impact on the accumulation of human and physical capital. Non-economic personal burden includes the cost of pain and suffering as well as other effects such as the loss of leisure.

For the present analysis, a modified approach to the above has been used. A cost benefit analysis for health intervention is carried out by incorporating many of the elements outlined above. The cost of health interventions includes the cost of the public programme (Vector-borne Diseases Division in SMC) as well as prevention costs (such as the cost of providing treated mosquito bed nets, etc.) incurred by households. The benefits of interventions in this case would be the avoidance in man-days lost due to illness as well as malaria treatment (institutional and private health centres) costs incurred by households.

The superimposition of disease incidence (predicted by the malaria model estimated earlier) with the value of days lost to disease provides and estimate for the burden of malaria borne by the city. For the valuation of days lost, it is crucially important to get the occupational patterns of people in the zones that are particularly vulnerable to disease, and use that information to get at their average wage levels (based on average occupational emoluments). For Surat we used numbers provided by the NSSO 68th Round Employment and Unemployment Survey (11-12), the Annual Survey of Industries 2013-14, among other databases. It should be noted that for more reliable estimates average expenditures for the state (Gujarat) have been used rather than district averages because of better representation of samples at the state level. A study of secondary sources such as the SMC Health department's website and Annual Reports was undertaken in order to build an estimate of the economic cost of Surat's public health programs. NSSO 68th Round Consumption Expenditure Survey (2011-12) For information on medical bills both institutional as well as private, as well as prevention costs; has been used as a database.

a. Estimation of Adaptation Benefits

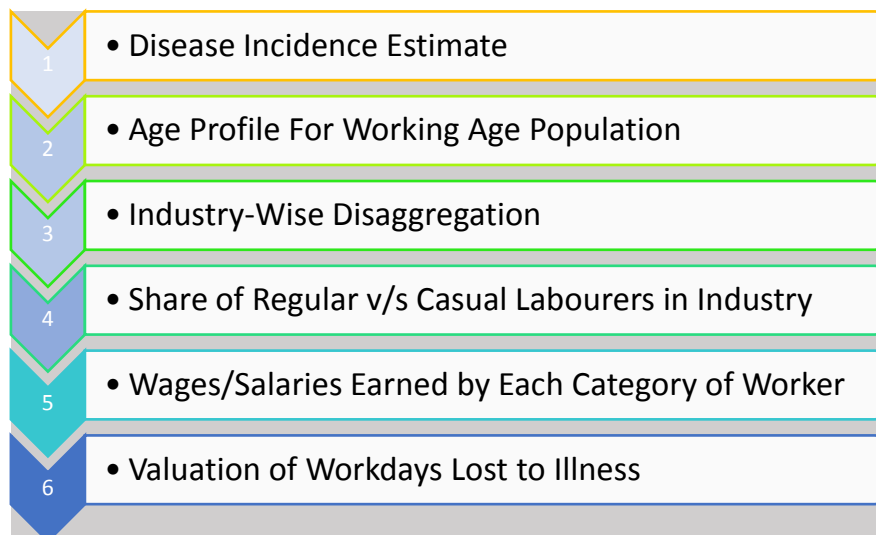
An important part of the adaptation benefits of health interventions stems from the avoidance of 'coping strategies' that households employ to mitigate the consequences of illness. This includes income used to pay for health care (treatment costs) as well as loss in household income flows due to leaves taken.

b. Avoidance of Workdays Lost to Illness

The second component for economic impact analysis of disease is the valuation of number of lost days of work. When the monetary value per day lost is attached with the loss of days estimate, a proxy measure for loss in value of output can be derived. While the lower bound to the days lost to illness is dependent upon medical prescribed treatment advice (generally held to be 3 days), some estimates show that the impact can last till 15 days. For the current analysis, the monetary value of lost days of work has been estimated based on the value of lost wages/salaries.

Each of the steps of the estimation process (Figure 13) is described in detail below.

Figure 13: Methodology for the Estimation Process



Levels of analysis:

Step 1: Disease Incidence Estimate

Taken from Section 5 above

Step 2: Determining the Age Profile of Malaria Cases

Age distribution of cases has been taken from an article written by Pawar, et. al. (2008) which estimates the age distribution of malaria cases in Surat from a survey conducted in Slum areas in 2006 that serve as field research areas of the Surat Municipal Institute of Medical Education and Research (SMIMER). Based on their survey results, a figure of 71%

can be derived that refers to population affected by Malaria that is within the working age group (16-64 years).

Table 2: Age Distribution of Malaria Cases in Surat

	Cases	Share in Total (%)
children<15 year	36	29.0%
15-25	31	25%
25-35	28	22.6%
35-45	18	14.5%
45-55	10	8.1%
>55	1	0.8%
Total Cases	124	

Source: Pawar, et.al (2008)

Step 3: Calculating the Industry-wise Distribution of Workforce

Of the working age population that is affected, the share of labour engaged in each particular industry is calculated using data from Annual Survey of Industries. The three industries of textiles, petrochemicals, and diamond cutting account for 82.6% of total labour force in Surat. Individually, these sectors employ 43% workforce in textiles, a little more than 2% in petrochemicals and 37% workers in gems and jewelry.

Table 3: Industry-wise Distribution of Workforce

NIC	Sector/Industry	Number of Workers	Share
13	Manufacture of Textile	54606	43.4%
20	Petrochemicals (Part of Chemical and Chemical Products)	2907.9	2.3%
32	Diamond cutting (part of other manufacturing)- regular salaried worker	46473	36.9%
	Total Workers in Above Industries	103987	82.6%
	All Workers	125887	

Source: Annual Survey of Industries Unit Level Data, 2008-09

Step 4: Share of Regular versus Casual Workers

For the analysis, workers in each of the sectors were further divided into regular workers and casual laborers. Note that the heads of employees directly employed and employees in supervisory and managerial positions are all part of the salaried workforce calculated above. From Table 4 below, it is easy to see that the largest share of formalized labour force is in the gems and jewelry sector. It is however surprising to see the high level of formalization in the textile sector as well. However, it needs mentioning that the ASI includes only registered enterprises. Given the nature of textile industry, there may be a large number of small scale textile units that rely primarily on informal contractual labour that are not featured as part of the survey.

Table 4: Estimate of Employment by Industry Type in 2011-11, Gujarat

NIC	Sector/Industry	Production Worker		Employee Other	Shares	
		directly employed	casual	employee other	Salaried	Casual
13	Manufacture of Textile	175416	36630	35068	0.851769	0.148231
20	Petrochemicals (Part of Chemical and Chemical Products)	61414	55435	43408	0.654087	0.345913
32	Diamond cutting (part of other manufacturing)-regular salaried worker	68896	4053	12977	0.952832	0.047168
No of persons engaged (no.)		247246	160575	85954		

Source: Annual Survey of Industries, 2011-12

Step 5: Wages and Salaries Earned

The next step is to calculate the average wage/salaries level for workers engaged in all 3 manufacturing sectors as well. This data has been taken from the NSSO Employment and Unemployment Survey 68th Round 2011-12. The EU Survey Round covered a sample of 1,01,724 households ; 59,700 in rural areas and 42,024 in urban areas. This data is extremely useful since captures aspects of labour force participation rate, worker population ratio, unemployment rate, wages of employees in detail. The indicators of the structural aspects of the workforce such as status in employment, industrial distribution and occupational distribution are also derived from the survey.

When compared against each other, the data show a clear disparity in wages between the regular salaried employees and casual workers, and between industrial sectors. The petrochemical industry pays the most to its employees.

Table 5: Average Wages in Urban Gujarat

NIC	Sector/Industry	Type of Work Force	
		Salaried	Casual
13	Manufacture of Textile	6180.7	2015.0
20	Petrochemicals (Part of Chemical and Chemical Products)	10416.9	2744.4
32	Diamond cutting (part of other manufacturing)- regular salaried worker	8276.3	1970.0

Source: Authors' Calculation. Data Source: NSSO 68th Round EUS (2011-12)

Step 6: Valuation of Workdays Lost to Illness

The final step brings together all the details collated thus far. Using the data above, we monetize the production loss of malaria incidence. We find that each case of malaria leads to a production loss worth Rs. 793 on an average. This estimate assumes that the workers are unable to work for 5 days post the onset of malaria. Multiplying this value with the average

number of malaria cases that would occur in the future, we estimate that malaria events every year would lead to a loss of Rs. 85 lakhs (or 8.6 million) annually.

Table 6: Economic Value of Workdays Lost to Illness

	Cases	Annual Valuation (in Rs. Lakhs)
Actual (Average 1995-2013)	10472	83.0
Projections (Average 2045-65)	10774	85.4

Source: Authors' Calculation

Healthcare Expenditure Avoided

The absence of social security and other forms of formal/ informal insurance and compensation mechanisms in India, can have an impoverishing and consumption impact of disease and injury. Increased health expenditures and lower productivity can cause or accentuate household poverty and households may be forced to cut back their consumption of non-health goods and services. To assess this, Table 7 provides estimates of average expenditures on health in Gujarat and their share in total consumption expenditures of households.

Average data for the period 2002-2013 shows that of all the cases examined that tested positive for malaria by the public health system, about 70% were *P. Vivax* cases and 30% were *P. Falciparum* cases. In our analysis we assume that this relative share would continue in future cases as well, although clearly from our literature review we are aware that this may not be the case. Given current data limitations and for the sake of a simple economic assessment, we make this crucial assumption to calculate the treatment cost of each new malaria case. Equally important is the share of cases that are treated by the public sector versus the private healthcare system. Based on existing studies that examined the health aftermaths of Surat's 2006 floods (Pawar et.al., 2008), we take the share of malaria cases treated by the public healthcare systems to be 70%. This figure has however reduced to 50% in recent times specifically in the case of malaria (SMC Personal Communication, 2015). It is important to emphasize that patients opting for public healthcare systems need to pay only a very nominal amount for treatment. For the purposes of our study, we assume that each patient in this case pays Rs. 10 for malaria testing. Other costs such as doctor's fees as well as medicines are taken care of by the Vector Borne Disease Control Department's initiatives of the SMC as part of the city's public health expenditures. Doctors are the employees of the SMC and are paid a non-practicing allowance by the government. In an economic sense, these costs are "free" for patients opting for the public or public supported system.¹²

Following the National Drug Policy prescription and widespread Chloroquine resistance found within Surat district, we assume that *P. Vivax* Malaria is treated with a combination dosage of chloroquine (CQ) for three days and primaquine (PQ) for 14 days. Two lines of

¹² Clearly, as the consumption of purely private health care services increases, the costs of disease and hence "savings" from adaptation will also increase.

treatment are used for *P. falciparum* Malaria i.e. Artemisinin based Combination Therapy (ACT) - SP for three days and PQ for 14 days.

Based on these data and assumptions, our results show that the average treatment costs for each case of malaria to the city is Rs. 240. This is a weighted average of the treatment costs incurred by cases that opt for the public and private healthcare systems. When looked at over the entire set of new cases of malaria that would emerge in the future, the city would lose Rs. 26 lakhs (or 2.6 million) annually as the burden of treatment or expenditure.

Table 7: Estimates of Average Expenditure on Health in Gujarat

Share of Patients Treated	Share	Private Healthcare	Public Healthcare	Average Treatment Cost (Rs.)
		50%	50%	Weighted Average of public & pvt. costs
<i>1. Medicine Cost</i>				
P. Vivax Malaria	70%			
Chloroquine and Primaquine		45	-	
P. Falciparum Malaria	30%			
Artemisinin Combo		630	-	
Average Treatment Cost		220		
2. Malaria Tests		150	10	
3. Doctor Fees		100	-	
4. Treatment Cost (1+2+3)		471	10	240

Source: Authors' Calculation

Table 8: Value of Treatment Costs for Illness

	Cases	Valuation (in Rs. Lakhs)
Actual (Average 1995-2013)	10472	25.2
Projections (Average 2045-65)	10774	25.9

Source: Authors' Calculation

Note that these costs are microeconomic in the sense that they reflect the treatment costs incurred by each individual that seeks malaria treatment. However, to the extent that public healthcare systems are subsidized these do not reflect the total costs of treatment. The macroeconomic costs would thus include the cost to the patient as well as all healthcare subsidies. As noted earlier, many of the expenditures on medicines and doctors fees are currently zero in our calculations since they are taken care of by the SMC or the public healthcare system itself. Building them into our calculations would lead to double counting as these figures are part of the public programme costs discussed and enumerated in later sections.

Estimation of Adaptation Costs

The second part of our analysis deals with estimating the adaptation costs of disease incidence. This comprises the cost of health interventions including public programme costs

(Vector-borne Diseases Division in SMC) as well as any prevention costs (such as mosquito bed net purchases, etc.) incurred by households.

Malaria Prevention Costs Incurred

NSSO data for the 68th Round on Consumption Expenditure Survey 2011-12 has been used to estimate the microeconomic prevention costs incurred by households. In the current analysis, household-level malaria prevention costs have been assumed to relate simply to the cost of purchasing mosquito nets (NSSO Item. 384) and mosquito repellent (NSSO Item. 472).

The NSSO 68th Round Consumption Expenditure Survey was conducted from July, 2011 to June, 2012. The survey covered a sample of 1,01,662 households (59,695 in rural areas and 41,967 in urban areas). The NSS consumer expenditure survey aims at generating estimates of household monthly per capita consumer expenditure (MPCE) and its distribution for rural and urban sectors of the country, for States and Union Territories, and for different socioeconomic groups. The survey collects comprehensive information on consumption items including 142 items of food, 15 items of energy (fuel, light and household appliances), 28 items of clothing, bedding and footwear, 19 items of educational and medical expenses, 51 items of durable goods, and 89 other items. It also collects details of particulars of each household member, such as age, sex and educational level. These indicators provide key measures of the level of living of different segments of the population. The distribution of MPCE highlights the differences in level of living is an effective tool to study the prevalence of poverty and inequality. These numbers enable planning and aid the ecision-making process in allocating the nation’s resources among sectors, regions, and socio-economic groups, and assess the “inclusiveness” of economic growth.

There are two types of prevention options and each is very different in terms of the treatment products’ useful life, upfront cost, and so on. The difference in useful life makes calculating the product diffusion (ownership per 1000 households) difficult since NSSO reports only products purchased that specific year. Since the life of a mosquito net is typically 5 years, at any given point in time the number of households owning/using bed nets would be a cumulative total of the purchases made in the past 5 year.

Table 9: Cost Incurred Per year for Bed nets Usage

Price	300
Life	5
Discount Rate	10%
CRF ¹³	0.264
Cost per Year	79.1

Source: Authors’ Calculation

¹³ A **capital recovery factor** is the ratio of a constant annuity to the present value of receiving that annuity for a given length of time. Using an interest rate i , the capital recovery factor is:

$$CRF = \frac{i(1+i)^n}{(1+i)^n - 1}$$

Table 10: Cost and Product Ownership for Bed nets in Surat

Item Code	Description	Average Expenditure (Rs.)	Units per 1000 population ¹⁴
384	Mosquito Net (Annual)	79.1	132

Source: NSSO consumption Expenditure Survey 68th Round 2011-12; NSSO CES 2009-10; Authors' Calculation

The cost incurred by an individual (per unit) for mosquito repellent or insecticide is comparatively easier to compute. We use the NSSO Consumer Expenditure Survey 2011-12 to gather information on per capita expenditure on mosquito repellants. Using figures for average household size, households reporting ownership, etc., we can easily calculate the annual expenditure per household.

Table 11: Cost and Usage of Mosquito Repellents in Surat

Item Code	Description	Expenditure in Past 30 days	Annual Expenditure (Rs.)	Ownership Distribution (per 1000 population)
472	Mosquito Repellent	3.24	38.88	469

Source: NSSO consumption Expenditure Survey 68th Round 2011-12; NSSO CES 2009-10; Authors' Calculation

Unlike the methodology adopted in earlier sections that relates primarily to the population likely to fall ill from malaria based on our projections, the figures for this section are for Surat's population as a whole. For the estimation of Surat's Population in future, we use numbers from Kundu, et al.'s study. In their paper titled "Demographic Projections for India 2006-2051: Regional variations" they provide country, state and district level population projections for the period extending from 2001 to 2051. The projections in the paper are unique in how they incorporate the age structure of the population in the Census of India 2001. Prior to this study, all the major population projections were made before the availability of the 2001 Census data. The authors use the Cohort Component method of population projection, which takes into account separately the future course of fertility, mortality and migration of both genders at various age groups. Table 12 shows the numbers used as the base for our analysis in this section.

Table 12: Estimated Population of Surat District- 2006 to 2051 (in Million)

State	District	2001	2006	2011	2016	2021	2026	2031	2036	2041	2046	2051
Gujarat	Surat	4.99	5.62	6.14	6.52	6.82	7.10	7.32	7.46	7.49	7.44	7.31

We used Census data to calculate the share of Surat City's population within the population of Surat district. We assume, for the purposes of this study, that this share would continue into the future, but as we pointed out in the literature review this need not be the case, and therefore should be interpreted with caution. We use the ratio of the city vs district population

¹⁴ Cumulative over previous 5 years

to calculate Surat city's population projection till 2046-51. Also, average household size figures from the NSSO consumption expenditure survey were used to calculate the number of households that would exist in the future. Again, these ratios might change in future years.

Pulling all elements of the expenditure estimation together, Table 13 shows the disease prevention costs incurred by residents of Surat. The data show that the city would incur about Rs. 40 million as prevention costs at a microeconomic level.

Table 13: Microeconomic Disease Prevention Costs in Surat

Year	Population	Households	Bed nets		Mosquito Repellents		Prevention Costs (in millions)
			Annual Expenditure Per capita (Rs.)	Ownership	Annual Expenditure Per capita (Rs.)	Ownership	
2011	4,462,002	1,174,211	79.1	13.2%	38.88	47%	34
2046-51 Avg.	5,414,319	1,424,821					41

Source: NSSO consumption Expenditure Survey 2011-12; NSSO CES 2009-10; Authors' Calculation

Public Programme Cost Estimation

The Vector Borne Diseases Control Department of the Surat Municipal Corporation boasts of a strong surveillance and disease monitoring system which has emanated from Surat's unique experience with vector borne diseases and sudden onset flooding events. There is strong commitment at various levels of the government to prevent and control Vector Borne Diseases (VBD) in Surat city.

The outbreak of plague in Surat in 1994 jolted the city authorities into action and it was realized that there was a need for a major revamp of the health administration system. The following year thus saw a significant turnaround in the state of affairs as the civic administration initiated a series of health measures to limit the impact of future disease outbreaks. One such initiative was the Public Health Mapping Exercise carried out by SMC where authorities undertake continuous spatial documentation of health related data. The parameters for mapping include quality of drinking water, leakage in water pipes, access to sanitation and drainage facilities and the occurrence of major diseases.

For the documentation of disease occurrence, Surat Municipal Corporation developed a network of about 274 surveillance centers, with a major presence in slum areas. The network includes two municipal hospitals, nineteen urban health centers, seven major private hospitals and a range of private medical practitioners. By plotting morbidity rates relating to major diseases on the city map, the city health manager is able to predict trends and focal point of outbreaks of epidemics. This mapping exercise is crucial for vector borne disease surveillance and it is of particular importance for Malaria surveillance as it allows government bodies to gauge the distribution of malaria occurrence in the urban and rural areas of Surat district. Another mapping exercise in use by the SMC is the Urban Service Monitoring System (UrSMS), developed under the Rockefeller Foundation's ACCCRN

initiative. The system, through its two interfaces- mobile phone and PC, sends and receives health data via SMS and provides auto-generated reports, graphs and statistics to SMC officials and decision makers. These exercises effectively capture the city's daily, weekly and monthly disease trends at different levels of aggregation for early action on any epidemic situation (Bhat et al. 2013, Desai et al. 2015).

The approach of the VBDC department is multipronged, combining an elaborate system of case detection using smart, digital technology and ground level networking, with prompt provision of effective health care. Thus, it not only aims to identify the foci and locus of transmission of the disease, but also seeks to reduce morbidity among already detected cases by providing rapid treatment to prevent its further spread. Under the SMC's parasitological measures, the guidelines of the Urban Malaria Scheme for early detection and complete treatment (EDCT) require that both active and passive surveillance is carried out on a regular basis. In 2011, 440 surveillance workers were deployed to undertake these activities. A total of 1,131,175 blood smears were collected, in which 12,369 smears were positive for malaria. The *P. Vivax* and *P. Falciparum* cases were treated with radical treatment (SMC data).

In terms of passive surveillance, and speedy treatment, such mechanisms have been strengthened substantially by the involvement of 104 private hospitals as well as sentinel hospitals. The inclusion of private hospitals in the malaria surveillance programs is extremely beneficial as a significant portion of the city's population seek treatment at private practitioners (71.8% as per a report on 2006 post flood scenario). This networking and partnership between public and private providers not only allows for better data collection and disease control, but also widens the reach of health programs to under-served populations, including migrants. Based on our personal communication with the SMC VBDC Department, this figure of private healthcare share may have fallen to 50% in recent times due to enhanced government interventions.

Apart from these surveillance and vector control activities, the Vector Borne Disease Control department has a very elaborate drug distribution system. Following the guidelines of the National Drug Policy on Malaria, the department distributes anti-Malarial drugs after confirmation of the diagnosis in each case. The dosage of treatment is as prescribed by the National Drug Policy. In each such case, patients were administered anti-malarial drugs in the presence of a primary health worker and each positive case was followed up by another domiciliary visit.

As part of its anti-larval measures, the SMC undertook both intra-domestic and peri-domestic entomological surveillance of each positive case along with indoor space spraying of around 50 houses in the vicinity of a positive case. Intra-domestic survey activities are carried out in breeding sites of buildings within both residential areas and commercial complexes. All sites that test positive are treated with appropriate insecticides. In 2011, around 14,971,336 residential houses were inspected. Peri-domestic activities were carried out throughout the year at weekly intervals in outdoor spaces by health workers. These health workers inspected ongoing construction sites, outdoor water bodies, underground tanks, overhead tanks, ground tanks, permanent water bodies and seepages of the canals and the identified breeding spots

were treated with appropriate insecticides such as MLO, Biolarvicides and Temephose 50% EC.

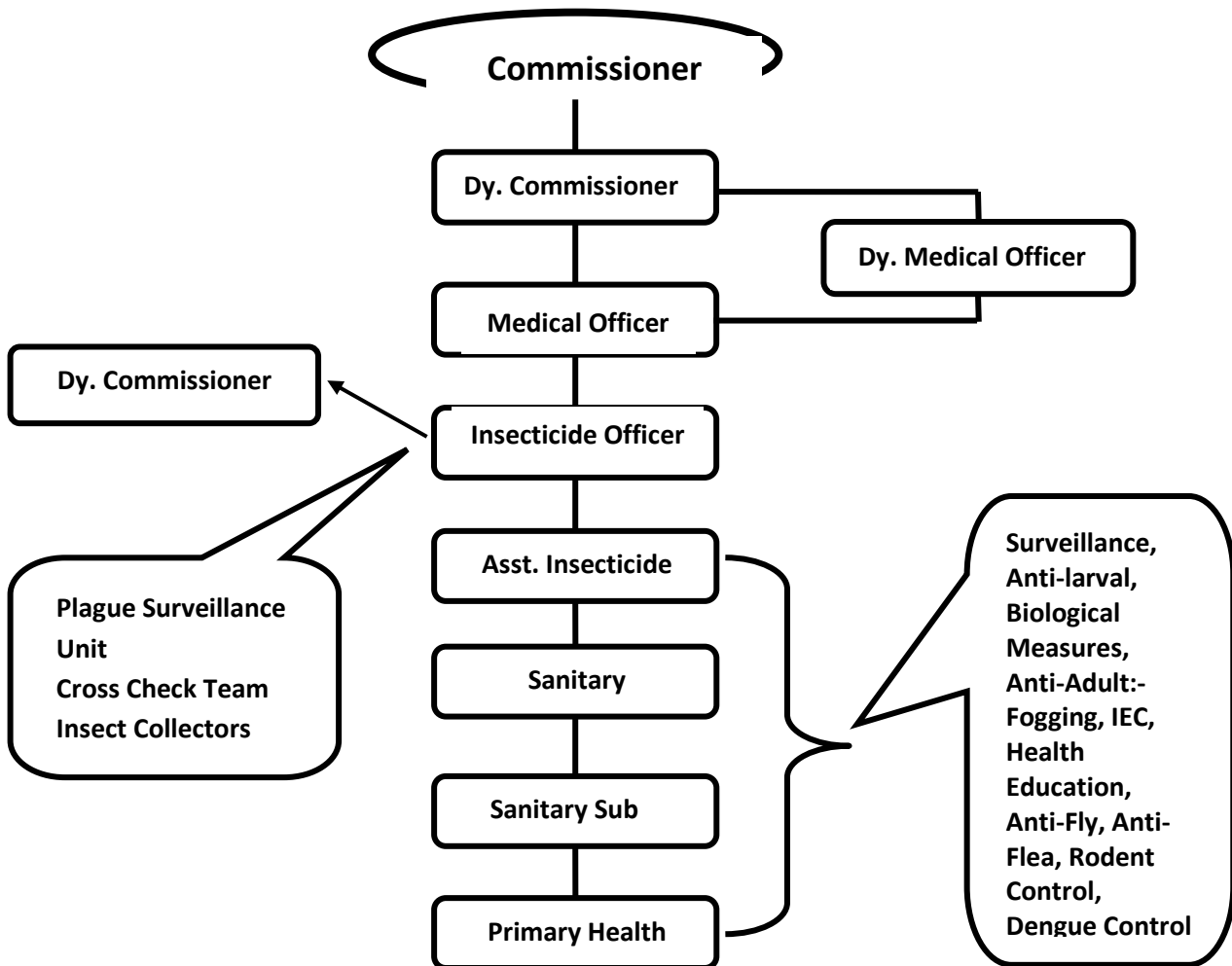
Apart from anti-larval measures, the SMC adopted a range of biological measures to prevent malaria transmission. These include the release of larvivorous fish in permanent water bodies, spraying of appropriate larvicides or fumigation of potential vector borne sites such as in and around city slums, or congested, low lying neighborhoods. Additionally, SMC and its VBDC department has organized various community health education initiatives to increase public awareness about Malaria. These awareness programmes were carried out through circulation of information via vernacular newspapers, television, leafletting, FM, puppet shows, streetplays and so on.

In addition to the above, The Bombay Provincial Municipal Corporation (BPMC) Act, 1949, which applies to all of Gujarat and Maharashtra, empowers the civic administration in Surat to initiate action in the interest of public health. Surat Municipal Corporation is extremely vigilant in the inspection of breeding sites. Under the BPMC Act, legal action can be pursued against anyone for negligence over mosquito breeding activity in or around their place of residence. A health worker can issue a notice to the resident of such a site. If the resident fails to comply with the notice, a fine is imposed. If there are multiple cases against an errant individual or organization for harboring mosquito breeding sites, a case may be filed in the courts on grounds of public nuisance. In 2011, a total of 2,005 complaints were filed and penalties of Rs. 1,98,800 were imposed as fine. Around 48,814 notices were issued and administrative charges of Rs. 4,851,049 were collected from defaulters.

Further details of vector control measure, biological measures and implementation of the BPMC Act are all shown in Annexure 3. The organogram of the Vector Borne Disease Control Department in SMC is shown in Figure 19 that reflects the roles and responsibility of key personnel engaged in the programme.

The annual cost incurred by the health programs of the department are cited to range from Rs. 4 - Rs. 5 million, all of which is borne by the Surat Municipal Corporation.

Figure 14: Organogram of VBDC Department



Source: VBDC Annual Report

7. Calculating Cost Effectiveness

As the literature review in section 2 pointed out, rigorous assessment of cost-effectiveness of adaptation initiatives involve complex modeling and discounting strategies about uncertain futures. More generally, cost effectiveness analyses compare the discounted costs and effects of an intervention (or adding new interventions or replacing existing practices with other interventions targeting the same condition), with the discounted stream of benefits measured as a given outcome, usually lives saved, cases prevented, or life years saved (corrected for quality and discounted for future years). For policy relevance, such assessments and comparisons can aid decision making among alternative policy options.

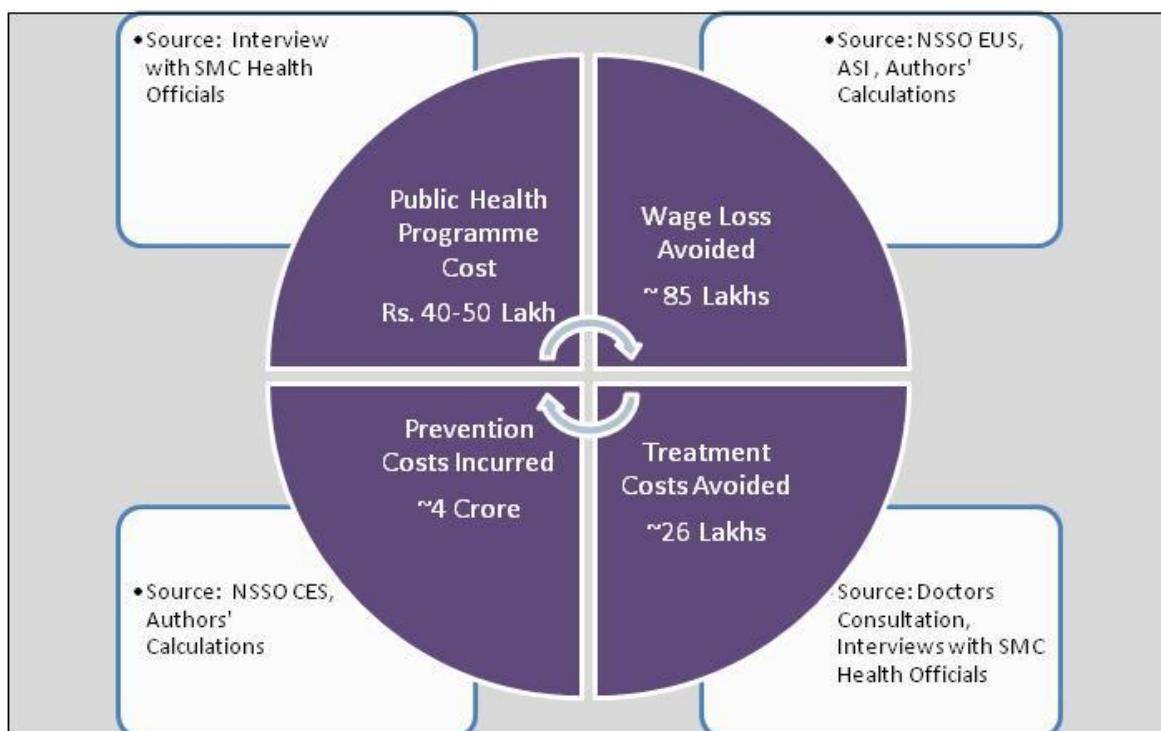
The basic scenario of such broad assessments would be to ask what would the effect on health be if all interventions ceased with immediate effect. One can also examine the implications for population health of adding all possible interventions singly and/or in various combinations, against the baseline of doing nothing. The difference is the gain in health due to the reduction in the burden of disease from the intervention(s).

In similar vein, we examined the cost of malaria incidence to the city of Surat. Our results show that the city would incur an annual cost of Rs. 85 Lakhs (Rs. 8.5 million) as well as shoulder a cost of Rs. 26 Lakhs (Rs. 2.6 million) from production losses and treatment costs incurred to fight malaria in the future. When viewed from a different vantage point, these amounts could also be seen as the gains that would be reaped by having a stronger public health programme and greater private awareness towards the adoption of disease prevention measures. While there are substantial gains to be made, in this section we assess the costs to the city of implementing these disease prevention programmes. Our estimates of the costs that the city would bear in a business as usual scenario are presented in Figure 15.

We find that against program costs of Rs. 40-50 Lakhs (Rs. 4-5 million), Surat incurs benefits of Rs. 111 Lakhs (Rs. 11.1 million) in productivity savings and treat costs avoided. These costs are not discounted, but comparing the costs and benefits we can make a strong case for the benefits of adaptation and stronger public health interventions to mitigate vector borne diseases (Malaria) in the context of a warming climate.

While it is true that the SMC has introduced a series of innovative steps to control vector-borne disease epidemics in its command area, the future may pose a number of severe challenges for the city that would require fresh thinking and greater effort.

Figure 15: Costs of Malaria Incidence for Surat City



Source: Authors' Calculations. Note: 1 crore = 10 million; 1 million = 10 lakh

8. Conclusions and Lessons for Surat

Studies show that in 1997, Surat city, with a population of 3.7% of Gujarat state, was contributing 16% of total malaria cases and 28.8% of total Falciparum malaria cases in the state. This number has fallen since then and despite the increase in city boundaries in 2006 the number of malaria cases reported has stayed stable. Regular surveillance of residential, commercial, institutional and construction sites for mosquito breeding and putting street level workers on the ground for early detection and prompt treatment of malaria has been an important factor in the reduction of the disease burden and mosquito density in Surat (Desai et al. 2015).

ARIMAX modeling for malaria incidence for Surat shows some interesting results. Using temperature and precipitation patterns for the city, as well as incidence figures that existed historically, the model shows that the prevalence of malaria would increase for the city in the future and the number of malaria cases would grow significantly, including malaria cases reported in the winter months as well. In addition to natural causes, checking or curbing anthropogenic causes could prove to be a very challenging for the city's government in absence of innovative adaptation and mitigation efforts.

In this paper, we make an attempt to estimate the costs of public health interventions for malaria in Surat city using a simple cost-benefit approach. In the estimation procedure, the cost of health interventions include programme costs (Vector-borne Diseases Division in SMC) as well as prevention costs (such as resident's purchase of mosquito bed nets, etc.) incurred by households. The benefits of interventions in this case are the avoidance of work-days and income lost due to illness as well as malaria treatment (institutional and private health centres) costs incurred by households.

We found that against a cost of Rs. 4 or 5 million in program costs, the city saves Rs. 11.1 million through income and productivity losses and treatment costs prevented. This suggests that there are real economic benefits from investing in climate adaptation to control vector borne diseases in rapidly growing urban areas. In future work more sophisticated modeling of projections as well the discounted stream of costs and benefits would be useful in taking these ideas forward.

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Annexure

Annexure 1: Malaria Forecasting Amrita Goldar and Flavy Sen

Malaria Forecasting Model

The exact model and best fit for the current paper was derived using the Box and Jenkins methodology. Box and Jenkins (1970) proposed an iterative approach to time series modeling with three steps:

1. Identification – determination of the order of the ARIMA model
2. Estimation: Once the model has been identified, the objective is to minimize the sum of square of errors
3. Diagnostic Checking – Model validation and adequacy checks using tests.

Forecasting of future disease incidence was done using the best fit framework derived following the above methodology.

Identification

The dependent variable i.e. the number of malaria cases was non-stationary however it was found that by taking first difference, the data series became stationary (Annexure 1). Dickey-Fuller test for testing unit roots were done for both actual and differentiated series. The scatter diagram of the differentiated series shows no evidence of increased variance over time.

Plausible models were identified from the autocorrelation functions (ACF) and partial autocorrelation functions (PACF). The model diagnostic was performed using Bayesian Information Criteria (BIC) and p-values. These helped identify the autoregressive and moving average processes of the dependent variable.

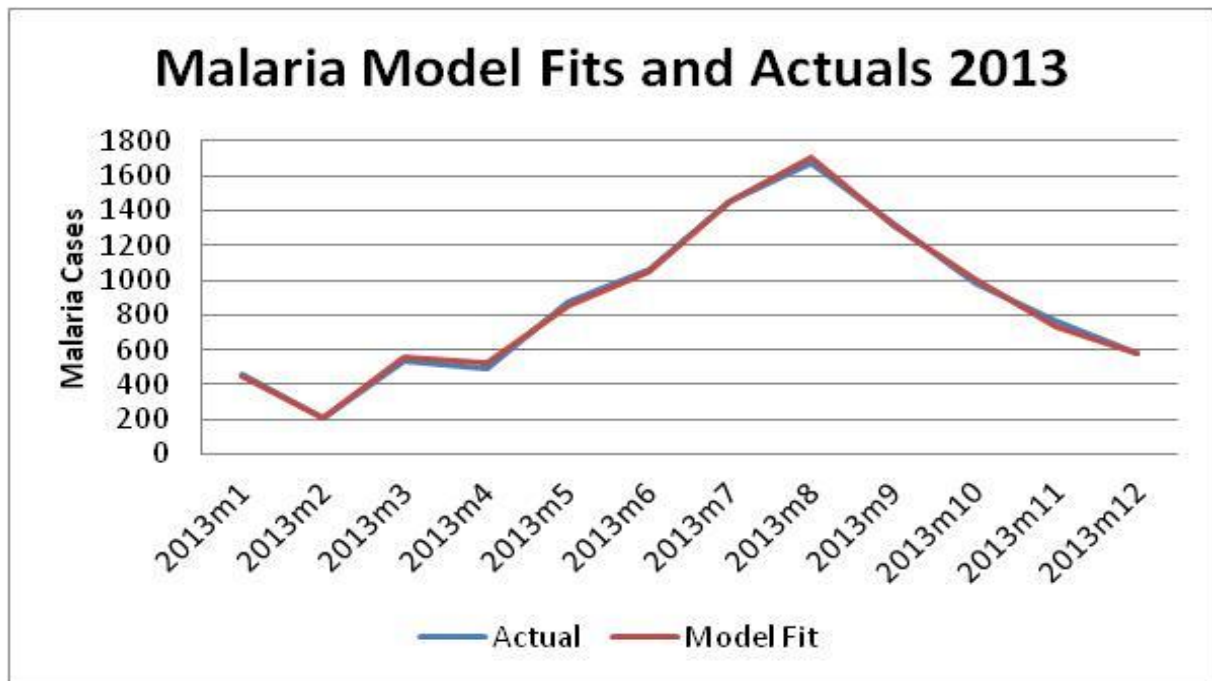
Note that the standard ARIMA framework uses past data for its model fits which may not be able to fully incorporate future shocks arising from unprecedented changes such as that of climate. Thus, to bring in the climate variability aspect, we use the ARIMAX model, to predict the malaria cases using data for both climatic factors and past cases as explanatory variables. The predictors in the model included the number of cases in the previous months, maximum and minimum temperature, and monthly cumulative precipitation levels. The climate covariates have been lagged by one month to model the time taken on an average for gonotrophic and sporogonic cycles to complete¹⁵. These climatic covariates were lagged at one month to allow for sufficient time to complete life cycle of vector which takes around two weeks and subsequently complete the generation of parasites in the new host for two weeks.

¹⁵ These climatic covariates were lagged at one month because *Anopheles* vector takes two weeks to complete their life cycle and additional two more weeks for the generation of parasites in the new host

Estimation

The last 12 observations in each area were used for validation of forecast accuracy of the different methods and are referred to as test observations. The best-fit models for the different districts and the predicted cases with the actual cases for the year 2013 are shown in Figure 2. The best model was fitted to forecast the malaria cases for the future period.

Figure 2: Malaria Cases and Model Fit for 2013

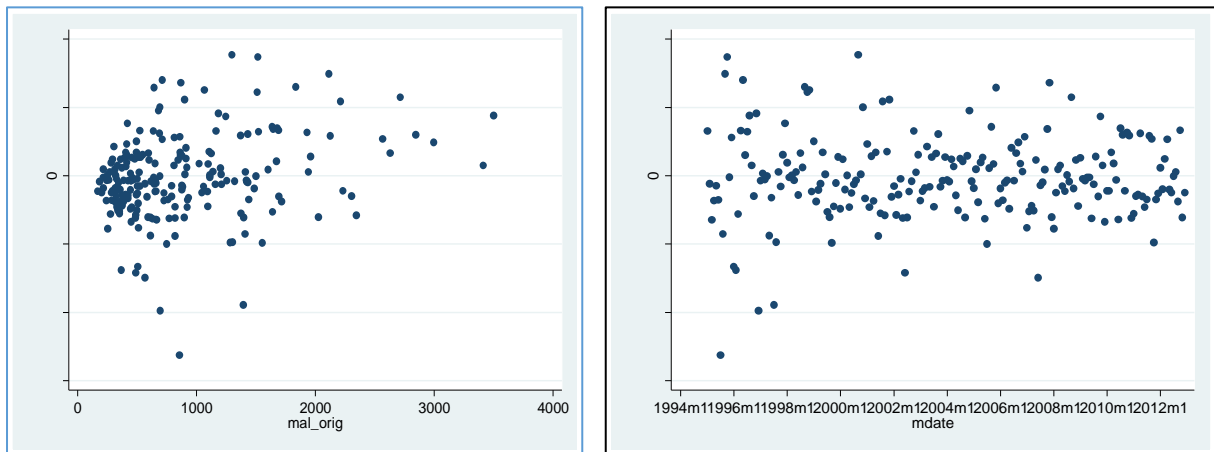


Source: Authors' Calculations

Diagnostic Checking

To test the model fits, scatter plots of the residual term i.e. r , against time and malaria cases were constructed. Figures 3 and 4 below show the distribution of error term to have a random distribution. Note that the residuals are evenly spread across the 0 mean.

Figure 3-4: Malaria Cases and Model Fit for 2013



As a second check, the correlation of the residual term with the explanatory variables was estimation. The correlation matrix (shown in Table 2) between the residual and other explanatory variables also shows the lack of correlation between the variables. This indicates that the error variable is random.

Table 2: Correlation Matrix between Residual and other Explanatory Variables

	Residual	Max. Temp (with 1 lag)	Min. Temp. (with 1 lag)	Precipitation (with 1 lag)
Residual	1.0000			
Max. Temp (with 1 lag)	0.0094	1.0000		
Min. Temp. (with 1 lag)	0.0567	0.2734	1.0000	
Precipitation (with 1 lag)	0.0939	-0.4001	0.4327	1.0000

Annexure 2: SMC Vector Borne Disease Control Programme- Information of Activities

	Intra Domestic Survey							Peri Domestic Survey							Fish Released	Notice	Adm. Charge	Source Reduction	Fogging Machine	
	No. of Houses checked	Breeding Spot	Anoph.	Aedes	Culex	Mix	Total	Checked Construction	Breeding Spot	Anoph.	Aedes	Culex	Mix	Total					Jeep Mounted	Handy Sets
2003	8381430	21438736	27917	58882	2617	6548	95964	36844	1086779	14466	2220	23076	10042	49804	12879	21569	1054300	0	2137	45335
2004	9345558	21888292	39974	59795	2278	11387	113434	48865	1249733	12677	2624	23889	10822	50012	10444	17207	980095	104161	2282	38626
2005	9491873	23272999	28605	52719	1626	6590	89540	45991	1244955	10026	1521	23818	8830	44195	11288	17125	945165	69903	2375	42129
2006	12032015	25418621	48882	61364	1685	10791	122722	44597	1423301	12081	2099	28157	12676	55013	12395	18692	1089741	95442	3241	42222
2007	12745881	28857567	41760	51712	1579	7743	102794	67395	1628437	10285	2512	26343	9890	49030	12675	23133	1886250	114449	1883	27973
2008	12239012	26780569	34063	42747	1571	7270	85651	62335	1751910	14081	3037	26604	11342	55064	13525	30405	2716600	77079	1949	30328
2009	15388463	29724560	49052	71526	808	9019	130417	55565	1573692	13381	2887	28560	11345	56173	12430	33122	2475410	72454	1234	30314
2010	19612589	39630246	54644	90599	1032	12493	158768	67574	1899497	21805	3501	33428	15112	73846	14047	41060	3986675	102214	1453	31967
2011	14971336	30197652	48888	64969	782	11216	125855	70609	2038143	20995	3368	31893	14875	71131	13044	48814	4851049	165933	1470	31513
2012	17373742	35093904	41859	66509	615	10670	119653	86082	2274208	17708	3930	27747	12565	61950	9181	45263	4476925	120792	2249	38180
2013	8227123	17785370	14132	21468	228	3527	39355	41954	1084035	5811	1220	12104	4471	23606	4056	20313	2699850	66867	1027	17513

Source: Surat Municipal Corporation

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