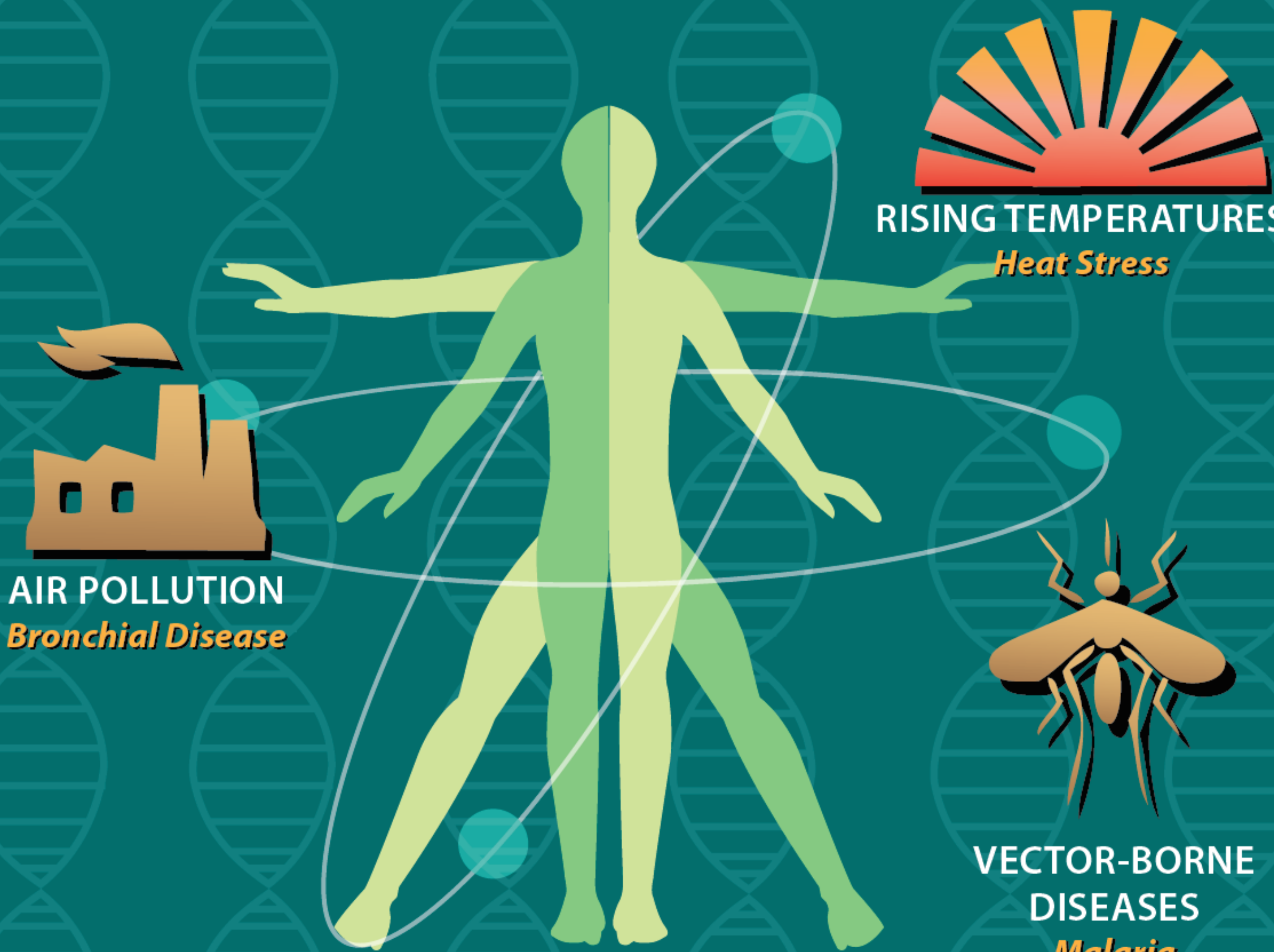
CLIMATE CHANGE & HUMAN HEALTH



Edited by
S.K. Dash, Akhilesh Gupta and Nisha Mendiratta

सत्यमेव जयते
Government of India
Ministry of Science & Technology
Department of Science & Technology
Strategic Programme, Large Initiatives and Coordinated Action Enabler (SPLICE) Division
Climate Change Programme
July, 2016

Climate Change and Human Health

A report of the DST's National Knowledge Network Programme on Climate Change and Human Health

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Climate Change Programme
June, 2016

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Dated: July 21, 2016

FOREWORD

The 5th Assessment report of Inter-governmental Panel on Climate Change (IPCC) has brought out new results on climate change impacts on different socio-economic sectors besides its impact on physical environment such as melting of icecaps, rising sea levels, heat-waves, storms, etc. There is increasing evidence of climate change impacting human health in various ways. It may bring with it an increase in malnutrition, mental health conditions, infectious disease spread and so on. One of the major impacts of climate change is the rise in rates of mortality and diseases caused by extreme weather events. Higher temperatures pose major health risks to older people and raise the likelihood that those who work outside – such as farmers and builders – will suffer from heat exhaustion and heat stroke. Many killer diseases, including malaria and cholera, increase as temperature and rainfall increase.

The Department of Science & Technology has been tasked with the coordination and implementation of two national missions on climate change under National Action Plan on Climate Change. The National Mission on Strategic Knowledge for Climate Change (NMSKCC) is one of them. Realising the need for setting up an inter-institutional group to study the impact of climate and climate change on human health, DST as part of NMSKCC initiated a National Knowledge Network on "Climate Change and Human Health" in partnership with Ministry of Health & Family Welfare; Ministry of Earth Sciences (MoES) and Ministry of Environment, Forest and Climate Change (MoEF & CC) in 2012.

I am delighted to see that a report on "**Climate Change and Human Health**" has been brought out by SPLICE Division, DST based on the results emanated from the Network Programme. I must compliment the sincere efforts made by **Prof S.K. Dash** of IIT Delhi; **Dr Akhilesh Gupta**, Head, SPLICE and **Dr Nisha Mendiratta**, Scientist-F, SPLICE in compiling and editing the report. I also wish to thank the project investigators and contributors of the Network Programme for their excellent work.

I sincerely hope that the report will be of immense use to students, researchers and policy makers working in the field of climate change and human health.

(Ashutosh Sharma)

PREFACE

Climate change is becoming one of the biggest threats facing human health today. As temperature and precipitation patterns change, the delicate balance of climate, weather events and life is disrupted. Although few people are aware of the impact climate change may have on their health, the health effects are serious and widespread. Disease, injury and death can result from climate-induced natural disasters, heat stress and strain, air and water pollutants. Children, the poor, the elderly, and those with a weak or impaired immune system are especially vulnerable. Some of the steps that need to be taken to reduce the impact of climate change on human health may include; enhancing the capacity of society to adapt, undertake coordinated R&D to unfold the climate and health nexus to device appropriate medicines and other protective measures; upscale health infrastructure and manpower to deal with the challenges posed by temporal and spatial spread of climate inflicted diseases, etc. Some of these steps can yield benefits for our health, environment, economy, and society.

The National Mission on Strategic Knowledge for Climate Change (NMSKCC) coordinated and implemented by the Department of Science & Technology was aimed at developing strategic knowledge on key climate change issues that include socio-economic sectors impacted by climate change. One of the deliverables of the NMSKCC was to set up National Knowledge Networks in the areas like Agriculture, Water, Human Health and Climate modeling.

Climate Change and Human health was one key area on which very little work has been in the country. Keeping in mind the urgent need for studying the impact of climate change on human health, the DST organized a Brainstorming Discussion on “Impacts of extreme weather events and climate change on human health” on November 21-22, 2011 at IIT Delhi. After detailed deliberations with leading experts and consultations with concerned ministries like; Ministry of Health & Family welfare; Ministry of Earth Sciences (MoES) and Ministry of Environment, Forest and Climate Change (MoEF&CC), DST launched a National Knowledge Network programme on “Climate Change and Human Health” in 2013. The Network programme identified three broad themes and selected eight projects to begin with. The three broad themes are, Vector-borne diseases; Air-pollution & health and Heat stress & health. Nearly 25 scientists from 12 institutions activelyparticipated in this programme.

The programme has been reviewed periodically by an Advisory Committee under the co-chairmanship of two veteran and renowned meteorologists, Shri Dev Raj Sikka, Former Director, Indian Institute of Tropical Meteorology, Pune and Dr. Shashi Mohan Kulshrestha, Former DG, India Meteorological Department, New Delhi. The other members include ; Prof. SK Dash, Centre for Atmospheric Sciences, IIT Delhi; Dr. PK Nag, National Institute of Occupational Health (NIOH), Ahmedabad; Dr. R.Dhiman, National Institute of Malaria Research, ICMR, New Delhi; Dr. D.Behera, PGIMER, Chandigarh, Dr. Akhilesh Gupta, Head, SPLICE, DST and Dr. Nisha Mendiratta, Scientist-F, CCP, DST.

The Network programme has completed 3 years and is now getting concluded. The programme brought out some significant results and strategic knowledge which may be of use for formulating appropriate policies. The present report is a compilation of the results brought out by different groups of scientists. The report has been organized theme-wise and chapter-wise. The strategic knowledge from each of the work has been presented in the last chapter.

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ACKNOWLEDGEMENTS

On behalf of SPLICE Division, DST, I would like to acknowledge with thanks the valuable contributions and inputs received from all Project Investigators of the Network Programme on “Climate Change and Human Health” for this report.

We are indeed extremely grateful to **Professor Ashutosh Sharma**, Secretary, DST for his invaluable guidance and support to the climate change programme. He has always been a source of inspiration to all of us.

I am grateful to **Dr. Akhilesh Gupta**, Advisor & Head,SPLICE-Climate Change Programme, who has ledthe Climate Change Programme right from its inception in 2009. He has been a motivating force behind the planning and implementation of the programme.

We are indebted to all the members of Advisory Committee of National Network Programme on Human Health particularly, the two co-chairs viz.; **Shri D.R. Sikka,** Former Director, IITM, Pune and **Dr. S.M. Kulshrestha**, Former DG, IMD for their interest, constant support and guidance. We will like to express our gratitude to two national coordinators of the network programme viz; **Prof. SK Dash,** Centre for Atmospheric Sciences, IIT Delhi; **Dr. PK Nag**, Former Director, National Institute of Occupational Health (NIOH), Ahmedabad; and thematic coordinators viz.; **Dr. R.C. Dhiman**, National Institute of Malaria Research, ICMR, New Delhi and **Dr. D. Behera**, PGIMER, Chandigarh for their painstaking efforts in successful implementation of the programme.

I would also like to express my gratitude to all the members of the Expert Committee of Climate Change especially Chairman and Co-Chairman viz., **Prof.S.K. Dube,** Former Director, IIT Kharagpur and **Dr Mangla Rai**, Former, DG, ICARfor their encouragement and guidance.

At the end, I wish to thank all the scientists and staff of SPLICE/CCP Division in DST especially our colleagues; **Dr. A. Kamavisdar,** Scientist-E, **Dr. Rajesh Kumar,** Scientist-D; **Dr. Susheela Negi,** Scientist-D; **Dr. Rabindra Panigrahy,** Scientist-C for providing their valuable support.

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Executive Summary

DST launched a National Knowledge Network programme on "Climate Change and Human Health" in 2013. The Network programme identified three broad themes and selected eight projects to begin with. The broad themes include; Vector-borne diseases; Air-pollution & health and Heat stress & health. Nearly 25 scientists from 12 institutions actively participated in this programme. The eight projects supported under each of these themes are given as under.

Thematic Area 1; **"VECTOR-BORNE DISEASES"**

(i) *Mapping of malaria risk in India in the context of climate change, NIMR, New Delhi*

(ii) *Climate change and malaria in sub-Himalayan region and Central India,IIHMR, New Delhi*

(iii) *Impact of irrigation change on the prevalence of malaria in arid and non-arid parts of Rajasthan, DMRC, Jodhpur*

Thematic Area 2: **"AIR POLLUTION AND HEALTH"**

(iv) *To study the effect of climate, air pollution and socio-economic factors on health (Immunological) disease state (Rheumatoid Arthritis), AIIMS, New Delhi*

(v) *Effect of seasonal variation in airborne fungal spore load on bronchial asthma and its control: a longitudinal study in north Indian adults, PGIMER Chandigarh*

(vi) *Impact of climate variability and change on respiratory health, morbidity and mortality, LRSI, New Delhi*

Thematic Area 3**-"HEAT STRESS AND HEALTH"**

(vii) *Vulnerability assessment to heat stress and its impacts on health and productivity for select occupational sectors in the context of climate change, SRU, Chennai*

(viii) *Impact of air quality and heat stress on health: future projections for India, IIT Delhi*

The Network programme has concluded in 2016 after a 3 year term and brought out some significant results and strategic knowledge which can be used for devising appropriate policy prescriptions. These are summarised in the following paragraphs.

1. **Thematic area "Vector-borne Diseases"**

1.1 Mapping of malaria vectors: District wise mapping of malaria vectors indicate the dominant role of different species in different regions of India. Results show that water deficient regions or urban centres in states like Rajasthan, northern Gujarat, Maharashtra, Karnataka, Andhra Pradesh and some parts of Tamil Nadu and West Bengal, have the presence of *An. stephensi.* No discernible change is expected in the distribution of major malaria species except in deforestated areas in North-Eastern states and parts of Odisha. *An. Minimus* has been reported as the main malaria vector from the dense forested areas of North-Eastern states. Though the foci from Uttarakhand, Uttar Pradesh and Jharkhand have recorded *An. minimus,* at present this species is not important in these areas due to ecological changes.

1.2 Suitability maps: It is well known that temperature influences the growth and development of malaria vector and parasite, but it alone cannot influence the malaria transmission. Suitability maps generated reveals that for *P falciparum,* the suitability period is long ie. 7-9 months. Further, more number of districts are suitable for *P vivax* transmission than *P falciparum.*

Based on the opening of transmission windows for 1-6 months (unstable malaria) or more than 6 months (stable malaria), maps are generated for outbreak prone areas (with less than 6 months of transmission). It reveals that parts of western Rajasthan and a few foci in North-Eastern states and J&K are classically suitable for malaria outbreaks. Maps reveal that areas for stable malaria have expanded.

When the temperature suitability is compared with reported high malaria endemicity, it becomes clear that southern part of India particularly Tamil Nadu, Karnataka, Kerala and parts of Maharashtra and Gujarat do not have high endemicity. The high endemic areas are the forested areas which provide moderate temperature (lesser than Tamil Nadu, Andhra Pradesh and parts of Karnataka etc) and high humidity. It further warrants that transmission windows of malaria should be determined based on both temperature and humidity, particularly in areas experiencing extremes of temperature i.e. >32^0C.

1.3 Community based knowledge: Based on the quantitative and qualitative data collected from two sites in Madhya Pradesh situated in central India and two sites in J&K, it is observed that community at large do not decipher the meaning of the term climate change (or its literal translation in vernacular language). However, when assisted with probes like changes observed in temperature, rainfall and humidity, many agreed to experience such changes mainly on temperature and rainfall variables. So far as the impact of climate change on human health is concerned, it is found that for them it is hard to relate climate change with the diseases such as malaria without any probing assistance. Nevertheless, in terms of awareness and knowledge related to malaria transmission, its symptoms, treatments, and prevention strategies, more or less half of community members have complete and correct knowledge. So far as the health related data collection is concerned, the presence of private health facilities and penetration of local unregistered medical practitioners in interior pockets make it difficult to account malaria cases treated by them into the national reporting system.

1.4 Impact of irrigation: Results based on field studies in Rajasthan show that the environmental conditions prevailing in canal irrigated areas are more supportive to anopheline fauna than those prevailing in non-irrigated areas. The environmental conditions include the intra-domiciliary temperature records and relative humidity range. There are high percentages of gravid females in canal irrigated area of Banswara and Jaisalmer districts which need more attention.

1.5 **Strategic Knowledge Generated**

a) Maps of hotspots of malaria based on atmospheric temperature and malaria endemicity provide insight that enhanced temperature alone is not likely to increase the intensity of malaria. Other factors such as moisture, surface conditions, rainfall, forest cover and other related parameters have also important roles to play.

b) Rainfall cut-off is found to be a very important method for early warnings for subsequent malaria outbreak and transmission. It is found that the rainfall cut-off value is not the same for the whole of India. In some states like Assam, 100 mm rainfall in the month of March while in Maharashtra state, more than 200 mm cumulative rainfall in the month of July-September could result into outbreak in the month of December. Thus it is important to find rainfall cut-off for each district of India.

c) Ecological risk maps for malaria outbreak in India is very much essential so as to know which areas are highly vunerable to stable/unstable transmission. Risk maps using temperature and relative humidity for the period 2008-2030 can be used as guide for the near future malaria scenario. The projections were done based on PRECIS simulations which were generated long back. CMIP5 simulations, when used, will give more accurate results.

Possible policy prescription from new knowledge generated in this thematic area: The outcome of this study would provide baseline maps of malaria outbreak prone areas, *P vivax* and *P falciparum* dominated areas, future scenario of malaria in view of climate change, rainfall as a simple tool for early warning of outbreaks and further ecological basis of high malaria endemicity would help the national programme in planning control strategies (timing of indoor residual spray, Number of rounds of Spray in a year and preparedness plan for outbreaks and in view of climate change). Early warnings of malaria outbreak based on rainfall intensity will help in formulating adequate policy for malaria prevention in different regions. More awareness generation on climate change and its relation with malaria vunerability is very much essential. Further, it is paramount to develop a reporting system which can integrate the unaccounted malaria cases in national reporting system. Such steps can help strengthening policy for the local level.

2 Thematic area "Air Pollution& Human Health"

2.1 Impact on Rheumatoid Arthrisis: Hospital observations indicate flares of Rheumatoid Arthrisis (RA) during certain periods of a year and air pollution seems to be one of the main reasons for these flares. Hence it is very important to identify air quality parameters which cause such flares of RA and to identify vulnerable population for autoimmune diseases. This study is based on 500 well known patients of RA recruited (during 2008-2013) from amongst those visiting AIIMS. Results show that high PM2.5 and PM10 levels positively correlate with flares of joint symptoms.

So far very little data are available to make any firm conclusions.Nevertheless, information available so far suggests poorer lung function (in terms of spirometric lung volumes) and slightly higher airway inflammation (in terms of FENO measurements) in patients with allergic bronchopulmonaryaspergillosis as compared to those with non-sensitized or aspergillus sensitized asthma. No conclusions can be made at this stage about any relationship between disease and environmental variables.

2.2 Airborne fungal spore load and Bronchial Asthma: Hospital records show that in some places there are instances of increase in brochial asthma, as for example in Chandigarh and its neighbouring regions amongst above 15yr olds and also life time non-smokers. Such occurrences can happen due to increasing fungal spore loads in the atmosphere due to changes in temperature and humidity. In order to examine this relationship, it is very important to collect clinical data and also those of environmental fungal spores burden and meteorological conditions. Relevant data have already been collected for about two years which contain a lot of valuable information.

2.3 Respiratory Health, Morbidity and Mortality: Increase in the respiratory diseases has been the greatest casualty due to air pollution worsening. It is very important to associate the type of diseases with the type of pollutants so as to take adequate steps in the right direction. In this study more than 12960 patients are examined during July 213 to February 2016 from OPD, emergency wards and hospitalized patients.

2.4 **Strategic knowledge generated:** Most important result of this thematic topic is that worsened air quality influences immunity of human beings resulting in aberrant immune response (autoimmunity). RA flares are significantly correlated with high levels of PM10 and PM2.5 in the air. Also, in normal healthy individuals residing in Delhi for more than 10 years, presence of auto-antibodies in blood suggeststhe evidence of autoimmunity. These results form the basis for further research to explore the role of air pollution and climatic factors in triggering changes at molecular level resulting in autoimmune diseases. Climate change adaptation strategies will be key to combat the anticipatedincrease in autoimmune diseases. This study will help in identifying vulnerable population for autoimmune diseases due to climatic factors and subsequently develop strategies needed to avoid health risks.This study demonstartes that increase in the respiratory diseases has been the greatest casualty due to air pollution worsening. At this satge, it is very important to associate the type of diseases with the type of pollutants so as to take adequate majors for healthy life in the urban areas.

2.5 Possible policy prescription from new knowledge generated in this thematic area: Based on the important results obtained in this thematic area it is evident that air pollutants, especially PM2.5 and PM10 affect the human health to a greta extent so as to be worried about its adverse impact on the society. In addition to causing various life taking diseases, pollutants can also affect our immune system. Although the present results may not be directly used in policy prescription, in general the air pollution needs to be curbed so as to make ourselves healthy, especially in the urban areas. The present results are encouraging enough and show sufficient evidence to pursue more research in this regard.

3 **Thematic area "Heat Stress & Human Health"**

3.1 Unsafe thermal conditions: The results of this study demonstrate the fact that heat-stress is an issue that is impacting about 90% of the workers engaged in certain sectors. This study provides the evidence that several workers in India are working in thermal environments that are much above the safe limits prescribed by the ACGIH. Workers in select sectors such as steel manufacturing industry, are engaged in heavy workload and are working in very high heat conditions (process generated heat) which when combined with ambient temperatures has very high potential to impact the health of the workers. Long working hours, lack of self pacing options and continuous exposures to very hot environments subject the workers to high risks of developing heat-related illnesses. Importantly, the perceptions of the workers on the impacts of occupational heat stress on their health and productivity also support the findings based on health data strongly.

3.2 Work-rest ratios: Physiological responses to occupational heat stress are not only dependent on ambient temperatures and cooling interventions but also are influenced by factors such as work-rest ratios and physiological workload. Work-rest ratios are proven to be the key factors in preventing/controlling any adverse health implications of occupational heat stress.

3.3 Gender sensitivity: Gender sensitivity in occupational heat stress has emerged as an important element in this study. Lack of welfare facilities at workplaces, including toilets has subjected woman to additional health risks that are very unique to women.

3.4 High Hsp70s levels: Results show that the levels of Hsp70s are high in workers exposed to very high heat and engaged in heavy work, which indirectly indicate the levels of stress/strain the body is subjected to.

3.5 Productivity losses: Heart-rate monitoring shows significant productivity losses due to health decrements for people working in the construction sector. This trend if seen in other sectors may come to affect the economy of the country with consequent social implications as indirect effects of occupational heat stress and climate change.

3.6 Heat stress mapping: Heat stress mapping of India is very important before going for early warning system to save people from heat wave conditions. In this study, mapping of India is done in terms of some heat stress indices. However, it is difficult to use only one index for the whole country. It is found that changes in temperature, wind and moisture have large spatio-temporal variations. Hence selection of proper heat stress index for different regions of India is a challenging job. Efforts are also going on to predict heat stress indices under future climate scenarios.

3.7 District level PM2.5 data: The relationship between PM2.5 and human diseases constitute an important component of the strategic knowledge which can be utilised for the benefit of the society. In this study, satellite-derived high resolution dataset of PM2.5 have been re-gridded to generate district level PM2.5 data for the last decade. Further, relative risks are quantified for diseases such as chronic obstructive pulmonary disease (COPD), ischemic heart disease (IHD), stroke and lung cancer (LC). It is known that relative risk helps in estimating excess adult mortality. Premature death can also be estimated using integrated exposure-response (IER) function.

3.8 **Strategic knowledge generated:**

a. Heat stress indices can be utilised to give warnings of the advent of heat waves. In several developed countries warnings are being given under different categories so that people take precautionary measures to save themselves from vagaries of heat waves. The results of this study will help developing an early warning system for the whole country so that lives of people can be saved on time.

b. Hot days contribute to loss in man power and hence the financial loss in different industrial sectors. Results of this study can be utilised in estimating the loss in working hours and hence in economy in different sectors under different temperature extremes.

c. Efforts in understanding the role of PM2.5 and PM10 in human health will help giving adequate warnings to save life. Premature mortality from a disease can be prevented to some extent if adequate healthcare support is affordable based on the estimates.

3.9 Possible policy prescription from new knowledge generated in this thematic area:

a. The Intergovernmental Panel on Climate Change warns of an imminentcrisis due to rising temperatures that may come to affect the poor workers with minimal or no access to cooling interventions at work places. At the same time, knowledge about new and more sustainable intervention approaches will emerge and this knowledge on potential implications of occupational heat stress and climate change becomes a vital asset for the NMSKCC/NMSHE for achieving its mandate.

b. The technical knowledge developed in this project can be translated into policy for the protection of the workers exposed to hot and hazardous environment. Adaptation measures may be taken so as to have minimal loss of work-hours and minimal damage to human health.

Climate Change and Human Health

A report of the DST's National Knowledge Network Programme on Climate Change and Human Health

Chapter 1: Introduction

Human health has always been influenced by weather and climate. Changes in climate and climate variability, particularly changes in weather extremes, affect the environment that provides us with clean air, food, water, shelter, and security. Climate Change (CC), together with other natural and human-made health stressors, threaten human health and well-being in numerous ways. Some of these health impacts are already being experienced in India. Given that the impacts of climate change are projected to increase over the next century, certain existing health threats will intensify and new health threats may emerge. Connecting our understanding of how climate is changing with an understanding of how those changes may affect human health can inform decisions onmitigating (reducing) the amount of future climate change, suggest priorities for protecting public health, and help identify research needs.The influences of weather and climate on human health are significant and varied. Exposure to health hazards related to climate change affects different people and different communities to different degrees. While often assessed individually, exposure to multiple climate change threats can occur simultaneously, resulting in compounding or cascading health impacts.Along with the change in climat, the frequency, severity, duration, and location of weather and climate phenomena—such asrising temperatures, heavy rains and droughts, and some other kinds of severe weather—are changing. This means that areas already experiencing health-threatening weather and climate phenomena, such as severe heat or hurricanes, are likely to experience worsening impacts, such as higher temperatures and increased storm intensity, rainfall rates, and storm surges. It also means that some locations will experience new climate-related health threats. Even areas that currently experience these health threats may experienceshift in the timing of the seasons that pose the greatest risk to human health. Climate change can therefore affect human health in two main ways: first, by changing the severity or frequency of health problems that are already affected by climate or weather factors; and second, by creating unprecedented or unanticipated health problems or health threats in places where they have not previously occurred.

Atmosphere is becoming warmer and observations support the fact that extreme temperature and rainfall events are getting more frequent. IPCC model inter-comparison programme also projects changes in to the future across the globe. Warming atmosphere has impacts felt over several sectors of the society. Human health is the most important sector where the impact of climate change is likely to be most visible. There are several examples of human related adverse effects of enhanced temperature and extreme weather events. India is not exception to the global warming related human health hazards such as vector-borne diseases, water related epidemics, air pollution ailments and heat stress.

1.1 National Action Plan and Missions on Climate Change

India had launched a National Action Plan on Climate Change (NAPCC) in 2008 to bring at the centre stage India's programmes, plans and strategy in dealing with the challenges posed by global climate change. The NAPCC outlined 8 national missions.

These are:

i. National Solar Mission
ii. National Mission for Enhanced Energy Efficiency
iii. National Mission on Sustainable Habitat
iv. National Green India Mission
v. National Water Mission
vi. National Mission on Sustainable Agriculture
vii. National Mission for Sustaining the Himalayan Ecosystem
viii. National Mission on Strategic Knowledge for Climate Change

First four missions are addressing CC mitigation, Missions at (iv) to (vii) focus on adaptation aspects and the last one deals with strategic knowledge generation.

The Department of Science & Technology, Ministry of Science & Technology was entrusted with the responsibility of coordinating two out of these eight national missions on climate change. These are: (a) National Mission for Sustaining Himalayan Ecosystem (NMSHE) and (b) National Mission on Strategic Knowledge for Climate Change (NMSKCC).

The NMSKCC has been launched with the broad objectives of building human and institutional capacities in the relevant areas of climate change; mapping of the knowledge and data resources relevant to climate change; positioning of a data sharing policy framework for building strategic knowledge among the various arms of the Government, Identification of knowledge gaps, formation of Global Technology Watch Groups (GTWGs) to help accomplish the task of technology selection and prioritization, Networking of knowledge institutions after investing critical mass of physical, intellectual and policy infrastructure resources, creation of new dedicated centres within the existing institutional framework, building international cooperation on S&T for climate change agenda through strategic alliances and assistance to the formulation of policies for a sustained developmental agenda.

One of the deliverables of the NMSKCC was to set up National Knowledge Networks in the areas of climate change impact on different socio-economic sectors like Agriculture, Water, Human Health, etc.

Climate change will increase health related stress from extreme weather-related disasters such as wider spread of vector-borne diseases as malaria and dengue and increasing frequency of heat and cold waves.

India is now formulating a ‘Health Mission’ under the ambit of NAPCC to evolve strategies for mitigating, containing and managing the adverse impact of Climate Change on health. The mission aims at analysing epidemiological data, identify vulnerable population and regions, build knowledge base and expertise, increase awareness and community participation. Apart from the overall public heath infrastructure at the national and sub national levels, the Government of India has launched programmes like Integrated Disease Surveillance Programme (IDSP), National Vector Borne Disease Control Programme (NVBDCP) to deal with vector borne diseases like malaria, dengue etc. As part of this programme India aims to eliminate malaria by 2030.

1.2 Establishment of a National KnowledgeNetwork Programme on "Climate Change and Human Health"

Realizing the importance of studying these emerging health issues, the Department of Science and Technology, Government of India helped organizing a couple of Brain Storming Workshops during 2010-12. After detailed deliberations with leading experts and consultations with concerned ministries like; Ministry of Health & Family welfare; Ministry of Earth Sciences (MoES) and Ministry of Environment, Forest and Climate Change (MoEF&CC), DST launched a National Knowledge Network programme on "Climate Change and Human Health" in 2013. The Network programme identified three broad themes and selected eight projects to begin with. The theme areas, respective theme coordinators and the projects sanctioned under each of these theses of the Network programme are illustrated in the table below.

Network Coordinators **Prof. S. K. Dash (IIT Delhi) and Dr. P. K. Nag (NIOH)**		
Thematic area	**Thematic Coordinator**	***Projects sanctioned***
Thematic Area 1 **"VECTOR-BORNE DISEASES"**	**Dr. R. C. Dhiman, NIMR, New Delhi**	1. *Mapping of malaria risk in India in the context of climate change, NIMR, New Delhi* 2. *Climate change and malaria in sub-Himalayan region and Central India,IIHMR, New Delhi* 3. *Impact of irrigation change on the prevalence of malaria in arid and non-arid parts of Rajasthan , DMRC, Jodhpur*
Thematic Area 2 **"AIR POLLUTION & HEALTH"**	**Dr. D. Behera, PGIMER, Chandigarh**	4. *To study the effect of climate, air pollution and socioeconomic factors on health (Immunological) disease state (Rheumatoid Arthritis), AIIMS, New Delhi* 5. *Effect of seasonal variation in airborne fungal spore load on bronchial asthma and its control: a longitudinal study in north Indian adults, PGIMER Chandigarh* 6. *Impact of climate variability and change on respiratory health, morbidity and mortality, LRSI, New Delhi*
Thematic Area 3 **"HEAT STRESS & HEALTH"**	**Dr. P. K. Nag, formerly NIOH**	7. *Vulnerability assessment to heat stress and its impacts on health and productivity for select occupational sectors in the context of climate change, SRU, Chennai* 8. *Impact of air quality and heat stress on health: future projections for India, IIT Delhi*

The next three chapters from Chapter 2 to Chapter 4 provide description, results and outcome of 8 projects taken up under the three broad themes viz., Vector-borne diseases, Air pollution & health and Heat stress & health respectively.

Chapter 2
Thematic area “Vector-borne Diseases”

Malaria is a public health problem in India and is distributed in almost the whole country, though its intensity varies from area to area depending on climatic, geographic and epidemiological conditions. This project aims to develop risk map of malaria in India based on climatic parameters so as to know the months of suitability of malaria transmission; prevalence of malaria; distribution of anopheline mosquito vectors and the population at risk. These information will help devise area specific control strategy. If we know the stability of malaria transmission at district level for the whole country, some areas will qualify for malaria elimination and others for the use of bed nets/ fully fledged intervention measures. The risk maps will also help preparedness plans for vulnerable areas coming in the fold of malaria transmission due to climate change. Through this study, the climatic cut-offs of rainfall are also determined which would help in developing interactive maps for early warning of malaria. The outcome of the project would be of immense help to the national vector borne disease control programme in devising control and preparedness strategy for malaria in India.

The three projects sponsored under this theme are the following:

- **Mapping of Malaria Risk in the context of Climate Change in India**
- **Climate Change and Malaria in Sub-Himalayan and Central India**
- **Impact of Irrigation Change on the Prevalence of Malaria in Arid and Non-arid parts of Rajasthan**

2.1 Mapping of Malaria Risk in the context of Climate Change in India

2.1.1 Broad Objective of the Project

To map the risk of malaria for all states of India from the viewpoint of malaria prevalence, climatic determinants, anopheline vector's distribution and ecological risk.

2.1.2 Studies Undertaken

Based on extensive literature search through standard methodology such as search engines, e-library, published documents (Fauna of British India 1933), manuals, catalogues, and monographs (Covell, 1927; Barraud, 1933; Puri, 1936, 1948), books (eg. The Anophelines of India 1984, Indian anophelines 1995) the district level distribution of malaria vector has been mapped. Expert consultations were also made for verification/confirmation of gathered information.

2.1.2.1 Determination of cut-off of rainfall for outbreak of malaria:

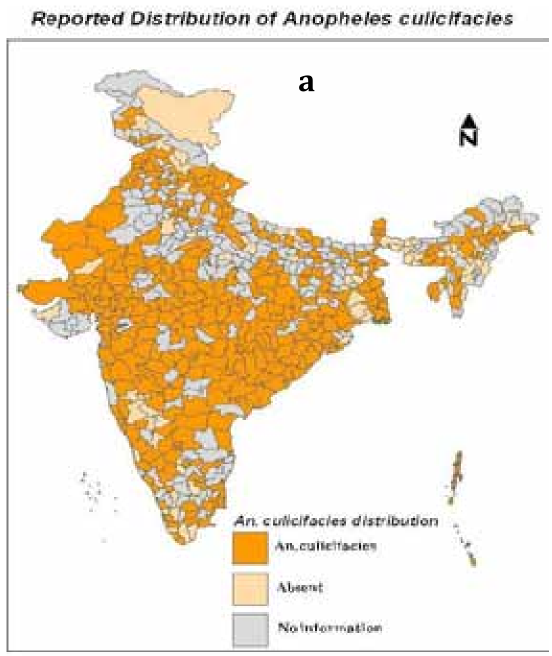
Cut-off of rainfall for outbreak of malaria in different states of India has been determined based on monthly average malaria outbreaks at a particular site. The values are given in Table 1. Lag period of 1-3 months was taken in to account for determining the amount of rainfall. Results indicate that in some states like Assam, 100 mm rainfall in the month of March while in Maharashtra more than 200 mm cumulative rainfall in the months of July-September could result into outbreak of malaria in the month of December. It may be mentioned here that *P. vivax* and *P. falciparum* are well known malaria causing protozoon in India. *P. falciparum* is known to cause malignant form whereas *P. vivax* is known for benign form of malaria. Both parasites have almost similar lifecycles except the fact that the dormant stage "Hypnozoite" in *P. vivax*which leads to relapses in malaria cases. Therefore, in the present study we have identified the cut-off of rainfall for causing outbreak of *P. falciparum* and *P. vivax*separately. Data for malaria cases and rainfall from 2010 to 2012 have been obtained from the National Vector Borne Disease Control Programme and Indian Meteorological Department (IMD) respectively. After analyzing the malaria cases from each district, outbreak prone districts from five states such as Assam, Gujarat, Madhya Pradesh, Maharashtra and Rajasthan are selected based on the outbreaks due to *P. falciparum*. Selected districts affected by *P. falciparum* are then analyzed with respect to rainfall in those districts. For *P. vivax* malaria, two endemic states Gujarat and Rajasthan are selected. In these endemic states *P. vivax* malaria persists throughout the year and hence to understand the effect of rainfall on outbreak, weighted average of rainfall causing malaria cases has been calculated. The number of *P. vivax* cases exceeding more than twice their average has been identified as the outbreak. In case of *P. falciparum*, outbreak of malaria has been determined based on monthly average malaria cases at a particular site reaching 3 times than their average.

Table 1 Cut-off of rainfall with time lag for causing outbreaks of malaria in different states of India

State	District	*P. vivax/ P. falciparum*	Month of Outbreak	Cut off of rainfall			Lag period in months
				Rainfall	Month	Cumulative	
Assam	Sonitpur	*P. falciparum*	April	> 100mm	March		1
Gujarat	Banaskantha	*P. vivax*	October	>200mm	September		1
	Kutch	*P. vivax*	October	>200mm		August and September	1
	Ahmedabad	*P. vivax*	October or September	>300mm		July and August or August and September	1
	Jamnagar	*P. vivax*	September	>400mm	August		1
	Rajkot	*P. falciparum and P. vivax*	November or January for *P. falciparum* and October for *P. vivax*	>300mm		August and September for P. vivax and P. falciparum	1 for P. Vivax and 4 for P. falciparum
	Porbander	*P. vivax*	October	>300mm		August and September	1
Madhya Pradesh	Hoshangabad	*P. falciparum*	September	>300mm	August		1
	Satna	*P. falciparum*	December	>100mm	September		4
	Gwalior	*P. falciparum*	September	>200mm	august		1
Maharashtra	Nagpur	*P. falciparum*	December	>200mm		July to September	3
Rajasthan	SriGanganagar	*P. vivax*	August or September	>50mm		June and July or July and August	1
	Bikaner	*P. vivax and P. falciparum*	September and October	>50mm	August or September	July and August	2
	Churu	*P. vivax*	September or October	>100mm		July and August or August and September	1
	Jodhpur	*P. vivax*	September	>100mm		July and August	1
	Ajmer	*P. vivax*	September	>100mm		July and August	1
	Jaipur	*P. vivax*	September	>100mm		July and August	1
	Barmer	*P. vivax*	September	>50mm		July and August	1
	Kota	*P. vivax*	September	>300mm		August	1
	Udaipur	*P. vivax*	September	>100mm		July and August	1

2.1.2.2 Malaria vectors distribution maps:

Analysis of data reveals that no malaria surveys have been undertaken in 191 districts of India and further approximately 37 districts where studies have already been undertaken do not report any vectors species.



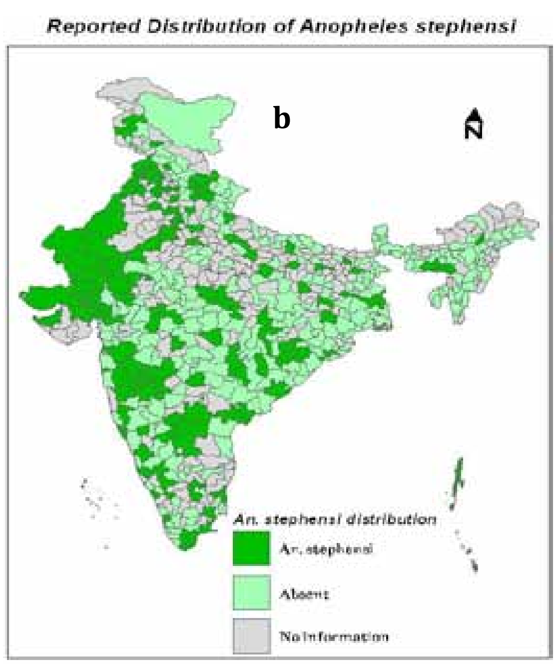


Figure 1: Distributions of (a) *An. culicifacies* and (b) *An. stephensi*

District wise reported distributions of An. culicifacies and An. stephensi are shown in Figure 1. The map reveals that in parts of Rajasthan, Uttar Pradesh, Bihar and Gujarat where *An. culicifacies* is known as vector of rural malaria, there are gaps in its distribution which warrants further studies. *An. culicifacies* has been reported from some districts of north-eastern area, but rarely and with low density. Recent studies have reported increase in spatial distribution as well as high density of rural vector

(Saxena et al. 2014 and Dhiman unpublished work).

As regards the distribution of *An. stephensi,* the states of Rajasthan, northern Gujarat, Maharashtra, Karnataka, Andhra Pradesh and some parts of Tamil Nadu and West Bengal, which are usually water deficient or urban centres, there is presence of this vector species (Fig 1b). It has to be further analysed in the context of urbanization.

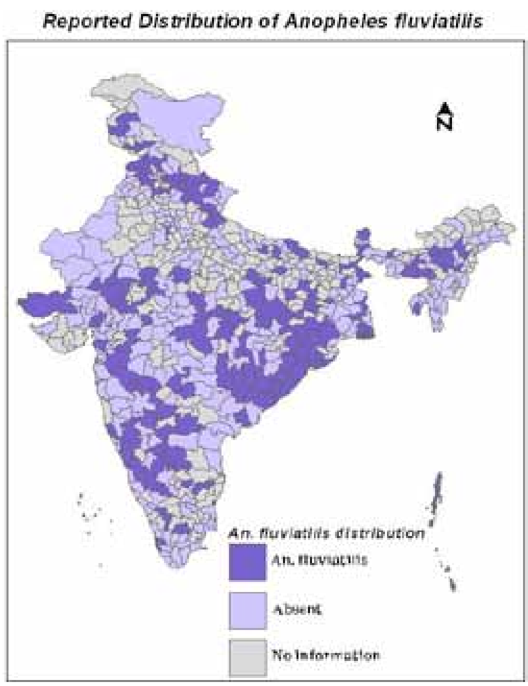


Figure 2: Distribution of *An. fluviatilis*

The distribution of *An. fluviatilis* matches with the forested and foot hill areas of the country. The forest map of India (Figure 2) corroborates this. However, the reported distribution does not necessarily mean that *An. fluviatilis* is the vector of malaria particularly in states like Punjab. Haryana, Rajasthan and Maharashtra etc, as there are sibling species (T and U are not reported as vectors) (Subarao et al. 1994). No discernible change is expected in the distribution of this species except in deforested areas of North-eastern region and parts of Odisha.

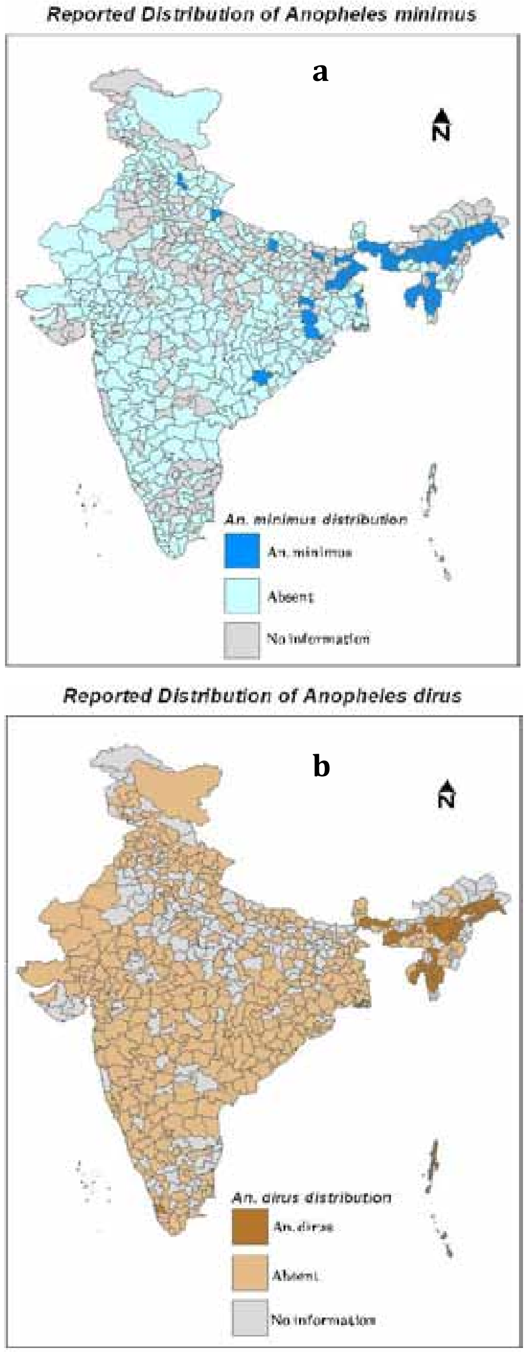


Figure 3: Reported distributions of (a) *An. minimus*and (b) *An. dirus*

As regards the distribution of *An. minimus,* the North-eastern states are the main domain of this vector. Though the foci from Uttarakhand, Uttar Pradesh and Jharkhand have recorded *An. Minimus,* presently ecological changes (Figure 3a) are occurring.

An. dirus has been recorded from the dense forested areas of North-eastern states with thick permanent vegetation cover. Some areas in Arunachal Pradesh and Nagaland appear to be unexplored for the recording of *An. dirus*. This vector is not reported from other parts of the country as the required ecological conditions are not met from areas other than North-eastern states (Figure 3b).

2.1.2.3 District-wise Annual Parasite Index (API) maps:

The generated map for API in India indicates that the highest (>40) endemicity of malaria is in parts of Chhattisgarh, Meghalaya, Mizoram followed by Jharkhand, Odisha and Arunachal Pradesh. The western part of India shows low endemicity in Dadar&Nagar Haveli, Bikaner, Barmer and Jaisalmer (Figure 4).

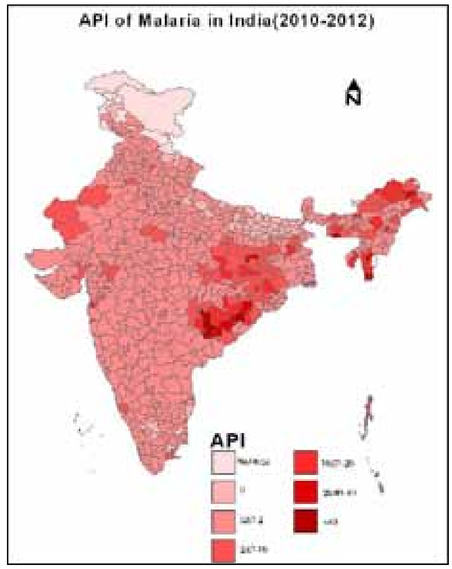


Figure 4: Annual parasite incidence of malaria

2.1.2.4 District-wise Plasmodium falciparum percentage (Pf %) maps:

Highest Pf is confined to the forested tribal areas of Odisha, Chhattisgarh, Jharkhand, and north-eastern states except Arunachal Pradesh. Highest proportion of *P. falciparum* was found during September to January months. Surprisingly, in the month of April, some districts of Rajasthan show Pf proportion. In the month of January some foci in Punjab also show *P falciparum*. The maps highlight the role of climatic conditions in the distribution of Pf particularly in low proportion in western part, northern belt and Arunachal Pradesh.

2.1.2.5 Generation of temperature suitability map of P vivax and P falciparum malaria:

Temperature is one of the important factors for the growth and development of malaria vector and parasite. In order to prepare temperature suitability maps, weekly Land Surface Temperatures were extracted from MODIS sensor with 1km spatial resolution for the year 2008 and monthly mean values were computed for all the districts of India. The threshold values of minimum and maximum temperatures required for transmission of malaria are widely known, i.e. 14.5-16^{0}C for P vivax and 16 -18^{0}C for P falciparum (Martens et al 1995) while the upper limit is taken as 32^{0}C. Based on this criteria, temperature suitability maps for *P vivax* and *P falciparum*have been generated using the open windows of transmission as 16-32^{0}C and 18-32^{0}C respectively. Maps of malaria outbreak areas, stable malaria areas and hotspots based on temperature suitability for 11-12 months are also generated. The areas having up to 6 month transmission suitability are labelled as outbreak prone while with more than six months suitability are labelled as stable areas.

A map of hotspots using information on 11-12 months open transmission based on temperature is also generated. If we compare the temperature suitability with reported high malaria endemicity, it becomes clear that southern part of India particularly Tamil Nadu, Karnataka, Kerala and part of Maharashtra and Gujarat are not having high endemicity. It indicates that only upper temperature limit does not result in high endemicity. It also provides hints that upper temperature limit may be lesser than what is being used for determining transmission windows. This fact provides a lead for further study. So far as climate change is concerned, the increasing temperature in already hot areas like Odisha, Andhra Pradesh, Tamil Nadu, Karnataka etc, is not likely to result in increase in malaria transmission. On the other hand, the high endemic areas are found to be forested areas (Figure 5) which provide moderate temperature (lesser than Tamil Nadu, Andhra Pradesh and parts of Karnataka etc) and high humidity. It further warrants that transmission windows of malaria should be determined based on temperature and humidity both particularly in areas experiencing extremes of temperature i.e. >32^{0}C. It is clear that the northern areas of Rajasthan, Haryana, Punjab, Uttarakhand, and parts of Gujarat and Maharashtra which show malaria suitability for 10-12 months are suitable for only 7-9 months in case of *P falciparum.* Since the minimum required temperature for *P vivax* is lower, in case of *P vivax* more number of districts are suitable for transmission than *P falciparum.* Similarly, non transmission area in *P vivax* is also less as compared to *P falciparum.*

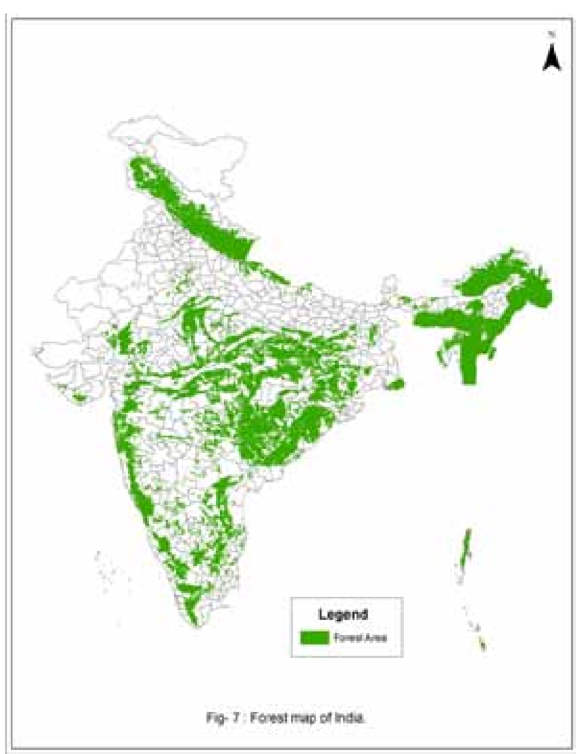


Figure 5: District forest map of India

2.1.2.6 Village level ecological risk maps based on analysis of satellite data:

For generation of ecological risk map, hot spots of malaria based on average API of 3 years (13 districts having API > 20) are identified (Table 2). IRS LISS IV (5.8 meter resolution) data for the months mentioned in Table 1 at four hotspot districts are procured from the National Remote Sensing Centre (ISRO), Hyderabad. False Colour Composite (FCC) images of all the districts are generated using ERDAS imagine software. Village level statistics of Landscape features i.e. human settlements; water bodies, forest cover, agriculture land and barren area etc. in the hotspot state Jharkhand are generated using unsupervised classification.

Table 2 Hotspot areas of malaria based on reported data

Sl. No.	State	District	Month of acquisition
1	Arunachal Pradesh	L/Dibang Valley	May
2	Chhattisgarh	Dantewada+ Narayanpur+Sukhma	November
3	Dadra & Nagar Haveli		June
4	Jharkhand	Latehar	July
5	Meghalaya	South Garo Hills	June
6	Mizoram	Aizawl East	May
7	Mizoram	Lawngtlai	June
8	Mizoram	Saiha	May
9	Nagaland	Kohima	June
10	Odisha	Phulbani (Kandhamal)	July
11	Odisha	Koraput	July
12	Odisha	Malkangiri	June
13	Odisha	Rayagada	July

Figure 6 shows false colour composite image of district Dantewada in Chhattishgarh. Thereafter, subset of villages within 1.5 km radius of a village was extracted. Village wise statistics of landscape features from the malariogenic conditions point of view were generated. For example, the FCC and classified output in respect of Balood and Nakulnar villages are given in Figures 7 & 8. The statistics of landscape feature (Tables 3 & 4) reveal that the hotspots of malarious areas have 40-60% permanent vegetation cover, presence of water body in the form of river and pond etc. while barren area being negligible. The human settlements are sparsely distributed in between forest and agriculture fields.

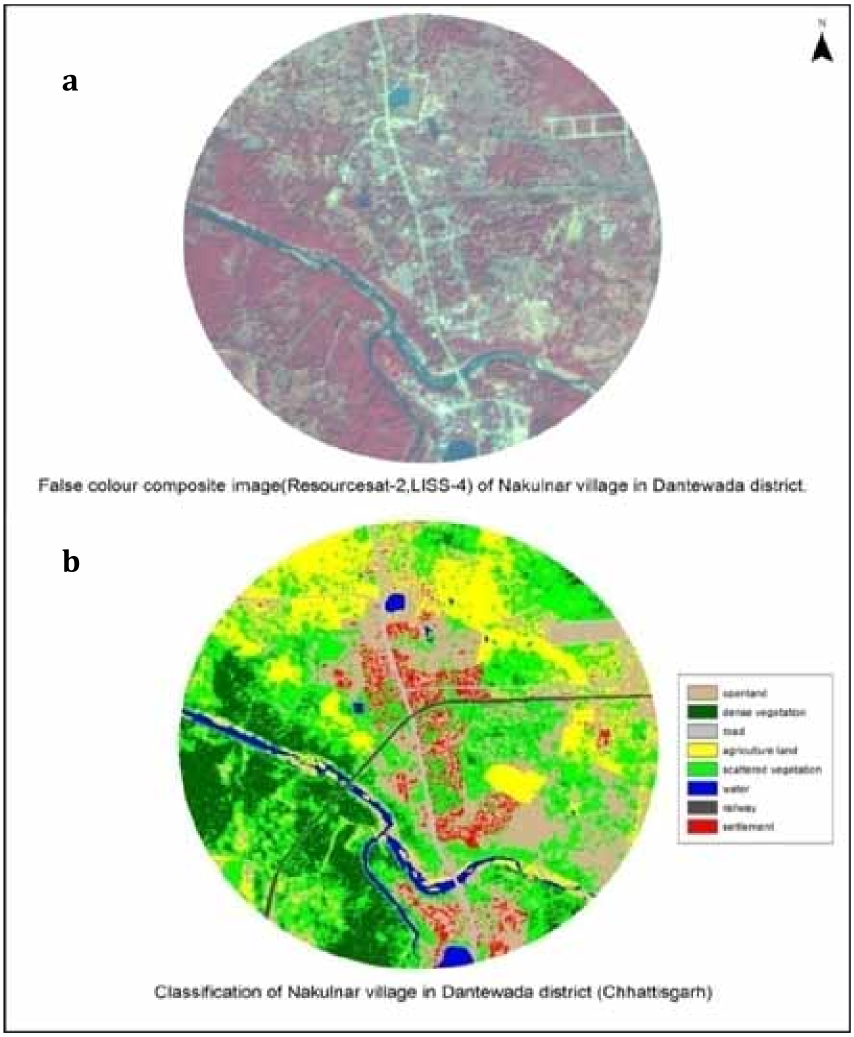


Figure 6: FCC of Dantewara District (Chhattishgarh)

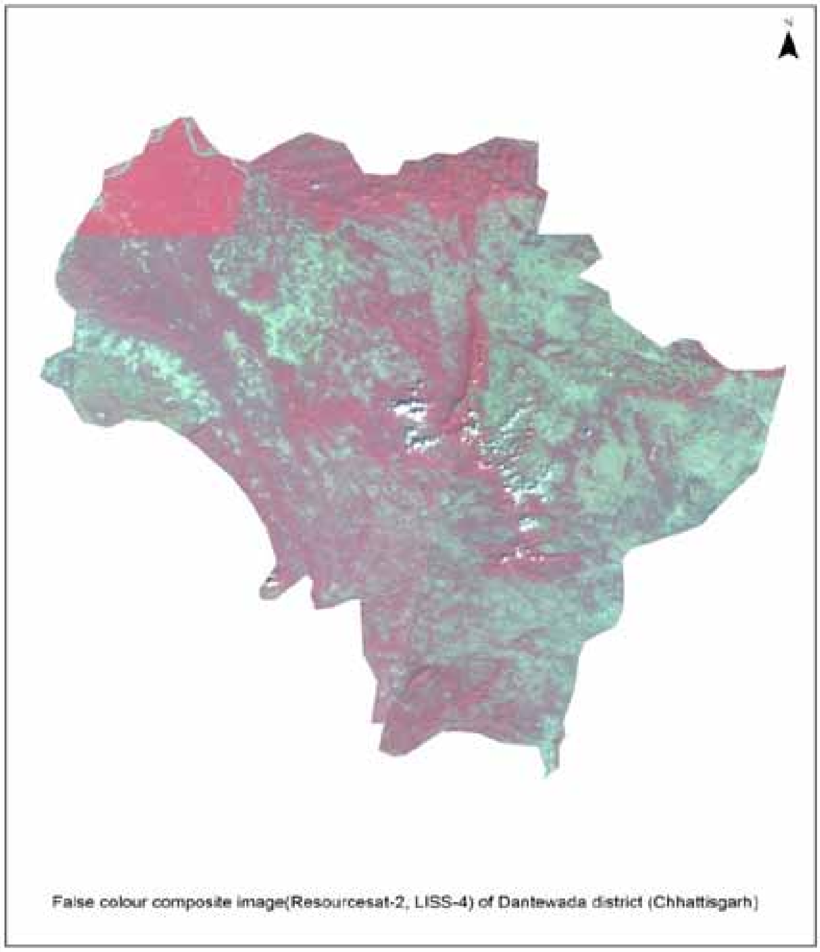


Fig 7: FCC and classified output of village Nakulnar (Dantewada)

Table 3. Statistics of landscape features of Nakulnar village (Dantewada)

Landscape features	Area (hectare)	% Area
Open land	180.378	25.5178
Dense vegetation	102.515	14.5027
Road	14.7975	2.0934
Agriculture land	124.85	17.6624
Scattered vegetation	230.25	32.5732
Water Body	18.4575	2.6112
Railway	7.3475	1.0394
Human Settlement	28.28	4.0007

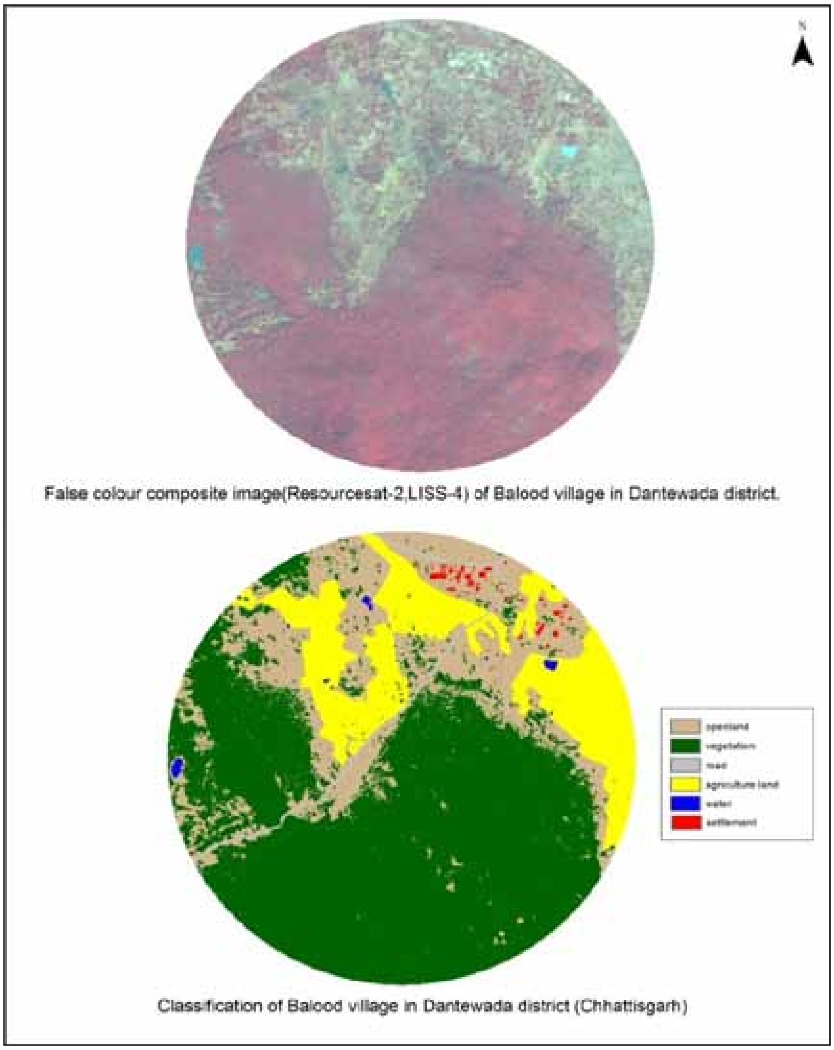


Figure 8 FCC and classified output of village Balood (Dantawada)

Table 4 Statistics of landscape features of Balood village (Dantewada)

Landscape features	Area (hectare)	% Area
Agriculture Land	123.338	17.3004
Dense vegetation	410.843	57.6282
Open land	169.645	23.7958
Human settlement	1.5375	0.2157
Water body	1.4875	0.2086
Road	6.0725	0.8518

2.1.4 Important Results

Mapping of malaria vectors:

District wise mapping of malaria vectors indicate the role of different species in different regions of India. Results show that Rajasthan, northern Gujarat, Maharashtra, Karnataka, Andhra Pradesh and some parts of Tamil Nadu and West Bengal, which are water deficient or have urban centres, indicate the presence of *An. stephensi* whichis usually distributed in the foothills and forested areas of India. No discernible change is expected in the distribution of this specie except in areas with deforestation e.g. North-Eastern states and parts of Odisha. *An. minimus*has been reported as the main malaria vector from the dense forested areas of North-Eastern states. Though the foci from Uttarakhand, Uttar Pradesh and Jharkhand recorded *An. minimus,* at present this specie is not important in these areas due to ecological changes.

It is well known that temperature influences the growth and development of malaria vector and parasite, but it alone cannot influence the malaria transmission. Suitability maps generated reveals that for *P falciparum,* the suitability period is long ie. for 7-9 months. Thus more number of districts are suitable for *P vivax* transmission than *P falciparum.*

Based on the opening of transmission windows for 1-6 months (unstable malaria) or more than 6 months (stable malaria), maps are generated for outbreak prone areas (with less than 6 months of transmission). It reveals that parts of western Rajasthan and a few foci in North-eastern states and J&K are classically suitable for malaria outbreaks. Maps reveal that areas for stable malaria have expanded.

When the temperature suitability is compared with reported high malaria endemicity, it becomes clear that southern part of India particularly Tamil Nadu, Karnataka, Kerala and parts of Maharashtra and Gujarat do not have high endemicity. The high endemic areas are forested areas which provide moderate temperature (lesser than Tamil Nadu, Andhra Pradesh and parts of Karnataka etc) and high humidity. It further warrants that transmission windows of malaria should be determined based on both temperature and humidity, particularly in areas experiencing extremes of temperature i.e. >32^{0}C.

Rainfall cut-off for malaria outbreak:

Due to the diverse physiographic variations in India, rainfall threshold cut-off for malaria outbreak is found to be highly variable. A method has been devised to determine the cut-off of rainfall for outbreaks of malaria in some eco-epidemiological paradigms of the country. Rainfall cut-off in Sonitpur district of Assam (representative district of Assam) indicates that >100mm rainfall in the month of March can cause outbreak in the month of April. In Gujarat, of 7 districts such as Deesa, Nalia, Bhuj, Ahemdabad, Okha, Porbander, Veraval and Rajkot are found outbreak-prone for *P.falciparum*. Analysis of rainfall and malaria cases in Rajkot indicates that >200mm rainfall in the month of August is likely to result in malaria outbreak subsequently. In Kutchh, Gujarat, outbreak of malaria is observed in October 2010 and 2011 when the average cumulative rainfall in August and September exceeds 200mm. Similarly, malaria outbreaks are witnessed with the average rainfall of >200mm in Banaskantha, >300mm in Ahmedabad, Rajkot and Porbander and >400mm in Jamnagar.

2.2 Climate Change and Malaria in Sub-Himalayan and Central India

2.2.1 Approved objectives of the project

i. To identify the association between malaria and mean temperatures, and rainfall and mean humidity.

ii. To study the social determinants for climate change and malaria in physically and socio-economically distinct districts.

iii. To study how non climatic factors modify the relationship between climate variables and malaria

2.2.2 Studies Undertaken

The study of climate change and malaria in the Sub-Himalayan Region and Central India is being carried out at four sites; two in Central India and two in Sub Himalayan region. The aim of this study is to analyse the impact of climate variability on malaria and to study the social determinants of malaria. The study follows mixed approach i.e. both quantitative and qualitative methodologies are adopted to achieve the objectives. Under the study, the following four sites have been selected to collect the data:

- Umaria
- Dindori Jammu
- Udhampur

Both primary and secondary data at the above mentioned four places have been collected in order to achieve the proposed study objectives. Primary data related to socioeconomic indicators, malaria prevalence, social determinants such as health seeking behaviour and factors effecting malaria has been collected. Further, qualitative data have been collected via Focus Group Discussion and in-depth Interviews of various stake holders.

Secondary data have been collected for time series analysis viz., daily meteorological data for 10 years and corresponding daily malaria cases from the health facility near meteorological stations of the India Meteorological Department. Monthly data of malaria have also been procured from the National Vector borne disease Control Programme.

Following are the details of data collected, procured and being used in the analysis:

PRIMARY DATA	
Quantitative Survey	Data related to socioeconomic conditions, family size, health seeking behavior and malaria related information on causes, and prevention have been collected with the help of structured questionnaire. 241 households have been surveyed in 25 villages selected on the basis of malaria prevalence and altitude.
QUALITATIVE RESEARCH	
Focus Group Discussion	5 Focus Group Discussions has been carried out in Umaria and Dindori with each of the following stakeholders ▪ Village Elders ▪ Village Health and Sanitation Committee ▪ Female Group
Key Informant Interview	24 Key Informant Interviews of the following stakeholders have been carried out in Umaria and Dindori each **The Public Functionaries were** District Magistrate or representative/Civil Surgeon/Malaria Officer/PH Engineer/ Met Dept Official/District Epidemiologist/ District Program Manager/PHC Medical Officer/Pharmacist/Lab technician **Community Response** School Teacher
SECONDARY DATA	
	Umaria **Meteorological data :** Noted from Indian Metrological Department Records - June 2003 to February 2014 ▪ Daily average Minimum Temperature ▪ Daily average Maximum Temperature ▪ Rain fall and Humidity **Malaria Data** Daily malaria cases (Pv, Pf and Total) from district hospitals for the years 2007, 2009, 2010, 2011, 2012, 2013, 2014 District and block wise monthly malaria cases, (Pv, Pf and Total) from 2004 to 2013 **Dindori** **Meteorological data :**From Central Water Commission , Dindori 10 years of metrological data ▪ Daily average Minimum Temperature ▪ Daily average Maximum Temperature ▪ Rain fall and Humidity **Malaria Data** Daily malaria cases (Pv, Pf and Total) of district hospitals for the years 2004 to 2013 District wise monthly malaria cases, (Pv, Pf and Total) from 2004 to 2013
Maps for GIS Analysis	**Umaria** District Map, Health facility location map, Forest cover map **Dindori** District map, Forest cover map, Health facilities location map

2.2.3 Quantitative Survey

A structured questionnaire, which was designed and pretested during the pilot visit and subsequently got approvedby the technical and ethical review committees has been administered in 241 households spread across 25 villages in each district (Sample size was already decided during the proposal submission). Villages were selected based on the Annual Parasitic Index of malaria sub-centre wise and altitude of the villages. Villages with low and high prevalence of malaria and in low and high altitudes were selected to study the impact of altitude on malaria and to study the factors affecting the incidence of malaria. Eight to ten questionnaires were filled in each village.

As the study follows mixed approach, qualitative data werealso collected. Focus Group Discussion and in-depth Interviews of stakeholders were carried out. In total five focus group discussions and 24 in-depth interviews have been carried out at each site.

Cross-sectional Survey

A two stage cluster sampling technique has been adopted. Cluster of villages has been identified based on altitude and prevalence of malaria. In total 25 villages from the 4 districts were selected based on the prevalence of malaria and altitude. These villages were the primary sampling units. Ten households were identified based on random sampling from each village.

Sample size calculation

Since there are no reliable estimates of community based prevalence of malaria, the sample size has been calculated based on the following factors; population size as per census 2011, anticipated frequency of 50, 95% confidence limit and design effect of 2. The sample size thus works out to be approximately 766. With a 20% non-response rate, the total sample size is approximately 960. With an average family size of about 5, this amounts to a total of approximately 200 households surveyed in each district.

Focus Group Discussions

Focus Group Discussions have been carried out to learn about the community perspective. It has been conducted with the following groups:

- Village Health and Sanitation Committee members
- Female Group
- Male Group

From Table 1 it is evident that more than 50 percent of respondents were aware of climate change. However, it needs to be highlighted that when people were asked about climate change without giving any hints/probes, many of them could not respond. It was only after probes or hints were given, that people responded positively and elaborated their understanding further in detail.

As seen from Table 2, respondents relate climate change largely with both increase in temperature and low rainfall followed by irregular pattern of rainfall and deforestation. Cases relating climate change with diseases was found to be very less. However, with further probing and assisted with hints, diarrhoea was followed by malaria and heat stress (Table 3).

Majority (79 percent) of the respondents were aware of how malaria spread as well as preventive measures to be adopted. The increased awareness about how malaria spread could possibly be due to the long term awareness which has been created for malaria prevention, treatment and control under the malaria control programme. An interesting finding which emerges out from the preliminary level of analysis is that though majority of respondents adopt different preventive measures at household level to prevent malaria spread, only few talked about preventive measures being followed at the community level.

It would not be unreasonable to conclude that people do feel about the changes happening in their environment and perceive it in the form of increasing temperature or decreasing rainfall or irregular pattern of rainfall or drought. However, relating climate change with the disease (without any assistance) was very minimal indicating that awareness about climate change and its implication on diseases occurrence and prevalence is quite low in the community. Nevertheless, as a separate issue, the awareness about malaria spread, its control and preventive measures is quite good in the community.

Table 1: Awareness about the Climate Change: (Response after probes/ hints were given)

Response	Number (%)
Yes	127 (56.2%)
No	99 (43.8%)
Total	**226 (100%)**

Table 2: What does climate change mean to people

Response	Number (%)
Increase in temperature and low rainfall	50 (43.9%)
Change in rainfall quantity	23 (20.2%)
Increase in temperature	22 (19.3%)
Change in rainfall pattern	5 (4.4%)
Causes diseases	5 (4.4%)
Drought and hot weather	3 (2.6%)
Deforestation	3 (2.6%)
Increase in temperature and irregular rainfall	2 (1.8%)
Low rainfall and low production	1 (0.9%)
Total	**114 (100%)**

Table 3: Awareness of climate sensitive diseases (Response after probes/hints were given)	
Diseases	**Number (%)**
Diarrhoea	110 (40.3%)
Malaria	97 (35.5%)
Heat stress	55 (20.1%)
Malnutrition	7 (2.6%)
Dengue	3 (1.1%)
Chikungunya	1 (0.4%)
Total	**273 (100.0%)**

Table 4: Source of knowledge about climate sensitive diseases	
Sources	**Number (%)**
Health workers	36 (35.0%)
Friends	19 (18.4%)
Television	14 (13.6%)
Family members/relatives	13 (12.6%)
Radio	10 (9.7%)
School teachers	6 (5.8%)
Bill board /hoarding/posters	3 (2.9%)
Internet	2 (1.9%)
Total	**103 (100.0%)**

Table 5: Percentage of respondents who are having awareness of malaria spread	
Response	**Number (%)**
Yes	175 (79.2%)
No	46 (20.8%)
Total	**221 (100.0%)**

Table 6: How malaria spreads (according to those who are aware of malaria spread)	
Response	**Number**
Mosquito or mosquito bite	163
Both due to mosquito bite and stagnant water	6
Dirty surrounding or unhygienic environment	7
Both due to drinking dirty water and without boiling	2
Both due to mosquito bite and due to weather	1
Don't Know	2

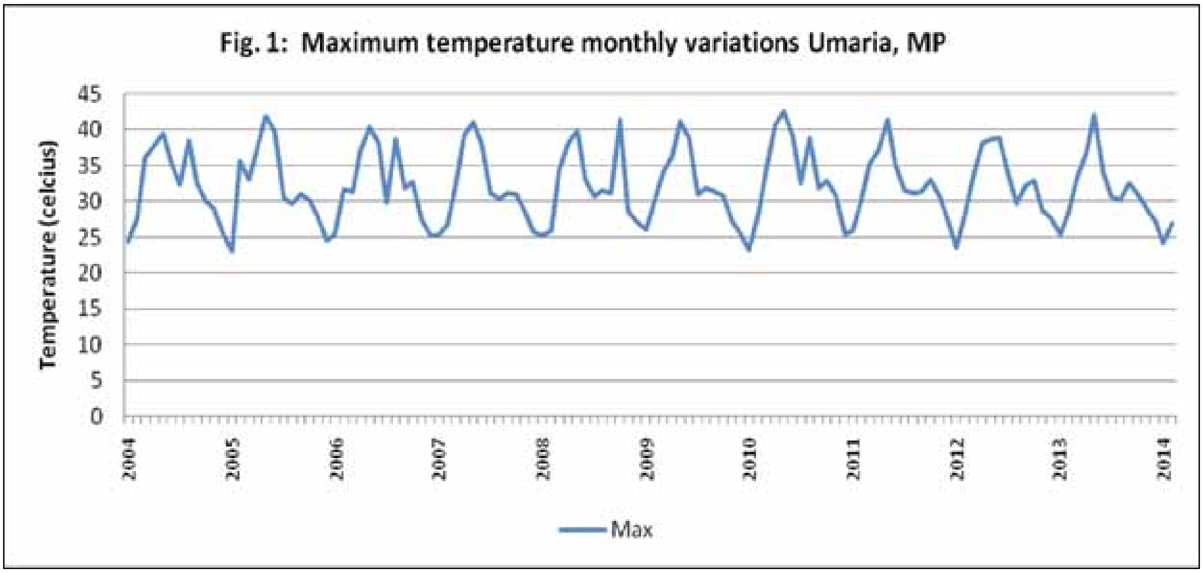
Table 7: Measures adopted at household level			
Measures	Responses		% of cases
	Number	Percent	
Use of mosquito net	88	31.8%	49.2%
Smoke of cow dung	89	32.1%	49.7%
Cover body with clothes	37	13.4%	20.7%
Smoke of foliage	35	12.6%	19.6%
Mosquito coil	13	4.7%	7.3%
Mosquito repellant liquid	5	1.8%	2.8%
Mosquito repellant mats	7	2.5%	3.9%
Putting up mesh in doors and windows	3	1.1%	1.7%
Total	**277**	**100.0%**	**154.7%**

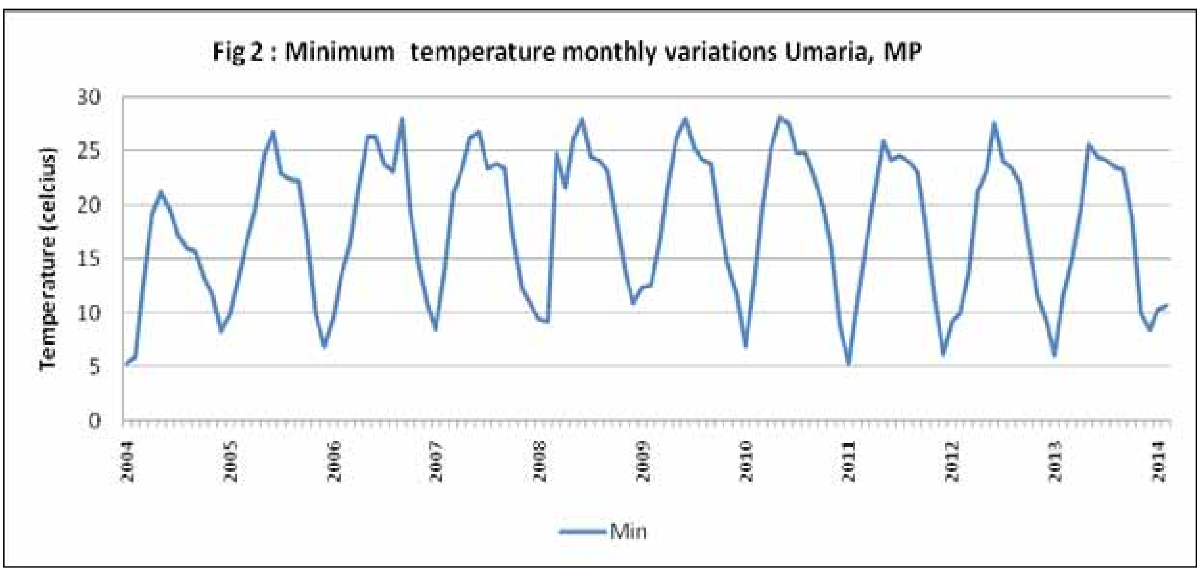
Table 8: Measures adopted to prevent breeding of mosquitoes in the vicinity			
Measures	Responses		% of Cases
	Number	Percent	
Kerosene Spray	13	25.5%	28.9%
Local insecticide spray	12	23.5%	26.7%
Cover water container	23	45.1%	51.1%
Empty water coolers	3	5.9%	6.7%
Total	**51**	**100.0%**	**113.3%**

Month wise variations in the selected meteorological parameters viz., rainfall, mean maximum temperature, minimum temperature relative humidity and rainfall have been presented in Figures 1 to 4. The mean annual maximum and minimum temperature is 32^0 and 18^0 respectively. The highest rainfall occurred in 2009. Maximum precipitation occurrd between July to September. The minimum and maximum temperatures reached 5^0 and 43^0 respectively.

Figure 5 shows the number of malaria cases reported in the district hospital of Umaria during 2007 to 2014. Data for 2008 was not available. After 2010, there has been sharp decline in the number of malaria cases. September or October were having maximum number of cases till 2011. After that there has been a sharp decline in the number of cases during these months. There has been a high pre-dominance of P. Vivax over P. falciparum. This diagram represents the number of malaria cases only at one health facility.

Monthly Variations of Temperature, Rainfall and Humidity (Umaria District)





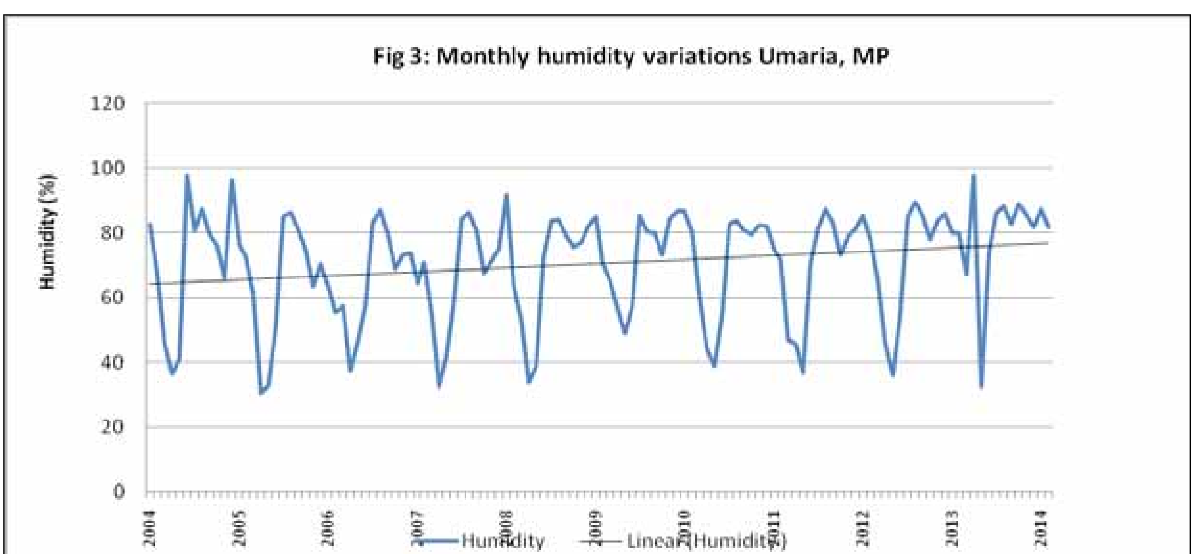


Fig 4: Monthly variations in average rainfall Umaria, MP

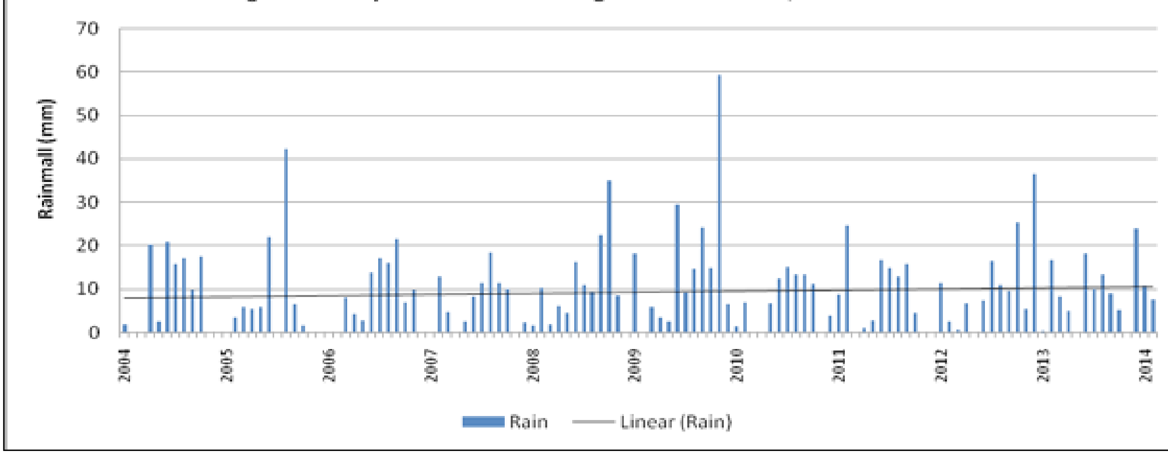


Fig 5: Monthwise malaria cases in district hospital of Umaria

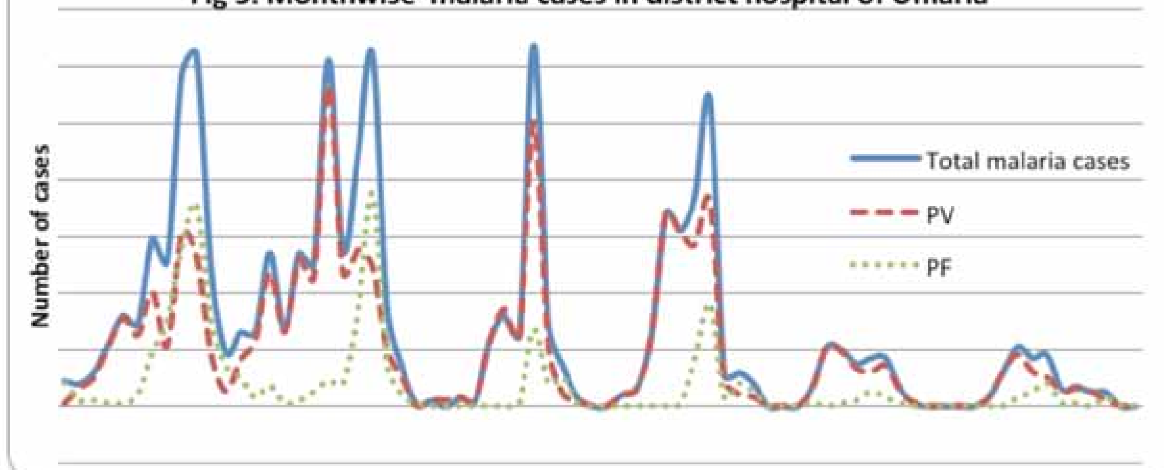
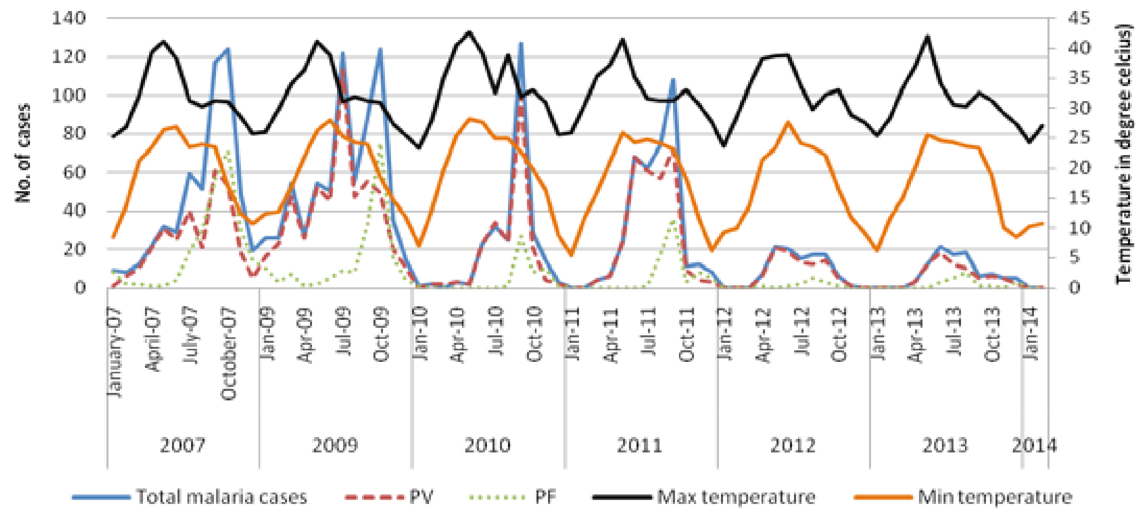


Fig 6: Monthwise malaria cases with respect to min and max temperature



2.2.4 Important Results

Community based knowledge:

Based on the quantitative and qualitative data collected from two sites in Madhya Pradesh situated in central India and two sites in J&K, it is observed that community at large do not decipher the meaning of the term climate change (or its literal translation in vernacular language). However, when assisted with probes likes changes observed in temperature, rainfall and humidity, many agreed to experience such changes mainly on temperature and rainfall variables.

So far as the impact of climate change on human health is concerned, it is found that for them it is hard to relate climate change with the diseases such as malaria without any probing assistance. Nevertheless, in terms of awareness and knowledge related to malaria transmission, its symptoms, treatments, and prevention strategies, more or less half of community members had complete and correct knowledge.

So far as the health related data collection is concerned, the presence of private health facilities and penetration of local unregistered medical practitioners in interior pockets make it difficult to account malaria cases treated by them into the national reporting system.

2.3 Impact of Irrigation Change on the Prevalence of Malaria in Arid and Non-arid parts of Rajasthan

2.3.1 Approved Objectives of the Project

i. To study the impact of irrigation change on the ecological conditions with respect to vector prevalence and malaria incidences.
ii. To determine key factors influencing vector/malaria prevalence and distribution using RS and GIS.

2.3.2 Studies Undertaken

Two ecologically different districts, Jaisalmer and Banswara have been considered for the studies. Villages in these two districts were selected from two areas, one having irrigation facilities and the other one being devoid of any irrigation facility except rains.

For entomological studies 10 households were inspected for detecting the presence of mosquito and immature stages and all potent breeding habitats/containers and their conditions will be recorded during each visit. The major water sources of the village were inspected in each survey, including the public containers for cattle, for detecting the mosquito breeding. Incidences of malaria in village were recorded actively by surveillance collecting slides of all fever cases during survey and passively through PHC/CHC level malaria data of the selected villages.

Geographic Reconnaissance (GR) wasmade for each village by using GPS and details of households, water body size, etc. The collected information of each village were linked with space imagery (RS image) through GIS software to add ground attributes of temperature, rainfall, soil type, vegetation and water bodies present. The variation in ecological factors like temperature, RH, etc. were also recorded.

Space imageries during three seasons i.e. pre-monsoon, post monsoon and winters wereacquired from Regional Remote Sensing and Application Centre (RRSC), Jodhpur. The ecological change detection were carried out using the expertise of RRSC by suitable methods such as image, vegetation deference, selective e principal component analysis, multi-date classification and combination image analysis to achieve accurate assessment of change.

The following entomological and epidemiological studies were undertaken:

Entomological studies:

- Collection methods of mosquito adults and immatures from different habitats, their storage and transportation from field to laboratory
- Identification of both adult and immature stages
- Mosquito colonization in the insectary
- Incrimination of the vector species-gut and gland infection detection

Epidemiological studies:

- Collection of blood slides

Examination of blood smears for the detection of malaria parasite infections Jaisalmer and Banswara villageswereselecetdto carry-out the studies and in both the districts the study areas were identified. In Banswara district, two areas, Kushalgarh Block, which represent characteristics of rain fed agriculture and Partapur block, characterized by canal irrigated agriculture, have been included. In Kushalgarh block four villages *viz*., Bhagatpura, Potaliya, Churada and Nathpura have been included in the study based on the past malaria incidences, whereas from Partapur block four villages namely Kheda, Nawagaon, Bhagora and Bodiya have been selected (Fig. 1).

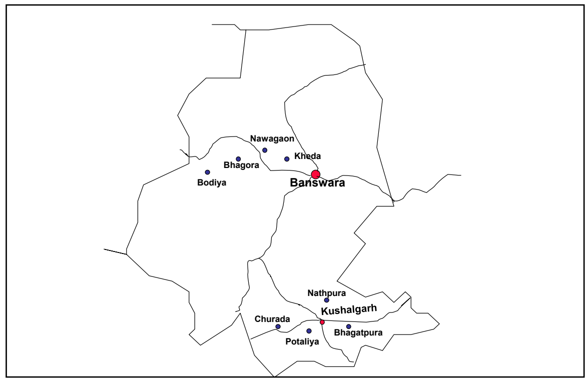


Fig. 1: Map of Banswara district showing study villages

In Jaisalmer district too two study areas were selected i.e. Nachna Block which represent the canal irrigated agriculture and Pokaran Block which represent desert characteristics and has rain-fed agricultural practices. In Nachna block four villages *viz*., Awai, Madasar, Sankaria and ShekhonkaTala in Canal irrigated area have been considered for the study.However, in Pokaran block the selected study villages are Ujjala, Mandwa, Beethuwas and Jhalaria (Fig. 2).

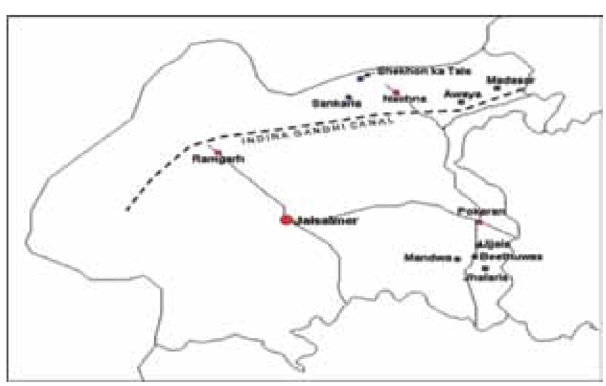


Fig. 2: Map of Jaisalmer district showing study villages

2.3.3 Important Results

Impact of Irrigation:

Results based on field studies in Rajasthan show that the environmental conditions prevailing in canal irrigated areas are more supportive to anopheline fauna than those prevailing in non-irrigated areas. The conditions include the intra-domiciliary temperature records and relative humidity range. There are high percentages of gravid females in canal irrigated area of Banswara and Jaisalmer districts which need more attention.

Chapter 3
Thematic Area "Air Pollution and Health"

Climate change affects air quality through several pathways including increase in toxic gases, particulate matters and production and allergenicity of aeroallergens such as pollen and fungal spores and increases in regional ambient concentrations of pollutants, ozone, fine particles, and dust. Precipitation-affected aeroallergens such as mold spores also are of concern. Some of these can directly contribute to bronchial asthma, or exacerbate it in susceptible individuals. Studies also link elevated exposure to ground-level ozone, fine particulates, and aeroallergens to decreased pulmonary function, aggravation of asthma, exacerbations of chronic obstructive pulmonary disease, rhinitis, hospitalizations for respiratory and cardiovascular diseases, and premature mortality. Physiology also plays a significant role, as individuals with existing respiratory conditions are most vulnerable to disease exacerbations triggered by the environment. Airborne fungal spores are well known to cause respiratory allergic diseases like bronchial asthma, allergic rhinitis, rhino-conjunctivitis and allergic bronchopulmonaryaspergillosis in both adults and children. Flares of Rheumatoid Artherities and autoimmune diseases are also known to be affected by pollutants. Some data are available to suggest that the frequency of outpatient visits, emergency room visits, and disease exacerbations are related to weather conditions. Variations in ambient pollutant levels may act as triggers for airway inflammation. In addition, temperature and humidity variations can influence levels of airborne pollutants such as pollen and molds. While these reports provide a tantalizing link between weather conditions / air quality on episodic worsening of asthma and ambient outdoor environmental conditions, there is no data on more short-term fluctuations in disease parameters of otherwise seemingly stable asthmatics.

The three projects sponsored under this theme were the following:

- **To study the effect of climate, air pollution and socioeconomic factors on health (Immunological) disease state (Rheumatoid Arthritis)**
- **Effect of seasonal variation in airborne fungal spore load on bronchial asthma and its control: a longitudinal study in north Indian adults**
- **Impact of climate variability and change on respiratory health, morbidity and m*ortality***

3.1 Effect of Climate, Air Pollution, and Socio-Economic Factors on Health (Immunological) and Disease State (Rheumatoid Arthritis)

3.1.1 Approved Objectives of the Proposal

Rheumatoid arthritis is a chronic inflammatory autoimmune disorder that typically affects the small joints in hands and feet. Environmental factors may play in the flare of the symptoms in patients having rheumatoid arthritis. Patients with rheumatoid arthritis often complain that certain meteorological conditions aggravate their disease symptoms.The prevalence of rheumatoid arthritis as studied in the adult Indian population near Delhi in the year 1993 was 0.75%. When projected to the whole population it becomes 7 million patients in India. Rheumatoid arthritis affects people differently. Some people have mild or moderate forms of the disease, with periods of worsening symptoms, called flares, and periods in which they feel better, called remissions. Others have a severe form of the disease that is active most of the time, lasts for many years or a lifetime, and leads to serious joint damage and disability. Incidence of autoimmune diseases has increased in past decades which not explainable with only genetic changes. It is realized that environmental factors affect the immunological health of individuals and in genetically predisposed individual cause apparent autoimmune disease. Review of the existing literature indicates that weather influences the flare of the joint symptoms in rheumatoid arthritis patients.In some studies the influence of low temperature, high humidity and high barometric pressure is found. To investigate the effects of weather conditions on the worsening in rheumatic patients due to RA related conditions, the following specific objectives are set inthis project:

1) Identifying modifiable climate and air pollution risk factors causing intermittent exacerbations of RA disease activity and non-response to treatment in rheumatoid arthritis.

(2) Developing knowledge network among institutions engaged in climate research and also promote data sharing.

(3) Identifying vulnerable population for autoimmune diseases because of climatic factors and to develop strategies needed to avoid health risks.

3.1.2 Studies Undertaken

Case records of 1500 rheumatoid arthritis (RA) patients who reside in Delhi for more than 10 years are retrieved from rheumatology clinic and outpatient department of Medicine and out of which 500 patients who fulfilled inclusion criteria were recruited in the study. Patients are called for follow up and their written consent have been taken. Out of 500 patients, 86.4% (432) are females and 13% (68) are male. The mean age of female and male patients is 43 ± 11years and 48±10 years respectively. Joint disease activity in RA patients are recorded at four time intervals (Jan-Feb, May-Jun, Jul-Aug and Nov- Dec) from case sheets and patient recall. Majority of patients have joint disease flare during Jan and Feb followed by Nov and Dec (as shown in Table 1). Here the flares are defined as increased numbers of swollen, tender joints and increased duration of early morning stiffness (or 'active joint disease' written in the case records of patients).

Table 1 Disease activity in RA patients (N=500) during 2008-2013

Months	2008	2009	2010	2011	2012	2013
Jan-Feb	300	312	288	290	296	328
May-Jun	83	93	94	91	89	70
Jul-Aug	90	106	82	73	74	87
Nov-Dec	204	224	214	196	187	198

Air quality data are provided by IMD for the years 2008-2009. The patients were segregated into five zones of Delhi i.e. East, West, North, South and Central zone for the purpose of statistical analysis to correlate air quality parameters with the flare of disease.

The disease activity has been recorded and compared with the air quality parameters from 2008 to 2009 at four time intervals in each year (Jan-Feb, May-Jun, Jul-Aug and Nov- Dec).

3.1.2.1 Retrospective component of study:

It is found that in 2008, PM2.5 levels are positively correlated with joint disease activity in North Delhi zone only ((Pearson r= 0.88, p value =0.05), but not in other four zones.

In 2009, joint disease activity positively correlated with PM2.5 in South zone (Pearson r = 0.97; p value =0.013) and West zone (Pearson r = 0.99; p value =0.001),East zone (Pearson r = 0.89; p value =0.05) North Zone (Pearson r= 0.93, p value =0.013) and total Delhi region (Pearson r = 0.90; p value =0.048).

PM10 co-related with disease activity in the entireDelhi region in the year 2008 (Pearson r= 0.943; p value= 0.02). Patients residing in North Delhi region had flare of disease in the year 2008 (Pearson r=0.93; p value =0.03). PM10 correlated with disease activity in South Delhi (p value = 0.018 Pearson r=0.96) region in 2009.

NOx inversely correlated with disease activity in West Delhi zone (Pearson r = -0.91; p value =0. 04) and East Delhi zone **(**Pearson r = -0.90; p value =0.01**)** in 2008.

It was found that SOx correlated with disease activity in Central Delhi(Pearson r = 0.93;p value =0.03) in 2008 and Central Delhi (P value = 0.013 Pearson r=0.97) zone in year 2009.

3.1.2.2 Prospective component of study:

In the prospective part of the study, the disease activity score is calculated by DAS 28 ESR to know the status of the disease activity during Jan-Feb and May –Jun 2014.It is found that 27.8% (139) patients have high disease activity, 16% (80) patients have moderate disease activity, 5.6% (28) have low disease activity and 50.6% (253) are in remission during Jan-Feb 2014.

During May–Jun 2014, 13.4% (67) patients had high disease activity, 17% (85) patients had moderate disease activity, 9.2% (46) had low disease activity and 60.4% (302) were in remission as per DAS 28 score.

300 normal subjects were recruited as controls in the study after screening 500 normal subjects who are staying in Delhi for past 10 years. 10ml blood was drawn for various pre-identified investigations. Sera were stored at -70^{0}C which was subsequently analyzed. There were 81.6% females and 18.3% (55) males. Blood sample analysis revealed positive tests for ANA 8.6% (26), Anti CCP antibody 3% (9),and RF 8.3% (25),and elevated inflammatory markers TNF 6.3% (19), IL17 A8.3%(25) IL1β 9(3%), IL6 4.3% (13) hscrp 9% (27).

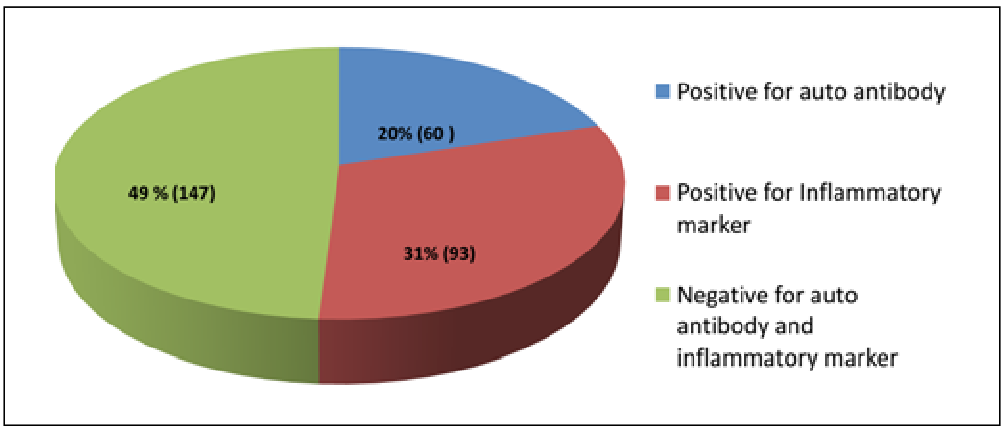


Figure 1 Percentage of patients having autoantibodies positivity and raised inflammatory markers

3.1.2.3 Patient recruitment:

Following are the inclusion and exclusion criteria for patient recruitment:

Inclusion criteria

1. RA patients fulfilling ACR (1987) classification criteria.
2. Patients staying in Delhi and NCR region for which climate and air pollution data areavailable.
3. Disease activity data available at 8-10 time points (Jan/Feb, May/June, Nov/Dec) during 2008-2013.
4. Patients giving consent to participate in this study

Exclusion criteria

1. Overlap syndrome.
2. Patients relocated or planning to relocate to areas other than Delhi/NCR in next three years from the start of the study.

3.1.2.4 Control recruitment:

Following are the inclusion and exclusion criteria for the control case:

Inclusion criteria

1. Normal healthy individuals residing in the same areas as patients preferably

from the same house.
2. Giving consent to participate in the study.

Exclusion criteria
1. Individuals detected having diabetes and renal dysfunction.

Age, gender, and body mass index (BMI) ofnormal healthy subjects residing in the same location for more than one year (preferably from the same house as the patients) are matched with thoseare recruited. Baseline information regarding years of stay at a particular location, smoker/ex-smoker, occupation, duration of sun exposure/outdoor, distance of the house from main road and petrol pump (ring road/main branch road) are also recorded. They were given questionnaire to fill regarding musculoskeletal and general health. 15-20 ml blood sample were collected for various investigations like Hemoglobin, TLC, DLC, Platelet, ESR, B Sugar, blood urea, S CreatininehsCRP, IL-6, IL-17, IL-1β, TNFα, Immunoglobulin levels,C3, C4, Serum 25 hydroxy vitamin D levels and oxidized LDL.Rheumatoid factor, Anti-nuclear antibody, Antineutrophilic cytoplasmic antibody, aCL (IgG, IgM), anti β2 glycoprotein-1,AntiDs DNA, LAC.

3.1.2.5 List of zones and locations selected in Delhi region:

Delhi has been divided in to the following five zones.

Table 1: Zones and areas in Delhi

S. No.	Name of zone	Areas in detail
1	South	HauzKhas, Malviya Nagar, Saket, PushpVihar, Mehrauli, Defence Colony, GulMohar Park, AIIMS, Lodhi Colony, PragatiVihar, Khanpur, Lajpat Nagar, Amar Colony, Garthi, Okhla, Sunlight Colony, New Friends Colony, SukhdevVihar, Bharat Nagar, Hz. Nizammudin, Jangpura, Sarai Kale Khan, Greater Kailash, Chitranjan Park, Ambedkar Nagar, Madangir, Sainik Farm, Kalkaji, Nehru Place, Badarpur, SaritaVihar, SangamVihar, East Kidwai Nagar, Panchasheel. VasantVihar,VasantKunj, Nanak Pura, Vinay Nagar, R.K. Puram,
2	North	Civil Lines, Bela Road, MajnuKaTila, SantNagar, Roop Nagar, Maurice Nagar, Shakti Nagar, Subzimandi, Tis Hazari, RanaPratapBagh, AndhaMugal, GulabiBagh, SaraiRohilla, InderLok, Sadar Bazar, AhataKedara, Bara Hindu Rao, Kashmere Gate, Sultanpuri, Mangolpuri, Narela, Kanjhawala, Ashok Vihar, Wazirpur, SaraswatiVihar, Pitampura, Rani Bagh, PrashantVihar, Jahangirpuri, Adarsh Nagar, Bawana, Alipur, Auchandi Border, Sameypur-Bodli, Mukherjee Nagar, Azadpur, Model Town, Sangam Park, Vijay Nagar, KeshavPuram, Shalimar Bagh, Rohini, Kingsway Camp, Nangloi.

3	**East**	Kalyanpuri, New Ashok Nagar, Trilokpuri, 27-Blk Trilokpuri, MayurVihar I & II, MandawaliFazad, VivekVihar, Laxmi Nagar, Patpargang, Gazipur, Anaz Mundi, AnandVihar, New ShahdaraKarkardooma, PreetVihar, Shakarpur, Gandhi Nagar, Krishna Nagar, Old Sheelampur, Gita Colony, Jheel. Seelampur,GokulPuri, KhazuriKhas, Karawal Nagar, BhajanPura, Yamuna ViharGamri, Shahdra, Welcome Colony, Mansarover Park, SeemaPuri, G.T.B. Nagar, NandNagri, Ashok Nagar, Sunder Nagri, Harsh Vihar.
4	**West**	Patel Nagar, Anand Parbat, Moti Nagar, Tilak Nagar, Khayala, Janakpuri, Uttam Nagar, Matiyala, Punjabi Bagh, VikasPuri, MeeraBagh, Madipur, PaschimVihar, Miawali Nagar, Mangolpuri, Tikri Border, Raja Garden, Rajouri Garden, Mansarover Garden, MIG Flats Hari Nagar, Kirti Nagar, Raghubir Nagar, Delhi Cantt., DhaulaKuan, Palam Colony, Palam Village, Dabri, Raghu Nagar,Naraina, Inderpuri, Mayapuri, Najaf garh, Kapashera, Jafferpur, Samalakha,
5	**Central**	Kotwali, Mori Gate, Red Fort, Yamuna Bazar, Lahori Gate, Church Mission, Town Hall, NaiSarak&ChandniChowk, Darya Ganj, ChandiniMahal, Turkman Gate, Jama Masjid, Kamla Market, Shahganj, HauzQuazi, Ballimaran, Lalkaun, I.P. Estate, LNJP Hospital, PaharGanj, DBG Road, Shidipura, Govt. Qtr. Dev Nagar, Karol Bagh,Prasad Nagar, Rajender Nagar, Pusa Road, Sita Ram Bazar, Sangtrashan, NabiKarim, Parliame ntStreet,ChanakyaPuri,ConnaughtPlace,BoatClub,North Avenue, South Avenue, MalchaMarg, R.M.L Hospital, SucheetaKriplani Hospital, Panckuian Road, Gole Market,Tuglak Road,Mandi House, Bapa Nagar, Rabindra Nagar, Kaka Nagar

In the present study, 500 patients of rheumatoid arthritis with regular follow up at AIIMS OPD have been recruited. There are 86.4% (432) females and 13% (68) male patients residing in Delhi for more than 10 years. The mean age of females and males are 43±11 years and 48±10 years respectively. Mean disease duration in males and females are10.2±4.9 years and 9.9±4.5 years respectively.

Out of the total number of patients, 20.4% (102) patients have hypothyroidism, 31.4% (157) have Hypertension, 7.8% (39) have Diabetes Type II and 5.2 % (26) patients have more than one co-morbidities associated with RA.

16.2% (81) patients were employed and 83.8% (419) patients were financially dependent on their family.There was a history of smoking in 5% (25) of patients and 26.6% (133) were passive smokers. 16.8% (84) patients had family history of rheumatoid arthritis. Majority of our patients belonged to middle class.

Table 2 Distribution of patients in various socioeconomic strata

S.no	Income group	Income in Rs per month	No. of patients (%)
1	Poor	Less than Rs 12,0000	15 (3%)
2	Lower Middle Class	Rs 12000- Rs 25000	27 (5.4%)
3	Middle Class	Rs 25,000- Rs 80,000	452 (90.4%)
4	Upper Middle class	Rs 80,000- Rs 2,00,000	6 (1.2%)

The numbers of patients segregated in to 5 zones in Delhi are given in Figure 2.

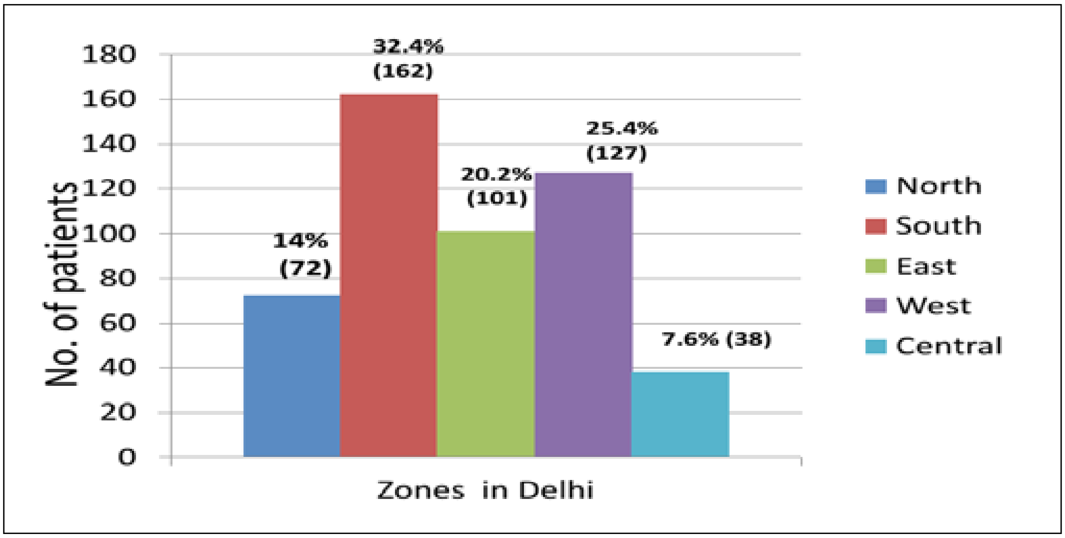
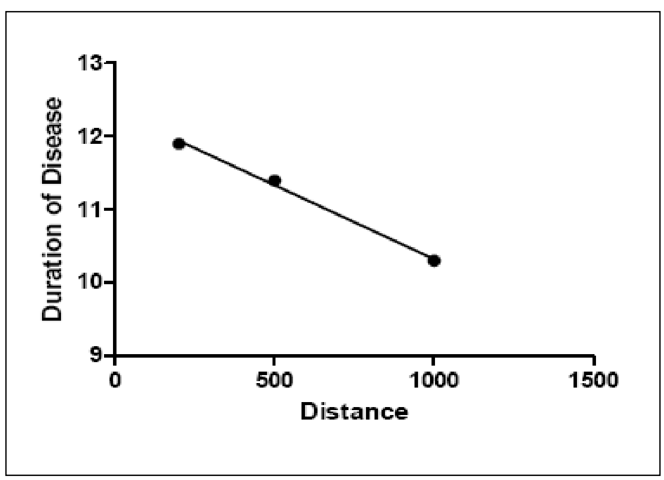


Figure 2 Distribution of patients in various zones of Delhi

The number of patients residing near the branching road has longer duration of disease than the patients staying 1000 meter far away the branching road.



p value=0.0445, R2= 0.99: 95% CI: Non parametric correlation

Figure 3 Correlation of disease duration with distance between residences and branching road (main road)

The study has been divided into two parts:

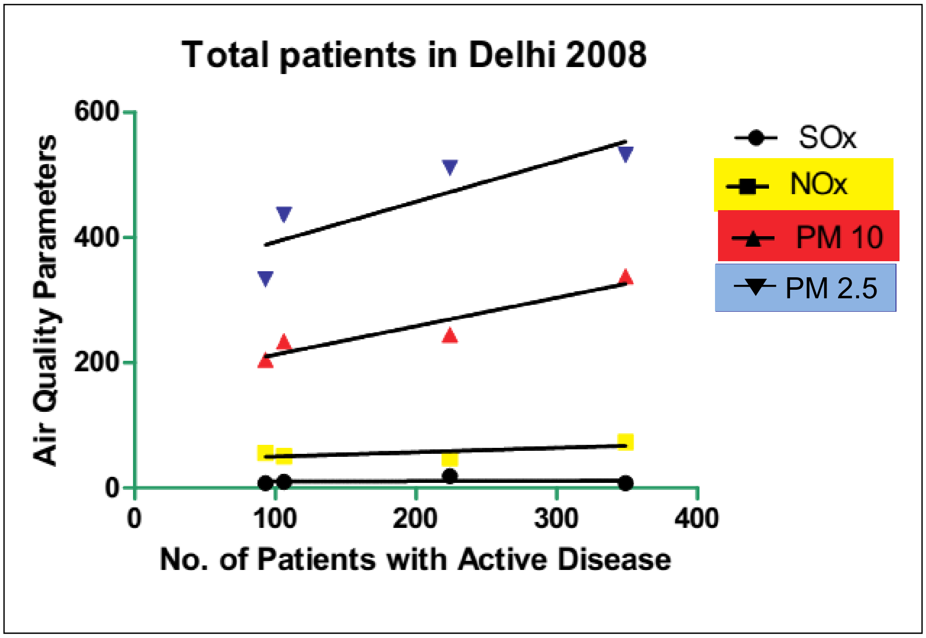
3.1.3.1 Part I (RETROSPECTIVE PART OF THE STUDY)

The overall status of disease activity of all the patients recruited in NCR Delhi is mentioned below year wise.

Table 3 Distribution of disease activity and air quality parameters during the years 2008 and 2009

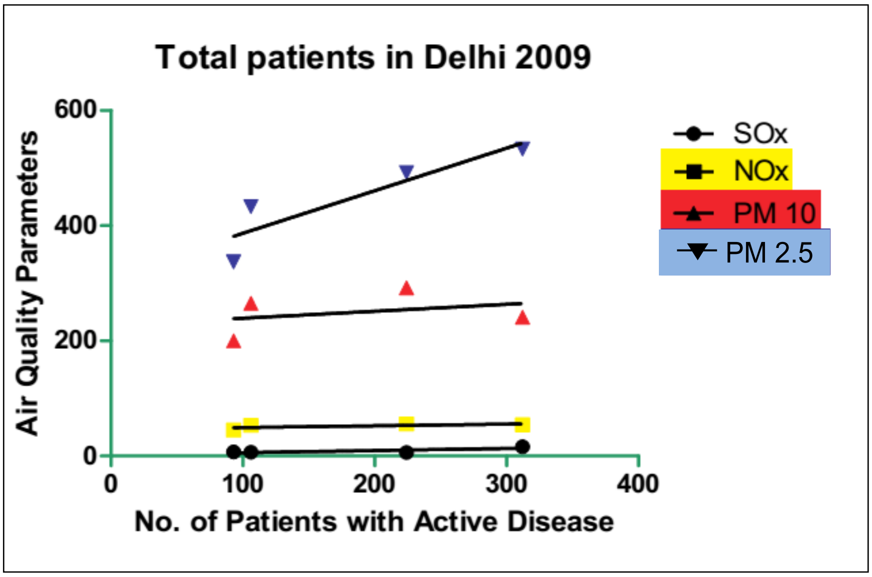
Month	No. of Patients with active disease		Available Air Quality Parameters							
			SOx		NOx		PM10		PM2.5	
	2008	2009	2008	2009	2008	2009	2008	2009	2008	2009
Jan-Feb	**300**	**312**	7.5	16	73.1	54.0	338.	241.	532.	533.
May-Jun	**83**	**93**	7.6	7	55.7	45.0	205.	200.	333.	337.
July-Aug	**90**	**106**	9.6	6.5	50.7	53.3	234.	265.	436.	433.
Nov-Dec	**204**	**224**	19.3	6.4	47.8	55.9	245.	292.	511.	492.

Statistical analysis was undertaken to study the correlation of RA disease activity with various air quality parameters. Figure 4 shows that PM10 is significantly correlated with the flare of disease in 2008. Whereas, Figure 5 indicates that PM2.5 is significantly correlated with the flare of disease in the year 2009. Further, Figure 6 shows that PM10 is significantly correlated with the flare of disease in 2008 in North Delhi. As per Figure 7, PM2.5 is significantly correlated with the flare of disease in 2009 in North Delhi.



PM10 = Pearson; r = 0.94; p value =0.028.
NOx= Pearson; r = 0.71; p value =0.14.
PM2.5= Pearson; r = 0.85; p value =0.072
SOx= Pearson r = 0.08; p value =0.45

Figure 4 Correlation of RA disease activity with various air quality parameters in 2008



PM10 = Pearson; r = 0.32; p value =0.33.

PM2.5= Pearson; r = 0.90; p value =0.048

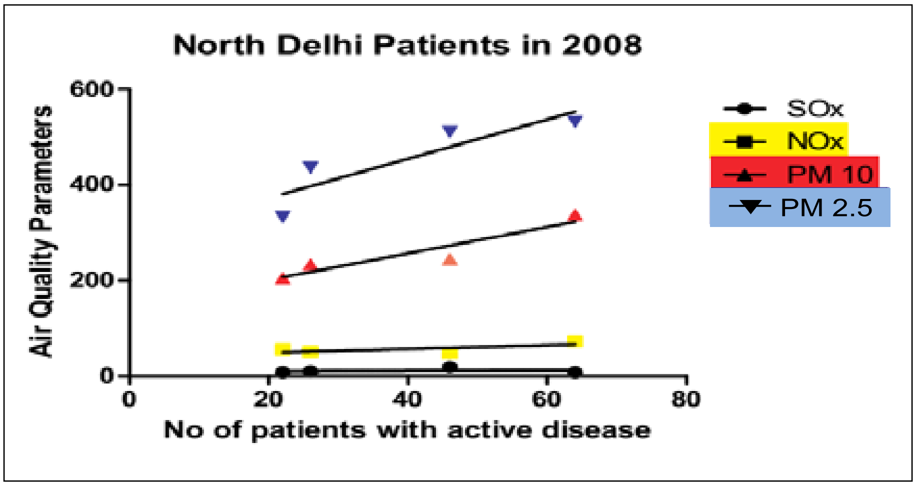
NOx= Pearson; r = 0.63; p value =0.18.

SOx= Pearson; r = 0.80; p value =0.10

Figure 5 Correlation of RA disease activity with various air quality parameters

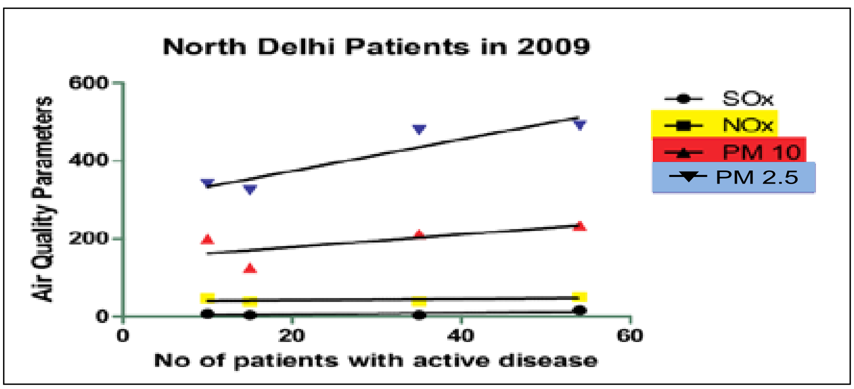
Table 4 Distribution of disease activity and air quality parameters during 2008 and 2009 in North zone

Months	No. of Patients with active disease		**Available Atmospheric Parameters**							
			SOx		**NOx**		**PM10**		**PM2.5**	
	2008	2009	2008	2009	2008	2009	2008	2009	2008	2009
Jan-Feb	64	54	7.5	15.5	73.1	51.5	338	234	532	491
May –Jun	22	10	7.6	7	55.7	48	205	199	333	341
July-Aug	26	15	9.6	4	50.7	37.6	234	125	436	324
Nov-Dec	46	35	19.3	4.2	47.8	38.4	245	212	511	479



PM10 = Pearson; r = 0.93; pvalue=0.03. PM2.5= Pearson; r=0.88; p value =0.05
NOx = Pearson; r = 0.67; pvalue=0.16. SOx= Pearson; r = 0.14; p value =0.42

Figure 6 Correlation of RA disease activity with various air quality parameters in 2008 in North Delhi

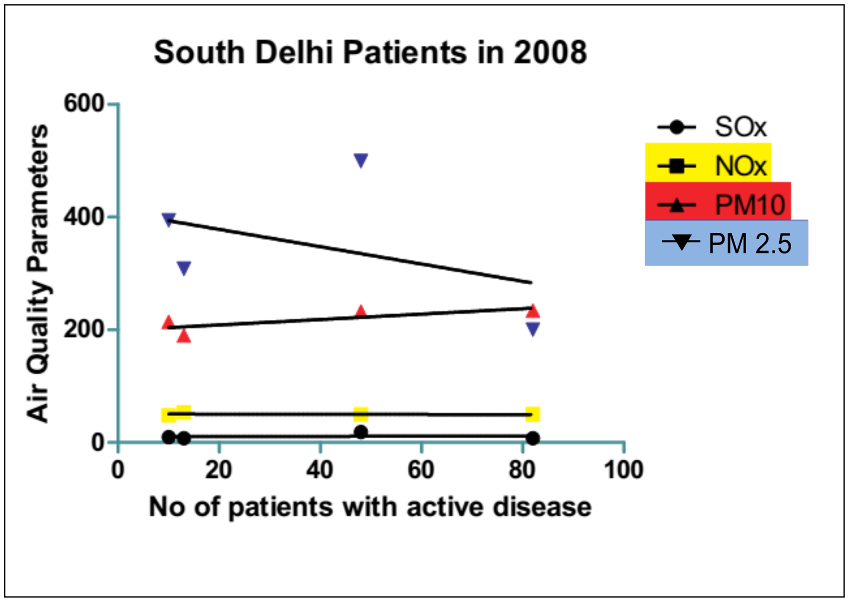


PM10 = Pearson; r = 0.69; p value=0.15. PM 2.5= Pearson; r= 0.93; p value=0.03
NOx= Pearson; r = 0.39; p value =0.30. SOx= Pearson; r = 0.73; p value =0.13

Figure 7 Correlation of RA disease activity with various air quality parameters in 2009 in North Delhi

Table 5 Distribution of disease activity and air quality parameters during 2008 and 2009 in South zone

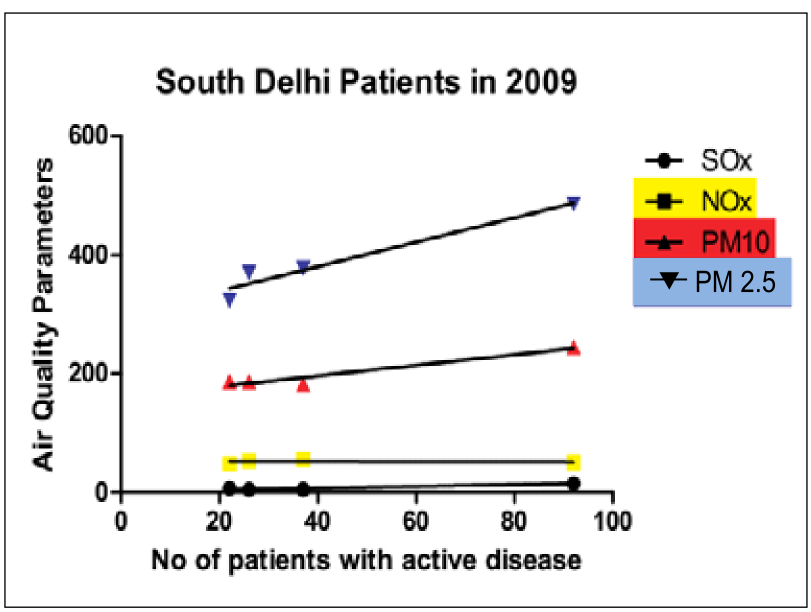
Month	No. of Patients with active disease		Available Atmospheric Parameters							
			SOx		NOx		PM10		PM2.5	
Months	2008	2009	2008	2009	2008	2009	2008	2009	2008	2009
Jan-Feb	82	92	7.5	14.9	50	50.1	234	245.	200	486.
May –Jun	13	22	7.7	6.5	53.3	48.2	190	187.	308	324.
July-Aug	10	26	9.6	4.8	48.2	52.3	214	187.	394	370.
Nov-Dec	48	37	18.8	4.6	49.5	55.6	232	182.	499	378.



PM10 = Pearson; r = 0.79; p value =0.10. PM2.5= Pearson; r = -0.40; p value0.29
NOx= Pearson; r = -0.16; p value =0.41. SOx= Pearson; r = 0.08; p value =0.45

Figure 8 Correlation of RA disease activity with various air quality parameters in 2008 in South Delhi

Figure 8 indicates that flare of joint disease has no correlation with the air quality parameters.



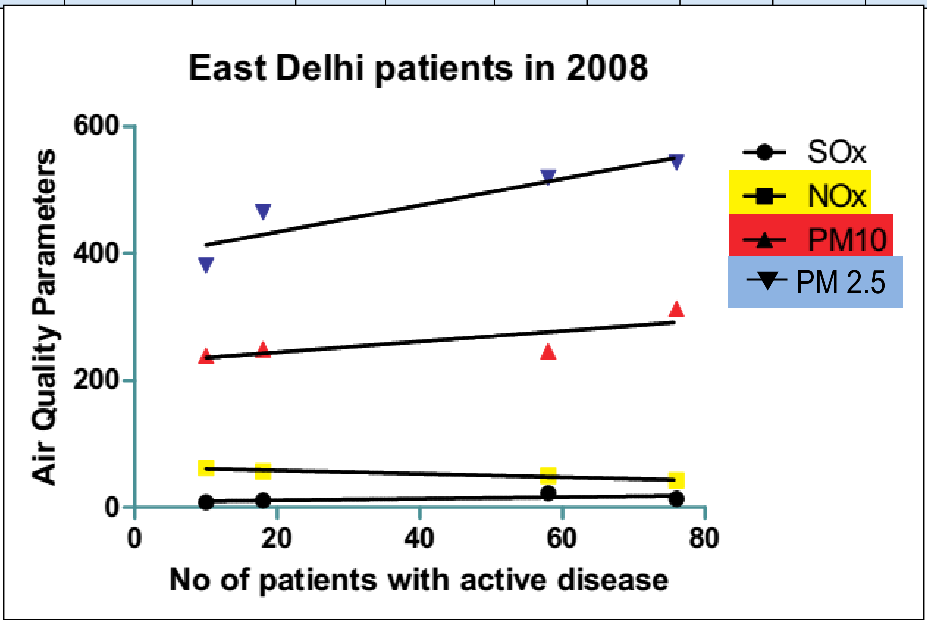
PM10 = Pearson; r = 0.96; p value =0.018 PM2.5= Pearson; r = 0.97; p value =0.013
NOx= Pearson; r = -0.12; p value =0.40 SOx= Pearson; r = 0.93; p value =0.03

Figure 9 Correlation of RA disease activity with various air quality parameters in 2009 in South Delhi

Figure 9 shows that flare of disease is correlated with PM10, PM2.5, and SOx.

Table 6 Distribution of disease activity and air quality parameters during the years 2008 and 2009 in East Delhi

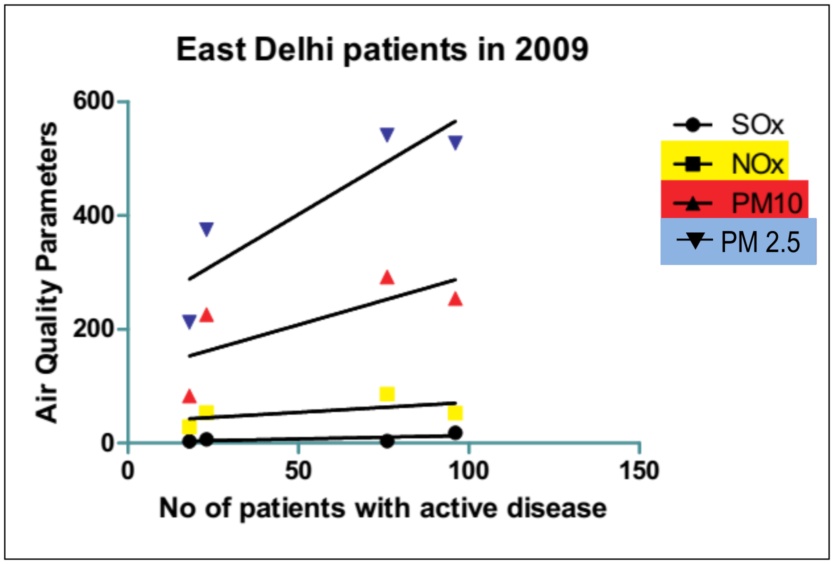
Months	No. of Patients with active disease		Available Atmospheric Parameters							
			SOx		NOx		PM10		PM2.5	
	2008	2009	2008	2009	2008	2009	2008	2009	2008	2009
Jan-Feb	83.	96	13.6	18.0	42.9	52.9	313.	254.	543.	527.
May –Jun	25.	23	8.4	6.8	62.7	53.6	239.	226.	381.	375.
July-Aug	27.	18	11.1	3.1	56.5	28.7	249.	83.	465.	212.
Nov-Dec	50.	76	22.7	3.5	50.0	86.0	246.	292.	519.	541.



PM10 = Pearson; r = 0.92; p value =0.03
NOx= Pearson; r = -0.90; p value =0.01
PM2.5= Pearson; r = 0.77; p value =0.11
SOx= Pearson; r = 0.63; p value =0.18

Figure 10 Correlation of RA disease activity with various air quality parameters in 2008 in East Delhi

Figure 10 shows that PM2.5 is positively correlated and NOx is inversely correlated with the flare of disease.



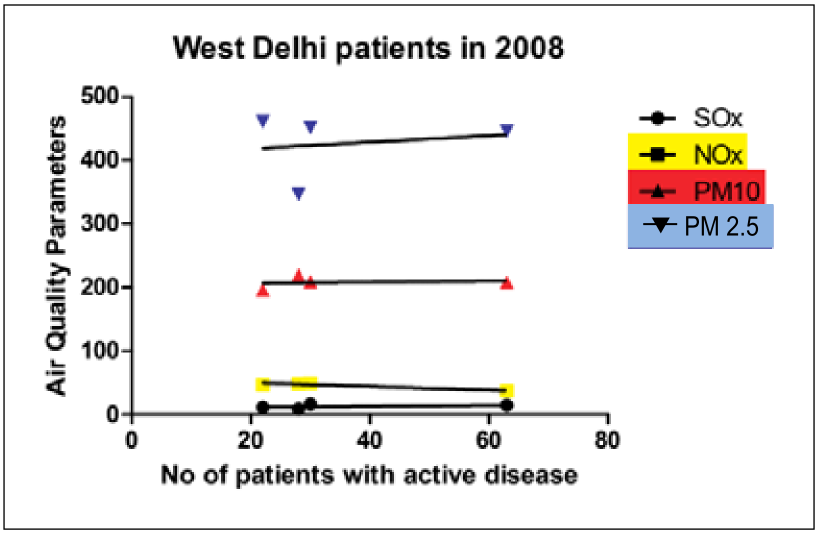
PM10 = Pearson; r = 0.72; p value =0.13.
PM2.5= Pearson; r = 0.89; p value =0.05
NOx= Pearson; r = 0.57; p value =0.21.
SOx= Pearson; r = 0.65; p value =0.17

Figure 11 Correlation of RA disease activity with various air quality parameters in 2009 in East Delhi

Figure 11 depicts that PM2.5 is positively co-related with the flare of disease in East Delhi.

Table 7 Distribution of disease activity and air quality parameters during the years 2008 and 2009 in West Delhi

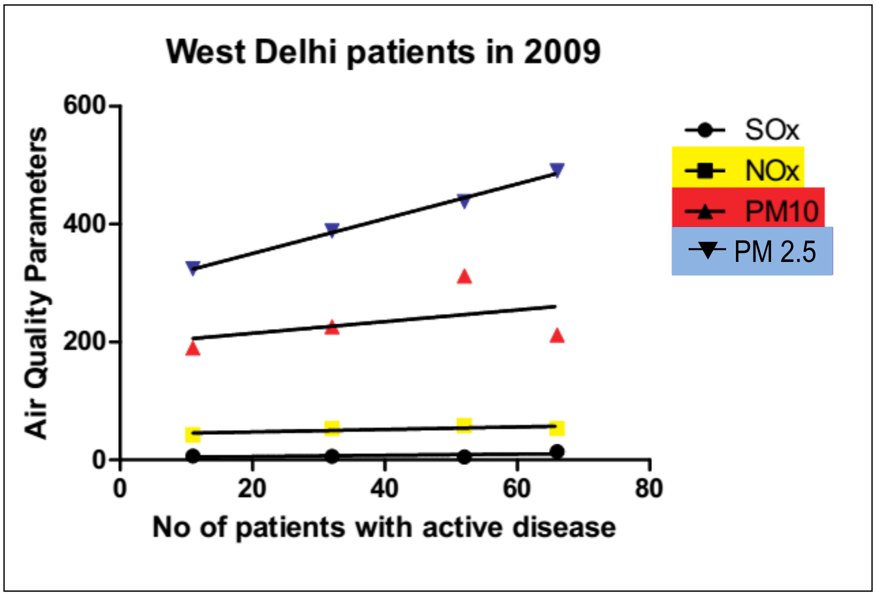
Months	**No. of Patients with active disease**		**Available Atmospheric Parameters**							
			SOx		**NOx**		**PM10**		**PM2.5**	
	2008	2009	2008	2009	2008	2009	2008	2009	2008	2009
Jan-Feb	63	66	14.8	14.0	36.9	53.1	196.	212.	446.	490.
May –Jun	28	11	8.8	6.7	48.7	42.7	208.	190.	347.	324.
July-Aug	22	32	11.4	6.3	46.5	53.3	219.	226.	461.	388.
Nov-Dec	30	52	16.3	5.1	49.5	58.4	209.	312.	452.	438.



PM10 = Pearson r = 0.14; p value =0.42.
NOx= Pearson r = -0.91; p value =0. 04.
PM2.5= Pearson r = 0.17; p value =0.41
SOx= Pearson r = 0.45; p value =0.27

Figure 12 Correlation of RA disease activity with various air quality parameters in 2008 in West Delhi

Statistically NOx has been found to be significantly inversely related with flare of disease.



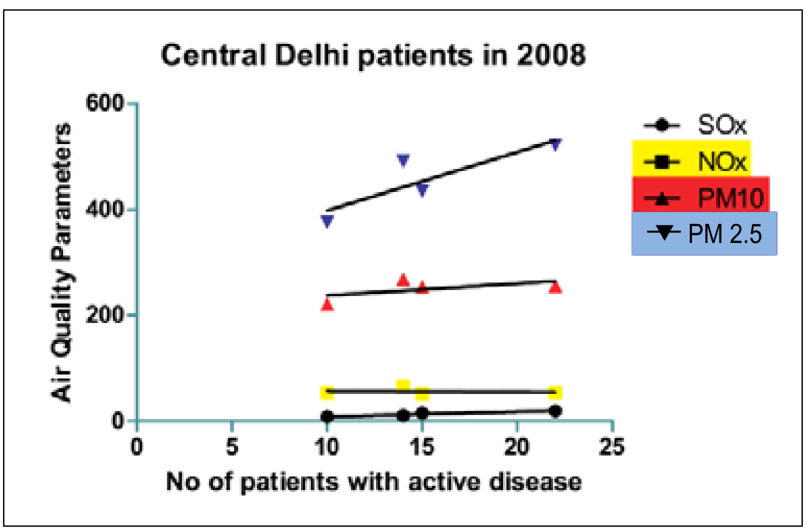
PM10 = Pearson; r = 0.44; p value =0.27.
NOx= Pearson; r = 0.76; p value =0.11.
PM2.5= Pearson; r = 0.99; p value =0.001
SOx= Pearson r = 0.59; p value =0.20

Figure 13 Correlation of RA disease activity with various air quality parameters in 2009 in West Delhi

Figure 13 shows that PM2.5 is significantly correlated with flare of disease in West Delhi.

Table 8 Distribution of disease activity and air quality parameters during the years 2008 and 2009 in Central Delhi

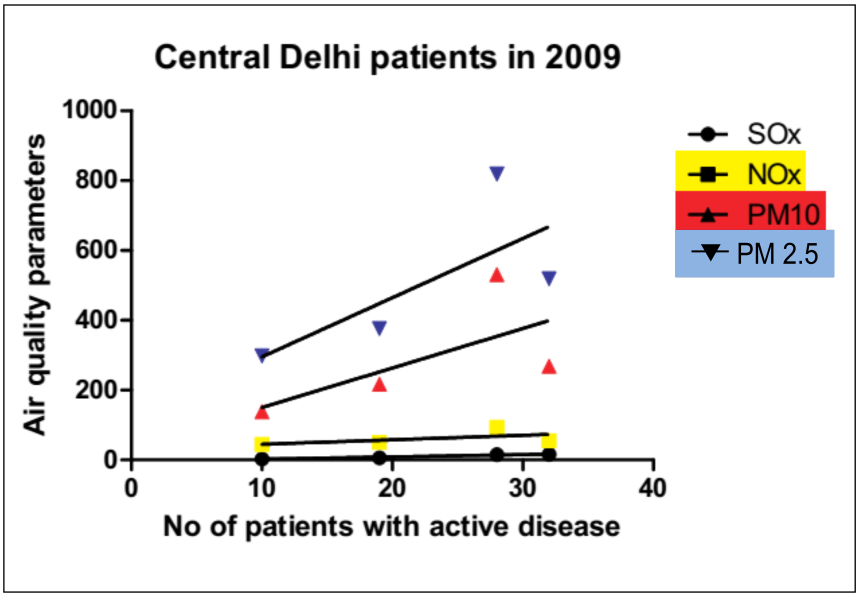
Months	No. of Patients with active disease		Available Atmospheric Parameters							
			SOx		NOx		PM10		PM 25	
	2008	2009	2008	2009	2008	2009	2008	2009	2008	2009
Jan-Feb	15	32	15.8	16.4	52.4	55.1	254.	269.	435.	519.
May –Jun	10	19	8.6	6.4	53.2	50.0	221.	217.	376.	376.
July-Aug	14	10	10.5	3.3	65.6	44.2	268.	139.	492.	298.
Nov-Dec	22	28	19.6	15.7	53.9	93.9	256.	531.	522.	819.



PM10 = Pearson r = 0.56; p value =0.21.
NOx= Pearson r =- 0.11; p value =0.44.
PM2.5= Pearson r = 0.85; p value =0.21
SOx= Pearson r = 0.93; p value =0.03

Figure 14 Correlation of RA disease activity with various air quality parameters in 2008 in Central Delhi

Figure 14 shows that SOx significantly correlated with flare of disease in Central Delhi



PM10 = Pearson r = 0.65; p value =0.17. PM2.5= Pearson r = 0.72; p value =0.13
NOx= Pearson r = 0.56; p value =0.21. SOx= Pearson r = 0.97; p value =0.013

Figure 15 Correlation of RA disease activity with various air quality parameters in 2009 in Central Delhi

Table 9 Joint disease activity in RA patients during the year 2014 (Jan-Feb, May – June) using DAS28 ESR

Disease activity	Disease activity in RA patients (n=500)	
	Jan – Feb 2014	May-Jun 2014
High disease activity (DAS = >5.1)	27.8% (139)	13.4% (67/500)
Moderate disease activity (DAS =3.2-5.1)	16% (80)	17% (85)
Low Disease activity (DAS 2.6-3.2)	5.6% (28)	9.2% (46)
Remission (DAS ≤2.6)	50.6% (253)	60.4% (302)

Table 10 Distribution of autoantibodies and inflammatory markers in normal subjects recruited as controls

Tests	No. of subject	%
ANA	26	8.6%
Anti CCp	9	3%
RF	25	8.3%
TNF	19	6.3%
IL 17 A	25	8.3%
IL1b	9	3%
IL6	13	4.3%
Hscrp	27	9.0%

3.1.4 Important Results

Impact on Rheumatoid Arthrisis:

Hospital observations indicate that there are flares of Rheumatoid Arthrisis (RA) during certain periods and air pollution seems to be one of the main reasons. Hence it is very important to identify air quality parameters causing flares of RA and to identify vulnerable population for autoimmune diseases. This study is based on recruiting 500 well known patients of RA (during 2008-2013) visiting AIIMS. Results show that high PM2.5 and PM10 levels positively correlate with flares of joint symptoms.

3.2 Effect of Seasonal Variation in Airborne Fungal Spore Load on Bronchial Asthma and its Control: A Longitudinal Study in North Indian Adults

3.2.1 Approved Objectives of the Project

It is noticed that a very high degree of Aspergillus sensitization among asthmatics attending clinics, have reported an unusually high prevalence of allergic bronchopulmonaryaspergillosis in these patients. It is possible that environmental exposure to Aspergillus, and subsequent lower respiratory tract colonization, may be contributing to poorer asthma control and/or progression to allergic bronchopulmonaryaspergillosis. It is also well known that weather conditions (especially temperature, humidity and precipitation) influence production, aerosolization and germination of fungal spores. We therefore hypothesize that the interplay between ambient outdoor conditions and burden of airborne fungal spores may be related to poorer asthma control and higher disease morbidity in adult asthmatics of our region, particularly those already sensitized with Aspergillus. A study to test this hypothesis is important as there is no data that explores this link. The specific objectives of this study are:

i. To assess seasonal variability in airborne fungal spore load (both total and Aspergillus) in the outdoor environment.

ii. To ascertain seasonal trends in airway inflammation, pulmonary function, disease control, disease morbidity and health related quality of life in adult asthmatics.

iii. To evaluate if seasonal variability in airborne fungal spore load influences disease parameters in Aspergillus sensitized and non-sensitized asthmatics.

3.2.2 Studies Undertaken

A cohort of individuals stratified into four groups (healthy, asthma, asthma with fungal sensitization, and asthma with allergic bronchopulmonaryaspergillosis) has been established and followed up for the entire duration of this study. Initial clinical workup, which includes collection of demographic and disease-related data, evaluation of pulmonary function, estimation of airway inflammation (through measurement of exhaled nitric oxide), assessment of health related quality of life, etc. were completed before the actual project work started. Estimation of outdoor fungal spore burden has been completed for several locations in the study area.

Persons residing in Chandigarh or the neighbouring towns of Panchkula (Haryana) or Mohali (Punjab), aged more than 15 years, lifetime nonsmokers, and not currently exposed to smoke from household biomass fuel combustion, are found eligible for enrolment into this study. Subjects having any other associated cardiopulmonary disorder, or those unwilling for repeated follow-up assessment as per the study schedule have been excluded.

Enrolled subjects are divided into four groups. Group A consists of 50 patients previously diagnosed to be suffering from bronchial asthma, who are not sensitized to

Aspergillus. Group B consists of 50 patients previously diagnosed to be suffering from bronchial asthma, who are sensitized to *Aspergillus*. Group C consists of 50 patients previously diagnosed to be having bronchial asthma and allergic bronchopulmonary-aspergillosis. Group D consists of 50 apparently healthy volunteers.

Asthma is diagnosed with a history of recurrent episodes of wheezing, dyspnea, chest tightness and/or cough that are reversible either spontaneously or with treatment, with documented airway obstruction on spirometry anytime during disease course. *Aspergillu*s sensitization are defined by presence of either immediate cutaneous hypersensitivity to intradermal injection of *Aspergillus* antigen (0.2 mL of 100 PNU/mL; 1 PNU = 0.00001 mg/mL) and/or *Aspergillusfumigatus* specific serum IgE levels >0.35 kUA/mL. Allergic bronchopulmonaryaspergillosis are diagnosed using criteria previously followed by us.Informed consent have obtained from all participants prior to actual inclusion. The protocol has already been cleared byour Institutional Ethics Committee

3.2.3 Clinical Data Collection

A structured questionnaire is used to enquire into the demographic and clinical details of all study participants at baseline. All subjects were followed up at two-monthly intervals for upto two years (i.e. twelve follow-up assessments). At initial and each follow up assessment, data on pulmonary function test and exhaled nitric oxide have been collected for all subjects, as per details provided below. Additionally, asthmatics have been evaluated for asthma control, asthma morbidity, asthma exacerbations since last visit, and health related quality of life, as per details provided below.

Pulmonary function test is carried out through spirometry. Forced vital capacity (FVC), forced expiratory volume in first second (FEV1) and FEV1/VC ratio were measured as per current standard guidelines. These values were compared to norms for healthy north Indian adults using regression equations previously derived at this centre. An observed value below the corresponding lower limit of normal (LLN; defined as predicted value minus 1.645 times the standard error of estimate of the relevant regression equation) are considered abnormal. A specific software previously developed by us has been used to make these calculations. Any spirometry record with FVC, FEV1 and FEV1/FVC values above corresponding LLNs were considered normal. A spirometry record with observed FEV1/FVC below its LLN has been categorized as having an obstructive defect. In addition, peak expiratory flow were recorded using a peak flow meter as the highest flow recorded from three acceptable manoeuvres.

Exhaled lower respiratory tract nitric oxide is measured through an online chemiluminescence-based system as per standard recommendations. Mean of two reproducible exhalations yielding plateau values within 10% of each other isrecorded. Any change greater than 20% for values over 50 ppb, or more than 10 ppb for values lower than 50 ppb, from one visit to the next is considered significant.

Asthma control over the four weeks preceding the clinical assessment is ascertained through the Asthma Control Test (ACT). This self-administered questionnaire has five items, and patient responses are summed to give a total score. Scores of 20 or more, 16-19, and below 16 are respectively considered to indicate good, partial and poor control of asthma. Asthma morbidity is detailed through indices previously followedby us For this purpose, details on emergency visits, hospitalizations, acute episodes, absence from work, need for extra bronchodilators, and requirement for systemic steroids over the previous two months are recorded. Asthma exacerbation are defined as an acute episode of worsening symptoms that requires increase in medication or unscheduled outpatient or emergency room visit. In case a patient has any such episode between visits, information on duration and severity of episode, need for systemic steroids, and for hospitalization is noted.

Health-related quality of life is objectively measured at each assessment using both generic and asthma-specific questionnaires. Hindi version of abbreviated World Health Organization Quality of Life (WHOQOL-Bref) scale is used as generic questionnaire. This 26-item self-administered generic instrument has been developed for Indians under a World Health Organization initiative and measures quality of life in four domains – physical, psychological, social relationships, and environment. The Mini Asthma Quality of Life Questionnaire (miniAQLQ) is employed as the asthma-specific tool. It has 15 items with a two-week recall, and generates four domain scores - symptoms, activity limitation, emotional function and environmental stimuli. We have already validated the use of Hindi version of this instrument in north Indian adult asthmatics.

3.2.4 Meteorological Measurements and Data on Air Quality

The meteorological database consists of mean values of various variables recorded for the three cities during the study period. These variables include temperature, relative humidity, atmospheric pressure, vapor pressure and total precipitation. Levels of various air pollutants such as carbon monoxide, nitrogen oxides, ozone and particulate matter are also obtained for all days. Any missing value is replaced by the mean of preceding and succeeding values. All data are obtained from records of India Meteorological Department and Central Pollution Control Board. Each patient assessment is tagged to the record for the corresponding previous day. In addition, to account for any lag between change in environment and its clinical expression, averages for previous five days are recorded for each parameter.

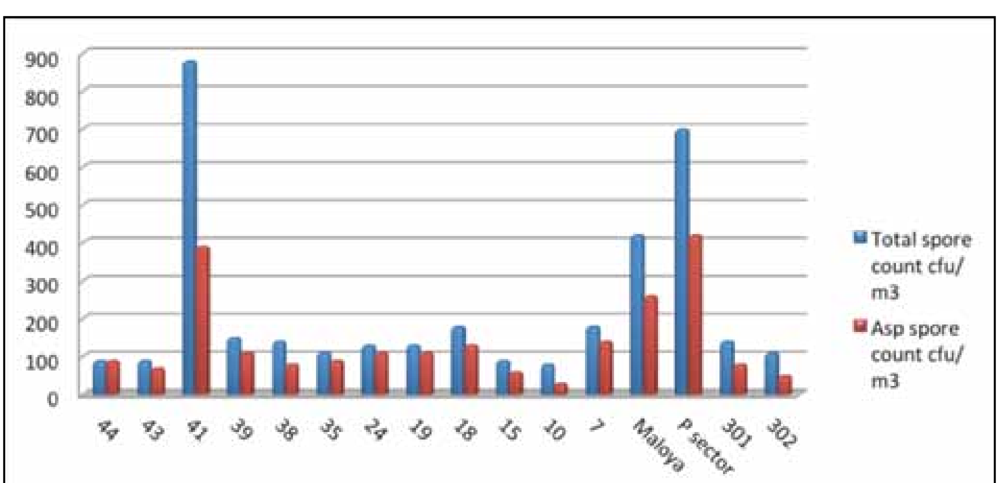
Automated air sampler is used at a suitable location for sampling 100 litres of air over a period of one minute. The sample is collected over Sabouraud dextrose agar media plate having chloramphenicol and gentamycin antibiotics to inhibit the growth of bacteria. After sampling the media plate is incubated at 25˚C for 24 to 48 hours.After incubation for 24 hours total number of spores are counted manually by noting the number of fungal imprints on the plate. The plate is incubated for a further 24 hours, and Aspergillus colonies are identified by morphological characteristics. In case of any doubt, staining with lactophenol cotton blue is performed for the confirmation of Aspergillus.
All participants with asthma are interviewed. Clinical parameters for which information is collected include:

(a) demographic profile (age, gender, residence, income, occupation, etc.)
(b) symptom profile and duration
(c) treatment details
(d) asthma morbidity parameters (daytime symptoms, nocturnal awakenings, limitation of activities, use of emergency inhalers, recent exacerbations or hospitalizations, need for systemic corticosteroids, etc.)
(e) radiologic investigations (plain chest radiograph and chest CT scan wherever indicated)

(f) investigations regarding fungal sensitization (Aspergillus skin test, *Aspergillusfumigatus* specific serum IgE)

Serial pulmonary function data are being collected for all study subjects using spirometry. Spirometry is being performed using standard American Thoracic Society and European Respiratory Society guidelines. Observed values of forced expiratory volume in first second (FEV1), forced vital capacity (FVC), and FEV1/FVC ratio are collected, and compared to reference equations for normal lung function in healthy north Indian adults. Data for both FVC and FEV1 are expressed as percentages of predicted values.

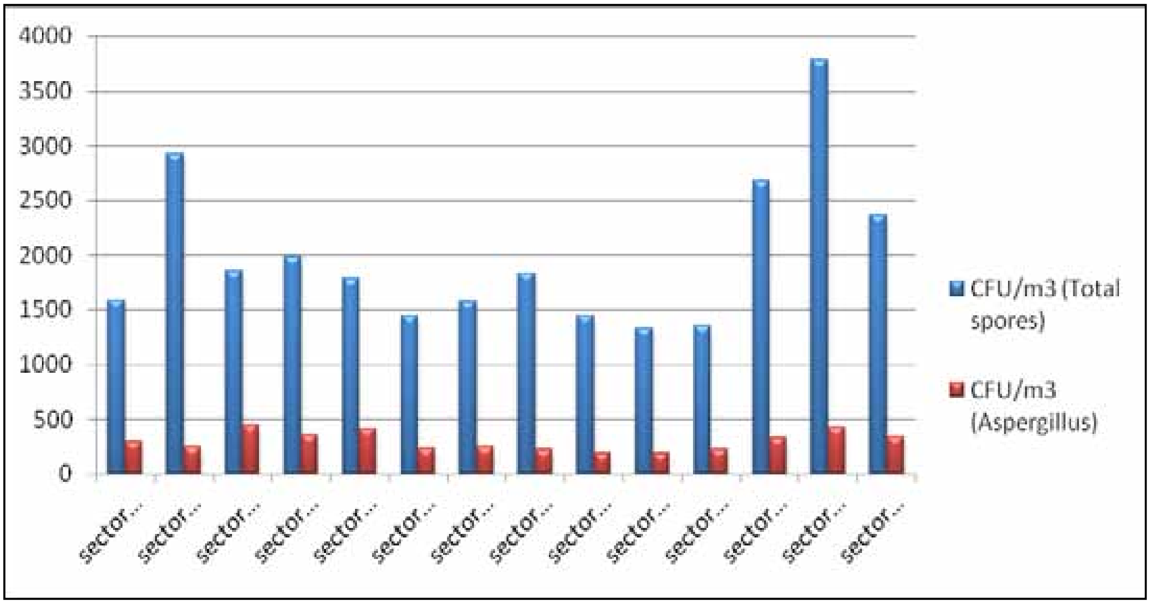
Fraction of nitric oxide in exhaled air (FENO) is serially recorded for all participants with a portable handheld device specifically procured for this purpose. Each subject performs three exhalations into the machine as per standard recommendations, with exhaled flow maintained in a suitable range as prescribed by the equipment manufacturer. The highest reading (expressed as parts per billion) is used for study purpose.
A study proforma has been designed specifically to collect patient data in this project. It has two sections that need to be independently filled up. Both sections are linked to each other through a unique project ID, which acts as a unique identifier to all patient records. The first section is the 'Mastersheet' which has important patient identifier and demographic data, details on clinical parameters (including project group assignment), and the patient consent form. This section is initially filled up at enrolment into the project. The second section relates to 'Patient Visit Information' and is filled up at time of first and subsequent evaluations. This portion has details on level of asthma control and morbidity, lung function assessment, exhaled nitric oxide measurementand assessment of health-related quality of life. The study proforma has already been transcribed into a MS Access database. Limited outdoor sampling for fungal spores is conducted in February 2014, which show variable fungal spore load across sites. Aspergillus is the predominant fungus during this period. Indoor evaluation in two households showed fungal spore concentrations largely similar to the outdoor concentrations.



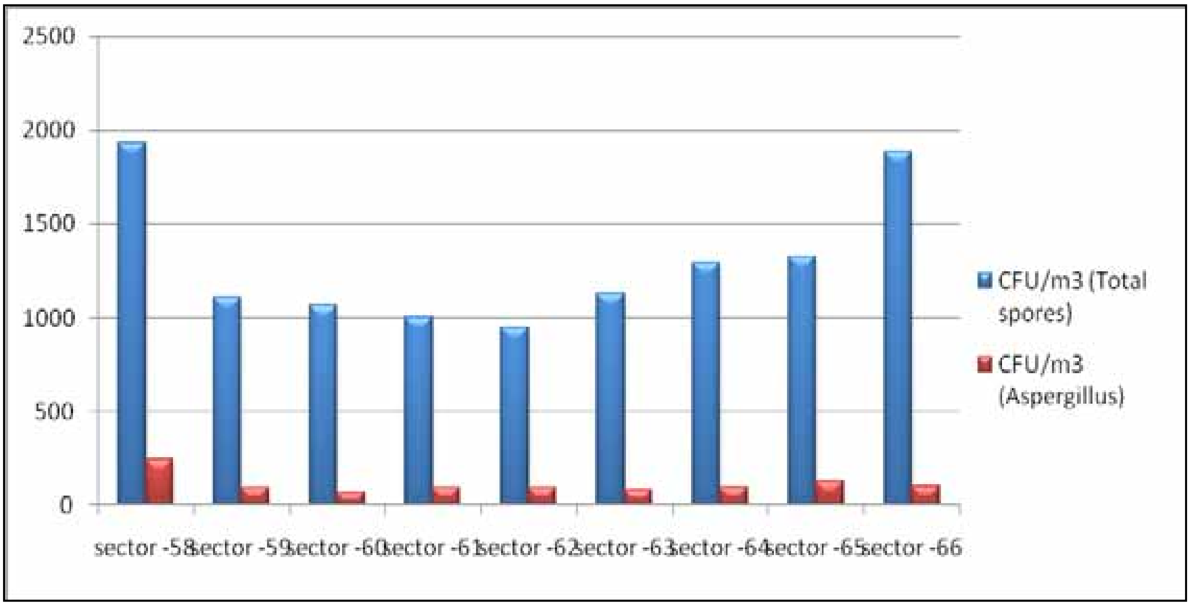
So far most outdoor sites across Chandigarh, Panchkula and Mohali have been covered. The results show that the fungal spore counts are much higher than the earlier assessment, and the proportion of Aspergillus spores. These observations are summarized in the graph below.

Most outdoor sites across Chandigarh, Panchkula and Mohali have been covered. The results show that the fungal spore counts are much higher than the earlier assessment, and the proportion of Aspergillus spores has much reduced. These findings are summarized in the graphs below.

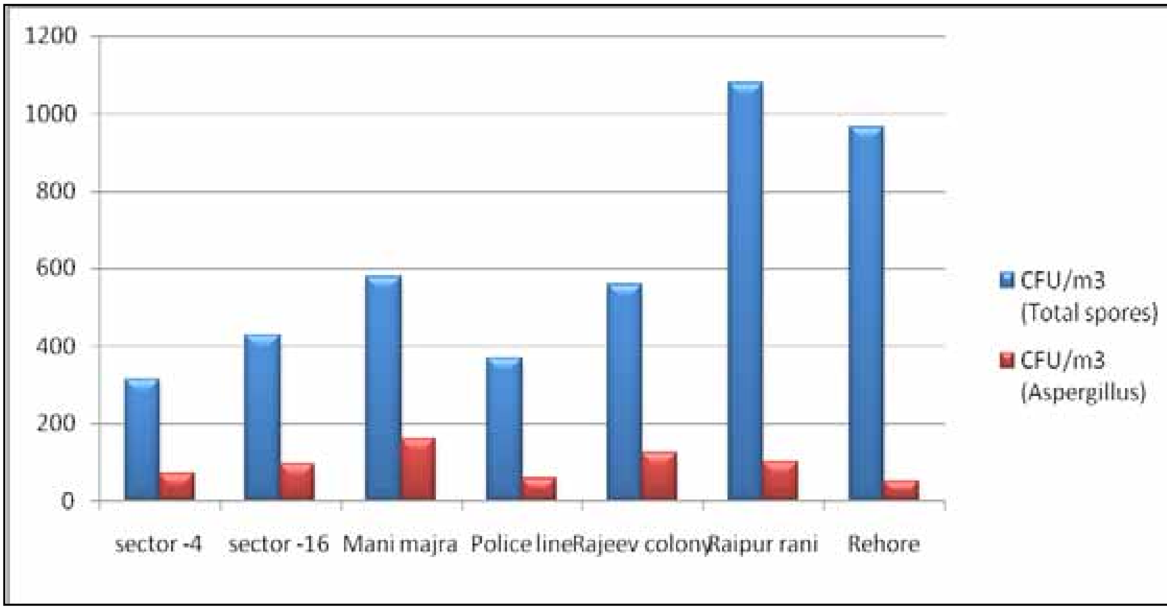
Chandigarh:



Mohali:

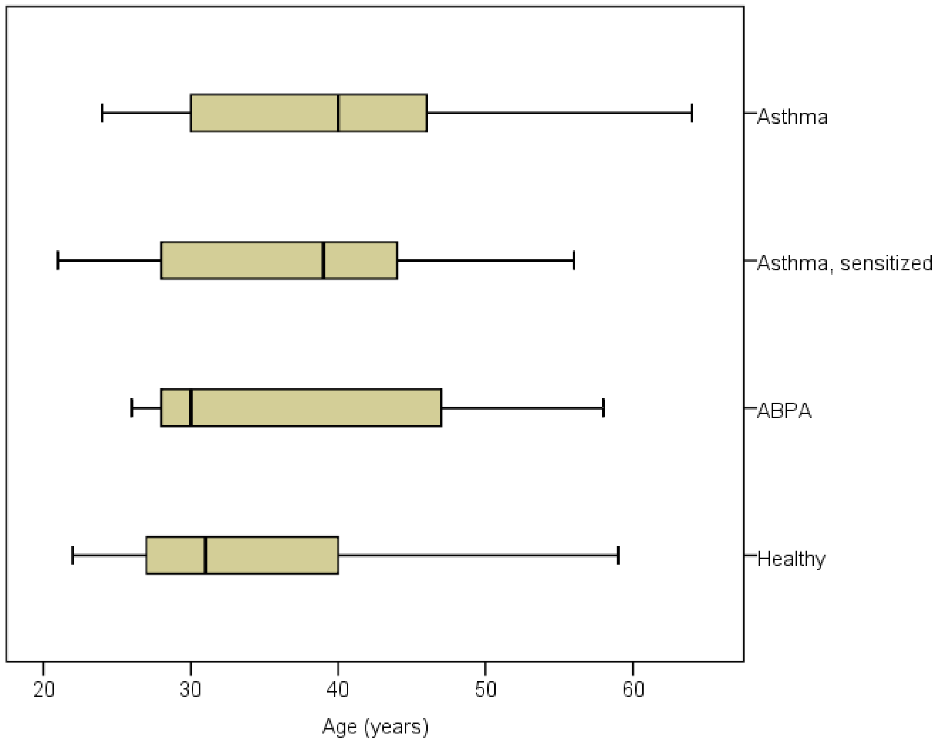


Panchkula:

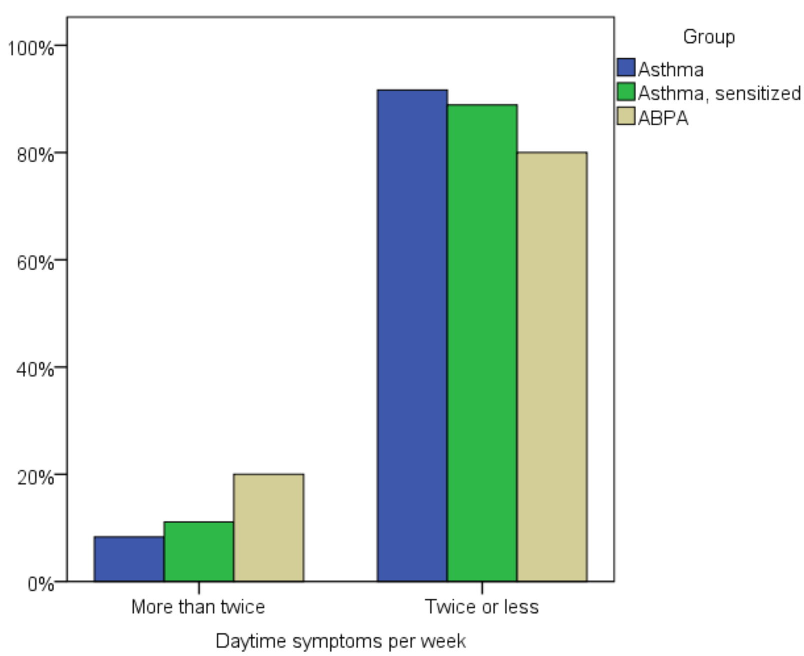


In total 91 subjects have been enrolled into the project. These include 25 healthy volunteers, 24 patients with asthma, 20 patients of asthma sensitized with Aspergillus, and 20 patients with allergic bronchopulmonary aspergillosis. Details of their clinical characteristics are summarized in the figures below.

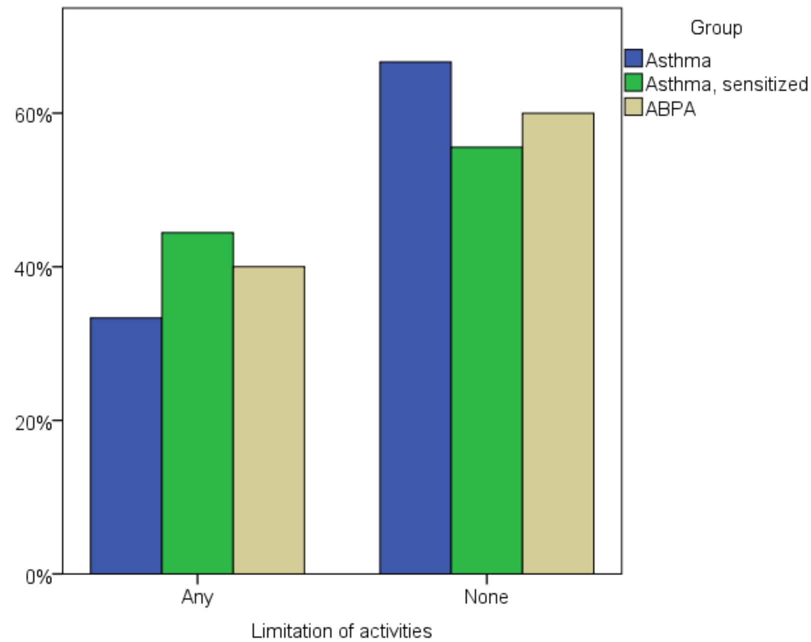
Age distribution in the study population



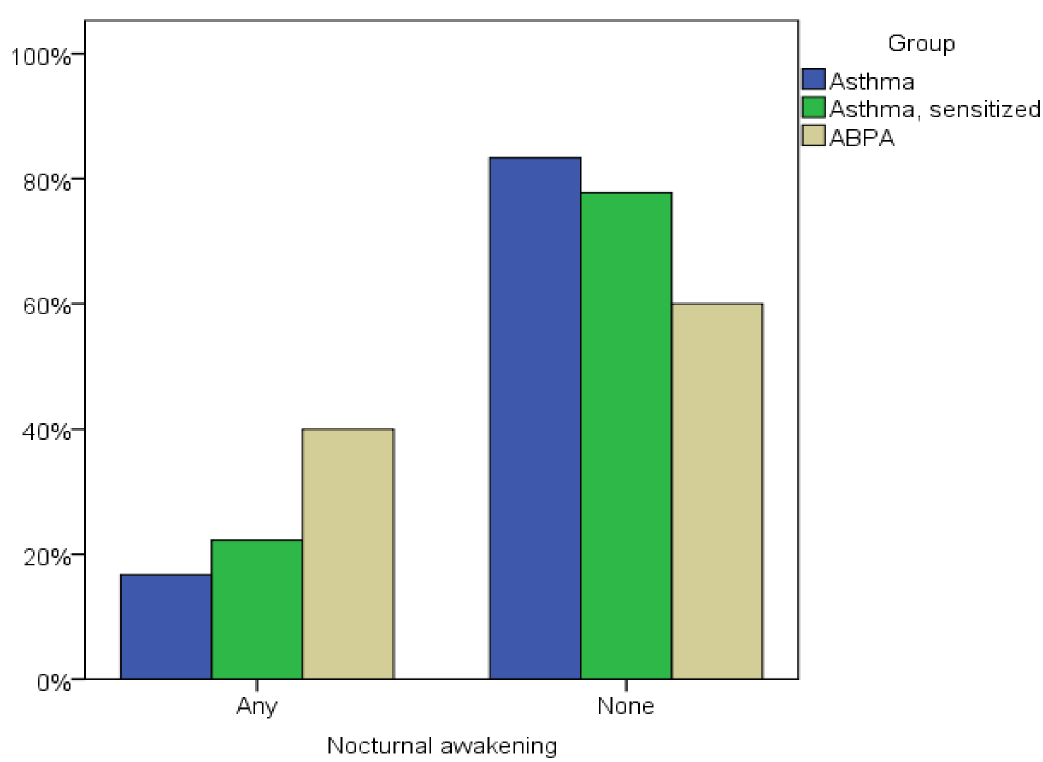
Daytime symptoms per week among the patients studied



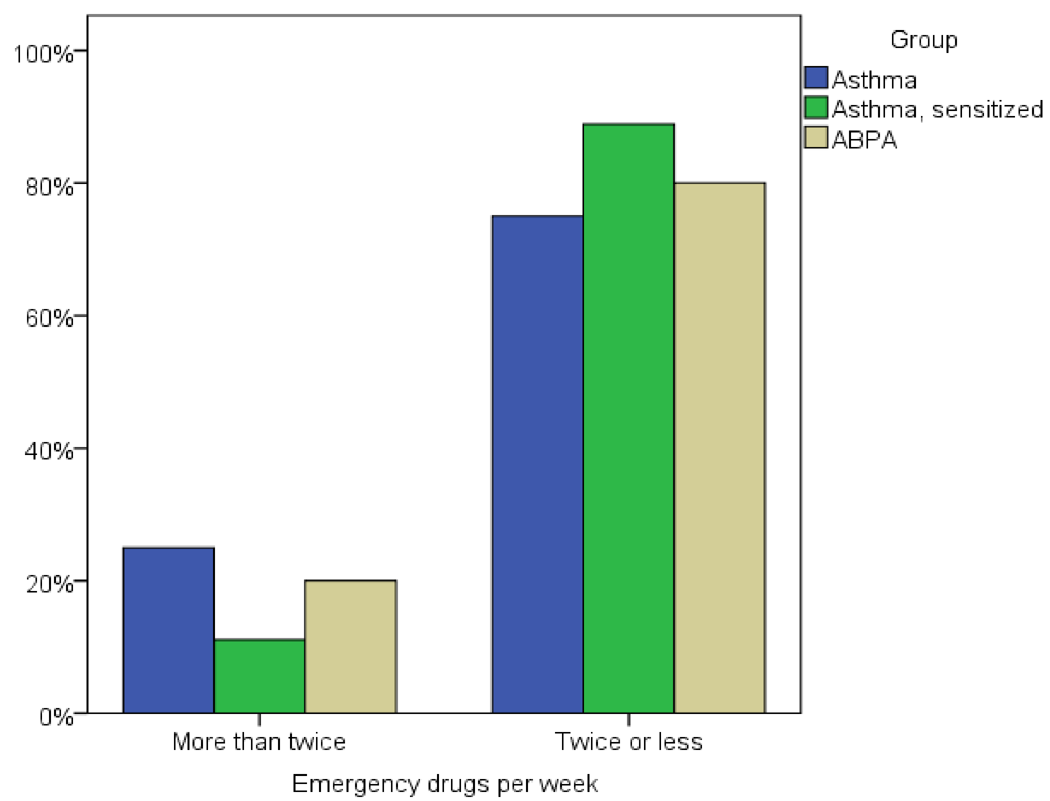
Limitation of activities among the patients studied



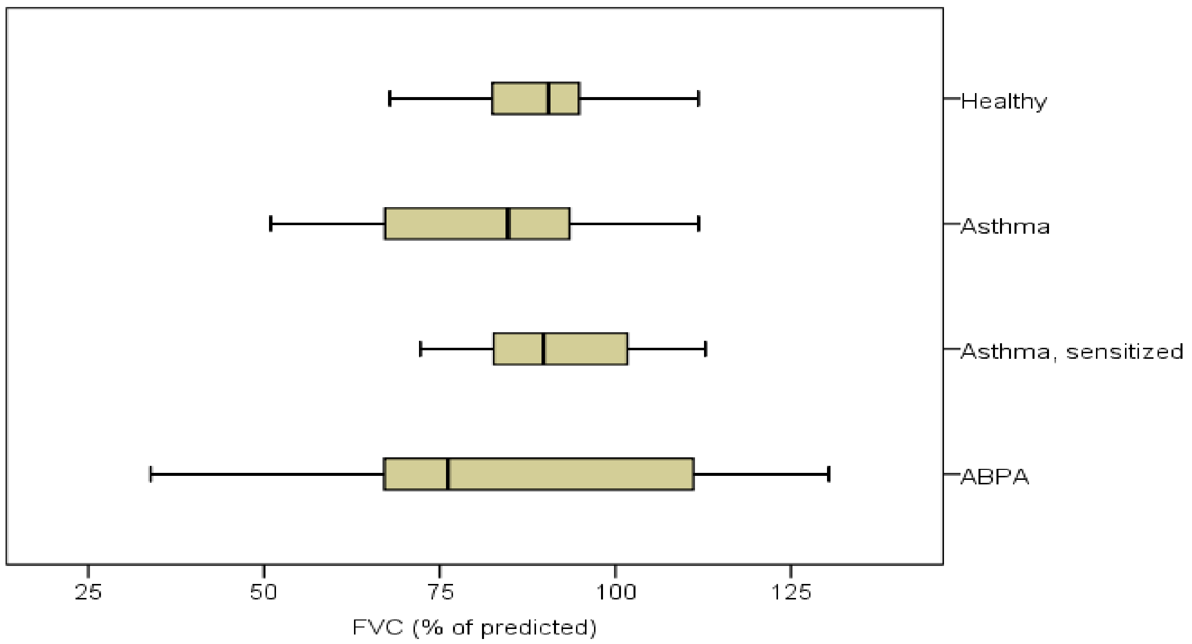
Nocturnal awakening among the patients studied



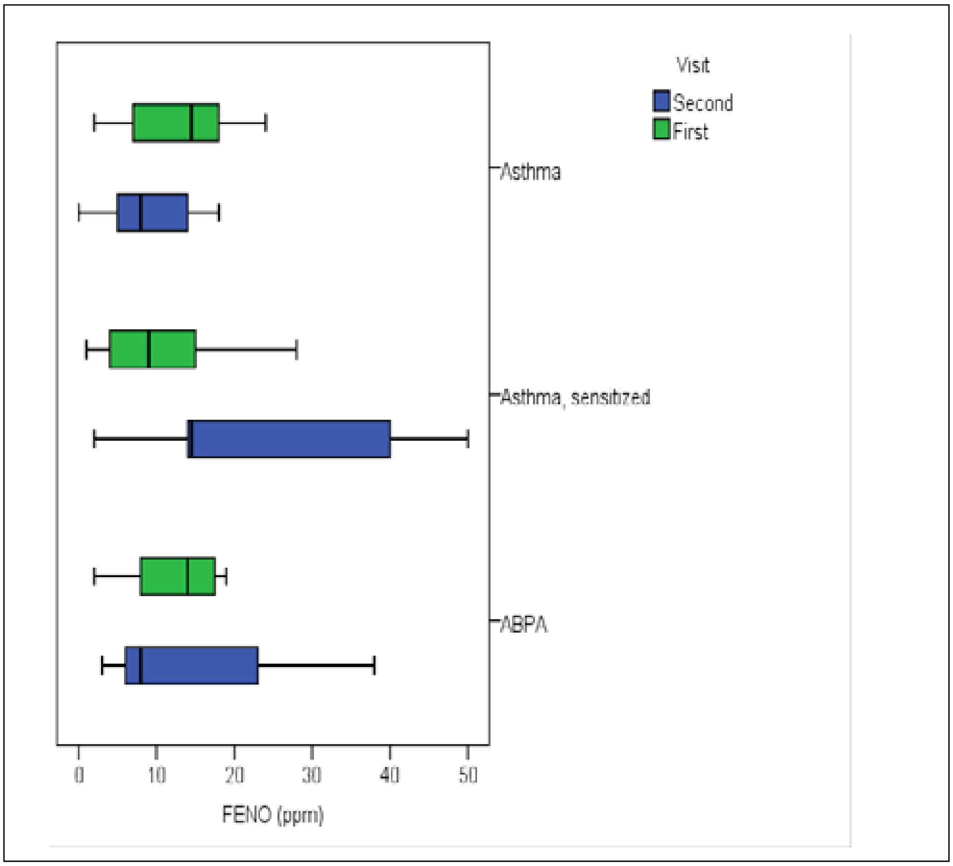
Emergency drugs per week among the patients studied



Baseline FVC in the study population



FENO (in ppm) in the study population at the two assessments



3.2.6 Important Results

Airborne Fungal Spore Load and Brocnhial Asthma:

Hospital records show that in some places there are instances of increase in bronchial asthma, as for example in Chandigarh and its neighbouring regions amongst above 15yr olds and also life time nonsmokers. Such occurrences can happen due to increasing fungal spore loads in the atmosphere due to changes in temperature and humidity. In order to examine this relationship, it is very important to collect clinical data and also those of environmental fungal spores burden and meteorological conditions. Relevant data have already been collected for about two years which contain a lot of valuable information.

3.3 Impact of Climate Variability and Change on Respiratory Health, Morbidity and Mortality

3.3.1 Objectives of the Project

The National Oceanic and Atmospheric Administration (NOAA) chronicled seven rising indicators of climate change: (1) air temperature over land, (2) seasurface temperature, (3) air temperature over oceans, (4) sea level, (5) ocean heat, (6) humidity, and (7) tropospheric temperature in the active weather layer of the atmosphere closest to the Earth's surface. Three indicators are found declining: (1) Arctic sea ice, (2) glaciers, and (3) spring snow cover in the Northern Hemisphere.

The present study aims to evaluate the link between climate change and respiratory health, morbidity and mortality through analysis of local climate data, air quality data, and hospital statistics over a three year period and to compare it with retrospectively with previous three year data. The specific objectives of this project are:

(i) To study association, if any, between the profile and number of patients attending the OPD, Respiratory ward, Emergency and ICU and prevailing weather and air pollution profile.
(ii) To analyze synergy between weather and air pollution variables and mortality related to respiratory diseases.
(iii) To compare this data set retrospectively with previous three years climatic data and hospital statistics.

3.3.2 Studies Undertaken

The present study aims at evaluating the link between climate variables and respiratory morbidity and mortality at tertiary care hospital in New Delhi through a prospective data collection of respiratory morbidity and mortality and simultaneous analysis of local climate and air quality data over a period for three years. These results of prospective data are compared with retrospective data of previous three years. About 300 to 400 patients haveattended the NITRD OPD daily; beside this the institute also has 472 functional indoor beds, 14 bedded respiratory intensive care unit and 24 hour respiratory emergency services. Besides this, the institute looks after the RNTCP of South Delhi comprising of a population of about a million where chest symptomatics attend for tuberculosis diagnosis and treatment. Data are used to evaluate associations between climatic variables and respiratory health.

Data on patients attending National institute of TB and Respiratory Diseases over a period of three years are abstracted from appropriate hospital records. Outpatient records of patient attending chest clinics are collected from the central registration services of the institute and information on patients' demographic, clinical profile and diagnosis is gathered from patients' duplicate OPD registration slip. Information on demography, disease profile and hospital outcome (death or survival) of patients admitted with us during the study period, both for patients in wards and respiratory ICU are collected in a pre designedproforma. In addition, information on patients presenting to emergency services of the institute are collected from the emergency record register. The institute already maintains a database of indoor admissions, both in the general wards and in the respiratory ICU. These databases are screened to provide similar information during the previous three years retrospectively. Information on patients and their underlying disease will be collected from these records. Project staff are trained to abstract and compile all information.

DATA collection has been started w.e.f. 01-07-2013 prospectively. Retrospective DATA collection is done for previous 3 years from 01-07-2010 to 30-06-2013. About 18444 patients' data are collected during July to December (except OPD data for the month of December 2013).

	July	August	September	October	November	December	Total
INDOOR	442	377	340	416	416	333	**2324**
EMERGENCY	492	460	411	462	401	304	**2530**
ICU	36	24	36	27	32	30	**185**
OUTDOOR	3029	2507	2978	2395	2496		**13405**
Total	**3999**	**3368**	**3765**	**3300**	**3345**	**667**	**18444**

Mortality Data: Data of 428 patient deaths collected from July to November.

	July	August	September	October	November	December	Total
INDOOR	62	56	40	64	53		**275**
EMERGENCY	16	19	22	24	22		**103**
ICU	8	17	10	8	7		**50**
Total	**86**	**92**	**72**	**96**	**82**		**428**

3.3.3 Important Results

Respiratory Health, Morbidity and Mortality:

Increase in the respiratory diseases has been the greatest casualty due to air pollution worsening. It is very important to associate the type of diseases with the type of pollutants so as to take adequate steps in the right direction. In this study more than 12960 patients are examined during July 213 to February 2016 from OPD, emergency wards and hospitalized patients.

Chapter 4
Thematic Area “Heat Stress and Human Health”

Heat stress and air quality are the two key areas considered to be vulnerable under the climate change scenarios. Large uncertainty continues to remain because of two factors: lack of robust health and air quality data at high spatial resolution and inadequate knowledge of suitable heat index to quantify the health impacts. The most certain impact of the climate change is temperature rise, which caused an increase in the number of temperature extremes. Heat waves have been more prevalent in states like Odisha and Andhra Pradesh on the east coast. Temperature increase due to urbanization can also add several degrees to local temperatures. Heat stress causes morbidity and loss of work capacity rendering individuals weak and more susceptible to diseases. Therefore, it is time to recognize the importance of heat stress as a public health issue and conduct more scientific studies in different parts of India to formulate guidelines for safety measures. Workers, soldiers, and travelers are often exposed to severe environmental heat stress, which may deteriorate work efficiency and productivity and may even threaten survival.

The following two projects were approved under this thematic area.

- **Vulnerability assessment to heat stress and its impacts on health and productivity for select occupational sectors in the context of climate change**
- **Impact of air quality and heat stress on health: future projections for India**

4.1 Vulnerability Assessment to Heat stress and its impacts on Health and Productivity for select Occupational sectors in the context of Climate Change

4.1.1 Approved Objectives of Project

The impact of heat stress on health and well being of the workers in many occupational settings have been studied in India as per WHO Collaborating Centre mandate. Preliminary results have shown that many occupational settings are vulnerable to the impact of heat stress, due to increasing temperatures and physical work load. IPCC has predicted increase in temperatures to the extent of 2-3°C around the globe in the coming decades. Hence it becomes imperative to focus on the health impacts of risingtemperatures in the South Asian region of the globe.Based on the studies undertaken so far, the following goals are set in this project proposal:

i. Profiling the risks associated with heat stress across identified occupational sectors.
ii. Assess current health risks due to heat stress and productivity losses and the existing capacity and infrastructure to manage them.
iii. Project future health risks and impacts under CC through modelling.
iv. Identify and prioritize measures to address future health risks in the face of climate change.

4.1.2 Studies Undertaken

This study has been undertaken during two seasons in 4 sectors, 3 formal sectors (Steel, Auto-spare part &Tyre manufacturing) and 1 informal sector (Brick)with the prior approval ofthe concerned managements.The field studies were conducted during the winter months between November 2013 to January 2014 and in the summer months assessments were carried out between March and June, 2014. The quantitative measurements were madebetween 10am to 4pm in almost all workplaces with the exception of the steel industry where the work timings were round the clock with 3 shifts. One study was conducted in the night shift to make an comparative assessment between workers with same work profile in different times of the day. In Southern India, temperatures start to rise by 9-10am depending on the time of the year. The usual work shift varies during7am – 5pm in various sectors, with two fifteen-minute breaks and one half-hour lunch break. Locations of the area were identified by trained Industrial Hygienists and workers in that zone were selected for questionnaire survey. Heat stress measurements were timed when workers wereworking at full-swing. Some work places preferred that questionnaire survey be conducted during their coffee breaks so that the productivity is not impacted. A “HOTHAPS” questionnaire in English was administered to the workers to obtain their perceptions on heat stress and its impacts on their health, productivity and social life. Most of the workers could speak and understand the local language which was used by the interviewers. The questions were translated by a translator for some migrant workers who did not understand the language.

The thermal environment of the workplaces assessed quantitatively and qualitatively are as follows:

A. Short term area measurements using Heat Stress Monitor quantitatively
B. Long term continuous area measurement using data loggers
C. Qualitative study using HOTHAPS questionnaire
D. Short term Personal Heat stress using 3M, Questemp II, Personal heat stress monitor
E. Physiological heat strain assessment using Masimo Radical -7.
F. Heart rate monitoring for subset of population using Polar Heart rate monitor

Role of environmental risk factors that impact the health in different occupational sectors are not well understood in India despite the ubiquity of extreme exposure situations. This project focuses on quantifying occupational heat stress risks and establishing relationship betweenhealth outcomes and productivity losses of working population, given the importanceof this issue in the context of climate change. Data for this project were collected from 4 sectors, 3 formal sectors (Steel, Auto-spare part &Tyre manufacturing) and 1 informal sector (Brick). Quantitative measurements of heat stress and workers perceptions were collected for 2 seasons for 1 sector and only summer season for 3 sectors. Quantitative measurements of environmental area heat stress were measured using WBGT and continuous monitoring using data loggers (Lascar). Physiological responses to heat stress was captured by measuring Sweat Rate (SwR), Heart Rate(HR), Perfusion Index(PI) and Pleth Variability Index(PVI) using Masimo Radical-7 Pulsoximeter. Questionnaires evaluating the perceptions of heat stress, its impacts on workers at workplace (health, productivity and social lives) were administered to the study subjects while conducting the environmental measurements. Observations were made at workplaces and information were collected from employees/managers about various control measures/interventions adopted to manage heat stress.

In total 133 WBGT measurements, 430-1/2 hourly measurements (temperature & humidity) and 232-perception questionnaires were completed in 4 industrial sectors. Physiological measurements were collected from 123 study-subjects that included SwR, PI & HR and continuous heart rate monitoring for 12 participants in 2 sectors.

4.1.2.1 Short term area measurements using Heat Stress Monitor:

The Heat Stress area measurements were carried out using an area heat stress monitor, Model QuesTemp°34 which is having accuracy level of ±0.5°C between 0°C and 120°C of dry bulb temperature and relative humidity (RH) of ±5% between measurement range of 20% and 95% RH manufactured by Quest Technologies, USA (Figure A).

Figure A: Heat Stress Monitor, Model Questemp°34

In the assessment of heat stress, the Wet-Bulb, Globe Temperature *(WBGT)* was used. The WBGT is recommended by the American Conference of Governmental Industrial Hygienist (ACGIH), USA. The WBGT combines the effect of the four main thermal components affecting heat stress: air temperature, humidity, air velocity and radiation, as measured by the dry bulb, wet bulb and globe temperatures. The instruments were calibrated at the initial time and end of the measurement day. While measuring area heat measurements using WBGT meter, the instrument was placed at a height of 3.5 feet (1.1m) for standing individuals and 2 feet (0.6m) for seated individuals. A tripod mounting was used to get the instrument away from anything that might block radiant heat or flow. The WBGT meter was placed in the workplace and the sampling individual was instructed to stand away from the instrument to minimize the variations in temperature and radiant heat. The work category of the workers was based on the ACGIH screening limits (Table A) and the judgment by a trained Industrial Hygienist based on ACGIH guidelines and (Table B).

Table A: ACGIH Screening limits tables

Sl. No	Allocation of Work in a Cycle of Work and Recovery	TLV®(WBGT values in °C)				Action Limit (WBGT values in °C)			
		Light	Moderate	Heavy	Very Heavy	Light	Moderate	Heavy	Very Heavy
	75 to 100%	31.0	28.0	-	-	28.0	25.0	-	-
	50 to 75%	31.0	29.0	27.5	-	28.5	26.0	24.0	-
	25 to 50%	32.0	30.0	29.0	28.0	29.5	27.0	25.5	24.5
	0 to 25%	32.5	31.5	30.5	30.0	30.0	29.0	28.0	27.0

Source: American Conference of Governmental Industrial Hygienists (ACGIH 1989)

Table B: Work Category and its Example#

Work Category	Examples
Rest	Sitting
Light	Sitting with light manual work with hands or hands and arms, and driving. Standing with some light arm work and occasional walking
Moderate	Sustained moderate hand and arm work, moderate arm and leg work, moderate arm and trunk work, or light pushing and pulling. Normal walking
Heavy	Intense arm and trunk work, carrying, shoveling, manual sawing; pushing and pulling heavy loads; and walking at a fast pace
Very Heavy	Very intense activity at fast to maximum pace

#: Thermal Stress - Threshold Limit Values & Biological Exposure Indices - prescribed by American Conference of Governmental Industrial Hygienists, USA.

4.1.2.2 Long term continuous measurement using Data Loggers:

All the samples were collected during times when regular operation was in progress. Sampling times and locations were decided by trained Industrial Hygienist cum project personnel based on the work process, workload, clothing and acclimatization. The hourly ambient temperature and relative humidity were collected from the meteorological data.

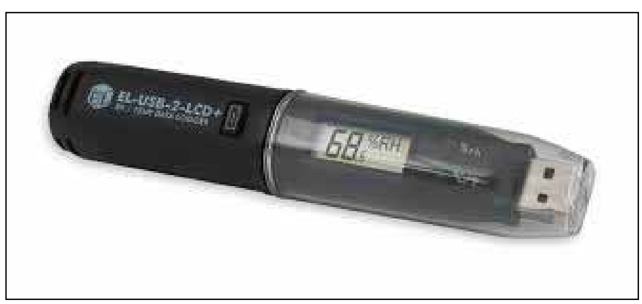


Figure B: Data logger, EL-USB-2-LCD+ model manufactured by Lascar electronics

Data loggers are portable monitoring devices that record ambient temperature, relative humidity and dew point. EL-USB-2-LCD+ model data loggers manufactured by Lascar electronics (Figure B) were used for the study. EL-USB-2-LCD+ data logger measures and stores up to 16,379 relative humidity and 16,379 temperature readings over 0 to 100%-RH and -35 to +80°C (-31 to +176°F) measurement ranges. Data loggers were put in selected work areas at distances away from direct heat. The device was programmed to data log every five minutes during the study period. The data which include temperature, relative humidity and dew point, weredownloaded, in an excel sheet and ½ hour and hourly averages were calculated.

Data logger monitoring was conducted for five days in winter and five days in summer respectively in select workplaces where workers were willing for the research work to be conducted. In some workplaces, continuous monitoring could not be done (Agriculture) as work was not in progress and no exposures were happening to the workers. To assess the short term personal exposure over a day, data loggers were tied to the shirt button of the male workers and tied around the neck using tags for female workers.

Start time and stop time were recorded manually in observation sheets. For long-term area samples (stationary) where wind speed is less than 1 m/s, WBGT was calculated based on the following equations recommended by Bruno Lemke and Tordkjellstrom (2012).

- **Equation 1:** WBGT indoor = 0.67Tpwb + 0.33Ta

  Tpwb - Psychrometric wet bulb temperature (°C)

  Ta - Air temperature (°C)

In locations where man coolers wereprovided or workers werewalking, the wind speed wasabove 1 m/s. In such cases, WBGT was calculated based on the following equation.

- **Equation 2:** WBGT indoor = 0.67Tpwb + 0.33Ta − 0.048 log10v (Ta - Tpwb)

  Tpwb - Psychrometric wet bulb temperature (°C)

  Ta - Air temperature (°C)

  v - Wind speed (m/s)

For the workplaces, where the activities were being carried out under direct sunlight, WBGT was estimated (Ramsey JD and Bernard TE , 2000) , Bernard TE and Pourmoghani M ,1999), Liljegren J at.al , 2008 , Thorsson S, Lindberg et. al , 2006) based on the air temperature, solar radiation and relative humidity.

4.1.2.3 Qualitative study using HOTHAPS questionnaire

Qualitative data about the perceptions on heat exposures, clothing acclimatization, health impacts, productivity losses, social impacts and coping mechanisms were collected by administering a standardized HOTHAPS questionnaire to the study participants. Prior clearance from the Institutional Ethics Committee (IEC) of Sri Ramachandra University and permission from the concerned management was obtained for the study. The risks and benefits of participating in the study were explained to the workers, informed consent was obtained from the workers before administering the questionnaires. The questionnaire has seven parts each with focus on the following information: General information, type of work, workers' exposure to heat, health impacts, productivity impacts, impacts of clothing, coping mechanisms & impacts of heat on social life. Major observations were made by the investigators and the workers about the workplace conditions.

Four different sectors across Southern India were administered with the questionnaire. The questions were framed in a fashion that their perceptions on health, productivity and the impact of heat stress on their social lives was very specific to that time period the questionnaire was administered. Any vague answers due to any ambiguity in understanding the question was clarified by the trained interviewer. Question pertaining to impacts of heat stress was very clearly directed towards the season in which the questions were administered. The responses about the health, productivity and social impacts were specifically related to workplace heat stress. An elaborate section on self-reported heat related health illnesses was administered and the symptoms of each illness were explained to the study participant by the interviewer. The questionnaire took about 20 minutes for each participant and the informed consent was signed by each participant for volunteering for the survey.

4.1.3 Heat Stress for Different Workplaces:

The WBGT index was measured with the same protocol and methodology used for area Heat Stress measurements in the representative units namely, Mixer (1st floor), BU 4 PCR-Curing (Trench 1), BU 9 TBR-Curing (Trench 1) and BU 5 (Hot & Cold Duplex Extruder 1).

Based on the Heat Stress measurements in four units stated earlier, mapping were constructed with the help of Map Info software where permanent features were transferred in digital format through digitization. The area of the representative units of the whole industry had been marked and the measurement strategy was followed as per the job process. A total of 201 measurements were completed maintaining approximately 1 to 3 meter distance between two consecutive measuring circles around the heat sources. Total number of measurements are comprised of about 73 measurements in Mixer (1st floor), 40 measurements in BU 4 PCR-Curing (Trench 1), 40 measurements in BU 9 TBR-Curing (Trench 1) and 48 measurements BU 5 (Hot & Cold Duplex Extruder 1). These zones are created as concentric contours with the given heat stress measurement values.

Table 1: Workers perceptions on impacts of heat stress on health, productivity and social lives as reported by questionnaires for SUMMER* season for WORK-PLACE I (Tyre Manufacturing Industry)

Variable	Characteristics	Summer (n=52)	
		N	Percent (%)
Impacts on Health	Excessive sweating	50	96.2
	Muscle cramps	19	36.5
	Tiredness/weakness/dizziness	37	71.2
	Headache	10	19.2
	Nausea/Vomiting	1	1.9
	Fainting	1	1.9
	Prickly heat	19	36.5
Production target & issues	Have production target	20	38.5
	Able to Complete production target	20	100.0
	Not able to complete production		
Impact on productivity	Absenteeism/ Taken sick leave due to heat	1	1.9
	Less productivity/ More time to complete task/ Work extra hours	15	28.9
	Irritation/Interpersonal issues	31	59.6
	Wages lost in summer	1	1.9
Coping mechanisms	Take rest	15	28.9
	Drink water	51	98.1
	Cool shower, bath or sponge bath	1	1.9
	Traditional methods	24	46.2
Impacts of clothing on productivity	Clothing-Comfortable	36	69.2
Impacts on Social Life	Yes	30	57.7
	Highly	20	38.5
	Moderately	6	11.5

Note: Summer (July 2013)*

Heat Stress assessments for WORKPLACE II (Brick Manufacturing Industry):

Table 2: The workers perceptions on Impacts of heat stress on health, productivity and social lives for SUMMER* season for WORKPLACE II (Brick Manufacturing)

Variable	Characteristics	Summer (n=76)	
		N	Percent (%)
Impacts on Health	Excessive sweating	71	93.4
	Muscle cramps	31	40.8
	Tyredness/weakness/dizziness	66	86.8
	Headache	51	67.1
	Nausea/Vomiting	6	7.9
	Fainting	13	17.1
	Prickly heat	21	27.6
Production target & issues	Have production target	2	2.6
	Able to Complete production target	2	100.0
Impacts on productivity	Absenteeism/ Taken sick leave due to heat	11	14.5
	Less productivity/ More time to complete task/Work extra hours	31	40.8
	Irritation/Interpersonal issues	15	19.7
	Wages lost in summer	None	0
Coping mechanisms	Take rest	54	71.1
	Drink water	76	100.0
	Cool shower, bath or sponge bath	18	23.7
	Traditional methods	39	51.3
Impacts on Social Life	Yes	18	23.7
	Moderately	14	18.4

Note: Summer (March – April, 2014)*

Table 2A: Physiological Heat Strain measurements for summer using Massimo Radical -7 monitor at Workplace II (Brick Manufacturing)

Parameters	(Mean±SD)
Pre Exposure Heart Rate (Beats/minute)	80.2± 9.1
Post Exposure Heart Rate (Beats/minute)	95±10.2
Pre exposure Core Body Temperature (^oC)	36.5± 1.75
Post Exposure Core Body Temperature (^oC)	37.4± 1.46
Sweat Rate (L/hr)	1.92 ± 0.9
Pre Exposure Met Hemoglobin (mg/dl)	1.5±0.8
Post Exposure Met Hemoglobin (mg/dl)	1.6±0.5
Pre Exposure Oxygen Saturation (%)	97.1±1.05
Post Exposure Oxygen Saturation (%)	98.4± 1.2

Parameters	(Mean±SD)
Pre Exposure Total Hemoglobin (mg/dl)	**12.5±1.1**
Post Exposure Total Hemoglobin (mg/dl)	**12.1±1.6**
Pre Perfusion index	**5.7 ± 1.9**
Post Perfusion index	**6.9± 2.1**
Pre Pleth Variability index	**19.2±3.5**
Post Pleth Variability index	**21.4± 2.9**

[*]All values are represented as mean±SD

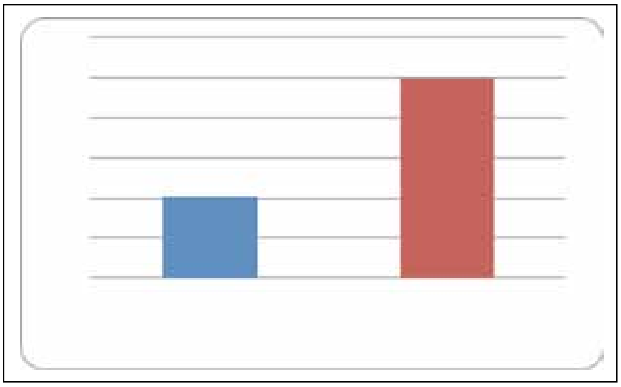


Figure 2A: Pre and post exposures Heart rate monitoring

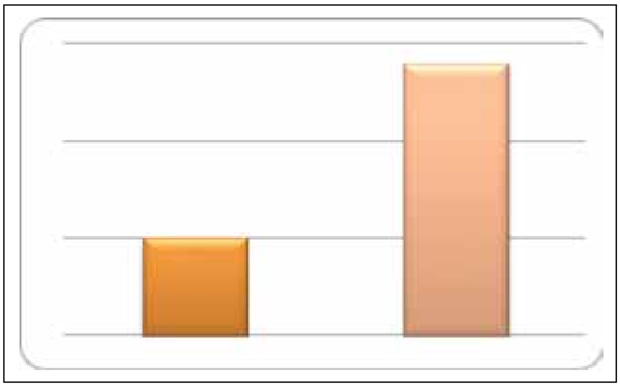


Figure 2B: Pre and post exposures Pleth Variability Index

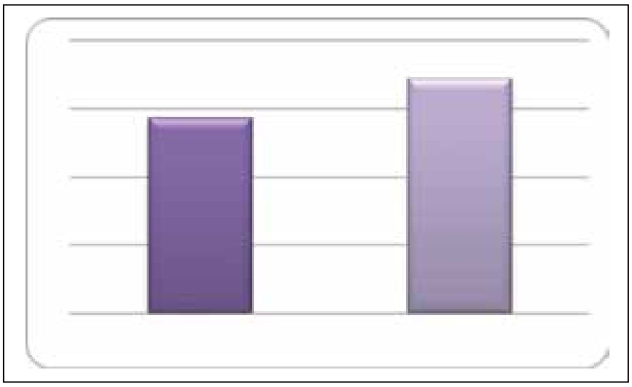


Figure 2C: Pre and post exposures Perfusion Index

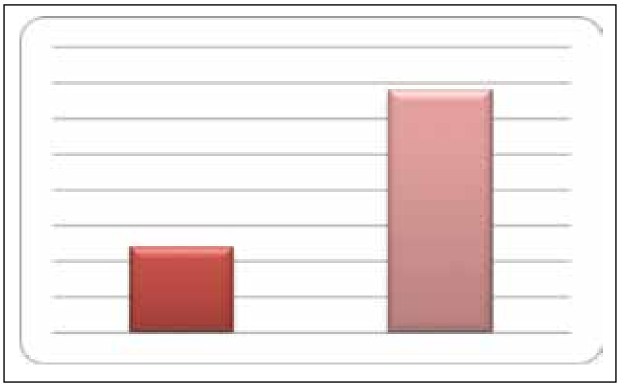


Figure 2D: Pre and post exposures Core body temperature

Table 3: Workers perceptions on Impacts of heat stress on health, productivity and social lives as SUMMER* season for WORKPLACE III (Steel Industry)

Variable	Characteristics	*Summer (n=104)	
		N	Percent (%)
Impacts on Health	Excessive sweating	90	86.5
	Muscle cramps	25	24.0
	Tiredness/weakness	49	47.1
	Headache	20	19.2
	Nausea/Vomiting	4	3.8
	Fainting	4	3.8
	Prickly heat	14	13.5
Production target & issues	Have production target	10	9.6
	Able to Complete production target	10	100.0
	Not able to complete production	NIL	
Impacts on productivity	Absenteeism/ Taken sick leave due to heat	1	0.96
	Less productivity/More time to complete task/Work extra hours	11	10.6
	Irritation/Interpersonal issues	8	7.7
	Wages lost in summer	NIL	
Coping mechanisms	Take rest	70	67.3
	Drink water	104	100.0
	Cool shower, bath or sponge bath	6	5.8
	Traditional methods	80	76.9
Impacts of clothing on productivity	Clothing-Comfortable	72	69.3
Impacts on Social Life	Yes	28	26.9
	Moderately	23	22.1

Note: Summer (April 2014)*

Table 3A: Physiological Heat Strain measurements for summer using Masimo Radical-7 monitor at Workplace III (Steel Industry)

Parameters	(Mean±SD) (n=98)
Pre Exposure Heart Rate (Beats/minute)	**81±12.5**
Post Exposure Heart Rate (Beats/minute)	**90±15.2**
Pre exposure Core Body Temperature (°C)	**36±3.5**
Post Exposure Core Body Temperature (°C)	**36.9±0.6**
Sweat Rate (L/hr)	**2.4±0.9**
Pre Exposure Met Hemoglobin (mg/dl)	**1.01±0.52**
Post Exposure Met Hemoglobin (mg/dl)	**1.1±1.23**
Pre Exposure Oxygen Saturation (%)	**98.2±1.01**
Post Exposure Oxygen Saturation (%)	**98.1±0.98**
Pre Exposure Total Hemoglobin (mg/dl)	**12.2±1.07**
Post Exposure Total Hemoglobin (mg/dl)	**12.1±1.06**
Pre Perfusion index	**4.89±2.92**
Post Perfusion index	**6.2±3.7**
Pre Pleth Variability index	**16±1.34**
Post Pleth Variability index	**15.9±1.06**

*All values are represented as mean±SD

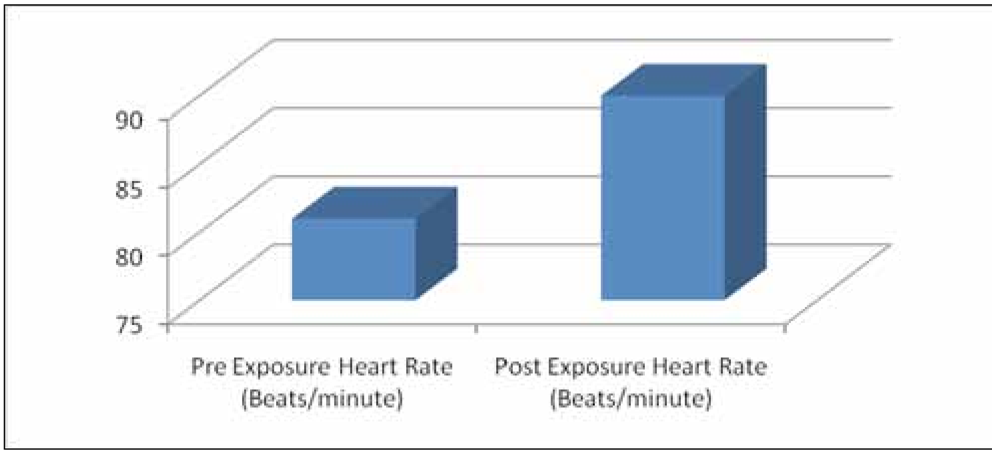


Figure 3A: Pre and post exposures Heart rate monitoring

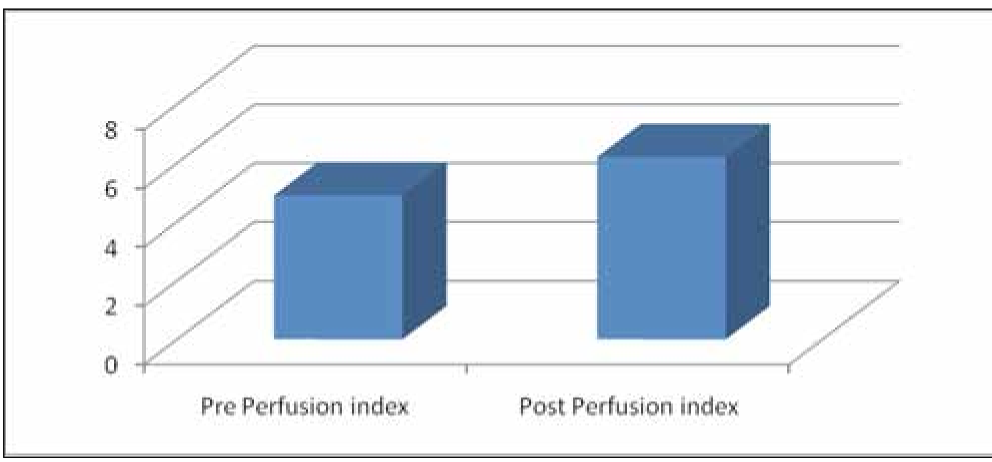


Figure 3B: Pre and post exposures Perfusion Index

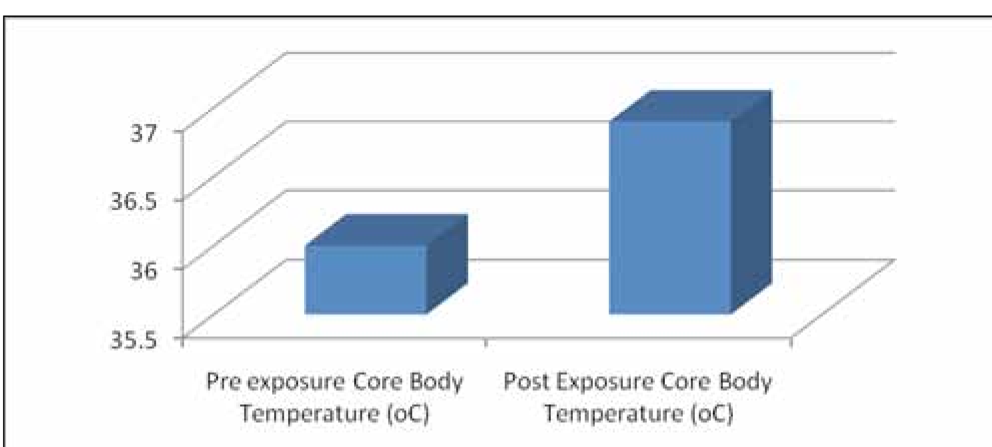


Figure 3C: Pre and post exposures Core body temperature

4.1.4 Continuous Heart Rate

- The heart rate was monitored continuously for subset of population using POLAR monitor which gives an idea about heart rate pattern (changes) over a period of time. The autonomic function of the subject also monitored.

- There was a progressive increase in heart rate above the resting level (72 bpm) even during the breaks in between work. In some cases, it went up to 170 bpm and the baseline heart rate was around 120 bpm. Workers in these categories need to be taking frequent breaks during work or by alternating with some lighter work during the shift.

- The heart rate if increased continuously can alter the sympatho vagal balance and leads to autonomic dysfunction and cardiac failure.

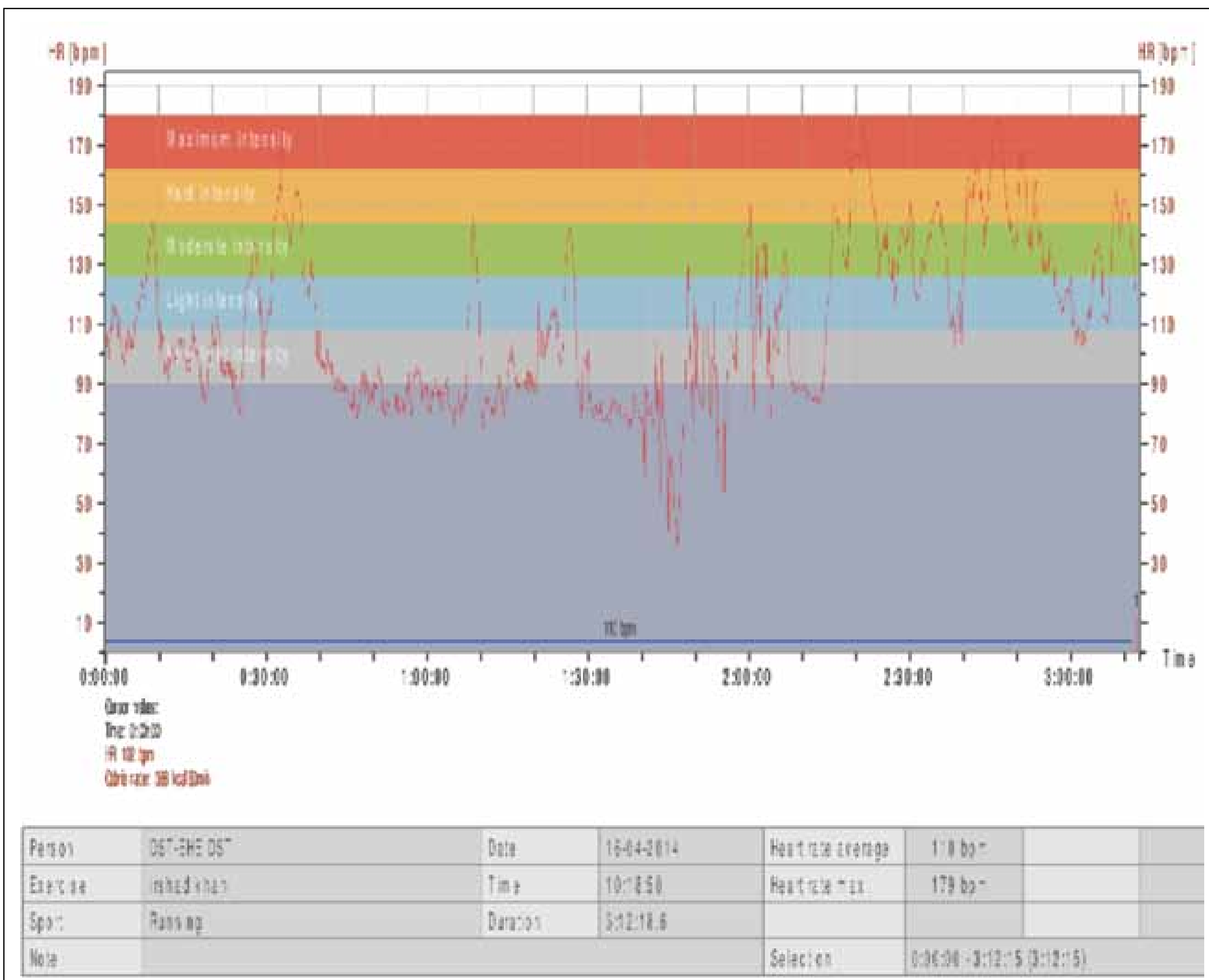


Figure 3D: Continuous Heart Rate monitoring

4.1.5 Deliverables

It is apparent from the Figure & Table below (Figure E & Table C/D) that about 90% of the workers in the sectors assessed are working in thermal environments that are much above the safe limits prescribed by the ACGIH. Workers in the steel manufacturing industry, with heavy workload, work in very high heat conditions and they have a high potential to be affected in terms of high heart rates and sweat rates. The perceptions of the workers also support the health data strongly. The long working hours, lacking of self pacing options and the very hot environments put the workers under highly vulnerable category and at high risk of heat-related illnesses. The work loads of other sectors assessed are categorized broadly under moderate work based on the work performed at the time of assessment. Independent of the category of workload, the workers are working under stressed conditions with respect to environmental heat stress. The sweat rates of at least about 50% of the workers are of concern if interventions are not made to avoid dehydration and consequent health impacts.

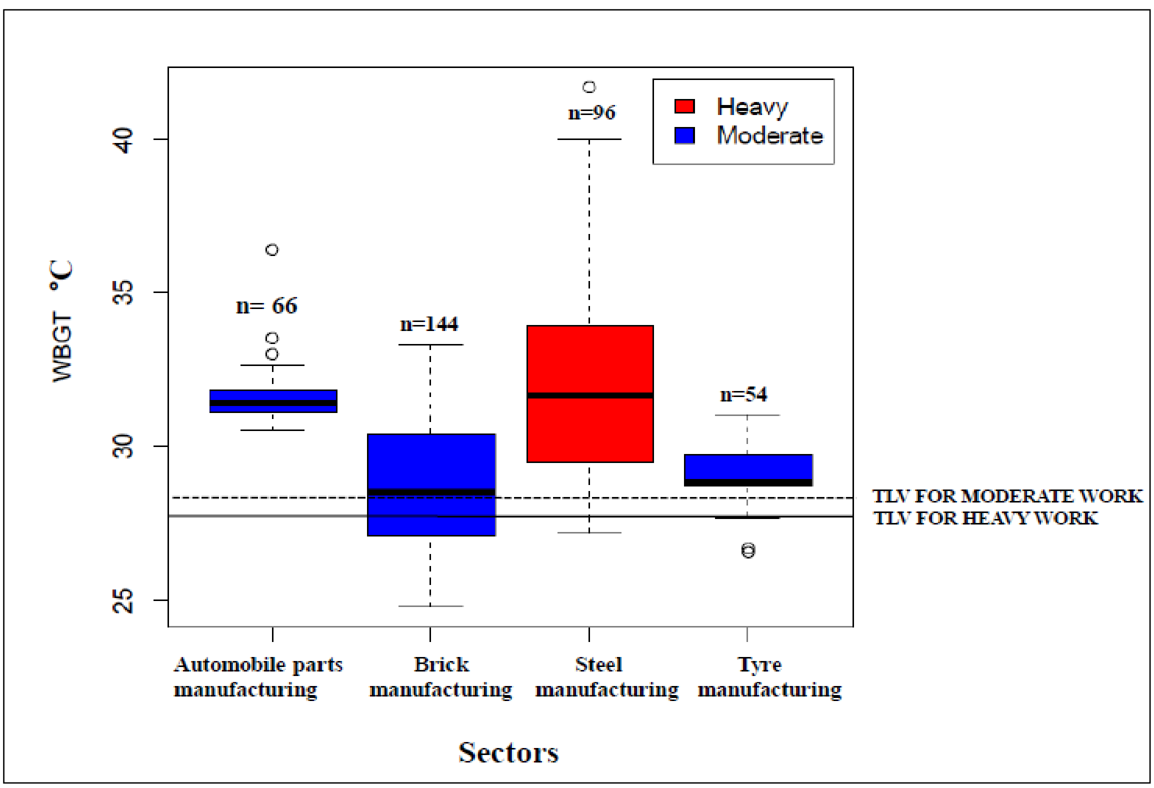


Figure E: Heat stress profile (WBGT °C) for various workplaces during summer 2014

Table C: Heat Stress measurements using Quest temp WBGT monitor at various workplaces

Sl.No	Type of Industry	Measured WBGT, (°C) Range, No. of samples	Comments
1	Tyre manufacturing	26.6-31.0, (n=18)	Above the limit value (n=15)
2	Brick manufacturing	24.8-33.3, (n=32)	Above the limit value (n=117)
3	Steel manufacturing	27.2-41.7, (n=49)	Above the limit value (n=48)
4	Automobile parts manufacturing (Summer)	28.2-36.4, (n=34)	Above the limit value (n=34)
5	Automobile parts manufacturing (Winter)	22.9-28.5, (n=22)	Above the limit value (n=2)

Table D: Hourly data of Heat stress monitoring using data loggers with Calculated WBGT (°C) values for various Work Places

Sl.No	Type of Industry	Temperature (°C)	Humidity (%)	WBGT (°C)
1	Tyre manufacturing, (n=10)	28.0 - 38	42 - 70	20.7 - 29
2	Brick manufacturing, (n=10)	25.0 – 36.5	16.5 - 68	24.4 – 36.2
3	Steel manufacturing, (n=15)	23.2 – 63.5	21.1 – 73.5	23.7 - 39.1
4	Automobile parts manufacturing (Summer)	NA		
5	Automobile parts manufacturing (Winter)			

4.1.6 Important Results

The results of this study demonstrate the fact that heat-stress is an issue that is impacting about 90% of the workers engaged in various job categories. The study provides the evidence that the workers are working in thermal environments that are much above the safe limits prescribed by the ACGIH. Workers in select sectors such as steel manufacturing industry, are engaged in heavy workload and are working in very high heat conditions (process generated heat) which when combined with ambient temperatures has very high potential to impact the health of the workers. Long working hours, lack of self pacing options and continuous exposures to very hot environments subject the workers to high risks of developing heat-related illnesses. Importantly, the perceptions of the workers on the impacts of occupational heat stress on their health and productivity also support findings based on health data strongly.

Physiological responses to occupational heat stress are not only dependent on ambient temperatures and cooling interventions but also are influenced by factors like work-rest ratios and physiological workload. Work-rest ratios are proven to be key factors in preventing/controlling any adverse health implications of occupational heat stress.

Gender sensitivity in occupational heat stress has emerged as an important element in this study. Lack of welfare facilities at workplaces, including toilets has subjected woman to additional health risks that are very unique to women.

Results show that the level of Hsp 70s are high in workers exposed to very high heat and engaged in heavy work, which indirectly indicates the level of stress/strain the body is subjected to.

Heart-rate monitoring shows significant productivity losses due to health decrements for people working in the construction sector. This trend if seen in other sectors may come to affect the economy of the country with consequent social implications as indirect effects of Occupational heat stress and Climate change.

4.2 Impact of Air Quality and Heat Stress on Health: Future Projections for India

4.2.1 Approved Objectives of the Project

As elucidated by the phrase '*heat stress*', it is the discomfort caused due to increased heat in human surroundings. It can be presented in the form of an index which is quantitative measure integrating into a single number one or more of the thermal, and/or physical and personal factors affecting heat transfer between the person and the environment.

Urban air pollution mainly in the form of aerosols (RSPM/PM_{10} and $PM_{2.5}$) serves as a 'precursor' to both short-term and long-term health problems of human beings. Identifying 'hotspots' within urban agglomeration and in turn forecast the aerosol concentration due to daily varying emission scenario and meteorological conditions is an important issue. Use of improved mathematical models (coupled model) serves as an alternative to monitoring stations, in providing daily forecast of aerosol concentration for entire urban Delhi. Moreover the knowledge of projected emission scenario on a regional scale is important in quantifying the nature of health risk posed through aerosols, in the future and devising appropriate mitigation plans. Based on the above facts, the specific objectives of this project are set to be the following.

(i) To identify suitable heat indices for different regions of India and project their future values.

(ii) To project the aerosol concentrations for future climate change scenarios in India using an integrated model with input from regional climate model RegCM.

(iii) To examine the changes in $PM_{2.5}$ in the last decade over India and to estimate the relative risks due to projected changes in $PM_{2.5}$ in future.

4.2.2 Studies Undertaken

4.2.2.1 Identifying suitable heat indices for India and future projections:

Five most commonly used heat indices – Wet Bulb Globe Temperature (WBGT), Humidex, Heat Index (HI), Effective Temperature (ET) and Universal Temperature Condition Index (UTCI) have been analyzed over four cities (Delhi, Mumbai, Kolkata and Chennai) for the period 1969-2005 using the meteorological data from India Meteorological Department (IMD). Regional Climate Model (RegCM 4.3) data has been analyzed to compute WBGT for whole India at 1°×1° resolution. Also the bias correction of this data has been done using the corresponding observed IMD data for the period 1975 to 2005 using regression technique.

Several indices exist in the literature to examine the heat stress, while none of them is tested for the Indian condition. We calculated all the commonly used indices (Wet Bulb Globe Temperature, WBGT; Humidex; Heat Index, HI; Effective Temperature, ET and Universal Temperature Condition Index, UTCI) for the four major metros (Delhi, Mumbai, Kolkata and Chennai) for the period 1969-2005 using the meteorological data from India Meteorological Department. After establishing the climatology, temperature threshold values (in °C) as shown in Table 1 are used to determine the comfort classes.

Table 1 Comfort classes and the various indices used for the present study

Comfort/Indices	HI	ET	WBGT	Humidex	UTCI
Frosty					
Very Cold		<1			
Cold		1-9			
Cool		9-17			0-9
Comfortable		17-21	<18	<30	9-26
Warm	27-32	21-23	18-24	30-40	26-32
Hot	32-41	23-27	24-28	40-45	32-38
Very Hot	41-54	>27	28-30	45-55	38-46
Sweltering	>54		>30	>55	>46

Fig. 1 shows the relative occurrences of the comfort classes in the four major metro cities of India. In Delhi, WBGT, Humidex and UTCI show more or less similar classification with WBGT showing sweltering condition in ~10% of the time. These thee indices show ~30% time as 'comfortable' in Delhi, while the values are much less (<10%) in the three other cities. The other two indices do not match with the common perception. WBGT and UTCI are close to each other in the three other coastal cities. It is to be noted that the 'sweltering' class is captured only by WBGT.

Comparison of the climatology and inter-annual variations of the indices with the three important meteorological parameters (near surface air temperature, RH and wind speed) reveals (not shown here) that UTCI is close to the temperature in some months.

In the other three coastal cities, UTCI is close to the temperature, while the WBGT is closer to the perception in all the cities. None of the existing indices capture the Indian condition accurately. WBGT and UTCI need to be suitably tuned for the Indian condition.

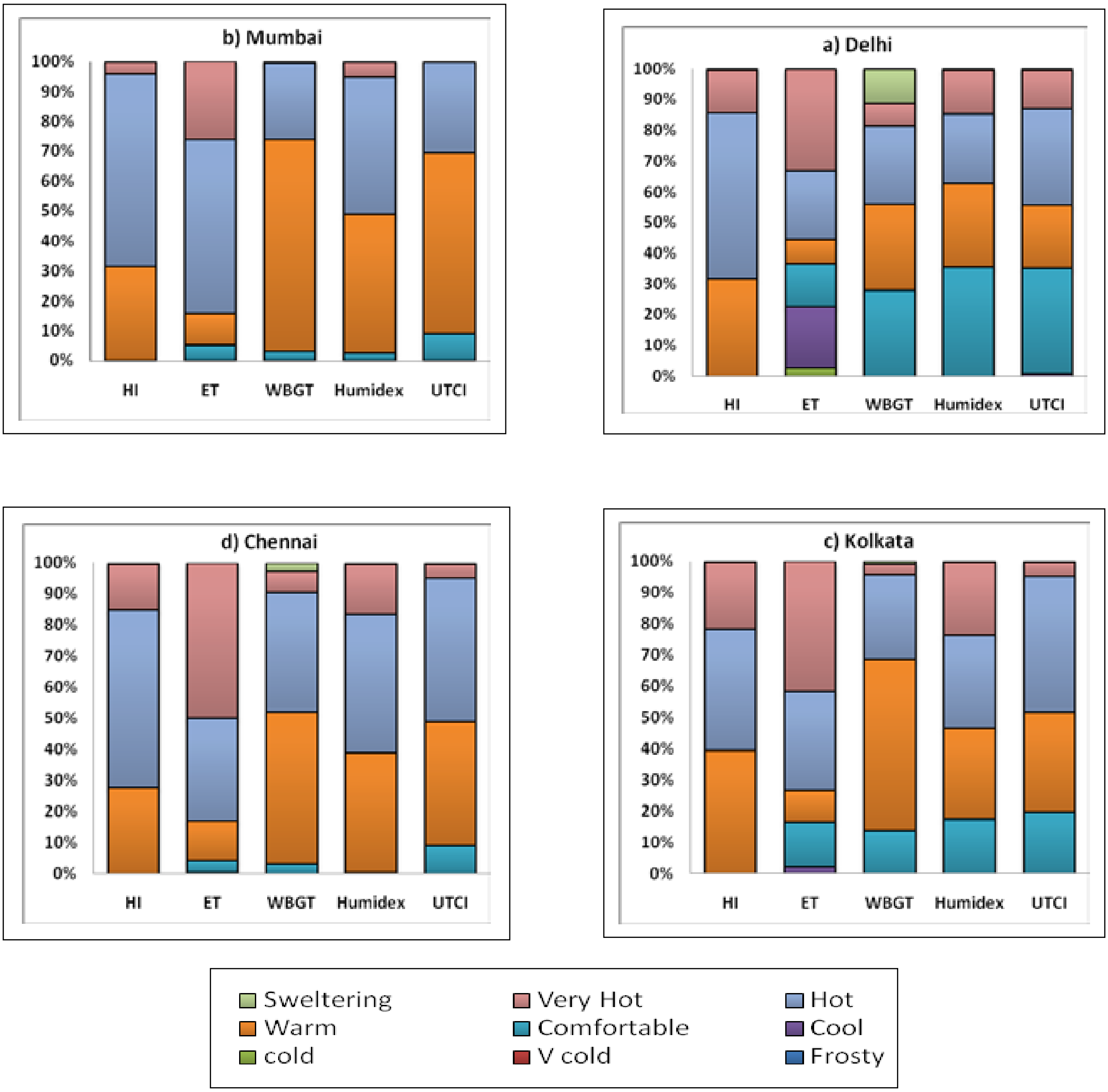


Fig. 1 Relative occurrences of various comfort classes in the four major cities determined from the threshold values listed in Table 1

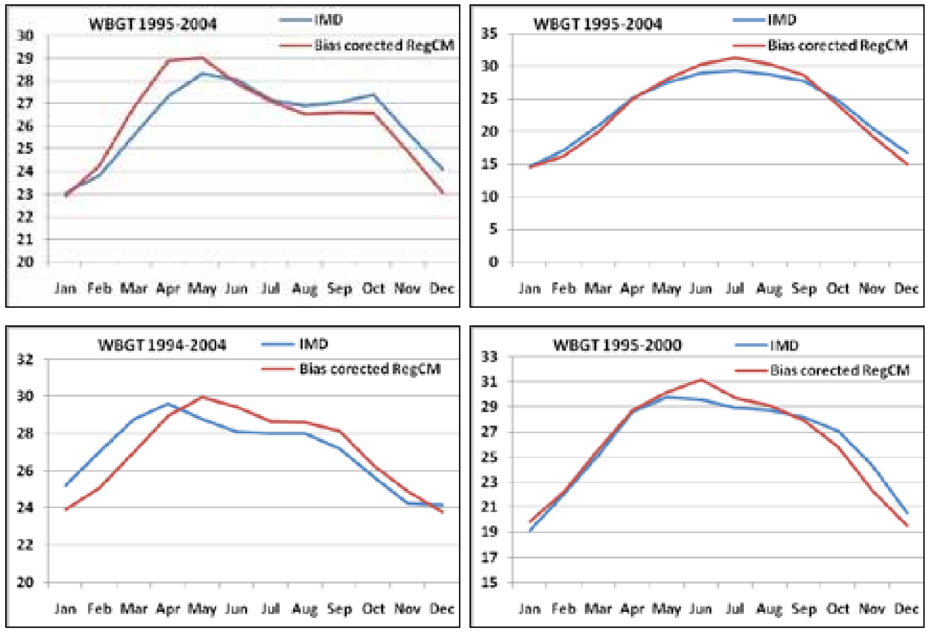


Fig. 2 Comparison between mean monthly WBGT calculated from IMD data and RegCM outputs for the period 1994-2005 in Delhi (top left), Mumbai (top right), Kolkata (bottom left) and Chennai (bottom right)

The two indices, WBGT and UTCI, derived based on IMD data are also calculated based on RegCM simulated data. This is done to tune the indices towards RegCM outputs, so that the same can be calculated for future climate projection scenarios. The indices calculated from RegCM dataset are well correlated with those from IMD dataset, but with a bias. For any scientific application, the biases are examined and corrected. Fig. 4 shows the bias-corrected WBGT over the four major cities for the period 1995-2004. Both datasets agree within 0.5ºC in most of the months in Delhi, except Jul and Aug, where the difference is larger (~2ºC). The pattern is similar in Kolkata. In Mumbai, the difference is larger during Mar-Apr, while in Chennai, one month lag of the peak WBGT is noticed. It is to be noted that several techniques exist for bias correction. Currently, work is going on to improve the bias correction of the RegCM datasets for both WBGT and UTCI.

4.2.2.2 Projecting aerosol concentration for climate change scenarios using an integrated model

Two approaches were adopted to forecast $PM_{2.5}$ concentration. Statistical relation between $PM_{2.5}$ and meteorological parameters were developed using adaptive neuro-fuzzy inference system and multi-linear regression. The models were trained with meteorological (temperature, dew point, RH, pressure, zonal and meridional wind and precipitation) data from RegCM simulations. Other meteorological data are available, but since the projected meteorological parameters of RegCM will be utilized for RCP4.5 and 8.5, the models were trained with RegCM outputs. A sensitivity test was carried out to check whether the choice of training samples impact the model forecast performance or not. In the second approach, WRF-Chem model was set up to simulate $PM_{2.5}$ and examine its relation with the meteorology.

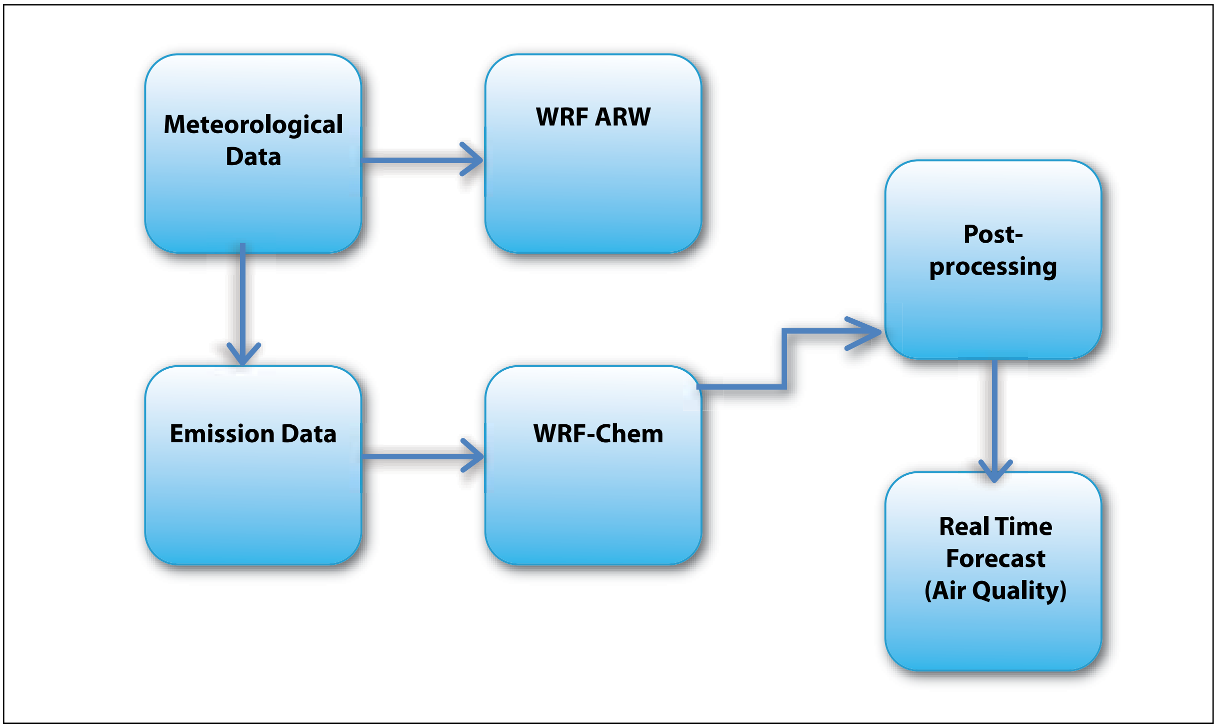


Fig. 3 Flow chart for air quality forecast, using WRF-Chem (version 3.6) modeling over India

Air quality estimation over India requires a sophisticated chemical transport model, which includes physical simulation of meteorological parameters as well as parameterized chemical reactions of the pollutants. The Weather Research and Forecasting (WRF ARW) model coupled with online chemistry (WRF-Chem) has been implemented over India in different domain for different years. WRF-Chem (Grell et al., 2005) consists of various options for gas-phase chemistry and aerosol chemistry and microphysics. These are RACM (Stockwell et al., 1997), RADM2 (Stockwell et al.,1990) and CBMZ for gas-phase chemistry while aerosols module include MADE/SORGAM(Schell et al., 2001) and MOSAIC. All these gas–phase chemistry option and aerosols options have been validated and it has been found that RADM/RACM scheme gives relatively best result.

The WRF ARW simulates meteorological data and using its output and emission inventory, WRF-Chem forecast the air quality in terms of PM2.5 and aerosols. Currently, the model simulation is going on to estimate the decadal change in PM2.5 over India using various emission inventories. For future projection the RegCm data will be used as input to WRF ARW with GAINS emission inventory to estimate the health risk associated with it.

The future projection of PM2.5 emission has been done using GAINS (Greenhouse Gas Air Pollution Interactions and Synergies) model output data for a particular scenario, over India in various states, using these emission inventories and meteorological data ,the air quality will be forecasted by WRF-Chem model over India by 2030. There are various sources which have been included for estimation of PM2.5 emission which are vehicles (2-stroke,4-stroke,heavy vehicles, light vehicles),power plant (both coal and gas based power plant) , waste(agriculture and residual waste), industrial production (brick, cement and lime, residential activities (food preparation, fireworks, cigarette smoking etc),agriculture activities etc. The figure (Fig. 4) shows Uttar Pradesh will contribute highest to PM2.5 emission for next decade. It will lead to high pollution in Indo-Gangeticplane.Though Delhi PM2.5 projection is remain low but long range transport from nearby area like Rajasthan may contribute significant pollution in Delhi.

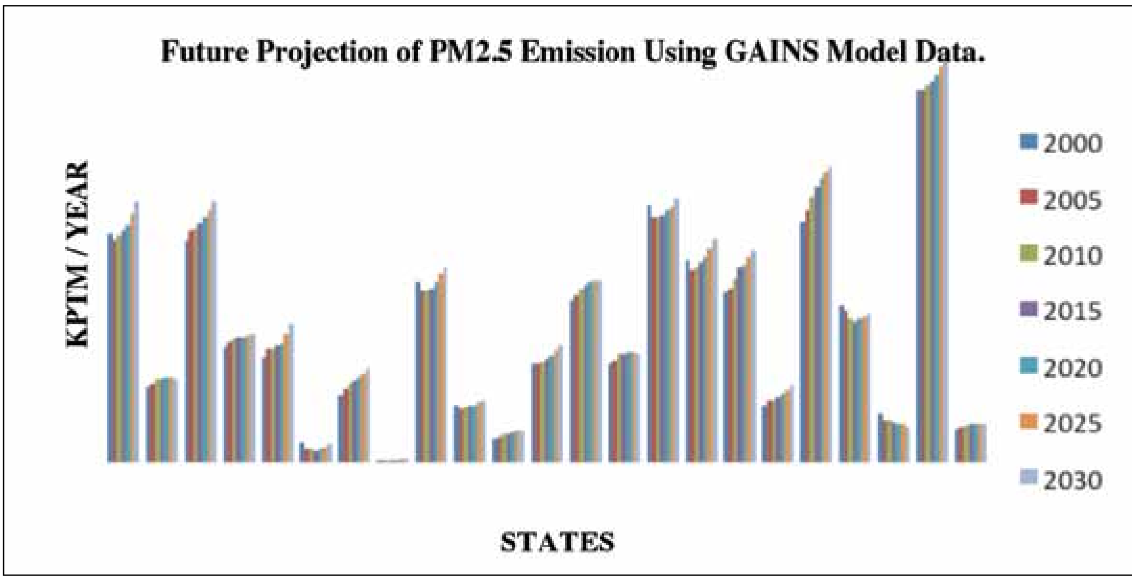


Fig. 4 Future projection of PM2.5 over India

Forecast of $PM_{2.5}$ using ANFIS technique

The fuzzy inference system that we have considered is a model that maps input characteristics to input membership functions,input membership function to rules,rules to a set of output characteristics,output characteristics to output membership functions, andoutput membership function to a single-valued output, or a decision associated with the output. Adaptive neuro-fuzzy inference system (ANFIS) is an approximation tool for non-linear functions more statistically than conventional statistical tools (Jang 1996). Considerable work has been done to integrate learning capability of neural networks with FIS for deriving the initial rules of a fuzzy system and tuning the membership functions (Jang 1993; Lin and Lee 1991; Horikawa et al. 1992; Ishibuchi et al. 1995; Morabito and Versaci 2003).

This work is done on National Capital Territory of Delhi (NCT), which is a special union territory jointly administered by the Central and local government. New Delhi is an urban area situated between the Himalayas and Aravali range in the heart of the Indian sub-continent, surrounded on three sides by the state Haryana and to the east, across the river Yamuna by the state Uttar Pradesh.

In this study, the design inputs include concentrations of $PM_{2.5}$ with previous day value of meteorological factors such as temperature (T), dew point (DP) relative humidity (RH), pressure (P), visibility (V) and mean wind speed (WS). The diurnal averages of monitored data from ITO monitoring station are collected from concerned agencies for the period Jan 2009 to Nov 2013. These data are subjected to ANFIS in order to develop a forecasting model, which can provide concentration of air pollutants accurately. Air quality of a region is depends on source of air pollutants, apart from this it highly depends on climate and geography of the region. Here relation between air quality and atmospheric factors is taken into consideration. Meteorological parameters (ambient temperature, dew point, relative humidity, pressure at sea level, visibility and mean wind speed) are selected as input variables and concentrations of $PM_{2.5}$ are taken as output variables in this study. For training and validation of ANFIS model various combinations of input variables (Meteorological parameters) were taken with one output variable (Air quality parameter).

The comparison of line plot of prediction and observed concentration is showing that both are following similar trend (Fig. 5). Apart from this some deviation can also be seen, in May month of 2011 and 2012 model is under predicting. Whereas is August 2013 model is over predicting concentration. Regression is a statistical process used to model the dependence of an independent variable on dependent variables. In order to map linear relation between the variables with more number of independent variables multiple linear regression is used. Here independent variables are fitted in a linear equation in order to predict dependent variables.

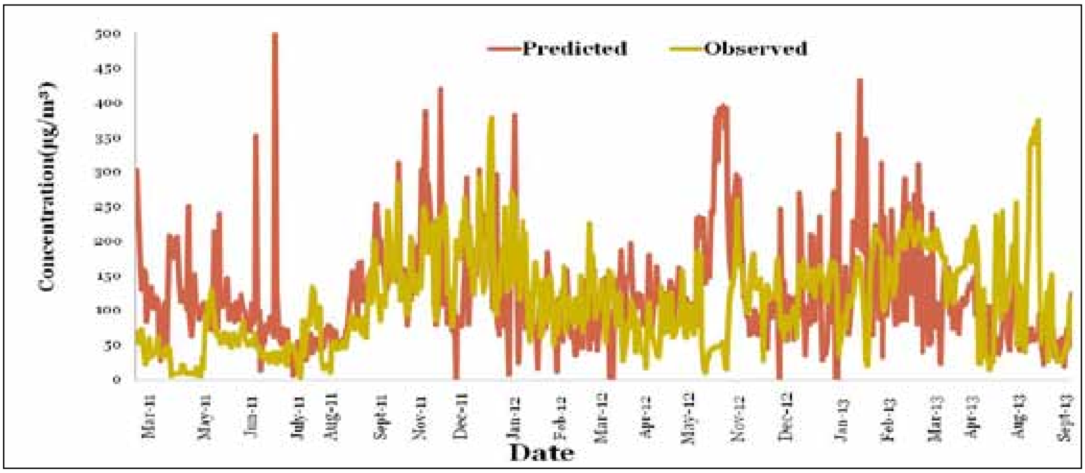


Fig. 5 Line graph of ANFIS output verses observed concentration (Training data size - 606)

The comparison of line plot of prediction and observed concentration is showing that both are following similar trend. Apart from this some deviation can also be seen, in May month of 2011 and 2012 model is under predicting. Whereas is August 2013 model is over predicting concentration. Three experiments have been performed with different sample size of 50, 75 and 90 percent training data sets respectively. The sensitivity of model due to change in data sets can be observed in Table 3. Figures like RMSE are not suggesting that the model is performing well for this case. But difference in mean and fractional bias for observed and predicted concentrations is low with 50 and 75 percent training data sample are indicating that there may be chance of improvement.

In this work the prediction is done for one day in advance i.e. concentration of $PM_{2.5}$ has been predicted one day earlier with one day advance meteorology as an input. If we are trying to predict/forecast the concentration for one or more years in advance with the same approach, it will be illogical as meteorology of present day will not appropriate for dispersion and transport of pollutants after one year. In various studies, Artificial intelligence technique has been proved to be very significant in the prediction of concentration by mapping non linear relationship between meteorology and pollutants. But for this particular case results are not that much satisfactory, it may be due to insignificant relationship between dependent and independent variables provided.

Table 3 Comparison of model output with different size of training-testing data size

	50% data for training	75% data for training	90% data for training
Training RMSE	68.39	66.04	67.19
Testing RMSE	95.77	100.04	111.03
NMSE	0.66	0.68	0.99
Index of Agreement	0.52	0.40	0.47
FB	0.094	-0.049	-0.59
Correlation	0.20	00	0.13
P value	0.0041	0.2978	0.0001
Statistical significance	Very Significant	Not significant	Extremely Significant

Regression is a statistical process used to model the dependence of an independent variable on dependent variables. In order to map linear relation between the variables with more number of independent variables multiple linear regression is used. Here independent variables are fitted in a linear equation in order to predict dependent variables. The linear regression model with more variables can be represented as

$$y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 \dots\dots\dots\dots\dots\dots. + \beta_n x_n$$

where '*y*' is the dependent variable, x_1, x_2.........,x_k are the independent variables, and $\beta_1, \beta_2, \dots \beta_n$ are regression co-efficient, β_o is a constant. The task of regression modeling is to estimate the $\beta_1, \beta_2, \dots \beta_n$, which can be achieved through least square error technique. In this study, concentration of $PM_{2.5}$ is the dependent variable, meteorological variables and emissions are independent variables, e is an estimated error term which is obtained from independent random sampling from the normal distribution with mean zero and constant variance.

Dependent and Independent variables for MLR

Meteorological parameters: Meteorological variables are taken RegCM 4.3 output. RegCM model has been run for Indian Region at ICTP, for emission scenario RCP-4.5. For this experiment RegCM surface output file has been selected, which is including 25 variables. Out of these 25 variables available following 8 variables are used in MLR as independent variables: topology (m), surface pressure (hPa), temperature (K), specific humidity (%), zonal wind (m/s), meridional wind (m/s), planetary boundary layer height

(m) and precipitation (kg/m²/day).

Resolution of RegCM output file is 0.22 X 0.22 in Rotated Mercator projection. These files are converted to 0.25 X 0.25 in equidistant projection. Annual mean of meteorological variables have been used for this work.

Emissions: Emission data has been taken from Chandra inventory for India with resolution of 0.25 X 0.25. This inventory is only available for year 2006.

$PM_{2.5}$ concentration: Concentration of $PM_{2.5}$ is determined for Indian region from AOD data collected from MISR. Conversion of MISR-AOD to $PM_{2.5}$ concentration is done on the basis of in Dey et al. (2012). This is interpolated for resolution of 0.25 X 0.25.

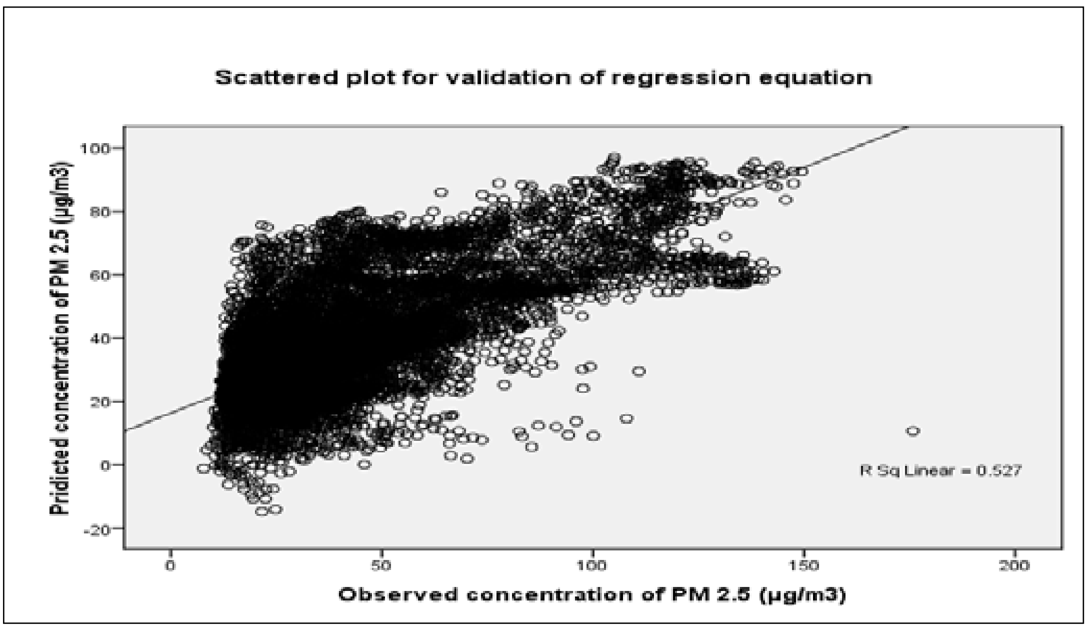


Fig. 6 Scattered plot between observed and predicted concentration of PM2.5 for 2010 -12 (training result)

MLR Model development

Meteorological parameters for year 2010-12 and emission data from year 2006 are taken as independent variables with concentration of PM2.5 for year 2010-12 as dependent variables. Annual average of each variable for each grid is acting as a sample, providing a sample size of 35,926. The linear equation obtained through this process:

$PM_{2.5}$ concentration = -1306.506 + 0.142*(topology) + 1.883*(pressure) – 1.273*(temp) – 8162.371*(specific humidity) + 1.084*(zonal wind) -0.394*(meridional wind) - 0.052*(boundary layer height) – 0.501*(precipitation) + 0.000*(emissions).

The correlation coefficient (R value) for this equation is 0.773 and R^2 value is 0.598. Standard error for this equation is 17.86.

Developed linear equation is validated for the prediction of concentration of $PM_{2.5}$ with different input data sets. The validation datasets should not be a part of training data sets and observed value corresponding to model output should be available, for this reason year 2013 data is chosen for validation. Sample size for validation process is 12,753.

Regression model is predicting concentration of $PM_{2.5}$ with correlation of 0.72 and showing coefficient of determination for observed and predicted concentration is 0.52 (Table 4). In statistical analysis for validation of showing slightly higher root mean square error, 18.08. Normalized mean square, 0.22 is approaching to zero but slightly bigger value. These two results are supporting each other and suggesting slight deviations in model predictions compared to observations, whereas index of agreement 0.82 and a correlation of 0.725 is showing a better performance of regression model. These all results are statistically significant as suggest by p-value.

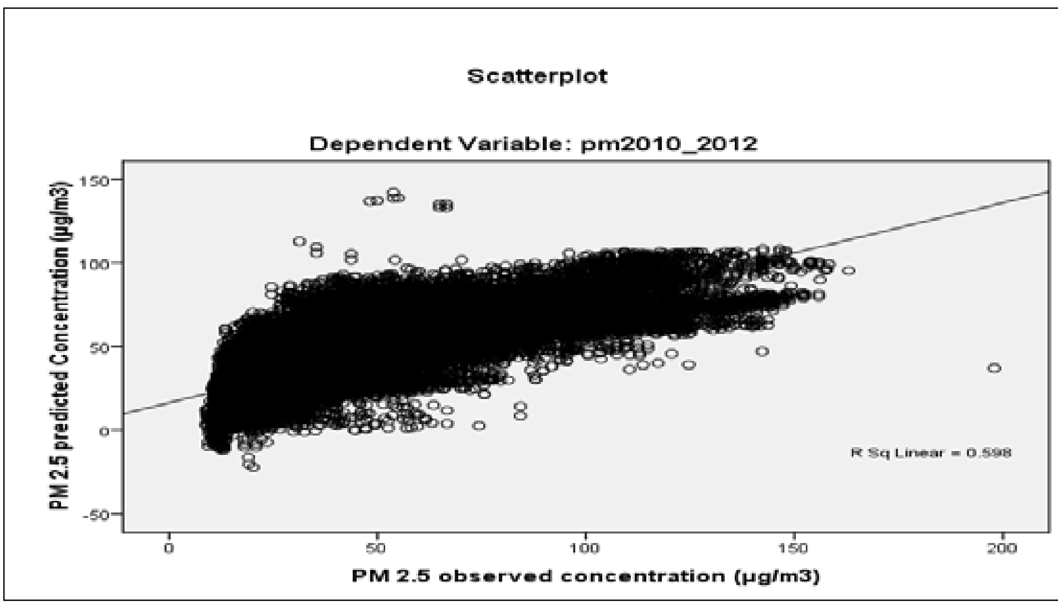


Fig.7 Scattered plot between observed and predicted concentration of PM2.5 for 2013 (validation result).

Table 4 Statistical analysis for validation of MLR output

Statistical Parameters	Observed and predicted concentration of year 2013
RMSE	18.08
NMSE	0.22
Index of Agreement	0.82
FB	-0.073
Correlation	0.725
Coefficient of determination	0.526
P value	0.00
Statistical significance	Significant

4.2.2.3 Health risks due to changes in $PM_{2.5}$ in the last decade and their future projections

The satellite-derived high resolution (50 km × 50 km) dataset of $PM_{2.5}$ have been re-gridded to generate a district level $PM_{2.5}$ database for the last decade (2000-2010). No India-specific cohort study exists to estimate the health risks due to exposure to this observed $PM_{2.5}$ concentration. To address this, more than 100 cohort studies from the literature are consulted and relative risks (RR) reported in these studies against the ambient $PM_{2.5}$ concentrations are utilized to derive a nonlinear power function. This approach allows us to quantify RR, which is required to estimate excess adult mortality, separately for four diseases – chronic obstructive pulmonary disease (COPD), ischemic heart disease (IHD), stroke and lung cancer (LC). In epidemiology literature, COPD, IHD and stroke are often considered together as cardiopulmonary diseases (CPD). This power function model is developed by using cohort studies which consider a wide variety of sample, highly heterogeneous in age, gender and socio-economic background. Therefore, it is considered to be better representative of RR in the context of India in absence of any India-specific cohort study rather than using response function based on individual cohort studies. The RRs are further used to estimate the additional adult mortality due to changes in $PM_{2.5}$ in the last decade. A higher resolution data (3 km × 3 km) have also been utilized to examine the $PM_{2.5}$ variation at local level for two mega cities, Delhi and Kolkata. Further, exposure risk maps at district level based on '*dose*' (which is a function of concentration, inhalation rate and time of exposure outside) are developed to identify the vulnerable districts.

Literature review of the epidemiological studies suggests two approaches to examine the health risk due to exposure to $PM_{2.5}$ – (i) estimate additional risk due to an increase in $PM_{2.5}$ relative to a baseline ambient $PM_{2.5}$ concentration and (ii) translate the relative risk (RR) to excess non-accidental mortality for the exposed population. In the first approach, additional mortality risks for CPD and LC due to an increase of 10 $\mu g\ m^{-3}$ in $PM_{2.5}$ concentration are estimated using the exposure response function reported in the review article of Chen et al. (2008). The mean $PM_{2.5}$ for each district and the trend in the last decade were estimated from the created $PM_{2.5}$ database. This analysis reveals the districts (where the background $PM_{2.5}$ may or may not be high compared to the national average), which are vulnerable to statistically significant trends in $PM_{2.5}$ in the last decade.

In the second approach, the excess adult mortality attributed to the exposure to $PM_{2.5}$ has been estimated using the RR shown in the following equation:

$$RR = \exp(\beta \times \Delta PM_{2.5})$$

where, b is the concentration-response function (CRF), RR is the relative risk and $\Delta PM_{2.5}$ is the change in $PM_{2.5}$ over a particular time period.

The excess adult mortality (DMort) then can be estimated as:

$$\Delta Mort = y \times \frac{RR - 1}{RR} \times Pop$$

where, y is the baseline mortality rate and 'pop' is the exposed population. Baseline mortality rate for India is taken from the World Health Organization (WHO) database (6.48 per 1000 person for CPD and 0.147 per 1000 person for LC). The exposed population is considered as 2001 census.

Since India-specific βvalues are not available, we adopted three RR functions to examine the possible ranges of variation in excess mortality attributable to exposure to outdoor $PM_{2.5}$. The first RR value was taken from the literature (Pope et al., 2002), where it was estimated using exponential relation (hereafter Case 1). More recently, a complex integrated response function (hereafter Case 2) was proposed (Burnett et al., 2014) to estimate RR. We have gone through the literature and found >100 cohort studies worldwide (the list is summarized in Table 1), where RR was calculated for exposure to $PM_{2.5}$. We categorized all these studies into four categories: (i) COPD, (ii) IHD, (iii) stroke and (iv) LC. The RR for each of the study was plotted against the exposed $PM_{2.5}$and the plots are fitted with various non-linear relations and the one with the highest correlation coefficient was chosen for each respective category. The RR (hereafter Case 3) using these relations are also used to estimate the excess mortality due to exposure in the last decade.

Table 5 Cohort studies considered for generating RR power law function. 1*s* in the second column represents the uncertainty of RR in that particular cohort study. Pollution types are categorized as ambient air pollution (AAP), second hand smoke (SHS), active smoke (AS) and household air pollution (HAP).

Disease Type	$PM_{2.5}$ (µg m^{-3})	Log (RR) (±1*s*)	Pollution Type	Reference
COPD	14.2	0.004879±0.005	AAP	Original analysis based on ACS
COPD	15.9	0.0157±0.015	AAP	Lepeule et al., 2012
COPD	15.6	0.17395±0.015	AAP	Lipsett et al., 2011
COPD	200	0.641854±0.25	HAP	Smith et al., 2014
COPD	330	0.993±0.17	HAP	Smith et al., 2014
COPD	1000	1.413423±0.36	AS	Original analysis based on ACS
COPD	3667	1.9451±0.2	AS	Original analysis based on ACS
COPD	6667	1.796747±0.15	AS	Original analysis based on ACS
COPD	10000	1.859418±0.19	AS	Original analysis based on ACS
COPD	13333	2.107786±0.11	AS	Original analysis based on ACS
COPD	16667	1.63119±0.3	AS	Original analysis based on ACS
COPD	20000	2.393339±0.15	AS	Original analysis based on ACS
COPD	23333	2.780993±0.33	AS	Original analysis based on ACS
COPD	26667	2.48574±0.15	AS	Original analysis based on ACS
COPD	30000	2.203869±0.28	AS	Original analysis based on ACS
IHD	14.2	0.023111±0.004	AAP	Original analysis based on ACS
IHD	15.9	0.028518±0.008	AAP	Lepeule et al., 2012
IHD	15.6	0.018232±0.007	AAP	Lipsett et al., 2011
IHD	13.9	0.07031±0.03	AAP	Puett et al., 2009
IHD	13.5	0.079299±0.032	AAP	Miller et al., 2009

IHD	29	0±0.007	AAP	Chen et al., 2005
IHD	17.9	-0.00202±0.016	AAP	Puett et al., 2011
IHD	28.3	-0.00408±0.012	AAP	Beelen et al., 2008
IHD	20	-0.10536±1.48	SHS	Svendsen et al., 1987 (Males)
IHD	20	0.737164±0.63	SHS	Hole et al., 1989 (Males)
IHD	20	0.076961±0.093	SHS	Hirayama et al., 1990 (Males)
IHD	20	0.122218±0.46	SHS	Le Vecchia et al., 1993 (Males)
IHD	20	0.476234±0.6	SHS	He et al., 1994 (Males)
IHD	20	0.270027±0.1	SHS	Steenland et al., 1996 (Males)
IHD	20	0.215111±0.36	SHS	Ciruzzi et al., 1998 (Males)
IHD	20	0.019803±0.16	SHS	Rosenlund et al., 2001 (Males)
IHD	50	1.166271±0.72	SHS	Svendsen et al., 1987 (Females)
IHD	50	1.415853±0.62	SHS	Hole et al., 1989(Males)
IHD	50	0.262364±0.1	SHS	Hirayama et al., 1990 (Females)
IHD	50	0.262364±0.48	SHS	LeVecchia et al., 1993 (Females)
IHD	50	1.269761±0.75	SHS	He et al., 1994 (Females)
IHD	50	0.131028±0.08	SHS	Steenland et al., 1996 (Females)
IHD	50	1.393766±0.71	SHS	Ciruzzi et al., 1998 (Females)
IHD	50	0.457425±0.24	SHS	Rosenlund et al., 2001 (Females)
IHD	1000	0.476234±0.11	AS	Pope et al., 2011
IHD	3667	0.494696±0.09	AS	Pope et al., 2011
IHD	6667	0.727549±0.05	AS	Pope et al., 2011
IHD	10000	0.779325±0.07	AS	Pope et al., 2011
IHD	13333	0.858662±0.03	AS	Pope et al., 2011
IHD	16667	0.828552±0.09	AS	Pope et al., 2011
IHD	20000	0.797507±0.05	AS	Pope et al., 2011
IHD	23333	0.947789±0.15	AS	Pope et al., 2011
IHD	26667	0.832909±0.05	AS	Pope et al., 2011
IHD	30000	0.693147±0.10	AS	Pope et al., 2011
Stroke	14.2	0.011333±0.004	AAP	Original analysis based on ACS
Stroke	15.9	-0.00408±0.01	AAP	Lepeule et al., 2012
Stroke	15.6	0.014842±0.01	AAP	Lipsett et al., 2011
Stroke	13.4	0.060432±0.02	AAP	Miler et al., 2007
Stroke	28.3	0.048243±0.02	AAP	Beelen et al., 2008
Stroke	35	-1.10866±1.08	SHS	Gillis et al., 1984 (Males)
Stroke	35	0.631272±1.09	SHS	Gillis et al., 1984 (Females)
Stroke	35	-0.03046±02.20	SHS	Sandler et al., 1989 (Males)
Stroke	35	0.215111±0.09	SHS	Sandler et al., 1989 (Females)
Stroke	35	0.122218±0.9	SHS	Yamada et al., 2003 (Males)

Stroke	35	-0.06188±0.25	SHS	Yamada et al., 2003 (Females)
Stroke	35	0.019803±0.18	SHS	Iribarren et al., 2004 (Males)
Stroke	35	0.157004±0.12	SHS	Iribarren et al., 2004 (Females)
Stroke	35	0.431782±0.41	SHS	Whincup et al., 2004 (Males)
Stroke	35	-0.10536±0.19	SHS	Qureshi et al., 2005 (Females)
Stroke	35	0.41871±0.17	SHS	Wen et al., 2006 (Females)
Stroke	35	0.46374±0.16	SHS	Hill et al., 2007 (Males)
Stroke	35	-0.10536±0.19	SHS	Hill et al., 2007 (Females)
Stroke	35	0.598837±0.21	SHS	Hill et al., 2007 (Males)
Stroke	35	0.157004±0.22	SHS	Hill et al., 2007 (Females)
Stroke	35	0.48858±0.3	SHS	Glymour et al., 2008 (Males)
Stroke	35	0.378436±0.19	SHS	Glymour et al., 2008 (Females)
Stroke	35	0.565314±0.15	SHS	Glymour et al., 2008 (Males)
Stroke	35	0.444686±0.31	SHS	Glymour et al., 2008 (Females)
Stroke	35	-0.06188±0.08	SHS	Jefferis et al., 2010
Stroke	1000	0.157004±0.27	AS	Original analysis based on ACS
Stroke	3667	0.708036±0.15	AS	Original analysis based on ACS
Stroke	6667	0.756122±0.11	AS	Original analysis based on ACS
Stroke	10000	0.582216±0.16	AS	Original analysis based on ACS
Stroke	13333	0.887891±0.08	AS	Original analysis based on ACS
Stroke	16667	1.026042±0.19	AS	Original analysis based on ACS
Stroke	20000	0.845868±0.13	AS	Original analysis based on ACS
Stroke	23333	0.824175±0.38	AS	Original analysis based on ACS
Stroke	26667	0.774727±0.14	AS	Original analysis based on ACS
Stroke	30000	0.741937±0.26	AS	Original analysis based on ACS
LC	14.2	0.013103±0.003	AAP	Lepeule et al., 2012
LC	15.9	0.031481±0.01	AAP	Lipsett et al., 2011
LC	15.6	-0.005827±0.01	AAP	Beelen et al., 2008
LC	28.3	0.00518794±0.74	AAP	Brownson et al., 1992
LC	35	-0.28768±0.28	SHS	Chang and Fung 1982
LC	35	0.727549±0.47	SHS	Correa et al., 1983
LC	35	0.239017±0.19	SHS	Garfnkel et al., 1985
LC	35	0.770108±0.35	SHS	Geng et al., 1987
LC	35	0.936093±0.63	SHS	Inoue and Hirayama 1987
LC	35	0.076961±0.29	SHS	Kabat et al., 1995
LC	35	-0.23572±0.58	SHS	Wynder et al., 1984
LC	35	0.641854±0.32	SHS	Kalandidi et al., 1990
LC	35	0.262364±0.32	SHS	Ko et al., 1997
LC	35	0.698135±0.31	SHS	Lam et al., 1987
LC	35	0±0.5	SHS	Lee et al., 2000
LC	35	0.506818±0.41	SHS	Liu et al., 1993
LC	35	0.076961±0.26	SHS	Shimizu et al., 1988

LC	35	0.122218±0.18	SHS	Sobue 1990
LC	35	0.875469±0.39	SHS	Trichopoulos et al., 1983
LC	35	0.425268±0.18	SHS	Zaridze et al., 1998
LC	35	0.405465±0.26	SHS	Akiba et al., 1986
LC	35	0.10436±0.11	SHS	Boffetta et al., 1999
LC	35	0±0.10	SHS	Brownson et al., 1987
LC	35	-0.22314±0.43	SHS	Bufler et al., 1984
LC	35	0.254642±0.10	SHS	Fontham et al., 1994
LC	35	0.173953±0.19	SHS	Gao et al., 1987
LC	35	0.587787±0.66	SHS	Humble et al., 1987
LC	35	0.494696±0.32	SHS	Koo et al., 1997
LC	35	0.500775±0.18	SHS	Lam et al., 1987
LC	35	-0.26136±0.47	SHS	Liu et al., 1991
LC	35	0.04879±0.28	SHS	Nyberg et al., 1997
LC	35	0.182322±0.28	SHS	Pershagen et al., 1987
LC	35	0.48858±0.44	SHS	Shen et al., 1998
LC	35	0.470004±0.34	SHS	Stockwell et al., 1992
LC	35	0.231112±0.4	SHS	Svenson et al., 1989
LC	35	0.10436±0.27	SHS	Wang et al., 1996
LC	35	0.182322±0.36	SHS	Wu et al., 1985
LC	35	-0.23572±0.12	SHS	Wu et al., 1990
LC	35	0.703098±0.86	SHS	Butler et al., 1998
LC	35	0.182322±0.20	SHS	Cardenas et al., 1997
LC	35	0.182322±0.19	SHS	Garfunkel et al., 1985
LC	35	0.336472±0.17	SHS	Hirayama 1981
LC	35	0.693147±1.12	SHS	Hole et al., 1989
LC	35	0.48858±0.37	SHS	Johnson et al., 2001
LC	35	0.173953±0.26	SHS	Wang et al., 2000
LC	35	0.262364±0.17	SHS	Seow et al., 2002
LC	35	0.231112±0.09	HAP	Smith et al., 2014
LC	35	0.593±0.268	HAP	Smith et al., 2014
LC	1000	2.345645±0.18	AS	Pope et al., 2011
LC	3667	2.083185±0.15	AS	Pope et al., 2011
LC	6667	2.453588±0.1	AS	Pope et al., 2011
LC	10000	2.634045±0.11	AS	Pope et al., 2011
LC	13333	2.989714±0.07	AS	Pope et al., 2011
LC	16667	3.170526±0.12	AS	Pope et al., 2011
LC	20000	3.289148±0.08	AS	Pope et al., 2011
LC	23333	3.285412±0.18	AS	Pope et al., 2011
LC	26667	3.42198±0.08	AS	Pope et al., 2011
LC	30000	3.667656±0.11	AS	Pope et al., 2011

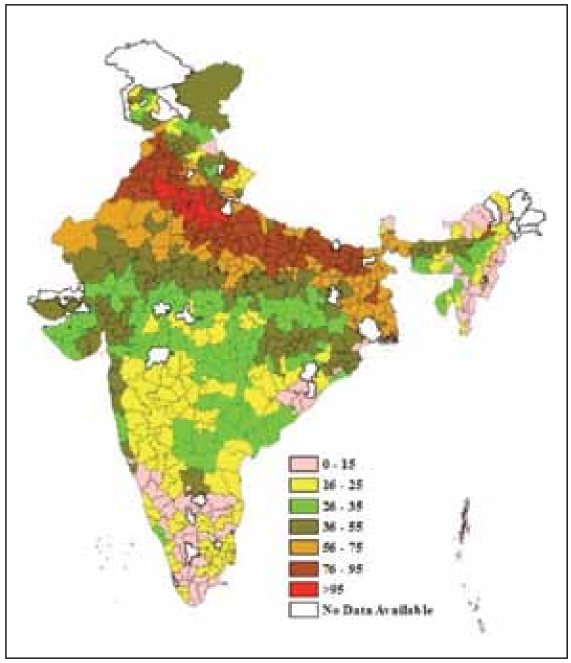


Fig. 8 Mean annual $PM_{2.5}$ concentration for the period 2000-2010 over India

The mean (±1*s*) annual $PM_{2.5}$ concentrations and the increase in the last decade for individual districts are summarized in Table 6. Both the parameters are important in the context of health impacts; but for similar magnitude of increase in $PM_{2.5}$ over a specific period, larger risk is involved for lower baseline concentration. All-India mean $PM_{2.5}$ concentration is 42 µg m^{-3}. Vulnerability of the districts is classified qualitatively based on $PM_{2.5}$ statistics (Table 6). For example, if $PM_{2.5}$ exceeds 95^{th}percentile for a district, it is categorized as extremely vulnerable. Similarly, $PM_{2.5}$ less than 12.5 µg m^{-3}(close to the World Health Organization air quality threshold of 10 µg m^{-3}) is considered to be safe in terms of health effects.

Table 6 Qualitative classes for vulnerability based on ambient $PM_{2.5}$ statistics

Percen-tile	$PM_{2.5}$ (µg m^{-3})	Category	Comment
$<5^{th}$	<12.5	Safe	*Close to WHO threshold of 10 µg m^{-3}*
5^{th} - 10^{th}	12.5 - 14.8	Low	*Close to WHO Interim Target III*
10^{th} - 25^{th}	14.8 - 22.1	Moderate	*Close to EU Air quality threshold*
25^{th} - 50^{th}	22.1 - 37.3	High	*Close to WHO IT-I and Indian Standard*
50^{th} - 75^{th}	37.3 - 69.8	Very High	*Upper limit is double of WHO Interim Target I*
75^{th} - 90^{th}	69.8 - 87.3	Severe	*More than twice of Indian Standard*
$>90^{th}$	>87.3	Extreme	*More than 8 times of WHO air quality standrad*

Following these categories, what is striking is that more than 50% of the Indian districts have $PM_{2.5}$ above the Indian standard. The statistics of the districts are estimated and some examples are given below.

Table 7 Mean annual $PM_{2.5}$ concentration for the period 2000-2010 and vulnerability following Table 5 for each district in India

	State	Districts	$PM_{2.5}$ (µg m^{-3})	Vulnerability	Population-weighted Exposure (µg/day)	Estimated Excess Mortality per year (±1s)
1	**Jammu & Kashmir**	Kupwara	20.8	Low	9.40	320±140
		Baramula	37.3	Moderate	16.54	706±276
		Srinagar	29.9	Moderate	12.43	763±311
		Pulwama	30.0	Moderate	12.90	384±157
		Anantnag	35.7	Moderate	15.71	702±277
		Leh	42.8	High	17.48	87±33
		Udhampur	36.5	Moderate	16.13	457±179
		Punch	17.0	Low	7.67	176±80
		Rajauri	28.4	Moderate	12.60	273±112
		Jammu	51.8	High	21.65	1185±436
		Kathua	70.1	Very High	30.31	419±146
2	**Himachal Pradesh**	Chamba	19.4	Low	8.48	241±107
		Kangra	45.7	High	19.03	969±364
		Lahul&Spiti	28.9	Moderate	11.65	23±10
		Kullu	38.9	High	16.67	252±98
		Mandi	44.9	High	18.99	636±240
		Hamirpur	44.6	High	18.53	298±113
		Una	50.8	High	21.40	328±121
		Bilaspur	49.4	High	20.68	251±93
		Solan	39.4	High	16.57	347±134
		Sirmaur	59.7	High	25.97	332±119
		Kinnaur	3.7	Very Safe	1.52	0
		Shimla	23.1	Moderate	9.58	437±187
3	**Punjab**	Gurdaspur	81.7	Very High	34.54	1721±586
		Amritsar	73.7	Very High	31.40	2434±843
		Kapurthala	85.5	Very High	35.79	634±215
		Jalandhar	92.4	Severe	38.17	1724±576
		Hoshiarpur	81.5	Very High	33.98	1240±423
		Nawanshahr	75.6	Very High	31.44	484±167
		Rupnagar	91.1	Severe	38.20	956±320
		Fategarh Sahib	88.9	Severe	37.10	462±155
		Ludhiana	95.3	Extreme	39.65	2666±886
		Moga	90.4	Severe	38.04	755±253
		Firozpur	86.1	Very High	37.24	1390±470

		Muktsar	95.0	Extreme	40.25	659±219
		Faridkot	95.8	Extreme	40.60	468±156
		Bhatinda	94.5	Extreme	39.60	1019±339
		Mansa	102.7	Extreme	43.84	585±193
		Sangrur	91.7	Severe	38.74	1685±564
		Patiala	88.9	Severe	37.51	1554±523
		Tarn Taran	100.1	Extreme	NaN	NaN
		SAS Nagar (Mohali)	70.2	Very High	NaN	NaN
		Barnala	91.0	Severe	NaN	NaN
4	**Chandigarh**	Chandigarh	70.2	Very High	29.33	738±258
5	**Uttaranchal**	Dehradun	47.9	High	20.36	909±339
		TehriGarhwal	35.3	Moderate	15.56	366±144
		Chamoli	88.1	Severe	38.28	293±99
		Uttarkashi	52.9	High	23.45	199±73
		Garhwal	36.6	Moderate	15.74	447±175
		Pithoragarh	23.0	Moderate	10.04	255±109
		Bageshwar	15.6	Low	6.88	121±56
		Almora	17.0	Low	7.46	312±143
		Champawat	39.3	High	17.71	136±53
		Nainital	57.4	High	24.99	545±197
		Hardwar	59.6	High	26.86	975±350
6	**Haryana**	Panchkula	70.2	Very High	29.79	372±130
		Ambala	69.4	Very High	29.32	802±281
		Kurukshetra	84.2	Very High	36.18	665±226
		Kaithal	93.5	Severe	40.83	755±252
		Karnal	86.3	Very High	37.62	1004±339
		Panipat	95.8	Extreme	42.35	763±254
		Sonepat	99.8	Extreme	43.55	1041±344
		Jind	97.5	Extreme	42.80	949±315
		Fatehabad	95.9	Extreme	42.26	638±212
		Sirsa	94.5	Extreme	39.27	900±300
		Hisar	97.5	Extreme	41.54	1169±388
		Bhiwani	92.3	Severe	40.53	1125±376
		Rohtak	81.1	Very High	34.85	748±255
		Jhajjar	99.0	Extreme	42.84	728±241
		Mahendragarh	72.6	Very High	31.83	604±210
		Rewari	77.1	Very High	33.48	593±204
		Gurgaon	102.5	Extreme	47.30	1227±404
		Faridabad	100.5	Extreme	44.98	1711±564
		Mewat	83.1	Very High	-	-
7	**Delhi**	Average of all districts	148.4	Extreme	63.13	12938±4064

Estimation of RR and its sensitivity to $PM_{2.5}$ concentration

A nonlinear power fit (NLP) of the following form was used to relate RR for each exposure criterion (AP, SHS, AS and HAP) and $PM_{2.5}$ concentration for all the four diseases considered:

$$RR = 1 + \alpha * (PM_{2.5})^{\beta}$$

Where α and β are specific constants for each disease, the values of which are mentioned in Table 2. The NLP curves for COPD (Fig. 9a), IHD (Fig. 9b), stroke (Fig. 9c) and LC (Fig. 9d) are shown in Fig. 9. The NLP fit was such that the RR becomes equal 1 below a counterfactual concentration of $PM_{2.5}$ exposure. In other words, no excess risk exists below this $PM_{2.5}$ level. RR estimates were evaluated at study specific $PM_{2.5}$ concentration minus the counterfactual concentration. Lim et al. (2012) suggested that a positive counterfactual concentration should be used unlike other studies (Pope et al 2002, Krewski et al 2009) where the minimum $PM_{2.5}$ concentration during the cohort study was used as the counterfactual concentration. In our estimates, we considered the WHO limit for annual mean $PM_{2.5}$ of 10 μg/m^3 as the counterfactual concentration. Ten districts (Table 7) with $PM_{2.5}$ concentration below 10 μg/m^3 were considered as safe.

The additional non-accidental mortality risk due to the increase in PM2.5 over the last decade over the large cities (>1 million population) is shown in Fig. 10 (arranged in the decreasing order of population). It is interesting to note that the health risk is not proportional to the population (widely considered as a proxy to pollution emitted from anthropogenic activities), rather it is higher than all-India average (additional mortality risk of 6%) mostly in cities in the Indo-Gangetic Plain and also in Mumbai. The same statistics for the states and the union territories is shown in Fig. 4. Punjab, Delhi, UP, Bihar, Manipur, Mizoram, West Bengal, Jharkhand, Odisha, Chhattisgarh and Maharashtra are identified to be the vulnerable states, where the additional mortality risk from CPD and LC is higher than the all-India average. West-Bengal, Jharkhand, Odisha, Chhattisgarh, MP, Maharashtra, Andhra Pradesh, Karnataka, Kerala and TN are identified as vulnerable states, where excess mortality from CPD due to exposure till 2030 (if the current rate of change continues unperturbed) exceeds 10000 and excess mortality from LC exceeds 300. Calculations show that by slowing down the current rate of change of PM2.5 by 50% after 2020 through policy intervention will reduce the excess mortality by ~19%. District level health survey data for the period 2007-2008 was collected from the Health Ministry and are being utilized to develop India-specific CRF values. After taking care of 'district fixed effect', 'seasonal effect' and 'impact of spikes in Tand precipitation', the excess mortality that can be attributed to exposure to $PM_{2.5}$was calculated as a function of age. Preliminary results suggest that the infant mortality is much higher than the values reported in the literature.

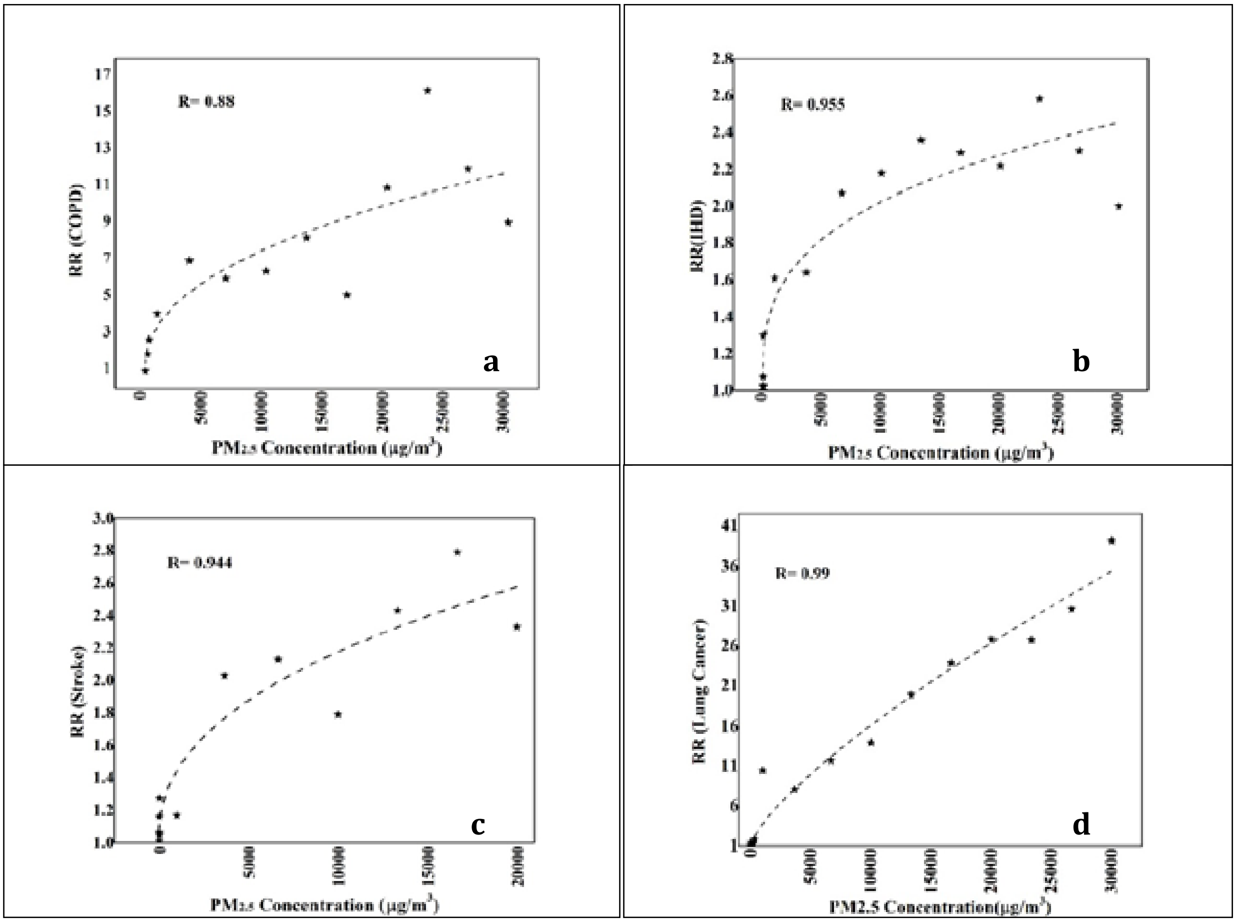


Fig. 9 Relative risk functions derived for (a) COPD, (b) IHD, (c) Stroke and (d) Lung cancer diseases due to long-term exposure to outdoor $PM_{2.5}$. Each of the points represents a cohort study as summarized in Table 2 (validated against health data at the respective countries). The fit represents a power-law function.

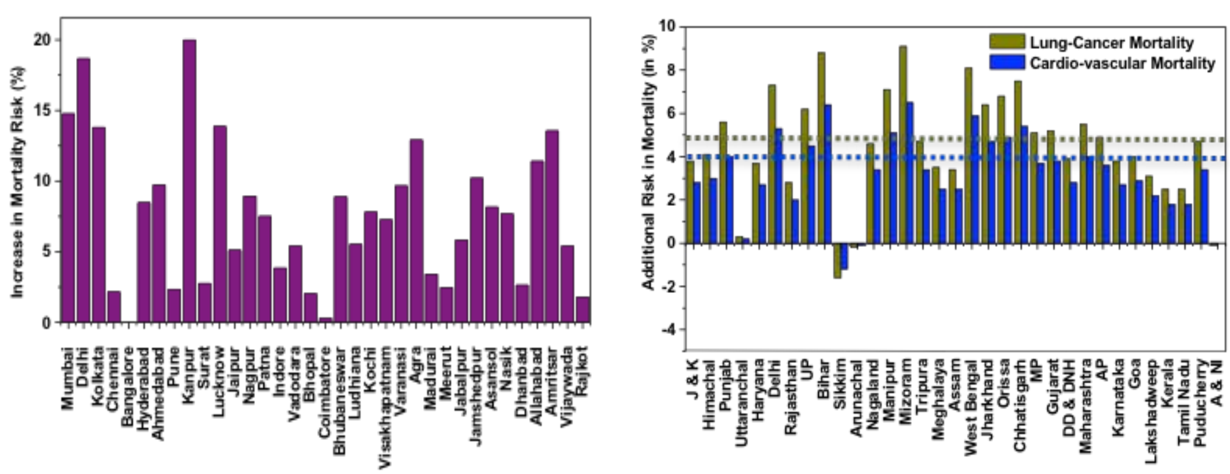


Fig. 10 Additional non-accidental mortality risk (in %) for the (left) major urban areas and (right) states of India (dashed lines show the all-India average)

Excess mortality due to exposure to $PM_{2.5}$

The district-wise excess mortality attributed to the CPD (COPD + IHD + Stroke) and LC due to the exposure to $PM_{2.5}$ in the last decade (2000-2010) is illustrated in Fig. 11. Estimates are done using three different RR as described in the 'Methods' section. Combining all districts, excess mortality attributed to CPD are 196925, 71997 and 490045 respectively for case 1, 2 and 3. The corresponding values for the LC are 12060, 2917 and 18107. It implies that the excess mortality estimates vary in a wide range, if RR is changed. Since India-specific cohort studies are not available to estimate RR; it is difficult to argue in favour of one case. Estimates for case 1 depends on very few cohort studies, that too carried out in developed countries where background $PM_{2.5}$ concentration is not high compared to Indian condition. Estimates for case 2 are on lower side, because of the constraints on the RR function. Estimates for case 3 are on a higher side, because the sensitivity of RR is very high to a small change in $PM_{2.5}$ at concentration less than 200 µg m^{-3}. However, case 3 considered >100 cohort studies extending over a wide variety of sample population in terms of various socio-economic factors. It seems that case 3 may be more appropriate estimates given the available resources.

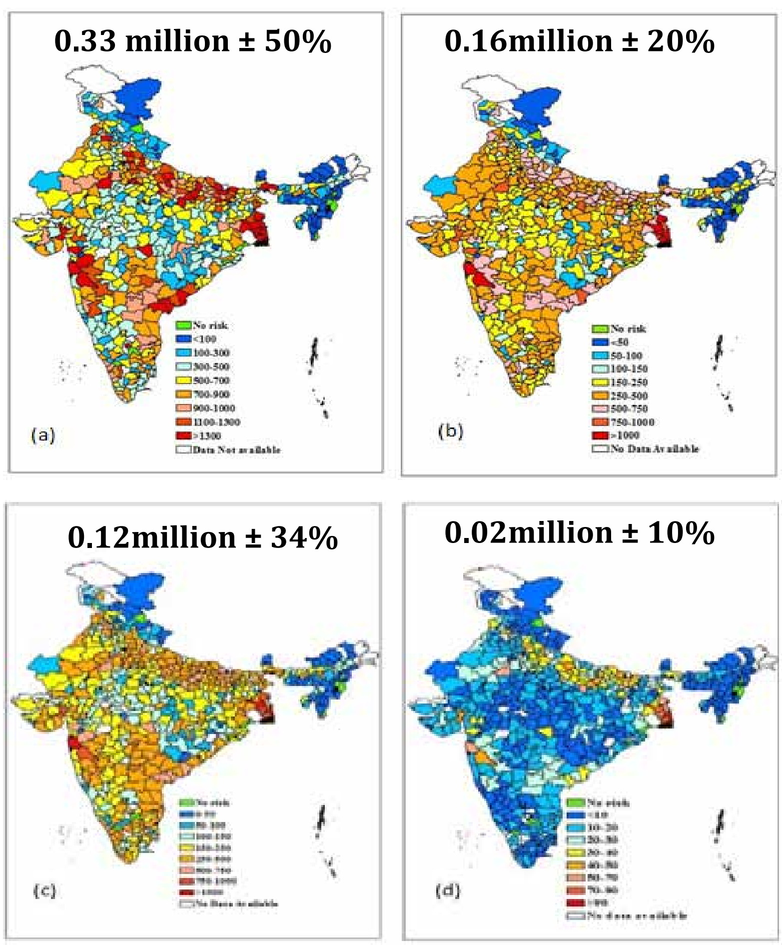


Fig. 11 Excess mortality for each district from (a) COPD, (b) IHD, (c) Stroke and (d) Lung Cancer. Total all-India mortality for each category (±uncertainty) is also mentioned.

Further partitioning the total excess mortality to the four diseases (Fig. 12), it was found that 64% can be attributed to COPD, while 13.8%, 18.6% and 3.6% are attributed to Stroke, IHD and LC respectively (for case 3). The numbers estimated for each district are utilized to identify the most vulnerable districts (in terms of number of excess mortality). It is important to note that the excess mortality depends not only on $PM_{2.5}$ concentration change over a given time period, but also on the number of exposed population. Hence, any district with a lower $\Delta PM_{2.5}$ relative to another district may have larger excess mortality if it has higher population.

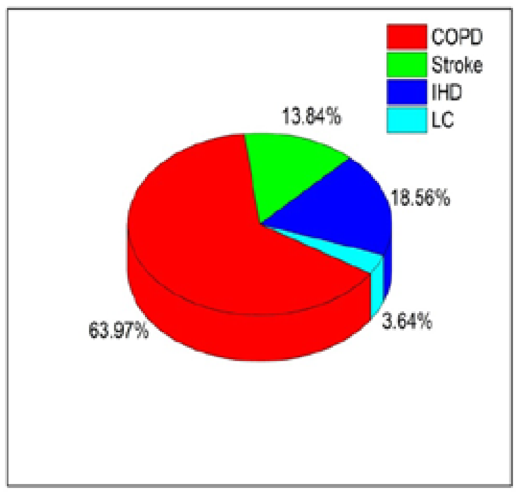


Fig. 12 Pie chart of the relative percentage of excess mortality attributed to each of the four diseases considered for health risk studies. Estimates are all-India average for the period 2000-2010.

Table 7 No of death/year attributed to COPD, IHD, stroke, LC and CP calculated from different approaches (uncertainties are mentioned in italics)

Approaches	COPD	IHD	stroke	LC	CP	Total
Simple exponential				12065 ±8671	588600 ±414040	600665 ±422711
Lin 50				9910 ±6895	469760 ±321600	479670 ±328495
NLP	334180 ±171220	161390 ±31838	122930 ±41829	21807 ±2077	618500 ±244887	640307 ±246964

Local variation (city level) using high resolution data

MODIS Aqua level 2 AOD data with spatial resolution 3 km (MODIS Collection 6 product MYD04_3K) is used for this study. This new product differs from the usual 10 km product only in the manner in which the reflectance pixels are ingested, organized and selected by the aerosol algorithm. The fine resolution product is able to retrieve over ocean closer to coastlines and islands and is better able to resolve fine aerosol features such as smoke plumes over ocean and land, however in regions traditionally difficult for dark target algorithm such as over bright or urban surfaces, the 3km product introduces isolated spikes of artificially high AOD (Remer et al., 2013). The error of the 3km product is higher than the 10km product over land: ±0.05±0.20AOD.

We calculate annual mean $PM_{2.5}$ from MODIS $[PM_{2.5}]_M$ concentration from monthly estimates of Level 2 AOD from MODIS sensor onboard Aqua satellite, for 11 year period (2003 to 2013) using spatially varying monthly climatological conversion factor (η) which is the ratio of $PM_{2.5}$ to columnar AOD. η is calculated from the GEOS-Chem chemical transport model at MISR overpass time, the GEOS-Chem solves for the temporal and spatial evolution of aerosol and trace gases using meteorological datasets, emission inventories and equations that represent the physics and chemistry of the atmospheric compositions. Daily η values from 2001-2006 were interpolated from 2kmx2.5km resolution to 3kmx3km resolution and averaged to monthly climatology for use in $PM_{2.5}$ estimation of the two cities. vanDonkelaar et al., (2012) found a large underestimation of the estimated $PM_{2.5}$ over India, the reason for this bias is unknown but could result if the lowest vertical layer of the model is too coarse relative to the injection heights of the emissions. To quantify this bias (Fig 4a) we compared the monthly averaged $[PM_{2.5}]_M$ with data from 6 CPCB and DPCB monitored air quality stations measuring $PM_{2.5}$ over Delhi ($[PM_{2.5}]_I$) at AnandVihar, MandirMarg, RK Puram, Punjabi Bagh, IGI Airport and ITO. The scatter plot between $[PM_{2.5}]_M$ and $[PM_{2.5}]_I$ shows a linear relationship with a R value of 0.28. Such low correlation can be attributed to the fact that satellite data include readings from only clear days whereas the in situ data includes both cloudy and clear measurements of AOD, there is also a possibility that MODIS observation and ground based monitoring may not have been taken on the same days for specific months which may have increased the uncertainty due to altered monthly average (Dey et al., 2012).

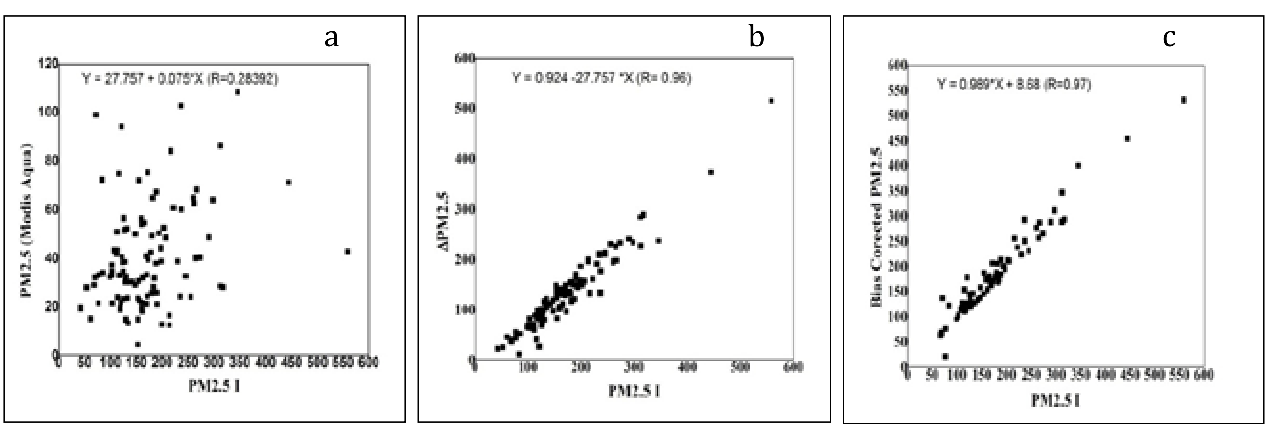
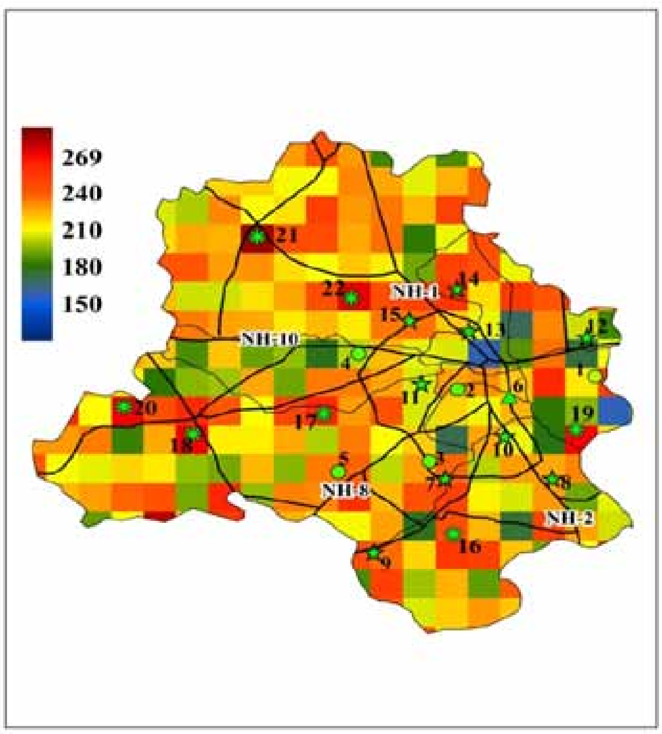


Fig. 13 (a) Scatter plot between monthly $[PM_{2.5}]_M$ and $[PM_{2.5}]_I$ at Delhi. (b) bias in $[PM_{2.5}]_M$ and $[PM_{2.5}]_I$. (c) $[PM_{2.5}]_{BC}$ and $[PM_{2.5}]_I$.

MODIS bias was then quantified ($\Delta PM_{2.5} = [PM_{2.5}]_I - [PM_{2.5}]_M$) based on coincidently sampled values in Delhi, which is linearly increasing with increasing $[PM_{2.5}]_I$ and can be represented as:

$$\Delta PM_{2.5} = 0.924[PM_{2.5}]_I - 27.76 \ (R = 0.94)$$

Thus the bias could be corrected only for values of $[PM_{2.5}]_M$ greater than 27.76 so as not to allow negative $PM_{2.5}$ values and then use the bias corrected $[PM_{2.5}]_M$ denoted as $[PM_{2.5}]$henceforth. There was a very good correlation (R= 0.97) between $[PM_{2.5}]$and $[PM_{2.5}]_I$ (Fig. 13c). $[PM_{2.5}]$was then plotted spatially over Delhi (Fig. 14) and Kolkata (Fig. 15).

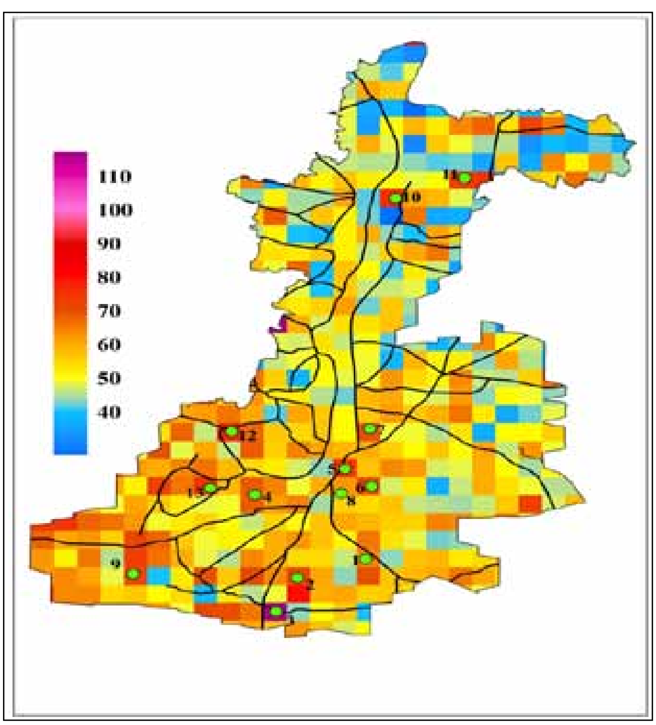


1. Anand Vihar
2. Mandir Marg
3. R. K. Puram
4. Punjabi Bagh
5. IGI. Airport
6. ITO
7. IIT Delhi
8. CRRI Mathura Road
9. IMD Aya Nagar
10. IMD Lodhi Road
11. IITM Delhi
12. Guru Teg Bahadur Hospital
13. Delhi University
14. CBR Dheerpur
15. DTTE Pitampura
16. Chattarpur
17. Janakpuri
18. Nazafgarh
19. Mayur Vihar Ph. 1
20. Zafarpur kalan
21. Rohini Sec. 37
22. Rohini Sec. 10

Fig. 14 Average $[PM_{2.5}]$ ($\mu g/m^3$) over Delhi for the period 2003 to 2013.

The average concentration at Delhi ranged for most parts of the city lies between 200 – 240 $\mu g/m^3$. The green stars in Fig 5a (no. 1-5) shows the Delhi Pollution Control Board (DPCB), the green pyramid (no. 6) is the CPCB monitoring station at ITO, the green circles show the SAFAR (System of Air Quality Forecasting and Research) stations (no. 7-15) the data of which are not publicly available, the green asterixes (no. 16-22) show some of the hot spots where the $[PM_{2.5}]_{BC}$concentrations are greater than 265 $\mu g/m^3$. As can be seen most of the hot spots such as MayurVihar Phase 1, which is bordered by the Okhla Industrial Area (OIA), OIA houses a large number of large scale as well as small scale industries manufacturing plastic parts, machines, pharmaceuticals etc. also presence of call centres for various MNCs make it a busy region, similarly Rohini Sector 10 and 37 houses a large number of industries such as copper and steel plants, chemical factories etc. On the other hand Najafgarh and JafarpurKalan are believed polluted by biomass burning activities and heavy vehicular pollution. The asterixes (no. 16-21) mark the areas where the $PM_{2.5}$ has been increasing at a rate greater than 8 $\mu g/m^3$ per year, as expected the concentration of $PM_{2.5}$ has been increasing over the industrial regions of Mundka, Bawana and Rohini Sector 32, besides increase over Najafgarh, Sonia Vihar and Ayanagar Extension, may be due to vehicular pollution in Ayanagar and Sonia Vihar and due to vehicular pollution clubbed with biomass burning at Najafgarh.

Most of the CPCB, DPCC and SAFAR monitoring sites are not situated in locations where the $PM_{2.5}$ concentration was found to be higher by this approach, which may lead to an underestimation of the city estimates of $PM_{2.5}$ monitored by CPCB, DPCC and SAFAR. Kolkata is a megacity which is following the footsteps of Delhi in terms of anthropogenic particulate matter concentrations, even though the particulate pollution level in Kolkata is not as high as in Delhi, limited road network and compact city design has resulted in a larger than expected negative impact. The West Bengal State Pollution Control Board(SPCB) has conducted various air pollution related studies, most of which come to conclusion that vehicular pollution significantly contributes to the concentration of particulate matter as low as 1.1 micron. The study carried out at Chittatranjan National Cancer Institute, Kolkata reports that problems such as dry cough, shortness of breath and elevated heart beats are initiated with rising amounts of PM_{10} concentrations. Although the drawback is that there are no air quality monitoring stations in Kolkata which monitor $PM_{2.5}$.



1. Narendrapur
2. Pailan
3. Mirpur
4. Metiabruj
5. Sealdah Rly. Stn.
6. East Topsia
7. South Dum Dum
8. Park Circus
9. Uluberia
10. Kalyani
11. Teghara
12. Domjur
13. Sankrail

Fig. 15 [$PM_{2.5}$] over greater Kolkata for the period 2003-2013 (in µg/m^3)

The green circles in Fig 7 show some of the hot spots in greater Kolkata, the $PM_{2.5}$ concentration ranged from 50- 70 µg/m^3 over most parts of Kolkata. Some of the hot spots such as Metiabruj, Domjur, Sankrail, Kalyani and Uluberia are home to a wide range of medium and large scale industries. Rest of the hotspots are expected to be polluted due to vehicular emissions. The rate of increase of $PM_{2.5}$ concentration over Kolkata is higher (4.57±2 / yr) than over Delhi (3.8±2.75 / yr) over Delhi, there are few places in

Kolkata such as Bandel and South Dum Dum where the $PM_{2.5}$ concentration has been decreasing at a rate greater than 3μg/m^3. Whereas in some places like Kalyani, Serampur, Baliaghata near Barrackpur, Kona, Narendrapur, Jaynagar and Sankrail the rate of increase has been more than 10 μg/m^3 over the last 11 years, which is very alarming, keeping in mind the worsening scenario of increasing $PM_{2.5}$ in Kolkata, CPCB should take the initiative to set up $PM_{2.5}$ monitoring stations in and around Kolkata where the increase of $PM_{2.5}$ is captured to be alarming.

4.2.3 Important Results

Heat stress mapping of India is very important before going for early warning system to save people from heat wave conditions. In this study, mapping of India is done in terms of some heat stress indices. However, it is difficult to use only one index for the whole country. It is found that changes in temperature, wind and moisture have large spatio-temporal variations. Hence selection of proper heat stress index for different regions of India is a challenging job. Efforts are also going on to predict heat stress indices under future climate scenarios.

The relationship between $PM_{2.5}$ and human diseases constitute an important component of the strategic knowledge which can be utilised for the benefit of the society. The satellite-derived high resolution dataset of $PM_{2.5}$ have been re-gridded to generate district level $PM_{2.5}$ dataset for the last decade. Relative risks are quantified for diseases such as chronic obstructive pulmonary disease (COPD), ischemic heart disease (IHD), stroke and lung cancer (LC). Relative risk helps in estimating excess adult mortality. Premature death can be estimated using integrated exposure-response (IER) function.

Chapter 5: Conclusions

5.1 Strategic Knowledge Genetrated

- Maps of hotspots of malaria based on atmospheric temperature and malaria endemicity provide insight that enhanced temperature alone is not likely to increase in high intensity of malaria. Other factors such as moisture, surface conditions, rainfall, forest and other related parameters have also important roles to play.

- Rainfall cut-off for subsequent malaria outbreak and transmission is found to be a very important method for outbreak early warnings. It is found that the cut-off value is not the same for the whole of India. In some states like Assam, 100 mm rainfall in the month March while in Maharashtra state, more than 200 mm cumulative rainfall in the month of July-September could result into malaria outbreak in the month of December. Thus it is important to find rainfall cut-offs for each district of India.

- Ecological risk maps for malaria outbreak in India is very much essential so as to know which areas are prone to malaria outbreak. Risk map using temperature and relative humidity for the period 2008 to 2030 can be used as guide for the near future atmospheric conditions. The projections are done based on PRECIS simulations which were generated long back. CMIP5 and CORDEX simulations, when used, will give more accurate results.

- The results demonstrate the fact that heat-stress is an issue that is impacting about 90% of the workers engaged in various job categories in India. The study provides the evidence that the workers are working in thermal environments that are much above the safe limits prescribed by the ACGIH. Workers in the select sectors for eg., steel manufacturing industry are engaged in heavy workload and are working in very high heat conditions (process generated heat) which when combined with ambient temperatures has very high potential to impact the health of the workers. Importantly, the perceptions of the workers on the impacts of occupational heat stress on their health and productivity also support the health data strongly. The long working hours, lack of self pacing options and continuous exposures to very hot environments subject the workers to high risks of developing heat-related illnesses.

- Physiological responses to occupational heat stress are not only dependent on ambient temperatures and cooling interventions but also influenced by factors like work-rest ratios and physiological workload. Work-rest ratios are proven to be one of the key factors in preventing/controlling any adverse health implications of occupational heat stress.

- Gender sensitivity in occupational heat stress has emerged as an important element in this study. Lack of welfare facilities at workplaces, including toilets has subjected woman to additional health risks that are very unique to women.

- Results show that the level of Hsp 70s are high in workers exposed to very high heat and engaged in heavy work, which indirectly indicates the level of stress/ strain the body is subjected to.

- Estimations via heart-rate monitoring have shown significant productivity losses due to health decrements for workers working in construction sector. This trend if seen in other sectors may affect the economy of the country with consequent social implications as indirect effects of Climate change.

- Heat stress indices can be utilised to give warnings on the advent of heat waves. In several developed countries warnings are being given under different categories so that people take precautionary measures to save themselves from vagaries of heat waves. Mapping of India is being done in terms of different categories of heat stress. Efforts are also going on to predict heat stress indices under future climate scenarios. These strategic knowledge will help estimating the man power loss and hence economic loss under heat wave conditions.

- Efforts in understanding the role of PM2.5 and PM10 in human health will help giving adequate warnings to save life. The relationship between PM2.5 and human diseases constitute an important component of the strategic knowledge which can be utilised for the benefit of the scoiety.

5.2 Possible Policy Prescription from New Knowledge Generated in the Programme

- ✓ The outcome of this study would provide baseline maps of malaria outbreak prone areas, *P vivax* and *P falciparum* dominated areas, future scenario of malaria in view of climate change, rainfall as a simple tool for early warning of outbreaks and ecological basis of high malaria endemicity would help the national programme in planning control strategies (timing of indoor residual spray, Number of rounds of Spray in a year and preparedness plan for outbreaks and in view of climate change). Early warnings of malaria outbreak based on rainfall quantity will help in formulating adequate policy for malaria prevention in different regions.

- ✓ More awareness generation on climate change and its relation with malaria outbreak is very much essential. Further, it is paramount to develop a reporting system which can integrate the unaccounted malaria cases in national reporting system. Such steps can help strengthening policy for the local level.
- ✓ Intergovernmental Panel on Climate Change warns of an imminent crisis due to rising temperatures that may come to affect the poor workers with minimal or no access to cooling interventions at work places. At the same time, knowledge about new and more sustainable intervention approaches will emerge and the knowledge on potential implications of occupational heat stress and climate change becomes a vital asset for the NMSKCC/NMSHE for achieving its mandate.

- ✓ The technical knowledge developed under this programme can be translated into policy for the protection of the workers exposed to hot and hazardous environment.

Adaptation measures may be taken so as to have minimal loss of work-hours and minimal damage to human health.

5.3 Way Forward for Knowledge Generation from Future Work:

- Further work on hot spots of malaria based on temperature and malaria endemicity maps would help determine the upper threshold of temperature for malaria transmission.

- Cut-off of rainfall for different malaria outbreak prone areas of the country would help in the development of simple and feasible early warning system for malaria outbreaks.

- The ecological risk maps would serve as basis for determining ecological change (positive or negative) from the viewpoint of increase or decrease in malaria endemicity. Similar maps are needed for Dengue, Chikungunya, Japanese encephalitis, Kala-azar and other vector borne diseases.

- An enabling framework or strategy to improve occupational health with respect to heat stress and climate change is essential for the benefit of the workers. Ensuring that all aspects of occupational health are built on and tightly embedded in an organization's work processes and products is much needed at this juncture.

- Today, climate projections at different resolutions are easily available from several sources such as CMIP and CORDEX. These model projections of climatic parameters should be utilised to project the outbreak of vector borne, water borne, pollution related and heat stress related projections which may serve as advisory for nrcessary precautionary measures.

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