

**Ben Hyman, Open-Source GIS Tutorial for J-PAL ETS Project**  
**Last Updated: July 8, 2013**

**Objective:** The goal of this tutorial is to describe in sufficient detail the steps necessary to analyze the environmental and health effects of pollution diffusion from ETS (treatment group) industries (“firms” in the non-Indian context) versus control group industries, using some specific modeling assumptions on the pollution diffusion side and pulling previous results on the linear relationship between PM abatement and infant mortality. With this short manual, and its associated video [tutorial](#) you should be able to recreate the results generated here. Doing so should also give you enough familiarity with GIS to venture into other types of GIS analysis, so hopefully this can serve as a general GIS reference guide as well.

**Basic Background:** The dominant state-of-the-art GIS software is called ArcMap (ArcGIS) and is produced by the ESRI company, but it is prohibitively expensive (usually in the \$1000s) and is heavy for laptop processors. While open-source software is advancing (as is computing power), these software remain quite buggy but with a little patience and resourcefulness (searching troubleshoot forums etc.), they do the job just fine. Based on my experience, two open-source softwares warrant attention, and these will be the two we will work with (in addition to Google Earth which can be used for generating raw data): *qGIS* and *MapWindow*. Each has its advantages and disadvantages, but qGIS tends to have a broader range of built-in analysis tools, while MapWindow mimics ArcMap in its output layout - the actual presentation of the map - which is important when presenting the final PDF or PPT versions of the maps.

*Step 1: Download the Programs*

- a. qGIS: <http://hub.qgis.org/projects/quantum-gis/wiki/Download>
- b. MapWindow: <http://mapwindow4.codeplex.com/releases> (Be sure to download v4.8)
- c. Google Earth: <http://www.google.com/earth/download/ge/agree.html>
- d. kml2shp plugin: <http://www.mapwindow.org/downloads/> (Note: if this plugin page does not work you may need to download MapWindow v4.7 on the right hand side of the downloads page from part (b.), and use the following v4.7-compatible kml2shp plugin: [http://shape2earthengine.com/apps/kml2shapefile-1.0.0.1\\_setup.zip](http://shape2earthengine.com/apps/kml2shapefile-1.0.0.1_setup.zip))

The plug-in listed in (d.) is important as it allows one to convert .kml or .kmz files, such as pins or points (placemarks) on a google map or anything created in Google Earth to .shp files (“shape files”), which can then be imported to GIS as “layers” of geographic data. Installing open-source plugins can be difficult as they are sometimes only compatible with certain program versions, however you can check in MapWindow>Menu>Plugins whether your plug-in was properly installed and turned on. Normally a plugin should be placed in your plugins folder within MapWindow, however if you have problems I would suggest doing a google search as others have likely had the same problem and documented it in a public forum.

## Step 2: Familiarize Yourself with the Main Objects of Mapping Software

**The Basic Steps:** A GIS map is constructed by importing “layers” of data (.shp files) one by one into a legend, and then operating on those layers (analyzing, merging with other layers, transforming the data, etc.), and exporting the newly operated layers as their own new .shp files. We then choose our preferred way to display the data by “symbolizing” the new (and/or old) layers with appropriate data ranges, colors schemes, and other considerations. Finally, before we export the map, we overlay the legend representing the chosen “symbolology” (ranges) on top of the displayed data and export our final map. For the remainder of the tutorial, you should have access to the following raw data on Indian census layers found in the directory GIS>Raw Data>Indian Census Layers:

1. 95feindiamap\_district.shp
2. 95feindiamap\_state.shp
3. 95feindiamap\_sub\_dist.shp
4. 95feindiamap\_town\_dist.shp

**Layers (.shp files):** Each .shp file can be imported as a layer (in MapWindow using +Add; in qGIS using Menu>Layer>Add Vector Layer or Control+Shift+v ), and can be displayed similar to how one would do so in Photoshop - layers can be turned off, turned on, and rearranged from top to bottom representing the priority of display (front to back). Each time a layer is added, turned on or off, or edited, the display on the right should adjust accordingly. What makes GIS layers unique is that each layer contains a database (matrix) associated with geographical characteristics “features”. These features are typically classified as point layers (for points like the town data) or polygon layers (for regions and shapes like districts). To begin, play around with these 4 .shp files.

**Useful Tools:** When playing around with layers, a few tools come in handy. There is usually some kind of information arrow tool that allows you to select a specific geographic feature and obtain information on it (for example on a single town or district). There will also however, be a *separate* selection arrow (or tool) that allows you to create a “selection” (either by clicking different pieces of data cummulatively holding shift or using some kind of broader selection swath). One can thus manually create a selection and then export it as a new layer, carrying over the same underlying data (explained later). Note: If you are ever lost from your main data (the feeling that you are in white purgatory space far from your geography or data), there is usually an “extent” button (in MapWindow / ArcMap) which adjusts the display to span the entire geography of the turned on layers - zooming just wide enough to circumscribe all of India in this case.

**The Attribute Table:** What makes GIS data different from regular data is that each GIS layer has an underlying attribute table, or database matrix associated with its geography. Sure enough, when you create a new .shp file (or import one), many other files with

different suffixes are saved, including a standard .dbf database file along with a .shx and .prj file. We will ignore the latter two for now. Either way, attribute tables should serve as your points of departure when it comes to analysis, symbology (displaying different variables of your database according to some criteria), operations and data mergers. Get comfortable with opening the attribute table under each layer and observing the data.

In MapWindow, right clicking any layer should present the “attribute table editor”, from which we can create operations and export freshly operated layers as new layers. This can be done manually using the selection tool as explained in the paragraph above, but more generally, we use “queries” to select specific data or geographic features that meet a certain mathematical or spatial expression criteria (the query builder is SQL based, for those of you familiar with MS Access). I will explain how this is done in detail in the analysis sections below, however the basic idea is that one can grab data that fits a certain range (i.e. >50), or that meets a certain string expression (i.e. == “Gujarat”), and there even exist “spatial queries” which can for example, select all districts within a specified kilometer radius from Delhi.

In qGIS, after adding a layer to the mainframe, you can right-click any layer and select “Open Attribute Table” or select it with Menu>Layer>Open Attribute Table. It bears noting that we often need multiple copies of the same layer if we want to display an intricate map. For example, you might want two copies of the district layer, one for ETS-affected districts and one for the remaining districts that have zero effect, so that you are not always operating on irrelevant data and displaying extra noise when it is not relevant. Most layers can be easily copy/pasted back into the legend to create multiple copies, or you can just import the layer twice if this does not work. More on this later.

**Important:** It is always good practice to keep all your layers in the same folder or in highly organized folders. If you move them around the relative directory will be broken, and you will have to re-set the directory for each layer which can be painful. In case you are worried that the operation you just performed was not successful, one can explicitly export any layer after it is created by using File>Export or Layer>Export, or right clicking a layer in either program and export the layer from the Attribute Table under the “Selection” tab. We will deal with this explicitly later on when we get into the example.

**.KML and .KMZ files, and using Google Earth:** One thing to keep in mind is that GIS reads .shp files exclusively. If you have a common .kml file - for example - you (or an RA) has manually searched each firm name and placed a pin at each GPS coordinate, and saved them under Google Earth Places in a joint folder - you cannot simply save and import the single .kml file for this group of firms from Google Earth into your GIS but have to directly convert the .kml file into a .shp file. Fortunately, the add-in kml2shp should be great for this in MapWindow. For the meantime, all you really need to know about using Google Earth is the following: if you create a “Place” under “Places”, and right-click that “Place” to add pins or placemarks, then when you are finished and “Save

As”, you can save the Place as a .kml file which will save all of the pins within that place.

In this tutorial, you will not need to edit the .kml file but simply will need to convert it. Be sure to locate the following .kml file under GIS>Raw Data>ETS Industries> (Note: as the sample is likely to have changed significantly since I last attained the data you will likely have to make several manual adjustments in Google Earth):

#### 1. Industries\_GU\_final.kml

Now, convert this into a .shp file and save the .shp file in the same directory. To see how this is done, refer to the example at the end of this tutorial or the video guide.

**Queries and the Field Calculator:** Using MapWindow for now, if you open an attribute table you will notice some important buttons (tools) on the bottom of the window - “Build Query” and “Field Calculator”. These allow you to do the types of things you would do in Stata and R (generating and editing variables) without importing and exporting or worrying about geography. For example, open the attribute table of any layer of your choosing, and at the top menu select Edit > New Field. Then, by hitting the “field calculator” button at the bottom of the attribute table window, you could let your New Field (whatever you named it) = Tot\_Pop\*2, which would give you a new variable that is double the size of Tot\_Pop for each object (district, town, etc.). This is a query, and the language used to build these queries is SQL based, so if your code does not work out this is the reference language (however the basic interface means you should rarely encounter coding errors here).

Finally you have to hit “apply” and then you can close the newly overwritten attribute table and re-open it to check that the new field (variable) is there. Note you can always remove this new field later (Edit>Remove Field), however, to avoid overwriting problems, it may be prudent to export your layer under a new name to circumvent overwriting problems (which we will do in a minute). Now we would like to create a new .shp layer based on just a selection of your data (for example, say you want to keep only those districts below a certain threshold population like 500,000 and create a map of just those districts). We use the “Query” tool/button at the bottom of the Attribute Table. Once the desired criteria are selected, hit “execute” and then “new selection”. Then to export your new selection, go to the top of the Attribute Table and hit Selection>Export Selected Features to create a .shp file for just those “features” of the data you have queried. Now you have a new layer!

**Toolboxes and Analysis Tools:** Finally we come to the meat of GIS - analysis tools. In addition to queries and new fields, both MapWindow and qGIS have built in tools that can perform a number of useful pre-set procedures. In MapWindow, locate the Legend, and switch tabs from Layers to Toolbox. In qGIS, locate Menu>Vector>Analysis Tools (and note that there are also geoprocessing and other tools available). I will focus on a few tools relevant to this analysis and that are useful in general, however there are many analysis tools available, including user-made plug-ins, and one also has the option to

write your own tools if ambitious. It is important to aware that not all the tools may be active unless the corresponding layers are already loaded. For example, tools that apply to polygon layers will not be available unless a polygon .shp file is already imported.

*MapWindow Important Analysis Tools:*

1. Database Tools>Export Shape File
2. Projections>Reproject Shape File
3. Vector Operations>Standard>Merge Shape File
4. Vector Operations>Standard>Spatial Query
5. Vector Operations>Standard>Create Centroids (Also available in qGIS)

*qGIS Important Analysis Tools:*

6. Vector>Analysis Tools>Distance Matrix
7. Vector>Data Management Tools>Join Attributes by Location (Spatial Join)

*These do the following:*

1. Exports any .shp file into a new name
2. Reprojects layers onto a new satellite coordinate system (and base unit)
3. Merges two shape files together according to some criteria
4. Creates a query but with spatial criteria (i.e. within 30km of each point, ...)
5. Uses a pre-designed algorithm to determine the centroid point of all polygons in a polygon layer, exports as a .shp file
6. Creates an nXn matrix of distances between two features (layers) (.csv)  
(Can also be exported as a 3-column Origin-Destination-Distance matrix)
7. Merges the data of a polygon with its overlying point

We primarily use these tools to merge newly generated data directly into current .shp files or as exported .csv files, which we will then need to merge back into the layers.

**Project Map Files, Symbology, and Map Exporting:** Once all analysis has been done to create the final set of layers to be displayed on the map, import them into MapWindow. Now it is time to represent our spatial data by “symbologizing” the layers, where each layer corresponds to a variable of interest. To see this more concretely, start with the 4 census layers and work on one of the polygon layers. Double-click on it or right-click the layer and hit properties, then move to “categories” and “labels.” In categories you can set ranges and choose a gradient color for a given variable, say *tot\_pop* in the sub-district layer, where hitting “generate” will split the the category cut-offs according to the desired number of quantiles. The “labels” tab further allows you to manually select the style and positioning of the label, or turn labels on and off for every given layer, which is useful for the final display. Getting good at symbology comes with practice and will help beautify your maps. For now, it is important to note that the “generate” button will erase whatever symbology you had previously chosen without saving the previous symbology. So to SAVE your symbology, you must save the entire project file. In MapWindow, this creates a .mwprf file that saves all of the symbology relations (gradients, cut-off numbers for your

bins, colors, etc.) for all layers, however this file does nothing with respect to saving your actual data (.shp files / layers) - it is merely a way to link all of your .shp files together.

**Note on Projections:** All GIS layers are projected onto specific coordinate systems (CRS), and there are many such CRSs. Sometimes two of your layers may be tailored to two different satellite projections and they need to be converted to conform to each other. Other times the CRS is not in the desired base unit and so any subsequent calculations that have to do with distance may not be in a unit like meters but rather in decimal degrees or other hard-to-convert units. In these cases, you must re-project your .shp files to different coordinate systems, which can be extremely painful and can suck up a large amount of your time on GIS. I show an example below, however note that online forums are your best friend when it comes to projections. Once you have figured out how to properly re-project a .shp file on to a new CRS, the learning curve lightens significantly.

### *Step 3: General Steps of the ETS Project*

Now, to put everything into practice, we will try to recreate a pollution diffusion map for the state of Gujarat like the one that is attached after the steps below (Map 1). Here is the **step-by-step** guide to do so (note that I perform these steps in the video tutorial, linked in the first paragraph):

**(1)** Locate the GIS Tutorial Materials folder. Check that it contains the following:

- 4 Census .shp Layers (State, District, Sub-District, Town)
- 1 .kml files (GU Industries)
- 1 “ Sub-Districts Split” .shp file (this file cuts the sub-districts into smaller blocks so that the pollution diffusion is finer. I did this manually in ArcGIS for each states, as I could not find the way to do this in open source software but I’m sure there is a way!)
- DiffusionFramework.R (R code for pollution diffusion model for data mergers)

**(2)** Add Layers. Open a new MapWindow map and load the 6 .shp files into the legend using Add+. Play around with the basic tools discussed above, and be sure that you’ve installed the MapWindow kml2shp plug-in (even if in v4.7). Note: there is no need to save any files in this step.

**(3)** Convert the .kml files into .shp files. Go to Menu>Plugins and select kml2shp (make sure that it is turned on or in the correct plugins folder for MapWindow if you do not already see it). If it is correctly installed, you should see “kml” in the menu bar. Once this is the case, go to Menu>kml>Import as Shape File, and then select the Gujarat .kml file containing all industries in Gujarat, and convert it into a .shp file name of your choosing. I will be calling it by the same name but with the suffix .shp, Industries\_GU\_Final.shp (which is the default). Note that here you have many options. Let me explain briefly what they do: “Convert to Shape File” is what you want. This creates a single .shp file. “Convert contents of folder to Shape File” will take the containing folder and make several layers out of each of its .kml files. One interesting feature is that you can check the “Save Placemark Name is Attribute” box, which will put the industry name right in the

attribute table! Check this box, and then be sure that the .shp file is added to your map, and you will have successfully converted a .kml into a .shp file!

**(4) Query for Gujarat.** So now we have a bunch of layers, and industries for the state of Gujarat. But to quicken our calculations and simplify our presentation, we should get rid of irrelevant parts of the census layers. In other words, we want to keep only those layers that comprise the state of Gujarat at the finest geographic level, which in this case would be the “split sub-district” level.

First, uncheck the box next to all layers except for your “split sub-district” layer. Next, right-click the selected layer and selected Attribute Table Editor. Proceed to hit the half-hour glass button called “Build Query” beneath the table. Next, double-click the variable STATE\_UT or type the variable name identically in the box below with [square brackets] around it. Then you want a space followed by an equals sign and another space, “ = “, which you can either type in or select with buttons. Then choose the expression that you want to query for, so in this case “Gujarat” with quotations around it. So the whole query should look like this: [STATE\_UT] = "Gujarat". Then hit “execute”. Once executed, a box should pop-up telling you the number of shapes created. In this case, 488 split sub-districts should be created. Then select “1-New Selection” which tells GIS to create a new storage rather than adding to an existing one. Think of this like a clipboard in copy/paste world. Then X out of the query-builder box until you are back to the Attribute Table. You will notice that the selection you just queried for should be highlighted on your map. (If your map isn’t properly scaled, hit the “extent” button at the top to zoom appropriately.) Now, back in the Attribute Table Editor, go to Menu>Selection>Export Selected Features and save your file in the tutorial folder as Split\_Subdistricts\_GU. Tell GIS to add the new .shp file to your map, and presto, you have successfully queried for Gujarat.

**(5) Create centroids layer for split sub-districts.** In order to get the distances we need between emissions sources (industries) and ground-level PM concentration, we first need a point measure of each split sub-district block. First, let’s make sure that our .shp file has the appropriate unique ID field. In MapWindow, right-click the layer Splits\_Subdistricts\_GU and then select Menu>Tools>Generate or Update MWSHAPEID Field. Then go back to the legend and move from the tab “layers” to the tab “toolbox.” Then, under “Vector Operations” and “Standard” select “Create Centroids”. Select the appropriate input .shp file and select “centroids” not “centers.” You also need to manually select all the attribute table variables you want associated with the centroids. Finally, change the suffix of the file to be Centroids.shp for simplicity, and leave the “add to map” box checked, and presto, you have centroids!

**(6) Create Distance Matrix.** Now we will use qGIS’s predetermined distance matrix tool to calculate the distance between all centroids and emission sources. This will export a .csv distance file to be used as an input in our diffusion model which will eventually allow us to attain a PM concentration figure for each split sub-district (or associated centroid.)

**(6a)** First, we encounter a projection issue that needs to be dealt with in MapWindow. The two

associated .shp files (Centroids.shp and Industries\_GU\_Final.shp) are projected to a coordinate system called WGS84 whose base unit is in decimal degrees (due to the elliptical nature of the globe), while we want to reproject these layers to WGS84-Pseudo-Mercator whose base unit is in linear meters. (All I can tell you about such projections and their nomenclature is that it usually refers to a geographic area - here the whole world - followed by its year.) To do this, load both layers into MapWindow and select the Toolbox tab in the Legend, Projections>Reproject Shape File. Add both layers with the “+” symbol, on the right, and then on the left under Projected select WGS84-Pseudo-Mercator at the bottom of the menu. Note that when you execute this tool with the “Reproject” button, the new projected layers may not add immediately, which is fine as long as they are exported back to your tutorial folder. Check that the new layers have saved - they should have a suffix “\_projected” (or something similar) added automatically to the original title.

**(6b)** Now that we have our projected layers, open qGIS and import the newly projected layers. Now select Menu>Vector>Analysis Tools>Distance Matrix. Be sure to set the Input Layer as the projected centroid layer, and the Target Layer as the industry layer. Set the unique ID fields appropriately - in this case they should each be set to MWSapeID. Then select the “Standard” button (Linear would create a 3-column .csv file with the input, target, and distance), and lastly create an export name for your .csv file and hit OK to process. (Note: you can see the difference between this and conducting the same distance matrix operation on the non-projected layers, which will produce a matrix of decimal degree units rather than meters.)

**(7)** Run R code DiffusionFramework.r\*. This code calculates ground level PM concentration for each split sub-district using a Gaussian Plume (SCREEN) Model based on <http://san.hufs.ac.kr/~gwlee/session9/gaussian.html>, and exports a .dbf file containing the total amount of ground-level PM concentration (mg/m<sup>3</sup>) in each sub-district owing to ETS industries. The model is as follows (thanks to Yuanjian Li for developing this):

$$x = \frac{Q}{\pi\sigma_y\sigma_z u} \exp\left[-\frac{1}{2}\left(\frac{H}{\sigma_z}\right)^2\right]$$

Where:

x = ground level concentration (g/m<sup>3</sup>)

Q = source strength (g/s)

$\sigma_y, \sigma_z$  = plume standard deviations (m)

H = effective height of emission

u = wind speed at height H (m/s)

y = distance between source and industry (m)

Assumptions:

1. Constant wind speed in direction of wind: u = 37 km/h = 10 m/s\*\*

2. Neutral Horizontal and Vertical Dispersion:

$\sigma_y = y * \alpha * \frac{1}{\sqrt{1+0.0001*y}}$  (Horizontal),  $\alpha = .008$

$\sigma_z = y * \beta * \frac{1}{\sqrt{1+0.00015*y}}$  (Vertical),  $\beta = .006$



3. Random Stack Heights between 5 - 30 meters, 10 stacks/industry.
4. Source strength of 15 g/s per stack.
5. 10 stacks/industry.
6. ETS reduces ground-level pollution to 60% of original level (simulation)

\*R is a free (open-source) statistical analysis software that can be downloaded here: <http://cran.r-project.org/bin/windows/base/>; R Studio has a better user interface but requires that R be installed first: <http://www.rstudio.com/ide/download/>

\*\*Lakshmanan, N. et al. Basic wind speed map of India with long-term hourly wind data. *Current Science*, Vol. 96, No. 7, 10 April 2009, Bombay~37, Chennai~38, Ahmedabad~35.)

**(8) Create Map (Symbologize Layers).** First, load the Split\_Subdistricts\_GU.shp file back into Mapwindow and open its attribute table to verify that the new PM concentration numbers are there. Note that when you run the R code over and over, it may not rewrite, so you may need to discard or rename old versions of the PM concentration variables if they have been overwritten. Now right-click the layer, and select “Shapefile Categories” and then the “+” button on the left. Then select “PM\_before” under “Classification Field”, 10 categories, and for now use “Natural Breaks” under “Classification Type.” Note that there are many classification types - one useful one is quantiles. Now under “Visualization” choose one of the gradient color schemes. Note, if you’re like me and were not satisfied with the existing color schemes, you can hit the “...” button to the right of the color schemes and hit “add” to create your own. Then hit “OK”. Lastly, hit “apply” and then “OK” and your map should populate nicely. Note, you can change the lowest category to be a “neutral” color to emphasize which sub-districts are actually affected by pollution since so many on the periphery of the state are not.

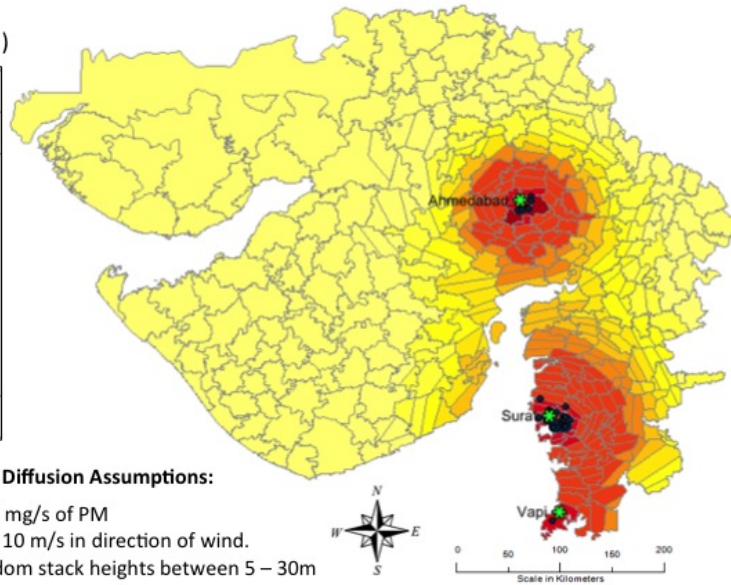
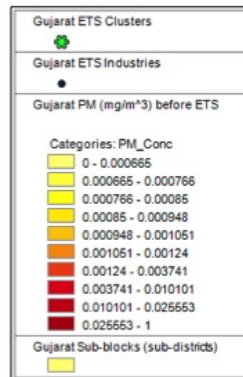
To verify that this is consistent with your industry locations, add the Gujarat industries layer and move it to the top of the legend. In the tutorial I show options on how one can change the symbol marker, add the main city names, and edit labels. Finally, to produce your map go to the menu bar and select Project>Export and export each item in the Export menu. You can piece these together on a powerpoint slide and then export it to .pdf to have your final map! I show more on the video tutorial on the options you have here. Note that you can add as many layers here as are appropriate, and export the map that is visually displayed to your liking. So for example, you may want to display some kind of ratio of pollution to population density, using the field calculator tool to add a new field and calculate this value, then symbologize it. See the example maps following this section for some ideas. Either way, the last thing you will want to do and remember once you have created all of your layers is you can save all of your symbologies simultaneously by exporting a project map file. So finally, go to Menu>Project>Save As, and you then have the final piece to your puzzle!

This tutorial scratches the surface of what can be done with GIS, but there is plenty of information online so with this base you should be able to navigate any GIS tool or operation required for your project!

Some Map Examples (note: different from tutorial)

## Map 1: ETS Industry Contribution to Gujarat PM Before Pilot Implementation

Legend (Units: mg/m<sup>3</sup>)

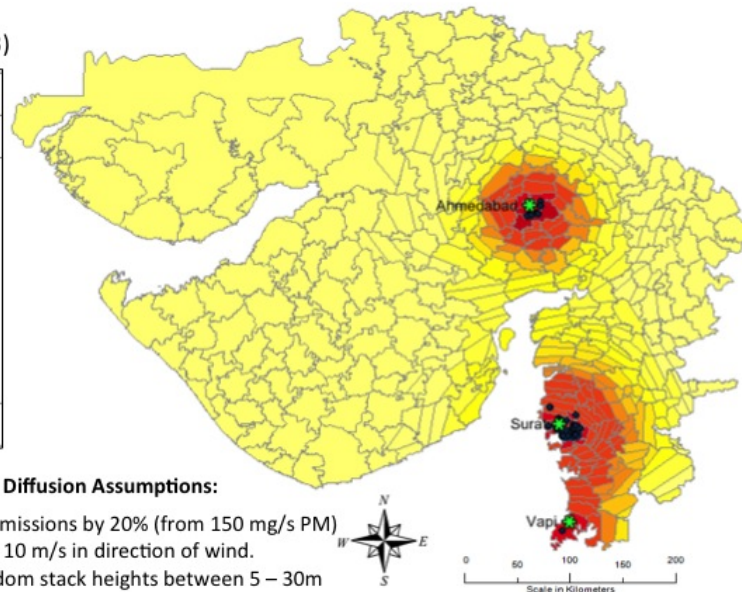
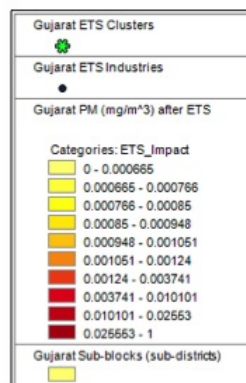


SCREEN Model Pollution Diffusion Assumptions:

- Each industry emits 150 mg/s of PM
- Constant wind speed of 10 m/s in direction of wind.
- 954 industries with random stack heights between 5 – 30m

## Map 2: ETS Industry Contribution to Gujarat PM After Pilot Implementation

Legend (Units: mg/m<sup>3</sup>)



SCREEN Model Pollution Diffusion Assumptions:

- Each industry reduces emissions by 20% (from 150 mg/s PM)
- Constant wind speed of 10 m/s in direction of wind.
- 954 industries with random stack heights between 5 – 30m

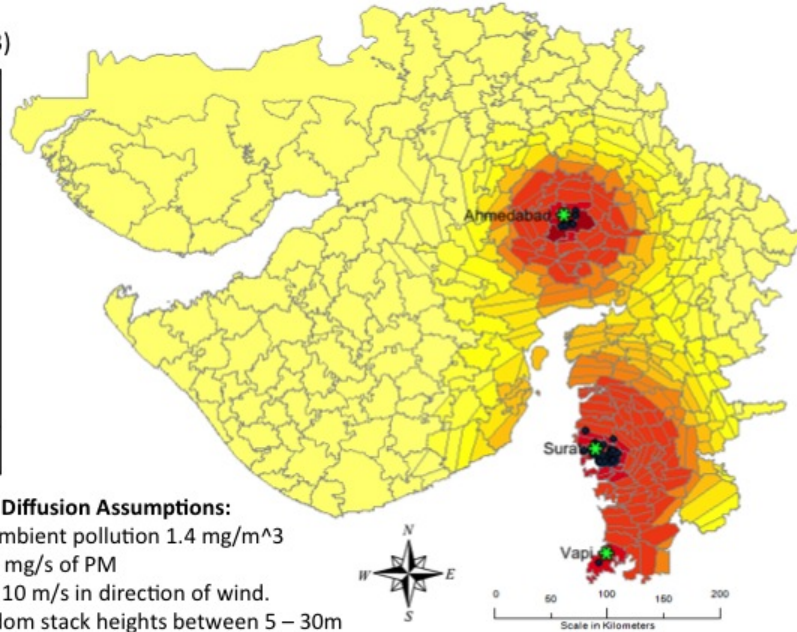
## Map 3: ETS Industry Contribution to Share of Gujarat PM Before Pilot Implementation

Legend (Units:  $\text{mg}/\text{m}^3$ )

Gujarat ETS Clusters	
Gujarat ETS Industries	
ETS Percent Ambient PM Before Pilot	
Categories: PM_ConcPC	
	0 - 0.000475
	0.000475 - 0.000547
	0.000547 - 0.000607
	0.000607 - 0.000677
	0.000677 - 0.000751
	0.000751 - 0.000886
	0.000886 - 0.002672
	0.002672 - 0.007215
	0.007215 - 0.018252
	0.018252 - 1
Gujarat Sub-blocks (sub-districts)	

### SCREEN Model Pollution Diffusion Assumptions:

- Constant ground level ambient pollution  $1.4 \text{ mg}/\text{m}^3$
- Each industry emits  $150 \text{ mg}/\text{s}$  of PM
- Constant wind speed of  $10 \text{ m}/\text{s}$  in direction of wind.
- 954 industries with random stack heights between 5 – 30m



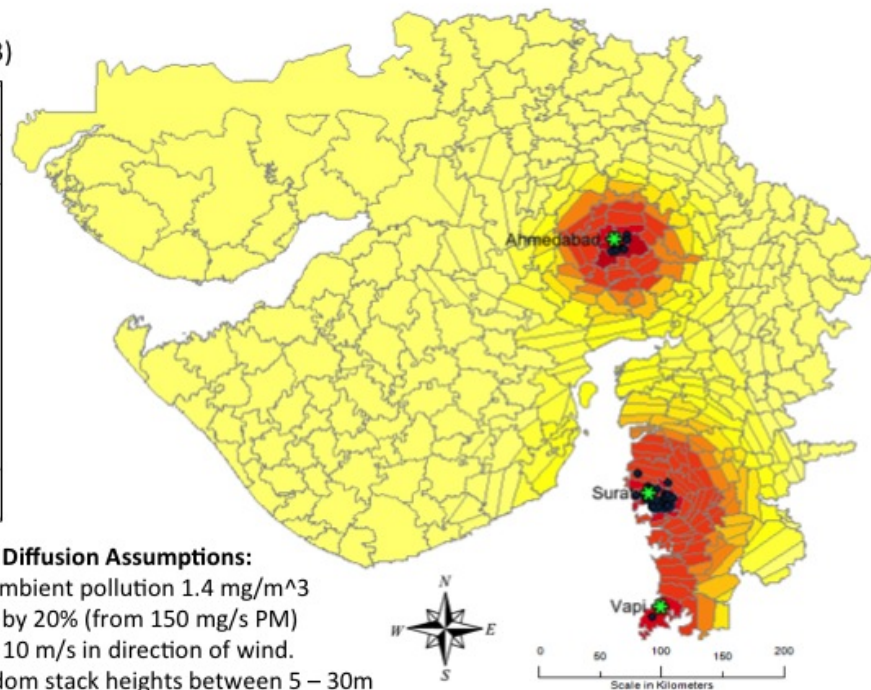
## Map 4: ETS Industry Contribution to Share of Gujarat PM After Pilot Implementation

Legend (Units:  $\text{mg}/\text{m}^3$ )

Gujarat ETS Clusters	
Gujarat ETS Industries	
ETS Percent Ambient PM After Pilot	
Categories: ETS_ConcPC	
	0 - 0.000475
	0.000475 - 0.000547
	0.000547 - 0.000607
	0.000607 - 0.000677
	0.000677 - 0.000751
	0.000751 - 0.000886
	0.000886 - 0.002672
	0.002672 - 0.007215
	0.007215 - 0.018252
	0.018252 - 1
Gujarat Sub-blocks (sub-districts)	

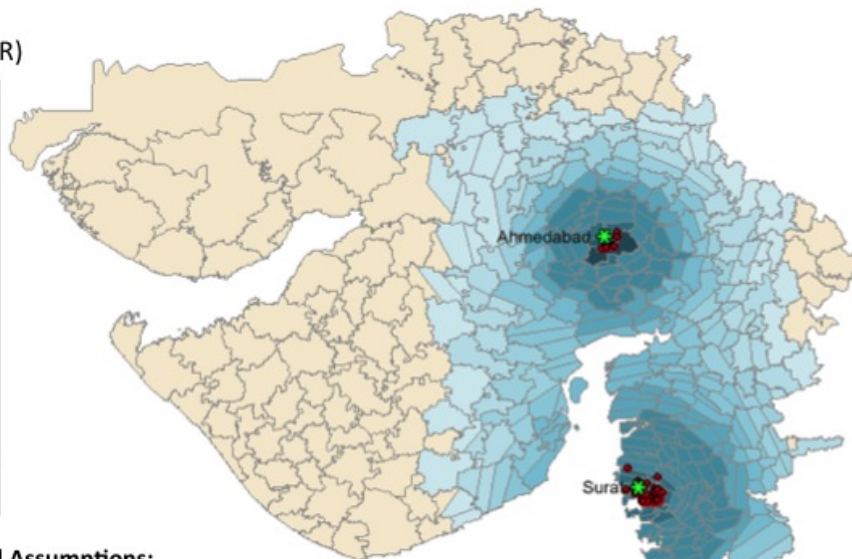
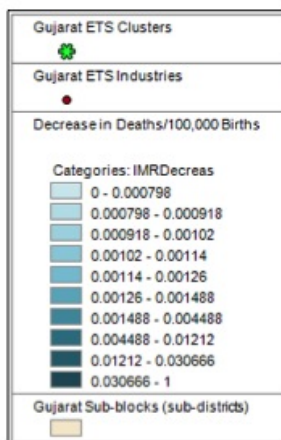
### SCREEN Model Pollution Diffusion Assumptions:

- Constant ground level ambient pollution  $1.4 \text{ mg}/\text{m}^3$
- Each reduces emissions by 20% (from  $150 \text{ mg}/\text{s}$  PM)
- Constant wind speed of  $10 \text{ m}/\text{s}$  in direction of wind.
- 954 industries with random stack heights between 5 – 30m



# Map 5: Reduction in Gujarat Infant Mortality (IMR: deaths/100,000 live births) from ETS Pilot

**Legend (Decrease in IMR)**



**ETS Health Impact Model Assumptions:**

- Decrease of  $1\text{mg}/\text{m}^3 \rightarrow 6$  fewer deaths / 100,000 births
- Decrease is uniform across all sub-districts
- Decrease in  $\text{mg}/\text{m}^3$  taken from previous SCREEN model

