Spatial Models for Groundwater Behavioral Analysis in Regions of Maharashtra

M.Tech Dissertation Report

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Declaration

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Abstract

In this project we have performed spatial analysis of groundwater data in Thane and Latur districts of Maharashtra. We used seasonal models developed using the water levels measured at observation wells (by Groundwater Survey and Development Agency, Maharashtra), shape files for watershed boundaries and drainage system, land use and forest cover information from census data in our work. We did regional analysis on groundwater and classified the years into good year if water levels are above the seasonal model in that year or bad year if water levels are below the seasonal model. We observe that the good error (error accumulated by observations above the model) or bad error (error accumulated by observations below the model) classification accounts for a substantial fraction of the error. We have understood the structure and classification of watersheds and used it in our global good/bad year analysis. We then investigated the relationship between site specific spatial attributes of observation wells. We grouped observation wells on the basis of watershed boundaries, elevation levels, natural neighborhood, etc. and performed spatial analysis with in groups and across groups. Much to our surprise, no spatial parameter which we analyzed, yielded any significant insight. The development of regional models will need additional attributes such as land-use, local hydrogeology.

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Chapter 1

Introduction

Growth in population, urbanization and standards of living has resulted in increased demand of water for diverse purposes of irrigation, domestic and industrial uses. On the other hand available fresh water resources are decreasing, due to overuse and pollution. There is a huge gap in the demand and supply of water. In order to meet this increased demand, surface water is not sufficient, so groundwater is being used. Wells are the main medium through which groundwater extracted from the ground. During rainy season the wells are enriched with water, but these wells are over extracted either for domestic use or commercial purpose as a result wells go dry within few months. This creates a problem for drinking water in non-monsoon periods and the dependency on other sources such as water tankers increases. With continuous extraction water table drops as the rate of recharge of groundwater is insufficient. To properly utilize groundwater one needs to understand groundwater behavior and its spatial and temporal aspects. This can be achieved by building the seasonal and spatial models for groundwater where seasonal model gives the temporal behavior of groundwater at particular place and spatial model gives the regional behavior of groundwater at particular time.

The single well seasonal model[6] predicts the behavior of groundwater at a particular observation wells. It takes the accumulated rainfall after monsoon period as input and provides a model that shows the behavior of groundwater for that year at that well. But how is one to know the groundwater behavior at any arbitrary point where there is no observation well. Does this single well seasonal model show the groundwater behavior of that entire village or region where the well is located? Can we depend on a single well behavior in a village or region to decide the groundwater behavior of that village or region. The answer is generally no. We need a model that can assess the groundwater behavior in a region. This can be achieved by developing spatial models. Given sample data at some points in a region spatial model will assess the groundwater levels at point in that region. It will divide the regions into subregions and provides models for predicting the groundwater levels in subregions. Such spatial models will be helpful to monitor and maintain balanced groundwater system.

1.1 Spatial Models

Spatial groundwater models stress on the spatial dependency of various data such as rainfall, groundwater and other attributes to build a model which takes into account such factors. In [6], we concentrated on the single well model which focused on a single location and observations there. At first, we only looked at the well level readings, and then we extended our model that includes rainfall at that location, as estimated by the 0.5 degree interval of coordinate system rainfall data. The rainfall data is inherently spatial and we did see an improvement in the predictive power of the model (i.e increase in R^2 value).

In this project, we concentrate on more of the region-specific single-well parameters and also on cross-relationships between single-well models in the vicinity. Thus, our starting point are the single-well models and we bring in various spatial data to bear on the problems.

The first attempt is to aggregate single well models to arrive at a global understanding of the role of monsoon for that year. There we show that considerable amount of errors in the single-well model can be explained by the so-called good year/bad year analysis. The second part is the study of the watershed layer which comes with the Maharastra Remote Sensing Application Center data-set. Watershed is an area of land enclosed within mountain ridges from which water drains to a particular point along a stream. We understand the structure of the the watersheds and their classification. Next, we look at the location of the observation wells vis-a-vis these water sheds. We then pick up certain clusters for detailed analysis.

Finally, we start with relating more site-specific attributes from the census data and from other data-sets to examine if a spatial model emerges.

1.2 Problem Statement

Groundwater Survey and Development Agency(GSDA) has been recording groundwater levels through observation wells in all districts of Maharashtra for over 30 years. Using these water levels and available surface water resources it prepares water budgets for a watershed at the end of monsoon period. Water budget contains the details of estimated available water resources, and details of amount of water required for drinking and general purpose, irrigation and industrial usage. Based on these water budget and other calculations(discussed in Section 1.3.2) it announces a region as critical, semi critical, safe, exploited and over exploited, in terms of water availability. Our goal is to use this groundwater data of past 30 years along with other data like rainfall, spatial data, geo-hydrological information and build spatial models. These spatial models should enhance the GSDA resource estimation techniques, and help in classifying the area as critical, safe and etc. This is the global objective of our project. To achieve this, following are the sub problems that we tried to answer in this work.

- Is there any trend in groundwater levels over the years at observation wells and at global or district level.
- How is groundwater behavior at watershed level i.e assess the groundwater levels at watershed level and compare it with GSDA warnings.
- Given water levels in a well can we define a vicinity range in which we can estimate the water levels.
- Do wells behave similarly with in the same watershed i.e. do watershed boundaries indicate the groundwater sharing domains. If not search for a property on which a region can be grouped to groundwater sharing domains.
- Investigate the correlations between wells across the watersheds.

1.3 Government Protocols and GSDA Procedures

Here, we discuss what are the government protocols in groundwater protection and maintenance. We mainly look in to the details of Maharashtra groundwater act 1993. We discuss GSDA procedure in estimating the groundwater resources, GSDA methods and calculations to announce an area as critical/safe etc.

1.3.1 Maharashtra Ground Water Act

[8] This act is made to regulate the exploitation of groundwater in order to protect the public drinking water sources. In this act the Government of Maharashtra has defined some terms like public drinking water source, public water supply system, wells, watersheds and etc. According to this act a watershed is said to be over exploited if its annual groundwater extraction is more than 85% of estimated average annual recharge. The following are the main points in this act

- No one should not sink any well with in 500 m distance from the public drinking water source except the state government and concerned authorities. If any one wants to sink a well he should get a prior permission from concerned authorities.
- An area can be declared as water scarcity area by district collector under Section 4 of the act at any time.
- After declaring an area as water scarcity area, concerned authorities can regulate the water extraction in wells that are within 1 km distance from a public drinking water source.
- On the advice of technical officer, concerned authority can declare an area as over exploited.
- These authorities can prohibit the sinking new wells or close down an existing well in or restrict the extraction of water from wells in over exploited areas.
- The authorities can also make orders to pay the compensation to owners of wells which are closed to protect the public water sources in case of causing any loss to owners.

1.3.2 Ground Water Resource Estimation Methodology

Here we summarize the report on groundwater resource estimation policy in DYNAMIC GROUNDWATER RESOURCES OF MAHARASHTRA prepared by GSDA [13]. GSDA uses the Ground Water Resources Methodology - 1997 (GEC'97) in estimating the groundwater resources. They mainly uses two methods, one is Water Level Fluctuation(WLF) method and the other is Rainfall Infiltration(RIF) Method in groundwater recharge assessment. They use watershed as the groundwater assessment unit. They remove the areas of hilly regions which have slope greater than 20% and other bad quality groundwater area from total assessment unit area and use the remaining area for estimation. Next they do the assessment in the monsoon period with the WLF method. The monsoon recharge is expressed as

$$R = h * S_y * A + D_G$$

Stage Of GW Development	Significant Long Term Decline		Category
	Pre-Monsoon	Post- Monsoon	
≤ 70 %	No	No	SAFE
> 70 to ≤ 90 %	No	No	SAFE
> 70 to ≤ 90 %	Yes/No	No/Yes	SEMI CRITICAL
> 90 to ≤ 100 %	Yes/No	No/Yes	SEMI CRITICAL
> 90 to ≤ 100 %	Yes	Yes	CRITICAL
> 100 %	Yes/No	No/Yes	OVER EXPLOITED
> 100 %	Yes	Yes	OVER EXPLOITED

Table 1.1: Categorizing criteria for Assessment units

where h is the rise in water table in monsoon period, S_y is the specific yield, A is the area for computation of recharge and D_G is gross groundwater draft. Rainfall is not the only source to groundwater recharge in monsoon period, there will be recharge from canals, ponds, irrigation etc. After assessing the recharge with WLF they compare these values with RIF values. If the difference is more than 20% then they use RIF values even in monsoon period. They use RIF method to assess the recharge in non monsoon period. Total annual groundwater recharge is sum of monsoon and non monsoon recharge. Then they compute the total annual groundwater availability using following expression.

Net Groundwater Availability=Annual Groundwater Recharge - Natural Discharge in Non monsoon

Ground Water Draft is total groundwater extraction from existing groundwater structures in monsoon and non-monsoon periods. Using **Net Groundwater Availability, Ground Water Draft** they compute stage of ground water development percentage. They use $StageOfGroundwaterDevelopment\%$ value and Significant Long Term Decline factor to classify the assessment area(watershed) in to 4 categories, i) Safe areas which have groundwater potential for development, ii) Semi-Critical areas where cautious groundwater development is recommended, iii) Critical areas, and iv) Over-exploited areas where there should be intensive monitoring and evaluation and future groundwater development be linked with water conservation measures. To determine Significant Long Term Decline factor value they use past 10 years data and they consider the long term decline or rise if water level change is greater than +5 or less than -5 cm per year.

$$StageOfGroundwaterDevelopment\% = \frac{GroundWaterDraftforalluses}{NetGroundwaterAvailability} * 100$$

Finally, the net annual available groundwater is distributed between domestic, industrial and irrigation usages in that priority order.

1.4 Data Sets

In this section, we discuss the data and its properties that we have used in our project. The main data in our project is groundwater levels collected from observation wells by GSDA. We

Tahsil	Village	Watershed	Site_Type	wls_date	wls	depth	Site_id
Bhiwandi	Akoli	WF-27	Dugwell	1991-01-31	3.5	5.5	W192915073024001
Bhiwandi	Akoli	WF-27	Dugwell	1991-03-31	3.7	5.5	W192915073024001
Murbad	Inde	WF-35	Dugwell	2004-05-30	3.3	7.8	W191700073333001
Murbad	Inde	WF-35	Dugwell	2004-09-30	1.7	7.8	W191700073333001
Bhiwandi	Padgha	WF-31	Borewell	2002-10-08	3.46	30	W192143073103001

Table 1.2: Sample GSDA Observation Data

have also used rainfall data, spatial data, site specific census data etc. The following sections describes each of these data sets in detail.

1.4.1 GSDA Data Set

GSDA has been collecting the groundwater levels(depth of water level from ground) since 1970's in entire Maharashtra. It has observation wells in each district through which it collects the groundwater levels. Table 1.2 shows few rows of GSDA data. In general they have collected the groundwater samples 4 times in a year from dug wells and 12 times in a year i.e once in a month from bore wells. We have collected this data set of entire Maharastra, but we have used only Thane and Latur districts data in our work. Thane has 120 observation wells in which 92 are dug wells and 28 are bore wells. Latur has 136 observation wells out of which 115 are dug wells and 21 are bore wells. In Figures 1.1 and 1.2, red color dots indicates bore wells, yellow color dots indicates dug wells and block color dots indicates 0.5 degree interval of coordinate system, rainfall grid points.

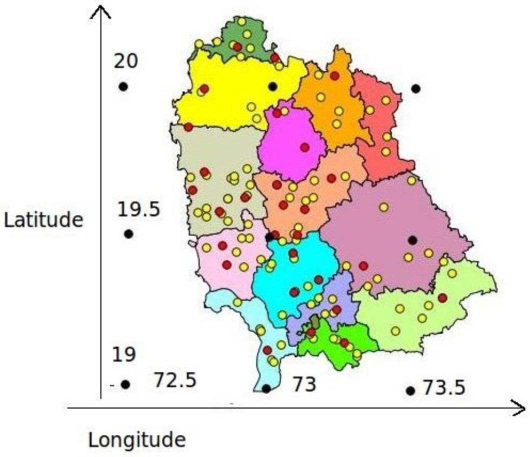


Figure 1.1: Thane Observation Wells

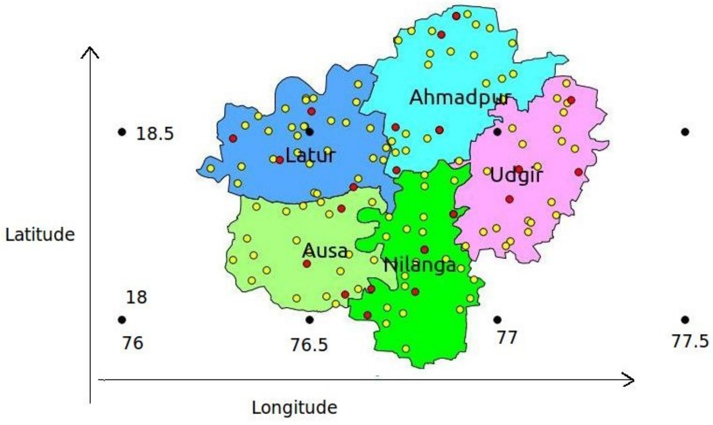


Figure 1.2: Latur Observation Wells

1.4.2 Rainfall Data

Rainfall data is also one of the important dataset that we have used in our work. we have collected rainfall data at three granularity levels from three different sources. We have collected rainfall data at one degree interval of Maharashtra from GISE lab IITB, at half degree interval of India from Prof. Subimal Ghosh, IITB and at Taluka level of Thane and Latur districts from GSDA. We have used rainfall data at 0.5 degree interval of coordinate system in comparing the Good or Bad year analysis with rainfall.

1.4.3 Spatial Data

While working on regional models it is very important to consider the spatial properties of the area like watershed boundaries,drainage system, elevation, slope and etc. We have collected some spatial data of Thane district from Maharastra Remote Sensing Application Center (MRSAC). This data contains shape files of village boundaries, micro,mini,sub watershed boundaries and drainage lines(rivers, canals and lakes etc). This shape files are used through QuantumGIS software to provide a graphical view of spatial data. This data was very much helpful to know the nearest water resource of an observation well, also in spatial grouping of mini water sheds in good/bad region analysis. Figures 1.3, 1.4 shows spatial data of Thane district imposed on QuntumGIS. The small polygons in Figure 1.3 are the Micro-Watersheds and group of Micro-Watersheds with same color indicates the Watersheds. Detailed discussion on the definition and types of watersheds is in Section 3.1. The dark and blue lines in Figure 1.4 are the drainage lines, canals and rivers of Thane district.

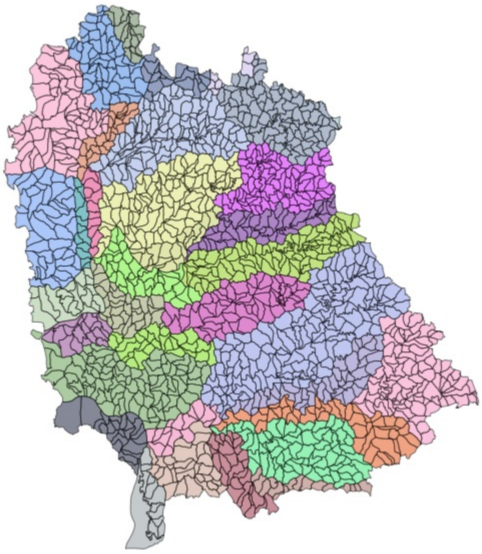


Figure 1.3: Watersheds in Thane

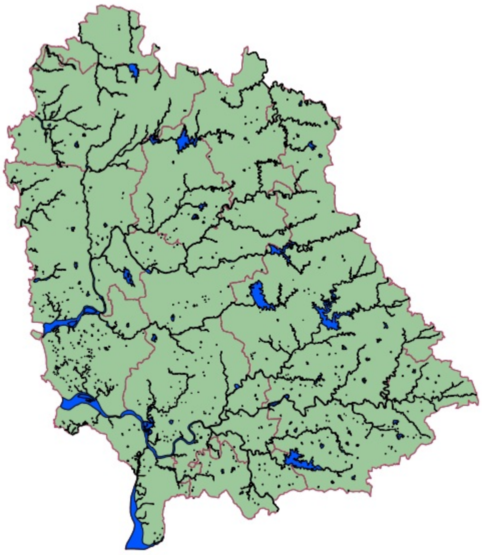


Figure 1.4: Drainage System in Thane

1.4.4 Census Data

We have also used Census data of Thane district in our project which we have collected form Census Department of India. It contains the details of total population, SC,ST population, number of wells, taps, forest cover, irrigated land and etc. at village level. See Appendix for complete attribute list of census data. We have used this data to understand the relation between groundwater levels and forest land, irrigated land, land not available for cultivation, population and other site specific census data.

1.4.5 District Resource Map

District resource map is map that shows the geological information of a district. It contains details of geohydrological properties, groundwater resources, minerals resources, irrigation projects and hazards mitigation etc. Geological Survey of India creates these maps. Generally these maps are used by district planners in taking the development and policy making decisions. We have accessed a copy of these DRM of Thane district from ACWADAM [1]. This data was helpful in doing the regional analysis of groundwater. Figure 1.5 is the snapshot of Thane District Resource Map. The left side bigger image shows the rock types in thane. The remaining images shows the geomorphology, geohydrology, geotechnical and natural hazards and land use structure of Thane district.

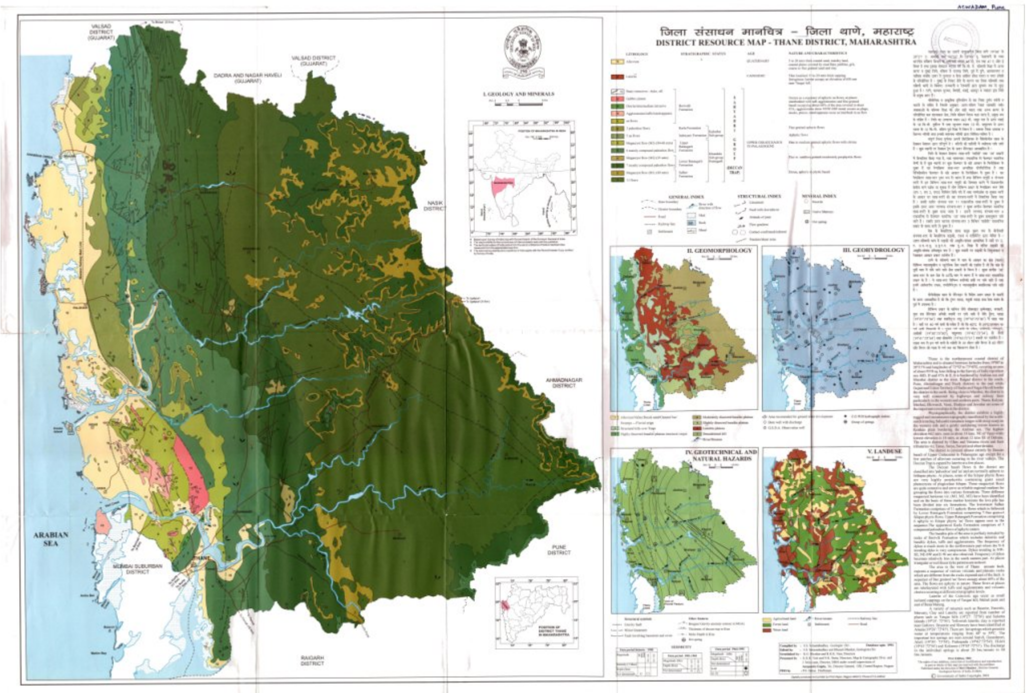


Figure 1.5: District Resource Map of Thane District

1.5 Supporting Softwares

In this section we discuss how we have organized the entire data and what are the soft wares that we have used in our work.

- **PostgreSQL** [9]: It is a data base management system. we have used this software to store the entire data. We have uploaded GSDA data sets and rainfall data in the form of tables and accessed it using queries. We have also used **PostGIS** spatial data extension of PostgreSQL to store our spatial shape files.

- **Quantum GIS** [10]: is a Geographical Information System, using which we can view, edit all kinds of spatial data. It has good user interface to manipulate spatial information. We have used it to modify and view shape files of Thane.
- **GeoServer** [4]: is similar to Quantum GIS i.e helps in manipulating the spatial data. Only difference is it provides the browser based view.
- **Google Earth** [3]: famous software which provides the visualization of earth and its geographical information. We can also impose spatial layers on Google Earth and view it. We have used it in our watershed analysis.
- **Surfer** [12]: is a software for developing contour maps, 3D maps, surface maps and etc.
- **Scilab** [11]: is an open source alternative to **MATLAB**, which provides programing environment. We have used Scilab to compute the correlations and developing the models etc.
- **Python** [7]: is programing language which helped us in cleaning the data and formatting the data. We also used SciPython for developing the high quality images.

All the above softwares are open source softwares except Surfer. We have used a demo version of Surfer in our work.

Chapter 2

Elementary Global Analysis

In this chapter, we discuss the behavior of groundwater levels in entire district over past 30 years. That is we check whether groundwater levels are satisfactory in a region or not and whether a year is good or bad in terms of groundwater recharge. For this purpose we have used our single well seasonal model as the base to determine whether the groundwater levels are satisfactory or not in a region in which that observation well is located. We did this analysis on both Thane and Latur district.

2.1 Good/Bad Year Definition

What is a good year or bad year? In a year if groundwater levels are high, then we consider it as a good year. If the groundwater levels are low, then we consider that year as bad year. Here we discuss the procedure in defining a year as a good year or bad year for a particular observation well. First we have built single well seasonal model for all observation wells using observation data of groundwater levels. For each well we first folded the observation data into single year(here we refer monsoon to summer as a year that is June to May. Consider this notation through out the report) and then built model by fitting a curve to these folded data. We used polynomial models from [6] for this analysis. For a particular well the actual observation data of a particular year may fall above the fitted curve or below the curve or may fall close to the curve. If the actual observations of a well in a particular year are above the model that indicates high rainfall in that year and higher groundwater recharge, which means a “good year”in terms of groundwater recharge for that well. If they are below the model, lower rainfall and subsequently lower recharge in that year, so the “bad year”for groundwater recharge. Now it may not the case that all the observations of the year will be above or below the curve. There are some observations which are above the model and some are below the model with in the same year. In order to consider such situations and decide a year good or bad, we have came up with following procedure.

We first take an year and its original observations, then we compute the model values at that date on which the original observations has taken. Next we compute the difference between the original observation water level and model given water level of same date (For example E1, E2, E3, E4 in Figure 2.1). If the value is positive which indicates the original observation is above model, then we add the squared difference to the good value of that year. If the value is negative which indicates the original observation is below the model, then we

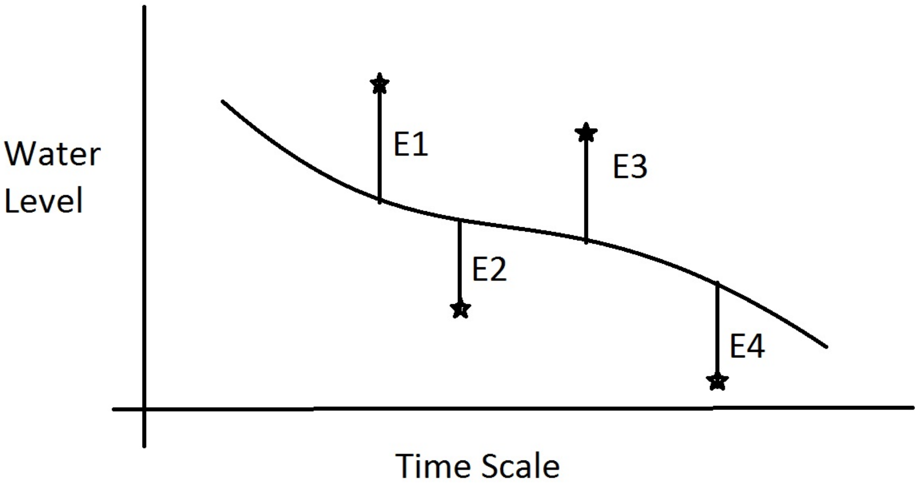


Figure 2.1: Sample Model

add the squared difference to the bad value of that year. We repeat this for all observations of the year. At the end if sum of all good values (i.e $E1^2 + E3^2$ in Figure 2.1) is greater than 5 times of sum of bad values (i.e $E2^2 + E4^2$ in Figure 2.1) we consider that year as a good year for that well. If bad value is 5 times greater than good value it is bad year for that well. Finally neither good value is 5 times greater than bad value nor bad value 5 times greater than good value we consider it as moderate year. We have computed these values for both Thane and Latur districts. Table 2.1 shows good bad values of some observation wells in Latur. The format in each cell is Label: Good value / Bad value. Label may be Good or Bad or Median depending on values.

village	2001	2002	2003
Ahmadpur_Dug_Well_15.1	Good :18.24/0	Good :0.36/0.02	Good :6.21/0.22
Arasnal_Bore_Well_60	Good :100.76/0	Median : 95.84/289.1	Good :136.08/1.32
Barmachiwadi_Dug_Well_16.9	Bad : 0.86/20.71	Bad : 0/61.12	Bad : 0/72.38
Chikurda_Bore_Well_27	Bad : 25.77/288.59	Bad : 0.29/460.94	Bad : 0/962.72
Dhanegaon_Dug_Well_15.7	Good :15.99/0	Bad : 1.58/91.045	Bad : 0.14/1.68
Haibatpur_Bore_Well_60	Bad : 4.16/117.41	Median : 475.03/127.61	Good :460.15/77.29
Karla_Dug_Well_9.3	Median : 3.14/3.63	Median : 1.587/7.058	Bad : 0/12.95
Khandali_Bore_Well_90	Good :616.83/0	Median : 576.31/2239.69	Good :670.70/0.08
Sarwadi_Bore_Well_30	Good :408.07/0.42	Bad : 38.07/347.22	Bad : 2.61/246.31
Selu_Dug_Well_8.9	Bad : 0.36/17.72	Median : 1.42/4.71	Bad : 0/88.43

Table 2.1: Good Bad values of Latur observation wells

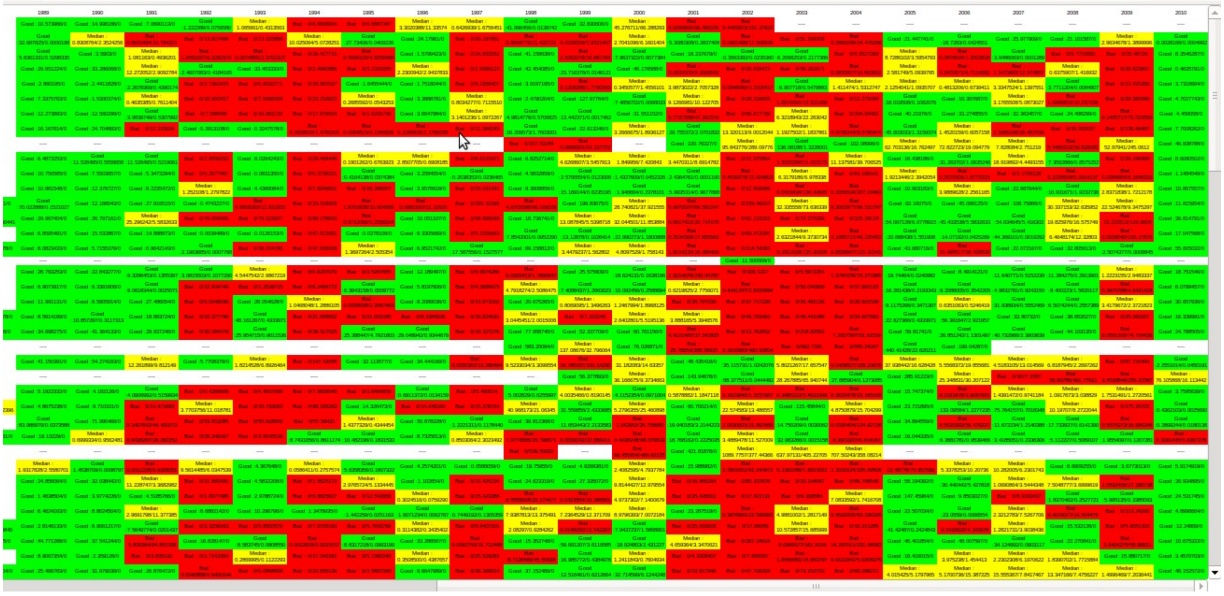


Figure 2.2: Good Bad values over the years of Latur

In Figure 2.2 the columns are years and rows are observation wells. Consider a cell i, j, green color indicates for i^{th} observation well, j^{th} year is good. Similarly red indicates bad year, yellow means median year. If we observe the Figure 2.2, in a column most of the rows are either green or most of them are red which indicates that in a year most of the wells are either good or bad. Let us see this in detail. The first column in Figure 2.2 is almost green, which indicates, in that year, groundwater levels at all those observation wells are good. We can consider this year as globally good year. Large part of the sixth column in Figure 2.2 is red, which indicates, in that year, groundwater levels at most of those observation wells are bad. We can consider this year as globally bad year. Let us see this in detail in next section.

2.1.1 Global Good or Bad Year

Till now we have observed whether a year is good or bad at a particular well. Now we examine globally what is the status of that year. That is for a particular year what is groundwater behavior at district level. To determine a year good/bad at global or district level we have adopted the following procedure. For a particular year we compute the average good value and average bad value of a observation well in that year. For example consider the Figure 2.1, in this $E1^2 + E3^2$ is total good value for that year according to our definition in Section 2.1 and $E2^2 + E4^2$ is total bad value for that year. There are four observations in that year the average good and average bad values are given by Equations 2.1 and 2.2 respectively.

$$Avg_{Good} = \frac{E1^2 + E3^2}{4} \tag{2.1}$$

$$Avg_{Bad} = \frac{E2^2 + E4^2}{4} \tag{2.2}$$

We compute these values for all observation wells. Now if the sum of Avg_{Good} of all

Year	Total Good	Total Bad	Good - Bad	Label
1991	507.5589	369.94899	137.60991	GOOD
1992	135.48005	446.44217	-310.96212	BAD
1993	237.1058	368.29595	-131.19015	BAD
1994	48.25768	1215.2763	-1167.01862	BAD
1995	300.31916	239.05062	61.26854	GOOD
1996	446.56428	77.798066	368.766214	GOOD
1997	75.444607	946.79267	-871.348063	BAD
1998	744.40502	461.44798	282.95704	GOOD
1999	689.06344	872.81259	-183.74915	BAD
2000	586.3261	959.0896	-372.7635	BAD

Table 2.2: Year wise Good Bad analysis of Latur District

Year	Total Good	Total Bad	Good - Bad	Label
1991	29.555873	83.374236	-53.818363	BAD
1992	34.502314	66.82016	-32.317846	BAD
1993	69.798209	24.56779	45.230419	GOOD
1994	50.225499	34.702623	15.522876	GOOD
1995	19.708159	87.921592	-68.213433	BAD
1996	56.627346	47.212031	9.415315	GOOD
1997	122.1914	25.468061	96.723339	GOOD
1998	171.35803	26.137216	145.220814	GOOD
1999	116.08434	23.124613	92.959727	GOOD
2000	69.782349	87.31481	-17.532461	BAD

Table 2.3: Year wise Good Bad analysis of Thane District

observation wells is greater than sum of Avg_{Bad} of all observation wells, which indicates that number of observations above the model are greater than the number of observations below the model over all observation wells. Then we consider that year as globally or district level good year. Otherwise it is a bad year.

$$Year = \begin{cases} \text{Good} & \text{if} \sum Avg_{Good} > \sum Avg_{Bad} \\ \text{Bad} & \text{if} \sum Avg_{Good} < \sum Avg_{Bad} \end{cases}$$

Like this we have examined years 1975 to 2010 for Thane and Latur districts. Table 2.2 and 2.3 shows some of these results for Latur and Thane districts. We can observe that Thane has more number of good years than the Latur. Is this because of higher rainfall in Thane. We investigate this in our next Section.

2.2 Validation of Good/Bad Year Analysis

We have seen our procedure and results in deciding a year globally good or bad in terms of groundwater recharge. Here we discuss the correctness of our procedure. That is we verify whether the years that are decided as good are really have good rainfall in that year. To know this we have cross verified our good year bad year analysis against rainfall.

As we have already discussed in Section 1.4.2 we have rain fall data which is sampled at 0.5 degree interval of coordinate system. Using this data we have computed the aggregate rainfall data of district for all the years for which rain fall data is available. We computed the difference between $\sum Avg_{Good}$ over all wells and $\sum Avg_{Bad}$ over all wells using the Equation 2.3 and the normalized difference using Equation 2.4.

$$Diff_{GB} = \sum Avg_{Good} - \sum Avg_{Bad} \tag{2.3}$$

$$NormDiff_{GB} = \frac{\sum Avg_{Good} - \sum Avg_{Bad}}{\sum Avg_{Good} + \sum Avg_{Bad}} \tag{2.4}$$

Then we computed correlation of aggregated rainfall with $Diff_{GB}$ and $NormDiff_{GB}$ over the years i.e from 1975 to 2005. It is 0.221 and 0.387 for Thane district and 0.56 and 0.719 for Latur district. We also plotted the trend of rainfall with $Diff_{GB}$ as show in Figures 2.3, 2.4. In Latur, for many years the $Diff_{GB}$ has captured the spikes in rainfall as shown in Table 2.4. That is for high rainfall years the $Diff_{GB}$ is positive which means the year is Good over the district. But in Thane the rainfall impact on overall good/bad year is unpredictable as shown in Table 2.5.

Year	Sum of Avg Good	Sum of Avg Bad	$Diff_{GB}$	$NormDiff_{GB}$	Aggregate Rainfall in mm
1991	507.5589	369.94899	137.60991	0.1568190002	611.226875
1992	135.48005	446.44217	-310.96212	-0.5343705899	671.19
1993	237.1058	368.29595	-131.19015	-0.216699324	756.160625
1994	48.25768	1215.2763	-1167.01862	-0.9236147492	563.703125
1995	300.31916	239.05062	61.26854	0.1135928305	883.63125
1996	446.56428	77.798066	368.766214	0.7032660083	919.85
1997	75.444607	946.79267	-871.348063	-0.8523931602	759.063125
1998	744.40502	461.44798	282.95704	0.2346530133	1173.783125
1999	689.06344	872.81259	-183.74915	-0.117646437	769.308125
2000	586.3261	959.0896	-372.7635	-0.2412059745	892.915

Table 2.4: $Diff_{GB}$, $NormDiff_{GB}$ Values of Latur

2.3 Significance of Good or Bad values on R^2 value

We have computed the good bad values using the single well seasonal model of observation wells which is nothing but a polynomial curve fitted to the folded observation data. Now we see the relationship between these good bad values and the quality of the model that is R^2 value. R^2 value shows the how successful the model in explaining the variation of fitted data.

$$\begin{aligned} SSE &= \sum (y_i - f_i)^2 \\ SST &= \sum (y_i - y)^2 \\ R^2 &= 1 - \frac{SSE}{SST} \end{aligned}$$

Year	Sum of Avg Good	Sum of Avg Bad	$Diff_{GB}$	$NormDiff_{GB}$	Aggregate Rainfall in mm
1990	24.772176	9.9296495	14.8425265	0.4277160145	1855.6725
1991	29.555873	83.374236	-53.818363	-0.4765634557	1183.29125
1992	34.502314	66.82016	-32.317846	-0.3189602931	1406.26125
1993	69.798209	24.56779	45.230419	0.4793084318	1701.0575
1994	50.225499	34.702623	15.522876	0.1827766308	1671.66125
1995	19.708159	87.921592	-68.213433	-0.6337786009	1111.520625
1996	56.627346	47.212031	9.415315	0.0906719134	1363.333125
1997	122.1914	25.468061	96.723339	0.6550432891	1524.631875
1998	171.35803	26.137216	145.220814	0.7353129604	1415.6925
1999	116.08434	23.124613	92.959727	0.6677711814	1135.49625
2000	69.782349	87.31481	-17.532461	-0.1116026611	1157.125625

Table 2.5: $Diff_{GB}$, $NormDiff_{GB}$ Values of Thane

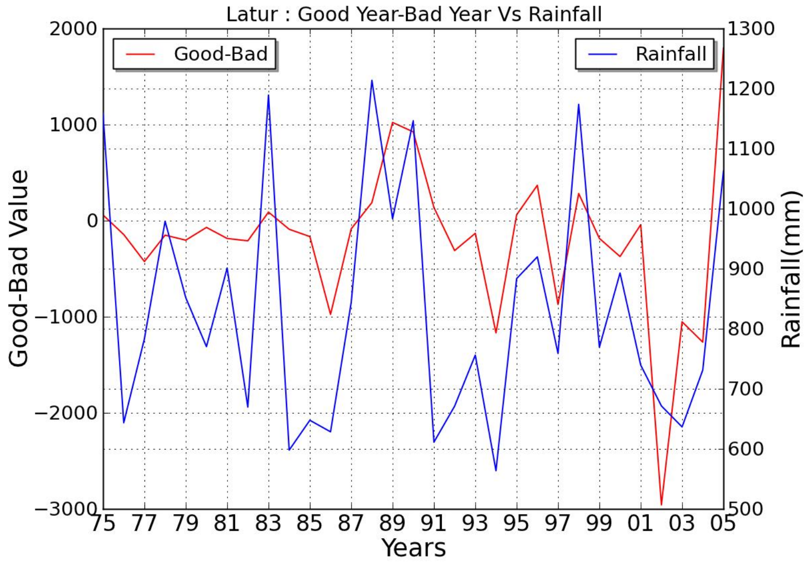


Figure 2.3: Comparison of Good-Bad value with Rainfall of Latur

From the definition of R^2 [14] it is clear that if error value decreases the R^2 value will increase, that is the quality of fit will increase. In our good/bad analysis the good or bad values are nothing but squared errors. In a good year the amount of good value is largely contributing to error in that year similarly in bad year. Ultimately these errors are affecting the R^2 value and reducing the quality of our seasonal model.

Let us assume that in a good year due to high rainfall the observations are high above the model causing the high good error value. Similarly in a bad year low rainfall causing the observations to fall below the model which resulted in high bad error value. That is due to rainfall, groundwater observations are falling above or below model and thus largely contributing to error. With this analysis it is clear that our seasonal model is not capturing

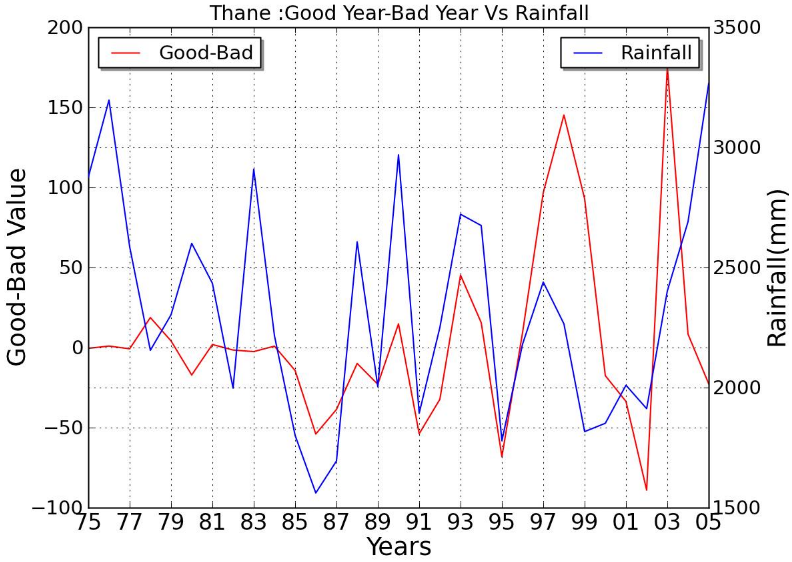


Figure 2.4: Comparison of Good-Bad value with Rainfall of Thane

the rain fall which indeed the reason for poor quality of fit, that is low R^2 value. To improve the quality of our model we have included the yearly rainfall in our seasonal model and built the rainfall incorporated seasonal models for each well. Detailed discussion can be found here [6].

In Table 2.6 second column shows the R^2 value of normal seasonal model and last column shows the R^2 values of rainfall included seasonal model. Third and fourth columns shows the good, bad, median year count with and without rainfall models. We have built the model using GSDA observation data from 1991 to 2005 since we have rainfall data from 1991 to 2005. If we observe the Table 2.6 the R^2 values are increasing. In most of the wells the

Village	R^2 Value		Good,Bad,Median	Year Count
	Without Rainfall	With Rainfall	Without Rainfall	With Rainfall
Aashiv_Dug_Well_15	0.2078617	0.3024008	6,4,4	7,5,2
Arasnal_Bore_Well_60	0.1572724	0.399788	3,2,2	3,3,1
Dapegaon_Bore_Well_30	0.4288577	0.5399494	5,0,2	3,3,1
Dawangaon_Dug_Well_7.15	0.6044405	0.7270438	7,8,2	7,6,4
Gangahipparga_Dug_Well_10.5	0.5165378	0.5531258	10,2,5	10,3,4
Kelgaon_Bore_Well_60	0.3233141	0.4658574	3,2,0	2,3,0
Latur_road_Bore_Well_80	0.1043065	0.1752429	2,2,1	2,1,2
Palshi_Dug_Well_6.6	0.6526907	0.7364118	8,8,1	6,6,5
Sindkhed_Bore_Well_61	0.1352716	0.1714149	3,1,4	3,2,3
Yerol_Dug_Well_16.8	0.5995343	0.64734	13,10,8	10,11,10

Table 2.6: R^2 values and Good, Bad, Median year count of Latur

median years count has reduced and good/bad year count has increased from without rainfall model to with rainfall model. It is obvious that with inclusion of rainfall the model will move up or down and hence it reduces the median year count. But there are some cases where the median years count has increased which is unexpected. We also verified the R^2 values of wells which have high median years count. In most of the cases these wells have R^2 values greater than the average R^2 value in both models i.e without and with rainfall. Complete results of Latur and Thane are available in Appendix.

From the Table 2.6 it is clear that even though the amount of increment is small, R^2 values are increasing from normal seasonal model to rainfall included seasonal model. It indicates our assumption that "ignoring the rainfall in seasonal model is the reason for poor quality of fit" is correct. But if we observe that the increase in R^2 value is very less and still the R^2 value is not satisfactory. Which indicates that there are some other factors that are affecting the groundwater levels which we did not consider yet.

2.4 Validation of Rainfall Models with Fraction of Error Value

In this section we discuss what is *FractionofError* and how we used it in verifying the improvement of rainfall included seasonal model over without rainfall model. We have computed the fraction of good error in bad year or bad error in good year for all years over the total error of all years. Here we don't use the "Median" year concept in computing the *FractionofError*. We just consider a year either good or bad depending on which error is larger. Consider an observation well's one year observation data and we compute the total of squared error. For example $TotalError = E1^2 + E2^2 + E3^2 + E4^2$ from Figure 2.1. Suppose if that year is good according to our method in Section 2.1, then we compute the squared bad error of that year as error, that is $Error = E2^2 + E4^2$ from Figure 2.1. Or if that year is bad, then we compute squared good error of that year as error, that is $Error = E1^2 + E3^2$ from Figure 2.1. We repeat this process for all years. Then the fraction of error is computed using the Equation 2.5.

$$Fraction_{Error} = \frac{\sum_i Error_i}{\sum_i TotalError_i} \tag{2.5}$$

If we compute this $Fraction_{Error}$ value using the rainfall included seasonal model it should be higher than the without rainfall model. This is because when we included the rainfall in model the curve will move up for good rainfall year and fall down for a bad rainfall year. As the model moves up in a good rain fall year the bad error will increases as shown in Figure 2.5. Similarly in a bad rainfall year as model moves down the good error will increase as shown in Figure 2.6. Ultimately with rainfall included model *Error* value will increase either in good or bad year. As the numerator in Equation 2.5 value increases, the $Fraction_{Error}$ value will also increase. Thus from normal model to rainfall included model the $Fraction_{Error}$ value will increase. We have computed the $Fraction_{Error}$ values of normal seasonal model and rainfall included seasonal model for both Latur and Thane attached these results in Appendix. Table 2.7 shows sample results of Latur district. In most of the wells the value has increased but we found some bore wells whose fraction value has decreased. For example the Dhalegaon_Bore_Well_90 in the Table 2.7. Its R^2 value for seasonal model is 0.2379479 and it is reduced to 0.0476049 in rainfall model. We observed the increase in median year count from seasonal model to rainfall model for those wells whose fraction value has decreased.

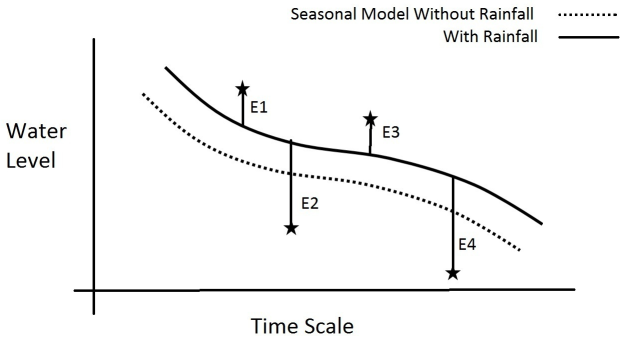


Figure 2.5: Rainfall Model for Good Rainfall Year

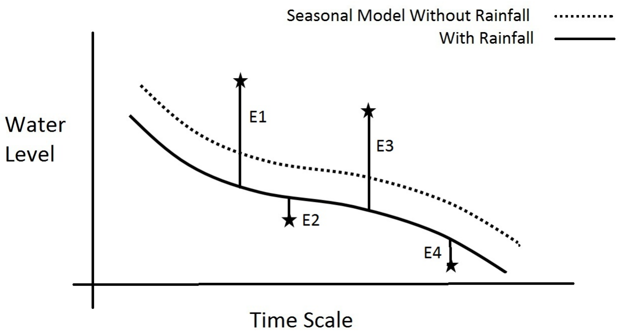


Figure 2.6: Rainfall Model for Bad Rainfall Year

Vilage	Without Rainfall	With Rainfall
Aashiv_Dug_Well_15	0.1130271	0.1302603
Chikurda_Bore_Well_27	0.0213859	0.0249582
Dhalegaon_Bore_Well_90	0.2379479	0.0476049
Ganjoor_Dug_Well_19.25	0.0293079	0.0506123
Kelgaon_Bore_Well_60	0.0843702	0.0954607
Latur_road_Bore_Well_80	0.0226794	0.092233
Rapka_Dug_Well_19.8	0.0456165	0.1002745
Tattapur_Dug_Well_8	0.0616008	0.0765699

Table 2.7: $Fraction_{Error}$ Values of Latur District

2.5 Summary

In this chapter we first defined good year/bad year using seasonal model and water levels at observation wells. Then using these values over all the observation wells we defined global good/bad year. We found that Thane district has more good years than Latur. Then we investigated the correctness of our good/bad year procedure with rainfall data. Surprisingly Latur has shown high correlations with rainfall than Thane. We discussed significance of good/bad error values on the quality of model, which resulted in inclusion of rainfall in seasonal models, and improved quality of models. We also defined fraction of error and verified whether it is increasing from normal models to rainfall models. We can conclude that our models are still underestimating the good rainfall year and over estimating the bad rainfall year, and there are other factors which we have not explored yet.

Chapter 3

Groundwater Behavior at Watershed Level

Watershed is an area of land enclosed within mountain ridges from which water drains to a particular point along a stream as shown in Figure 3.1. In Figure 3.1 red lines indicates the boundaries of watershed, white lines indicates ridges, yellow lines indicates the flow lines and blue lines indicate valley or drain. It is the basic assessment unit in groundwater estimation. Each watershed is divided into three regions i)Runoff ii)Recharge iii)Storage depending on the rainfall infiltration. A watershed with large runoff region will have low groundwater levels, where a watershed with large storage region will have good groundwater levels. It is important to understand the physical and hydro-geological properties of watershed in developing the groundwater models. In this chapter, we observe the watershed boundaries demarcations, types of watersheds. Then we discuss our analysis of groundwater at watershed level which helps in understanding the regional behavior.

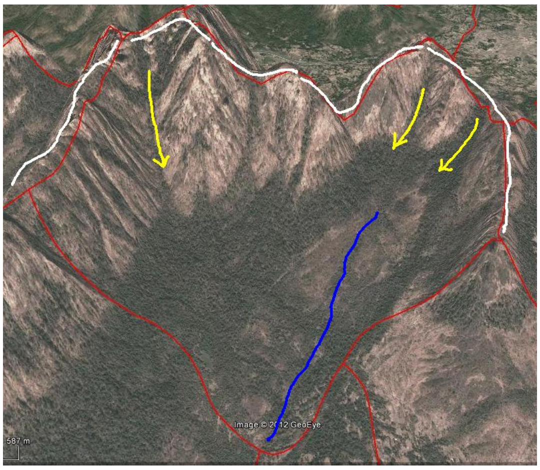


Figure 3.1: Sample Watershed

In Maharastra Remote Sensing Application Center(MRSAC) data watersheds have been classified in to four types by their size. i)Watershed ii)Sub-Watershed iii) Mini-Watershed iv) Micro-Watershed. All these watersheds have same properties except their size. Micro-

Watershed is smallest in size, next Mini-Watershed, Sub-Watershed and Watershed are in increasing order of size. A group of Micro-Watersheds will form a Mini-Watershed, Mini-Watersheds will form Sub-Watersheds and finally this Sub-Watersheds will form in to Watersheds. We used shape files of watershed in our analysis on watersheds. We did this Watershed analysis only for Thane district, due to unavailability of shape files for other districts.

3.1 Thane Watershed Analysis

Thane district has 21 Watersheds, 48 Sub-Watersheds, 124 Mini-Watersheds, 1650 Micro-Watersheds. According to watershed definition it is an area which comprises the mountain ridges, valleys and drains and a single exit point for drains. Let us look in detail where these watersheds are located i.e in hills or valleys and how their boundaries demarcation has done in Thane district.

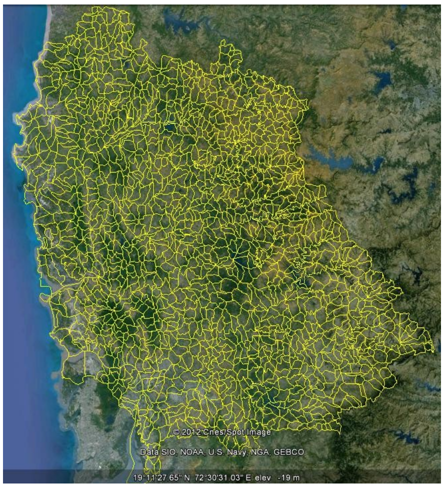


Figure 3.2: Micro-Watersheds

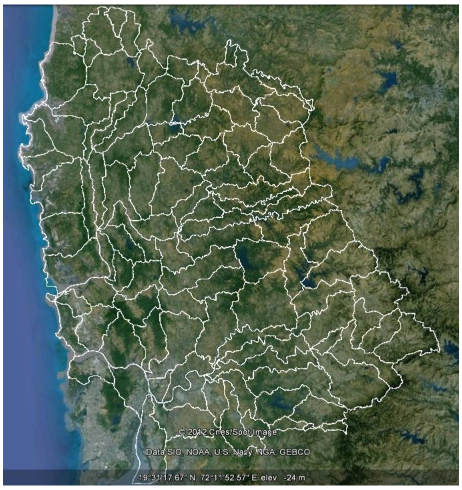


Figure 3.3: Mini-Watersheds

Figure 3.4: Sub-Watersheds

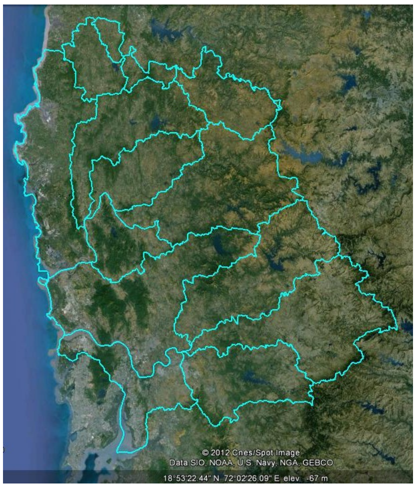


Figure 3.5: Watersheds

We first uploaded the watershed shape files in QuntumGIS. QuantumGIS just provides the graphical view of shape files, but we are interested in geophysical properties of watersheds. We converted these watershed boundaries into KML files using QuantumGIS and imposed them on Google Earth. We have then examined some Micro-Watersheds of Thane. Some watersheds are located in hill ridges, valleys and some are located in flat areas with slight elevation change. The edges or boundaries of these watersheds are combinations of ridges, flow lines and valleys or drains. Some water sheds have ridges connected to flow lines as boundaries, some have ridges connected to drains through flow lines as boundaries and etc. The Figure 3.6 shows some general combinations of ridges, flow lines and drains as watershed boundaries.

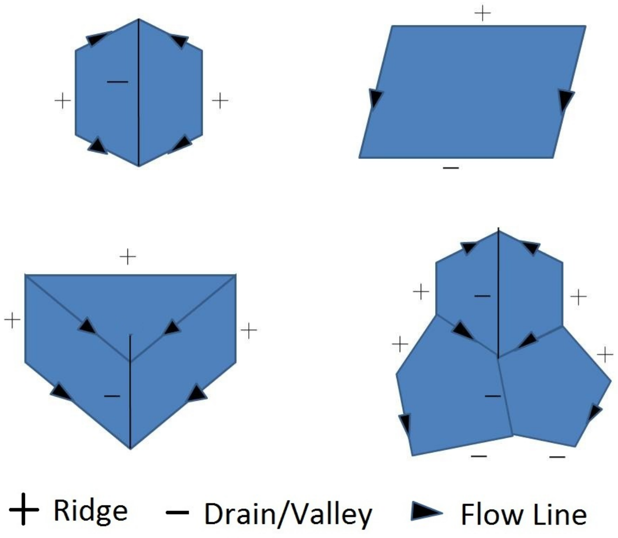


Figure 3.6: General Watershed Boundary Combinations

Most of the Micro-Watershed boundaries demarcation is proper. There are few Micro-Watersheds whose boundaries demarcation could have been done better. For example observe Figure 3.7 of a Micro-Watershed whose id is 707. Red lines indicates the actual boundaries of a Micro-Water shed. It has a ridge (highlighted with white line in Figure) inside it, which is not a boundary. From that ridge, there is steep slope in opposite directions (block arrows in Figure) leading to words two different drainage exits with in same watershed. It could have been divided in to two separate Micro-Watersheds along with ridge highlighted with white line. Similarly in Figure 3.8 with Micro-Watershed id 680.

3.2 Classification of Watersheds

We thought that it would be interesting to know what is the groundwater behavior at watershed level. The behavior of groundwater is good/bad at any watershed in a particular year and maps showing the good/bad watersheds of a particular year will be helpful in understanding the groundwater pattern. In order to generate these maps we have to use the results from Section 2.1 where we did good/bad year analysis at observation well level. For this purpose we have to classify the watersheds in to groups where each group will have exactly

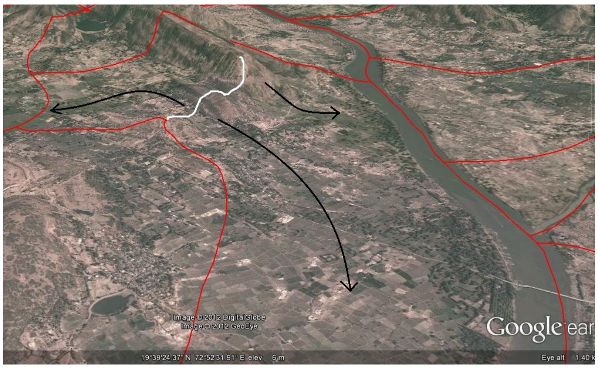


Figure 3.7: Micro-Watershed with ID:707

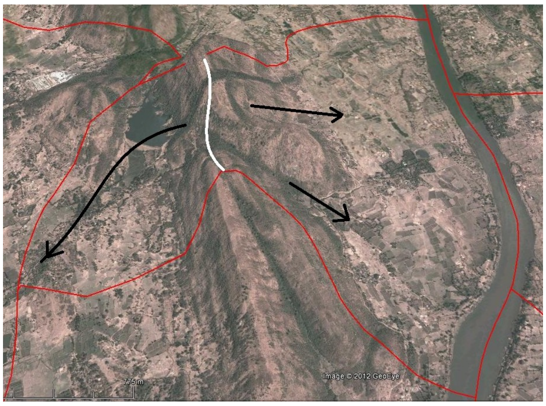


Figure 3.8: Micro-Watershed with ID:680

one observation well located in it. We did this classification using Mini-Watersheds of Thane district.

Out of 124 Mini-Watersheds, 72 have one or more observation wells, remaining 52 have no observation wells. These 52 Mini-Watersheds are grouped to nearby Mini-Watersheds with observation wells considering elevation, slope and drainage lines. In the remaining 72 Mini-Watersheds 38 have single observation wells and 34 have more than one observation wells. For these 34 Mini-Watersheds we have chosen any one of the observation well as the deciding observation to that Mini-Watershed. Thus we have divided the entire Thane region into groups of Mini-Watersheds where each group has exactly one observation well. Figure 3.9 shows these groups.

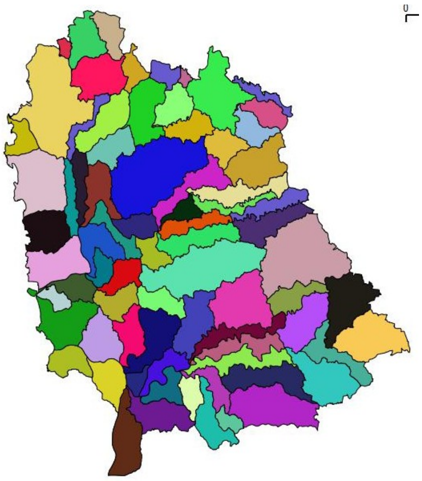


Figure 3.9: Mini-Watershed Groups

3.3 Good/Bad Watershed Analysis

Now we have used Mini-Watershed groups for global good/bad watershed analysis. Our assumption is that if an observation well shows good or bad behavior in a year then the entire Mini-Watershed group in which it is located, will also show the same good or bad behavior. As each watershed group has a observation well, we can classify all watershed groups in to good/bad regions based on the corresponding well. Figures 3.10,3.11 shows good/bad water analysis of year 2006 and 2007. The Red color indicates bad region, green indicates good region and yellow color indicates the median region as discussed in Section 2.1. Where white color indicates either there is no sufficient data to decide or the region has no observation well. We have observed that good, bad, median regions are almost equal in number.

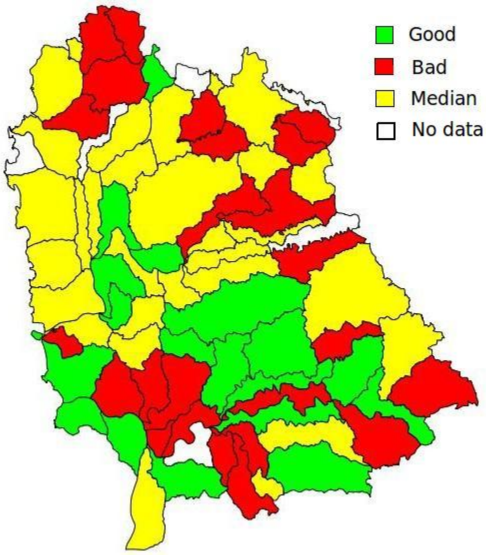


Figure 3.10: Good/Bad/Median Areas of Thane district in year 2006

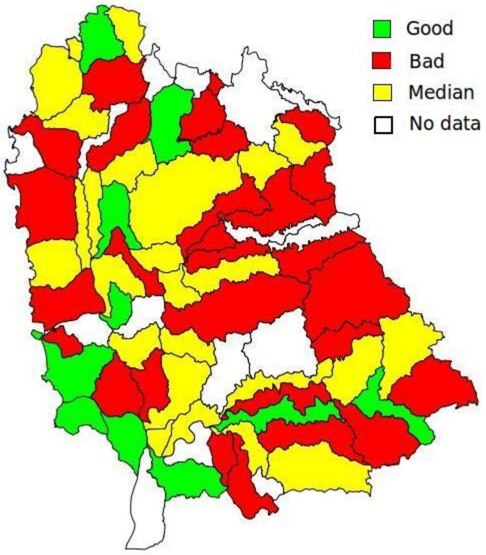


Figure 3.11: Good/Bad/Median Areas of Thane district in year 2007

Similarly we have used Mini-Watershed groups for visualizing the R^2 values with and without rainfall as shown in Figures 3.12,3.13. We used R^2 values of observation wells to color the watershed group to which it is allocated.

3.4 Comparing with GSDA Warnings

As discussed in Section 1.3.2 GSDA uses $StageOfGroundwaterDevelopment\%$ and past ten years groundwater levels to estimate the groundwater resources at taluka level, in every year and announces talukas as safe, critical, over exploited and etc. according to their assessment all talukas in Thane are safe for year 2007-08 [13], but our analysis shows many bad regions (As shown in Figure 3.11).

The main reasons for difference between GSDA assessment and our analysis might be the procedure. They use actual groundwater recharge values of a year and past 10 year information to predict the resources of that year. Where in our mechanism we just used the

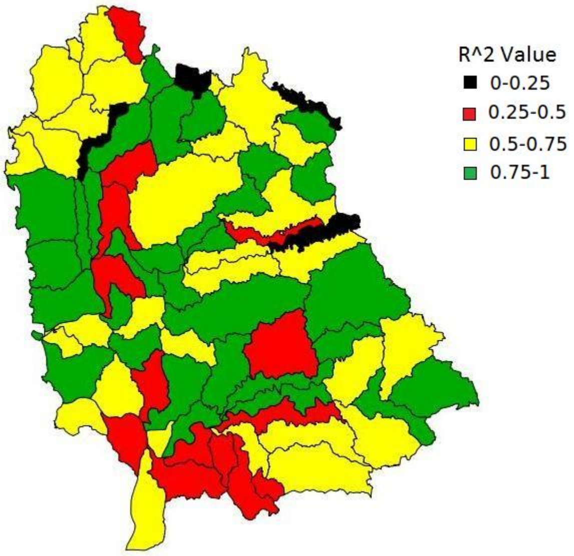


Figure 3.12: Seasonal Model R^2 Values imposed on Watershed Groupas

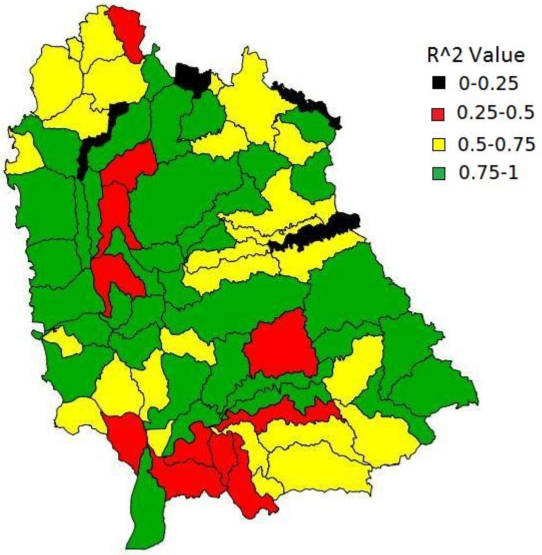


Figure 3.13: Rainfall Model R^2 Values imposed on Watershed Groupas

groundwater observation readings of at a particular well and our single well seasonal model to compute the error values and using those error values we decided the good/bad year. They use watershed level measured recharge rates and infiltration values in assessment, where we used single well readings and models in assessing the entire Mini-Water shed group. It is inappropriate to compare the results of these two mechanisms. We should come up with a procedure that uses the sufficient data to predict groundwater levels at watershed level, then we can compare our results with GSDA announcements. This will be done in future.

3.5 Summary

We began with definition, types of watersheds and examined boundary demarcations of watersheds in Thane district. We grouped Mini-Watersheds where each group contains one observation well and used that well to assess the behavior of watershed group to which it is assigned. Then we did good/bad year analysis at watershed level and verified whether our results can be compared with GSDA warnings.

Chapter 4

Hunt for Spatial Correlations

The main goal of our work is to develop spatial models. Spatial model is a form of dividing spatial area in to number of grids or polygons of similar type [16]. In general the output of a spatial model is a map that is subdivided in to number of regions, where the area that share a similar value of a particular property is grouped in to a single region. Since we are interested in groundwater behavior, we have to build these spatial models using groundwater as dividing property. Hence we divide the area in to regions, where each region has its own model to assess the groundwater which is independent of other regions. In this section we discuss our approach in finding a spatial property on which we can divide an area in to regions, with in each region groundwater behavior is similar. Using this property we can develop regional models.

4.1 Watershed Level Analysis

We first thought that watershed boundaries could be a property on which we can develop spatial models. In all watersheds, if there exists high correlations of water levels between observation wells within a watershed then we can say that groundwater follows the watershed boundaries. To verify this assumption we have computed the correlations of groundwater levels between the observation wells that are located in same watershed. We have used groundwater levels recorded by GSDA for past 30 years in 120 observation wells of Thane district.

We have computed the correlations in two methods. In first method we used GSDA observed groundwater levels of one well and model given levels of the other well to compute the correlations. That is suppose first well has observed 4 times in a year on 120th, 210th,270th and 330th day of a year(i.e June to May). We compute the groundwater levels of second well on the same days by supplying day as input to single well seasonal model of that well. This is because we may not have the observations of two wells on the same date. We repeat this process for all the years and gather the data observed data of first well and model data of second well on same days, then compute the correlation 1. Next we repeat the same procedure by interchanging the wells i.e model given values of first well and original values of second well and compute the correlation 2. Finally the average of these two correlation is the actual correlation between those two wells.

Well1	Well2	Ws-ID	Distance(km)	Method1	Method2
Durves_Dug_Well_9.6	Satiwali_Dug_Well_7.2	WF-21	3.889867	0.3974	0.624453
Musarne_Dug_Well_6	Satiwali_Dug_Well_7.2	WF-21	19.787202	0.4076015	0.635822
Durves_Dug_Well_9.6	Musarne_Dug_Well_6	WF-21	21.917641	0.9421095	0.999893
Agashi_Boling_Dug_Well_10	Mandvi_Dug_Well_9.1	WF-25	11.613958	0.8661655	0.995336
Agashi_Boling_Dug_Well_10	Pelhar_Dug_Well_7	WF-25	9.674376	0.832781	0.991388
Mandvi_Dug_Well_9.1	Pelhar_Dug_Well_7	WF-25	5.492145	0.883688	0.999398

Table 4.1: Correlations between dug wells within watershed of Thane

Well1	Well2	Distance	Method1	Method2
Agashi_Boling_Dug_Well_10	Deoli_Dug_Well_6.2	39.830845	0.857165	0.999349
Agashi_Boling_Dug_Well_10	Met_Dug_Well_8.3	28.503467	0.865985	0.978601
Agashi_Boling_Dug_Well_10	Pali_Dug_Well_6	33.905566	0.878929	0.984008
Agashi_Boling_Dug_Well_10	Musarne_Dug_Well_6	28.052064	0.872801	0.996172
Agashi_Boling_Dug_Well_10	Sange_Dug_Well_4.7	41.573339	0.873624	0.984433

Table 4.2: Agashi_Boling_Dug_Well correlation with wells of other watersheds

In second method we have computed the correlations between the model generated values of both wells. That is we take the seasonal model, probe it on 15 days interval i.e 15th, 30th, 45th, and so on days of year and collect the model given groundwater levels. Next we repeat the same procedure for the second well to collect the values. Finally we compute the correlation between these values. All our correlation results in this chapter are computed using polynomial model(without rainfall) of degree 2.The Table 4.1 shows some correlations between observations wells with in watershed, computed using above discussed two methods.

We have observed high correlations between wells with in a same watershed. For example in above Table 4.1 wells of watershed 25 has high correlations. But we have also found high correlations between wells from different watersheds. Table 4.2 shows Agashi_Boling_Dug_Well high correlations with wells of other watersheds. The average method 1 correlation between wells with in same watershed is 0.7628 and across watershed is 0.7627 in Thane district. In some watersheds, correlation is high between all the wells with in watershed, and in some watersheds it is low. After observing all these results it is clear that watersheds do not seem to determine groundwater sharing property between observation wells. All results of watershed analysis and cross watershed analysis for both Thane and Latur are available at our website [2].

4.2 Elevation Groups - Analysis

Elevation means height from mean sea level. Figure 4.1 shows the elevation of Thane district, here black color indicates low elevation and white indicates high elevation. Next we investigate if elevation of a location has any impact on groundwater levels at that location. If so can we use this elevation as a spatial property with which we can develop spatial model. To answer this we must know the impact of elevation on groundwater level. We first divided the

Well1	Well2	Distance(km)	Method1	Method2
Shendrun_Dug_Well_4.7	Talasari_Dug_Well_8	87.789223	0.474632	0.444973
Inde_Dug_Well_7.8	Talasari_Dug_Well_8	100.374036	0.583782	0.214156
Sasne_Dug_Well_8.85	Talasari_Dug_Well_8	107.35728	0.642293	0.661667
Sasne_Dug_Well_8.85	Kasa_bk_Dug_Well_6.5	85.613653	0.7284945	0.902232
Shendrun_Dug_Well_4.7	Shivale_Dug_Well_11	13.426613	0.8304255	0.976907

Table 4.3: Correlations between wells within elevation group

Well1	Well2(Elevation)	Distance	Method1	Method2
Sasne_Dug_Well_8.85	Shirgaon_Dug_Well_9(15.32)	84.321077	0.816007	0.983132
Sasne_Dug_Well_8.85	Talegaon_Dug_Well_6.1(149)	28.968629	0.825655	0.996663
Sasne_Dug_Well_8.85	Veyour_Dug_Well_10.1(15)	81.123143	0.808222	0.999097
Shendrun_Dug_Well_4.7	Thunepada_Dug_Well_5.95(133)	21.267329	0.893165	0.994849
Shendrun_Dug_Well_4.7	Varaskol_Dug_Well_7(202)	26.517092	0.886842	0.984048

Table 4.4: Correlations between wells across elevation groups

observation wells into groups, according to their elevations. That is wells between 0 to 20 m elevation as Group-1, 20 m - 40 m as Group-2 etc. Then we have computed the correlations of groundwater levels between observation wells in each group method one and method two that we have discussed in Section 4.1. Table 4.3 shows the some sample results.

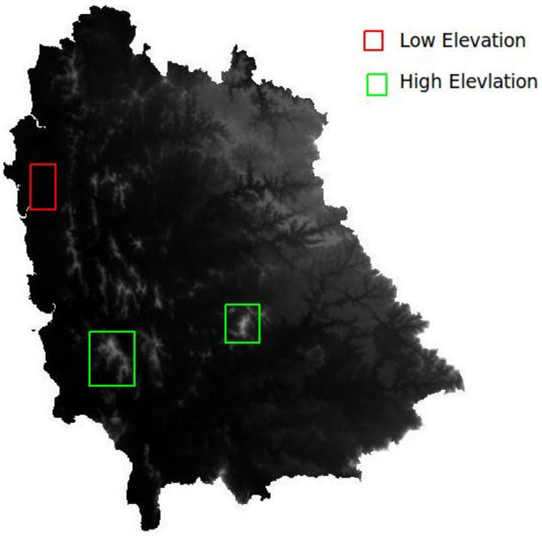


Figure 4.1: Elevation of Thane District

In Table 4.3 all wells are located in elevation range 75 m to 100 m and belongs to same group. If we observe the correlations they vary from high to low with in the same group, and across the groups as shown in Table 4.4. In Table 4.4 wells Sasne_Dug_Well_8.85, Shendrun_Dug_Well_4.7 from elevation range 75 to 100 are showing high correlations with wells of different elevations.

All the results of elevation group correlations for Latur and Thane are available here [2].

We also verified whether the groundwater levels at higher elevations are going farther down in summer than the lower elevations. We verified relationship between groundwater levels in summer with elevations. We have computed the March 31^{st} groundwater levels of wells using seasonal model and plotted them over wells elevations for both Thane and Latur. Figure 4.2 shows the groundwater level from ground on March 31^{st} and Figure 4.3 shows the how much water is available in wells on March 31^{st} i.e subtracted value of water level from depth of well. We have observed that at higher elevations some wells are completely dried (dots at zero meter in Figure 4.3) on March 31^{st} and some wells have persisted some water. From these results we can say that wells that are located at same elevation levels does not necessarily behave similarly. Graphs for Latur bore wells and thane dug wells are available in Appendix.

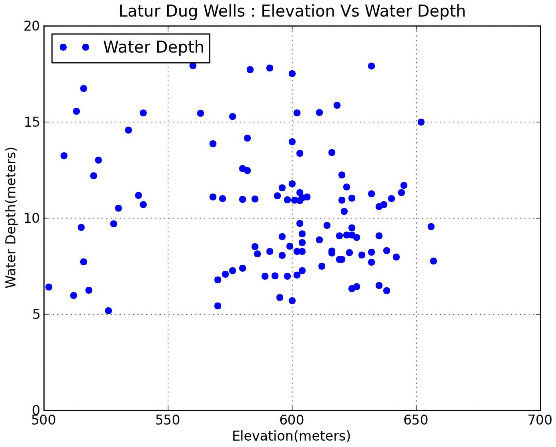


Figure 4.2: Elevation Vs Waterlevel of Latur Dug Wells

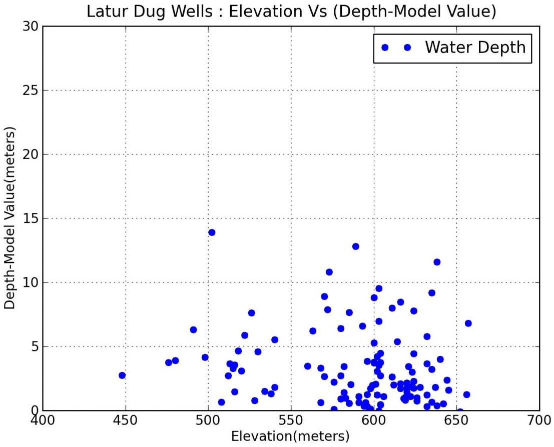


Figure 4.3: Elevation Vs (Depth - Waterlevel) of Latur Dug Wells

4.3 Natural Neighbors Analysis

Two objects are said to be natural neighbors or voronoi adjacent if there exists a location which is at same distance to both these objects and not closer to any other object. The Delaunay triangulation gives the voronoi adjacency of objects that are located in a region. The edges in Delaunay traingle represent the voronoi adjacency[15]. We investigate whether the natural neighborhood plays any role in groundwater sharing, that is do the adjacent observation wells show similar groundwater levels. If so can we group adjacent wells in to a region in which groundwater levels can be predicted using the surrounding observation wells.

In order to answer the above question we first computed the Delaunay triangulation of all observation wells. Using this we have generated the adjacency list of all observation wells. The Figure 4.4 shows the Delaunay triangulation of Thane observation wells. Then we have computed the correlations between these adjacent wells using the method one and method that we have discussed in Section 4.1. Table 4.5 shows some results.

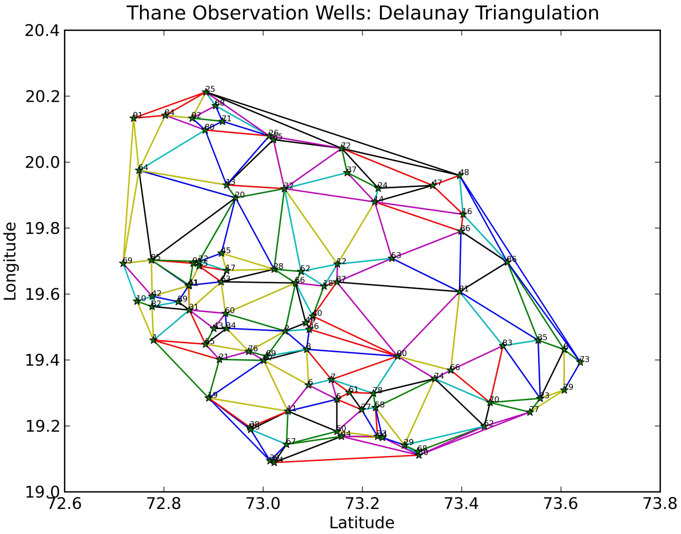


Figure 4.4: Dealaunay Triangulation of Thane Dug Wells

Well1	Well2	Distance(km)	Method1	Method2
Pimpalas_Dug_Well_6.55	Satiwali_Dug_Well_7.2	11.776794	0.2957035	0.430285
Satiwali_Dug_Well_7.2	Durves_Dug_Well_9.6	3.889867	0.3974	0.624453
Pawane_Dug_Well_5	Karav_Dug_Well_8	31.515013	0.435419	0.690293
Bapgaon_Dug_Well_7.4	Sange_Dug_Well_4.7	3.418022	0.926297	0.977967
Kanhor_Dug_Well_8.5	Tembhare_Dug_Well_5.5	23.246688	0.883206	0.999877
Thilher_Dug_Well_6.2	Akoli_Dug_Well_5.5	9.581595	0.905495	0.998412

Table 4.5: Correlations between Voronoi adjacent wells

If we observe the results, some adjacent wells are highly correlated and some are poorly correlated. If we see the relationship between the correlation and distance between adjacent wells, we can not say that closely located wells will have high correlation and wells which are located far away will have low correlation. Figure 4.5 shows the relationship between distance and correlation of adjacent observation wells. From the above results we can conclude that natural neighborhood between observation wells has no visible impact on groundwater levels of wells. Complete results of natural neighbor analysis are available at [2]

4.4 Census Data Analysis

In search of finding a hint for spatial relationship between observation wells we have verified whether there exists any pattern in census data of highly correlated adjacent wells. Is there any other site specific factor that is causing high correlation between wells. To know this we did a comparative study of census data between observation wells. As we have already mentioned in the first chapter the Census data contains information like total population, male, female, child population, SC, ST population, drinking water sources, number of wells,

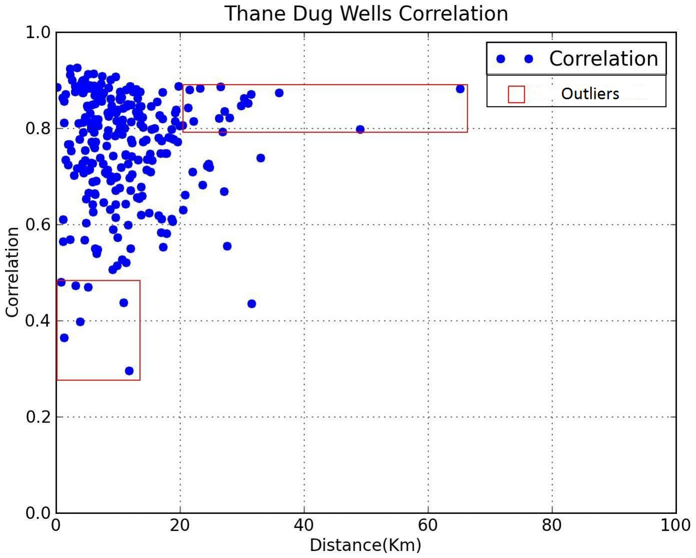


Figure 4.5: Distance Vs Correlation between adjacent Thane Dug Wells

taps, other drinking water sources, forest land, irrigation land and etc at village level. We used this information village of observation wells in which it is located. Along with above data we have also computed the distance to nearest surface water resource to each observation well and used it to find the pattern between highly correlated wells. Table 4.6 shows this comparison between two pairs of wells.

If we observe the Table 4.6 it is clear that the nearest water resource to all the observation wells is river. This is the only common factor between those pairs. Except this we haven't found any similarity between other factors of those pairs. This analysis also didn't help us in finding the factor that is influencing the groundwater correlations. We have not used the drainage information properly in our analysis. The census data at watershed level would be an interesting data to analyze i.e forest cover, land use information and etc. at watershed level. This could be a positive direction in our future work.

4.5 District Resource Map Analysis

District Resource Map is the map that contains details of rock types, minerals, land use, Geomorphological data, Geohydrological data and etc of a district. We know that groundwater levels are much depend on hydro-geological properties, rock types and structures. We thought that in a region with same rock type and structure the groundwater behavior will be same. To verify this we chosen a region in Thane district which has same rock type i.e pohoehoe one of the deccan basalt flow in upper ratanghar formation area. The box in Figure 4.6 shows this area. We have chosen the observation wells that fall in this region and computed correlations between the wells using the method one and two as discussed in Section 4.1. The Table 4.7 shows the results.

Well1	Lalthan_Dug_Well_6.4		Zhari_Dug_Well_7.4	
Well2	Nihe_Dug_Well_7		Kajali_Dug_Well_14	
Distance between wells(km)	0.189729		8.834531	
Correlateion (Method 1,2)	0.8849335, 0.999023		0.70035, 0.999998	
Elevation	59	17	39.15	57.6
Sub- Watershed ID	WF-23	WF-26	WF-12	WF-10
Near by Water source	River	River	River	River
Distance to Near Water Source(km)	0.71	0.53	26.09	5.61
Population	1078	1941	3251	869
Area (in Hectares)	417	620	1296	230
Forrest land (in Hectares)	299	252	487.89	115.72
Irrigated land (in Hectares)	0	0	9.47	1.21
Unirrigated land(in Hectares)	56	313	745.71	93.89
Area not available for cultivation	39	19	48.10	19.22

Table 4.6: Comparison of Census data between highly correlated well pairs

Well1	Well2	Distance	Method 1	Method 2
Chahade_Dug_Well_5.7	Satiwali_Dug_Well_7.2	7.58661	0.447398	0.735039
Govade_Dug_Well_6.6	Satiwali_Dug_Well_7.2	7.651724	0.451073	0.743587
Durves_Dug_Well_9.6	Musarne_Dug_Well_6	21.917641	0.94211	0.999893
Khaniwade_Dug_Well_5	Bhinar_Dug_Well_6.25	24.629979	0.922442	0.999191
Musarne_Dug_Well_6	Met_Dug_Well_8.3	2.247389	0.923762	0.992843

Table 4.7: Correlations between wells located in Pohoehoe flow region

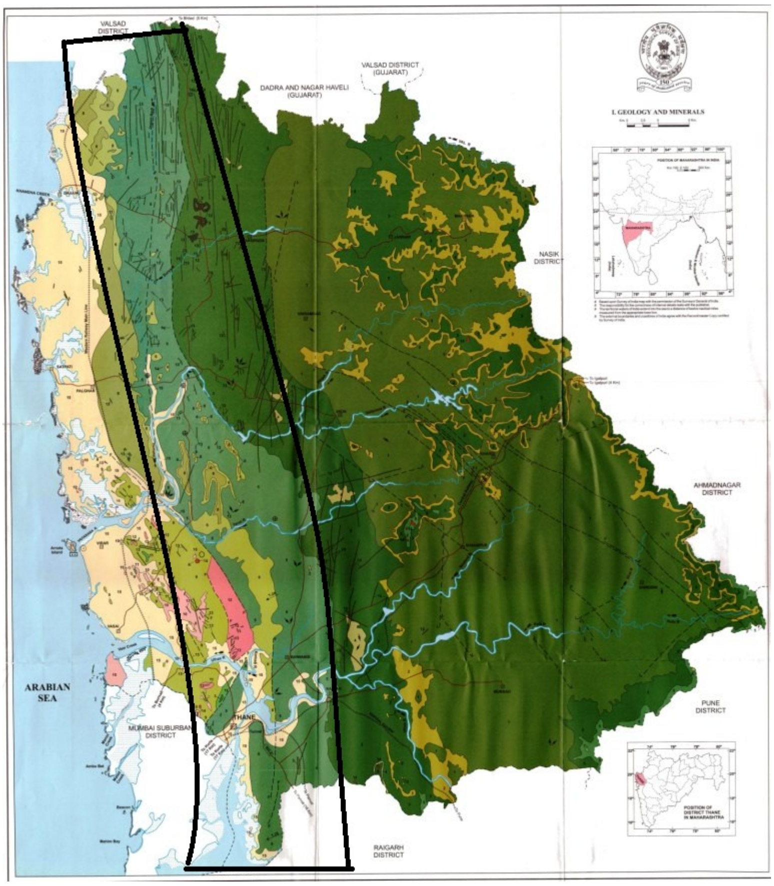


Figure 4.6: Pohoehoe rock region in Thane

From the Table 4.7, we can see that there exist some low correlations between some observation well pairs and high correlations between some pairs, where all the observation wells are from the same region with same rock type and structure. Hence we can not say that wells that are located on same rock type and structure will show similar groundwater behavior.

4.6 Water Table Contour Maps using Kriging

In this Section, we discuss the kriging interpolation technique and its usage in developing the contour maps for Thane and a selected region in Thane.

4.6.1 Kriging Interpolation Technique

Kriging is a spatial interpolation technique. To estimate a value at any arbitrary point it uses all the sample data with appropriate weights associated with them. We can use kriging to interpolate elevations, slope, rainfall and other spatial properties.

Given observations at the points $(x_i)_{i=1}^{n}$, kriging tries to arrive at an estimate for a function value at a point x_0. If Z is to be this function, the kriging method constructs (λ_i) (which depend on the point x_0 and the sequence (x_i)) and an estimator for $Z(x_0)$, viz.,$\sum_{i=1}^{n} \lambda_i Z(x_i)$.

The kriging technique prescribes these λ_i under certain assumptions.

[5] Let Z be the random function of stationary model. A random function satisfying the following conditions is said to be the stationary model.

- Constant mean i.e $E[Z(x_i)] = \mu \; i = 1, 2, ..n$
- The two point covariance function should depend only on the distance between those two points.
  $R(\|x - x^{'}\|) = R(h) = E[(Z(x) - \mu)(Z(x^{'}) - \mu)]$, where $\|x - x^{'}\|$ is the distance between $x, x^{'}$

Given n measurements of Z $x_1, x_2, ...x_n$ at different locations, Estimated value of Z at x_0 is

$$\hat{Z_0} = \sum_{i=1}^{n} \lambda_i Z(x_i)$$

Where $Z(x_i)$ is sample data at x_i,$\hat{Z_0}$ is estimated value at x_0. Now the problem is reduced to select $\lambda_1, \lambda_2, ...\lambda_n$. The difference between actual value at x_0 i.e $Z(x_0)$ and estimated value $\hat{Z_0}$ is the estimation error.

$$\hat{Z_0} - Z(x_0) \quad = (\sum_{i=1}^{n} \lambda_i Z(x_i)) - Z(x_0)$$

For a good estimator we should select the coefficients $\lambda_1, \lambda_2, ...\lambda_n$ in such a way that the estimator meets the following conditions.

- **Unbiasedness:** On the average the estimation error should be minimum. That is

  $$E[\hat{Z_0} - Z(x_0)] \quad = \sum_{i=1}^{n} \lambda_i \mu - \mu \quad = (\sum_{i=1}^{n} \lambda_i - 1)\mu \quad = 0$$

  But the value of μ is not known. For any value of μ to make the estimator unbiased it is required that $\qquad \sum_{i=1}^{n} \lambda_i = 1$

- **Minimum Variance:** The mean square estimation error must be minimum.

  $$\begin{aligned} E[(\hat{Z_0} - Z(x_0))^2] &= -\sum_{i=1}^{n}\sum_{j=1}^{n} \lambda_i \lambda_j \gamma(\|x_i - x_j\|) + 2\sum_{i=1}^{n} \lambda_i \gamma(\|x_i - x_0\|) \\ \gamma(\|x - x^{'}\|) &= \frac{1}{2} E[(Z\hat{(x)} - Z(x^{'}))^2] \end{aligned}$$

  Where γ is variogram or average of variance.

Now we have to find the values of coefficients $\lambda_1, \lambda_2, ...\lambda_n$ that minimizes the above variance expression. We can solve this problem by Lagrange multipliers. The necessary condition for the minimization are given by the linear kriging system of $n + 1$ equations with $n + 1$ unknowns.

$$-\sum_{j=1}^{n} \lambda_j \gamma(\|x_i - x_j\|) + v \quad = -\gamma(\|x_i - x_0\|) i = 1, 2, ..n$$

$$\sum_{j=1}^{n} \lambda_j = 1$$

Where v is Lagrange multiplier. We now convert the above equation in to matrix form of $Ax = b$, where

$$x = \begin{bmatrix} \lambda_1 \\ \lambda_2 \\ \vdots \\ \lambda_n \\ 1 \end{bmatrix} \qquad b = \begin{bmatrix} -\gamma(\|x_1 - x_0\|) \\ -\gamma(\|x_2 - x_0\|) \\ \vdots \\ -\gamma(\|x_n - x_0\|) \\ 1 \end{bmatrix}$$

$$A = \begin{bmatrix} 0 & -\gamma(\|x_1 - x_2\|) & \cdots & -\gamma(\|x_1 - x_n\|) & 1 \\ -\gamma(\|x_2 - x_1\|) & 0 & \cdots & -\gamma(\|x_2 - x_n\|) & 1 \\ \vdots & \vdots & & \vdots & \vdots \\ -\gamma(\|x_n - x_1\|) & -\gamma(\|x_n - x_2\|) & \cdots & 0 & 1 \\ 1 & 1 & \cdots & 1 & 0 \end{bmatrix}$$

By solving the above matrix equation we will get the coefficients $\lambda_1, \lambda_2, ...\lambda_n$. Using this coefficients we can estimate the Z at any location x_0.

4.6.2 Water Table Contours

A topographic map or contour map is a detailed and accurate graphical representation of natural features on the ground. Generally elevations, groundwater levels, forest cover, pollution density etc are well represented using contour maps. We have used Surfer software to develop contour maps of groundwater. Surfer uses kriging technique in developing the contour maps. We have generated the contour maps of groundwater levels for entire Thane district using 120 observation wells data. We first converted the depth to groundwater level in to height from sea level. i.e we have subtracted the groundwater level values from elevations of wells, thus we got the groundwater elevations. Like this we have computed the groundwater elevations of all wells. Using this data we have generated the groundwater levels contour map of Thane district.

Kriging interpolation may or may not provide accurate results in interpolating the groundwater. This is because it uses all the sample data in estimating at some point assuming that every sample point will show some impact in computing the value at that point. This may be true for elevation, rainfall and other factors. But in case of groundwater interpolation at a point x, sample points that are tapping the same aquifer that x is tapping will show some impact, the other samples that are not tapping the same aquifer do not show any impact. While interpolating the groundwater levels if all sample points are located in same aquifer and we estimate a point with in the same aquifer then kriging will provide good estimations.

Considering this we have chosen a region (The square in Figure 4.7) in thane where six observation wells are showing similar groundwater levels and we observed that groundwater elevations for these wells are varying between 100 m to 150 m. so we assumed that these wells are tapping the same aquifer and generated the contour maps for this region. Figures 4.8, 4.9, 4.10 and 4.11 shows the groundwater levels on dates 1991-10-31, 1992-01-31, 1992-03-31 and 1992-05-31 respectively of selected region. If we observe these maps the water levels are dropping evenly in entire region i.e 4 m drop in water levels from 1991-10-31 to 1992-05-31 in entire region. This strengthens our assumption that the region is tapping the same aquifer. We can observe that the water table is moving towards the right most bottom of the region which is south west. In Figure 4.7 the drainage in selected region is flowing towards the south west direction, hence the underlying ground water is also following the same.

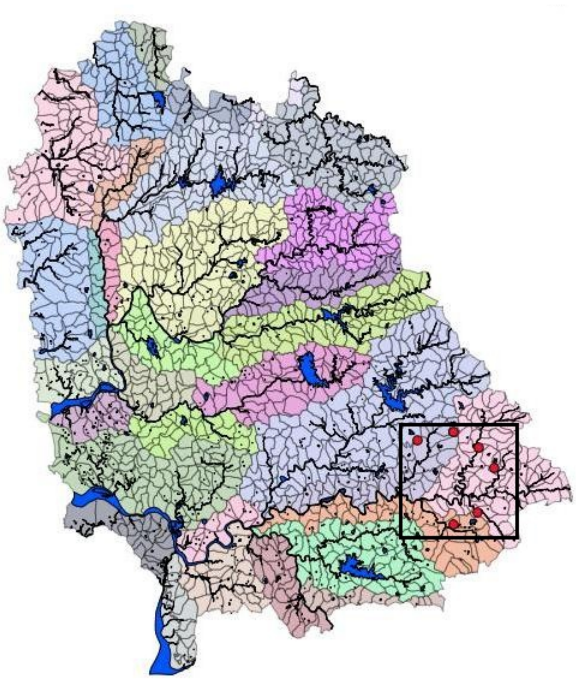


Figure 4.7: Region in which observation wells are showing the similar Groundwater Behavior

4.7 Summary

Our intention in this chapter is to find a spatial parameter which can define the spatial relationship between observation wells and can be used to develop spatial models. We first verified the behavior of wells with in a watershed. Then we divided wells in to elevation groups and computed the correlations within the groups. We also compared the behavior of natural neighbor wells using Delaunay triangulations. We observed high correlations between wells with in the same group and also across the groups. Table C.1 shows the average correlations of all these techniques. We also compared site specific census data of high correlated wells, except the near by river no parameter has shown any significance. We selected a wells from “pohoehoe rock region ”and compared the behavior i.e. some wells have shown high correlations and some have shown low correlations. Finally, we used kriging to develop contours in a selected region and found that entire region is located above the same aquifer. Due to mixed results in our attempts to find the ground water sharing spatial parameter we can’t commit to any particular spatial property yet.

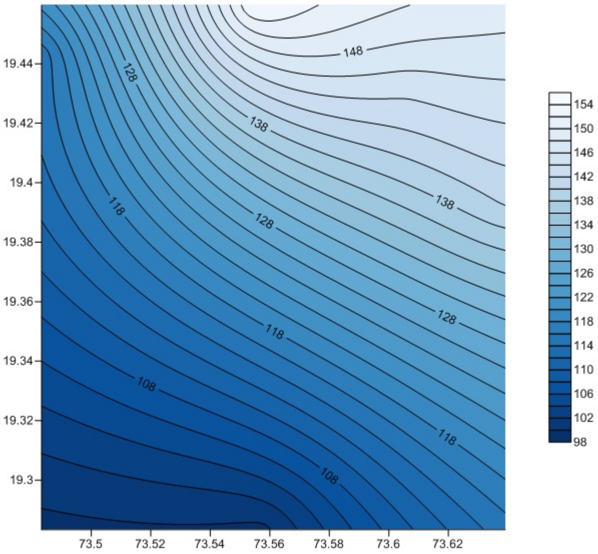


Figure 4.8: Water Levels on 1991-10-31 of Selected Region

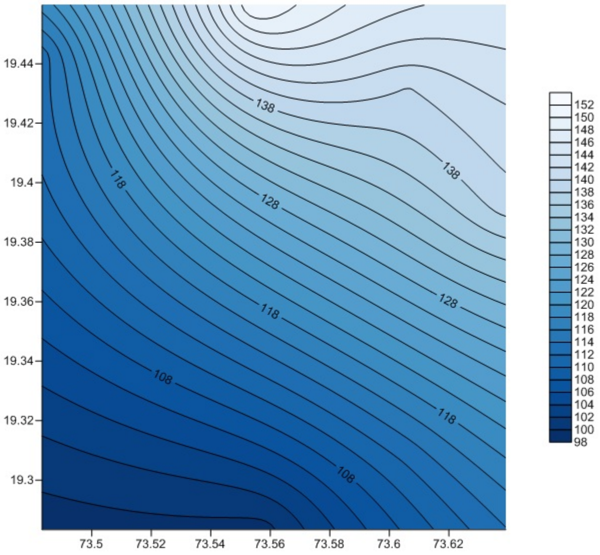


Figure 4.9: Water Levels on 1992-01-31 of Selected Region

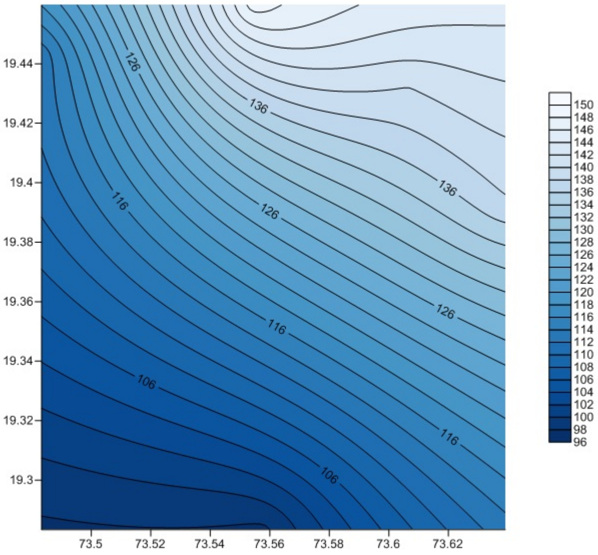


Figure 4.10: Water Levels on 1992-03-31 of Selected Region

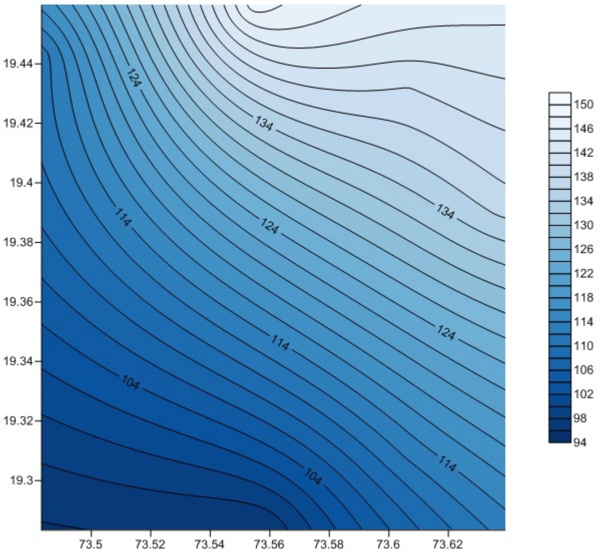


Figure 4.11: Water Levels on 1992-05-31 of Selected Region

Chapter 5

Conclusion and Future Work

5.1 Conclusion

- In [6] thesis, we saw the analysis of single wells and the conclusions that could be drawn. In this thesis, we have considered the spatial and the broader temporal aspects of the groundwater data. Our first observation is in the good/bad year classification. We have seen that the counter-cyclical errors (i.e., positive errors in a bad year and negative errors in a good year) are small as compared to the overall error. This leads to an important conclusion that our single well seasonal models systematically underestimate levels in a good year and overestimate levels in a bad year. The analysis also seems to indicate that some important factor is as yet uncovered.

- The good/bad year does correlate well with the observed rainfall, especially in deep aquifer areas with moderate rainfall. This coupled with the above analysis indicates that location specific good/bad predictions may be made by observing the initial readings of the year.

- Our second attempt was to extend groundwater readings from a specific location to a region. We chose watersheds as the natural such unit. We studied the current watershed delineations and created a well-to-region map.

- However, our attempt to correlate levels of wells within the same watershed did not yield positive results. Moreover, nor was there observed correlation with distance of elevation. However, results in the literature do indicate such a correlation. This indicates perhaps that the density of observation wells is too little.

- Overall, in our opinion, our single well model is an important first step in the analysis of groundwater. Getting the R^2 values to 0.8 will require us to understand many factors which are related to geology and regional use by residents. These will play a crucial role in building spatial models which will have a greatly enhanced predictive value than our models. As of now, the models are more indicative of the trend than of exact levels and can address some of the broader predictive needs of GSDA. For village specific modeling especially for regulation, there needs to be finer data, and studies which analyze two proximate wells.

5.2 Future Work

- To enhance the single well seasonal model quality in assessment, future work could be to use (i) the first reading of the year, and/or (ii) the previous year's summer reading, as something to regress on. These may model the use of groundwater in the locality, for example in irrigation.
- In our work kriging interpolation technique and its effectiveness in groundwater estimation hasn't explored fully. It could be used to estimate the groundwater levels of nearby wells.
- Assessment of groundwater levels in a watershed group using a single observation well is not fair approach. Future work could be develop a technique that uses the data from multiple observation wells to estimate at watershed.
- Currently density of observation wells is very sparse. In future to understand the spatial relationship one approach could be select a region with proper density of wells and do the extensive analysis to understand the groundwater regime.
- We haven't used the drainage data properly. Better understanding the drainage system and its use along with watershed level census data (land cover, forest land and etc at watershed level) will be a positive future direction in search of spatial relationship between wells.
- Current work didn't concentrate on aquifer boundaries, infiltration, specific yield and other hydro-geological properties. Use of this data will definitely improve the quality regional models.

Appendix A

Census Attribute Table

ST_CODE	STATE CODE
DIST_CODE	DISTRICT CODE
THSIL_CODE	TAHSIL/TALUK CODE
BLOCK_CODE	C.D. BLOCK CODE
V_CT_CODE	VILLAGE CODE
VILL_NAME	VILLAGE NAME
AREA	Area of Village (in hectares)
Population data based on 2001 Census	
T_HH	Number of Households
T_P	Total population- Persons
T_M	Total population- Males
T_F	Total population- Females
SC_P	Scheduled Castes population- Persons
SC_M	Scheduled Castes population- Males
SC_F	Scheduled Castes population- Females
ST_P	Scheduled Tribes population- Persons
ST_M	Scheduled Tribes population- Males
ST_F	Scheduled Tribes population- Females
Amenities data	
EDU_FAC	Educational facilities (A/NA)
	If not available range code is to be provided for primary school middle school and collage
P_SCH	Number of Primary School

RANG_P_SCH	If not available Provide the Range Code
M_SCH	Number of Middle School
RANG_M_SCH	If not available Provide the Range Code
S_SCH	Number of Secondary School
S_S_SCH	Number of Senior Secondary School
COLLEGE	Number of Collage
RANG_COLL	If not available Provide the Range Code
IND_SCH	Number of Industrial School
TR_SCH	Number of Training School
ADLT_LT_CT	Number of Adult literacy Class/Centre
OTH_SCH	Number of Other educational facilities
MEDI_FAC	Medical facilities (A/NA)
	If not available Range Code is to be provided for Allopathic hospital Maternity and Child Welfare Centre and Primary Health Centre
ALL_HOSP	Number of Allopathic Hospital
RANG_ALL	If not available Provide the Range Code
AYU_HOSP	Number of Ayurvedic Hospital
UN_HOSP	Number of Unani Hospital
HOM_HOSP	Number of Homeopathic Hospital
ALL_DISP	Number of Allopathic Dispensary
AYU_DISP	Number of Ayurvedic Dispensary
UN_DISP	Number of Unani Dispensary
HOM_DISP	Number of Homeopathic Dispensary
MCW_CNTR	Number of Maternity and Child Welfare Centre
RANG_MCW	If not available Provide the Range Code
M_HOME	Number of Maternity Home

CWC	Number of Child Welfare Centre
H_CNTR	Number of Health Centre
PH_CNTR	Number of Primary Health Centre
RANG_PHC	If not available Provide the Range Code
PHS_CNT	Number of Primary Health Sub Centre
FWC_CNTR	Number of Family Welfare Centre
TB_CLN	Number of T.B. Clinic
N_HOME	Number of Nursing Home
RMP	Number of Registered Private Medical Practiotioners
SMP	Number of Subsidised Medical Practitioners
CHW	Number of Community Health workers
OTH_CNTR	Number of Other medical facilities
DRNK_WAT_F	Drinking Water facility (A/NA)
RANG_WAT_F	If not available Provide the Range Code
TAP	Tap Water (T)
WELL	Well Water (W)
TANK	Tank Water (TK)
TUBEWELL	Tubewell Water (TW)
HANDPUMP	Handpumb (HP)
RIVER	River Water(R)
CANAL	Canal (C)
LAKE	Lake (L)
SPRING	Spring (S)
OTHER	Other drinking water sources (O)
SOU_SUMM	Source of Drinking Water during Summer (indicate code from above)
RANG_SS	If not available Provide the Range Code
SS_CODE	Source code from above as applicable

P_T_FAC	Post Telegraph and Telephone facilities (A/NA) if available
POST_OFF	Number of Post Office
RANG_PO	If not available Provide the Range Code
TELE_OFF	Number of Telegraph Office
POST_TELE	Number of Post and Telegraph Office
PHONE	Number of Telephone connections
RANG_PHONE	If not available Provide the Range Code
COMM_FAC	Communication (Y/N)
BS_FAC	Bus services
RANG_BS	If not available Provide the Range Code
RS_FAC	Railways services
RANG_RS	If not available Provide the Range Code
NW_FAC	Navigable water way including River Canal etc.
RANG_NW	If not available Provide the Range Code
BANK_FAC	Banking facility (Y/N)
COMM_BANK	Number of Commercial Bank
RANG_COMM	If not available Provide the Range Code
COOP_BANK	Number of Co-operative Commercial Bank
RANG_COOP	If not available Provide the Range Code
CRSOC_FAC	Credit Societies (Y/N)
AC_SOC	Number of Agricultural Credit Societies
RANG_ACS	If not available Provide the Range Code
NAC_SOC	Number of Non Agricultural Credit Societies
RANG_NAC	If not available Provide the Range Code
OTHER_SOC	Number of Other Credit Societies
RANG_OTH	If not available Provide the Range Code

RC_FAC	Recreational and Cultural facilities (Y/N)
C_V_HALL	Number of Cinema/Video-hall
RANG_CV	If not available Provide the Range Code
SP_CL_FAC	Number of Sports Club
RANG_SPCL	If not available Provide the Range Code
ST_AU_FAC	Number of Stadium/Auditorium
RANG_STAU	If not available Provide the Range Code
	Approach to Village (Y/N)
APP_PR	Approach - Paved Road
APP_MR	Approach - Mud Road
APP_FP	Approach - Foot Path
APP_NAVRIV	Approach - Navigable River
APP_NAVCAN	Approach - Navigable Canal
APP_NW	Approach - Navigable water-way other than river or canal
NEAR_TOWN	Nearest Town
DIST_TOWN	Distance from the nearest Town (in Kilometer(s))
POWER_SUPL	Power supply (A/NA)
POWER_DOM	Electricity for Domestic use
POWER_AGR	Electricity of Agricultural use
POWER_OTH	Electricity of other purposes
POWER_ALL	Electricity for all purposes
PAP_MAG	News paper/Magazine (Y/N)
NEWS_PAP	News Paper (Indicate N if arrived)
MAGAZINE	Magazine (indicate M if arrived)
	Income and Expenditure of the village (in Rs.' 00)
A_INCEXP	Separate figures available (Y/N) if Yes:
TOT_INC	Total Income
TOT_EXP	Total Expenditure
	Most Important Commodities manufactured
MAN_COMM1	Manufactured Item No. 1
MAN_COMM2	Manufactured Item No. 2

MAN_COMM3	Manufactured Item No. 3
	Land use i.e. area under different types (rounded upto two decimal places) in hectares
LAND_FORES	Forest
	Irrigated (by source)
CANAL_GOVT	Government Canal
CANAL_PVT	Private Canal
WELL_WO_EL	Well (without electricity)
WELL_W_EL	Well (with electricity)
TW_WO_EL	Tube-well (without electricity)
TW_W_EL	Tube-well (with electricity)
TANK_IRR	Tank
RIVER_IRR	River
LAKE_IRR	Lake
W_FALL	Waterfall
OTH_IRR	Others
TOT_IRR	Total Irrigated Area
UN_IRR	Unirrigated Area
CULT_WASTE	Culturable waste (including gauchar and groves)
AREA_NA_CU	Area not available for cultivation

Table A.1: Attributes of Census Data

Appendix B

Elementary Global Analysis Results

B.1 Good Bad Year Analysis Results

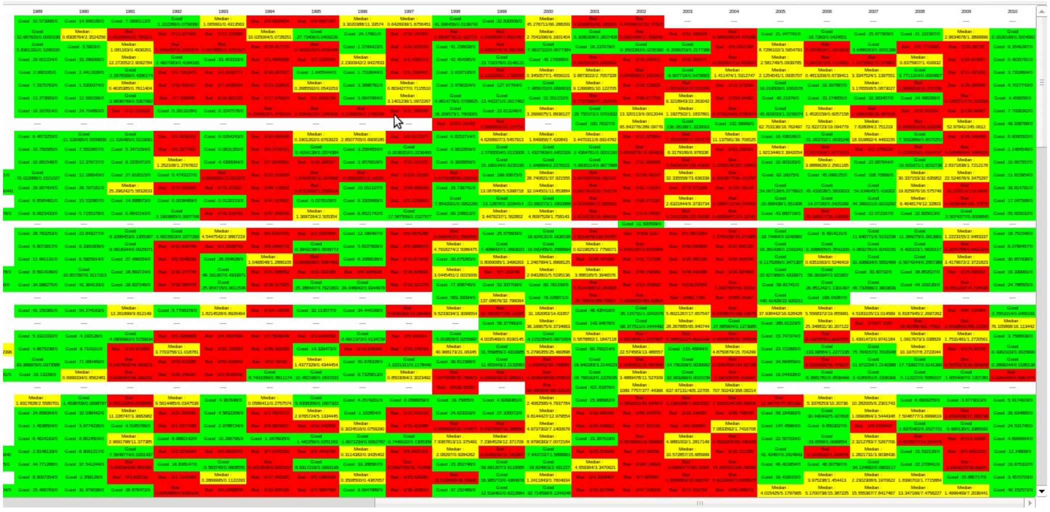


Figure B.1: Good Bad values over the years of Latur With Polynomial Model

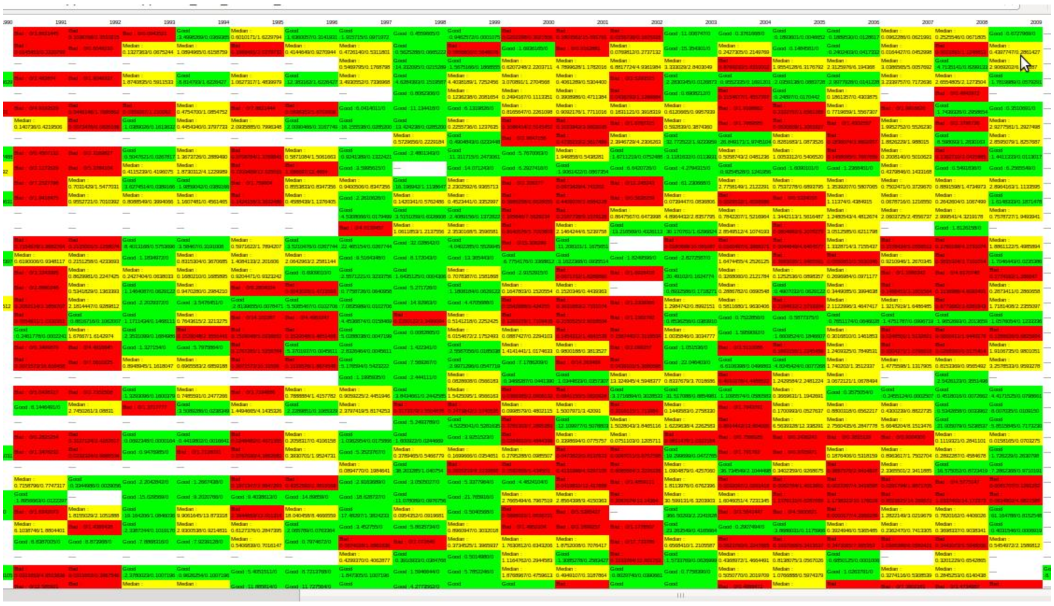
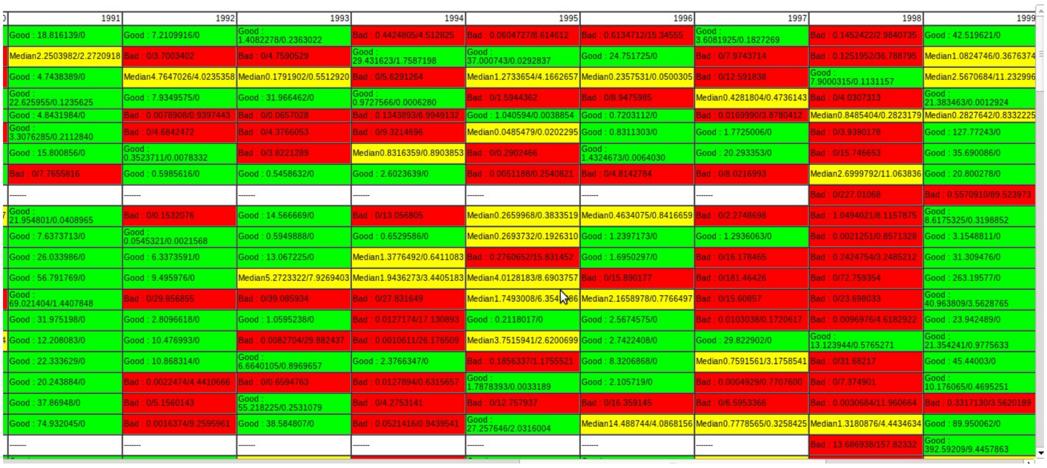


Figure B.2: Good Bad values over the years of Thane With Polynomial Model



1991	1992	1993	1994	1995	1996	1997	1998	1999
Good : 18.816139/0	Good : 7.2109916/0	Good : 1.4082278/0.2363022	Bad : 0.4424805/4.512825	Bad : 0.0604727/8.614612	Bad : 0.6134712/15.34555	Good : 3.6081925/0.1827269	Bad : 0.1452422/2.9840735	Good : 42.519621/0
Median2.2503982/2.2720918	Bad : 0/3.7003402	Bad : 0/4.7590529	Good : 29.431623/1.7587198	Good : 37.000743/0.0292837	Good : 24.751725/0	Bad : 0/7.9743714	Bad : 0.1251952/36.788795	Median1.0824746/0.3676374
Good : 4.7438389/0	Median4.7647026/4.0235358	Median0.1791902/0.5512920	Bad : 0/5.6291264	Median1.2733654/4.1662657	Median0.2357531/0.0500305	Bad : 0/12.591838	Good : 7.9000315/0.1131157	Median2.5670684/11.232996
Good : 22.625955/0.1235625	Good : 7.9349575/0	Good : 31.966462/0	Good : 0.9727566/0.0006280	Bad : 0/1.5944362	Bad : 0/8.9475985	Median0.4281804/0.4736143	Bad : 0/4.0307313	Good : 21.383463/0.0012924
Good : 4.8431984/0	Bad : 0.0078908/0.9397443	Bad : 0/0.0657028	Bad : 0.1343893/6.9949132	Good : 1.040594/0.0038854	Good : 0.7203112/0	Bad : 0.0169990/3.8780412	Median0.8485404/0.2823179	Median0.2827642/0.8332225
Good : 3.3076285/0.2112840	Bad : 0/4.6842472	Bad : 0/4.3766053	Bad : 0/9.3214696	Median0.0485479/0.0202295	Good : 0.8311303/0	Good : 1.7725006/0	Bad : 0/3.9390178	Good : 127.77243/0
Good : 15.800856/0	Good : 0.3523711/0.0078332	Bad : 0/3.8221289	Median0.8316359/0.8903853	Bad : 0/0.2902466	Good : 1.4324673/0.0064030	Good : 20.293353/0	Bad : 0/15.746653	Good : 35.690086/0
Bad : 0/7.7655816	Good : 0.5985616/0	Good : 0.5458632/0	Good : 2.6023639/0	Bad : 0.0051188/0.2540821	Bad : 0/4.8142784	Bad : 0/8.0216993	Median2.6999792/11.063836	Good : 20.800278/0
--------	--------	--------	--------	--------	--------	--------	Bad : 0/227.01068	Bad : 0.5570910/89.523973
Good : 21.954801/0.0408965	Bad : 0/0.1532076	Good : 14.566669/0	Bad : 0/13.056805	Median0.2659968/0.3833519	Median0.4634075/0.8416659	Bad : 0/2.2748698	Bad : 1.0494021/8.1157875	Good : 8.6175325/0.3198852
Good : 7.6373713/0	Good : 0.0545321/0.0021568	Good : 0.5949888/0	Good : 0.6529586/0	Median0.2693732/0.1926310	Good : 1.2397173/0	Good : 1.2936063/0	Bad : 0.0021251/0.8571328	Good : 3.1548811/0
Good : 26.033986/0	Good : 6.3373591/0	Good : 13.067225/0	Median1.3776492/0.6411083	Bad : 0.2760652/15.831452	Good : 1.6950297/0	Bad : 0/16.178465	Bad : 0.2424754/3.2485212	Good : 31.309476/0
Good : 56.791769/0	Good : 9.495976/0	Median5.2723322/7.9269403	Median1.9436273/3.4405183	Median4.0128183/8.6903757	Bad : 0/15.890177	Bad : 0/181.46426	Bad : 0/72.759354	Good : 263.19577/0
Good : 69.021404/1.4407848	Bad : 0/29.856855	Bad : 0/39.085934	Bad : 0/27.831649	Median1.7493008/6.354[illegible]86	Median2.1658978/0.7766497	Bad : 0/15.60857	Bad : 0/23.698033	Good : 40.963809/3.5628765
Good : 31.975198/0	Good : 2.8096618/0	Good : 1.0595238/0	Bad : 0.0127174/17.130893	Good : 0.2118017/0	Good : 2.5674575/0	Bad : 0.0103038/0.1720617	Bad : 0.0096976/4.6182922	Good : 23.942489/0
Good : 12.208083/0	Good : 10.476993/0	Bad : 0.0082704/29.882437	Bad : 0.0010611/26.176509	Median3.7515941/2.6200699	Good : 2.7422408/0	Good : 29.822902/0	Good : 13.123944/0.5765271	Good : 21.354241/0.9775633
Good : 22.333629/0	Good : 10.868314/0	Good : 6.6640105/0.8969657	Good : 2.3766347/0	Bad : 0.1856337/1.1755521	Good : 8.3206868/0	Median0.7591561/3.1758541	Bad : 0/31.68217	Good : 45.44003/0
Good : 20.243884/0	Bad : 0.0022474/4.4410666	Bad : 0/0.6594763	Bad : 0.0127894/0.6315657	Good : 1.7878393/0.0033189	Good : 2.105719/0	Bad : 0.0004929/0.7707600	Bad : 0/7.374901	Good : 10.176065/0.4695251
Good : 37.86948/0	Bad : 0/5.1560143	Good : 55.218225/0.2531079	Bad : 0/4.2753141	Bad : 0/12.757937	Bad : 0/16.359145	Bad : 0/6.5953366	Bad : 0.0030684/11.960664	Bad : 0.3317130/3.5620189
Good : 74.932045/0	Bad : 0.0016374/9.2595961	Good : 38.584807/0	Bad : 0.0521416/0.9439541	Good : 27.257646/2.0316004	Median14.488744/4.0868156	Median0.7778565/0.3258425	Median1.3180876/4.4434634	Good : 89.950062/0
--------	--------	--------	--------	--------	--------	--------	Bad : 13.686938/157.82332	Good : 392.59209/9.4457863

Figure B.3: Good Bad values over the years of Latur With Rainfall Model

B.1.1 Global Good/Bad Year Results

Year	Total Good	Total Bad	Good - Bad	Label
1975	0.1337858	0.626927	-0.4931412	BAD
1976	0.9945325	0.0568191	0.9377134	GOOD
1977	16.239672	17.020615	-0.780943	BAD
1978	26.137345	7.4074056	18.7299394	GOOD
1979	18.252065	14.073285	4.17878	GOOD
1980	18.675719	35.811256	-17.135537	BAD

1981	17.843951	15.929847	1.914104	GOOD
1982	20.37555	21.915801	-1.540251	BAD
1983	39.776405	42.297022	-2.520617	BAD
1984	18.710392	17.820794	0.889598	GOOD
1985	20.615127	34.914017	-14.29889	BAD
1986	7.8067093	61.805381	-53.9986717	BAD
1987	8.4898746	47.140982	-38.6511074	BAD
1988	15.421222	25.347461	-9.926239	BAD
1989	10.26761	33.209183	-22.941573	BAD
1990	24.772176	9.9296495	14.8425265	GOOD
1991	29.555873	83.374236	-53.818363	BAD
1992	34.502314	66.82016	-32.317846	BAD
1993	69.798209	24.56779	45.230419	GOOD
1994	50.225499	34.702623	15.522876	GOOD
1995	19.708159	87.921592	-68.213433	BAD
1996	56.627346	47.212031	9.415315	GOOD
1997	122.1914	25.468061	96.723339	GOOD
1998	171.35803	26.137216	145.220814	GOOD
1999	116.08434	23.124613	92.959727	GOOD
2000	69.782349	87.31481	-17.532461	BAD
2001	49.834118	83.478166	-33.644048	BAD
2002	29.056328	118.11933	-89.063002	BAD
2003	216.24158	40.631295	175.610285	GOOD
2004	70.083822	61.730418	8.353404	GOOD
2005	31.083266	53.699758	-22.616492	BAD
2006	43.758553	53.241167	-9.482614	BAD
2007	23.15531	44.738741	-21.583431	BAD
2008	71.20773	52.447498	18.760232	GOOD
2009	82.815991	38.869928	43.946063	GOOD
2010	7.5900349	0	7.5900349	GOOD

Table B.1: Year wise Good/Bad Analysis for Thane

Year	Total Good	Total Bad	Good -Bad	Label
1975	202.47772	143.53161	58.94611	GOOD
1976	88.461939	232.33776	-143.875821	BAD
1977	47.11167	472.01445	-424.90278	BAD
1978	118.12097	268.38234	-150.26137	BAD
1979	73.67015	276.28626	-202.61611	BAD
1980	57.361463	127.19525	-69.833787	BAD
1981	45.068406	229.83967	-184.771264	BAD
1982	47.835274	257.4349	-209.599626	BAD
1983	156.33103	66.792224	89.538806	GOOD
1984	114.04033	203.1593	-89.11897	BAD

1985	16.357625	181.43029	-165.072665	BAD
1986	12.392019	987.08895	-974.696931	BAD
1987	69.916369	154.82111	-84.904741	BAD
1988	237.25437	48.226209	189.028161	GOOD
1989	1040.4946	17.691196	1022.803404	GOOD
1990	933.14723	8.5155562	924.6316738	GOOD
1991	507.5589	369.94899	137.60991	GOOD
1992	135.48005	446.44217	-310.96212	BAD
1993	237.1058	368.29595	-131.19015	BAD
1994	48.25768	1215.2763	-1167.01862	BAD
1995	300.31916	239.05062	61.26854	GOOD
1996	446.56428	77.798066	368.766214	GOOD
1997	75.444607	946.79267	-871.348063	BAD
1998	744.40502	461.44798	282.95704	GOOD
1999	689.06344	872.81259	-183.74915	BAD
2000	586.3261	959.0896	-372.7635	BAD
2001	827.5085	868.75434	-41.24584	BAD
2002	566.20356	3523.7738	-2957.57024	BAD
2003	646.97898	1699.206	-1052.22702	BAD
2004	566.04018	1829.9284	-1263.88822	BAD
2005	2127.6491	331.51766	1796.13144	GOOD
2006	1393.884	518.67269	875.21131	GOOD
2007	582.06047	1049.7806	-467.72013	BAD
2008	1609.4438	1056.175	553.2688	GOOD
2009	418.0159	1715.9782	-1297.9623	BAD
2010	1678.998	183.7955	1495.2025	GOOD

Table B.2: Year wise Good/Bad Analysis for Latur

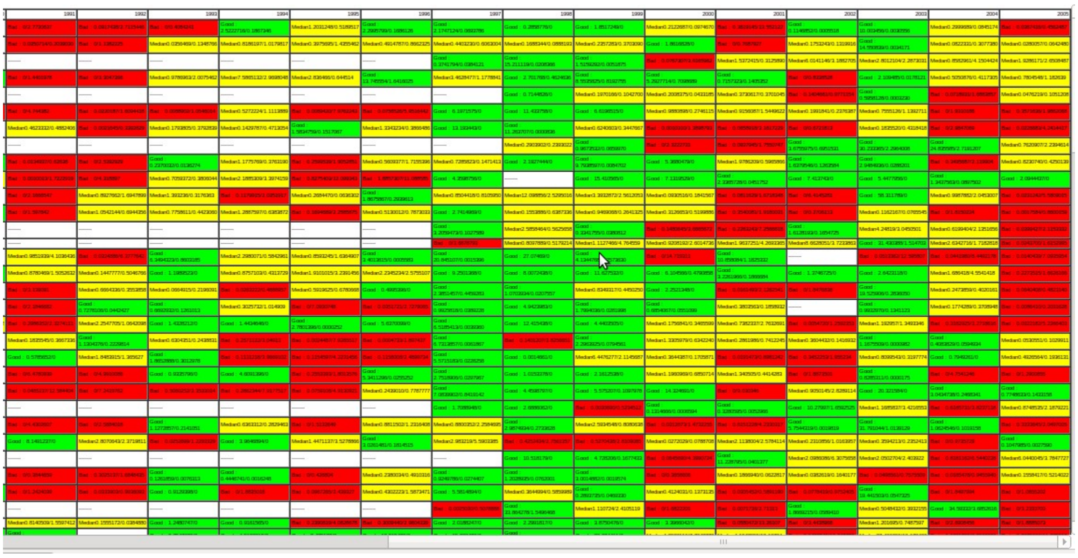


Figure B.4: Good Bad values over the years of Thane With Rainfall Model

B.2 Significance Of Good/Bad Values on R^2 values

village	Polynomial Model	Rainfall Model
Agashi_Boling_Dug_Well_10	0.6271242	0.6510139
Akoli_Dug_Well_5.5	0.7262411	0.7358774
Ambiste_kh_Bore_Well_17	0.8589014	0.8835335
Awale_Dug_Well_7.35	0.8328803	0.841312
Badlapur_Bore_Well_30	0.4877849	0.5221814
Badlapur_Dug_Well_7.95	0.3848814	0.388347
Bapgaon_Dug_Well_7.4	0.8711035	0.8845438
Bhatsai_Bore_Well_18	0.3028709	0.3260892
Bhinar_Dug_Well_6.25	0.8292937	0.8499378
Borivali_T_Padgha_Dug_Well_10.6	0.5161599	0.529898
Bursunge_Dug_Well_8.65	0.7408089	0.7874082
Chahade_Dug_Well_5.7	0.870772	0.8736838
Chavindra_Bore_Well_13.5	0.8559873	0.889361
Chndansar_Bore_Well_24	0.731444	0.781102
Dahisar_Dug_Well_9.5	0.7648706	0.7664238
Dapode_Dug_Well_5.25	0.5457258	0.5732979
Deoli_Dug_Well_6.2	0.7896029	0.795212
Dhanivri_Dug_Well_5.5	0.7984613	0.8134596
Dhanoshi_Dug_Well_6.5	0.770056	0.7738362
Dhuktan_Dug_Well_6.1	0.8219456	0.8447702
Dolhare_Dug_Well_5.5	0.8033087	0.8128984
Durves_Dug_Well_9.6	0.9004203	0.9021983
Gates_Bk_Dug_Well_7.5	0.6983489	0.7249018

village	Polynomial Model	Rainfall Model
Ghansoli_Bore_Well_12.7	0.7124353	0.7617074
Ghodbandar_Dug_Well_8.2	0.6265196	0.6353988
Ghol_Dug_Well_10.4	0.2887625	0.3080064
Gokhiware_Bore_Well_18	0.9051068	0.9186675
Gokhiware_Dug_Well_5.5	0.71382	0.7494071
Govade_Dug_Well_6.6	0.7576133	0.758067
Goveli_Bore_Well_17.25	0.54869	0.5943489
Inde_Dug_Well_7.8	0.6056734	0.6109089
Jawhar_Dug_Well_7.65	0.5087791	0.5141589
Kajali_Dug_Well_14	0.3367222	0.3379075
Kalamdevi_Dug_Well_5.5	0.6224004	0.6561725
Kambe_Dug_Well_6.9	0.4444535	0.4795193
Kanchad_Bore_Well_18	0.8644606	0.8885406
Kanchad_Dug_Well_7.5	0.8768661	0.9005844
Kanhor_Dug_Well_8.5	0.7882911	0.8042779
Karav_Dug_Well_8	0.1632565	0.1895069
Karvele_Dug_Well_6.3	0.291439	0.2917039
Kasa_bk_Dug_Well_6.5	0.7739379	0.7766442
Katrap_Dug_Well_3.1	0.4376605	0.442862
Khaniwade_Dug_Well_5	0.8998362	0.9141445
Kharade_Dug_Well_8.2	0.5509675	0.5639737
Khodala_Dug_Well_5.8	0.5137655	0.5328543
Kogde_Dug_Well_7	0.8260521	0.8284839
Kopar_Karane_Dug_Well_4.7	0.5339688	0.5387726
Kopari_Dug_Well_7.55	0.2770935	0.4029002
Kudan_Bore_Well_30	0.6950237	0.7433341
Kudus_Dug_Well_6	0.8272861	0.8461353
Lalthan_Dug_Well_6.4	0.7682949	0.7827106
Mahim_Bore_Well_20	0.8306836	0.8395158
Makunsar_Dug_Well_9.8	0.8114041	0.8147035
Mandawa_Bore_Well_30	0.3796041	0.5051498
Mandvi_Dug_Well_9.1	0.842756	0.8560269
Mangrul_Dug_Well_7.6	0.4559383	0.4843877
Manor_Dug_Well_7	0.4526686	0.474363
Met_Dug_Well_8.3	0.852923	0.8583244
Mokhada_Dug_Well_9	0.703321	0.7080539
Morhande_Dug_Well_5.1	0.7704008	0.7832691
Musarne_Dug_Well_6	0.8758711	0.8978713
Nare_Bore_Well_18	0.9327665	0.942
Neharoli_Bore_Well_24	0.5263182	0.6806413
Newale_Dug_Well_8.2	0.5560998	0.5664686
Nihe_Dug_Well_7	0.7595795	0.7836614
Nimbavali_Bore_Well_30	0.7127208	0.7675683
Padgha_Bore_Well_30	0.7646035	0.7797427

village	Polynomial Model	Rainfall Model
Palghar_kolgaon_Bore_Well_30	0.8474375	0.8733791
Pali_Dug_Well_6	0.8983412	0.9022613
Parli_Dug_Well_5.1	0.6005649	0.618679
Pawane_Dug_Well_5	0.432239	0.4498261
Pelhar_Dug_Well_7	0.7736241	0.7798413
Pimpalas_Dug_Well_6.55	0.7148802	0.7281179
Pimpalshet_Dug_Well_8.5	0.7292415	0.7515184
Rayta_Dug_Well_4	0.5930637	0.6044533
Safala_Dug_Well_10.5	0.8166724	0.8326102
Safale_Bore_Well_25.9	0.8825665	0.8876111
Sakharshet_chalatwad_Bore_Well_22.5	0.5281183	0.6105416
Sakwar_Dug_Well_6	0.5746863	0.595954
Sange_Dug_Well_4.7	0.8622391	0.8694652
Saravali_Bore_Well_24	0.6741036	0.7455786
Sasne_Dug_Well_8.85	0.5361942	0.5459075
Satiwali_Bore_Well_18	0.2742347	0.446877
Satiwali_Dug_Well_7.2	0.3590811	0.419896
Sawta_Dug_Well_8.4	0.7422277	0.7529376
Shelonde_Dug_Well_12.5	0.6763364	0.6865479
Shendrun_Dug_Well_4.7	0.8023329	0.8129365
Shil_t_chon_Dug_Well_7.1	0.7758495	0.7904979
Shilphata_Dug_Well_4.8	0.4725937	0.4915141
Shirgaon_Dug_Well_9	0.7991924	0.8549223
Shivale_Dug_Well_11	0.6127032	0.619314
Suksale_Bore_Well_30	0.7161548	0.8092644
Talasari_Dug_Well_8	0.7930512	0.8110449
Talasarimal_Dug_Well_8.2	0.6492487	0.6560371
Talegaon_Dug_Well_6.1	0.8130821	0.8258078
Talwada_Bore_Well_30	0.8977466	0.9315646
Tembhare_Dug_Well_5.5	0.8030916	0.8189154
Thane_Dug_Well_7.05	0.3243469	0.3543081
Thilher_Dug_Well_6.2	0.857445	0.8856092
Thunepada_Dug_Well_5.95	0.8277952	0.8289057
Titwala_Dug_Well_7	0.3702703	0.4517264
Tokavde_Bore_Well_24	0.8868853	0.9206414
Tokawade_Dug_Well_5	0.6667911	0.6685623
Udawa_Bore_Well_30	0.8734637	0.9034096
Vadoli_Dug_Well_5.6	0.5906731	0.5987547
Varaskol_Dug_Well_7	0.8547586	0.8596181
Vasar_Bore_Well_30	0.3058883	0.333441
Vedhi_Dug_Well_8.7	0.7425231	0.7446964
Vehaloli_Dug_Well_5.1	0.820199	0.821921
Vevaji_Dug_Well_7.6	0.5715307	0.5744005
Veyour_Dug_Well_10.1	0.8006669	0.8020004

village	Polynomial Model	Rainfall Model
Vihigaon_Dug_Well_7.5	0.69484	0.6961868
Wada_Dug_Well_9	0.6227825	0.6569679
Waret_Bore_Well_30	0.8328676	0.8425024
Warwade_Dug_Well_7.6	0.6918846	0.698345
Washind_Dug_Well_3.05	0.3907839	0.6898296
Washind_Dug_Well_7	0.4192221	0.4219621
Zhai_Dug_Well_7.7	0.6212	0.6375898
Zhari_Bore_Well_30	0.901024	0.9059797
Zhari_Dug_Well_7.4	0.5297735	0.5662066
Average	0.033928922	0.698767675

Table B.3: R^2 Values of Thane District

village	Without Rainfall	With Rainfall
Aashiv_Dug_Well_15	0.2078617	0.3024008
Achola_Dug_Well_12.3	0.7036274	0.7217829
Ahmadpur_Dug_Well_15.1	0.6766383	0.787028
Almala_Dug_Well_9.5	0.2673044	0.4907628
Ambanagar_Dug_Well_6.5	0.6427713	0.7454313
Ambulga_Dug_Well_10.5	0.3339626	0.4086357
Ambulga_Dug_Well_12.9	0.3904659	0.5009347
Andhori_Dug_Well_16.1	0.8645985	0.8938833
Arasnal_Bore_Well_60	0.1572724	0.399788
Ashta_Dug_Well_9.9	0.6933716	0.7482377
Aurad_shahjani_Dug_Well_8.1	0.45544	0.4962424
Ausa_Dug_Well_19.9	0.2982508	0.3576027
Babalgoan_Dug_Well_19.7	0.6004387	0.6144843
Barmachiwadi_Dug_Well_16.9	0.4067154	0.6251243
Bhadi_Dug_Well_11.3	0.6449499	0.7237205
Bhatkheda_Dug_Well_18.65	0.2228324	0.4528372
Bhuisamudraga_Dug_Well_16.65	0.1830515	0.2377243
Borfal_Dug_Well_8.5	0.5564323	0.6470967
Borgaon_n_Dug_Well_12.5	0.2647819	0.3789864
Budhada_Dug_Well_23.5	0.4582271	0.6040349
Chikurda_Bore_Well_27	0.1706532	0.5802016
Dangewadi_Dug_Well_17.7	0.6141814	0.648932
Dapegaon_Bore_Well_30	0.4288577	0.5399494
Dawangaon_Dug_Well_7.15	0.6044405	0.7270438
Deokara_Dug_Well_21.4	0.7702333	0.8049017
Deoni_bk_Dug_Well_18.9	0.6349359	0.8079243
Deoni_kh_Dug_Well_17.9	0.4715714	0.5370604
Dhalegaon_Bore_Well_90	0.4239464	0.5131821
Dhanegaon_Dug_Well_15.7	0.1699485	0.1991464
Dighol_deshmukh_Dug_Well_11.9	0.2119368	0.4554519

Gadwad_Dug_Well_12.5	0.3228699	0.449894
Gangahipparga_Dug_Well_10.5	0.5165378	0.5531258
Gangapur_Dug_Well_11.5	0.4445734	0.6179838
Ganjoor_Dug_Well_19.25	0.2193533	0.341571
Garsuli_Dug_Well_10.2	0.6226287	0.6731545
Gategoan_Dug_Well_13.8	0.2730353	0.5110498
Gaur_Dug_Well_13.9	0.5108132	0.6956745
Gharni_Dug_Well_9.6	0.6996876	0.7288377
Ghonshi_Dug_Well_20.3	0.5709755	0.7305386
Hadolti_Dug_Well_12.8	0.4167604	0.4266551
Haibatpur_Bore_Well_60	0.1798611	0.3223553
Halsi_t_Dug_Well_14.4	0.2804941	0.4279637
Hanchnal_Dug_Well_21.7	0.5805993	0.7277264
Harangul_bk_Dug_Well_10	0.3917773	0.5690137
Hipparga_kopdev_Dug_Well_18.9	0.5551978	0.5825166
Hisamabad_ujed_Dug_Well_15.4	0.2641007	0.4446243
Hosur_Dug_Well_8.9	0.4403985	0.6303935
Ismailpur_Dug_Well_17.6	0.5493019	0.6721661
Jalkot_Dug_Well_19.2	0.5932888	0.6608892
Jawala_bk_Dug_Well_19.8	0.3132745	0.3725639
Kabansangvi_Dug_Well_11.2	0.5484545	0.588131
Karadkhel_Dug_Well_14.9	0.4949902	0.5557546
Karla_Dug_Well_9.3	0.4791636	0.6356899
Karsa_Dug_Well_8.7	0.4742586	0.5675543
Kasarshirshi_Dug_Well_11.9	0.517724	0.6335788
Kelgaon_Bore_Well_60	0.3233141	0.4658574
Kelgaon_Dug_Well_15.5	0.5195362	0.5937756
Khandali_Bore_Well_90	0.3292486	0.4006174
Khandali_Dug_Well_9.2	0.6998863	0.7733862
Kharola_Dug_Well_11.5	0.5808175	0.6907475
Kharosa_Dug_Well_23.7	0.5560107	0.6726649
Khuntegaon_Bore_Well_95	0.1225478	0.6412344
Killari_Dug_Well_18.7	0.2333598	0.42823
Kiniyalladevi_Dug_Well_21	0.6716199	0.7408095
Kodli_Dug_Well_8.7	0.5372426	0.5990396
Kolnoor_Dug_Well_10.9	0.504464	0.57858
Kolwadi_Dug_Well_15.3	0.6636329	0.6991126
Kumbhari_Bore_Well_30	0.6353561	0.687208
Kumtha_Bore_Well_21	0.4502205	0.8013583
Lambota_Dug_Well_12.8	0.3427361	0.5422377
Lamjana_Dug_Well_17.3	0.7014035	0.7771965
Latur_road_Bore_Well_80	0.1043065	0.1752429
Latur_road_Dug_Well_13.3	0.5517155	0.5792167
Madansuri_Dug_Well_10.2	0.4720802	0.5437607

Mahalangra_Dug_Well_14.5	0.7157523	0.7831695
Mal_hipparga_Bore_Well_85	0.5205347	0.6247956
Mamdapur_Dug_Well_11.1	0.5840228	0.6754424
Mankhed_Dug_Well_13.9	0.747745	0.8052089
Mannatpur_Dug_Well_10.1	0.7397916	0.7676064
Mogha_Dug_Well_20.6	0.423477	0.6747491
Murdhav_Dug_Well_12.2	0.2645969	0.2796193
Murud_bk_Dug_Well_21	0.2336786	0.2495667
Nagzari_Dug_Well_4.9	0.532101	0.6309267
Nalgir_Dug_Well_12.8	0.3810614	0.5248425
Nandgaon_Dug_Well_7.7	0.6752599	0.771017
Nandgaon_Dug_Well_9.9	0.1258774	0.2698042
Neoli_Dug_Well_14.6	0.3302598	0.4851828
Nilanga_Dug_Well_14.8	0.4542431	0.5727477
Pakharsangvi_Dug_Well_13.5	0.2805282	0.4142367
Palshi_Dug_Well_6.6	0.6526907	0.7364118
Pangaon_Dug_Well_10.75	0.4142516	0.5609625
Patoda_kh_Dug_Well_10.1	0.3830546	0.4004676
Rapka_Dug_Well_19.8	0.3143521	0.4232057
Renapur_Dug_Well_13	0.4031742	0.5378756
Sakol_Bore_Well_30	0.0481792	0.5009932
Sakol_Dug_Well_19	0.2625634	0.4084241
Samsapur_Dug_Well_11.4	0.664482	0.7542849
Sangvi_s_Dug_Well_12.9	0.4020493	0.5136019
Sarwadi_Bore_Well_30	0.2572217	0.358524
Selu_Dug_Well_8.9	0.5426354	0.6033901
Shelgi_Dug_Well_11.9	0.6287748	0.7254659
Shirur_tajband_Dug_Well_12.5	0.3957292	0.5044816
Shivankhed_Bore_Well_70	0.1926561	0.1958358
Shivpur_Dug_Well_9.5	0.4661041	0.5156909
Sindgi_bk_Dug_Well_14.2	0.6613201	0.6726172
Sindgoan_Dug_Well_10.1	0.5256802	0.7477772
Sindkhed_Bore_Well_61	0.1352716	0.1714149
Sirsi_Bore_Well_23.3	0.2980848	0.361919
Somnathpur_Dug_Well_7.2	0.6848219	0.7384995
Sugaon_Bore_Well_60	0.3049088	0.3443079
Tajpur_Dug_Well_11.9	0.5790534	0.6734409
Taka_Dug_Well_10	0.2431002	0.338685
Taka_Dug_Well_13.7	0.2142064	0.3402565
Takli_Dug_Well_12.75	0.2049279	0.3259947
Talni_Dug_Well_18.9	0.1950648	0.3625007
Tambatsangvi_Dug_Well_20.3	0.1999448	0.2372976
Tattapur_Dug_Well_8	0.7561907	0.7862715
Tiruka_Dug_Well_14.6	0.6980146	0.7226411

Togari_Dug_Well_9.5	0.5158108	0.6767416
Udgir_Bore_Well_70	0.6671063	0.6955167
Wadmurumbi_Dug_Well_13.6	0.273033	0.3619967
Waigaon_Dug_Well_10.5	0.6138892	0.6676051
Walsangi_Dug_Well_12.5	0.3802228	0.5311319
Wanjarkheda_Dug_Well_9.5	0.649131	0.7809592
Yekambi_Dug_Well_13.7	0.4180082	0.5128639
Yelwat_Bore_Well_79	0.6301784	0.8163918
Yerol_Dug_Well_16.8	0.5995343	0.64734
Average	0.4509737819	0.5609678441

Table B.4: R^2 Values of Latur District

B.3 Fraction of Error Results

Village	Without Rainfall	With Rainfall
Agashi_Boling_Dug_Well_10	0.0083027	0.03812
Akoli_Dug_Well_5.5	0.0378324	0.1054018
Ambiste_kh_Bore_Well_17	0.0536388	0.1870923
Awale_Dug_Well_7.35	0.0480984	0.1239454
Badlapur_Bore_Well_30	0.0428254	0.1381919
Badlapur_Dug_Well_7.95	0.0382223	0.067564
Bapgaon_Dug_Well_7.4	0.0271953	0.0436655
Bhatsai_Bore_Well_18	0.0232273	0.0938895
Bhinar_Dug_Well_6.25	0.0340173	0.0653187
Borivali_T_Padgha_Dug_Well_10.6	0.0212149	0.0556174
Bursunge_Dug_Well_8.65	0.0312285	0.0807593
Chahade_Dug_Well_5.7	0.0937112	0.1851869
Chavindra_Bore_Well_13.5	0.0390542	0.1541068
Chndansar_Bore_Well_24	0.0322317	0.1597287
Dahisar_Dug_Well_9.5	0.0173598	0.0361486
Dapode_Dug_Well_5.25	0.0423643	0.0854329
Deoli_Dug_Well_6.2	0.0258593	0.0654149
Dhanivri_Dug_Well_5.5	0.0279199	0.0438398
Dhanoshi_Dug_Well_6.5	0.0297664	0.0625141
Dhuktan_Dug_Well_6.1	0.0227624	0.0674181
Dolhare_Dug_Well_5.5	0.0539848	0.1385686
Durves_Dug_Well_9.6	0.0256856	0.0335659
Gates_Bk_Dug_Well_7.5	0.0237565	0.0316562
Ghansoli_Bore_Well_12.7	0.0406641	0.1471684
Ghodbandar_Dug_Well_8.2	0.0333323	0.0789888
Ghol_Dug_Well_10.4	0.0655918	0.213372
Gokhiware_Bore_Well_18	0.0370422	0.1474594
Gokhiware_Dug_Well_5.5	0.0331186	0.0777372

Govade_Dug_Well_6.6	0.0242156	0.0282636
Goveli_Bore_Well_17.25	0.011644	0.0771962
Inde_Dug_Well_7.8	0.0174923	0.0466185
Jawhar_Dug_Well_7.65	0.0249978	0.0950241
Kajali_Dug_Well_14	0.0239949	0.0608667
Kalamdevi_Dug_Well_5.5	0.0324516	0.1268476
Kambe_Dug_Well_6.9	0.029468	0.0323994
Kanchad_Bore_Well_18	0.0226558	0.092521
Kanchad_Dug_Well_7.5	0.0237894	0.0630188
Kanhor_Dug_Well_8.5	0.0174044	0.0297313
Karav_Dug_Well_8	0.021354	0.0650833
Karvele_Dug_Well_6.3	0.0037872	0.0071542
Kasa_bk_Dug_Well_6.5	0.0191054	0.0680899
Katrap_Dug_Well_3.1	0.0524638	0.0998778
Khaniwade_Dug_Well_5	0.011758	0.0730681
Kharade_Dug_Well_8.2	0.0343743	0.0596099
Khodala_Dug_Well_5.8	0.0513154	0.1186348
Kogde_Dug_Well_7	0.0357923	0.0740996
Kopar_Karane_Dug_Well_4.7	0.0065311	0.0319955
Kopari_Dug_Well_7.55	0.010062	0.0603414
Kudan_Bore_Well_30	0.0285316	0.0746756
Kudus_Dug_Well_6	0.0450711	0.1295096
Lalthan_Dug_Well_6.4	0.0195847	0.0527254
Mahim_Bore_Well_20	0.0442375	0.1602258
Makunsar_Dug_Well_9.8	0.0743211	0.1494216
Mandawa_Bore_Well_30	0.0333304	0.1126776
Mandvi_Dug_Well_9.1	0.0250504	0.0666996
Mangrul_Dug_Well_7.6	0.0210896	0.0392443
Manor_Dug_Well_7	0.0188012	0.0458878
Met_Dug_Well_8.3	0.0208127	0.0273099
Mokhada_Dug_Well_9	0.0586971	0.1219231
Morhande_Dug_Well_5.1	0.0243734	0.0916986
Musarne_Dug_Well_6	0.0387749	0.2647669
Nare_Bore_Well_18	0.0354624	0.0800328
Neharoli_Bore_Well_24	0.0797108	0.206358
Newale_Dug_Well_8.2	0.0212373	0.0308897
Nihe_Dug_Well_7	0.0442124	0.084533
Nimbavali_Bore_Well_30	0.0457381	0.1378938
Padgha_Bore_Well_30	0.0237534	0.0578597
Palghar_kolgaon_Bore_Well_30	0.0240811	0.1848437
Pali_Dug_Well_6	0.0578164	0.1956445
Parli_Dug_Well_5.1	0.0232681	0.0574928
Pawane_Dug_Well_5	0.0146021	0.0525588
Pelhar_Dug_Well_7	0.0624573	0.1376794

Pimpalas_Dug_Well_6.55	0.0267164	0.0746216
Pimpalshet_Dug_Well_8.5	0.0338547	0.0800948
Rayta_Dug_Well_4	0.0378462	0.06145
Safala_Dug_Well_10.5	0.0220945	0.0734586
Safale_Bore_Well_25.9	0.046585	0.2080566
Sakharshet_chalatwad_Bore_Well_22.5	0.0548528	0.1507805
Sakwar_Dug_Well_6	0.0314352	0.0784485
Sange_Dug_Well_4.7	0.0130617	0.0353228
Saravali_Bore_Well_24	0.0503926	0.2509176
Sasne_Dug_Well_8.85	0.0355425	0.0822635
Satiwali_Bore_Well_18	0.0373992	0.1944121
Satiwali_Dug_Well_7.2	0.0597153	0.1409107
Sawta_Dug_Well_8.4	0.0251701	0.0764901
Shelonde_Dug_Well_12.5	0.0203929	0.0542168
Shendrun_Dug_Well_4.7	0.035194	0.0699983
Shil_t_chon_Dug_Well_7.1	0.0502829	0.0800968
Shilphata_Dug_Well_4.8	0.0139842	0.023897
Shirgaon_Dug_Well_9	0.0221528	0.1182493
Shivale_Dug_Well_11	0.0380719	0.077328
Suksale_Bore_Well_30	0.0640196	0.0778577
Talasari_Dug_Well_8	0.0379864	0.0672339
Talasarimal_Dug_Well_8.2	0.0582388	0.1065035
Talegaon_Dug_Well_6.1	0.0606576	0.1130317
Talwada_Bore_Well_30	0.0183096	0.1225583
Tembhare_Dug_Well_5.5	0.0816283	0.2673053
Thane_Dug_Well_7.05	0.007557	0.0319031
Thilher_Dug_Well_6.2	0.0294952	0.10658
Thunepada_Dug_Well_5.95	0.0506957	0.107261
Titwala_Dug_Well_7	0.0744074	0.1118207
Tokavde_Bore_Well_24	0.0073915	0.0667426
Tokawade_Dug_Well_5	0.0305637	0.081803
Udawa_Bore_Well_30	0.0389191	0.1468506
Vadoli_Dug_Well_5.6	0.0363703	0.1279056
Varaskol_Dug_Well_7	0.0650863	0.1811543
Vasar_Bore_Well_30	0.008093	0.0293011
Vedhi_Dug_Well_8.7	0.0221203	0.0491888
Vehaloli_Dug_Well_5.1	0.0281789	0.0508165
Vevaji_Dug_Well_7.6	0.0188219	0.0372341
Veyour_Dug_Well_10.1	0.0273818	0.0485482
Vihigaon_Dug_Well_7.5	0.0128432	0.0403608
Wada_Dug_Well_9	0.0388247	0.0972635
Waret_Bore_Well_30	0.0270987	0.0787415
Warwade_Dug_Well_7.6	0.0197456	0.0386176
Washind_Dug_Well_3.05	0.0129305	0.0881255

Washind_Dug_Well_7	0.0245673	0.0447836
Zhai_Dug_Well_7.7	0.0497863	0.0765092
Zhari_Bore_Well_30	0.0481338	0.0584083
Zhari_Dug_Well_7.4	0.0471924	0.1518582
Average	0.0339289217	0.092817905

Table B.5: Fraction of Error values for Thane district

Village	Without Rainfall			With Rainfall		
	G	B	M	G	B	M
Agashi_Boling_Dug_Well_10	8	6	1	7	5	3
Akoli_Dug_Well_5.5	4	5	6	2	3	10
Ambiste_kh_Bore_Well_17	2	1	6	3	1	5
Awale_Dug_Well_7.35	8	13	8	9	11	9
Badlapur_Bore_Well_30	3	2	3	2	2	4
Badlapur_Dug_Well_7.95	11	10	8	10	10	9
Bapgaon_Dug_Well_7.4	4	6	5	3	6	6
Bhatsai_Bore_Well_18	3	2	3	4	2	2
Bhinar_Dug_Well_6.25	8	13	7	7	15	6
Borivali_T_Padgha_Dug_Well_10.6	11	14	3	11	14	3
Bursunge_Dug_Well_8.65	4	5	6	2	5	8
Chahade_Dug_Well_5.7	8	10	11	8	9	12
Chavindra_Bore_Well_13.5	3	2	4	3	3	3
Chndansar_Bore_Well_24	2	3	4	1	2	6
Dahisar_Dug_Well_9.5	7	6	1	6	5	3
Dapode_Dug_Well_5.25	9	10	8	9	10	8
Deoli_Dug_Well_6.2	5	3	7	5	5	5
Dhanivri_Dug_Well_5.5	6	3	5	7	4	3
Dhanoshi_Dug_Well_6.5	11	12	6	9	11	9
Dhuktan_Dug_Well_6.1	6	7	2	5	4	6
Dolhare_Dug_Well_5.5	6	5	4	5	5	5
Durves_Dug_Well_9.6	7	6	2	7	6	2
Gates_Bk_Dug_Well_7.5	7	6	2	7	6	2
Ghansoli_Bore_Well_12.7	4	1	4	5	2	2
Ghodbandar_Dug_Well_8.2	5	5	5	5	6	4
Ghol_Dug_Well_10.4	3	5	7	4	4	7
Gokhiware_Bore_Well_18	3	2	3	3	2	3
Gokhiware_Dug_Well_5.5	5	7	3	5	6	4
Govade_Dug_Well_6.6	5	8	4	6	8	3
Goveli_Bore_Well_17.25	2	4	3	3	4	2
Inde_Dug_Well_7.8	7	6	2	6	6	3
Jawhar_Dug_Well_7.65	11	13	6	11	15	4
Kajali_Dug_Well_14	8	13	7	6	12	10
Kalamdevi_Dug_Well_5.5	11	12	6	8	14	7

Village	Without Rainfall			With Rainfall		
Kambe_Dug_Well_6.9	5	5	5	5	6	4
Kanchad_Bore_Well_18	4	1	4	4	1	4
Kanchad_Dug_Well_7.5	11	14	4	11	12	6
Kanhor_Dug_Well_8.5	8	4	3	8	6	1
Karav_Dug_Well_8	7	7	1	7	6	2
Karvele_Dug_Well_6.3	9	6	0	9	5	1
Kasa_bk_Dug_Well_6.5	9	14	5	11	14	3
Katrap_Dug_Well_3.1	5	5	5	4	7	4
Khaniwade_Dug_Well_5	10	8	11	9	7	13
Kharade_Dug_Well_8.2	6	6	3	6	7	2
Khodala_Dug_Well_5.8	3	5	7	4	4	7
Kogde_Dug_Well_7	4	7	4	4	6	5
Kopar_Karane_Dug_Well_4.7	9	3	3	8	6	1
Kopari_Dug_Well_7.55	12	16	0	11	11	6
Kudan_Bore_Well_30	3	3	2	3	3	2
Kudus_Dug_Well_6	12	9	7	11	8	9
Lalthan_Dug_Well_6.4	5	6	4	4	6	5
Mahim_Bore_Well_20	3	2	3	3	1	4
Makunsar_Dug_Well_9.8	5	5	5	4	3	8
Mandawa_Bore_Well_30	2	2	2	3	2	1
Mandvi_Dug_Well_9.1	6	5	4	6	6	3
Mangrul_Dug_Well_7.6	4	9	2	4	9	2
Manor_Dug_Well_7	10	13	6	12	12	5
Met_Dug_Well_8.3	6	6	3	6	8	1
Mokhada_Dug_Well_9	9	9	13	8	11	12
Morhande_Dug_Well_5.1	6	3	6	5	4	6
Musarne_Dug_Well_6	7	2	5	4	4	6
Nare_Bore_Well_18	4	1	3	4	2	2
Neharoli_Bore_Well_24	2	1	5	2	2	4
Newale_Dug_Well_8.2	5	7	3	5	8	2
Nihe_Dug_Well_7	7	4	4	6	4	5
Nimbavali_Bore_Well_30	4	1	3	3	2	3
Padgha_Bore_Well_30	0	1	5	1	1	4
Palghar_kolgaon_Bore_Well_30	1	3	4	3	2	3
Pali_Dug_Well_6	5	3	7	4	3	8
Parli_Dug_Well_5.1	11	12	6	9	12	8
Pawane_Dug_Well_5	6	4	5	6	5	4
Pelhar_Dug_Well_7	6	6	9	7	6	8
Pimpalas_Dug_Well_6.55	6	5	3	6	5	3
Pimpalshet_Dug_Well_8.5	7	4	4	5	6	4
Rayta_Dug_Well_4	7	4	4	7	6	2
Safala_Dug_Well_10.5	8	16	5	9	13	7
Safale_Bore_Well_25.9	0	2	4	0	1	5
Sakharshet_chalatwad_Bore_Well_22.5	2	2	5	2	2	5

Village	Without Rainfall			With Rainfall		
Sakwar_Dug_Well_6	3	5	5	6	5	2
Sange_Dug_Well_4.7	5	7	3	5	9	1
Saravali_Bore_Well_24	2	2	4	2	1	5
Sasne_Dug_Well_8.85	3	7	5	3	5	7
Satiwali_Bore_Well_18	3	2	3	2	3	3
Satiwali_Dug_Well_7.2	9	9	11	8	10	11
Sawta_Dug_Well_8.4	6	7	4	4	8	5
Shelonde_Dug_Well_12.5	6	8	1	6	8	1
Shendrun_Dug_Well_4.7	5	8	2	3	6	6
Shil_t_chon_Dug_Well_7.1	11	12	6	12	10	7
Shilphata_Dug_Well_4.8	8	14	5	10	12	5
Shirgaon_Dug_Well_9	6	5	4	4	5	6
Shivale_Dug_Well_11	7	15	7	7	14	8
Suksale_Bore_Well_30	3	2	3	3	3	2
Talasari_Dug_Well_8	11	13	5	11	14	4
Talasarimal_Dug_Well_8.2	12	6	11	12	7	10
Talegaon_Dug_Well_6.1	6	5	4	5	5	5
Talwada_Bore_Well_30	4	4	0	4	2	2
Tembhare_Dug_Well_5.5	5	4	6	3	4	8
Thane_Dug_Well_7.05	13	13	2	13	12	3
Thilher_Dug_Well_6.2	7	5	2	4	5	5
Thunepada_Dug_Well_5.95	5	6	4	5	6	4
Titwala_Dug_Well_7	9	12	8	11	11	7
Tokavde_Bore_Well_24	3	4	1	3	3	2
Tokawade_Dug_Well_5	10	14	5	9	14	6
Udawa_Bore_Well_30	2	1	5	2	2	4
Vadoli_Dug_Well_5.6	5	6	4	5	5	5
Varaskol_Dug_Well_7	6	3	6	5	5	5
Vasar_Bore_Well_30	4	4	0	4	4	0
Vedhi_Dug_Well_8.7	5	6	4	5	6	4
Vehaloli_Dug_Well_5.1	6	5	4	6	5	4
Vevaji_Dug_Well_7.6	7	6	2	7	6	2
Veyour_Dug_Well_10.1	12	12	5	12	13	4
Vihigaon_Dug_Well_7.5	6	7	2	5	8	2
Wada_Dug_Well_9	10	13	6	11	11	7
Waret_Bore_Well_30	2	1	5	2	1	5
Warwade_Dug_Well_7.6	4	6	5	5	7	3
Washind_Dug_Well_3.05	3	1	0	2	1	1
Washind_Dug_Well_7	8	11	8	9	11	7
Zhai_Dug_Well_7.7	5	5	5	5	7	3
Zhari_Bore_Well_30	2	2	4	2	3	3
Zhari_Dug_Well_7.4	5	3	5	4	4	5

Table B.6: Good, Bad, Median Year count for Thane district

village	Without Rainfall	With Rainfall
Aashiv_Dug_Well_15	0.1130271	0.1302603
Achola_Dug_Well_12.3	0.0318983	0.0405665
Ahmadpur_Dug_Well_15.1	0.0393439	0.0970031
Almala_Dug_Well_9.5	0.0256607	0.0040507
Ambanagar_Dug_Well_6.5	0.0838697	0.0964128
Ambulga_Dug_Well_10.5	0.0485225	0.0601364
Ambulga_Dug_Well_12.9	0.0201839	0.0602916
Andhori_Dug_Well_16.1	0.0467389	0.1850794
Arasnal_Bore_Well_60	0.1126197	0.1850794
Ashta_Dug_Well_9.9	0.0943204	0.1887101
Aurad_shahjani_Dug_Well_8.1	0.0613389	0.0800444
Ausa_Dug_Well_19.9	0.0165535	0.0118327
Babalgoan_Dug_Well_19.7	0.0765569	0.0987769
Barmachiwadi_Dug_Well_16.9	0.0526766	0.0514857
Bhadi_Dug_Well_11.3	0.0251331	0.0428286
Bhatkheda_Dug_Well_18.65	0.0398215	0.1066001
Bhuisamudraga_Dug_Well_16.65	0.0112825	0.0272186
Borfal_Dug_Well_8.5	0.0373729	0.02082
Borgaon_n_Dug_Well_12.5	0.0198121	0.0156786
Budhada_Dug_Well_23.5	0.0183632	0.0249582
Chikurda_Bore_Well_27	0.0213859	0.0249582
Dangewadi_Dug_Well_17.7	0.0867872	0.0980022
Dapegaon_Bore_Well_30	0.041912	0.0980022
Dawangaon_Dug_Well_7.15	0.0561135	0.0716605
Deokara_Dug_Well_21.4	0.0588253	0.096313
Deoni_bk_Dug_Well_18.9	0.0145736	0.0311263
Deoni_kh_Dug_Well_17.9	0.0430012	0.0476049
Dhalegaon_Bore_Well_90	0.2379479	0.0476049
Dhanegaon_Dug_Well_15.7	0.057733	0.0433619
Dighol_deshmukh_Dug_Well_11.9	0.047798	0.0401793
Gadwad_Dug_Well_12.5	0.0231758	0.0219498
Gangahipparga_Dug_Well_10.5	0.0731213	0.1022611
Gangapur_Dug_Well_11.5	0.0563894	0.0908034
Ganjoor_Dug_Well_19.25	0.0293079	0.0506123
Garsuli_Dug_Well_10.2	0.0807502	0.0546478
Gategoan_Dug_Well_13.8	0.0450435	0.029232
Gaur_Dug_Well_13.9	0.0961671	0.0953468
Gharni_Dug_Well_9.6	0.0671666	0.0972927
Ghonshi_Dug_Well_20.3	0.0740341	0.0992755
Hadolti_Dug_Well_12.8	0.0257601	0.0506274
Haibatpur_Bore_Well_60	0.1294059	0.0506274
Halsi_t_Dug_Well_14.4	0.06061	0.0878809
Hanchnal_Dug_Well_21.7	0.0824782	0.068802

Harangul_bk_Dug_Well_10	0.0609393	0.0274901
Hipparga_kopdev_Dug_Well_18.9	0.0691827	0.0958311
Hisamabad_ujed_Dug_Well_15.4	0.0305901	0.0351002
Hosur_Dug_Well_8.9	0.0242865	0.0253395
Ismailpur_Dug_Well_17.6	0.1267495	0.1827528
Jalkot_Dug_Well_19.2	0.0588476	0.0663521
Jawala_bk_Dug_Well_19.8	0.02734	0.0298023
Kabansangvi_Dug_Well_11.2	0.0561765	0.075944
Karadkhel_Dug_Well_14.9	0.0260065	0.0123603
Karla_Dug_Well_9.3	0.0767775	0.1029288
Karsa_Dug_Well_8.7	0.0743392	0.1162079
Kasarshirshi_Dug_Well_11.9	0.0410448	0.0954607
Kelgaon_Bore_Well_60	0.0843702	0.0954607
Kelgaon_Dug_Well_15.5	0.0363508	0.0378755
Khandali_Bore_Well_90	0.0572765	0.0378755
Khandali_Dug_Well_9.2	0.0944404	0.1299752
Kharola_Dug_Well_11.5	0.0473049	0.0221923
Kharosa_Dug_Well_23.7	0.0378157	0.0450693
Khuntegaon_Bore_Well_95	0.0240302	0.0450693
Killari_Dug_Well_18.7	0.0199637	0.02133
Kiniyalladevi_Dug_Well_21	0.024715	0.0397132
Kodli_Dug_Well_8.7	0.0656187	0.1238806
Kolnoor_Dug_Well_10.9	0.0234002	0.0710991
Kolwadi_Dug_Well_15.3	0.0750091	0.0830712
Kumbhari_Bore_Well_30	0.2947732	0.0830712
Kumtha_Bore_Well_21	0.1369698	0.0830712
Lambota_Dug_Well_12.8	0.0214848	0.0304782
Lamjana_Dug_Well_17.3	0.0442022	0.092233
Latur_road_Bore_Well_80	0.0226794	0.092233
Latur_road_Dug_Well_13.3	0.038327	0.0754726
Madansuri_Dug_Well_10.2	0.0966678	0.0827794
Mahalangra_Dug_Well_14.5	0.0449452	0.0620633
Mal_hipparga_Bore_Well_85	0.0004245	0.0620633
Mamdapur_Dug_Well_11.1	0.0389899	0.0497261
Mankhed_Dug_Well_13.9	0.040334	0.0866935
Mannatpur_Dug_Well_10.1	0.0365497	0.0387823
Mogha_Dug_Well_20.6	0.0084242	0.0116275
Murdhav_Dug_Well_12.2	0.0421377	0.0316705
Murud_bk_Dug_Well_21	0.0188268	0.0403147
Nagzari_Dug_Well_4.9	0.2277816	0.0455125
Nalgir_Dug_Well_12.8	0.0313202	0.0505085
Nandgaon_Dug_Well_7.7	0.0299345	0.1043863
Nandgaon_Dug_Well_9.9	0.0547279	0.0872347
Neoli_Dug_Well_14.6	0.0500469	0.0591144

Nilanga_Dug_Well_14.8	0.0172342	0.1299373
Pakharsangvi_Dug_Well_13.5	0.048083	0.0404325
Palshi_Dug_Well_6.6	0.0293188	0.0612903
Pangaon_Dug_Well_10.75	0.0130974	0.1096407
Patoda_kh_Dug_Well_10.1	0.0815459	0.0717026
Rapka_Dug_Well_19.8	0.0456165	0.1002745
Renapur_Dug_Well_13	0.0085244	0.0218416
Sakol_Bore_Well_30	0.0197526	0.0218416
Sakol_Dug_Well_19	0.1471233	0.2063535
Samsapur_Dug_Well_11.4	0.0200045	0.0192865
Sangvi_s_Dug_Well_12.9	0.049579	0.1084331
Sarwadi_Bore_Well_30	0.0905505	0.1084331
Selu_Dug_Well_8.9	0.0504908	0.0356239
Shelgi_Dug_Well_11.9	0.0429203	0.0427331
Shirur_tajband_Dug_Well_12.5	0.0871616	0.0564477
Shivankhed_Bore_Well_70	0.1614425	0.0564477
Shivpur_Dug_Well_9.5	0.0407033	0.0486636
Sindgi_bk_Dug_Well_14.2	0.0714624	0.0596568
Sindgoan_Dug_Well_10.1	0.0427106	0.0526147
Sindkhed_Bore_Well_61	0.0932667	0.0526147
Sirsi_Bore_Well_23.3	0.237763	0.0526147
Somnathpur_Dug_Well_7.2	0.0649819	0.08922
Sugaon_Bore_Well_60	0.2043374	0.08922
Tajpur_Dug_Well_11.9	0.0273272	0.0535998
Taka_Dug_Well_10	0.0689556	0.1103216
Taka_Dug_Well_13.7	0.1485496	0.1756557
Takli_Dug_Well_12.75	0.084894	0.1147453
Talni_Dug_Well_18.9	0.0535049	0.008132
Tambatsangvi_Dug_Well_20.3	0.0498498	0.0393798
Tattapur_Dug_Well_8	0.0616008	0.0765699
Tiruka_Dug_Well_14.6	0.0580366	0.0540012
Togari_Dug_Well_9.5	0.0971899	0.1314138
Udgir_Bore_Well_70	0.1422136	0.1314138
Wadmurumbi_Dug_Well_13.6	0.0552526	0.0715794
Waigaon_Dug_Well_10.5	0.0110279	0.0220702
Walsangi_Dug_Well_12.5	0.033997	0.033704
Wanjarkheda_Dug_Well_9.5	0.1292507	0.1563668
Yekambi_Dug_Well_13.7	0.1898566	0.1358397
Yelwat_Bore_Well_79	0.2076918	0.1358397
Yerol_Dug_Well_16.8	0.0699268	0.0706408
Average	0.0644370307	0.0714159228

Table B.7: Fraction of Error values for Latur

village	Withou Rainfall			With Rainfall		
	G	B	M	G	B	M
Aashiv_Dug_Well_15	6	4	4	7	5	2
Achola_Dug_Well_12.3	5	9	3	6	8	3
Ahmadpur_Dug_Well_15.1	8	7	2	5	5	7
Almala_Dug_Well_9.5	7	7	3	8	8	1
Ambanagar_Dug_Well_6.5	7	6	4	6	6	5
Ambulga_Dug_Well_10.5	7	6	4	7	7	3
Ambulga_Dug_Well_12.9	8	7	2	9	5	3
Andhori_Dug_Well_16.1	8	6	3	6	6	5
Arasnal_Bore_Well_60	3	2	2	3	3	1
Ashta_Dug_Well_9.9	6	5	6	4	5	8
Aurad_shahjani_Dug_Well_8.1	11	4	2	10	3	4
Ausa_Dug_Well_19.9	10	6	1	10	5	2
Babalgoan_Dug_Well_19.7	11	16	4	10	10	11
Barmachiwadi_Dug_Well_16.9	13	13	5	11	13	7
Bhadi_Dug_Well_11.3	11	5	1	9	6	2
Bhatkheda_Dug_Well_18.65	11	15	5	15	10	6
Bhuisamudraga_Dug_Well_16.65	8	8	1	11	4	2
Borfal_Dug_Well_8.5	8	7	2	8	7	2
Borgaon_n_Dug_Well_12.5	13	15	3	15	15	1
Budhada_Dug_Well_23.5	15	13	1	12	10	7
Chikurda_Bore_Well_27	3	4	1	3	4	1
Dangewadi_Dug_Well_17.7	7	4	6	8	3	6
Dapegaon_Bore_Well_30	5	0	2	3	3	1
Dawangaon_Dug_Well_7.15	7	8	2	7	6	4
Deokara_Dug_Well_21.4	9	11	11	8	12	11
Deoni_bk_Dug_Well_18.9	9	7	1	7	8	2
Deoni_kh_Dug_Well_17.9	12	15	4	12	14	5
Dhalegaon_Bore_Well_90	1	2	3	1	1	4
Dhanegaon_Dug_Well_15.7	8	5	4	9	4	4
Dighol_deshmukh_Dug_Well_11.9	7	7	3	8	7	2
Gadwad_Dug_Well_12.5	5	9	3	6	7	4
Gangahipparga_Dug_Well_10.5	10	2	5	10	3	4
Gangapur_Dug_Well_11.5	14	14	3	12	11	8
Ganjoor_Dug_Well_19.25	15	11	5	17	11	3
Garsuli_Dug_Well_10.2	4	10	3	5	8	4
Gategoan_Dug_Well_13.8	15	14	2	16	12	3
Gaur_Dug_Well_13.9	6	8	3	9	3	5
Gharni_Dug_Well_9.6	12	12	7	10	11	10
Ghonshi_Dug_Well_20.3	8	11	12	10	11	10
Hadolti_Dug_Well_12.8	12	4	1	8	4	5
Haibatpur_Bore_Well_60	3	2	3	4	2	2
Halsi_t_Dug_Well_14.4	11	16	4	9	18	4
Hanchnal_Dug_Well_21.7	11	11	9	12	13	6

village	Withou Rainfall			With Rainfall		
Harangul_bk_Dug_Well_10	6	9	2	8	5	4
Hipparga_kopdev_Dug_Well_18.9	8	5	4	6	4	7
Hisamabad_ujed_Dug_Well_15.4	6	9	2	7	7	3
Hosur_Dug_Well_8.9	9	7	1	9	7	1
Ismailpur_Dug_Well_17.6	4	7	6	3	7	7
Jalkot_Dug_Well_19.2	9	14	7	8	15	7
Jawala_bk_Dug_Well_19.8	8	6	3	9	6	2
Kabansangvi_Dug_Well_11.2	9	5	2	7	6	3
Karadkhel_Dug_Well_14.9	6	9	2	8	8	1
Karla_Dug_Well_9.3	17	7	7	15	10	6
Karsa_Dug_Well_8.7	8	6	3	7	5	5
Kasarshirshi_Dug_Well_11.9	7	7	3	5	8	4
Kelgaon_Bore_Well_60	3	2	0	2	3	0
Kelgaon_Dug_Well_15.5	7	7	3	10	3	4
Khandali_Bore_Well_90	5	0	3	3	2	3
Khandali_Dug_Well_9.2	16	9	6	12	10	9
Kharola_Dug_Well_11.5	13	13	3	11	13	5
Kharosa_Dug_Well_23.7	10	16	4	12	11	7
Khuntegaon_Bore_Well_95	1	6	0	1	1	5
Killari_Dug_Well_18.7	4	9	4	7	8	2
Kiniyalladevi_Dug_Well_21	11	13	2	10	14	2
Kodli_Dug_Well_8.7	9	5	3	7	5	5
Kolnoor_Dug_Well_10.9	12	4	1	6	4	7
Kolwadi_Dug_Well_15.3	8	5	4	7	6	4
Kumbhari_Bore_Well_30	1	1	3	0	0	5
Kumtha_Bore_Well_21	2	1	1	0	1	3
Lambota_Dug_Well_12.8	6	9	2	7	7	3
Lamjana_Dug_Well_17.3	6	7	4	8	7	2
Latur_road_Bore_Well_80	2	2	1	2	1	2
Latur_road_Dug_Well_13.3	5	9	3	7	6	4
Madansuri_Dug_Well_10.2	8	5	4	9	5	3
Mahalangra_Dug_Well_14.5	8	5	4	9	5	3
Mal_hipparga_Bore_Well_85	2	1	0	1	1	1
Mamdapur_Dug_Well_11.1	9	6	2	8	6	3
Mankhed_Dug_Well_13.9	7	5	5	7	6	4
Mannatpur_Dug_Well_10.1	14	11	6	14	13	4
Mogha_Dug_Well_20.6	13	15	3	17	13	1
Murdhav_Dug_Well_12.2	5	8	4	5	8	4
Murud_bk_Dug_Well_21	10	20	1	9	15	7
Nagzari_Dug_Well_4.9	0	0	0	6	6	5
Nalgir_Dug_Well_12.8	9	6	2	7	6	4
Nandgaon_Dug_Well_7.7	9	7	1	7	7	3
Nandgaon_Dug_Well_9.9	9	5	3	8	5	4
Neoli_Dug_Well_14.6	13	13	5	13	12	6

village	Withou Rainfall			With Rainfall		
Nilanga_Dug_Well_14.8	6	10	1	7	5	5
Pakharsangvi_Dug_Well_13.5	7	7	3	9	6	2
Palshi_Dug_Well_6.6	8	8	1	6	6	5
Pangaon_Dug_Well_10.75	8	8	1	7	5	5
Patoda_kh_Dug_Well_10.1	10	5	2	7	8	2
Rapka_Dug_Well_19.8	8	4	5	8	4	5
Renapur_Dug_Well_13	11	18	2	12	18	1
Sakol_Bore_Well_30	4	2	1	3	4	0
Sakol_Dug_Well_19	8	6	3	7	6	4
Samsapur_Dug_Well_11.4	11	4	2	8	7	2
Sangvi_s_Dug_Well_12.9	16	11	4	15	8	8
Sarwadi_Bore_Well_30	5	3	0	3	4	1
Selu_Dug_Well_8.9	7	6	4	9	4	4
Shelgi_Dug_Well_11.9	13	15	3	11	12	8
Shirur_tajband_Dug_Well_12.5	11	8	11	14	11	5
Shivankhed_Bore_Well_70	3	2	3	3	2	3
Shivpur_Dug_Well_9.5	9	5	3	8	5	4
Sindgi_bk_Dug_Well_14.2	9	3	5	10	3	4
Sindgoan_Dug_Well_10.1	6	9	2	8	5	4
Sindkhed_Bore_Well_61	3	1	4	3	2	3
Sirsi_Bore_Well_23.3	3	2	3	3	2	3
Somnathpur_Dug_Well_7.2	15	6	10	17	9	5
Sugaon_Bore_Well_60	3	2	3	4	2	2
Tajpur_Dug_Well_11.9	10	6	1	7	7	3
Taka_Dug_Well_10	7	7	3	6	5	6
Taka_Dug_Well_13.7	1	7	9	3	8	6
Takli_Dug_Well_12.75	10	5	2	9	5	3
Talni_Dug_Well_18.9	9	19	3	13	17	1
Tambatsangvi_Dug_Well_20.3	13	4	0	10	4	3
Tattapur_Dug_Well_8	8	7	2	6	5	6
Tiruka_Dug_Well_14.6	8	7	2	7	7	3
Togari_Dug_Well_9.5	8	5	4	7	6	4
Udgir_Bore_Well_70	4	2	2	4	2	2
Wadmurumbi_Dug_Well_13.6	11	4	2	7	4	6
Waigaon_Dug_Well_10.5	15	9	2	13	9	4
Walsangi_Dug_Well_12.5	9	4	4	15	13	3
Wanjarkheda_Dug_Well_9.5	10	5	2	6	3	8
Yekambi_Dug_Well_13.7	0	0	0	10	3	4
Yelwat_Bore_Well_79	0	1	3	0	2	2
Yerol_Dug_Well_16.8	10	11	10	13	10	8

Table B.8: Good, Bad, Median Year count for Latur

Appendix C

Results of Hunt For Spatial Corelation Chapter

C.1 Elevation Vs March 31^{st} Waterlevels of Thane District

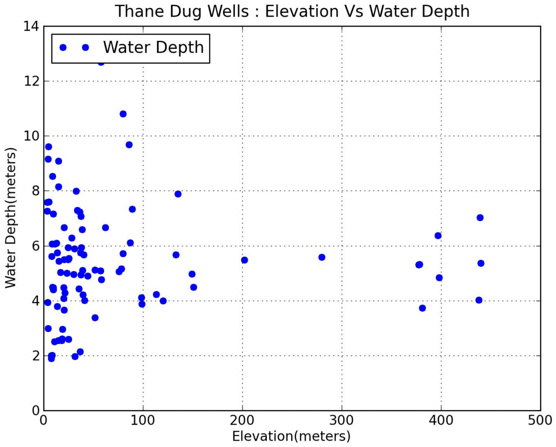


Figure C.1: Elevation Vs Waterlevel of Thane Dug Wells

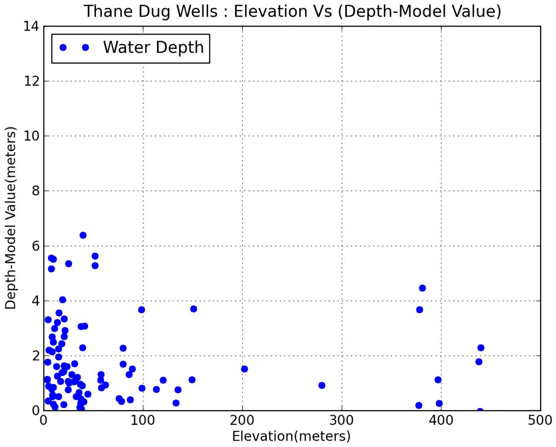


Figure C.2: Elevation Vs (Depth - Waterlevel) of Thane Dug Wells

C.2 Average Results of All Spatial Correlation Techniques

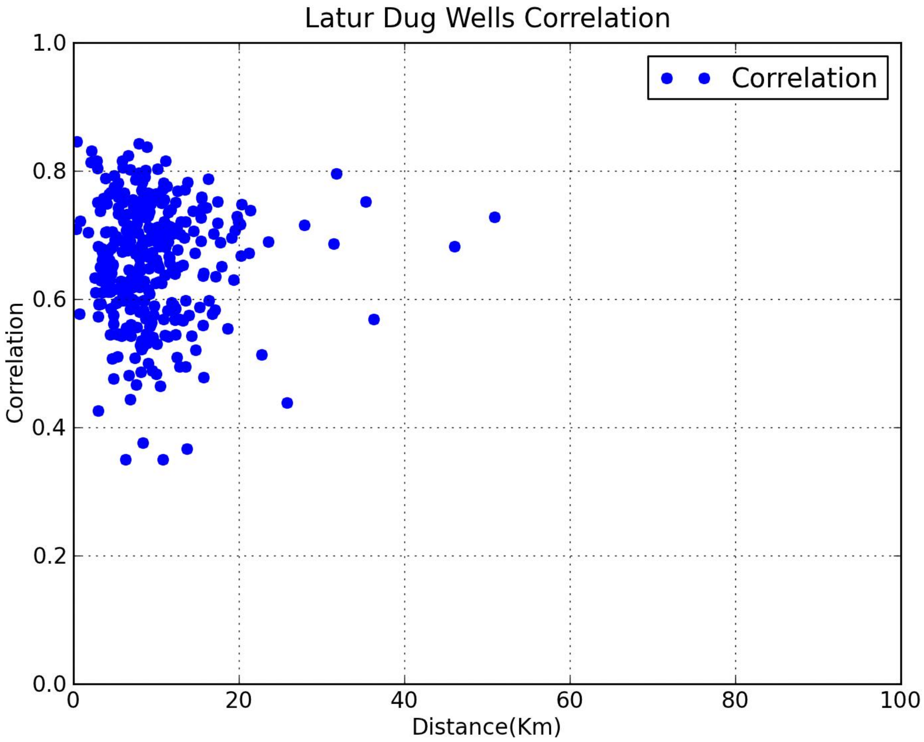


Figure C.3: Distance Vs Correlation between adjacent Latur Dug Wells

C.3 Water Table Contours

District	Well Type	Watershed	Group	Elevation	Group	Natural	Neighbour	Cross	Group
		Method1	Method2	Method1	EMethod2	Mehod1	Method2	Method1	Mrthod2
Thane	Dug	0.7629	0.7655	0.7551	0.8417	0.7614	0.8494	0.7628	0.8360
	Bore	0.8441	0.9716	0.8261	0.9671	0.8189	0.9619	0.8192	0.9585
Latur	Dug	0.6556	0.7306	0.6567	0.7397	0.6588	0.7375	0.6605	0.7262
	Bore	0.4262	0.8206	0.4741	0.6992	0.4563	0.7919	0.4614	0.7482

Table C.1: Average Correlations of all Techniques

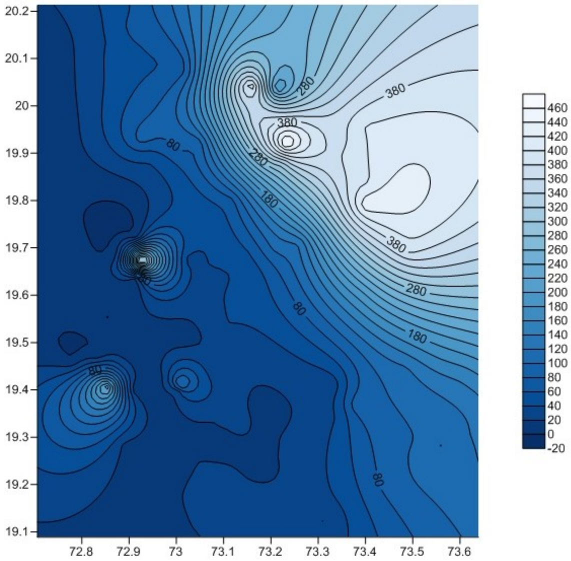


Figure C.4: Thane Water Table on 2003-10-31

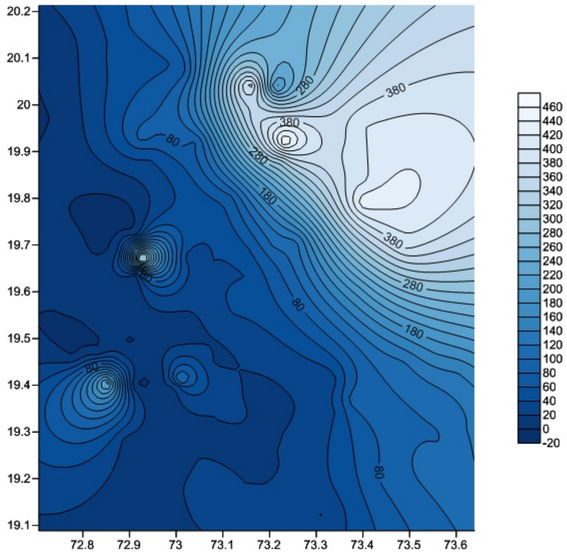


Figure C.5: Thane Water Table on 2004-01-31

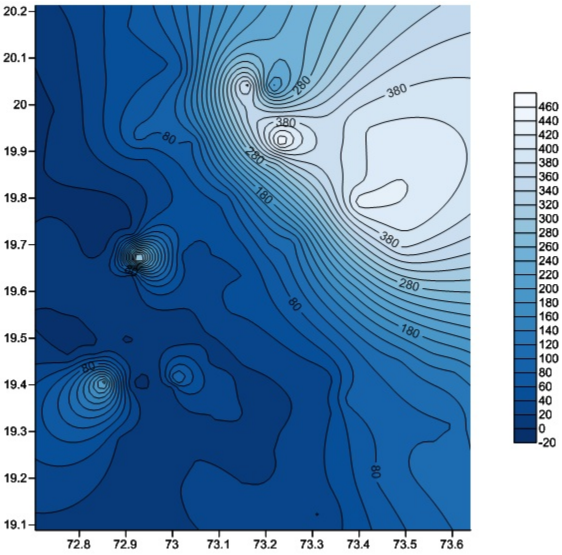


Figure C.6: Thane Water Table on 2004-03-31

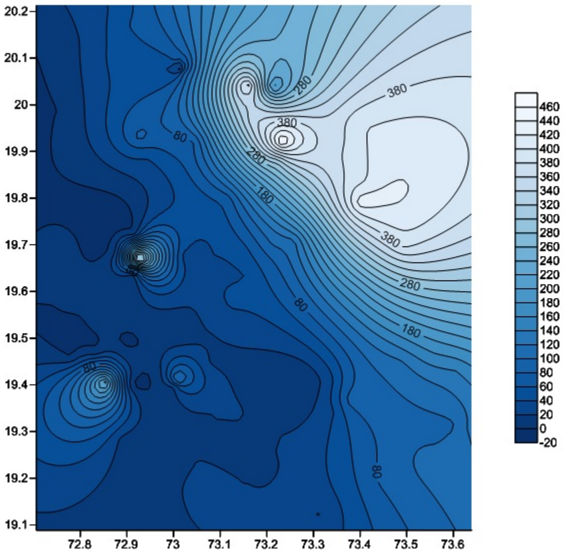


Figure C.7: Thane Water Table on 2004-05-31

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