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COMPARISON OF SPATIAL INTERPOLATION METHODS FOR THE ESTIMATION OF WATER QUALITY INDEX

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ABSTRACT

This paper focuses on comparison of three spatial interpolation methods in terms of their accuracy in the assessment of groundwater quality for Peenya Industrial Area of Bangalore City. Groundwater samples were collected from thirty wells in the Peenya Industrial Area during pre-monsoon and post-monsoon season in the year 2010. Physico-chemical analysis and water quality indices estimated for all 30 samples, both for the pre-monsoon and post-monsoon season was carried out. ArcGIS was used to produce the spatially distributed Water Quality Index (WQI) values by using three methods namely Inverse Distance Weighting (IDW), KRIGING and SPLINE. A statistical assessment of the resultant continuous surfaces indicates that there is substantial difference in the estimating ability of the three interpolation methods. IDW method performed better compared to other method. Hence it was concluded that the IDW method may be preferred in developing the WQI thematic maps, with areas similar to Peenya Industrial area.

KEYWORDS: Arcgis, Groundwater Quality, Water Quality Index (WQI), Inverse Distance Weighting (IDW), KRIGING And SPLINE

I.INTRODUCTION

Interpolation predicts values for cells in a raster from a limited number of sample data points. It can be used to predict elevation, rainfall, chemical concentrations, noise levels, and so on for any geographic locations (Legendre et.al 1998),. In the absence of criteria for selecting the better among the available techniques, comparative analysis is required. This paper compares three spatial interpolation techniques ‘Inverse Distance Weighting (IDW), KRIGING and SPLINE’ with the goal of determining which method creates the best representation of reality for calculated Water Quality Index (WQI). The benefits and limitations of these commonly used interpolation methods (Burrough, 1998) are also discussed.

Interpolation is a method or mathematical function that estimates the values at locations where no measured values are available. Spatial interpolation assumes that the attribute data are continuous over space. This allows the estimation of the attribute at any location within the data boundary. Another assumption is the attribute is spatially dependent, indicating that the closer values together are more likely to be similar than the values farther apart. These assumptions allow for the spatial interpolation methods to be formulated. The goal of spatial interpolation is to create a surface that is intended to best represent empirical reality thus the method selected must be assessed for accuracy (Anderson et.al 2001).

The IDW (Inverse Distance Weighted) tool uses a method of interpolation that estimates cell values by averaging the values of sample data points in the neighborhood of each processing cell. The closer a point is to the center of the cell being estimated, the more influence, or weightage in the calculation process.

Kriging is an advanced geostatistical procedure that generates an estimated surface from a scattered set of points with z-values. More so than other interpolation methods, a thorough investigation of the spatial behavior of the phenomenon represented by the z-values should be done before selecting the best estimation method for generating the output surface.

The Spline tool uses an interpolation method that estimates values using a mathematical function that minimizes overall surface curvature, resulting in a smooth surface that passes exactly through the input points. The Spline with Barriers tool uses a method similar to the technique used in the Spline tool, with the major difference being that this tool honors discontinuities encoded in both the input barriers and the input point data.

Many researchers have used GIS techniques to analyze the groundwater potential zone using different criteria (Conforti, Aucelli, Robustelli, & Scarciglia, 2011), drainage pattern (Shankar & Mohan, 2005), lineament (Mondal, Pandey and Garg, 2008), (Dunhill, 2012), and soil (Giordano & Liersch, 2012) etc. Several researches have been done on comparing different interpolation methods in a variety of situations using GIS in particular areas (Chao, Chou, Yang, Chung, & Wu, 2009; Chiang et al., 2010; Iescheck, Sluter, & Ayup-Zouain, 2008) such as groundwater depth, groundwater contamination, groundwater quality etc. Geostatistics provides a set of statistical tools for analyzing spatial variability and spatial interpolation. These techniques generate not only prediction surfaces but also error or uncertainty surface. Many geostatistical interpolation methods have been widely used in the past decades such as Kriging Splines and IDW for interpolation of yields or contaminants in groundwater (Kumar, 2007). An attempt has been made to select a better interpolation method from different interpolation methods namely Inverse Distance Weighting (IDW), Splines and Kriging, and it is also used to assess the Water Quality Index of the study area.

Water Quality Index is one of the easy ways to communicate information on the quality of water to the citizens and policy makers. Thus, it has become an important parameter for the assessment and management of groundwater. A Water Quality Index (WQI) may be defined as a rating, reflecting the composite influence of a number of water quality parameters on the overall quality of water. The main objective of WQI is to express complex water quality data in simple manner that is understandable and usable by the public.

Study Area

Bangalore city is located between latitude 12^o46’N to 13^o11’N and longitude 77^o24’E to 77^o48’E, covering over an area of approximately 725 sq-km. The Peenya Industrial area of Bangalore city was considered for the study, Peenya Industrial area covers in the part of the Survey of India Topo sheet No. 57 H/9. It comprises of 12.15 sq-kms, lies in the Northern part of Bangalore City and houses more than 3000 industries dominated by chemical, leather, pharmaceutical, plating, polymer and allied industries. This industrial area was established in late 1970s. Location of the study area is as shown in Figure 1.

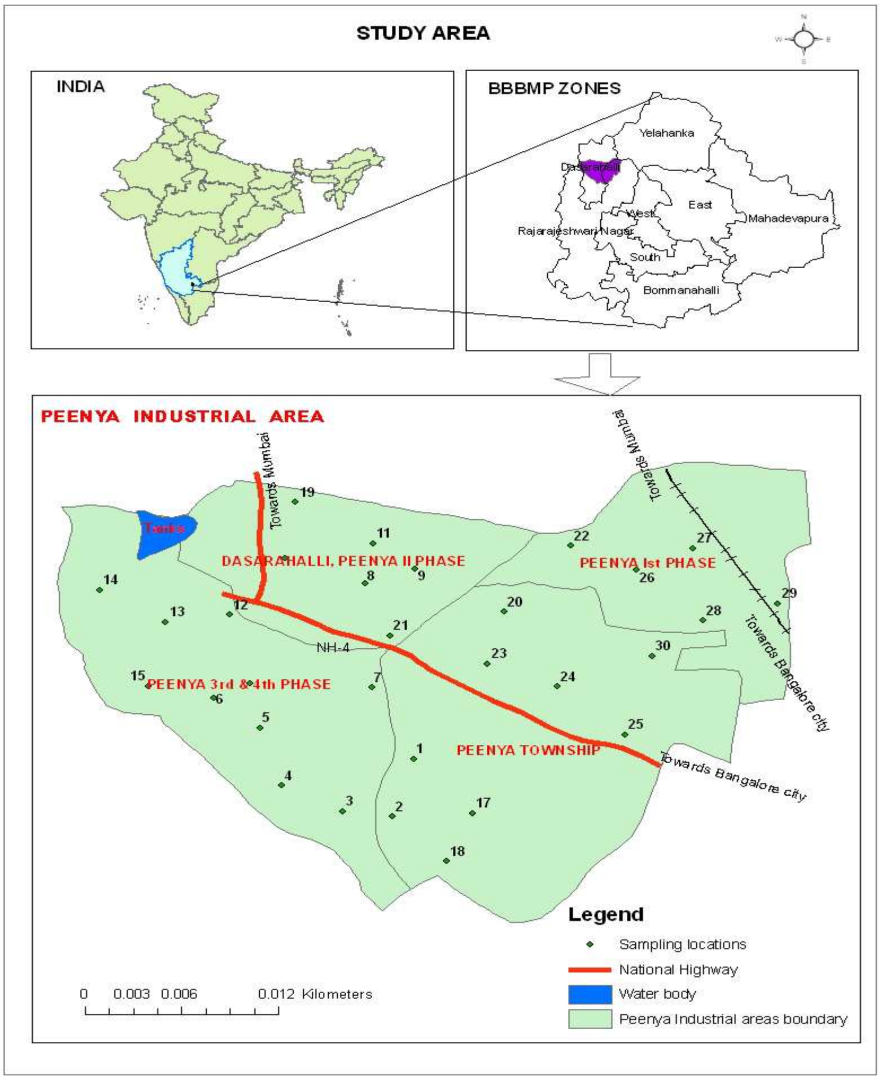


Figure 1: Location Map of the Study Area

The mean annual rainfall of Bangalore City is 859.6 mm. Most of it is received during the southwest monsoon between June and September and during northwest monsoon period. September is the wettest and January the driest month of the year. Ambient air temperature generally varies between 14°C and 34°C. The lowest temperature ever recorded was 7.8°C and the highest 38.9°C. April is the hottest month of the year while December to January marks the coldest period. The lowest relative humidity of 30% is noticed during the month of March and the highest between June and October, reaching up to 85%.

MATERIALS AND METHODS

The groundwater samples from thirty different locations were collected during pre-monsoon and post monsoon seasons in the year 2010 and analyzed for physico-chemical parameters as per standard methods for examination of water and wastewater (APHA, 2002). pH and Electrical Conductivity were determined at the time of sample collection. The results obtained were assessed in accordance with 'Indian Standard Drinking Water Specification IS 10500: 1991 of Bureau of Indian Standards 2003. Water Quality Index was calculated by selecting fifteen drinking water quality parameters. The geographic coordinates were taken for different locations using GPS and were imported into GIS software as a point layer. Each sample point was assigned a unique code and stored in the attribute table. Data for WQI was linked to the sampling locations using the geodatabase creation function of ArcGIS 10.1 software. The geodatabase was used to generate the spatial distribution maps of WQI by three different methods viz. IDW, KRIGING and SPLINE. The collected data were analyzed using geographical information systems, with the objective of using interpolation techniques to estimate the spatial distribution of Water Quality Index (WQI).

Assessment Methods: Different measures of fit may be used to determine how well an interpolated map represents the observed data. With most methods, some measure may be constructed of the closeness of the interpolated values *E*(*x, y*) to the values *Ei* observed at control sites. In this work, the mean absolute error ‘’MAE", the mean squared error ‘’MSE" and the Euclidean distance ‘’*D*", between a set of control points (on which measurements of WQI were done) were calculated and the interpolated results. All the sampling locations are considered as control points and 10 interpolation points have been established within a buffer of 200m for all 30 control points (Figure 2). The WQI values have been extracted from the raster surface to the interpolated points established. The equations used in the calculations were:

$$MAE = \frac{1}{n}\sum_{i=1}^{n}|E(x,y) - E_i| \quad \text{-------} \quad 1$$

$$MSE = \frac{1}{n}\sum_{i=1}^{n}(E(x,y) - E_i)^2 \quad \text{-------} \quad 2$$

$$D = \sqrt{\sum_{i=1}^{n}(E(x,y) - E_i)^2} \quad \text{-------} \quad 3$$

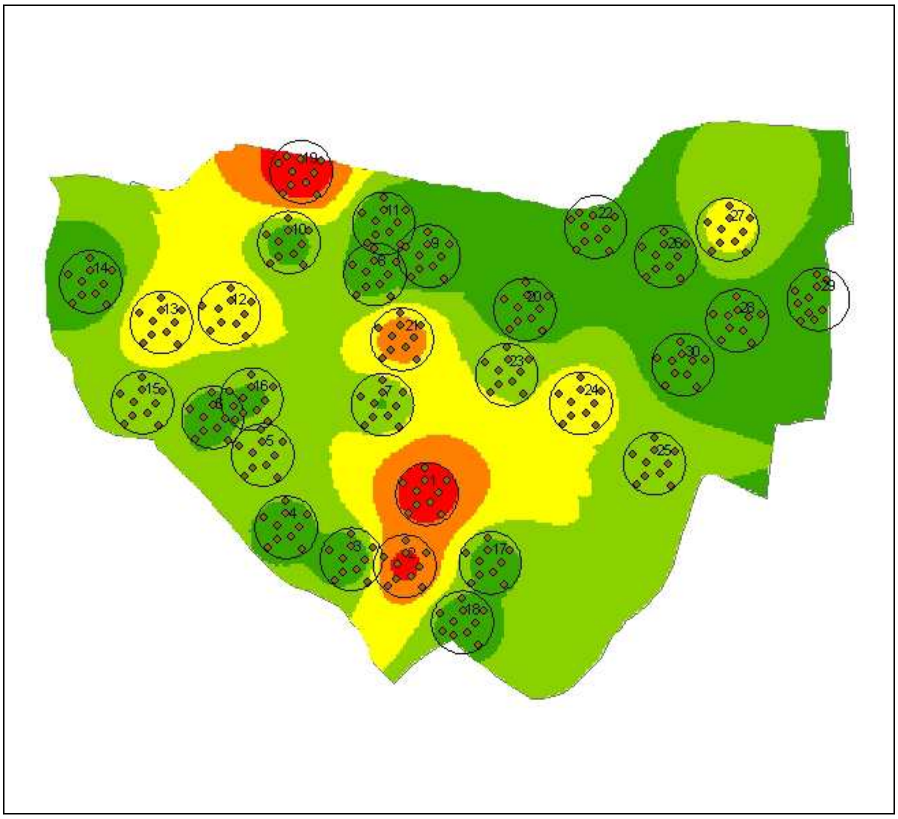


Figure 2: Establishment of Interpolated Points around Sampling Locations

RESULTS AND DISCUSSIONS

The interpolation process was carried out using: IDW, SPLINES and KRIGING method. The results of each interpolation process were represented over the study area as shown in Figure 3. Also the computation of extent of spatial distribution of different categories of Water Quality Index (WQI) was derived from the resultent maps of IDW, KRIGING and SPLINE interpolation methods and the same is shown in Table 1.

The Water Quality Indices for all the 30 sampling stations were calculated using the groundwater quality data as per the standard procedure. It was observed that, the overall quality of the groundwater of the area was reflected with the values of WQI ranged between 12.23 and 394. Nearly 35 % of the samples exceeded the value of WQI 100, the upper limit of WQI for drinking water.

Table 1: Results of the Computation of Area in to Different Categories on the Basis of Water Quality Index by Interpolation Methods

Interpolation Methods	**Spatial Distribution of Different Wqi Categories in Sq-Km**									
	0-25 Excellent		**26-50 Good**		**51-75 Poor**		**76-100 Very Poor**		**>100 Unfit For Drinking**	
	Prm	**Pom**	**Prm**	**Pom**	**Prm**	**Pom**	**Prm**	**Pom**	**Prm**	**Pom**
IDW	0.06	0.04	0.99	0.62	3.4	2.52	3.66	2.76	4.04	6.21
KRINGING	0.07	0.001	0.90	0.89	2.95	1.77	3.51	2.51	4.72	6.98
SPLINE	3.2	2.99	1.48	1.37	1.55	1.31	1.32	1.18	4.60	5.30

PrM: Pre-Monsoon, PoM: Post--Monsoon

The high value of WQI may be attributed due to higher concentrations of iron, nitrate, total dissolved solids, hardness and fluorides beyond desirable limits in the groundwater samples. During post monsoon season, groundwater of about 6.21 Sq Km area was unfit for drinking. The analysis reveals that the groundwater of the Peenya industrial area needs some treatment before using it for domestic applications and it also necessitates for protection from the risk of further contamination. By using GIS software the thematic maps have been generated based on the results obtained for the entire study area separately for pre monsoon and post monsoon seasons, thus making GIS as a decision support system. The spatial distribution of WQI is depicted in the Figure 2.

The measures of fit carried out, yielded the results shown in Table 2. It shows that within the interpolation methods used, the IDW method is the one that best estimated the measurement results of the Water Quality Index(WQI). The relationship between the interpolated values and true observed data was also evaluated using the interpolated raster surface created by ARCGIS as shown in Figure 3. The comparison of cross-validation plots provided by three interpolation methods is shown in Figure 4. It shows that within interpolation methods used, the IDW is one that best estimated the measurements results of the Water Quality Index.

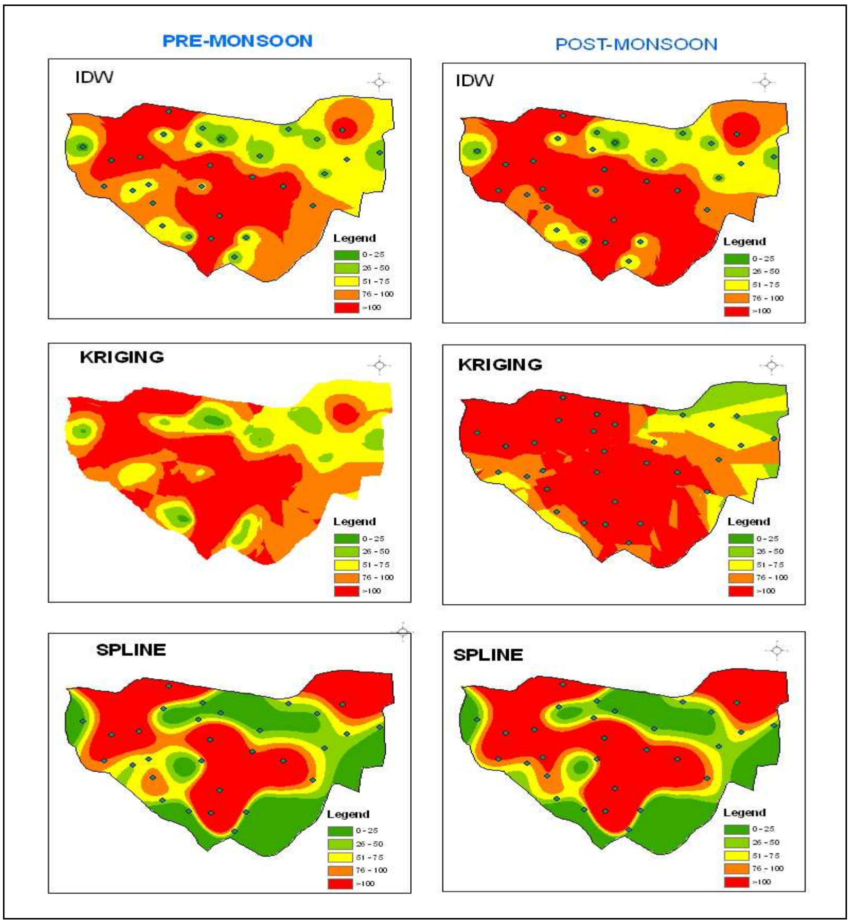


Figure 3: Spatial Distribution of Water Quality Index

Table 2: Results of the Measures of Fit Applied to the Interpolation Methods

Data Sets for the Season: Pre- Monsoon									
Observed Sampling Location	Measures of Fit								
	IDW			KRINGING			SPLINE		
	MAE	MSE	D	MAE	MSE	D	MAE	MSE	D
1	51.86	3471.19	186.31	59.00	4106.14	202.64	23.14	1071.12	103.49
2	50.65	2659.40	163.08	48.98	2693.70	164.12	47.76	3301.67	181.71
3	40.14	2253.78	150.13	41.00	2884.12	169.83	54.40	4475.47	211.55
4	10.59	146.94	56.25	15.42	359.32	23.45	24.86	908.25	30.93
5	2.37	12.31	11.09	8.11	83.60	28.91	6.63	78.90	28.09
6	12.50	195.60	44.23	11.70	168.04	40.99	6.72	72.13	26.86
7	18.96	488.39	69.88	20.12	580.33	76.18	36.55	1645.35	128.27
8	12.22	261.54	51.14	21.76	807.03	89.83	23.81	827.76	90.98
9	20.00	522.83	72.31	25.39	908.33	95.31	23.19	825.54	90.86
10	25.96	913.93	95.60	27.14	1463.95	120.99	28.65	1380.28	117.49
11	14.43	284.35	53.32	17.77	587.60	76.66	20.42	666.33	81.63
12	12.18	195.49	44.21	11.01	203.01	45.06	16.71	389.18	62.38
13	16.34	348.28	59.02	16.08	371.70	60.97	10.05	163.37	40.42

14	15.70	356.30	59.69	27.19	853.48	92.38	24.23	851.27	92.26
15	2.89	14.01	11.84	6.84	59.21	24.33	11.10	184.72	42.98
16	5.47	51.50	22.69	8.49	130.56	36.13	4.23	36.93	19.22
17	31.28	1001.16	100.06	26.02	1094.69	104.63	68.13	5976.82	244.48
18	18.72	467.81	68.40	26.18	919.21	95.88	63.82	5393.14	232.23
19	57.22	4721.06	217.28	79.30	7281.35	269.84	79.56	8284.34	287.83
20	14.52	288.97	53.76	17.38	363.53	60.29	11.95	233.38	48.31
21	39.57	2016.21	141.99	36.21	1496.48	122.33	22.65	835.60	91.41
22	2.34	7.21	8.49	6.84	66.74	25.83	11.15	177.41	42.12
23	4.29	42.62	20.64	9.48	148.92	38.59	16.80	372.83	61.06
24	12.54	205.26	45.31	13.26	200.37	44.76	8.87	130.01	36.06
25	1.55	4.66	6.83	3.67	18.47	13.59	12.86	266.71	51.64
26	10.53	147.53	38.41	13.10	248.02	49.80	11.87	223.81	47.31
27	17.19	405.24	63.66	20.38	492.94	70.21	19.99	526.52	72.56
28	1.68	4.62	6.79	3.41	26.77	16.36	7.07	83.18	28.84
29	5.47	38.68	19.67	10.13	116.19	34.09	18.24	406.55	63.76
30	5.50	46.56	21.58	7.93	107.16	32.73	4.95	40.80	20.20
Mean	**17.82**	**719.11**	**65.45**	**21.31**	**961.37**	**77.56**	**24.01**	**1327.65**	**89.23**
Data Sets for the Season: Post- Monsoon									
Observed Sampling Location	**Measures of Fit**								
	IDW			**KRINGING**			**SPLINE**		
	MAE	**MSE**	**D**	**MAE**	**MSE**	**D**	**MAE**	**MSE**	**D**
1	55.08	3916.62	59.05	235.18	55323.69	743.80	25.90	1313.29	114.60
2	55.89	4073.98	201.84	188.05	35387.59	594.87	52.19	4113.49	202.82
3	45.67	2911.61	170.63	80.88	6637.87	257.64	59.51	5344.78	231.19
4	13.36	233.30	70.26	32.34	1160.69	146.50	25.36	979.76	30.25
5	2.36	8.82	9.39	21.48	565.56	75.20	6.94	69.91	26.44
6	12.03	189.65	43.55	8.90	124.30	35.26	12.52	232.81	48.25
7	21.03	598.13	77.34	50.41	2688.44	163.96	54.05	5670.79	238.13
8	9.58	182.36	42.70	56.48	3213.61	179.27	27.59	1037.38	101.85
9	23.53	730.37	85.46	97.96	9607.02	309.95	29.19	1240.59	111.38
10	29.30	1152.80	107.37	95.99	9271.13	304.49	27.87	1352.28	116.29
11	17.74	418.93	64.73	97.98	9640.30	310.49	19.42	623.13	78.94
12	8.04	85.40	29.22	24.90	639.41	79.96	16.01	364.37	60.36
13	16.99	374.92	61.23	55.28	3091.22	175.82	9.45	145.42	38.13
14	17.10	421.91	64.95	111.63	12539.29	354.11	26.39	1017.35	100.86
15	1.42	4.30	6.56	27.94	935.79	96.74	16.16	394.55	62.81
16	5.75	62.99	25.10	14.54	236.13	48.59	8.50	115.95	34.05
17	22.98	728.98	85.38	59.39	3540.20	188.15	73.34	6909.32	262.86
18	19.16	491.21	70.09	52.35	2752.61	165.91	69.15	6337.92	251.75
19	60.48	5280.74	229.80	238.67	56988.15	754.90	85.57	9605.1	309.92

								5	
20	16.52	377.29	61.42	52.30	2851.84	168.87	15.28	364.96	60.41
21	41.91	2273.28	150.77	114.67	13241.80	363.89	21.76	784.48	88.57
22	3.95	20.67	14.38	7.32	102.68	32.04	13.04	245.43	49.54
23	6.60	100.41	31.69	7.13	76.06	27.58	19.53	505.43	71.09
24	11.26	166.72	40.83	42.64	1849.87	136.01	11.13	199.79	44.70
25	1.14	3.12	5.58	14.07	269.54	51.92	11.86	243.07	49.30
26	13.17	232.96	48.27	28.54	835.35	91.40	16.32	406.33	63.74
27	22.26	678.49	82.37	112.08	12573.72	354.59	23.86	753.57	86.81
28	1.12	2.75	5.24	4.85	37.63	19.40	9.62	142.30	37.72
29	7.31	69.40	26.34	30.42	1227.36	110.79	21.68	607.54	77.94
30	8.02	93.74	30.62	38.43	1490.34	122.08	3.37	28.55	16.90
Mean	**19.03**	**862.86**	**66.74**	**66.76**	**8296.64**	**215.47**	**27.09**	**1704.9**	**102.25**

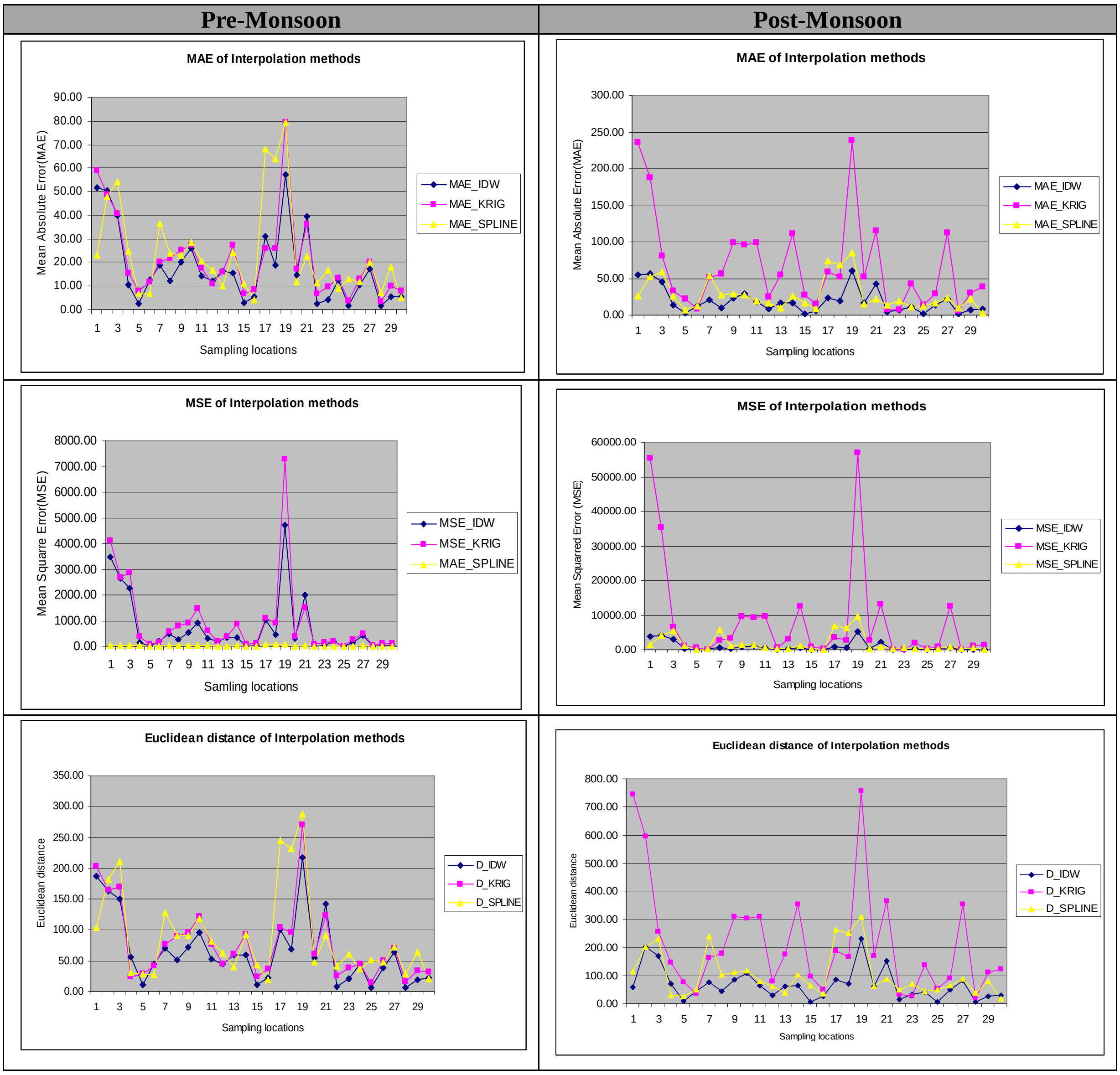
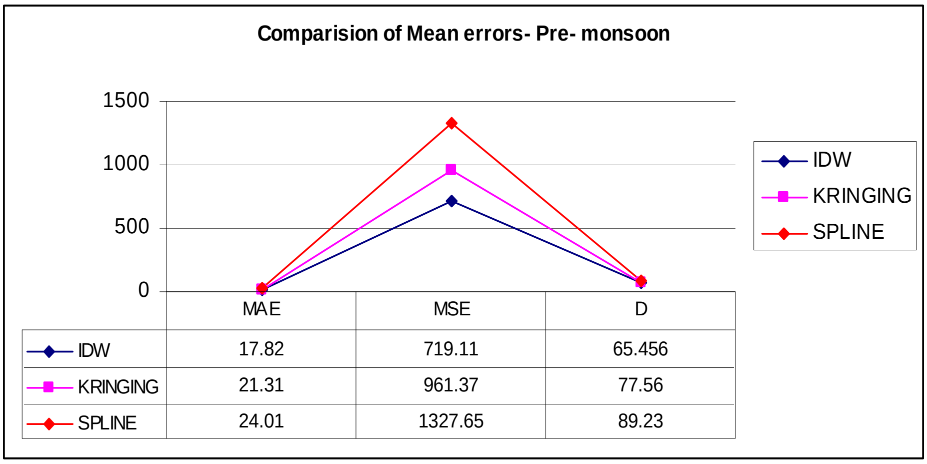


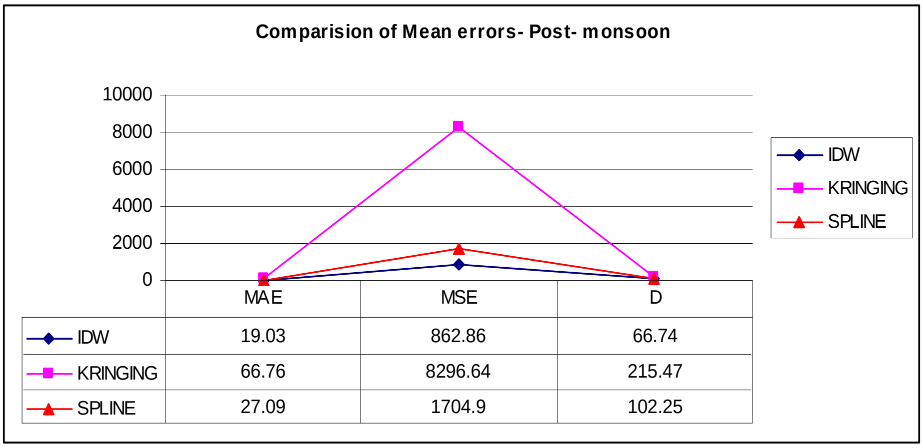
Figure 4: Comparison of Interpolation Methods for Water Quality Index

The error distribution in the calculation of the Mean error of Water Quality Index using the spatial interpolation methods IDW, KRIGING and SPLINES. The measures of the fit carried out, yielded the results shown in Figure 5 & 6. It shows that within the interpolation methods used, the IDW method is the one that best estimated the measurement results of the Water Quality Index.


Comparision of Mean errors- Pre- monsoon

	MAE	MSE	D
IDW	17.82	719.11	65.456
KRINGING	21.31	961.37	77.56
SPLINE	24.01	1327.65	89.23

Figure 5: Comparison of Mean Errors- Pre-Monsoon


Comparision of Mean errors- Post- monsoon

	MAE	MSE	D
IDW	19.03	862.86	66.74
KRINGING	66.76	8296.64	215.47
SPLINE	27.09	1704.9	102.25

Figure 6: Comparison of Mean Errors- Post-Monsoon

CONCLUSIONS

This study has shown that IDW interpolation method is most likely to produce the best estimation of a continuous surface of the average Water Quality Index (WQI). The IDW method exactness was superior to the one shown by the SPLINES and KRIGING techniques.

The analysis of groundwater samples from the Peenya Industrial Area has shown that almost, 35% of the samples are unfit for drinking purpose. The analyzed data clearly indicates that the groundwater is getting polluted at an alarming rate due to rapid industrialization. From the perspective of improving the quality of groundwater in the area and protecting the people from the troubles of groundwater contamination, and it is absolutely essential to initiate measures to check the pollution of industrial effluents through strict enforcement of legislation for industries, setting up effluent treatment plants. Replacing of the damaged pipelines and lining of sewer drains is necessary to prevent the leakage of sewage in pipes and seepage through unlined channels and to prevent the mixing of sewage with groundwater. Water treatment facility shall be established in order to provide potable water to the residents of the area.

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