Chapter: 4

Materials and Methodology

4.1 General

The objective of this study is to carry out an assessment of groundwater quality around the open dumping sites with a special focus within 1.5 km range from the dumping sites because most of the researcher were observed the impact of the dumping sites on groundwater within this range [1][2]. Physico-chemical analysis of MSW leachate and groundwater samples was carried out during the pre-and post-monsoon period. Leachate pollution index and water quality index were evaluated to know the leachate characteristic and status of groundwater quality respectively in the study area. Visual modflow software was used for groundwater modelling which is used for predicting the groundwater flow direction and fate of leachate contaminants. This developed model was calibrated and validated with observed field data. Some remedial measure would also discuss to improve groundwater quality around the municipal dumping sites.

4.3 Data collection

Spatial and non-spatial data were collected for the study area. Spatial data is also known as geospatial data. These data are represents in a geographical space such as location, size and shape of an object on the Earth. To acquire these data survey was done in the study area.

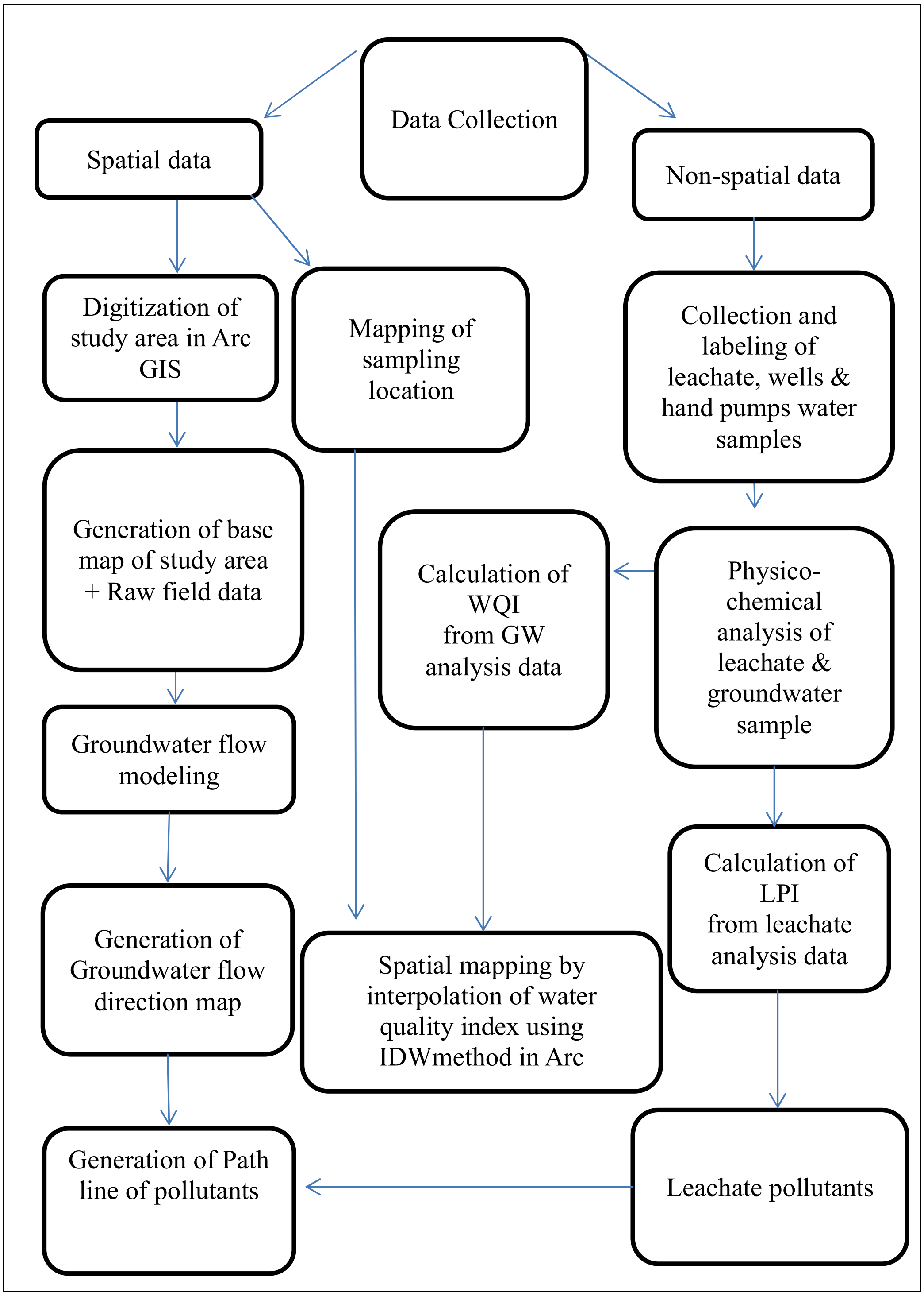
Non-spatial data are the data that are not linked with any location.These data generally stored in number or character and information about the what, where, and why. Generally, it provides characteristic of spatial data.

4.3.1 Spatial data collection

In spatial data, location and elevation of landfill site, open wells and hand pumps was collected using DGPS instrument.

4.2Flowchart of the methodology

Stepwise research methodology is briefly shown in following flow chart.



In spatial data collection data is stored with their coordinate system and elevation which is used in digitization of study area and generation of a base map of study area. This map is incorporated in visual MODFLOW software for groundwater flow and transport modeling.

4.3.1.1 Land use and land cover of study area

Any alterations in land use land cover (LU/LC) are possible to result in change in groundwater quality. LU/LC study can be used by the field investigators and modellers in evaluating the groundwater vulnerability[3].Land use/land cover map of study area was prepared by using supervised classification (maximum likelihood) method in ENVI software. Planet imaginary data of three meter spatial resolution was used for image classification. The land use/land cover categories classified as Ganges River, canopy, agriculture, barren land, settlement and sandy land.

Table 4.1 LU/LC classification of Ramna study area

S. No.	LU/LC categories	Area (km^2)	% LU/LC categories
1	Ganges river	3.27	15
2	Canopy	2.1	10
3	Agriculture	11.34	51
4	Barren land & settlement	0.91	4
5	Sandy	4.41	20
	Total Area	22.03	

Ganges River covers an area of 15 % of total area. Maximum area i.e. 51% is covering by agricultural filed while minimum i.e. 4% area is cover by barren land and settlement. Canopy and sandy area covers 10% and 20 % of total study area respectively as shown in table 4.1

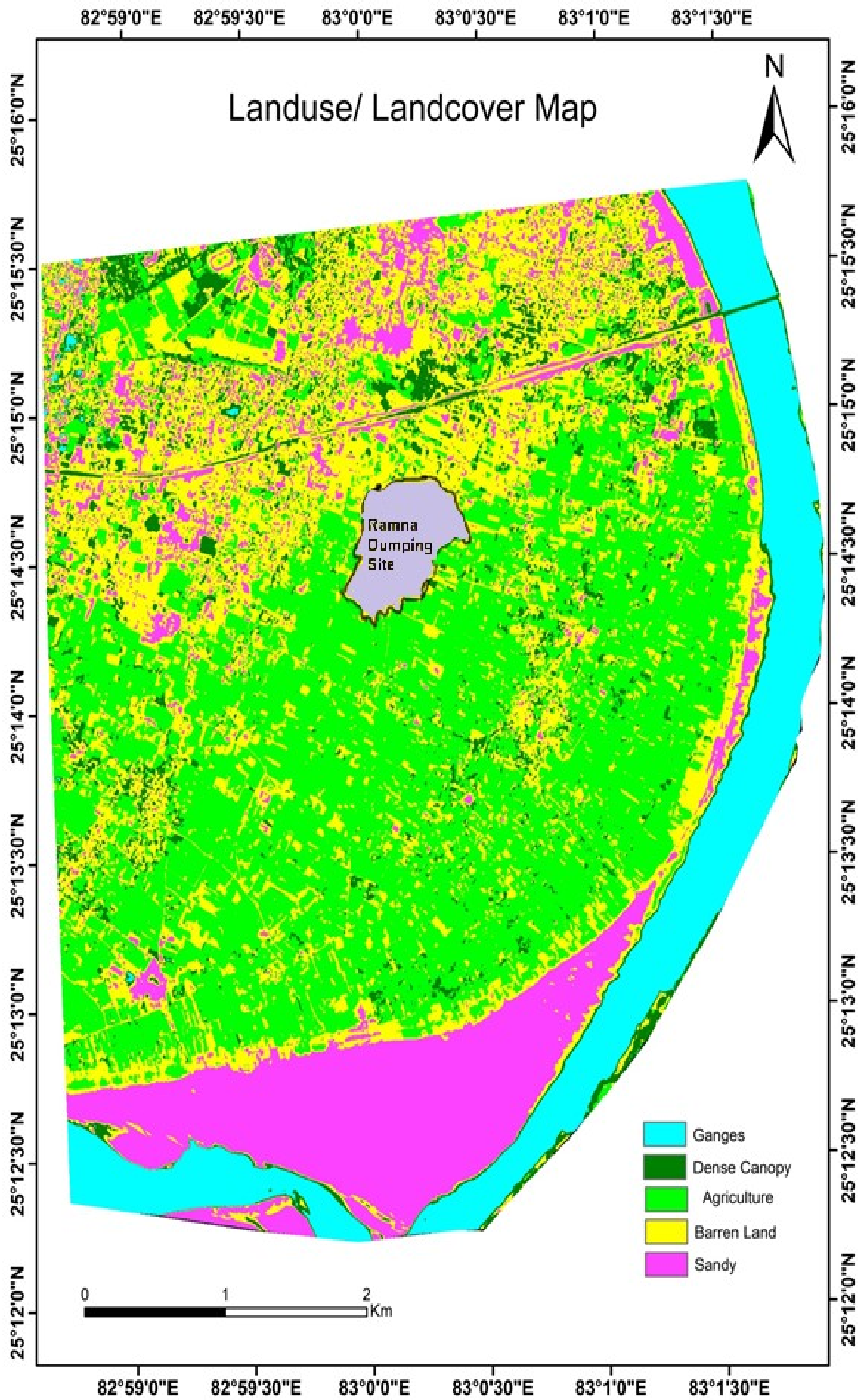


Figure 4.1 Land-use land-cover map of study area.

LU/LC pattern can influences the groundwater characteristic of the study area by natural weathering reaction that causes the change in the level of some cations such as Ca^{2+},Mg^{2+},$Na^{+}Cl^{-}$and SO_4^{2+}[4]. Increased recharge rate associated to LU/LC change responsible for the movement of salt in unsaturated zone of aquifer that affects the degrading groundwater quality[5].

4.3.1.2 Digital elevation map of study area

The digital elevation model (DEM) was prepared by SRTM (Shuttle Radar Topography Mission) with spatial resolution of 30 meter using ARC GIS 10.1 software. DEM is considered as a practical substitute to traditional surveys and manual estimation of topographic maps.Topography map plays an significant role in the distribution and flux of water and energy within natural landscapes [6]. The elevation of study area ranged from maximum 92 meter to minimum 44 meter shown in figure 4.2. The regional slope of the study area is from southwest to north east direction.

4.3.1.3 Surveying of Study area

A survey has been conducted to identify potential sources of pollution. Location of different open dug wells and hand pumps are taken using Differential Global Position System (DGPS) i.e. SOKKIA GRX2 (figure 4.3). DGPS uses a network of fixed, ground-based reference stations to broadcast the difference between the positions indicated by the GPS satellite systems and the known fixed positions.These stations broadcast the difference between the measured satellite pseudo ranges and actual (internally computed) pseudo-ranges, and receiver stations may correct their pseudo ranges by the same amount. The pseudoranges produced due to atmospheric interference, discrepancies between satellite clocks and satellite orbit errors. In order to provide these corrections, a base station with a GPS (Global Position System) receiver fixed at a known position.

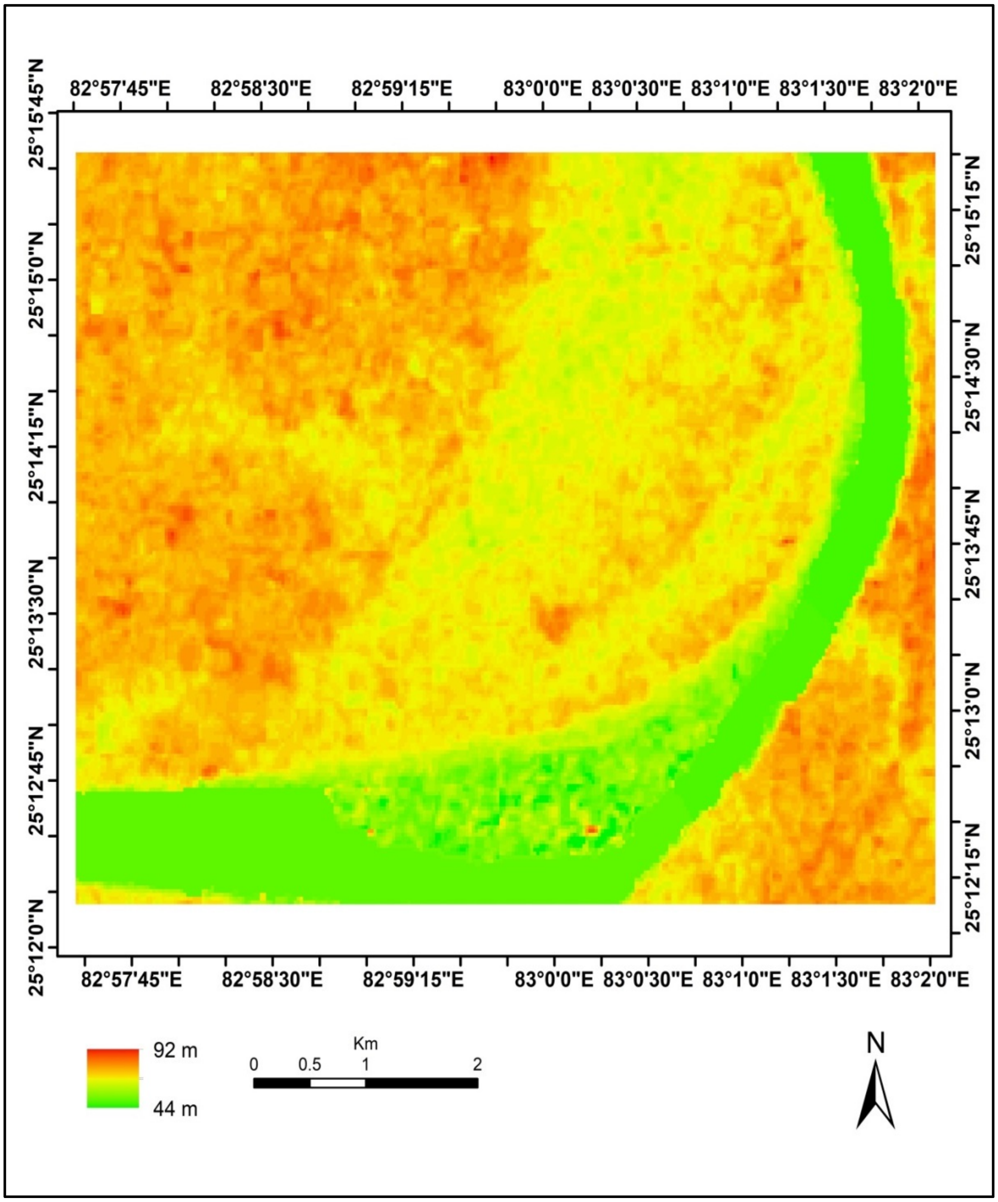


Figure 4.2 Digital elevation map of study area

Figure 4.3DGPS Surveying A) The base station B) Controller (C) Rove

This survey will give an overview of the geographical location (latitude, longitude & elevation) of the area to be monitored. The survey may include the acquisition of the following information:

a) Location map

b) Background information of the area to be a study

c) Identification of potential polluting sources

d) Water abstraction- quantity and uses

4.3.1.4 Location of observation wells

In the year 2015 and 2016 survey was done to know the water table fluctuation in the study area. Open well water level was measure in pre-monsoon and post- monsoon period. 56 open wells were selected for groundwater table monitoring during pre- and post-monsoon period. Observed groundwater table data used in groundwatermodeling for analysis of groundwater flow systems around Ramna municipal dumping site. The depth of the observation wells from the ground surface fluctuated from minimum 2.1 meters to maximum 15.1 meters in the year 2015 while in the year 2016 it varied from minimum 0.8 meters to maximum 16.8 meters in the year 2016.

Figure 4.4 Taking geo-location of open well by DGPS

Table 4.2 Groundwater table monitoring data in 2015

Well	Latitude	Longitude	Ground elevation (m)	Depth June 2015 (m)	Pre-monsoon water table(m)	Depth November 2015 (m)	Post monsoon water table (m)
W1	25°14'50.30"N	82°59'43.06"E	73.65	10.3	63.35	5.3	68.35
W2	25°14'50.30"N	82°59'43.06"E	76.71	11.6	65.11	5.1	71.61
W4	25°14'50.30"N	82°59'43.06"E	75.06	14.9	60.16	6.5	68.56
W5	25°14'50.30"N	82°59'43.06"E	79.82	10.1	69.72	4.1	75.72
W6	25°14'50.30"N	82°59'43.06"E	77.36	12.3	65.06	6.1	71.26

Well	Latitude	Longitude	Ground elevation (m)	Depth June 2015 (m)	Pre-monsoon water table(m)	Depth November 2015 (m)	Post monsoon water table (m)
W7	25°14'50.30"N	82°59'43.06"E	77.6	11.4	66.2	7.1	70.5
W8	25°14'50.30"N	82°59'43.06"E	78.15	9.4	68.75	7.3	70.85
W9	25°14'50.30"N	82°59'43.06"E	75.34	13.5	61.84	4.4	70.94
W10	25°14'50.30"N	82°59'43.06"E	80.02	12.7	67.32	9.1	70.92
W11	25°14'50.30"N	82°59'43.06"E	75.69	13.3	62.39	7.6	68.09
W12	25°14'50.30"N	82°59'43.06"E	77.89	12.3	65.59	9.4	68.49
W14	25°14'50.30"N	82°59'43.06"E	77.41	12.1	65.31	7.4	70.01
W16	25°14'50.30"N	82°59'43.06"E	76.74	12.1	64.64	8.1	68.64
W17	25°14'50.30"N	82°59'43.06"E	78.28	13.5	64.78	7.3	70.98
W18	25°14'50.30"N	82°59'43.06"E	78.99	13.1	65.89	7.2	71.79
W19	25°14'50.30"N	82°59'43.06"E	76.48	12.7	63.78	4.2	72.28
W20	25°14'50.30"N	82°59'43.06"E	76.73	8.6	68.13	5.8	70.93
W21	25°14'50.30"N	82°59'43.06"E	73.4	13.7	59.7	4.6	68.8
W22	25°14'50.30"N	82°59'43.06"E	79.34	13.8	65.54	8.5	70.84
W23	25°14'50.30"N	82°59'43.06"E	79.02	8.4	70.62	7.3	71.72
W24	25°14'50.30"N	82°59'43.06"E	78.08	11.6	66.48	9.7	68.38
W25	25°14'50.30"N	82°59'43.06"E	73.81	13.7	60.11	3.7	70.11
W26	25°14'50.30"N	82°59'43.06"E	74.08	14.2	59.88	5.9	68.18
W27	25°14'50.30"N	82°59'43.06"E	75.04	11.7	63.34	4.5	70.54
W28	25°14'50.30"N	82°59'43.06"E	76.07	13.3	62.77	9.8	66.27
W29	25°14'50.30"N	82°59'43.06"E	72.56	10.1	62.46	6	66.56
W30	25°14'50.30"N	82°59'43.06"E	75.74	12.5	63.24	9.3	66.44
W31	25°14'50.30"N	82°59'43.06"E	76.11	13.8	62.31	9.6	66.51
W32	25°14'50.30"N	82°59'43.06"E	74.94	13.7	61.24	8.9	66.04
W33	25°14'50.30"N	82°59'43.06"E	78.36	14.1	64.26	9.7	68.66
W34	25°14'50.30"N	82°59'43.06"E	75.94	13.6	62.34	9.8	64.14
W35	25°14'50.30"N	82°59'43.06"E	75.23	12.5	62.73	8.9	66.33
W36	25°14'50.30"N	82°59'43.06"E	75.27	12.3	62.97	5.8	69.47
W37	25°14'50.30"N	82°59'43.06"E	76.7	13.3	63.4	9.1	63.6
W39	25°14'50.30"N	82°59'43.06"E	74.69	12.9	61.79	8.3	66.39
W40	25°14'50.30"N	82°59'43.06"E	76.15	14.8	61.35	9.4	66.75
W41	25°14'50.30"N	82°59'43.06"E	75.22	14.6	60.62	7.7	67.52
W42	25°14'50.30"N	82°59'43.06"E	72.34	12.6	59.74	6.2	66.14
W44	25°14'50.30"N	82°59'43.06"E	70.89	11.5	59.39	5.8	65.09
W45	25°14'50.30"N	82°59'43.06"E	77.25	11.7	65.55	9.4	67.85
W46	25°14'50.30"N	82°59'43.06"E	72.67	12.9	59.77	7.6	65.07
W47	25°14'50.30"N	82°59'43.06"E	73.79	11.7	62.09	7.3	66.43
W48	25°14'50.30"N	82°59'43.06"E	75.95	12.1	63.85	8.3	67.65
W49	25°14'50.30"N	82°59'43.06"E	74.73	14.8	59.93	7.3	67.43
W50	25°14'50.30"N	82°59'43.06"E	75.97	14.2	61.77	6.8	69.17
W51	25°14'50.30"N	82°59'43.06"E	80.8	14.1	66.7	5.1	75.7
W52	25°14'50.30"N	82°59'43.06"E	75.92	14.6	61.32	9.1	66.82
W54	25°14'50.30"N	82°59'43.06"E	80.35	13.1	67.25	8.9	65.45
W55	25°14'50.30"N	82°59'43.06"E	80.35	11.6	68.75	6.1	74.25
W56	25°14'50.30"N	82°59'43.06"E	77	15.1	61.9	6.8	70.2

Table 4.3 Groundwater table monitoring data in 2016

Wells	Latitude	Longitude	Ground elevation (m)	Depth June 2016 (m)	Pre-Monsoon table (m)	Depth November2016 (m)	Post-Monsoon table (m)
W1	25°14'50.30"N	82°59'43.06"E	73.65	16.8	56.85	3.3	70.35
W2	25°14'50.30"N	82°59'43.06"E	76.7	16.5	60.2	2	74.7
W3	25°14'50.30"N	82°59'43.06"E	76.71	16.2	60.51	2.2	74.51
W4	25°14'50.30"N	82°59'43.06"E	75.05	16	59.05	4.3	70.75
W5	25°14'50.30"N	82°59'43.06"E	79.82	15.9	63.92	2.5	77.32
W6	25°14'50.30"N	82°59'43.06"E	77.36	15.9	61.46	3.1	74.26
W7	25°14'50.30"N	82°59'43.06"E	70.59	15.9	54.69	3.5	67.09
W8	25°14'50.30"N	82°59'43.06"E	85.15	15.8	69.35	6.3	78.85
W9	25°14'50.30"N	82°59'43.06"E	75.34	15.6	59.74	3.5	71.84
W10	25°14'50.30"N	82°59'43.06"E	84.02	15.5	68.52	8	76.02
W11	25°14'50.30"N	82°59'43.06"E	73.69	15.5	58.19	6.2	67.49
W12	25°14'50.30"N	82°59'43.06"E	77.88	15.4	62.48	7.9	69.98
W13	25°14'50.30"N	82°59'43.06"E	77.5	15	62.5	5.8	71.7
W14	25°14'50.30"N	82°59'43.06"E	77.4	14.9	62.5	2.5	74.9
W15	25°14'50.30"N	82°59'43.06"E	71.75	14.5	57.25	4.1	67.65
W16	25°14'50.30"N	82°59'43.06"E	76.74	14.3	62.44	3.4	73.34
W17	25°14'50.30"N	82°59'43.06"E	78.28	14.1	64.18	2.4	75.88
W18	25°14'50.30"N	82°59'43.06"E	78.99	14.1	64.89	5.2	73.79
W19	25°14'50.30"N	82°59'43.06"E	76.48	14	62.48	3.7	72.78
W20	25°14'50.30"N	82°59'43.06"E	76.72	13.7	63.02	2.1	74.62
W21	25°14'50.30"N	82°59'43.06"E	73.39	13.1	60.29	9.1	64.29
W22	25°14'50.30"N	82°59'43.06"E	79.34	13	66.34	9.3	70.04
W23	25°14'50.30"N	82°59'43.06"E	79.02	12.8	66.22	8.8	70.22
W24	25°14'50.30"N	82°59'43.06"E	78.07	12.6	65.47	7.6	70.47
W25	25°14'50.30"N	82°59'43.06"E	73.81	12.5	61.31	7.6	66.21
W26	25°14'50.30"N	82°59'43.06"E	74.07	12.5	61.57	7.6	66.47
W27	25°14'50.30"N	82°59'43.06"E	75.04	12.6	62.62	8.6	66.44
W28	25°14'50.30"N	82°59'43.06"E	77.06	12.4	64.66	9.6	67.46
W29	25°14'50.30"N	82°59'43.06"E	72.56	12.2	60.36	8.6	63.96
W30	25°14'50.30"N	82°59'43.06"E	75.74	12.1	63.64	9.2	66.54
W31	25°14'50.30"N	82°59'43.06"E	76.1	11.9	64.2	9	67.1
W32	25°14'50.30"N	82°59'43.06"E	74.93	11.8	63.13	8.6	66.33
W33	25°14'50.30"N	82°59'43.06"E	78.35	11.7	66.65	8.9	69.45
W34	25°14'50.30"N	82°59'43.06"E	75.93	12.3	63.63	9.4	66.53
W35	25°14'50.30"N	82°59'43.06"E	75.22	9.8	65.42	7.9	67.32
W36	25°14'50.30"N	82°59'43.06"E	75.26	9.7	65.56	8.7	66.56
W37	25°14'50.30"N	82°59'43.06"E	76.69	9.9	66.79	9.9	66.79

Wells	Latitude	Longitude	Ground elevation (m)	Depth June 2016 (m)	Pre-Monsoon table (m)	Depth November2016 (m)	Post-Monsoon table (m)
W38	25°14'50.30"N	82°59'43.06"E	74.98	8.8	66.18	6.9	68.08
W39	25°14'50.30"N	82°59'43.06"E	74.69	9.6	65.09	8.7	65.99
W40	25°14'50.30"N	82°59'43.06"E	72.14	13.4	58.74	9.5	62.64
W41	25°14'50.30"N	82°59'43.06"E	75.22	10.1	65.12	8.2	67.02
W42	25°14'50.30"N	82°59'43.06"E	72.33	9.9	62.43	8.9	63.43
W43	25°14'50.30"N	82°59'43.06"E	72.72	13.4	59.32	8.5	64.22
W44	25°14'50.30"N	82°59'43.06"E	70.88	10.4	60.48	7.4	63.48
W45	25°14'50.30"N	82°59'43.06"E	77.25	10.1	67.15	8.1	69.15
W46	25°14'50.30"N	82°59'43.06"E	72.66	15.6	57.06	6.6	66.06
W47	25°14'50.30"N	82°59'43.06"E	73.79	11.1	62.69	7.1	66.69
W48	25°14'50.30"N	82°59'43.06"E	75.95	11.1	64.85	8.2	67.75
W49	25°14'50.30"N	82°59'43.06"E	74.73	10.2	64.53	5.2	69.53
W50	25°14'50.30"N	82°59'43.06"E	75.97	11	64.97	7	68.97
W51	25°14'50.30"N	82°59'43.06"E	80.79	10.2	70.59	4.2	76.59
W52	25°14'50.30"N	82°59'43.06"E	75.91	11.1	64.81	6.1	69.81
W53	25°14'50.30"N	82°59'43.06"E	75.91	11.1	64.81	7.2	68.71
W54	25°14'50.30"N	82°59'43.06"E	80.35	7.5	72.85	5.5	74.85
W55	25°14'50.30"N	82°59'43.06"E	80.34	8.8	71.54	5.9	74.44
W56	25°14'50.30"N	82°59'43.06"E	77	15.1	61.9	6.8	70.2

*Groundelevation is measured relative to mean sea level.

Water table value was ranged between 59.39 m to 70.62 during pre-monsoon while in post-monsoon its value fluctuates between 65.05 m to 75.72 m in year 2015 (table 4.2). In year 2016 water table value ranged between 54.69 m to 72.85 m in pre-monsoon and in post-monsoon it fluctuated between 61.96 m to 78.85 m (table 4.3).

4.3.1.5 MSW Leachate Sampling

The leachate sample was collected randomly from leachate pond near the Ramna open dumping site after the rainy season in October and November month of 2014. 500-ml properly washed and clean airtight plastic bottle was used for sampling then this sample were immediately transported to the laboratory and kept at 4˚C for physic-chemical analysis.

KarsaraMSW leachate sample was collected from the drain system after the rainy season of 2014, in clean plastic bottles made airtight by capping it then transported in the laboratory forphysico-chemicalanalysis of parameter i.e. Temperature, pH, electrical conductivity, TDS, DO, chloride, hardness, nitrate, total alkalinity, BOD_5, COD, BOD_5, COD, Ca, Mg, Na, K, fluoride, Cr, Zn, Cu, Cd, Pb, Fe, Ni, Mn, As and phosphate.

4.3.1.6 Groundwater Sampling

Samples location for groundwater quality monitoring were collected from two types of sources i. e. Open dug wells and Indian Mark-II Hand Pump as shown in figure 4.5 and 4.6.

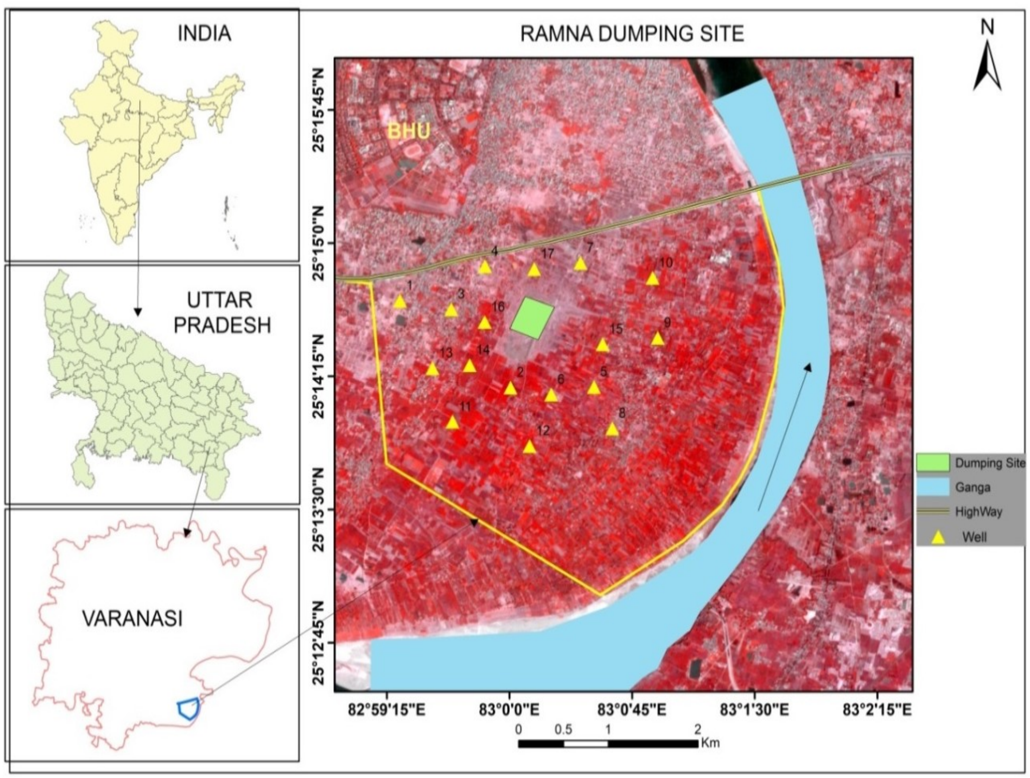


Figure 4.5 Map showing sampling location around the Ramna MSW dumping site during 2015

4.3.1.6.1 Groundwater sampling locationaround Ramna dumping site

Groundwater samples were collected randomly from open wells and hand pumps during pre- and post-monsoon period of2015 and 2016 in 500 ml properlywashed and clean plastic bottles made airtight by capping it and instantly transported to the laboratory and stored at 4°C for physic-chemical analysis. The hand pumps were continuously pumped for at least 15 minutes prior to the sampling, to ensure that groundwater to be sampled was representative of the groundwater aquifer. All the groundwater samples were collected from the drinking water sources, which are being used extensively by local peoples.

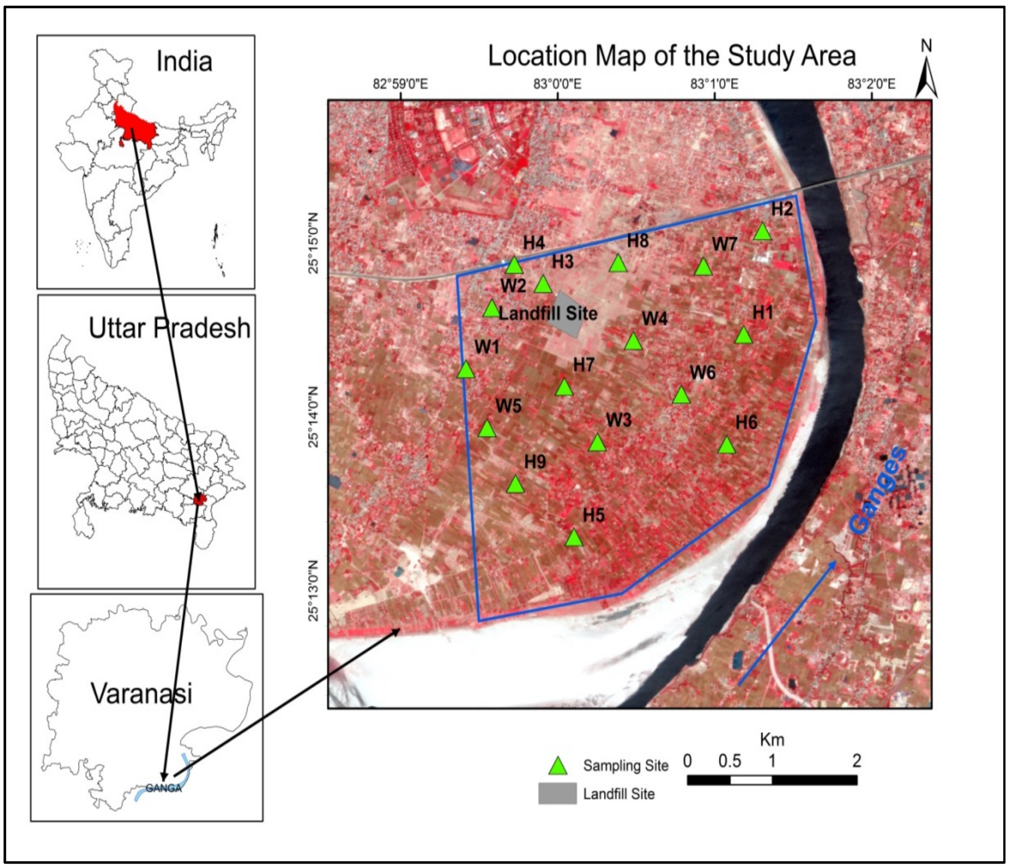


Figure 4.6 Map showing sampling location around the Ramna MSW dumping site during and 2016.

4.3.1.6.2 Groundwater sampling location around Karsara dumping site.

Groundwater samples were collected in properly washed and clean plastic bottles during the pre- and post-monsoon period of 2016 from 7 wells and 13 hand-pumps around Karsara dumping site. The depth of the Sampling wells varies from 8 to 16 meter during pre- and post-monsoon period. The distance between the dumping site and sampling wells ranges from 480 to 2220 meter.Demarcation of the location of monitoring wells and hand pumps in the study area are shown in figure 4.7.

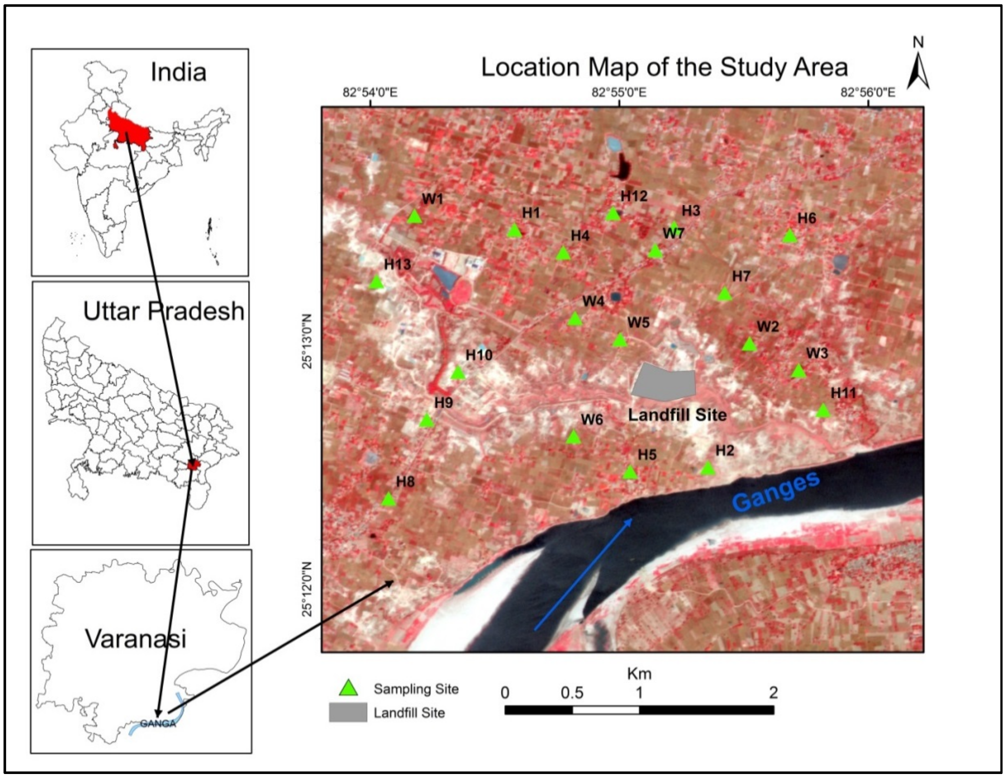


Figure 4.7 Karsara study area map showing sampling location around the MSW dumping site.

4.3.1.6.3 Photographs of groundwater sampling locations

There are some following photographs of hand pumps and open wells which have been taken during groundwater sampling period

Figure 4.8 Indian Mark-II Hand Pump for groundwater sampling

Figure 4.9 Indian Mark-II Hand Pump for groundwater sampling

Figure 4.10 Indian Mark-II Hand Pump for groundwater sampling

Figure 4.10 Indian Mark-II Hand Pump for groundwater sampling

Figure 4.11open dug well for groundwater sampling

Figure 4.12open dug well for groundwater sampling

Figure 4.13 open dug well for groundwater sampling

Figure 4.14 Open dug well for groundwater sampling

4.3.2 Non spatial data collection

In non-spatial data, leachate samples were collected from the municipal dumping site for their physico-chemicalcharacterization then this data used in the calculation of leachate pollution index (LPI).Groundwater samples were taken from the nearest open wells and handpumps located around the dumpingfor their physicochemical analysis which is used in calculation of water quality index (WQI).

4.4 Software used

To accomplish the objective of the work following software were used.

a) Spectrum survey

Spectrum survey is post processing software. This software helps in extracting the field surveying data, which has been taken from DGPS. It provides full-featured environment for processing and adjusting field observation. Mainly it used for the post processing GPS base line, exporting data to files on a computer or to a device, network adjustment, importing files on a computer.

b) Arc GIS 10.1

ARCGIS Desktop 10.1 the newest version of popular GIS software produced by ESRI (Environmental System Research Institute). It provides functionality to capture, store, query, analyse, display and output geographic information.Used to create maps, query attributes, analyze spatial relationships, and layout final projects. [7]This software used for study area mapping, digitization of study area and spatial mapping of WQI.

c) SPSS 10.1data

It isdata analysis software containing a multitude of features designed to simplify the accomplishment of a wide range of data. SPSS means statistical package for social science. It is well suited to evaluating data from surveys and database. This software mainly used in the descriptive statistical analysis of groundwater quality testing data.

d) Visual MODFLOW

Visual MODFLOW is very user-friendly, modelingsoftware for hands-on applications in three-dimensional groundwater flow and contaminant transport modeling. This is developed by Waterloo Hydrogeologic since 1989, and it is well accepted software used by more than 10,000 groundwater professionals in over 90 different countries around the world. Theresults and model input parameters can be pictured in 2D view or 3D during the displaying of the output results. Soil profile surveys, watershed analyses, landfill leachate contamination, agriculture, airfields, constructed wetlands, climate change, drought studies, Environmental impact assessment (EIA), mining operations, river and flood plain monitoring, salt water intrusion are the areas where the software has been purportedly used till the present date.[8]

e) Visual MODPATH

Particle tracking is a important tool in numerical groundwater modelling for this purpose MODPATH software is used. MODPATH is incorporated in Visual MODFLOW to calculate 3D particle tracking path lines from the simulation output. The advective flow of pollutants for forward tracking and backward tracking are simulated by this software in the study area.

f) MT 3D

It used for solute transport simulation with expanded functionality for undertaking increasingly complex water-quality issues. Contaminants mass transport modeling was done by MT3D software. Advection, dispersion, and other chemical process of pollutants in aquifer systems are simulated by MT3D. It also solves the transport equation.

4.5 Analytical methodology for groundwater and leachate testing

All the groundwater sample and leachate sample wereanalyzed for important physicochemical parameters according to internationally recognized procedures and standard methods [9]. Temperatures, pH, electrical conductivity (EC), total dissolved solids (TDS) and dissolved oxygen (DO) of water sample were determined by Multi-parameter detector instrument at the sampling location. Biochemical oxygen demand (BOD_5), Chemical oxygen demand (COD), alkalinity, hardness, and chloride content in groundwater and leachate samples were determined by titrimetric analysis in the laboratory. Heavy metals (Fe, Cr, Zn, Pb, Ni, As and Cu) content were determined by flame AAS 4141instrument (Electronic Corporation of India Ltd). Estimation of heavy metals for the leachate sample was done by digesting 50 ml sample in 10 ml of concentration. HNO_3 at 80°C until the solution becomes transparent [10]. Na, K and Ca were determined by Flame Photometer. Nitrate and Fluoride were determined by using an ion selective electrode (ISE) meter.

The Merck, India and analytical grade chemicals were used to determine the physico-chemical parameter. Double distilled water was used throughout the testing. All glass wares, conical flask, test-tube burette and other secondary requirement were thoroughly cleaned and finally rinsed properly with double distilled water during titration of samples.

4.6 Physico-chemical parameters analysis

Temperatures, pH, electrical conductivity, total dissolved solids (TDS) and dissolved oxygen (DO) of water sample were determined by multi-parameter detector HANNA instrument at the sampling site by electrode membrane methodology. Before measured this parameter the instrument was calibrated with their respective standard value then reading noted down by dipping the electrode in sample water.

4.6.1 Measurement of Alkalinity

a) Materials: 0.02 N H_2SO_4, phenolphthaline indicator, methyl orange indicator.

b) Method: Took 50 mL of the water sample andadded 2-3 drops of phenolphthaline indicator. Pink color develops, titrated the solution with 0.02 N H_2SO_4 until the first permanent pink colordisappear. The disappearance of pink color indicates phenolphthaline alkalinity. Further, added 2-3 drops methyl orange indicator to the solution in which phenolphthaline alkalinity was determined. Titrated with 0.02 N H_2SO_4 acids to the proper equivalence point. The color changed from yellow to pink. The reappearance of pink color indicates total alkalinity.

c) Calculations:

$$\text{Total Alkalinity (mg/L)} = \frac{(u+v) \times N \times 1000 \times 50}{\text{mL sample}} \quad (1)$$

Where; u = Initial volume of 0.02 N H_2SO_4 in titration

V = Final volume of 0.02 N H_2SO_4 in the titration

N = Normality of H_2SO_4

4.6.2 Measurement of Hardness

a) Materials: 0.01 M EDTA (Ethylene diaminetetra acetate) solution, buffer solution, Erichrome black T indicator,

b) Method: Took 50 mL of water sample in a conical flask. Added 1 mL of buffer solution. Then added 4-5 drops of erichrome black T indicator, the solution turns wine red. Titrated the contents against EDTA solution. At the end point color changes from wine red to blue.

c)Calculations:

$$\text{Hardness} = \frac{\text{EDTA used} \times 1000}{\text{Sample in mL}} \quad (2)$$

4.6.3 Measurement of Chloride

a) Materials: Potassium di chromate indicator ($K_2Cr_2O_7$), Silver nitrate ($AgNO_3$) solution.

b) Method: 50 mL of water sample was taken in a conical flask then1 ml $K_2Cr_2O_7$ indicator added to it. The solution was titrated with $AgNO_3$ till permanent brick red color appeared.

c) Calculations:

$$\text{Chloride (mg/L)} = \frac{(A-B) \times N \times 35.5 \times 1000}{\text{The sample used (mL)}} \quad (3)$$

Where: N= Normality of $AgNO_3$
A = volume of $AgNO_3$ used for the sample titration
B = volume of $AgNO_3$ used for the sample titration

4.6.4 Calculation of Dissolved Oxygen (DO)

a) Materials: Concentrated H_2SO_4, Starch Indicator, Na azide, $MnSO_4$ solution, Sodium thiosulphate solution ($Na_2S_2O_3$) 0.025N, Titration setup.

b) Method: Azide modification of Winkler's method

c) Collection of sample

Water sample collected in narrow mouth glass stoppered BOD bottles of 300 mL capacity with tapered glass stoppers and flared mouth. Take special precautions to avoid dissolution of atmospheric oxygen. Allow overflow two or three times its volume and replace the stopper by avoiding the air bubbles.

d) Addition of reagents

2 mL of $MnSO_4$ solution was added followed by 2 mL of alkaline iodide solution to fix the DO. Separate pipettes used for each solution. Introduce the reagents by keeping the tip of the pipettes well below the water surface in the bottle, then it

mixed thoroughly by inverting the bottle several times so as to distribute the precipitate uniformly throughout the bottle. A white brownish colour precipitate is formed on the introduction of the reagents.

e) Acidification

2 mL of Conc. H_2SO_4 was used for acidifying by allowing the acid to run down the neck of the bottle. To avoid the reduction of manganic salts by organic materials, it is desirable that the samplebe shaken as soon as possible after the addition of acid when organic substances are present. The precipitate will dissolve leaving a clear solution.

f) Titration:

Took 101.4 mL of sample in a conical flask and titrated it against $Na_2S_2O_3$ until the straw yellow colour appears. 1-2 drops of starch solution added in solution then blue colour develops. Continue the titration with $Na_2S_2O_3$ to the first disappearance of blue colour. Noted the volume of $Na_2S_2O_3$ usedin the titration.

g) Reactions:

$$MnSO_4 + 2KOH \rightarrow Mn\ (OH)_2 + K_2SO_4$$

$$2Mn\ (OH)_2 + O_2 \rightarrow 2MnO\ (OH)_2$$

Brown ppt. (Oxygen Present)

$$MnO\ (OH)_2 + 2H_2SO_4 \rightarrow Mn\ (SO_4)_2 + 3H_2O$$

$$Mn\ (SO_4)_2 + 2KI \rightarrow MnSO_4 + K_2SO_4 + I_2$$

$$2Na_2S_2O_3 + I_2 \rightarrow Na_2S_4O_6 + 2NaI$$

Azide modification was used in case of excess of nitrite is present in water

$$2NaN_3 + H_2SO_4 \rightarrow 2N_3H + Na_2SO_4$$

$$HNO_2 + N_3H \rightarrow N_2 + N_2O + H_2O$$

h) Calculation:

$$DO\ (mg/l) = \frac{V \times N \times 8 \times 1000}{\text{Volume of water sample taken (101.40 mL)}} \quad (4)$$

Where:

V= volume of $Na_2S_2O_3$ used

N= normality of $Na_2S_2O_3$ (0.025 N)

4.6.5 Measurement of Biochemical Oxygen Demand (BOD)

a) Materials: Phosphate buffer solution, $MgSO_4$, $CaCl_2$, $MnSO_4$, $Na_2S_2O_3$, NaN_3, conc.H_2SO_4, $FeCl_3$.

b) Method: For measurement of BOD in the leachate sample took 10 mL of the leachate sample. Add 250 mL of distilled water to it. To this added 1 mL each of Phosphate buffer (to maintain pH), $MgSO_4$, $CaCl_2$, $FeCl_3$ (to provide nutrition to the microbes) and made the volume to 1 liter. 250 mL of this solution filled in two BOD bottles. Incubate one bottle in BOD incubator for 5 days at 20 ^{0}C. Use other bottle for the initial DO readings as done in the DO estimation experiment. At the end of 5 days incubation period, measure the amount of dissolved oxygen in the incubated bottle by winkers titration method.

c) Calculation: BOD (mg/L) = D_1-D_2

Where; D_1 = initial dissolved oxygen of diluted sample taken immediately.

D_2 =final dissolved oxygen of diluted sample taken after 5 days incubation.

4.6.6Chemical Oxygen Demand (COD)

20 ml of sample was taken in a 150-500 ml COD flask. A pinch of Ag_2SO_4 and $HgSO_4$ and 30 ml of sulphuric acid was added. This was refluxed for 4 hours on a hot plate then 2-3 drops of the ferried indicator was mixed thoroughly and titrated with 0.1N ferrous ammonium sulphate.

Calculation: COD, mg/L= (B-A) XN of Ferrous Ammonium Sulphate $\times$ 8000

Where A= ml of tartan with sample

B = ml of tartan with blank

4.6.7 Measurement of Phosphate (PO_4^{3-})

Materials: Concentrated H_2SO_4, ammonium molybdate, sodium Meta bisulfate, and sodium sulfate, ANSA reagent (1-amino-2-napthal-4-sulphonic acid & K_2HPO_4).

Method: 2 mL of water sample was taken in a test-tube. Then 1ml ANSA reagent was added followed by 0.1 ml of brucine maintains it to 10 ml by adding 6.9 ml of distilled water. Keep it for 10 minutes results in the development of blue colour appears. The intensity (optical density) of blue colour was determined by spectrophotometer at 660 nm. An appropriate blank (distilled water) and KH_2PO_4 were used for preparing the standard curve between the concentration of phosphate and intensity. Then with the help of this curve phosphate concentration calculated.

Figure 4.15 Spectrophotometer for phosphate analysis

4.6.8 Measurement of Heavy Metals

Heavy metals such as Fe, Cr, Zn, Pb, Ni, As and Cu content was determined by flame AAS 4141instrument.

a) Standard preparation for heavy metal testing:

From 1000 mg/l stock solution of Fe, Cr, Zn, Pb, Ni, As and Cu, 10 ml solution was taken and diluted with distilled water up to100 ml to make 100 mg/l or ppm standard of each metal respectively then 1, 2, 3 ml solutions were taken from 100 mg/l solution and diluting them with distilled water up to 100 mg/l, which represented standard of concentration 1, 2, 3 mg/l respectively.

b) Sample analysis:

The water samples were analysed for the presence of Heavy metals by Atomic Absorption Spectrophotometer shown in figure 4.16. The calibration plot method was used for the analysis. Air-acetylene flame and hollow cathode lamp of the corresponding elements were used for heavy metal analysis. The concentration of each heavy metal was read directly at their specific wavelength. The samples were analysed in duplicates with the average concentration of the metal present being displayed in mg/l by the instrument after extrapolation from the standard curve.

c) Stepwise procedure for detecting heavy metal by AAS

Firstly switch on all mains, UPS, Computer, Compressor etc.

1. Switched on the computer system.

2. Double clicked **AAS NEW** software.

3. Clicked **POWER** icon.

4. Selected the element (eg. Cu, Cr, Fe. etc.) that needed to detect and their respective element lamp number fitted in AAS then element lamp will circulate and allied automatically, checked the lamp beam at burner alienation if required.

5. Clicked **Peak** icon, a notification comes on screen accepted by clicking yes.
NOTE: a. Appeared peak on the screen should be sharp and then compared present wavelength with element wavelength. Difference should vary between +1 & -1

b. If the peak is not ok OR difference is more then 1, clicked **INDEX --> yes** after indexing clicked peak again.

6. If Peak ok then clicked **Analysis** icon.

7. Switched on compressor, open gas cylinder & adjust pressure 10 to20 kg/cm^2

8. Ignited the flame when **Ignition button** green.

9. Adjusted HCL **GREEN** by increasing/decreasing**EHT value.**

10. Clicked **CALIBRATION** Icon then selected the no. of standard (minimum 3

11. Dipped suction tube in the blank (distilled water) and clicked **ZEROING** icon.

12. Dipped no. of standards one by one and click **READ** icon respectively.

After completion of standard calibration click **Graph** icon ->**close** ->

13. Clicked **sample** icon then select the no. of sample and name of the sample by keyboard & enter button.

14. Dipped suction tube in sample one by one and clicked **READ** icon respectively.

15. After reading completion -> Clicked **REPEATS --> PRINT FILE-->**Selected file to print

Figure 4.16 Atomic Absorption Spectrophotometer (AAS)

Table 4.4 The details of analytical methods and equipments used in the parameters analysis

S. No.	Parameter	Method	Equipment Used
1	Temperature	Electrometric	Multi-Parameter meter
2	Dissolve Oxygen	Membrane electrode method	Multi-Parameter meter
3	Total Dissolved Solid	Membrane electrode method	Multi-Parameter meter
4	Electrical Conductivity	Electrometric	Multi-Parameter meter
5	pH	Electrometric	Multi-Parameter meter
6	Hardness	EDTA Titration	Titrimetric
7	Alkalinity	Titration	Titrimetric
8	Chloride	Argentometric titration	Titrimetric
9	Biological oxygen demand	Winkler method	Titrimetric
10	Sodium	Flame emission	Flame photometer
11	Calcium	Flame emission	Flame photometer
12	Potassium	Flame emission	Flame photometer
13	Nitrate	Nitrate ion selective electrode method	Hanna Lab Bench Meter- Hi4222
14	Fluoride	Fluoride ion selective electrode method	Hanna Lab Bench Meter- Hi4222

15	Chemical Oxygen Demand	Titration	HI839800 COD REACTOR and Test Tube Heater
16	Arsenic	Colour Comparison method	AQUASOL Parameter Kit
17	Heavy metals		Atomic absorption spectrophotometer

4.6.9 Measurement of Na, K, Ca

Na, K, and Ca in samples were determined by flame photometer.

Firstly, the instrument was calibrated with the standard value of the desired element then suction tube dipped in the sample and clicked readicon, reading of respective element noted down from the digital screen of the flame photometer (Figure 4.17).

a) Sodium standard solution (Na)

Weighted accurately 635 mg of 'Anal R' grade of NaCl and dissolved it in exactly 250 ml of double distilled water. The solution soobtained would have 1000 ppm Na. Diluted this solution 1:10 with double distilled water to make a standard solution of 100 ppm (mg/l).

b) Potassium standard solution (K)

Weighted accurately 477 mg of 'Anal R' grade of KCl and dissolved in exactly 250 ml of double distilled water solution so obtained would have 1000 ppm Na. Diluted this solution 1:10 with double distilled water to make a standard solution of 100 ppm.

c) Calcium standard solution (Ca)

624 mg of 'Anal R' grade of $CaCO_3$ Weighted accurately in a minimum quantity of 1:1 HCl and makeup exactly 250 ml of double distilled water. The solution soobtained would have 1000 ppm Ca. Diluted this solution 1:10 with double distilled water to make a standard solution of 100 ppm.

Figure 4.17 Microprocessor Flame photometer (Labtronics)

Figure 4.18 COD Digester and Flame Photometer

4.6.10 Measurement of Fluoride by ion selective electrode method

a) Principle

A potential difference develops between the measuring electrode and the reference electrode due to contact of fluoride ion-selective electrode with fluoride containing solution. According to Nernst equation this potential difference is proportional to the logarithm of the of the fluoride ion activity

b) Procedure

Instrument was calibrated with series of standard fluoride solutions i.e. 0.1 mg/l, 1.0 mg/l & 10 mg/l. 50 mL of sample was taken in a beaker and 2 mL of total ionic strength adjustment buffer ((TISAB)) added in it. The sample was stirred with a magnetic stirrer for 1 minute. Finally, the electrode was immersed in the sample and potential reading was recorded, when this reading becomes stable.

4.6.11Measurement of Nitrateby ion selective electrode (ISE) method

a) Procedure

The instrument was calibrated with a series of standard nitrate solutions i.e. 1ppm, 10 ppm & 100 ppm. 50 mL of sample was taken in a beaker and 2 mL of total ionic strength adjustment buffer (TISAB) added in it. The sample was stirred with a magnetic stirrer for 1 minute. Finally, nitrate ion selective electrode was immersed in a sample and potential reading was recorded, when reading becomes stable.

Figure 4.19 Hanna Lab Bench Meter- Hi4222 for analysis of Nitrate & Fluoride

Figure 4.20 Multiparameter detector

4.7 Calculation of LPI

In order to assess the leachate pollution potential of MSW dumping sites, leachate pollution index (LPI) was calculated by using the following equation which is based on the Rand Corporation Delphi technique.

$$\text{LPI} = \sum_{i=1}^{m} w_i p_i \,/\, \sum w_i \quad (5)$$

wherew_i is the weight factor for the i^{th} pollutant variable, p_i is the sub-index score of the i^{th} pollutant variable and m is the number of known concentration of leachate contaminant variables. The sub-index scores were calculated from averaged sub-index curves reported by [11]. The Cumulative pollution rating ($w_i p_e$) was calculated by multiplying the weight factor with the sub-index value. Sum of cumulative pollution rating of all variables gives LPI of the landfill sites.LPI used as quantitative and comparative measure tool for the leachate pollution potential of a MSW landfill.

The DELPHI method has been used to extract information from a group of expert panelists from different field of waste management. The procedure used to formulate the LPI attempts to incorporate many aspects of the Delphi technique.

These panellists give the rating to each considered parameter marked on the basis of importance of its influence to complete leachate pollution. The rating is given on a scale of ‘1’ to ‘5’. The value ‘1’ is to be consider for lowest relative importance to the leachate pollution and value ‘5’ is to be consider highest relative significance.At the end, eighteen significant leachate pollutants are selected for developing the LPI.Eighteen selected pollutants variable with their significance levels is given in table 4.5.

Table 4.5 Selected pollutants with significance values and weights[12].

S.No.	Pollutant	Significance	Pollutant weight (wi)
w	Total chromium	4.057	0.064
2	Lead	4.019	0.063
3	COD	3.963	0.062
4	Mercury	3.923	0.062
5	BOD_5	3.902	0.061
6	Arsenic	3.885	0.061
7	Cyanide	3.694	0.058
8	Phenolic compounds	3.627	0.057
9	Zinc	3.585	0.056
10	pH	3.509	0.055
11	TKN	3.367	0.053
12	Nickel	3.321	0.052
13	Total coliform bacteria	3.289	0.052
14	Ammonia nitrogen	3.250	0.051
15	Total dissolved solids	3.196	0.050
16	Copper	3.170	0.050
17	Chlorides	3.078	0.048
18	Iron	2.830	0.045
	Total	63.165	1.000

$$\text{LPI} = \sum_{i=1}^{n} w_i p_i \,/\, \sum w_i \quad (6)$$

Then a rating curve graph is developed for all 18 selected pollutants, In this curve of leachate contamination (sub-index score) from '0' to '100' are specified. The curves are started with a least value of 5 of leachate contamination for each pollutant variable even if there is not any pollution from thecontaminant to the total leachate. The least value of 5 of leachate contamination used to confirm that the LPI value does not outcome in zero even if few of pollutant do not show any contamination. That's why LPI are ranges between 5 to 100.

Then the obtained sub index value from the graphs for all the parameters are multiplied with the respective weights given to each parameter. The sum of all weighted of the parameter gives the LPI.

4.8 Calculation of WQI

Water quality index was determined by using a weight arithmetic method which is helpful to identify the status of the water resource [13]. Arc GIS 10.1 is used for spatial estimation of the WQI in the present studied area through the IDW method. For the WQI calculation Firstly, a weight (w_i) was assigned to each parameter on the basis of their significance to the complete groundwater quality. The highest weight was given to parameter that causes a serious health effect when its value increases above the certain critical concentration limits [14]. The weight factor (Wi) of the parameter is determined by the dividing the individual weight of each parameter by the sum of all parameter weight

$$(Wi = w_i / \sum_{i=1}^{n} wi)(7)$$

W represents the relative weight while w_i denotes the weight of each parameter, n is the total number of the parameter. Finally, water quality index (WQI) was calculated by the following formula

$$WQI=\sum_{i=1}^{n} SIi \times W_i \ (8)$$

where $SI_i$is the sub-index value of the $_i$th parameter and which calculated by sub-index curve developed by Ramesh and his colligues in 2010 by giving rating value between 0 to 100 based on its desirable and acceptable limits prescribed by BIS (2012) and WHO (2008). As per the water quality index values, the water quality classified into six classes [15].

Table 4.6 Classification of drinking water quality index.

Category	The range of WQI Score	Remark
Excellent	≥ 97.5 to 100	Best Quality
Good	≥92.5 to <97.5	Good Quality
Fair	≥85.0 to <92.5	Acceptable Quality
Marginal	≥75.0 to <85.0	Threatened Quality
Poor	≥60.0 to <75.0	Poor Quality
Very Poor	<60.0	Worst Quality

4.9 Ground Water Modeling

Visual MODFLOW software was used to know the groundwater flow direction and velocity in the study area and to find out the link between leachate contamination and groundwater pollution.

U.S. Geological Survey (USGS) developed the three-dimensional (3D) finite-difference groundwater model for simulating and predicting groundwater conditions and groundwater water interactions. MODFLOW has been used for more than 30 years and IT is commonly accepted for its easy use and flexibility in operating with other programs (waterloo hydrogeology).

The combination of Darcy's law and continuity equation explain the flow of groundwater in the non-homogenous anisotropic aquifer system.The application of groundwater modeling for flow and pollutant transport estimation is used in the risk-based decisions making phases. This model varies from simple mathematical equations to complex computer-generated models.

The groundwater flow equation is the mathematical relationship which is used to describe the flow of groundwater through an aquifer. The transient flow of groundwater is described by a form of the diffusion equation, similar to that used in heat transfer to describe the flow of heat in a solid (heat conduction).

4.9.1 Governing equation in groundwater flow modeling

A French Hydraulic Engineer, Henry Darcy, developed an empirical relationship for flow through porous media. He found that the specific discharge was directly proportional to the energy driving force (the hydraulic gradient) according to the following relationship that is known as Darcy equation:

$$Q = -\frac{kA(p_b - p_a)}{\mu L} \quad (9)$$

The above equation for single phase flow is the defining equation for absolute permeability. The total discharge, Q (m^3/s) is equal to the product of the intrinsic permeability of the medium κ (m^2), the cross-sectional area to flow A (m^2), and the total pressure drop $p_b - p_a$ (pascals), all divided by the viscosity μ (Pa·s) and the length over which the pressure drop is taking place (L). The negative sign is needed because fluid flows from high pressure to low pressure. Note that the elevation head must be taken into account if the inlet and outlet are at different elevations. If the change in pressure is negative (where $p_a > p_b$), then the flow will be in the positive x-direction.

The groundwater flow equation is often derived for a small representative elemental volume, where the properties of the medium are assumed to be effectively constant. A mass balance is done on the water flowing in and out of this small volume, the flux terms in the relationship being expressed in terms of the head by using the constitutive equation of Darcy's law, which requires that the flow is slow.

Groundwater flow direction equation:

$$\frac{\partial}{\partial x}\left(Kxx\frac{\partial h}{\partial x}\right) + \frac{\partial}{\partial y}\left(Kyy\frac{\partial h}{\partial x}\right) + \frac{\partial}{\partial z}\left(Kzz\frac{\partial h}{\partial x}\right) \pm W = Ss\frac{\partial h}{\partial t} \quad (10)$$

Kxx, KyyandKzz are hydraulic conductivity along the x, y and z coordinate axes, h indicates the potentiometric head, W is a volumetric flux per unit volume indicates sources and sinks of the water, Ss is the specific storage of the porous material and t is the time.

4.9.2 Groundwater transport modeling

Pollutant transport modelling is performed by visual MODPATH and MT3D.

To develop to compute 3-dimensional flow paths in steady or transient state particle-tracking post-processing package is used. For incoming and discharging of water in groundwater system conceptualisation and quantification can support by MODPATH, which are calculated numerically. It mainly simulates 3D advective-dispersive transport of dissolved solutes in the groundwater system. MT3D can simulate the reactive transport of dissolved solutes in groundwater including common problems such Dissolved plumes, simple reactive transport, injection wells, landfills and non-point source pollution are simulated by MT3D.

4.9.3 General methodologies for pollutant transport modeling

MT3D is a transport model for simulation the advection, dispersion and chemical reaction of contaminants in groundwater flow system, it solves the transport equation after the flow solution has been gained from the groundwater flow model (MODFLOW). The general adjective dispersion equation described the fate and transport of species inthree-dimensional transient groundwater flow system.

$$\frac{d}{dt}(\theta c^k) = \frac{d}{dx_i}[\theta D_{ij}\frac{dc^k}{dx_j}] - (\frac{d}{dx_i}\theta v_i C^k) + q_s c_s^k + \sum R_n \quad (11)$$

Dispersion-term Advection-term Sink-term Reaction-term where,

C^k = Dissolved concentration of species k

ɵ = Porosity of the subsurface medium

t = time

x_i, = Distance along the respective cartesian coordinate axis

Dij = Hydrodynamics dispersion coefficient tensor

Vi = Seepage or linear pore water velocity. It is related to specific discharge

q_s = Volumetric flow rate per unit volume of aquifer representing the fluid source and sink

c_s^k = Concentration of source the and sink flux for species k

$\sum R_n$= Chemical reaction term

4.9.4 Model Conceptualization

Model conceptualization is the process in which data describing field conditions are assembled in a systematic way to describe groundwater flow and contaminant transport processes at a selected dumping site. A developing conceptual model includes the following aspect:

- Are there adequate data to describe the hydrogeological conditions at the dumping site?
- In which directions is groundwater moving?
- Does it appear that the aquifer's hydrogeological characteristics remain relatively uniform, or do geologic data show considerable variation over the site?

4.9.5 Model Calibration

Model calibration involves of fluctuating values of model inputparameters in an effort to compare observed field conditions within some acceptablecriteria. This needs the field circumstances at a site be accurately characterized. Thecalibration procedure usually includes calibrating to steady-state and transientconditions. With steady-state simulations there are no observed deviations inhydraulic head or contaminant concentration with time for the field circumstancesbeing modeled while transient simulations include the change in the hydraulic head orcontaminant concentration with time.Model calibration should include comparisonsbetween model-simulated conditions and field conditions for the followingdata: hydraulic head data, groundwater-flow direction, hydraulic-headgradient, contaminant concentrations, and migration directions. These comparisons should be presented in graphs comparison between measured and computed heads. The closer the heads fall on the straight line, the better is the “goodness-of-fit. It is important that the modeler make every attempt to minimize the difference between model simulations and measured field conditions.

In order to achieve the above objective Visual mudflow is used for groundwater flow and 3-dimensional contaminants transport simulation. With the help of primary and secondary data, the model is calibrated and validated. The validated model is used to predict the groundwater level contours and flow direction.

4.9.6 Inputdata for model preparation

a. Observation Wells

A total of 56 wells were identified around the Ramna dumping site for initial head value. Their x, y coordinates and ground elevation was recorded using DGPS (Sokkia GRX2). The groundwater level data from 56 observation wells were calculated using a meter tape. The difference between ground elevation and depth of observed well indicates the groundwater table.

b. Base map of the study area

c. Location of observed wells (x, y coordinates, and elevation)

d.The water table of observed well

e. Hydraulic conductivities of soil (Kx, Ky, Kz)

Conductivity data used to simulate the flow rate through the sediments.

f. Porosity, effective porosity

g. Specific storage ($\mathbf{S_s}$) and Specific yield ($\mathbf{S_y}$), taken from secondary sources

These lithological data were calculated from the soil testing data shown in figure 4.21.

						Grain Size distribution				Atterberg's limit			Density (g/cc)				Shear parameters		Consolidation test				
Depth (m) b.g.l	Depth (m) R.l	Type of sample	Soil description	SPT 'N' Value	Corrected SPT 'N' Value	Gravel (%)	Sand(%)	Silt(%)	Clay(%)	LL(%)	PL(%)	PI(%)	Bulk density	Dry density	Natural Moisture content (%)	Specific gravity ,G	Cohesion 'C'(kg/cm^2)	Angle of friction (degree)	COMPRESSION INDEX	Void ratio .e	Silt factor	IS classification	Hatching
1	2	3	4	5		6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
G.L.	74.0		Bed level																				
1.0	73.0	DS	Yellowish silty clay of low plasticity			3	21	43	23	32	22	10											
2.0	72.0	DS	Yellowish silty clay of low plasticity																			CL	
3.0	71.0	SPT	Yellowish clayey sandy silt	13	16																		
4.0	70.0	UDS	Yellowish clayey sandy silt			4	22	43	22	34	24	10	1.86	1.65	12.5	2.67	0.35	13	0.159	0.84	1.52		
5.0	69.0	SPT	Yellowish clayey sandy silt	16	16																		
6.0	68.0	DS	Yellowish clayey sandy silt			2	24	43	24	32	20	12											
7.0	67.0	UDS	Silty clay with kankar										1.84	1.62	13.5	2.68	0.35	17	0.168	0.79	1.85	CL	
8.0	66.0	SPT	Silty clay with kankar	19	16	3	26	43	20	34	23	11											
9.0	65.0	DS	Silty clay with kankar																				
10.0	64.0	SPT	Silty clay of low plasticity	24	19	4	24	43	21	32	19	13											
11.0	63.0	DS	Silty clay of low plasticity																			CL	
12.0	62.0	SPT	Silty clay of low plasticity	21	15																		
13.0	61.0	UDS	silty clay			3	26	43	24	32	21	11	1.87	1.62	15.4	2.66	0.43	16	0.165	0.81	1.45		
14.0	60.0	DS	silty clay																				
15.0	59.0	SPT	Silty clay of low plasticity + kankar	26	17																	CL	
16.0	58.0	DS	Silty clay of low plasticity + kankar			4	19	39	24	31	19	12										CL	
17.0	57.0	UDS	Silty clay of low plasticity + kankar			5	22	47	26	32	18	14	1.95	1.63	19.7	2.67	0.65	12	0.175	0.84	1.58	CL	
18.0	56.0	SPT	Silty clay of low plasticity + kankar	37	22																	CL	
19.0	55.0	DS	Medium plastic clay + kankar			3	22	49	26	40	27	13										CI	
20.0	54.0	SPT	Medium plastic clay + kankar	51	28																		

						Grain Size distribution				Atterberg's limit			Density (g/cc)				Shear parameters		Consolidation test				
Depth (m) b.g.l	Depth (m) R.l	Type of sample	Soil description	SPT 'N' Value		Gravel (%)	Sand(%)	Silt(%)	Clay(%)	LL(%)	PL(%)	PI(%)	Bulk density	Dry density	Natural Moisture content (%)	Specific gravity ,G	Cohesion 'C'(kg/cm^2)	Angle of friction (degree)	COMPRESSION INDEX	Void ratio .e	Silt factor	IS classification	Hatching
1	2	3	4	5		6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
21.0	53.0	DS	Medium plastic clay + kankar			1	42	36	31	38	22	16											
22.0	52.0	SPT	Medium plastic clay + kankar	42	22																		
23.0	51.0	DS	Medium plastic clay + kankar			3	29	37	32	40	27	13											
24.0	50.0	UDS	Medium plastic clay + kankar			4	31	39	33	37	22	15	1.95	1.69	15.5	2.68	0.55	13	0.153	0.82	2.55		
25.0	49.0	SPT	Medium plastic clay + kankar	49	23																		
26.0	48.0																					CI	
27.0	47.0	DS	Medium plastic clay + kankar			1	31	28	31	40	26	14											
28.0	46.0	SPT	Medium plastic clay + kankar	42	18	2	26	43	29	38	25	13											
29.0	45.0	UDS	Medium plastic clay + kankar			1	27	42	30	39	25	14	1.93	1.66	16.5	2.67	0.43	15	0.146	0.77			
30.0	44.0	SPT	Yell. Stiff clay with kankar+charri	59	24																		
31.0	43.0	DS	Yell. Stiff clay with kankar+charri			2	23	41	34	42	27	15											
32.0	42.0	UDS	Yell. Stiff clay with kankar+charri			1	21	47	31	39	26	13	1.98	1.67	18.7	2.69	0.75	13	0.189	0.97			
33.0	41.0	SPT	Yell. Stiff clay with kankar+charri	56	21																		
34.0	40.0	UDS	Yell. Stiff clay with kankar+charri			8	26	42	24	31	20	11	2.04	1.75	16.9	2.67	0.5	20	0.145	0.95			
35.0	39.0	SPT	Stiff silty clay + kankar	71	25	2	19	59	20	33	22	11											
36.0	38.0	DS	Stiff silty clay + kankar			1	24	51	24	31	19	12											
37.0	37.0	SPT	Stiff silty clay + kankar	76	25																	CL	
38.0	36.0	DS	Stiff silty clay + kankar			3	25	51	21	34	24	10											
39.0	35.0	UDS	Stiff silty clay + kankar			2	22	56	20	31	20	11	2.05	1.72	19.3	2.69	0.43	15	0.142	0.91			
40.0	34.0	SPT	Stiff silty clay + kankar	81	24	1	24	51	24	30	18	12											

Figure 4.21 Theresult of soil testing data for calculation of lithological data of the model

Table 4.7 Lithology input data[16],[17]

Layers	Lithology	Kx, Ky	Kz	S_s	S_y	Total porosity	Effective porosity
Horizon 1	Coarse Sand	$9x10^{-6}$	$9x10^{-7}$	0.0011	0.06	0.42	0.21
Horizon 2	Sandy clay	$3x10^{-5}$	$3x10^{-6}$	0.008	0.32	0.55	0.35

Kx, Ky, Kzwere calculated by Darcy equation and total porosity &effective porosity by density method

Table 4.8 Input parameters for river

Riverbed thickness (m)	River width (m)	Riverbed Conductivity (m/s)
3	800	$3x10^{-4}$

h) Pumping rate calculation

Pumping rate data calculated from the population and population density data of the Varanasi city**.**

Per capita water uptake in Varanasi city approximately 180 liter per day (Varanasi Municipal Corporation)

Studied Area = 21 km^2

Water demand in study area = population density of village x village area x water uptake per capita= 1711.858x 21 x180

= 6470882.14 litre/day

= 6470.88214 m^3/day

Total no of assumed pumping wells for modelling in study area = 150

Therefore per well water uptake = 6470.88214 / 150

= 43.13 m^3/day

- Average pumping rate of tube well for rice crop in July month = 100 m^3/day while in monsoon period = 10 m^3/day
- Average pumping rate of tube well for the wheat crop in winter season = 60 m^3/day (FAO Data)

i) Recharge rate calculation

Krishna Rao gave the following empirical relationship in 1970 to determine the groundwater recharge in limited climatological homogenous areas.

R = K (P - X) (R = recharge, P = precipitation)

The following relation is stated to hold good

R = 0.20 (P - 400) for areas with P between 400 and 600mm

R = 0.25 (P - 400) for areas with P between 600 and 1000mm

R = 0.35 (P - 600) for areas with P above 2000 mm

where R (rechargerate) & P (precipitation) are expressed in millimeters

In Varanasi, the average precipitation between 2012-2017 year was 961.14 mm/year, so recharge rate calculated as:

$$R = 0.35 (P - 600)$$

$$R = 0.35 (961.14 - 600)$$

$$R = 0.35 \times 361.14$$

$$R = 126.39 \text{ mm/year}$$

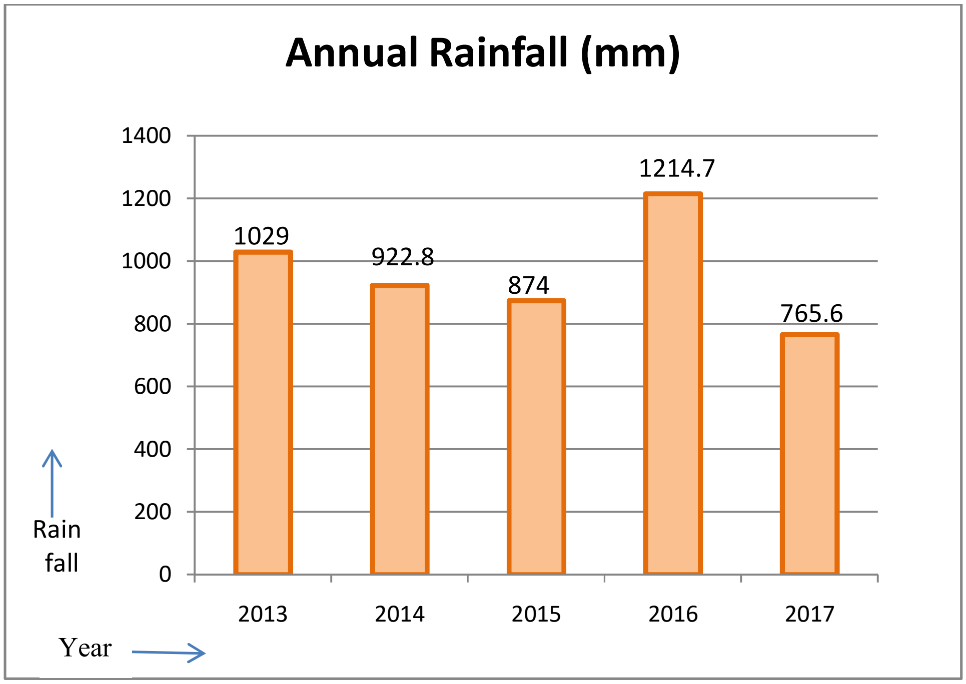


Figure 4.22 Graph showing Rain fall data of Varanasi city from 2012 -2017

Five year rainfall data of Varanasi city shown in figure 4.22, these data was downloaded from the Indian metrological department sites. This data used for calculation of recharge rate for the study area.