MSIS 637L Decision Support Systems

Project Report

Evaluating DRASTIC Parameters For Assessing Groundwater Vulnerability

Contents

1. Abstract

The groundwater vulnerability of a region is defined as the rate up to which the region is affected by ground pollution. The extent to which land has been contaminated is determined by several methods, among which DRASTIC method is the popular method which is accurate and precise compared to other methods. In this method the significant parameters which sensitively affect the groundwater are considered- these are depth of water, net recharge, aquifer media, soil media, topography, impact of vadose zone and hydraulic coefficient. These parameters are individually mapped and classified to different ranks and each layer is assigned with a weighted score. ArcGIS is one mapping software platform where reclassification, ranking and weighing can be easily done. These rankings and scores are assigned based on the parameter and layer influence in affecting the whole groundwater vulnerability. The ranked parameters and weighted layers are overlaid one over the other, on ArcGIS software, and the outcome map thus gives a DRASTIC map which gives DRASTIC index at each and every point on the map.

This project focuses on formulating the data and evaluating ranks and weights by analytical hierarchy process. In this DRASTIC methodology lot of data is required and based on the precision and accuracy of the data, the results are anchored. A slight variation in the gives a completely different DRASTIC map where the indices are changed. Hence a lot of importance is associated with the DRASTIC data. But in reality, due to equipment installations, weather conditions and ground conditions, data collection becomes difficult. So, the data cooking is done by simulations by using Analytical Solver tool – from the available data points, more data points are generated by simulations, under certain assumptions. Also, instead of traditionally assigning ranks and weights on trial and error basis to the DRASTIC parameters, a technical approach of Analytical Hierarchy Process (AHP) is followed in calculating this.

The present project work is mainly a preparation of data for calculating and mapping the seven parameters in ArcGIS tool. The process and details of the project work progresses in below sections

2. Necessity, thereby Objective

The DRASTIC methodology is more a subjective method than technical. The process of assigning ranks and weights in the process is mostly random than following a technical process. Many of times the DRASTIC index may be miscalculated with random ranks and weights which can give Saaty's consistency ration >0.1 and there is no check on this assigning. Hence this project gives and insight to how to assign ranks and weights by Saaty's AHP.

Moreover, data inaccuracy and unavailability are mostly seen in many studies. This is the main problem which effects the output, mainly when geographical factors like climatic conditions, ground undulations are concerned. In developing countries like India, the equipment installation is a big problem to fetch the data. Hence this work is attempted to develop more data points based on existing ones. In this work, the existing 8 to 39 data points are extended to 50 data points for all seven parameters, under certain assumptions. Few parameters are simulated under normal distribution and few under uniform distribution, there is no pre-confined notion for making these assumptions; the assumptions are just random based on few research studies. Since the DRASTIC methodology is completely worked under mapping tool, ArcGIS, when more data points are developed by simulations, there is a chance of getting more accurate maps than generating maps with existing data points.

Before getting into methodology, the data used in this project is collected with respect to a region Dindigul in Tamil Nadu state of India, which is mostly a granite terrain with red sandy and black soil. Approximately an area of 200km^2 study data points are considered, where there are very few existing data points. Since the DRASTIC maps gets refined by plotting more data, this work holds its significance.

3. Methodology

The simulation in this work purely based on assumptions which backs up research knowledge as there is no literature reference. The reclassification for analytical hierarchy process is carried on reference to the journal paper "Determining shallow aquifer vulnerability by DRASTIC model and hydrochemistry in granite terrain, southern India" by NC Mondal, S Adike et al in 2017 from Journal of Earth System and Sciences. The ranking and weights for AHP are considered with reference to journal paper "Assessment of groundwater vulnerability using analytical hierarchy process and evidential belief function with DRASTIC parameters, Cuddalore, India; by T Saranya and S Saravanan in 2022 from International Journal of Environmental Science and Technology.

Before getting into the process, the below are definitions to some technical terms which are being used in this work.

3.1.Groundwater and Groundwater Vulnerability

Groundwater is underground accumulation of water coming from various sources above and below land surface. vulnerability is a measure of contamination and pollution that the subject has undergone. Combining both the terms, no single standardized definition for groundwater vulnerability exists; however, the concept describes the relative ease with which the groundwater resource could be contaminated. It is the measure of contamination on the land surface to reach deep down into the ground, meaning, a measure of degree of insulation that natural or man-made factors provide to keep the pollution away from the groundwater. Higher groundwater vulnerability indicates that ground has prone to contamination and the land is more sensitive to take anymore contaminants, and vice versa.

3.2. DRASTIC Methodology and DRASTIC Index

The word "DRASTIC" is an acronym, illustrating seven hydro geological parameters – Depth to groundwater (D), Recharge rate (R), Aquifer media (A), Soil media (S), Topography (T), Impact of vadose zone area (I), and hydraulic Conductivity of the aquifer (C). In methodology, all these parameters are reclassified and ranks are assigned to it. Reclassification is done into five intervals based on the available data and rankings on the scale of 1 to 10 are assigned to it. 1 being good zone with negligible vulnerability and 10 being highly vulnerable region. Succeeding this, weights are assigned to each D,R,A,S,T,I,C layer, on scale from 1 to 5, relative to the importance of the layer contributing to vulnerability; 1 being least important and 5 being highly important in influencing groundwater vulnerability. The reclassified ranked layers are overlaid one over the other and weights are attached to it in ArcGIS mapping tool software and relative DRASTIC index is calculated by the equation given below. A high DRASTIC index indicates high vulnerability.

DRASTIC Index = $D_rD_w + R_rR_w + A_rA_w + S_rS_w + T_rT_w + I_rI_w + C_rC_w$;

where uppercase letters indicate parameters and suffixes indicate assigned ranks and weights, respectively.

The following table figure shows DRASTIC pairwise comparison matrix, developed in this project. (attached as ‘DRASTIC’ sheet in ‘FinalProject_AHP.xlsx’). The reason behind taking particular priority weights taken in this table will be explained in the below sections

3.2. DRASTIC Pairwise comparison matrix

	D	R	A	S	T	I	C
D	1	3	5	7	7	2	4
R	1/3	1	2	5	8	1/2	1/3
A	1/5	1/2	1	5	8	1/3	1/4
S	1/7	1/5	1/5	1	3	1/7	1/5
T	1/7	1/8	1/8	1/3	1	1/8	1/7
I	1/2	2	3	7	8	1	3
C	1/4	3	4	5	7	1/3	1
Sum	**2.57**	**9.83**	**15.33**	**30.33**	**42.00**	**4.43**	**8.93**

Normalized matrix

	D	R	A	S	T	I	C	Average	Consistency Measure	
D	0.39	0.31	0.33	0.23	0.17	0.45	0.45	33.11%	8.151	
R	0.13	0.10	0.13	0.16	0.19	0.11	0.04	12.39%	7.622	
A	0.08	0.05	0.07	0.16	0.19	0.08	0.03	9.32%	7.441	
S	0.06	0.02	0.01	0.03	0.07	0.03	0.02	3.54%	7.302	
T	0.06	0.01	0.01	0.01	0.02	0.03	0.02	2.22%	7.237	
I	0.19	0.20	0.20	0.23	0.19	0.23	0.34	22.53%	8.216	
C	0.10	0.31	0.26	0.16	0.17	0.08	0.11	16.89%	8.312	
						Average Consistency Measure			**7.754**	
							Consistency index		**0.126**	
							Consistency ratio		**0.095**	(<0.1 good)

3.3.DRASTIC Parameters

Below are the basic definitions of the DRASTIC parameters and its significance. As the work is more concentrated on simulation and AHP, the data collection and detailed analysis of these seven parameters goes beyond the scope of project and so are not discussed here.

3.3.1. Depth to Groundwater (D)

It is the distance between the ground surface to the available groundwater table. It gives the vertical time travel of contaminant land surface. 25 data points are available for this parameter, as shown in below figure (also attached as 'D,I' sheet in 'FinalProject_Simulations.xlsx')

Sl.No	Latitude	Longitude	D, Depth of water level (m, bgl)
1	10.287	78.006	17.30
2	10.312	78.005	15.60
3	10.319	78.017	12.40
4	10.389	78.018	14.30
5	10.436	78.013	14.85
6	10.356	78.025	10.60
7	10.34	77.944	10.50
8	10.382	77.943	6.70
9	10.416	77.933	7.65
10	10.417	77.921	10.04
11	10.437	77.957	17.20
12	10.412	77.961	14.99
13	10.381	77.926	13.20
14	10.354	77.943	5.20
15	10.302	77.956	22.00
16	10.248	77.945	30.00
17	10.295	77.884	16.30
18	10.314	77.897	11.65
19	10.316	77.931	23.20
20	10.341	77.913	7.40
21	10.342	77.946	2.30
22	10.376	77.947	8.10
23	10.383	77.927	4.95
24	10.365	77.906	17.10
25	10.406	77.911	9.60

Original data points

These data points are simulated, assuming that there holds a normal distribution with calculated average and standard deviation, which comes to be as shown in below figure

Average	**12.93**
Minimum	**2.30**
Maximum	**30.00**
Standard deviation	**6.30**

Calculations based on assumptions

The results are as below

Sl.No	Latitude	Longitude	D, Depth of water level (m, bgl)
26			9.59
27			23.78
28			6.84
29			14.46
30			8.05
31			24.13
32			12.16
33			9.53
34			20.48
35			17.44
36			16.13
37			7.74
38			9.56
39			15.07
40			17.26
41			8.80
42			13.34
43			4.30
44			3.22
45			21.01
46			17.67
47			12.73
48			10.41
49			11.61
50			7.40

Generated data points

Based on the data after simulation, this parameter is reclassified into five zones as shown in the below table. Higher the depth to groundwater, the less is its affinity to get polluted, hence high priority is given to low depths and priority descends as the depth ascends; in deciding AHP ranks. Since this is the most significant parameter and explicitly plays a key role in taking the contaminants to the groundwater, it is assigned with highest weights. (attached as 'D' sheet in 'FinalProject_AHP.xlsx')

	2.30–9.52	9.53–12.20	13.4-18.7	18.8-25.6	25.7-35.8
2.30–9.52	1	3	6	8	9
9.53–12.20	1/3	1	3	4	8
12.21–15.07	1/6	1/3	1	3	5
15.08–18.40	1/8	1/4	1/3	1	3
18.41–25.90	1/9	1/8	1/5	1/3	1
Sum	1.74	4.71	10.53	16.33	26.00

	2.30–9.52	9.53–12.20	13.4-18.7	18.8-25.6	25.7-35.8	Average	Consistency Measure	D Average	Overall Priority
2.30–9.52	0.58	0.64	0.57	0.49	0.35	0.52	5.48	0.33	0.17
9.53–12.20	0.19	0.21	0.28	0.24	0.31	0.25	5.40	0.33	0.08
12.21–15.07	0.10	0.07	0.09	0.18	0.19	0.13	5.22	0.33	0.04
15.08–18.40	0.07	0.05	0.03	0.06	0.12	0.07	5.07	0.33	0.02
18.41–25.90	0.06	0.03	0.02	0.02	0.04	0.03	5.07	0.33	0.01
				Average Consistency Measure			**5.25**		
					Consistency index		**0.06**		
					Consistency ratio		**0.06**	(<0.1 good)	

3.3.2. Recharge Rate (R)

It is the amount of water that infiltrates into the ground and saturates the groundwater table. It measures the ground's ability to carry contaminants. 10 data points are available for this parameter, as shown in below figure (also attached as 'R' sheet in 'FinalProject_Simulations.xlsx')

Sl.No	Well_id	Latitude	Longitude	Recharge percent	R, Recharge
1	83520	10.409	78.006	11.1	73.8621
2	83029A	10.323	77.9507	7.63	50.747
3	83503	10.274	77.921	7.33	48.751
4	83514	10.366	77.906	4.86	32.324
5	83029	10.314	77.947	4.36	28.998
6	83515A	10.37	77.985	3.37	22.414
7	1	10.244	77.927	6.44	42.832
8	2	10.269	77.886	6.045	40.205
9	3	10.324	78.024	6.15	40.903
10	4	10.447	77.952	6.44	42.832

Original data points

These data points are simulated, with an assumption that there holds a uniform distribution within minimum and maximum ranges. The output resulting in remaining 40 data points along with assumptions are as shown in below figure

				Minimum	22.414
				Maximum	73.862
Sl.No					**R, Recharge**
11					35.371
12					52.827
13					25.389
14					37.547
15					71.192
16					48.225
17					42.794
18					60.632
19					60.626
20					42.559
21					46.785
22					25.186
23					26.952
24					33.600
25					54.941
26					49.099
27					71.130
28					30.648
29					54.985
30					67.574
31					58.337
32					28.965
33					44.002
34					52.448
35					22.507
36					40.890
37					30.048
38					29.142
39					60.061
40					27.615
41					65.577
42					68.337
43					69.297
44					39.509
45					33.815
46					55.237
47					22.643
48					49.896
49					41.383
50					44.122

Calculations based on assumptions

Generated data points

Similar to Parameter D, depth to groundwater, after simulation, the data is reclassified into five zones as shown in the below table. High recharge represents high groundwater infiltration and contamination also increases with high recharge. So, a proportional ranking has been assigned.

Hence a relative weight is accordingly, is given to this parameter. The ranks and weights are assigned with reference to the journal paper "Assessment of groundwater vulnerability using analytical hierarchy process and evidential belief function with DRASTIC parametrs, Cuddalore, India; by T Saranya and S Saravanan in 2022 from International Journal of Environmental Science and Technology. The below figure shows reclassification and corresponding ranks (attached as 'R' sheet in 'FinalProject_AHP.xlsx')

	22.42–31.91	31.92–38.12	38.13–42.50	42.51–51.27	51.28–64.96
22.42–31.91	1	5	6	8	9
31.92–38.12	1/5	1	3	5	8
38.13–42.50	1/6	1/3	1	3	5
42.51–51.27	1/8	1/5	1/3	1	3
51.28–64.96	1/9	1/8	1/5	1/3	1
Sum	1.60	6.66	10.53	17.33	26.00

	22.42–31.91	31.92–38.12	38.13–42.50	42.51–51.27	51.28–64.96	Average	Consistency Measure	R Average	Overall Priority
22.42–31.91	0.62	0.75	0.57	0.46	0.35	0.55	5.89	0.12	0.07
31.92–38.12	0.12	0.15	0.28	0.29	0.31	0.23	5.56	0.12	0.03
38.13–42.50	0.10	0.05	0.09	0.17	0.19	0.12	5.24	0.12	0.02
42.51–51.27	0.08	0.03	0.03	0.06	0.12	0.06	5.07	0.12	0.01
51.28–64.96	0.07	0.02	0.02	0.02	0.04	0.03	5.11	0.12	0.00
				Average Consistency Measure			**5.38**		
					Consistency index		**0.09**		
					Consistency ratio		**0.08**	(<0.1 good)	

3.3.3. Aquifer Media (A)

An aquifer is nothing but an underground water body, in simple terms. The aquifer media represent the properties of aquifer such as change in water level fluctuation along with other properties like discharge of surface water into ground and storage capacity of the aquifer. It is a measure of saturated zone which controls the ground to get polluted. Only 8 data points (with a missing data) on a study area of 200 km^2 are available as shown in below figure

pump_no	Latitude	Longitude	A, Aquifer media
1	10.28	77.943	4239.908
2	10.343	77.998	58535.800
3	10.39883137	77.99210678	22961.136
4	10.4652	77.973	Data missing
5	10.395	77.8695	28642.396
6	10.245	77.926	32170.396
7	10.322	78.025	42750.466
8	10.447	77.951	11196.660

Original data points

These data points are simulated, with an assumption that there holds a uniform distribution within 10% increase and decrease in the average of the available data points. Since the aquifer media, by definition tells that it's a measure of fluctuation in water, the assumption is considered.

Average	28642.395
10% increase on mean	31506.634
10% decrease on mean	25778.155

Calculations based on assumptions

The output resulting in remaining data points are as shown in below figure

Sl No	Latitude	Longitude	A, Aquifer media
9			29179.299
10			27176.454
11			25867.440
12			25841.724
13			28172.033
14			30388.750
15			27431.148
16			29712.894
17			30565.666
18			28988.413
19			31459.541
20			28007.225
21			28867.846
22			30581.023
23			27783.036
24			30287.942
25			31062.866
26			26348.808
27			28041.463
28			28294.295
29			29407.783
30			30805.010
31			28492.386
32			29793.122
33			29251.774
34			26412.507
35			28314.210
36			26378.382
37			30376.159
38			27260.127
39			28591.580
40			29593.997
41			27533.410
42			26658.695
43			26410.891
44			27486.102
45			27338.299
46			27666.064
47			31034.635
48			28115.081
49			28250.284
50			30922.903

Generated data points

High water fluctuation results in high contamination in groundwater, yielding a high vulnerability rating. Hence the aquifer media ranks and layer weights are appropriately chosen. While the pairwise comparison matrix shows the score bit less than recharge rate parameter, the reclassification and ranks are shown as in the below figure (attached as 'A' sheet in 'FinalProject_AHP.xlsx')

	0.00–1.50	1.51–3.00	3.01–4.50	4.5–6.00	6.00–7.20
0.00–1.50	1	3	7	8	9
1.51–3.00	1/3	1	3	5	8
3.01–4.50	1/7	1/3	1	3	5
4.5–6.00	1/8	1/5	1/3	1	4
6.00–7.20	1/9	1/8	1/5	1/4	1
	1.71	4.66	11.53	17.25	27.00

	0.00–1.50	1.51–3.00	3.01–4.50	4.5–6.00	6.00–7.20	Average	Consistency Measure	A Average	Overall Priority
0.00–1.50	0.58	0.64	0.61	0.46	0.33	0.53	5.64	0.09	0.05
1.51–3.00	0.19	0.21	0.26	0.29	0.30	0.25	5.55	0.09	0.02
3.01–4.50	0.08	0.07	0.09	0.17	0.19	0.12	5.41	0.09	0.01
4.5–6.00	0.07	0.04	0.03	0.06	0.15	0.07	5.05	0.09	0.01
6.00–7.20	0.06	0.03	0.02	0.01	0.04	0.03	5.09	0.09	0.00
				Average Consistency Measure			**5.35**		
					Consistency index		**0.09**		
					Consistency ratio		**0.08**	(<0.1 good)	

3.3.4. Soil Media (S)

Soil media represents the upper most ground soil texture. The soil/sand particles in the ground play a key role in sending the surface running water into the ground, which is a simple definition to infiltration. The nature of soil particles, its size, the porosity (gap between one soil particle to another), its density all collectively represent soil media. This media influence vulnerability in retaining infiltered water (contaminated water) in clogs of soil, thereby contaminating underground. Now, when fresh water infiltrates from this place, the contaminants are either flushed deep into groundwater or transported along the water flow.

A high of 39 data points are available for this parameter, as shown in below figure (also attached as ‘S’ sheet in ‘FinalProject_Simulations.xlsx’)

Sl.No	Latitude	Longitude	S, Soil media m_bgl
1	77.94	10.44	1.27
2	77.93	10.39	1.15
3	77.93	10.39	1.42
4	77.93	10.37	2.1
5	77.951	10.437	3.2
6	77.959	10.421	1.34
7	77.974	10.413	1.35
8	77.946	10.412	1
9	77.9515	10.394	1.64
10	77.953	10.377	1.52
11	77.931	10.378	0.72
12	77.934	10.3639	1.04
13	77.939	10.354	1.05
14	77.961	10.361	1.07
15	77.934	10.348	0.88
16	77.953	10.286	1.88
17	77.9285	10.286	2.77
18	77.902	10.273	2.36
19	77.894	10.288	1.13
20	77.8903	10.3081	3.31
21	77.918	10.336	2.34
22	77.914	10.321	0.52
23	77.923	10.303	0.63
24	77.905	10.324	1.45
25	77.939	10.317	5.35
26	77.956	10.335	2.98
27	77.959	10.303	0.6
28	77.968	10.315	0.92
29	77.982	10.332	0.73
30	77.998	10.323	1.98
31	77.971	10.347	1.33
32	78.002591	10.2984388	0.89
33	77.976	10.3914	1.18
34	77.984	10.404	0.89
35	77.9958	10.3633	0.71
36	77.926	10.245	2.34
37	77.886	10.267	2.27
38	78.024	10.323	1.08
39	77.951	10.446	1.7

Original data points

These data points are simulated, with an assumption that there holds a uniform distribution within 10% increase and decrease in the average of the all available 39 data points. Since there are more data points and the soil media, by definition is a soil property which can fluctuate, the assumption is considered. The output resulting in remaining 11 data points along with assumptions are as shown in below figure

		Average	1.59
		10% increase	1.75
		10% decrease	1.43
Sl.No			**S, Soil media m_bgl**
40			1.47
41			1.64
42			1.45
43			1.75
44			1.63
45			1.63
46			1.69
47			1.71
48			1.48
49			1.51
50			1.44

Calculations based on assumptions

Generated data points

Based on reference journal papers, reclassification and ranking is given as follows (attached as 'S' sheet in 'FinalProject_AHP.xlsx'). As this is very small measure and do not show much impact on vulnerability, second lower weights are given to this layer.

	0-2.5	**2.6-5.35**
	Red sandy soil	**Black cotton soil**
Red sandy soil	1	1/5
Black cotton soil	5	1
Sum	6.00	1.20

	0-2.5	**2.6-5.35**				
	Red sandy soil	**Black cotton soil**	**Average**	**Consistency Measure**	**S Average**	**Overall Priority**
Red sandy soil	0.17	0.17	0.17	2	0.04	0.070866
Black cotton soil	0.83	0.83	0.83	2	0.04	0.070866
	Average Consistency Measure			2.00		
		Consistency index		0.00		
		Consistency ratio		0.00	(<0.1 good)	

3.3.5. Topography (T)

Topography represents the measure of slope of the ground surface and undulations on ground. It considers trees and pits which retain water on ground surface, slowly forcing water to percolate into the ground. This parameter, too, has only 8 available data points, as shown in below figure.

pump_no	Latitude	Longitude	T, Topography
1	10.28	77.943	15
2	10.343	77.998	200
3	10.39883137	77.99210678	96
4	10.4652	77.973	53
5	10.395	77.8695	4
6	10.245	77.926	107.5
7	10.322	78.025	148
8	10.447	77.951	51

Original data points

Similar to Aquifer media parameter, uniform distribution within 10% increase and decrease in the average of the available data points is considered to simulate remaining data points

Average	84.3
10% increase on mean	92.7
10% decrease on mean	75.9

Calculations based on assumptions

And the simulated results are as follows

Sl No	Latitude	Longitude	T, Topogra
9			84.9
10			87.5
11			84.9
12			77.0
13			79.6
14			82.6
15			81.7
16			76.6
17			90.9
18			83.0
19			76.4
20			86.3
21			77.0
22			84.9
23			88.7
24			79.8
25			78.4
26			80.1
27			87.8
28			81.5
29			81.2
30			86.5
31			87.2
32			89.7
33			87.3
34			83.6
35			85.8
36			89.1
37			91.4
38			84.0
39			88.3
40			76.2
41			92.3
42			91.4
43			92.1
44			77.6
45			78.2
46			92.3
47			77.7
48			86.7
49			81.6
50			87.8

Generated data points

A least weight (0.02 in pairwise comparison matrix) is assigned to this layer, as it has very least prominence in influencing groundwater vulnerability. The reclassification and ranks are as follows

	230.01–258.43	258.44–283.58	283.59–308.17	308.18–334.96	334.97–369.39
230.01–258.43	1	3	5	8	9
258.44–283.58	1/3	1	2	4	8
283.59–308.17	1/5	1/2	1	4	6
308.18–334.96	1/8	1/4	1/4	1	4
334.97–369.39	1/9	1/8	1/6	1/4	1
Sum	1.77	4.88	8.42	17.25	28.00

	230.01–258.43	258.44–283.58	283.59–308.17	308.18–334.96	334.97–369.39	Average	Consistency Measure	T Average	Overall Priority
230.01–258.43	0.57	0.62	0.59	0.46	0.32	0.51	5.53	0.02	0.011
258.44–283.58	0.19	0.21	0.24	0.23	0.29	0.23	5.43	0.02	0.005
283.59–308.17	0.11	0.10	0.12	0.23	0.21	0.16	5.42	0.02	0.003
308.18–334.96	0.07	0.05	0.03	0.06	0.14	0.07	5.07	0.02	0.002
334.97–369.39	0.06	0.03	0.02	0.01	0.04	0.03	5.08	0.02	0.001
				Average Consistency Measure			**5.31**		
					Consistency index		**0.08**		
					Consistency ratio		**0.07**	(<0.1 good)	

3.3.6. Impact of Vadose Zone (I)

It is dry and unsaturated portion of the earth between land surface and top layer of underground water body. This is most significant layer next to Depth to groundwater (D). Because, as discussed in soil media and aquifer media, when contaminants get trapped into this dry zone and when surface water flushes these deep into the ground, the contaminants becomes much more dangerous because of chemical decomposition. 25 data points are available as shown in the below figure

Sl.No	Latitude	Longitude	I, Impact of vadose zone (m, amsl)
1	10.287	78.006	360.00
2	10.312	78.005	340.00
3	10.319	78.017	308.00
4	10.389	78.018	260.00
5	10.436	78.013	228.35
6	10.356	78.025	290.00
7	10.34	77.944	210.00
8	10.382	77.943	250.00
9	10.416	77.933	240.00
10	10.417	77.921	240.00
11	10.437	77.957	230.00
12	10.412	77.961	250.00
13	10.381	77.926	245.00
14	10.354	77.943	260.00
15	10.302	77.956	300.00
16	10.248	77.945	320.00
17	10.295	77.884	280.00
18	10.314	77.897	270.00
19	10.316	77.931	280.00
20	10.341	77.913	270.00
21	10.342	77.946	260.00
22	10.376	77.947	250.00
23	10.383	77.927	245.00
24	10.365	77.906	260.00
25	10.406	77.911	240.00

Original data points

Similar to Depth of groundwater, these data points are simulated, assuming that there holds a normal distribution with calculated average and standard deviation, which comes to be as shown in below figure

Average	**267.45**
Minimum	**210.00**
Maximum	**360.00**
Standard deviation	**35.80**

Calculations based on assumptions

The results generated are as below

Sl.No	Latitude	Longitude	I, Impact of vadose zone (m, amsl)
26			290.05
27			224.52
28			217.25
29			256.42
30			329.94
31			211.23
32			289.64
33			242.15
34			219.96
35			267.10
36			291.42
37			287.01
38			267.20
39			297.23
40			311.75
41			299.94
42			300.13
43			267.34
44			200.07
45			250.90
46			255.58
47			199.11
48			199.15
49			267.83
50			287.83

Generated data points

After simulation, reclassified into five zones is done as shown in the below table. Higher the thickness of vadose zone, the less is its affinity to get polluted, hence high priority is given to low depths and priority descends as the depth ascends; in deciding AHP ranks. (attached as 'I' sheet in 'FinalProject_AHP.xlsx')

	0.52–1.41	1.42–1.90	1.91–2.51	2.52–3.59	3.60–5.35
0.52–1.41	1	3	5	9	9
1.42–1.90	1/3	1	3	6	8
1.91–2.51	1/5	1/3	1	3	5
2.52–3.59	1/9	1/6	1/3	1	4
3.60–5.35	1/9	1/8	1/5	1/4	1
Sum	**1.76**	**4.63**	**9.53**	**19.25**	**27.00**

	2.6-8.98	8.99-13.3	13.4-18.7	18.8-25.6	25.7-35.8	Average	Consistency Measure	I Average	Overall Priority
2.6-8.98	0.57	0.65	0.52	0.47	0.33	0.51	5.56	0.23	0.11
8.99-13.3	0.19	0.22	0.31	0.31	0.30	0.27	5.55	0.23	0.06
13.4-18.7	0.11	0.07	0.10	0.16	0.19	0.13	5.37	0.23	0.03
18.8-25.6	0.06	0.04	0.03	0.05	0.15	0.07	5.07	0.23	0.02
25.7-35.8	0.06	0.03	0.02	0.01	0.04	0.03	5.08	0.23	0.01
				Average Consistency Measure			**5.33**		
					Consistency index		**0.08**		
					Consistency ratio		**0.07**	(<0.1 good)	

3.3.7. Hydraulic Conductivity (C)

It is the ability of the groundwater body to transmit water. It is nothing but measure of transmitting the water from one water body to another. This layer also holds an importance and scored as third largest layer in weightage. Even here, only 8 data points are available.

pump_no	Latitude	Longitude	C, Hydraulic coefficient
1	10.28	77.943	0.000035
2	10.343	77.998	0.000010
3	10.39883137	77.99210678	0.000310
4	10.4652	77.973	0.000950
5	10.395	77.8695	0.000500
6	10.245	77.926	0.000023
7	10.322	78.025	0.000160
8	10.447	77.951	0.000588

Original data points

Similar to all other parameters, except Depth to groundwater and Impact of vadose zone layer, here also uniform distribution with 10% increase and decrease on average value is considered to generate remaining data points.

Average	0.000322
10% increase on mean	0.000354
10% decrease on mean	0.000290

Calculations based on assumptions

The then generated data points are

Sl. No			Hydraulic coefficie
9			0.000294
10			0.000349
11			0.000325
12			0.000339
13			0.000309
14			0.000342
15			0.000338
16			0.000293
17			0.000345
18			0.000317
19			0.000291
20			0.000346
21			0.000320
22			0.000335
23			0.000322
24			0.000336
25			0.000290
26			0.000310
27			0.000292
28			0.000311
29			0.000325
30			0.000291
31			0.000291
32			0.000322
33			0.000331
34			0.000333
35			0.000314
36			0.000338
37			0.000348
38			0.000325
39			0.000321
40			0.000299
41			0.000325
42			0.000301
43			0.000343
44			0.000325
45			0.000292
46			0.000339
47			0.000352
48			0.000301
49			0.000327
50			0.000294

Generated data points

The reclassifications and ranks for AHP are as in below figure

	15.00–51.27	51.28–81.02	81.03–115.83	115.84–156.73	156.74–199.96
15.00–51.27	1	1/3	1/5	1/8	1/9
51.28–81.02	3	1	1/2	1/4	1/7
81.03–115.83	5	2	1	1/2	1/4
115.84–156.73	8	4	2	1	1/3
156.74–199.96	9	7	4	3	1
Sum	**26.00**	**14.33**	**7.70**	**4.88**	**1.84**

	15.00–51.27	51.28–81.02	81.03–115.83	115.84–156.73	156.74–199.96	Average	Consistency Measure	C Average	Overall Priority
15.00–51.27	0.04	0.02	0.03	0.03	0.06	0.03	5.03	0.17	0.01
51.28–81.02	0.12	0.07	0.06	0.05	0.08	0.08	5.06	0.17	0.01
81.03–115.83	0.19	0.14	0.13	0.10	0.14	0.14	5.10	0.17	0.02
115.84–156.73	0.31	0.28	0.26	0.21	0.18	0.25	5.17	0.17	0.04
156.74–199.96	0.35	0.49	0.52	0.62	0.54	0.50	5.26	0.17	0.08
				Average Consistency Measure			**5.12**		
					Consistency index		**0.03**		
					Consistency ratio		**0.03**	(<0.1 good)	

4. Conclusions

The resulting data points obtained after simulating the existing data points are used in reclassification, ranking and weighing for Saaty's analytical hierarchical process and checked for the Saaty's condition, which is consistency ration should be less than 0.1. For this, from the average consistency measure obtained in the above pairwise comparison matrix and normalized D,R,A,S,T,I,C AHP matrices, consistency index is calculated by the below formula

$$\boxed{\mathrm{CI} = \frac{\lambda - n}{n - 1}}$$

λ : average consistency measure for all alternatives
n : number of alternatives
RI: the appropriate random index (taken from a table)

and consistency ratio = Consistency index/Random index

Where Random index is taken from Saaty's table

n	RI
2	0.00
3	0.58
4	0.90
5	1.12
6	1.24
7	1.32
8	1.41

Since the consistency ratio for all the pairwise and criterion matrices is less than 0.1, the model ranks and weights can be directly used on the maps for calculating DRASTIC index.

5. References

N C Mondal, S Adike et al., 2017 Determining Shallow Aquifer Vulnerability by the DRASTIC model and Hydrochemistry in Granite Terrain, Southern India, Journal of Earth Science

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T Saranya and S Saravanan., 2022 Assessment of groundwater vulnerability using analytical hierarchy process and evidential belief function with DRASTIC parameters, Cuddalore, India, International Journal of Environmental Science and Technology