World Journal of Advanced Research and Reviews

eISSN: 2581-9615 CODEN (USA): WJARAI

Cross Ref DOI: 10.30574/wjarr

Journal homepage: https://wjarr.com/

(Research Article)

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Cumulative impact assessment of groundwater quality using water quality index, leachate pollution index, and GIS: A case study of Shivri Municipal Landfill Site, Lucknow, India

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World Journal of Advanced Research and Reviews, 2024, 23(01), 1150–1160

Publication history: Received on 07 June 2024; revised on 12 July 2024; accepted on 15 July 2024

Article DOI: https://doi.org/10.30574/wjarr.2024.23.1.2115

Abstract

The current research shows the analysis of the quality of groundwater close to a landfill in Lucknow City, in Uttar Pradesh, India. Calculating the leachate pollution index (LPI) and water quality index (WQI) has been done to evaluate the quality of the groundwater and the leachate near the site. A very high value of LPI (27.54) indicates that there was a substantial amount of contaminants at the landfill site. the calculation of WQI for the groundwater samples has been done and a map for showing its spatial distribution has been prepared for the analysis of the WQI, revealing that 40% of the groundwater specimens are excellent alongside 60% of the groundwater is in a good category. the spatial distribution of WQI illustrates that the majority of the region around the site of the landfill is in the good category and the remaining is in the excellent category. The experimental result of the physicochemical analysis for groundwater revealed that water is satisfactory and fit for drinking and other domestic use and only some parameters like total alkalinity, total hardness, EC, TDS, sodium, magnesium, calcium, and sulfate are above the desirable limit set by Indian standard (IS10500: 2012). This study also emphasizes the importance of LPI and WQI as a monitoring tool for the policymakers and the government body for preventing and safeguarding the risk of groundwater contamination from leachate.

Keywords: Leachate; Landfill; Groundwater; LPI; MSW; WQI

1. Introduction

In various developing nations one of the major sources of domestic, industrial, and agricultural water is groundwater. The pollution of groundwater by landfills has been a very concerning problem in recent times. Landfills not only affect groundwater but they also have negative impacts on air and soil. Most of these problems arise due to unmanaged or non-engineered landfill sites which eventually lead to risks such as disability, disease, and death. These problems may also hamper the development and economic growth in various developing countries (Dermatas 2017). In many South Asian countries such as ours, groundwater resources have been overutilized by poor management and a lack of technical skills within government bodies. Today, engineered sanitary landfill sites are designed to protect groundwater from the various wastes disposed at the site. A study by Sharholy et al. 2008 suggests that about ninety percent of the total Municipal Solid Waste (MSW) produced in India is thrown away openly in a very unsanitary way. MSW management is a high-priority matter in various countries worldwide, including India. The waste management efforts are affected by limitations in landfill spaces, changes in legislation, climate, and social attitudes. According to a report by the Indian Infrastructure Report (IIR) and Central Pollution Control Board, India produces about 55 to 60 million tons of MSW annually which may rise to about 270 million tons in 2047.

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As per the report of CPCB published for the year 2020-21, 160039 tons per day of MSW were approximately produced. The amount of collected solid waste was about 152750 tons per day (TPD) which was approximately 95% of the total MSW generated. Similarly, 79956 TPD solid wastes were treated, accounting for about 50% of the total MSW generation. The amount of waste used for landfilling was about 29427 TPD which accounts for about 18% of the total MSW generated. Landfills have been observed to be the prime threats to groundwater which can be contaminated by either infiltration from precipitation or groundwater underflow (Mor et al. 2006). "Municipal Solid Waste (Management and Handling) Rules, 2016" of the country guarantees proper gathering, segregation, transfer, treatment, and dumping of MSW while upgrading current facilities to prevent future pollution of groundwater and soil the scenario in recent times has changed in the sense that now the majority of the MSW is disposed-off on land in a controlled and scientific way. But still, there are places with poor disposal practices causing problems to the surrounding ecosystem and the health of people by being exposed to processes like consumption, inhalation in the shower, and dermal contact (Iwalewa and Makkawi 2015). A study conducted by Nandimandalam 2012 shows that if the pollutants that persist for a long time get into the groundwater, the water turns unfit for consumption by humans. Change in the status of groundwater over a region is an outcome of physical and chemical variables, which are essentially affected by human activities and geological processes. The toxicity of landfill leachate should be assessed for proper management of MSW landfills which will eventually help in reducing the contamination of groundwater.

The contamination of leachate is generally seen in the periphery of 6.1 km from the site of the landfill and high pollution is observed towards the drift of groundwater flow (Abu-Rukah and Al-Kofahi 2001). Many studies suggest that landfill leachate may cause health problems by the process of solubilization and hydrolysis of MSW (Kale et al. 2010; Talalaj 2014; Singh et al. 2016; Chakraborty and Kumar 2016). Some studies suggest that heavy metals such as Fe, Pb, Zn, Cd, and Cr behave identically in leachate from landfills and groundwater nearby the site (Iwalewa and Makkawi 2015). Naveen et al. 2017 observed that heavy metals accumulated as traces of metals via the procedure of coprecipitation in the leachate pond mechanism and simply precipitation. Mishra et al. 2018 revealed the risks that are not cancer-causing for humans due to some chosen heavy metals out of MSW leachate from landfills. Pollutant leaching is increased by the direct dissolution of the waste by the colloid-facilitated mechanism of transport (State et al. 2013). These all facts prove that an environmentally friendly scientific approach should be adopted for continual monitoring of MSW.

The LPI is employed for assessing and monitoring the potential of leachate pollution mainly in places that are at high risk of leachate contamination (Pratap Singh and Kumar Patel 2024). The leachate quality assessment by evaluation of LPI helps in (a) identifying the hazardous nature of leachate, (b) recognizing appropriate landfill structure, (c) developing ecologically sound treatment techniques, and (d) forecasting the impacts of leachate on surrounding groundwater through various investigation and monitoring methods (Sharma et al. 2008). The WQI is employed to evaluate the groundwater's suitability for consumption by humans lacking any harmful chemicals, that has been observed in samples of groundwater close to a landfill site (Talalaj 2014; Singh et al. 2015; Varol and Davraz 2015; Şener et al. 2017; Rabeiy 2018). A study by Deshmukh and Aher 2016 used spatial assessment through the application of the Inverse Distance Weight (IDW) in a Geographic Information System (GIS) for assessing groundwater near a landfill site and found that the groundwater was not fit for human consumption or domestic usage.

The groundwater pollution in the city of Lucknow is mainly due to the uncollected waste which is about 5% of the total MSW (1200 MT/day) generated as per a report by CPCB in 2015 for 60 major cities of India. This results in about 60 MT/day of uncollected MSW leading to a huge amount of solid waste. These solid wastes have great potential for affecting both the subsurface water and atmosphere mainly throughout the time of monsoon. The purpose of this investigation is to assess WQI for groundwater water quality and LPI for leachate and also show the results of WQI in the form of spatial distribution using the GIS technique for the Shivri landfill site in the city of Lucknow.

1.1. Study area description

Lucknow has become one of the places in India where advancement happens at an explosive rate. It also serves as the capital of the state city as well as among the most extremely inhabited states in India. This city lies in the northern hemisphere with a longitudinal extent of 80.30 degrees east to 81.13 degrees east and a latitudinal extent of 26.30 degrees north to 27.10 degrees north. The environment of Lucknow is constantly exacerbated by the unprecedented need for land, water, public transportation, education, healthcare centers, housing, and various other means, which has grown due to the explosive increase in urban development. Over the entire region, the average elevation is around 123 meters above mean sea level. This location lies in the centre of the region known as northern India. It takes up land beside the Gomti rivers, which run across the city.

the city of Lucknow tends to be marked by moderate dry conditions across the entire year except for Rainy weather conditions. The region also receives substantial precipitation primarily throughout the monsoon period with an annual average precipitation of around 827.2 mm. The overall extent of the water level alternates from 1-15.78 m in Lucknow city beneath ground level.

the city of Lucknow city possesses an approximate population of 38,00,000, which is expected to culminate in approximately two thousand metric tons of waste every day. A typical individual produces a quantity of solid waste between 100 to 650 g in the city, which relies on the socioeconomic status of individuals inhabiting it. The MSW produced in city areas may be classified into bio-medical, commercial, and domestic garbage. The amount of waste produced in rural regions is between 0.65-0.45 kg/capita/day.

A landfill located near Shivri began operating in the city of Lucknow in 2007 at an estimated separation of roughly 25 kilometers from the city. The waste site was suggested for being a designed and adequately lined site yet under construction up to 2024 at the moment when I began drafting this current paper. The description of the area of study is shown in **Figure 1**.

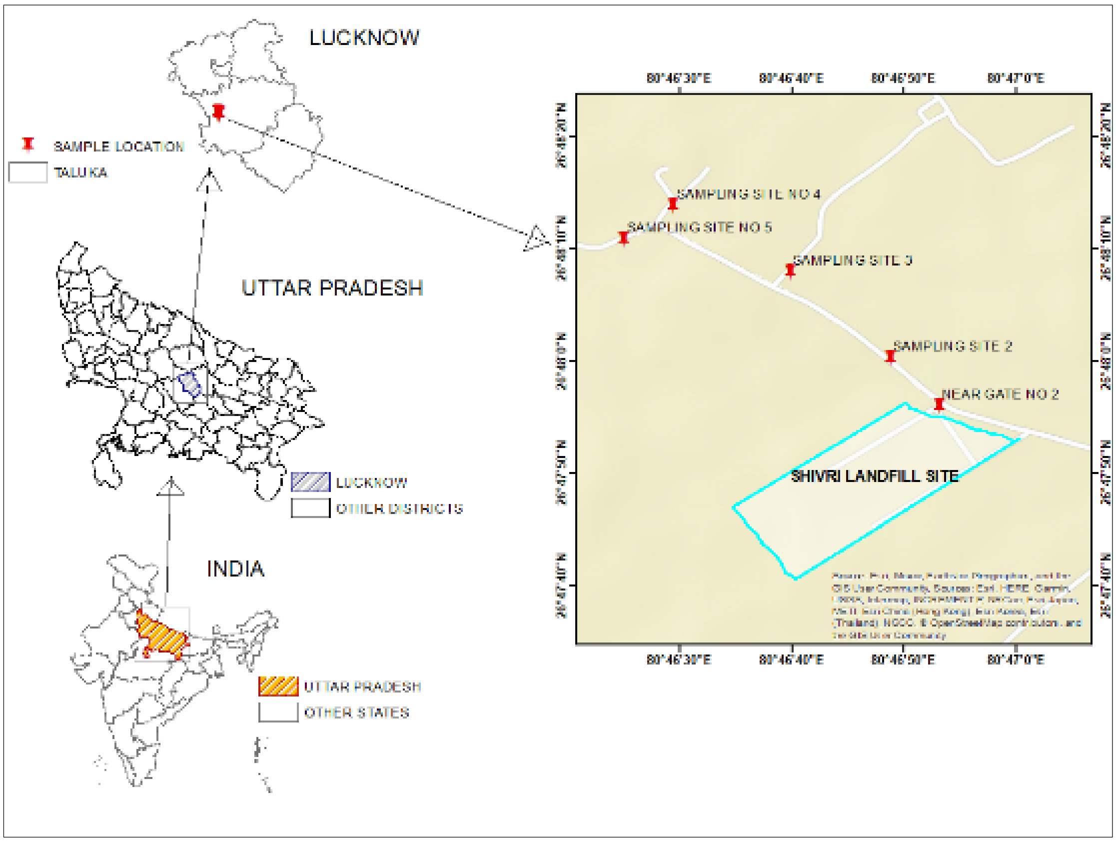

Figure 1 Study area description

1.2. Shivri landfill site, Lucknow

Established in 2007, the Shivri landfill plant has remained operational. It has a location in the western section of the city and spans an area of roughly 41 hectares. The site is still under construction as I write this paper. 1200 T/day of trash is usually deposited at the site, which is spread out over the region and varies in height from 15 to 22 meters. Household debris from all across the Lucknow region, including plastics, glass, paper, and glassware, as well as kitchen waste, clothing, and cardboard containers, makes up the majority of the rubbish dumped at this landfill. Moreover, this location also handles the disposal of garbage from the adjacent fish market, plant market, and slaughterhouse. The waste disposal site is an adequately designed dumping zone that reaches a height of 15 to 22 meters, giving the impression that it is a huge mound of garbage. The garbage from municipalities is transported to this site by trucks as well as other means of transportation from different locations of the city and dumped here. They also operate a recycling facility where they frequently gather glass items, metal, and plastic to ship for other uses. Our investigation aims to comprehend how the amount of moisture in the garbage gathered in this location leads to the production of leachate.

2. Material and method

2.1. Sampling and testing of Leachate and groundwater

The collection of leachate samples was done from the drainage of the landfill site using clean and airtight plastic bottles. Similarly, the extraction of samples of groundwater was done inappropriately by cleaning and washing disposable bottles from five handpumps close to the Shivri landfill site. The accurate sampling spots were acquired by the application of a differential global positioning system (DGPS) which was then employed in the mapping of the study area. The evaluation of the essential physical and chemical variable was carried out for the leachate and groundwater samples by applying the standard processes and techniques at the Environmental lab of the Department of Civil Engineering, IET Lucknow, Lucknow, Uttar Pradesh, India. The separation distance of the locations for sampling of groundwater from the landfill site ranges from 188 to 973 m. Total dissolved solids (TDS), pH, Total alkalinity, total hardness (TH) Electrical conductivity (EC), Calcium, sodium, magnesium, fluoride, sulfate, and boron belong to the chemical and physical characteristics examined in groundwater samples. An SCM was applied to measure pH and electrical conductivity. The parameters which are included in the leachate sample were TSS, phosphate, BOD, COD, NO_3, NH_3, and Cd. Total alkalinity (TA), TH, and chloride in the specimen of groundwater were obtained by titrimetry. Flame AAS 4141 instrument (Electronic Corporation of India Limited) and inductively coupled plasma-mass-spectrometry (ICP-MS) were applied to know the heavy metals (Zn, Pb, Cr, Fe, and Cd) content. Digestion of a 50 ml sample in 10 ml of concentrated HNO_3 till the solution becomes transparent was done to estimate heavy metals in leachate samples. Flame photometry was employed for the assessment of K, Na, and Ca in the samples of groundwater. UV-spectrophotometer (Systronics) was used for the determination of nitrate using the colorimetric method. An ion-selective electrode (ISE) meter was employed for the determination of fluoride content in the samples of groundwater. The weight arithmetic method was used for the evaluation of WQI and LPI which will help identify water resource status (Tyagi et al. 2014; Balathandayutham et al. 2015; Chakraborty and Kumar 2016).

2.2. LPI calculation of the landfill site

For assessing the polluting potential of leachate at the Shivri landfill site, the following equation which is derived from the rand corporation Delphi technique was implemented for calculating the LPI of leachate.

$$\text{LPI} = \sum_{i=1}^{m} wi\ pi \ / \ \sum wi \ldots\ldots\ldots.. (1)$$

Where m denotes the total number of known concentrations of leachate variables, *wi* is used for the weight factor *i*th contaminant parameter, and *pi* is used for the sub-index score of *i*th contaminant parameter. Each pollutant's level of significance has been taken into account while determining the weights for all 13 parameters. Averaged sub-index curves were used to obtain the calculation of sub-index values as suggested by (Kumar and Alappat 2005). Sub-index curves denote the relationship between the considered pollutant concentration and leachate contamination. The calculation of cumulative pollution rating (*wi pi*) is done by the multiplication of the weight factor and sub-index value. The weight factor gives specification about the significance of the contaminating parameter about the overall leachate contamination. Lastly, the cumulative contamination ratings of all metrics are added up to determine the landfill leachate LPI.

2.3. WQI calculation

The weight arithmetic method was used for the determination of the WQI which helps in identifying the water resource status (Chakraborty and Kumar 2016). The calculation of the WQI for all the groundwater samples was done employing the weighted arithmetic index method (Kumari and Sharma 2019). The WQI value and the water quality status are given in Table 1.

$$\text{WQI} = \Sigma(qn \times wn)/\Sigma wn \ldots\ldots\ldots (2)$$

First of all, the unit weight (wn) was calculated for every variable by applying the following equation

$$wn = K/Sn \ldots\ldots\ldots. (3)$$

wn = Unit weight of nth parameters
Sn = Standard desirable value
K = proportionality Constant

$$K = [1/(\Sigma(1/Sn))] \ldots\ldots (4)$$

$$qn = (Vn / Sn) \times 100 \text{ .... } (5)$$

Where, Vn = measured value of the nth variable, qn = Sub-index value.

Table 1 WQI values and their water quality status

S.No.	Range of WQI values	Category
1	0 to 25	Excellent
2	26 to 50	Good
3	51 to 75	Fair
4	76 to 100	Poor
5	101 to 150	Very poor
6	Above 150	Unfit for drinking

3. Result and discussion

3.1. Calculation of LPI for Shivri landfill leachate

Estimation of LPI for the Shivri landfill site was done using pollution concentration, weight factor, and sub-index value of 13 significant LPI variables as given in **Table 2**.

Table 2 LPI of Shivri landfill leachate

Parameters	Weight factor (*wi*)	Pollutant concentration	Sub-index value (*pi*)	Cumulative pollution rating (*wi×pi*)
pH	0.009	7.89	87.66	0.759
TSS	0.001	132.8	13.28	0.010
PO_4	0.016	1.55	31	0.484
F	0.039	1.56	78	3.042
Fe	0.026	0.65	21.66	0.56
Zn	0.016	0.34	6.8	0.106
Pb	0.78	0.01	10	7.8
Cd	0.039	0.08	4	0.156
Cr	0.039	0.41	20.5	0.799
BOD	0.003	100.1	333	11.1
COD	0.001	500.3	200	0.062
NO_3	0.008	12.2	122	0.952
NH_3	0.016	1.33	26.6	0.41

Note - Except for pH, all values are in mg/l.

$$LPI = \sum_{i=1}^{m} wi\ pi\ /\ \sum wi$$

$$LPI = 26.71/0.97$$

$$LPI = 27.54$$

LPI of the Shivri landfill site was observed to be 27.54 which is comparatively very high. If the LPI value is greater than 7.50 then it will be detrimental to the health and surrounding environment. The environmental condition of the landfill site can be considered non-stabilized, and hazardous as the value of LPI was found to be much higher than 7.50. So, if the landfill leachate enters the groundwater, it will have a hazardous effect. The excessive amount of BOD, COD, and TSS accounted for the excessive LPI value. The TSS value was observed to be 132.8 mg/l, which is in excess of the leachate disposal standard (100 mg/l), a significant factor for allowing disposal in many countries (Koshy et al. 2008). BOD concentration was found to be 100 mg/l which was again higher than the prescribed limit for inland water discharge (30 mg/l). This shows that there was high organic pollution in the leachate sample. The concentration of COD was observed to be 500 mg/l which was two times the permissible standard for inland water discharge of 250 mg/l. there was a notable amount of heavy metal presence observed in the shape of Fe (0.65 mg/l), Zn (0.34 mg/l), Cd (0.08 mg/l), and total chromium (0.41 mg/l). the presence of heavy metals plays an essential part in the detrimental effects because of their lasting persistent and reducing properties in the surroundings. However, the simplification of the concentration variation of leachate contamination in particular periods is very difficult, and in the majority of instances, the increase observed was within a very short period (Abdelaal et al. 2014).

3.2. Groundwater quality statistical analysis for physicochemical parameters

Statistical analysis of groundwater quality for physicochemical variables in terms of standard deviation, the maximum, minimum, and mean concentration is given in Table 3 the pH of the sample varies from 7.18 to 7.55 with an overall mean of 7.344. the standard deviation for the given samples was found to be 0.14. the slightly basic nature of the samples can be due to the presence of bicarbonates (Adams et al. 2001). The value of the electrical conductivity (EC) fluctuates from 656 μS/cm to 885 μS/cm alongside a mean of 775.2 μS/cm for all the groundwater samples. The observed standard deviation value for EC was 77.90 μS/cm for all the groundwater samples. The amount of TDS varies from 505 to 566.4 mg/l alongside a mean of 524.46 mg/l. standard deviation for TDS values was 21.82 mg/l. at some groundwater sampling locations, elevated values for EC and TDS can be caused by landfill waste leaching near the sampling locations. The alkalinity was observed to have levels ranging from 220.4 to 254.1 mg/l. Mean alkalinity and its standard deviation were found to be 239.792 and 12.52 respectively. The hardness value fluctuates from 219.36 mg/l to 242.36 mg/l with a mean of 232.488 mg/l. the standard deviation value for the hardness of the samples of groundwater was found to be 9.41. The weathering of silicate in the dry season and wet season may be responsible for the high hardness values (Nandimandalam 2012; Varol and Davraz 2014).

Table 3 Statistical evaluation of physicochemical properties of samples of groundwater

Parameters	Minimum	Maximum	Mean	Standard deviation	Guideline for drinking water (BIS-10500:2012)
pH	7.18	7.55	7.344	0.13	7.5
EC	656	885	775.2	77.90	500
TDS	505	566.4	524.46	21.82	500
Total alkalinity	220.4	254.1	239.792	12.52	200
Hardness	219.36	242.36	232.488	9.40	200
Ca	79.21	97.33	87.71	6.62	75
Mg	34.62	49.09	42.546	5.26	30
Na	205.36	253.13	234.234	18.54	200
Sulphate	213.21	243.01	232.966	10.74	200
Cl	248.19	259.1	254.398	3.66	250
F	0.19	0.44	0.334	0.10	1
B	0.1	0.6	0.38	0.17	0.5
Fe	0.09	0.13	0.108	0.01	0.3
Zn	0.09	0.18	0.13	0.03	5
Pb	0.002	0.004	0.0028	0.0007	0.01
Cr	0.001	0.003	0.0024	0.0008	0.05

Note – Except for pH and EC (μS/cm), all parameter values are expressed in mg/l.

The chloride values obtained for the samples of groundwater range from 231.56 to 248.19 mg/l the mean value for these obtained samples was 240.008 mg/l and it had a standard deviation of 5.57. all the chloride values were found to be under the prescribed limit of Indian standards. The mean values obtained for Na, Mg, and Ca were found to be 234.324 mg/l, 42.546 mg/l, and 87.71 mg/l respectively. The fluoride values fluctuate from 0.19 to 0.44 mg/l with an average of 0.33 mg/l and standard deviation of 0.10. low fluoride concentration indicates a controlled lithogenic impact in a groundwater sample. This may also indicate the non-availability of fluoride-bearing minerals in the study area (Janardhana Raju et al. 2011). The iron concentration of the samples of groundwater was found to have an average of 0.108 mg/l and a standard deviation of 0.015. The Domestic wastes that consist of iron-containing steel may be responsible for the iron concentration observed in the groundwater samples (Nagarajan et al. 2012). The other explanation that may be given for the presence of iron in groundwater is the reduction of ferric ions into ferrous ions by the weather materials (Raju 2006). The higher consumption of water containing iron may cause a disease named hemosiderosis (Rajappa et al. 2010). The observed chromium concentration was observed to have an average of 0.0024 mg/l with a standard deviation of 0.0008. these characteristics of the samples show that the hardness, alkalinity, and sodium concentrations were found to be more than the desirable limit set by BIS.

3.3. Using WQI for the evaluation of the quality of groundwater close to the landfill site

The experimental results obtained for all 5 samples of groundwater were used for the evaluation of WQI. The Indian standards and WHO standards were put into use for the calculation of WQI as shown in **Table 4** and **Table 5**. As per the calculated WQI value, the water quality may be divided into 6 categories, i.e., Excellent, good, fair, poor, very poor, and not fit for drinking. The range of the WQI values calculated was from 18.04 to 34.23 at all the sampling locations. Two samples; sample 4 and sample 5 with WQI values of 18.04 and 18.11 respectively were in the excellent category the other 3 samples; samples 1, 2, and 3 with WQI values of 34.23, 26.42, and 26.88 respectively were in the good category. the results obtained for the samples show that 60% of the samples were in the good category and 40% were in the excellent category. So, the result suggests that the groundwater close to the landfill was not much affected by its presence.

Table 4 Weighting of the parameters related to water quality3

Parameters	WHO standards (2011) (mg/l)	BIS standards (2012) (mg/l)	Relative weight (wn)
pH	6.5-8.5	7.5	0.0010604
EC	-	500	0.00001591
TDS	500	500	0.00001591
Total alkalinity	-	200	0.00003976
Hardness	-	200	0.00003976
Ca	300	75	0.000106
Mg	-	30	0.0002651
Na	200	200	0.00003976
Sulphate	-	200	0.00003976
Cl	250	250	0.00003181
F	1.3	1	0.0079528
B	1	0.5	0.0079528
Fe	0.3	0.3	0.0265094
Zn	-	5	0.0015906
Pb	-	0.01	0.7952834
Cr	0.05	0.05	0.1590567

Table 5 WQI values and water type for groundwater samples

Location	Sample	WQI	Water type
Near Gate No. 2 (188 m)	W1	34.23	Good
Shivri Village Road (360 m)	W2	26.42	Good
Near residential area (524 m)	W3	26.87	Good
Near Mohan Road (863 m)	W4	18.04	Excellent
Near Mohan Road (973 m)	W5	18.12	Excellent

3.4. WQI Spatial distribution

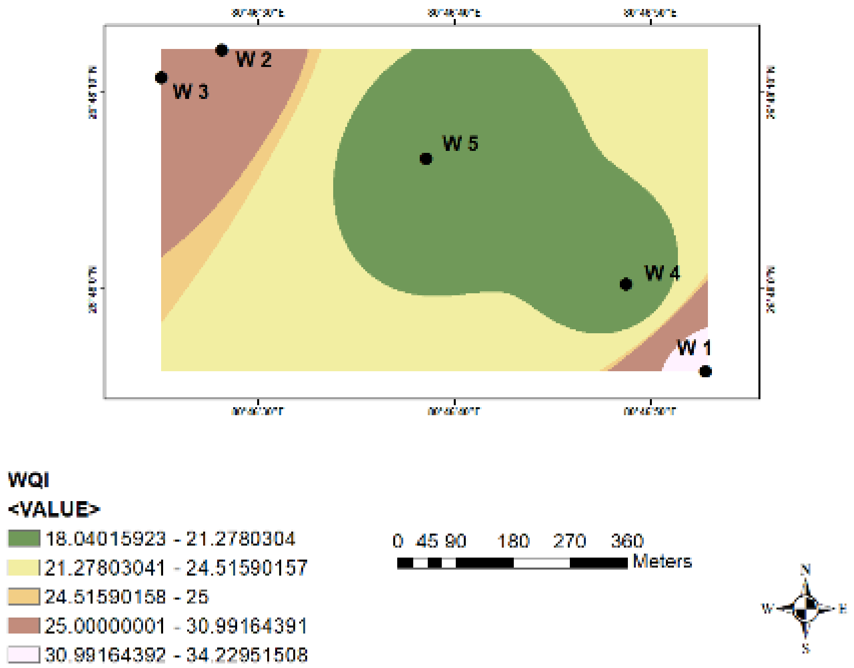

Figure 2 Spatial distribution map for the WQI

The spatial distribution mapping for the study area was done using IDW for interpolation in ArcGIS (Figure 2). The third class in the spatial distribution map was set manually at 25 for a clear distinction between excellent and good classification of the samples. The distribution clearly shows that three samples were in excellent and two were in good category. It can be interpreted from the mapping that most of the area was in an excellent category and only a small portion near the landfill site was in good category. Although there was not much impact found on the groundwater but still the groundwater near the landfill site was somewhat poorer than the groundwater away from the site.

4. Conclusion

The groundwater near the Shivri landfill site located in Lucknow was analyzed for its physicochemical parameters. The groundwater from the handpumps near the landfill site was tested as it is the primary option for drinking water for the families in the region. From the results of this study, we may conclude that the water was fit for drinking and household purposes even though a minor fluctuation was observed from the desirable limit for some of its parameters like EC, TDS, TA, Hardness, Ca, Mg, Na, and SO_4. A high value (27.54) of LPI shows that the landfill leachate has a substantial proportion of pollutant presence. The WQI results indicate that 40% of the samples of groundwater were in the excellent category and 60% of the specimens were in the good category. The WQI spatial distribution indicates that the majority of the area near the landfill site was unaffected by the presence of the landfill site since there was a good collection system in use. This study shows that groundwater quality close to the Shivri landfill site has not been affected by its presence.

Compliance with ethical standards

Acknowledgments

The Institute of Engineering and Technology Lucknow's Department of Civil Engineering is acknowledged by the authors for providing the resources needed to carry out the study.

Authors Contributions

Vishvanath Pratap Singh: Data curation, Formal analysis, Investigation, Methodology, Writing – original draft, Writing – review & editing, Validation. Shashank Pandey: Validation, Visualization, Writing – review & editing. Vipin Kumar: Writing & Editing.

Disclosure of conflict of interest

The writers clearly state that they do not have any contradictory agendas.

Role of Funding Sources

Public, private, or nonprofit funding agencies did not provide a particular grant for this research.

Statement of ethical approval

The instructions for authors contain a statement on the "Ethical responsibilities of authors," which all authors have read, understood, and complied with as relevant.

Statement of informed consent

Informed consent was obtained from all individual participants included in the study.

References

[1] Abdelaal FB, Rowe RK, Islam MZ (2014) Effect of leachate composition on the long-term performance of a HDPE geomembrane. Geotextiles and Geomembranes 42:348–362. https://doi.org/10.1016/J.GEOTEXMEM.2014.06.001

[2] Abu-Rukah Y, Al-Kofahi O (2001) The assessment of the effect of landfill leachate on ground-water quality—a case study. El-Akader landfill site—north Jordan. J Arid Environ 49:615–630. https://doi.org/10.1006/JARE.2001.0796

[3] Adams S, Titus R, Pietersen K, et al (2001) Hydrochemical characteristics of aquifers near Sutherland in the Western Karoo, South Africa. J Hydrol (Amst) 241:91–103. https://doi.org/10.1016/S0022-1694(00)00370-X

[4] Balathandayutham K, Mayilswami C, Tamilmani D (2015) Assessment of Groundwater Quality using GIS: A Case Study of Walayar Watershed, Parambikulam-Aliyar-Palar Basin, Tamilnadu, India. Current World Environment 10:602–609. https://doi.org/10.12944/cwe.10.2.25

[5] Chakraborty S, Kumar RN (2016) Assessment of groundwater quality at a MSW landfill site using standard and AHP based water quality index: a case study from Ranchi, Jharkhand, India. Environ Monit Assess 188:335. https://doi.org/10.1007/s10661-016-5336-x

[6] Dermatas D (2017) Waste management and research and the sustainable development goals: Focus on soil and groundwater pollution. Waste Management and Research 35:453–455

[7] Deshmukh KK, Aher SP (2016) Assessment of the Impact of Municipal Solid Waste on Groundwater Quality near the Sangamner City using GIS Approach. Water Resources Management 30:2425–2443. https://doi.org/10.1007/s11269-016-1299-5

[8] Iwalewa TM, Makkawi MH (2015) Site characterization and risk assessment in support of the design of groundwater remediation well near a hazardous landfill. Arabian Journal of Geosciences 8:1705–1715. https://doi.org/10.1007/s12517-014-1300-7

[9] Janardhana Raju N, Shukla UK, Ram P (2011) Hydrogeochemistry for the assessment of groundwater quality in Varanasi: a fast-urbanizing center in Uttar Pradesh, India. Environ Monit Assess 173:279–300. https://doi.org/10.1007/s10661-010-1387-6

[10] Kale SS, Kadam AK, Kumar S, Pawar NJ (2010) Evaluating pollution potential of leachate from landfill site, from the Pune metropolitan city and its impact on shallow basaltic aquifers. Environ Monit Assess 162:327–346. https://doi.org/10.1007/s10661-009-0799-7

[11] Koshy L, Jones T, BéruBé K (2008) Bioreactivity of municipal solid waste landfill leachates—Hormesis and DNA damage. Water Res 42:2177–2183. https://doi.org/10.1016/J.WATRES.2007.11.030

[12] Kumar D, Alappat BJ (2005) Analysis of leachate pollution index and formulation of sub-leachate pollution indices. Waste Management & Research: The Journal for a Sustainable Circular Economy 23:230–239. https://doi.org/10.1177/0734242X05054875

[13] Kumari R, Sharma RC (2019) Assessment of water quality index and multivariate analysis of high altitude sacred Lake Prashar, Himachal Pradesh, India. International Journal of Environmental Science and Technology 16:6125–6134. https://doi.org/10.1007/s13762-018-2007-1

[14] Mishra H, Karmakar S, Kumar R, Kadambala P (2018) A long-term comparative assessment of human health risk to leachate-contaminated groundwater from heavy metal with different liner systems. Environmental Science and Pollution Research 25:2911–2923. https://doi.org/10.1007/s11356-017-0717-4

[15] Mor S, Ravindra K, Dahiya RP, Chandra A (2006) Leachate Characterization and Assessment of Groundwater Pollution Near Municipal Solid Waste Landfill Site. Environ Monit Assess 118:435–456. https://doi.org/10.1007/s10661-006-1505-7

[16] Nagarajan R, Thirumalaisamy S, Lakshumanan E (2012) Impact of leachate on groundwater pollution due to non-engineered municipal solid waste landfill sites of erode city, Tamil Nadu, India. Iranian J Environ Health Sci Eng 9:35. https://doi.org/10.1186/1735-2746-9-35

[17] Nandimandalam JR (2012) Evaluation of hydrogeochemical processes in the Pleistocene aquifers of Middle Ganga Plain, Uttar Pradesh, India. Environ Earth Sci 65:1291–1308. https://doi.org/10.1007/s12665-011-1377-1

[18] Naveen BP, Mahapatra DM, Sitharam TG, et al (2017) Physico-chemical and biological characterization of urban municipal landfill leachate. Environmental Pollution 220:1–12. https://doi.org/10.1016/J.ENVPOL.2016.09.002

[19] Pratap Singh V, Kumar Patel P (2024) Characterization of Leachate and assessment of groundwater contamination near Shivri landll site, Lucknow, Uttar Pradesh (India). https://doi.org/10.21203/rs.3.rs-4483983/v1

[20] Rabeiy RE (2018) Assessment and modeling of groundwater quality using WQI and GIS in Upper Egypt area. Environmental Science and Pollution Research 25:30808–30817. https://doi.org/10.1007/s11356-017-8617-1

[21] Rajappa B, Manjappa S, Puttaiah ET (2010) Monitoring of Heavy Metal Concentration in Groundwater of Hakinaka Taluk, India

[22] Raju NJ (2006) Iron contamination in groundwater: A case from Tirumala-Tirupati environs, India

[23] Şener Ş, Şener E, Davraz A (2017) Evaluation of water quality using water quality index (WQI) method and GIS in Aksu River (SW-Turkey). Science of The Total Environment 584–585:131–144. https://doi.org/10.1016/J.SCITOTENV.2017.01.102

[24] Sharholy M, Ahmad K, Mahmood G, Trivedi RC (2008) Municipal solid waste management in Indian cities – A review. Waste Management 28:459–467. https://doi.org/10.1016/J.WASMAN.2007.02.008

[25] Sharma A, Meesa S, Pant S, et al (2008) Formulation of a landfill pollution potential index to compare pollution potential of uncontrolled landfills. Waste Management & Research: The Journal for a Sustainable Circular Economy 26:474–483. https://doi.org/10.1177/0734242X07086515

[26] Singh S, Raju NJ, Gossel W, Wycisk P (2016) Assessment of pollution potential of leachate from the municipal solid waste disposal site and its impact on groundwater quality, Varanasi environs, India. Arabian Journal of Geosciences 9:131. https://doi.org/10.1007/s12517-015-2131-x

[27] Singh S, Raju NJ, Ramakrishna Ch (2015) Evaluation of Groundwater Quality and Its Suitability for Domestic and Irrigation Use in Parts of the Chandauli-Varanasi Region, Uttar Pradesh, India. J Water Resour Prot 07:572–587. https://doi.org/10.4236/jwarp.2015.77046

[28] State W, Chatterjee N, Flury M, et al (2013) Chemical and Physical Characteristics of Compost Leachates-A Review-Report prepared for the

[29] Talalaj IA (2014) Assessment of groundwater quality near the landfill site using the modified water quality index. Environ Monit Assess 186:3673–3683. https://doi.org/10.1007/s10661-014-3649-1

[30] Tyagi S, Singh P, Sharma B, Singh R (2014) Assessment of Water Quality for Drinking Purpose in District Pauri of Uttarakhand, India. Applied Ecology and Environmental Sciences 2:94–99. https://doi.org/10.12691/aees-2-4-2

[31] Varol S, Davraz A (2015) Evaluation of the groundwater quality with WQI (Water Quality Index) and multivariate analysis: a case study of the Tefenni plain (Burdur/Turkey). Environ Earth Sci 73:1725–1744. https://doi.org/10.1007/s12665-014-3531-z

[32] Varol S, Davraz A (2014) Assessment of geochemistry and hydrogeochemical processes in groundwater of the Tefenni plain (Burdur/Turkey). Environ Earth Sci 71:4657–4673. https://doi.org/10.1007/s12665-013-2856-3