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Assessment of Water Contamination at Municipal Solid Waste Disposal Site, Jawaharnagar, Hyderabad, Telangana, India

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Authors' contributions

This work was carried out in collaboration among all authors. Author PN analyzed the data and interpreted the results. Author SR contributed in data analysis and writing the manuscript. Authors RK and BJM did fieldwork, data generation and compilation. Author RB did geophysical investigations. Author MP did water analysis. All authors read and approved the final manuscript.

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Original Research Article

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ABSTRACT

The impact of uncontrolled municipal solid waste disposal of 3800 tons per day on surface and groundwater downstream of the Jawaharnagar dumping site was studied. The un-engineered solid waste dumping yard site spreading over about 300 hectares (ha) is located on topographic high (hillock) and falls in Madyala stream and Dammaiguda watersheds of Musi sub-basin. Granites of the Archaean age underlie the area. Both surface and groundwater samples, collected covering hydrological cycles of 2011and 2012, were analyzed for major chemical constituents. Fifteen samples belonging to both seasons of 2012 were tested for BOD, COD, and TOC. The mean values of some tested chemical constituents of surface water samples (15) were - EC 13066 m S/cm, TH 753, Na^+ 813, K^+ 530, HCO_3^- 978, Cl^- 1304, and NO_3^- 262 (all in mg/l), which prove that tanks and stream near the dump yard were pools of leachate. The average values of contaminated groundwater samples among the four sampled sessions (17) indicate EC was above 5000 m S/cm, TH 1624, Cl^- 1502, and SO_4^{2-} 284(all in mg/l), which were found much above the threshold values. Very high TOC (mean SW 241; GW 154 mg/l), BOD (5410; 117), and COD (6427; 176) content in

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both surface (SW) and groundwater (GW) samples indicate the presence of organic pollutants sourced from domestic waste dumps. Wide temporal and spatial variability in the concentration of many ion species could be due to rainfall deviation, point source changes, and heterogeneous fracture patterns. Low resistivity values (5 to 25 ohm.m) at a distance of 4 km from the dumping site and high infiltration rate (29 cm/hr) at the Madyala stream indicate hydrological features controlled the mass flux. The chloride-sulphate alkaline-earth water facies, K^{+}:Mg^{2+} and BOD/COD ratios demonstrate apart from anthropogenic input water-rock interaction and evapotranspiration governed the evolution of water chemistry. The study supports the hypothesis that solid waste dumps, which attained the methanogenic phase, were a point source of pollution that generates leachate and dissipates contaminants to the aquatic environment through preferred pathways influenced by factors like soils, topography, aquifer hydraulics, and contaminant kinetics.

Keywords: Municipal solid waste; Leachate; groundwater; surface water; mass flux; water contamination.

1. INTRODUCTION

Rapid industrialization and population explosion in India have led to the migration of people from villages to cities, which resulted in the generation of thousands of tons of municipal solid waste (MSW). Presently 90 million tons of solid wastes are generated annually in the country, and the amount is estimated to increase at a rate of 1 to 1.33% annually. The collection, transportation, and disposal of MSW were primarily done unorganized in open dumps and landfills in most cities in India and across the globe [1,2,3]. Daniel Hoornweg et al, [4] observed by 2000, the 2.9 billion people living in cities (49% of the world's population) were creating more than 3 million tons of solid waste per day. By 2025 it will be twice that - enough to fill a line of rubbish trucks 5,000 kilometers long every day.Sharholy et al. [5], in their review on municipal solid waste management in Indian, noted - various studies reveal that about 90% of MSW was disposed of unscientifically in open dumps and landfills, creating problems to public health and the environment. The MSW contains, generates, and discharges many harmful inorganic, organic chemicals, heavy metals, radioactive elements, microbes through the preferential and primary pathway from leachate or plume into surrounding environs. The location of disposal sites of Bhagalpur city represents the unconsciousness about the environmental and public health hazards arising from disposing of waste in the wrong location [6].

The MSW is turning more hazardous by E-waste; unused electronic items became part of MSW due to their extensive usage in cities. E-waste containing waste from electrical and electronic equipment (WEEE) may exceed eight lakh tones by 2012 in India [7]. The E-waste recycling and recovery options practiced in India are very outdated and hazardous, causing severe environmental and occupational hazards [8]. Nearly all the Indian cities dispose of their wastes by dumping them in un-engineered sites. Many studies were carried out on municipal dumping yards to illustrate their adverse impact on the environment in general and water resources in particular [9,10,11,12,13,14,15,16]. Potable water is the first victim of improper disposal of urban solid waste because of which in India more than 6% of the population lack access to safe water. The Ministry of Housing and Urban Affairs suggested 135 litre per capita per day (lpcd) as the benchmark for urban water supply and 55 lpcd for rural areas (https://pib.gov.in/). Even this modest quantity of water could not be supplied due to water contamination by various sources including solid waste dumps.

Even though urban solid waste is disposed of in certain cities adopting several safety methods and practicing the latest solid waste management techniques, the aquatic environment in the vicinity remains affected. Landfill leachate, which contains many toxic and harmful substances such as heavy metals, persistent organic pollutants, and bacteria, has become one of the primary anthropogenic sources of groundwater pollution[17]. Further research has shown that 0.1%−0.4% of groundwater was polluted by landfills and industrial reservoirs [18]. Dejan et al., [19] reported that groundwater quality at the landfill in Subotica, Serbia, is degrading over time, with PAH_{16}, TOC, Cr, Cu, Pb, and Zn. MSW dumping sites, irrespective of their location, either on sub-surface or uphill and in-use or abandoned, are deteriorating the surrounding aquatic environment. Rusu et al., [20], in their studies at Neamt County, Romania, noted that the landfill affected the groundwater and the surface water quality, both during the period when it was in use and after its closure. Maiti et al., [21], in their study on surrounding water resources of closed dumping sites at Dhapa (Kolkata, West Bengal, India), have observed that post-closure management of closed landfill sites is required to reduce environmental hazards.

MSW management (MSWM) is one of the significant environmental problems of many urban agglomerates. Adopting the best management measures, including protective procedures and treatment techniques to minimize the adverse impact of solid waste, could yield desired results. Tawfiq et al.,[22] concluded that although the aeration and stabilization systems reported a significant reduction in the level of leachate parameters at the collection pond, the level of parameters at aeration and stabilization ponds is still higher than the standard limits and can influence groundwater and surface water quality in the area. Kumar et al. [23], while discussing the MWSM issues, have commented that MSW dumped in landfills generates greenhouse gases like methane, which has 21 times more global warming potential than carbon dioxide. Improper solid waste management contributes to 6% of India's methane emissions and is the third-largest emitter of methane in India. In addition, improper waste management, which is rampant in many cities of developed and third-world countries, is identified as a cause of many human diseases (Navarro and Vincenzo 2019). The current study aims to assess the chemical quality of surface and ground waters downstream of the uncontrolled waste disposal site - the Hyderabad Integrated MSW processing and disposal facility (HIMSW) at Jawaharnagar. Many researchers and environmental experts have carried out extensive studies on the dumping yard [10,11,24,25,26,27,28, 29,30].

The study initiated the hypothesis that the water resource in the vicinity of the Jawaharnagar dumping yard was contaminated due to plume propagation in vulnerable local hydrogeological conditions.

1.1 Study Area

The MSW dumpsite spreading over approximately 304 ha is located near Jawaharnagar town, Keesara Mandal, Ranga Reddy district at about 35 km north Hyderabad city (Fig. 1). The site is on topographic high at an elevation varying between 550 m and 633 m, amsl, whereas the general topographic elevation of the area ranges from 510 to 560 m. The study area spreads over 17 sq km in and around the MSW site (17^{o} 30’ to 17^{o} 32’ N latitude and 78^{o} 35’ to 78^{o} 38’ E longitude). The climate in the area is semi-arid with an average annual rainfall of 753 mm, of which southwest monsoon contributes 73 %, northeast monsoon 19 %, and rest by winter and summer seasons. At Keesara (areal distance of 10km from dumpsite), annual rainfall in the year 2010 was high (1080 mm), low (422 mm) in 2011, and during the year 2012, the area received 634 mm rainfall. The area is covered with red loamy soils but the soil thickness is meager at the dump yard since it is located on massive ridge. The legacy dump on 70-80 meters high pseudo hillock now containing about 12 million tons of waste came into existence in 2001.

2. METHOD OF STUDY

The hydrogeological survey was carried out in 2011, and based on the outcome, sampling sources were identified. Surface and groundwater samples were collected in pre-monsoon and post-monsoon seasons of 2011 and 2012, both in the core area and lower reaches of the municipal dumping yard (MDY). (Fig. 1). In the four sampling sessions, the surface water samples gathered were 2 to 4 from tanks and one from the stream. The groundwater samples collected from bore wells of different depths were 17 in pre-monsoon 2011, 12 in post-monsoon 2011, and 25 each in pre and post-monsoon seasons of 2012. Variable sampling pattern was followed based on the availability of sources and to have a broad representation. The pH and EC were recorded in situ at sampling with digital pH and EC meters. All the water samples were tested for major ionsin the chemical laboratory of Central Ground Water Board, Southern Region Hyderabad.15 samples collectedin 2012 were analyzed for TOC, BOD, COD in Centre for Environment, JNTU, Hyderabad following standard procedures of APHA [31].The results were tested for reliability using the cation and anion charge balance method, and all samples fall within +3.12 to -1.33%. As part of geophysical investigations, 94 vertical electrical soundings (VES) were carried out to estimate the weathering thickness and delineate the fracture pattern in the area. Infiltration tests were carried out at three different sites to measure the soil infiltration rates. WQI was calculated applying the method used by Asit and Surajit [32] in which the authors have assigned weight (*wi*) 2 to TH, Ca, and Mg; 3 to HCO_3 and Cl; 4 to pH, TDS, SO_4, and F; only NO_3 is assigned a weight of 5. The weight for each parameter (*wi*) was chosen according to its relative importance for drinking purposes. The water chemistry results were analyzed and inferred using MS EXCEL and AQUACHEM software.

2.1 Geomorphology

The study area falls in the Madyala stream watershed and Dammaiguda mini watershed. Mayalavagu (stream) is a tributary of the Musi River, part of the Krishna river basin. Significant surface water bodies in the area are the Irlagutta, Cherial, and Dammaiguda tanks. The drainage pattern is dendritic to sub-dendritic (Fig. 1). Pediment (shallow, moderate), pediment inselberg complex, denudational hills are the major landforms in the area. The major lineaments (>5 km) confined to northern and southern parts trend in NW-SE direction, while in the east, the lineaments trend in near N-S direction. The thickness of the topsoil cover extends down to 2 m, and soils are loamy in texture.

India with Telangana State (marked in red); Telangana State with Districts; Medchal-Malkajgiri Distirct with Mandals.

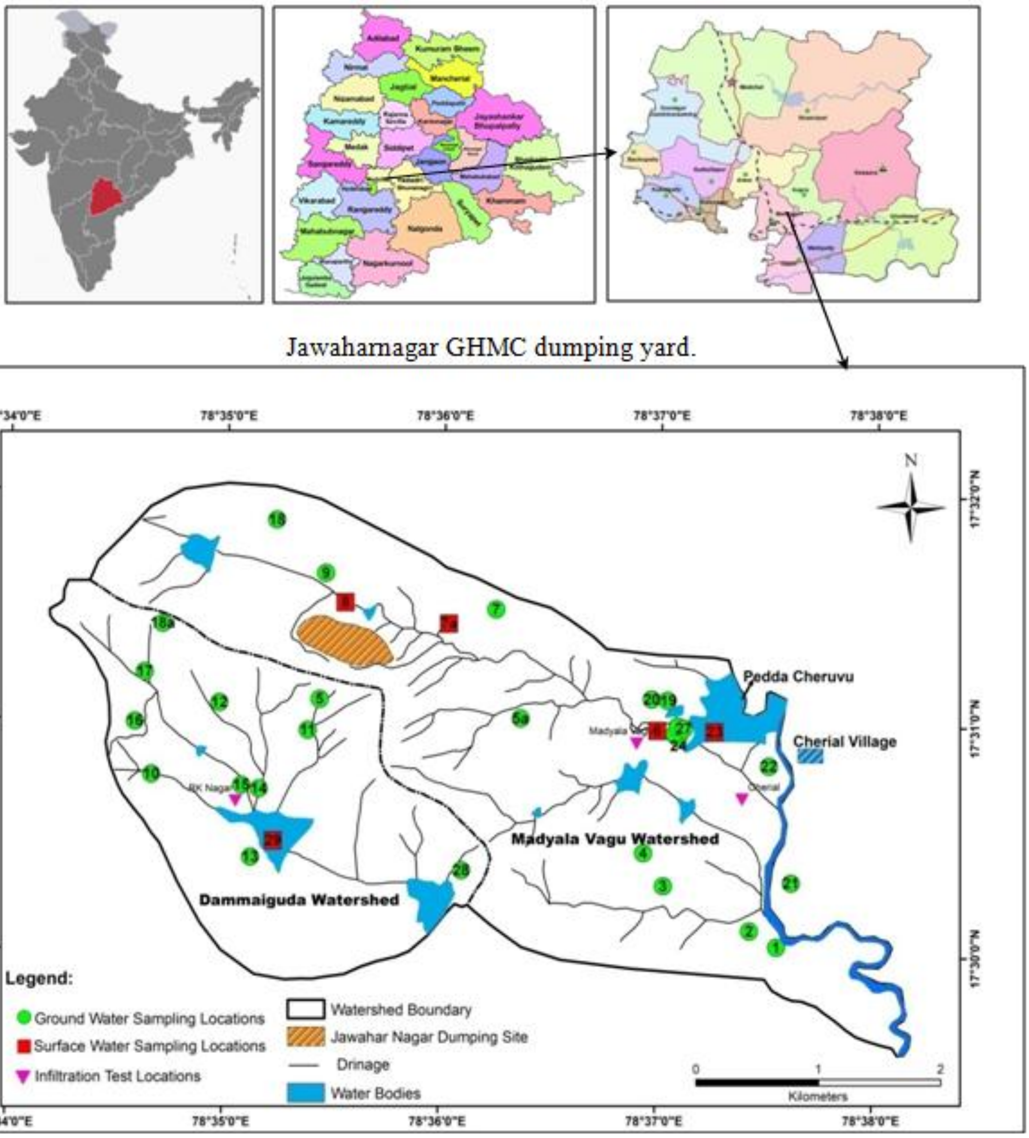

Fig. 1. Key Map with Study area and samples locations

2.2 Hydrogeology

The area is underlain by grey granite gneisses and granites of the Archaean age. The thickness of weathering extends down to 18m, while the fractures are recorded down to 106 m. The depth to water levels ranges from 6.08 to 29.4 m and 4.14 to 22.54 m, bgl (below ground level) during the 2011 pre-monsoon and post-monsoon seasons, respectively. Water table elevation contour ranges from 500 to 560 m with a gradient of 10 m/km. The groundwater flow is towards the southeast. The infiltration rate was high (29 cm/hr) at the Madyala stream, low at Rajiv karmika Nagar (9.2 km/hr) and Cherial village (9.6 km/hr;Rao, [25]).

3. RESULTS AND DISCUSSION

3.1 Inorganic Chemistry

Surface water: The surface water samples collected from tanks and streams, present in downstream of the dumping yard, have very high concentrations of many tested parameters (Tables 1 to 4). The Irlagutta tank (Sample No. 8), occurring in the foothill of hillock contains many tested parameters in abnormally higher concentrations than the background values. In 2011 pre-monsoon the EC (m S/cm) was 17640, which rose to 90560 in 2012 pre-monsoon. It could be because the part of solid waste and leachate from the dumping yard was directly flowing into the tank due to a hydraulic gradient. The Haridaspalli tank (Sample No. 7a), located close to MDY, was also severely affected; it recorded an EC of 12220 m S/cm in pre-monsoon 2011 (Table 1). The Cherial tank (Sample No. 23), located 4 km E of MDY, also had very high EC (m S/cm) 7094 in 2011 pre-monsoon; it increased to 11390 in the following year. The Dammaiguda tank (Sample No. 29), located at about 4 km SSE, contains moderate EC in pre-monsoon 2011. However, it has risen by about 50% in 2011 post-monsoon and pre-monsoon of 2012, reflecting progressive dissipation of contaminant load. The dumping yard hillock forms the recharge zone of the area. The Madyala stream originates from it and flows into the nearby tanks located downstream. The surface runoff carries leachate from MDY polluting nearby surface water bodies (Tables 1 to 4). The tremendous increase of EC in post-monsoon at Irlagutta tank substantiates that infiltrating rainwater from dumping yard hillock directly carry contaminant load into the tank. The contaminants get dissipated and diluted as water flows downwards and farther from the source, asevident from reduced EC at Hardaspalli (12220 m S/cm), Cherial tank (7094 m S/cm). Dammaiguda tank, though located 4 km south of the dumping site, recorded a moderate EC of 2970 m S/cm. The turbidity (40 NTU), total hardness (800 mg/l), sodium (1495 mg/l), chloride (2907 mg/l), sulphate (1008 mg/l), and nitrate (229 mg/l) were unusually high in the Cherial tank, indicating the unabated spread of pollution to as far as 4 km from the source (Table 3). During the post-monsoon season, dilution of many chemical constituents was observed, reflected in the significantly reduced EC in the Cherial tank. Similarly, the sample from the Irlagutta tank has turned more basic with 9.06 pH and was tested with elevated content of K^+, CO_3^{2-} SO_4^{2-}. The Madyalavagu stream water sampled at JNNURM (Sample No. 6) reported the lowest mineralization (EC 1220 m S/cm; Table 4). Fresh inflow from the monsoon, together with reduced propagation of pollutants from the source, could have diluted the ion content of water.

Groundwater: The mean content of all the sampled sessions of groundwater displays that water had 7.66 pH, EC was 2064 m S/cm, and many other tested parameters were in tune with threshold values except TH, Cl^- and NO_3^-which were 624, 463, 57 mg/l respectively. In pre-monsoon 2011, the average EC was 2189 m S/cm, being higher than other sampling episodes, similar was the HCO_3^- (459 mg/l) and NO_3^- (71 mg/l). EC was the maximum in this sampling session at Rajiv Karmik Nagar (Sample No. 14), which was about 4 km SE of MDY but hydraulically well connected by drainage network of Madyala stream. Plume dissipation as far as 4 to 5 km downstream of MDY was evident in this sample as TH, Ca^{2+}, Na^+, HCO_3^-, Cl^- and NO_3^- were abnormally high (Table 1). In post-monsoon 2011 the groundwater turned less acidic with mean pH of 7.14, and dissolved ions were the lowest in this sampling episode as the mean EC was 2000 m S/cm. Ca^{2+} was higher, and Mg^{2+} was lower than those of other sampling sessions. Low variability in ion content among different season samples can be accounted for by enhanced natural attenuation process, and fewer samples (12) might be another factor (Table 2).

The samples of pre-monsoon 2012 have average parametric content, but for TH and Cl^- which were 729 and 527 mg/l, respectively, being higher than all other sampling sessions. It was also distinct by having the lowest mean content of Na^+ (145 mg/l) and the maximum Mg^{2+} (729 mg/l). Inconsistency in Na^+ and Cl^- concentration and very high TH and Ca^{2+} supports the contention of an unnatural source of ions (Table 3). The abnormal value of total hardness may be due to the domestic, paper, textile, and chemical waste [33]. In post-monsoon 2012 the groundwater turned more basic, with mean pH being 8.45. Wide variation in EC, TH, and Ca^{2+} was noticed among the analyzed samples. Abnormally high range of Cl^- concentration (25 - 3205 mg/l) with a mean of 478 mg/l and low Na^+ (mean 172 mg/l) substantiate the influence of pollution in the vicinity. Another unique feature of this sampling session was high K^+, CO_3^{2-} and low HCO_3^-. The SO_4^{2-} was doubled compared to three other sampling sessions (Table 4). Though the concentration of specific ions was reduced between the pre and post-monsoon seasons of 2012, the extent of contaminated zones remained the same in two seasons.

3.2 Organic Constituents

Surface water: Select samples from both surface (4 nos) and groundwater (15 nos) sources tested for TOC, BOD, and COD in pre and post-monsoon 2012 validate that the area was polluted with municipal waste. During pre-monsoon 2012, the TOC in surface water was as high as 395 mg/l in the Cherial tank, whereas in the Dammaiguda tank, it was only 49 mg/l. A contradictory picture emerged in post-monsoon 2012; the TOC reduced drastically in the Cherial tank to 24 mg/l and rose in the Dammaiguda tank to 108 mg/l. However, the TOC has reduced significantly in other surface water bodies (Table 5). The BOD and COD were high (18000 and 16000 mg/l respectively) in the Iralagutta tank proving it a leachate pool. Rusu et al. [20] inferred that the high values of the COD indicator might be attributed to the contagion of the surface water with persistent organic pollutants from landfill leachate. Other surface water bodies have moderate content of BOD and COD, and their intensity was diminishing with distance from the Source (MDY). The impact of organic compounds reduced remarkably in peripheries (3-4 km) of the watershed. A BOD/COD ratio (0.50) indicates that the majority of the organic compounds were biodegradable [34].

Groundwater: The TOC content in groundwater varied between 42 and 345 mg/l with a mean of 154 mg/l in pre-monsoon 2012. It has reduced significantly in all the samples except one (Maisamma temple; Sample No. 2) in post-monsoon. The very high content of TOC in the surface water body (Cherial tank; Sample No. 23) was also reflected in the groundwater sample located close to the tank. The average COD and BOD were 176 and 117 mg/l, respectively, in pre-monsoon 2012. The highest content of COD (360 mg/l) and BOD (330 mg/l) was found in bore well at Masjid Rajivgruhakalpa (Sample No. 5; Table 5). The high COD content in groundwater samples indicates an abundance of organic contaminants sourced from MDY [35]. The spread of organic contamination even to fringe areas of the watershed in groundwater rather than surface water might be due to subsurface conduits facilitating the migration of pollutants. Uneven spatial distribution of organic compounds within proximity (near Cherial tank and Cherial village) can be accounted for hydraulic discontinuity and natural attenuation.

3.3 Variability in Water Chemistry

Seasonal variation in surface water: Contradictory seasonal variation was reflected in two sets of surface water samples of pre and post-monsoon 2011. All the tested chemical constituents except HCO_3^- increased in post-monsoon in Dammaiguda tank whereas the concentration of all but TH, Mg^{2+}, and SO_4^{2-} decreased in Cherial tank (Supplementary Material 1). These surface water bodies are located in fringe areas and fed by diverse channels; thus, they display independent seasonal variations. Significant fall in bicarbonate concentration in post-monsoon at both locations could be for the meager freshwater flow due to low monsoon rainfall (358mm) in 2011. Drastic reduction in many chemical constituents at Cherial tank was noticeable in the following year (2012) post-monsoon. Apart from rainwater, inflow from other sources, including base flow might be diluting solute concentration.

Temporal variation in surface water: Annual variation trend in surface water chemistry was similar to seasonal variation. The concentration of many ion species increased between pre-monsoon 2011 and 2012 in Dammaiguda and Cherial tanks. In contrast, ion content decreased remarkably in the Cherial tank during post-monsoon 2012 compared to 2011 (Supplementary Material 1). The commonality was a significant reduction of HCO_3^- over a year (2011 to 2012) in pre and post-monsoon seasons. Increase of Ca^{2+}, Mg^{2+}, and SO_4^{2-} and decrease of Na^+, K^+, Cl^- and NO_3^- in a year in post-monsoon 2012 support the contention that natural ionization processes also contributed to mineralization of water in the wet season. In addition to direct leachate discharge, evapotranspiration (ET) might be leading to the enrichment of specific ions in tank water during the pre-monsoon period. The semi-arid climate and long hot summer of the area might be accelerating plume dissipation in the non-monsoon period (Sanjay et al., 2010, Saber et al., [36]). Annual variation in surface water chemistry was high between pre-monsoon 2011 and 2012. However, a contradictory trend was evident in the post-monsoon for the same year. Seasonal and temporal variations among the tested parameters were erratic, depicting the anthropogenic source of many ion species.

Seasonal variation in groundwater: The seasonal variation in groundwater chemistry was studied considering the chemical analysis of the same samples of pre and post-monsoon. The seasonal variation trend was similar to the surface water, but in groundwater, the dilution of many chemical constituents was moderate in post-monsoon. The content of many chemical constituents reduced in post-monsoon 2011, about 60% decrease of K^+ and 36% that of NO_3^- indicate plume penetration was diminishing (Supplementary Material 1). The reduced concentration in monsoon can be attributed to the dilution taking place on account of recharge of the shallow aquifer due to the monsoon rains [37], Pujari et al., [38]). Nevertheless, diverse seasonal variation trends can be noticed in the year 2012. The concentration of K^+, SO_4^{2-},and NO_3^- has increased remarkably, contradicting the earlier contention. The addition of more representative sampling points might be providing the ground truth.

Temporal variation in groundwater: Increase in intensity of contamination over a year from 2011 to 2012 was evident as many physicochemical characters like pH, Mg^{2+}, K^+, Cl^-, SO_4^{2-},NO_3^- have raised (Supplementary Material 1). Soujanya et al. [39] also made a similar observation in their study on this area. In both the seasons between 2011 and 2012, the concentration of Ca^{2+}, Na^+, and HCO_3^- was reduced; these were primarily controlled by a natural process. Lack of distinct seasonal or annual trends infers influx of ion constituents was from external sources. The similarity in chemical variations among surface and groundwater substantiate interconnectivity. Consistent decrease of HCO_3^- content in both seasonal and temporal period indicate meager fresh recharge to the aquifer. The inconsistency in concentrations of specific ions can be accounted for variations in rainfall, quantum, and nature of solid waste and hydrogeological characteristics.

Spatial variation in groundwater: Spatial distribution of chemical constituents and their variation was studied using pre and post-monsoon 2012 results to understand the plume kinetics and demarcate the area of influence from MDY. In pre-monsoon 2012, highly mineralized water (TDS) was confined to small isolated patches in SW, which is in the downhill part of MDY, and in the SE part, which is 4 km away from the core area but falls in the discharge zone of the watershed (Fig. 2a). In post-monsoon, the water having high TDS was found dominantly in the north and east of MDY. In the SW part, the TDS was reduced, displaying the dilution effect of rainfall recharge (Fig. 2b). TH was distinctly high in many of the tested samples, which was reflected in its spatial spread. In both the seasons of 2012, large areas in the central part (encircling MDY) and in the E as well as SE corner, the groundwater had high (>600 mg/l) TH. The hardness of the water was <300 mg/l in the peripheries of the watershed, which authenticate that seepage from municipal solid waste, was responsible for this malady (Figs. 3a and b). Slight seasonal variation was noticed in the spatial distribution of TH. Cl^- distribution was similar to TH. It was >500 mg/l in a large area around MDY and Cherial tank (Fig. 4a). In post-monsoon 2012 more wells in the area around the Cherial tank had high Cl^-, whereas the extent of Cl^- rich area in the central part had reduced (Fig. 4b). In the northern part of Madiyalvagu (stream) catchment, nitrate was less (<45 mg/l), while, in the southern part near the Dammaiguda catchment, it was more (>45 mg/l) both during pre-monsoon and post-monsoon seasons. It could be probably due to the dumping of waste containing nitrogenous compounds (domestic waste) in the southern part of the dumping site, from where the leaching was more towards the south. The intensity of the adverse effect on water resources from the point source (MDY) diminished with distance. It was primarily confined to a 2 to 3 km radius but extending more on the southern and eastern side due to natural flow pattern [37]. In their studies on two designated landfills, at Perungudi in the south and Kodungaiyur in the north of Chennai city, observed that measured levels of contaminants are found to decrease progressively with increasing distance from the site.

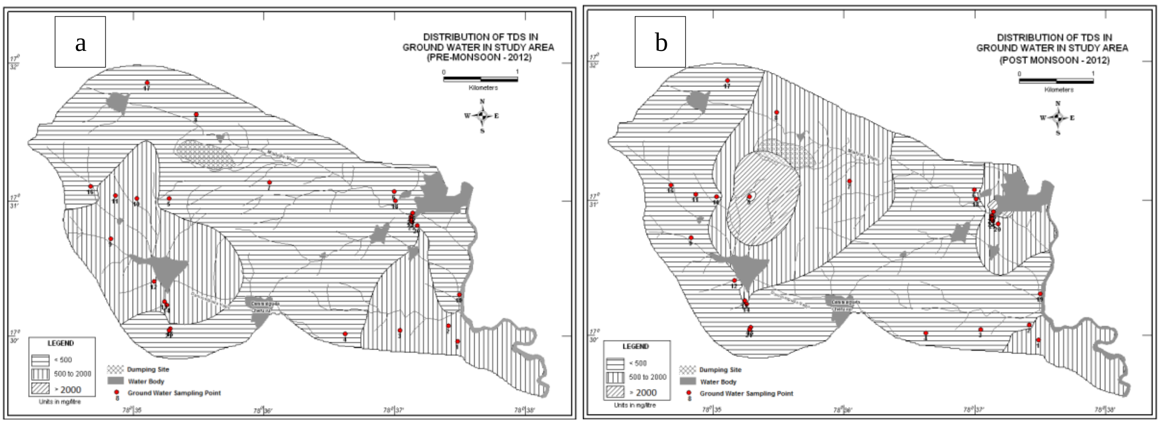

Fig. 2. Spatial distribution of TDS in Pre-monsoon 2012 (a), Post-monsoon 2012 (b).

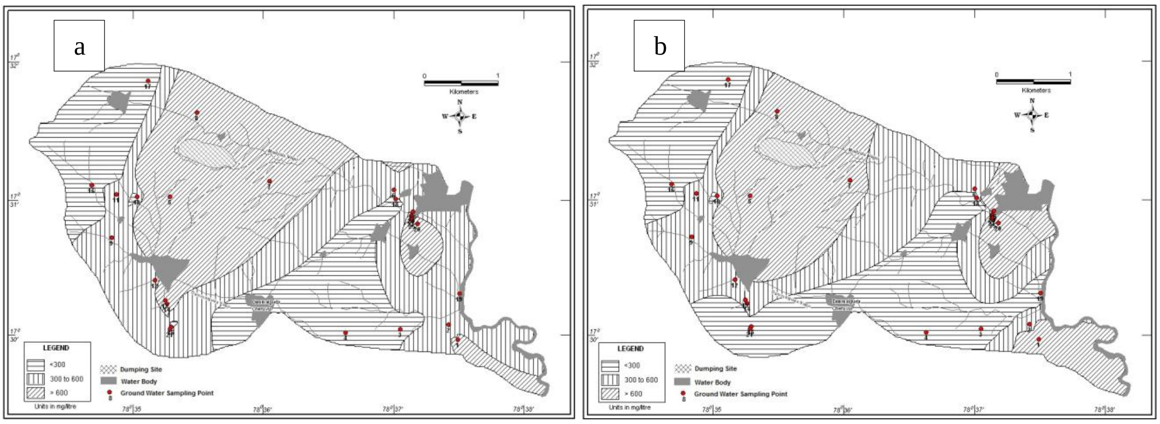

Fig. 3. Spatial distribution of TH in Pre-monsoon 2012 (a), Post-monsoon 2012 (b).

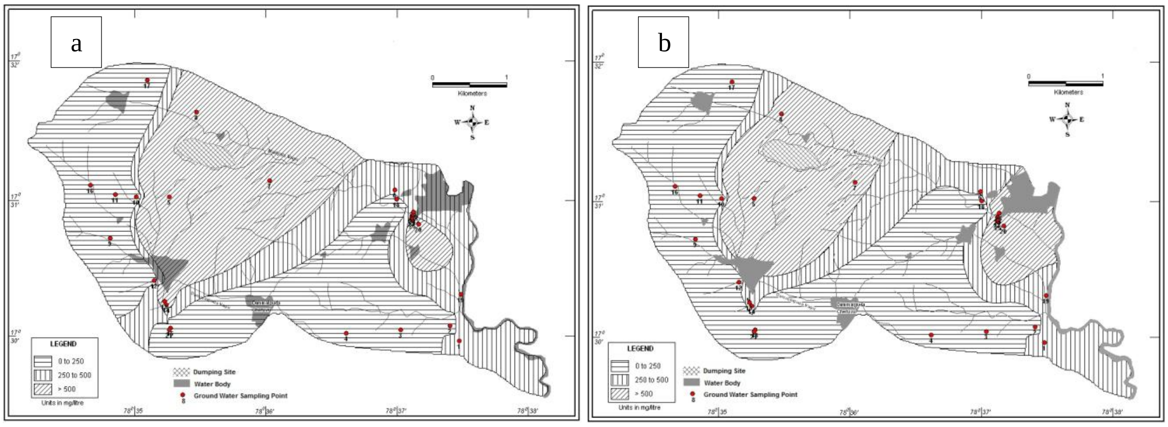

Fig. 4. Spatial distribution of Cl^- in Pre-monsoon 2012 (a), Post-monsoon 2012 (b)

Contaminated surface water: Water samples gathered from tanks and stream in the watershed has many tested parameters in very high concentration demonstrating the prevalence of high rate of toxicity. These surface water bodies were almost converted into reservoirs of leachate, which was evident with higher Mg^{2+} content than Ca^{2+} (average Mg^{2+} 118; Ca^{2+} 107 mg/l) in many samples, high K^+/Mg^{2+} ratio (average 4.07), and EC (average 13066 m S/cm). High turbidity (37 to 54 NTU) and about 9 NTU in stream waters support the above observation. It can be further substantiated by comparing the results with the leachate discharge standards for inland surface water [Municipal solid waste (Management and handling) rules, 2013]. Most of the surface water samples of all the sampling sessions have the tested parameters above the leachate discharge standards (Tables 1 to 5). In leachate, Mg^{2+} dominates Ca^{2+}, and it has the highest K^{+}/Mg^{2+} ratio and EC value [40]. Irlaguttatank, which lies in the foothill of the MDY site, was filled with leachate. The EC value of 90560 m S/cm in pre-monsoon 2012 substantiates the inference. The chemical analysis results of the sample for pre-monsoon 2011 display highly high values of all the tested parameters except Ca^{2+} and SO_4^{2-} (Table 1). The Haridaspalli tank, another closely spaced one, was also covered mainly by leachate as reflected in its chemical analysis by very high EC (12220 m S/cm), Ca^{2+}, and SO_4^{2-} apart from other significant ions. Leachate content was found relatively less in the other two tanks (Dammaiguda and Cherial tanks) located about 4 km from the dumping site. The mean EC of these water samples ranged between 4000 and 7200 m S/cm. The Cherial tank has the highest K^{+}/Mg^{2+} ratio (>9 in pre-monsoon 2011 and 2012) as well as Cl^{-} concentration (2907 mg/l), proving the presence of leachate. The Madyala stream water, though it originates from the recharge area at the dumping yard, does not display the effect or influx of leachate (Table 3 and 4). It could be due to feeble surface runoff and high hydraulic gradient. However, the stream contributes contaminants to the surface and subsurface waters through the base flow. Leachate content was significantly reduced in the post-monsoon season, which can be accounted for dilution by precipitation and outflow through surface runoff. High EC TH, Ca^{2+}, Cl^{-} and K^{-}/Mg^{2+} ratio in groundwater samples in the vicinity of tanks and streams demonstrate percolation of contaminant load from surface waters to the sub-surface domain, (Tables 1 to 4). The distribution of samples points in K vs Mg cross plots (Supplementary Material 2) confirm the observation. Many surface water and few groundwater samples were plotted close to the 1:1 line, but surface water points were present in 10:1 $K^{+}:Mg^{2+}$ and groundwater in 1:10 $K^{+}:Mg^{2+}$ ratios. Loss of K^{+} in the transition to the aquifer environment could be due to natural attenuation and its conservation in the leachate in surface water. Low and high ratios of $K^{+}:Mg^{2+}$ in few samples in both the waters emphasize the influence of external factors in attaining the saturation point of these cations. All the surface water samples had a very high concentration of organic compounds (TOC - 380, COD - 18000, and BOD - 16000). The COD and BOD were very much above the leachate discharge standards (Table 5). High BOD/COD ratios in many samples indicate the point source crossed the intermediate methanogenic phase.

Contaminated groundwater: Groundwater samples showing signs of contamination were segregated to evaluate the chemistry of those waters. Samples with EC >3000 m S/cm (17 nos) were identified as highly contaminated and distinctly displayed in *italics* in Tables 1 to 4. The average values of these samples specify EC was above 5000 m S/cm, TH 1624, Cl^{-} 1502, and SO_4^{2-} 284(all in mg/l). Some of the samples [e.g., Rajiv Gandhi Karmik Nagar (Sample No. 14), Cherial cross-roads (Sample No. 21), Masjid Rajivgruakalpa (Sample No. 5)] in the four sampling sessions have TDS, Cl^{-}, NO_3^{-} above the leachate discharge standards for inland surface water, which proves surface water leachate as the point source (Tables 1-5). The intensity of contamination can be further ascertained from the fact that only few samples were found suitable for drinking purposes compared with the *Permissible limit* criteria of Indian Standard Drinking Water-Specification (BIS 2012). Water quality indices also reflected high contaminant content in water (WQI; [32]. The mean WQI values for groundwater samples were very high in the first three sampling sessions (82 to 89) and significantly reduced to 65 in post-monsoon 2012 (Tables 1 to 4). The classification of water-based on WQI displays that very few samples belong to the *Excellent* class, whereas the majority fall in the *Good* class. Classification of many samples in *Good* class could be due to the quality rating (*qi*), which is based on Indian drinking water suitability. In surface water, the mean WQI for all the sampled secessions was 170, and most all belong to the *Poor* class. The noncompliance to drinking water specifications and high WQI indices establish leachate generated from MDY spreads contaminants through mass flux to vulnerable water sources. Deshmukh and Aher 2016 [41] inferred that a high level of electrical conductivity in groundwater was attributable to the impact of a nearby landfill site. The high chloride, TH values in groundwater may be ascribed due to solid waste dumping, leaching from upper soil layers in dry climates, and natural geochemical activities in the area [42]; Naveen et al., [13]; Conglian et al., [43]).

Table 1. Water chemsitry results for Pre-monsoon 2011 along with water quality assessment based on BIS drinking water specifications and WQI values

Sl. No.	Sample No.	Village	pH	EC	TDS	TH	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	HCO_3^- (as $CaCO_3$)	Cl^-	SO_4^{2-}	NO_3^-	F^-	WQI (Asit and Surajit 2015)
				m S/cm		mg/l										
		BIS DWS-IS 10500 : 2012 - Permissible Limit in the Absence of Alternate Source.	**<6.5->8.5**		**2000**	**600**	**200**	**100**	**NS**	**NS**	**600**	**1000**	**400**	**45**	**1.50**	
		Leachate discharge standards for Inland surface water*	5.5-9.0		2100							1000		45	2.00	
		Surface water														
1	*6*	*JNNURM Madyala vagu (Stream)*	*7.60*	*4620*	*2957*	*600*	*160*	*49*	*679*	*352*	*988*	*1134*	*10*	*100*	*1.40*	*127*
2	*7a*	*Haridaspalli Tank*	*7.70*	*12220*	*7821*	*1400*	*257*	*185*	*1840*	*860*	*2105*	*1999*	*1440*	*500*	*2.10*	*385*
3	*8*	*Irlagutta Tank*	*7.70*	*17640*	*11290*	*1440*	*56*	*316*	*2128*	*2151*	*5368*	*1950*	*5*	*2000*	*1.30*	*912*
4	*23*	*Cherial Tank*	*7.60*	*7094*	*4540*	*660*	*120*	*87*	*943*	*860*	*1403*	*1773*	*19*	*150*	*1.60*	*170*
5	29	DammaigudaTank	7.60	2970	1901	420	56	68	437	196	470	815	17	50	1.10	87
		Groundwater														
1	1	Ahmedguda kaman	7.40	2362	1512	660	104	97	281	16.42	653	340	86	200	1.60	145
2	2	Maisamma temple	7.40	1835	1174	610	108	83	156	3.91	476	241	115	130	0.77	109
3	3	Ahmedguda/ Bandlaguda	7.50	1037	664	290	78	23	120	0.39	451	64	36	60	0.76	70
4	4	Aqua house Laxminagar colony	7.50	756	484	260	96	5	59	0.78	372	32	19	20	1.30	57
5	5a	*Santhi nagar*	*7.30*	*3014*	*1929*	*730*	*156*	*83*	*340*	*20*	*458*	*652*	*59*	*120*	*0.93*	*115*
6	7	Haridaspalli	7.50	2310	1478	530	180	19	288	2.35	525	482	5	4	0.75	66
7	9	Malakaram X Roads	7.40	1685	1078	460	164	12	170	0.78	323	312	93	30	1.20	72
8	10	Jami Masjid Bhagaya nagar colony	7.17	576	369	220	68	12	28	0.39	201	32	35	35	1.50	59
9	11	E. Nandamuri colony	7.50	1101	705	410	144	12	46	0.78	183	145	24	160	0.92	104
10	12	Gabbilalapeta	6.90	917	587	320	98	18	62	1.56	183	138	39	50	1.50	68
11	13	NTR colony Ambedkar nagar	7.40	1570	1005	570	116	68	115	0.78	415	241	93	50	1.10	81
12	14	Rajiv Karmika nagar	*6.50*	*10540*	*6746*	*1660*	*505*	*97*	*1725*	*8.60*	*1232*	*3049*	*19*	*100*	*0.27*	*183*
13	18a	Army college	7.60	824	527	270	104	2	63	1.56	317	60	41	20	1.70	61
14	19	JNNURM Buildings	7.90	1491	954	470	156	19	120	0.78	543	142	77	8	1.10	66
15	22	*Cherial village*	*7.00*	*3680*	*2355*	*660*	*208*	*34*	*564*	*3.13*	*598*	*922*	*10*	*100*	*0.36*	*107*
16	27	Near Cherial Tank		2082	1332	780	136	107	117	1.17	519	326	130	14	NA	70
17	28	Venkateswara nagar	7.40	1434	918	410	152	7	140	0.78	348	184	84	100	0.56	87
Mean of Groundwater samples			**7.34**	**2189**	**1401**	**548**	**152**	**41**	**258**	**3.75**	**459**	**433**	**57**	**71**	**1.02**	**89**

NS: Not specified; *NA: Not analysed;* *104* *Paramater content =>AL$;* *660* *Paramater content =>PL#.*

3680: Highly contaminated *87* *WQI - Good water* *385* *WQI -Poor water*

*Municipal solid waste (Management and handling) rules, 2013 (The gazette of India, 2013)

$Acceptable Limit of BIS DWS; #Permissible Limit of BIS DWS

Table 2. Water chemistry results for Post-monsoon 2011 along with water quality assessment based on BIS drinking water specifications and WQI values

Sl. No.	Sample No.	Village	pH	EC	TDS	TH	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	HCO_3^- (as $CaCO_3$)	Cl^-	SO_4^{2-}	NO_3^-	F^-	WQI
				m S/cm	mg/l											
		Surface water														
1	*23*	*Cherial Tank*	*7.67*	*5958*	*3813*	*720*	*88*	*122*	*690*	*665*	*1055*	*1446*	*101*	*68*	*1.20*	*131*
2	*29*	*Dammalguda Tank*	*7.50*	*4510*	*2886*	*580*	*88*	*87*	*575*	*313*	*226*	*1276*	*185*	*56*	*1.30*	*106*
		Groundwater														
1	2	Maisamma temple	7.13	1670	1069	535	76	84	140	3.91	500	188	110	65	1.10	86
2	3	Ahmedguda/ Bandlaguda	7.30	736	471	210	70	9	71	0.39	342	32	19	20	1.30	55
3	5a	*Santhinagar*	*6.65*	*3100*	*1984*	*1140*	*409*	*29*	*198*	*2.35*	*390*	*780*	*102*	*20*	*1.00*	*91*
4	7	*Haridaspalli*	*6.44*	*3479*	*2227*	*1000*	*377*	*15*	*359*	*2.35*	*354*	*950*	*49*	*118*	*0.77*	*118*
5	9	Malkaram X Roads	8.10	1503	962	545	132	52	106	0.39	360	234	81	74	1.40	92
6	11	E. Nandamuri colony	7.38	646	413	155	52	6	76	1.17	195	67	22	43	1.50	61
7	13	NTR colony Ambedkar nagar	7.40	1140	730	385	70	51	81	1.17	342	110	74	50	2.10	80
8	14	*Rajiv Gandhi karmiknagar*	*6.49*	*3770*	*2413*	*1200*	*417*	*39*	*322*	*1.17*	*500*	*1007*	*55*	*12*	*0.82*	*92*
9	18a	Army college	7.30	863	552	280	94	11	60	1.17	232	99	48	38	1.80	67
10	19	JNNURM Buildings	7.42	1633	1045	355	132	6	209	0.39	421	269	65	16	1.10	64
11	22	*Cherial village*	*6.75*	*3973*	*2543*	*1020*	*393*	*10*	*460*	*3.52*	*567*	*1021*	*50*	*81*	*0.45*	*111*
12	28	Venkateswaranagar	7.33	1491	954	415	124	26	150	0.39	445	199	78	6	0.82	59
Mean of Groundwater samples			**7.14**	**2000**	**1280**	**603**	**196**	**28**	**186**	**1.53**	**387**	**413**	**63**	**45**	**1.18**	**81**

Table 3. Water chemistry results for Pre-monsoon 2012 along with water quality assessment based on BIS drinking water specifications and WQI values

Sl. No.	Sample No.	Village	pH	EC	TDS	TH	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	HCO_3^- (as $CaCO_3$)	Cl^-	SO_4^{2-}	NO_3^-	F^-	WQI
				m S/cm	mg/l											
		Surface water														
1	6	JNNURM Madyalavagu (Stream)	7.79	1762	951	575	128	62	131	1.56	153	461	63	10	0.70	62
2	23	*Cherial Tank*	*7.88*	*11390*	*7269*	*800*	*100*	*134*	*1495*	*1212*	*299*	*2907*	*1008*	*229*	*1.41*	*239*
3	29	*Dammaiguda Tank*	*8.79*	*4390*	*2630*	*560*	*76*	*90*	*681*	*119*	*207*	*993*	*392*	*110*	*0.19*	*121*
		Groundwater														
1	1	Ahmedgudakaman	7.96	1900	1158	610	50	118	184	9.38	476	312	122	72	0.90	93
2	2	Maisamma temple	8.15	1200	762	385	50	63	124	1.96	403	138	75	62	0.96	79
3	3	Ahmedguda/ Bandlaguda	8.17	744	477	270	30	47	71	0.78	366	35	28	40	0.97	64
4	4	Aqua house Laxminagar colony	8.04	475	306	140	38	11	58	1.17	262	18	12	7	0.95	46
5	5	*Masjid Rajivgruakalpa*	*7.10*	*9098*	*4654*	*4000*	*401*	*729*	*262*	*1.96*	*122*	*3120*	*35*	*31*	*0.33*	*193*

Sl. No.	**Sample No.**	**Village**	**pH**	**EC**	**TDS**	**TH**	**Ca^{2+}**	**Mg^{2+}**	**Na^{+}**	**K^{+}**	**HCO_3^- (as $CaCO_3$)**	**Cl^-**	**SO_4^{2-}**	**NO_3^-**	**F^-**	**WQI**
				m S/cm							**mg/l**					
6	7	Haridaspalli	7.54	2510	1438	860	253	56	184	3.91	85	737	123	28	0.70	80
7	9	*Malakaram X Roads*	*7.48*	*3150*	*1784*	*1240*	*236*	*158*	*179*	*1.17*	*220*	*922*	*136*	*17*	*0.68*	*92*
8	10	Jami Masjid Bhagaya Nagar colony	8.06	859	508	340	56	49	46	0.78	275	78	50	59	1.90	79
9	11	E. Nandamuri colony	7.90	725	445	265	92	9	46	1.17	159	96	46	58	1.30	69
10	12	Gabbilalapeta	7.97	1042	688	435	138	22	51	1.17	153	152	43	186	1.02	116
11	13	NTR colony Ambedkar nagar	7.83	1200	765	445	68	67	97	1.17	287	174	94	89	1.02	88
12	14	*Rajiv Karmikanagar*	*7.18*	*4864*	*2656*	*1480*	*441*	*92*	*405*	*1.17*	*146*	*1489*	*110*	*28*	*0.41*	*105*
13	15	Rajiv Karmikanagar-II	7.52	1944	1064	705	200	50	106	0.78	98	521	59	67	0.85	85
14	16	Ven.brickind.Bhagyangr colony	7.96	508	324	225	56	21	28	1.17	220	39	32	12	1.84	57
15	17	Rajiv swagrua, Ahmedguda	7.83	526	331	200	60	12	35	1.17	171	50	43	24	1.50	57
16	18	Malakaram	7.84	610	388	230	54	23	46	3.13	201	64	39	33	1.84	64
17	19	JNNURM Buildings	7.54	1447	823	505	106	58	108	1.17	250	326	66	4	0.62	57
18	20	Near JNNURM	8.01	578	368	200	34	28	55	1.17	275	35	24	21	1.36	57
19	21	Cherial X Road	7.82	1946	1197	325	50	49	322	1.17	348	404	144	13.95	1.36	70
20	22	Cherial village	7.30	2332	1308	890	208	90	133	2.74	134	695	53	43	0.36	80
21	24	*Near Cherial Tank*	*7.23*	*4278*	*2245*	*1390*	*192*	*221*	*322*	*3.91*	*299*	*1276*	*22*	*25*	*0.12*	*97*
22	25	*Near Cherial Tank*	*7.31*	*4358*	*2266*	*1480*	*216*	*228*	*294*	*3.13*	*220*	*1347*	*31*	*11*	*0.41*	*97*
23	26	Near Cherial Tank	7.93	1560	882	370	50	60	189	1.96	348	312	53	4	1.41	63
24	27	Near Cherial Tank	7.65	2236	1289	760	112	117	196	2.35	262	638	59	4	0.84	71
25	28	Venkateswaranagar	7.58	1351	827	465	106	49	92	0.78	171	209	87	179	0.23	110
Mean of Groundwater samples			**7.72**	**2058**	**1158**	**729**	**132**	**97**	**145**	**2.02**	**238**	**527**	**63**	**45**	**0.96**	**83**

Table 4. Water chemistry results for Post-monsoon 2012 along with water quality assessment based on BIS drinking water specifications and WQI values

Sl. No.	Sample No.	Village	pH	EC	TDS	TH	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	HCO_3^- (as $CaCO_3$)	Cl^-	SO_4^{2-}	NO_3^-	F^-	WQI
				m S/cm							mg/l					
		Surface water														
1	6	JNNURM Madyalavagu (Stream)	8.50	1220	686	350	56	51	117	1.04	43	305	117	7	0.75	36
2	8	Iralagutta Tank	9.06	3230	1911	460	56	78	440	153	85	695	279	85	0.74	75
3	23	Cherial Tank	8.02	4260	2345	1220	144	209	415	3.80	317	1191	152	36	0.13	122
		Groundwater														
1	1	Ahmedgudakaman	7.47	2320	1346	840	112	136	140	11	561	312	101	190	0.99	73
2	2	Maisamma temple	8.67	1360	738	430	24	90	113	2.35	98	199	129	78	0.70	40
3	3	Ahmedguda/ Bandlaguda	8.85	860	530	192.5	14	38	108	0.24	64	78	84	147	0.49	24
4	4	Aqua house Laxminagar colony	8.94	440	241	107.5	19	15	51	0.83	101	25	30	20	0.92	12
5	5	Masjid Rajivgruakalpa	7.23	9920	5483	4040	1174	270	421	2.12	73	3205	330	36	0.25	333
6	7	Haridaspalli	7.91	2100	1203	640	168	53	184	4.58	85	567	160	12	0.55	64
7	9	Malakaram X Roads	8.20	2070	1132	800	128	117	107	0.83	98	567	125	28	0.92	68
8	10	Jami Masjid Bhagayanagar colony	8.66	1100	649	425	52	72	55	0.63	49	160	125	139	1.70	37
9	11	E.Nandamuri colony	8.48	900	541	268	72	21	82	0.63	64	151	92	72	0.78	28
10	12	Gabbilalapeta	8.20	1100	692	445	100	47	46	0.83	79	170	82	196	0.68	39
11	13	NTR colony Ambedkar nagar	8.87	1290	743	420	38	79	101	0.63	61	184	137	136	1.03	40
12	14	Rajiv Karmikanagar	8.11	2330	1401	600	180	36	258	0.63	73	567	205	108	0.66	67
13	15	Rajiv Karmikanagar-II	8.07	1420	897	485	152	26	102	0.63	49	277	117	193	0.64	47
14	16	Ven.brick ind. Bhagyanagar colony	8.83	420	230	165	31	21	19	1.04	61	43	39	22	1.43	14
15	17	Rajiv swagrua, Ahmedguda	8.66	510	291	180	33	24	32	0.83	92	53	65	19	0.88	17
16	18	Malakaram	8.60	470	267	140	24	19	41	2.58	12	37	73	37	1.67	14
17	19	JNNURM Buildings	8.01	610	345	205	35	29	44	0.83	275	43	1	25	1.13	18
18	20	Near JNNURM	9.00	1680	958	230	20	44	278	1.04	134	337	159	8	1.25	39
19	21	Cherial X Road	7.95	3470	1970	1080	240	117	299	2.58	73	978	244	44	0.28	105
20	22	Cherial village	8.77	1510	892	225	36	33	192	86	85	298	146	12	0.58	36
21	24	Near Cherial Tank	8.51	3430	1860	1030	96	192	313	3.06	49	943	234	20	0.14	100
22	25	Near Cherial Tank	8.20	4620	2530	1410	184	231	412	2.82	134	1390	218	10	0.32	136
23	26	Near Cherial Tank	9.04	1520	830	345	22	70	189	1.68	79	330	121	14	1.14	40
24	27	Near Cherial Tank	9.24	400	223	130	24	17	30	0.43	85	35	34	17	0.91	13
25	28	Venkateswaranagar	8.79	4390	2630	560	76	90	681	119	207	993	392	110	0.19	101
Mean of Groundwater samples			**8**	**2010**	**1145**	**616**	**122**	**75**	**172**	**10**	**110**	**478**	**138**	**68**	**0.81**	**60**

Table 5. Organic compounds in surface and groundwater samples for 2012

Sl. No.	Sample No.	Location	TOC			COD	BOD	
			Pre-monsoon	Post-monsoon	Seasonal Variation	Pre-monsoon		BOD/COD
		Surface water			**mg/l**			
		Leachate discharge standards for Inland surface water				250	30	
1	6	JNNURM Madyalavagu (Stream)	139	12	-127	240	130	0.54
2	8	Iralagutta Tank	380	81	-299	18000	16000	0.89
3	23	Cherial Tank	395	24	-371	1040	100	0.10
4	29	Dammaiguda Tank	49	108	59	NA	NA	
		Groundwater						
1	1	Ahmedgudakaman	191	152	-39	248	145	0.58
2	2	Maisamma temple	128	131	3	NA	NA	
3	5	Masjid Rajivgruhakalpa	256	141	-115	360	330	0.92
4	7	Haridaspalli	98	6.2	-92	NA	NA	
5	9	Malakaram X Roads	NA	NA		152	140	0.92
6	11	E. Nandamuri colony	42	4.3	-38	NA	NA	
7	13	NTR colony Ambedkarnagar	108	88.6	-19	184	170	0.92
8	14	Rajiv Karmikanagar	206	16.4	-190	176	155	0.88
9	15	Rajiv Karmikanagar-II	NA	NA		152	60	0.39
10	16	Ven.brick ind. Bhagyanagar colony	72	3.8	-68	NA	NA	
11	20	Near JNNURM	97	3.5	-94	64	52	0.81
12	22	Cherial village	149	6.2	-143	96	60	0.63
13	24	Near Cherial Tank	NA	NA		200	55	0.28
14	25	Near Cherial Tank	345	138	-207	184	90	0.49
15	27	Near Cherial Tank	NA	NA		120	35	0.29
		Note: Not analysed						

The deterioration of water quality in space and time has risen over the years. Isolated contaminated patches were noticeable in the fringe area of the watershed at Rajiv Gandhi Karmik Nagar (Sample No. 14) and Masjid Rajivgruhakalpa (Sample No. 5), where EC was >9000 m S/cm, TH >4000 mg/l, and Cl^->3000 mg/l. These could be perched aquifers, having hydrological connectivity with MDY apart from a local source of pollution. SO_4^{2-} has progressively increased and in post-monsoon 2012, its concentration was more than doubled, whereas HCO_3^- and NO_3^- content reduced. Soujanya et al. [39], in their study on Jawaharnagar municipal solid waste dumpsite, opined that - the spatial maps of critical parameters like TDS, Cl^-, and NO_3^- display leachate contamination in groundwater wells about 2 km from the dumpsite. Domestic waste in the solid waste also contributes NO_3^- and Cl^- in its leachate [44]. Wide dispersion and lack of correlation (low r^2 and r) between NO_3^-, Cl^-, K^+ and SO_4^{2-} in samples of both surface and ground waters confirm that the water pollution was not from local domestic sewerage or agriculture activity but from MDY (Supplementary Material 3). In the dumping yard and its vicinity, neither agriculture nor human habitation was noticeable. Low NO_3^- and high organic compounds content (TOC, COD, and BOD; Table 5) substantiates that most MSW contains domestic (kitchen) waste. Higher BOD content than leachate discharge standards for inland surface water (30mg/l) in many samples supports the inference that un-engineered dump site was responsible for high concentration of Cl^-, SO_4^{2-}, K^+,TH apart from other chemical constituents in local waters.

3.4 Ionization Mechanism

The source of the solutes and operating mechanisms in the ionization process was deduced using the Langelier-Ludwig diagram (modified), which displays the relative abundance of ions. The Fig. 5 indicates that chloride-sulphate alkaline-earth waters dominate as most sample points fall in the second block of quadrangle plot, and very few were bicarbonate alkaline-earth waters. Apart from massive input by contamination, interaction with the country rocks like intrusive magmatic or metamorphic rocks contributed to ion enrichment. The alignment of the sample points almost in a straight line and swing of most of the sample points towards the y-axis point out that the possible phenomena in evolution could be the mixing processes involving anthropogenic addition of Cl^- and SO_4^{2-}[45]. The Ca, Mg, and Na could be added by water-rock interaction with gray granite gneisses and granites, which have abundant minerals containing these elements.

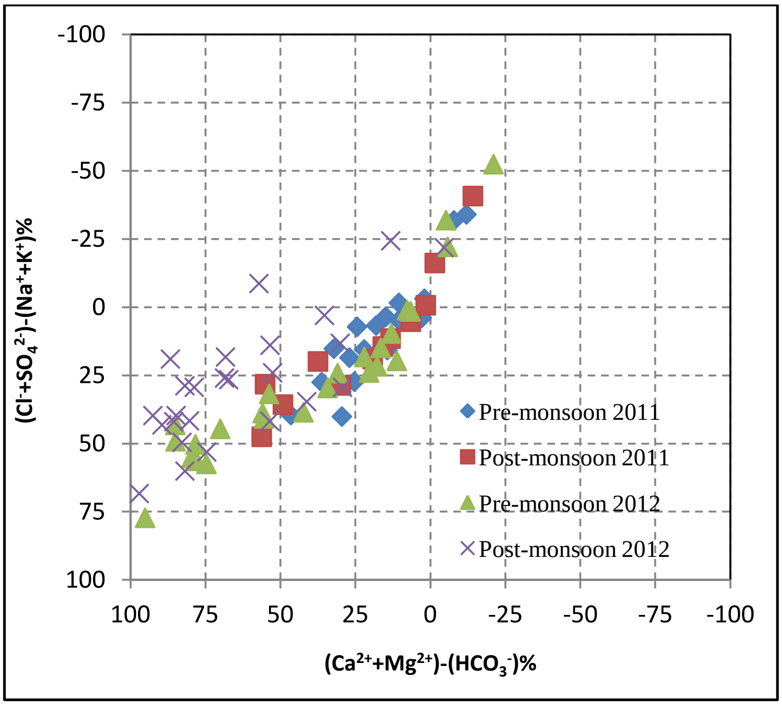

Fig. 5. Langelier and Ludwig plot (modified)

3.5 Contaminant Dynamics

Contaminant transport was slow towards the north, but it was rapid due to high relief in the south and east. The mass flux was along with surface-runoff flow into the stream and surface water bodies and accumulated in the low-lying areas of the watershed, turning them into pools of leachate. The highly contaminated water from these tanks percolates into sub-surface strata based on aquifer hydraulics. The pollution path from the landfill to the surrounding water environment was towards the east through the Madyala stream and in the south by first and second-order streams draining the Dammiaguda tank. The impact of contamination was minimal in central areas, which are on the water divide. The propagation pattern of pollutants implies that local hydraulics controlled the solute transport. Sarala and Ravi [11] noted in their studies on assessment of groundwater quality parameters in and around Jawaharnagar, Hyderabad that the rainwater drains into the solid waste polluting during the monsoon seasons the land leachate existing in the surrounding areas and the low lying areas. The resistivity values display the extent of deterioration of water quality along the Madyala stream downstream of the site and around the Cherial tank. A high infiltration rate of 29 cm/hr at the Madyala stream made it a preferential flow path for mass-flux transfer. Geophysical surveys also reveal the prevalence of lineaments and highly fracture zones towards the south of the dumping site. The thickness of weathering zone was as high as 27 m near the Irlagutta tank, which promote plume propagation. Progressive decrease in contaminant concentration from source to sink is not visible in the area due to prevailing anisotropic and heterogeneous hydrogeological conditions. The isolated highly contaminated patches in south and east could be due to hydrological connectivity (by drainage pattern and rivulet) and they constitute the discharge zone to watershed. These favorable hydrological features of the watershed and continuous mass flux made them exceedingly vulnerable to pollution. Water samples from these areas demonstrate the enduring effect of effluents. Similar observations were made by Tawfiq et al.,[22], Xiang et al.,[18]; Han et al., [46], Przydatek and Kanownik[47], Alam et al.,[15], and Negi et al.,[16].

3.6 Conceptual Mass Flux Model

The plume proliferation can be predicted as - leachate generated by solid-liquid reactions between decomposing solid waste and percolating water in the core area of MDY leak down into natural water tanks and get accumulated which during monsoon or due to hydraulic gradient flow into streams. The leachate from these surface water bodies seeps into the sub-surface domain through the soil and highly weathered mantle, undergoing hydrochemical and natural attenuation processes. The fluid flow to deep aquifer horizons passes through a network of fracture systems where water-rock interactions and other ionization processes occur, altering the groundwater chemistry. The part of the polluted pore water under hydrostatic pressure conditions joins the stream in effluent seepage. The plume flow velocity and direction depend on the fluid density and hydrodynamics of receptive aquifers. The age and maturity level of the solid waste dumps also control the contaminant kinetics. Propagation of point pollution from MYD, which attained methanogenic phase, to different watershed components, occurs through hydrogeochemical cycle resulting in temporal and spatial variability in contaminant concentration. Boulding, R., and JS GInn [48] inferred-contaminant transport in the groundwater could be in nonlinear flow systems along streamlines in a non-uniform flow field. Thomas et al. [49] explained contaminant transport in reactive chemistry approach as - when sufficient organic matter and other reduced components leak from a point source into an aquifer, strongly reduced redox conditions will develop close to the source. The plume will develop a redox gradient along as well as transversal to the main groundwater flow direction. These theories were aptly reflected in the present study area.

7. CONCLUSIONS

The high concentration of tested parameters, including organic compounds in all four sampling episodes, demonstrates that unprotected MDY contaminates the surface and groundwater. Many surfaces and some groundwater samples contain TDS, Cl^-, NO_3^-, F^-, BOD, and COD much above the leachate discharge standards for Inland surface water. The surface waters turned into leachate which attained intermediate methanogenic phase as substantiated by slightly alkaline pH and low BOD/COD ratio. Noncompliance of many samples to drinking water specifications and high WQI values in several samples support the contention. The preferred plume path was east and south from the point source, following the local hydrological features. Geophysical investigations corroborate that pollution was high on the northern side of the Madyala stream near Cherial tank. The resistivity of 20 Ohm m confirms the deterioration of groundwater quality in areas around the tank. The presence of contaminants in groundwater even at a distance of 5 km near Ahmedguda amply supports that MSW adversely affected distant but hydraulically connected aquifers. Various factors like soils, topography, and flow dynamics have controlled leachate migration to the groundwater system. Besides anthropogenic input, ionization processes like water-rock interaction might have contributed to the evolution of hydrochemistry. The study attribute that detail hydrogeological investigations followed by the development of engineered structure are necessary to minimize the adverse effect of solid waste dumps on the environment.

SUPPLEMENTARY MATERIAL

Supplementary Material is available in this link:https://www.journalijecc.com/index.php/IJECC/libraryFiles/downloadPublic/9

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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