Evaluation of Water Chemistry in the Environs of Municipal Solid Waste Disposal Site, Jawaharnagar, Hyderabad, Telangana, India.

A G S Reddy (sugriveadla@gmail.com)
Rajiv Gandhi National Ground Water Training and Research Institute https://orcid.org/0000-0002-5532-3005
P N Rao
Central Ground Water Board
G Ravi Kumar
Central Ground Water Board
G Raja Babu
Central Ground Water Board
K Maruti Prasad
Central Ground Water Board

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Abstract

The impact of uncontrolled municipal solid waste disposal of 3800 tons per day on surface and groundwater in the downstream of Jawaharnagar dumping site was studied. The un-engineered solid waste dumping yard site spreading over an area of about 300 ha is located on topographic high (hillock), and falls in Madyala stream and Dammaiguda watersheds of Musi sub-basin. The area is underlain by granites of the Archaean age. Both surface and groundwater samples, collected covering hydrological cycles of 2011and 2012, were analyzed for major chemical constituents. During 2012, 15 samples of both seasons 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 the tanks and stream near 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 few samples were found suitable for drinking purpose and most of the samples fall in Good class of WQI. Very high content of TOC, BOD, and COD in both surface and groundwater samples indicate the presence of organic pollutants sourced from domestic waste dumps. Wide temporal and spatial variability in the concentration of many ion species can be attributed to deviation in rainfall, topography, plume dynamics, and aquifer hydraulics. 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 Madyala stream, which were contaminant hotspots, indicate the mass flux was controlled by hydrological features. Scattered and limited distribution of contaminants can be accounted for heterogeneous nature of country rocks, retarded lateral and vertical flow of water which restricts the movement of contaminants to certain preferred pathways. The study supports the hypothesis of solid waste dumps were the epicenter of pollution which generates leachate and dissipate contaminants to the aquatic environment influenced by factors like soils, topography, and aquifer hydraulics and contaminant kinetics.

Introduction

Rapid industrialization and population explosion in India has led to the migration of people from villages to cities, which resulted in 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 largely done unorganized in open dumps and landfills in most of the cities not only in India but across the globe. Daniel Hoornweg et. al, (2013) 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., (2007a) in their review on municipal solid waste management in Indian cities noted - various studies reveal that about 90% of MSW is disposed of unscientifically in open dumps and landfills, creating problems to public health and the environment. It is needless to mention that MSW contains, generates, and discharges many harmful inorganic, organic chemicals, heavy metals, radioactive elements, microbes, etc., through the preferential and primary pathway from leachate or plume into surrounding environs. The location of disposal sites of Bhagalpur city represents the unconscious about the environmental and public health hazards arising from disposing of waste in improper location (Pandey et. al., 2011). Off late 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) is expected to exceed 8lakh tones by 2012 in India (IRGSSA 2005). The E-waste recycling and recovery options practiced in India are very outdated and hazardous, causing severe environmental and occupational hazards (Sushant et. al., 2011). Nearly all the Indian cities dispose of their wastes by dumping 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 resource in particular (Mor et. al., 2006, Kumar et. al., 2006, Rathi 2006, Siddiqui et. al., 2006, Sharholy et. al., 2007b, Paras et. al., 2007, Vasanthi et. al., 2008, Umesh et. al., 2008, Jhamnani 2009, Sanjay et. al., 2010, Paras et. al., 2011, Vandana et. al., 2011, Sarala and Ravi 2012, Samadder et. al., 2016, Naveen et. al., 2018, Sachin et. al., 2019, Alam et. al., 2020, Negi et. al., 2020). Even though in certain cities urban solid waste is disposed-off adopting several safety methods and practicing the latest solid waste management techniques, yet they are relentlessly causing severe damage to the sub-surface water resource. Landfill leachate, which contains many toxic and harmful substances such as heavy metals, persistent organic pollutants, and bacteria, has become one of the main anthropogenic sources of groundwater pollution (Dan et. al., 2017). Further research has shown that 0.1%–0.4% of groundwater is polluted by landfills and industrial reservoirs (Xiang et. al., 2019). Dejan et. al., (2018) reported that the quality of groundwater 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., (2017) 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., (2016) in their study on surrounding water resources of closed dumping site at Dhapa (Kolkata, West Bengal, India) have observed that post-closure management of closed landfill site is needed for averting environmental hazards. MSW management (MSWM) is one of the major environmental problems of many urban agglomerates. Adoption of best management measures including protective procedures and treatment techniques to minimize the adverse impact of solid waste could yield desired results. Tawfiq et. al., (2019) 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., (2014) while discussing the MWSM issues have commented 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. Improper waste management which is rampant in many cities of developed as well as third world countries is identified as a cause of many human diseases (Navarro and Vincenzo 2019). The current study was taken up to assess the chemical quality of surface and ground waters downstream of the uncontrolled waste disposal site. The study initiated with hypothesis that the water resource in the vicinity of the Jawaharnagar dumping yard was contaminated due to plume propagation in conjunction with local hydrogeological conditions.

Stats of water contamination at Jawaharnagar dumping yard

Hyderabad, a major Indian city with a population of 6.99 million (City plus Out Growths, Census 2011), is one of the fastest-growing cities globally. It is spread over 625 sq km, its basic amenities are managed by Greater Hyderabad Municipal Corporation (GHMC). The city generates about 3800 tons municipal solid waste per day and has the dubious distinction of generating the highest per capita waste in India - 570 gm per day (http://timesofindia.indiatimes 2018). The majority of total MSW (about 60%) constitute household domestic waste, from commercial establishments, markets, hotels, hospitals, various offices, and construction sites, etc. Earlier, the solid wastes were disposed of at several different isolated locations. Since 1995, all the wastes are disposed of in Hyderabad Integrated MSW processing and disposal facility (HIMSW) at Jawaharnagar. Initially, the solid waste was dumped haphazardly on and around a ridge. As the waste material piled up it spilled into nearby surface water bodies. Over a few years, leachate was generated from un-scientifically dumped solid waste which in due course percolated down to the sub-surface domain. There has been a serious concern about the possible spillover of toxic chemicals into soils, surface and, ground waters. This dumpsite has been in active use over two decades and has now attained saturation level. The problems faced by the residents of this locality have been getting worse every year and they have now reached a point where they are afraid to even drink water from their own homes. The air here is impossible to breathe and the groundwater has been contaminated by the leachate that is seeping into the ground and polluting the sub-surface water. Officials from the State Groundwater Directorate claim that the groundwater here is full of harmful chemicals (http://www.saheindia.org/). Increased urbanization has led to the sprouting up of many residential colonies in the vicinity of dumpsite raising apprehension about public health. GHMC additional commissioner (sanitation) Ravi Kiran told a newspaper (Times of India/ Oct 22, 2017) “in an unprecedented way during the recent rains, leachate problem has spread to several colonies and villages around”. GHMC solid waste management superintending engineer Koteswara Rao said, “From 1995 to 2012, solid waste was not treated, and can’t be treated now, and has been producing leachate” (http://timesofindia.indiatimes.com/2017). Many researchers and environmental experts have carried out extensive studies on the dumping yard (Vandana et. al., 2011, Sarala and Ravi 2012, Ravi Babu et. al., 2014, Rao 2015, Kurakalva et. al., 2016, Soujanya 2016, Unnisa and Bi 2017, Alimuddin 2019, Venkat Charyulu 2019, Konda et. al., 2020).

Study area

The MSW dumpsite spreading over an area of approximately 304 ha is located in Jawaharnagar village, Keesara Mandal, Ranga Reddy district at about 35 km north Hyderabad city (Fig. 1). The site is situated 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 was spread 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 normal annual rainfall of 753 mm, of which southwest monsoon contribute 73 %, northeast monsoon 19 %, and rest by winter as well as 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.

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 as well as 2012 both in the core area and lower reaches of the municipal dumping yard (MDY) spreading over 5 km radius (Fig. 1). In the four sampling sessions the surface water samples gathered were 2 to 4 from tanks and 1 from 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 wide representation. The pH and EC were recorded in situ at the time of sampling with a digital pH and EC meters. All the water samples were tested for major ions and 15 samples gathered in 2012 were analyzed for TOC, BOD, COD in the chemical laboratory of Central Ground Water Board, Southern Region, Hyderabad following standard procedures of APHA (2017). The results were tested for reliability using the cation and anion charge balance method, 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. The water chemistry results were analyzed and inferred using MS EXCEL and AQUACHEM software.

Geomorphology

The study area falls in Madyala stream watershed and Dammaiguda mini watershed. Madyala vagu (stream) is a tributary of the Musi River, part of the Krishna river basin. Major surface water bodies (tanks) in the area are the Irlagutta tank, Cherial tank, and Dammaiguda tank. 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.

Hydrogeology

The area is underlain by grey granite gneisses and granites of 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 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 Madyala stream, low at Rajiv karmika nagar (9.2 cm/hr) and Cherial village (9.6 cm/hr, Rao, 2015).

Results And Discussion

Inorganic chemistry

Surface water: The surface water samples collected from tanks and streams present within the 5 km radius of the dumping yard have a very high concentration of many tested parameters (Tables 1 to 4). Among them Irlagutta tank, occurring in the foothill of hillock and downstream of Madyala stream, contains many tested parameters in abnormally higher concentration than the background values. In 2011 pre-monsoon the EC (m S/cm) was17640, this was shot up to 90560 in 2012 pre-monsoon. It could be because the part of solid waste and leachate from the dumping yard were directly flowing into the tank due to hydraulic gradient. The Irlagutta tank has gained the notoriety of being locally referred as Malkaram Legacy Leachate Pond. The Haridaspalli tank, 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, located 4 km E of MDY, too had very high EC (m S/cm) 7094 in 2011 pre-monsoon, it has increased to 11390 in the following year. The Dammaiguda tank located at about 4 km SSE, contain moderate EC in pre-monsoon 2011 but 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 originate from it and flows into the nearby tanks located in downstream. The surface runoff carries leachate from MDY polluting nearby surface water bodies. A very high concentration of TH, Na^+, K^+, HCO_3^-, Cl^-, SO_4^{2-} and NO_3^- in these samples establishes that domestic waste, which constitutes the bulk of MSW, was the epicenter of contamination (Tables 1 to 4). In post-monsoon 2011 despite low annual rainfall concentration all other tested ions except Mg^{2+} and SO_4^{2-} was reduced remarkably especially in Cherial tank but in the following year the content of Ca^{2+}, Mg^{2+} and HCO_3^- increased significantly (Table 2). Apart from the mixed variation trend, the drastic reduction of bicarbonate content in post-monsoon indicate unnatural source contributed for the chemical enrichment of surface water in the watershed. The stream water samples (Kundanpalli vagu and Madyala vagu) show little or no effect as they were located out of the core area and devoid of hydraulic connectivity. Tremendous increase of EC in post-monsoon at Irlagutta tank substantiates that infiltrating rainwater from dumping yard hillock could be directly carrying contaminant load into the tank. The contaminants get dissipated and diluted as water flows downwards and farther from the source which was evident 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 moderate EC of 2970 m S/cm. During the 2012 pre-monsoon season the EC was very high at Irlagutta (90560 m S/cm), and Cherial tanks (11390 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 unabated spread of pollution to as far as 4 km from the source (Table 3). The high amount of chloride in leachate was due to the mixing of domestic waste (Mor et. al., 2006). During post-monsoon season, dilution of many chemical constituents was observed which was reflected in the significantly reduced EC in the Cherial tank. But the water still contains TH, Ca^{2+}, Mg^{2+}, Cl^- in unusually high concentration. Similarly the sample from Irlagutta tank has turned more basic with 9.06 pH and is tested with elevated content of K^+, CO_3^{2-},

SO_4^{2-}. The Madyala vagu stream water sampled at JNNURM reported the lowest mineralization (Ec 1220 m S/cm) among all surface water samples (Table 4). Fresh inflow from the monsoon together with reduced propagation of pollutants from source could have diluted the ion content of water.

Groundwater: The major ion chemistry of groundwater of the area, based on the mean content of all the sampled sessions, display that water was basic with 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. The mean content of the analyzed parameters of each sampling session was broadly in concurrence with each other. 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). Total ion content, exhibited in the form of EC, was the maximum in this sampling session at Rajiv Gandhi karmik nagar which was about 4 km SE of MDY but hydraulically well connected by a 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). The high disparity in EC and Na^+ within a limited number of samples show solute transport was controlled by hydraulic conductivity and source intensity. In post-monsoon 2011 the groundwater has turned less acidic with mean pH being 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 samples of the season can be accounted for enhanced natural ionization process than anthropogenic action for ion enrichment. High Ca^{2+} and low Na^+ content substantiate the contention and less number of samples (12) might be another factor (Table 2). The samples of pre-monsoon 2012 have normal 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 value of Mg^{2+} (729 mg/l). Inconsistency in Na^+ and Cl^- concentration together with very high TH and Ca^{2+} supports the contention of an unnatural source for ions (Table 3). The abnormal value of total hardness may be due to the discharge of domestic sewage, paper, textile, and chemical waste (MPCB report 2005). In post-monsoon 2012 the groundwater turned more basic with mean pH being 8.45 and maximum was 9.24. Wide variation in EC was noticed among the analyzed samples so was the case with TH and Ca^{2+}. 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^+ and CO_3^{2-}, low HCO_3^- furthermore the SO_4^{2-} was doubled in comparison with three other sampling sessions (Table 4). Though the concentration of certain ions was reduced between pre and post-monsoon 2012 the contaminated hotspots were akin in two seasons.

Organic constituents

Surface water: Select samples from both surface (4 nos) and groundwater (15 nos) sources were tested for TOC, BOD, and COD in pre and post-monsoon 2012 which point out 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 Cherial tank whereas in Dammaiguda tank it was only 49 mg/l. A contradictory picture emerged in post-monsoon 2012, the TOC reduced drastically in Cherial tank to 24 mg/l and rose in Dammaiguda tank to 108 mg/l (Table 5). But the TOC has reduced significantly in all other three surface water bodies. The tanks have feeding channels other than the first-order streams originating from the hillock on which MDY is located. The BOD and COD were extremely high (18000 and 16000 mg/l respectively) in Iralagutta tank which has turned into a pool of leachate. Rusu et. al., (2017) inferred the high values of the COD indicator may 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). Impact of organic compounds reduced remarkably in peripheries (3-4 km) of the watershed. A low BOD/COD ratio (0.50) indicates that the majority of the organic compounds were biodegradable (Fatta et. al., 1999).

Groundwater: The TOC content in groundwater varies between 42 and 345 mg/l with a mean of 154 mg/l in pre-monsoon 2012 the same 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) 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 a sample from bore well at Masjid Rajivgruhakalpa (Sample No. 3, Table 5). The high COD content in groundwater samples indicates an abundance of organic contaminants sourced from MDY (Mor et. al., 2006). Spread of organic contamination even to fringe areas of the watershed in groundwater rather than surface water bodies 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. The high value of COD in well water and bore well water could be due to domestic and industrial sewage (Naik et. al., 2007).

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 (Table 6). Both the surface water bodies are located in fringe areas in different directions and are fed by diverse channels thus they display independent seasonal variations. Significant fall in bicarbonate concentration in post-monsoon at both locations was incongruent as freshwaters normally contain high HCO_3^-. One of the reasons could be the meager freshwater flow to surface water bodies due to low monsoon rainfall (358mm) in 2011. Inflows from local sewer and return flow from irrigation might be contributing water along with harmful elements to these tanks. Drastic reduction in many chemical constituents at Cherial tank was noticeable in the following year (2012) post-monsoon (Table 6). Apart from rainwater, inflow from other sources including base flow might be contributing to the dilution of solute concentration. But the very high reduction in certain ion content in post-monsoon could be possibly by the cessation or retardation of leachate leakage in monsoon which could not be authenticated.

Temporal variation in surface water: Annual variation trend in surface water chemistry was similar to that of seasonal variation. The concentration of many ion species increased over the year between pre-monsoon 2011 and 2012 in Dammaiguda and Cherial tanks. In contrast, ion content decreased remarkably in Cherial tank during post-monsoon 2012 in comparison with that of 2011 (Table 6). The commonality was significant reduction of HCO_3^- over a year (2011 to 2012) in both pre and post-monsoon seasons. The marginal increase in the concentration of Ca^{2+}, Mg^{2+}, and SO_4^{2-} together with a considerable decrease in ionic strength of Na^+, K^+, Cl^- and NO_3^- in a year in post-monsoon 2012 support the contention that natural ionization processes were also contributing to mineralization of water particularly in the wet season. In addition to direct leachate discharge, evapotranspiration (ET) might be leading to the enrichment of certain 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. Almost all cations show higher concentrations during pre-monsoon possibly due to a higher evaporation effect under a semi-arid climatic setup (Sanjay et. al., 2010). TDS values rise in July 2010 and during the summer of 2011 which may be attributed to the greater solubility of ions at the higher temperature, the increase in water demand, the evaporation increase, and the lack of rainfall (Saber et. al., 20l3). Annual variation in surface water chemistry was high between pre-monsoon 2011 and 2012, 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 all but TH, Ca^{2+}, and SO_4^{2-} reduced in post-monsoon 2011, about 60% decrease of K^+ and 36% that of NO_3^- indicate plume penetration was diminishing (Table 6). The less concentration of total dissolved solids, chlorides, and total hardness during the post-monsoon period was due to dilution resulting from rainfall (Vasanthi et. al., 2008). 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 (Pujari et. al., 2011). But diverse seasonal variation trend can be noticed in the year 2012, the concentration of K^+, SO_4^{2-}, and NO_3^- has increased remarkably contradicting the earlier contention (Table 6). 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. Soujanya et. al., (2020) also made similar observation in their study on this area- the TDS, $Cl^−$ and NO3 $^−$ concentrations in groundwater increased in 2015 compared to 2014. Though in pre-monsoon of 2011 and 2012 the sign of raise in degradation of water quality was not noticeable it was distinct in the post-monsoon season of these years. In both the seasons between 2011 and 2012 the concentration of Ca^{2+}, Na^{+}, and HCO_3^- was reduced which were largely controlled by natural process (Table 6). Lack of distinct seasonal or annual trends infers influx of ion constituents 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 lack of fresh recharge to the aquifer. The inconsistency in concentrations of certain ions can be accounted for variations in rainfall, quantum and nature of solid waste and hydrogeological characteristics.

Spatial variationin 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 were 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. Little seasonal variation was noticed in the spatial distribution of TH. The hardness of the water was <300 mg/l in peripheries of the watershed which authenticate that seepage from municipal solid waste was responsible for this malady (Figs. 3a and b). Cl^- distribution was similar to TH, it was >500 mg/l in a large area around MDY and Chirala tank (Fig. 4a). In post-monsoon 2012 more wells in the area around the Chirala tank had high Cl^-, whereas the extent of Cl^- rich area in the central part had reduced (Fig. 4b). In the northern part at Madiyal vagu (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. This 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 resource from point source (MDY) was found diminishing with distance and was largely confined to a 2 to 3 km radius extending more on the southern side. Vasanthi et. al., (2008) 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. Accumulation of highly ionized water near the Cherala tank might be due to leachate flow from solid waste disposal site through the Madyala stream (stream) and its percolation in the course of sub-surface channels.

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). Very high turbidity in the tank (37 to 54 NTU) and about

9 NTU in stream waters support the above observation. In leachate Mg^{2+} dominates Ca^{2+}, it has the highest K^+/Mg^{2+} ratio and EC value (Umesh et. al., 2008). Irlagutta tank, which lies in the foothill of the MDY site, was filled with leachate, it has exorbitant EC values and in pre-monsoon 2012 it reached a peak of 90560 m S/cm. The chemical analysis results of the sample for pre-monsoon 2011 display extremely 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 largely covered 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 major ions. Leachate content was found relatively less in the other two tanks (Dammaiguda and Cherial tanks) located at 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 presence of leachate. Suman et. al., (2018) inferred that landfill leachate in India has significant potential to contaminate the groundwater resources. The Madyala stream water, though originate from recharge area at dumping yard, does not display the effect or influx of leachate. It could be due to feeble surface runoff and high hydraulic gradient. But the stream contributes contaminants to the surface and groundwater 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. Percolation of contaminant load from surface waters to the sub-surface domain was demonstrated by high EC, TH, Ca^{2+}, Cl^- and K^-/Mg^{2+} ratio in groundwater samples in the vicinity of tanks and streams (Tables 1 to 4 and Fig. 5a). It can be inferred from Figs. 5a and b, that the many surface water and few groundwater samples were plotted close to the 1:1 line, but sample points of surface water were present in 10:1 K^+:Mg^{2+} and groundwater in 1:10 K^+:Mg^{2+} ratios (Fig. 5b). Loss of K^+ in the transition to the aquifer environment could be due to natural attenuation and its conservation in the leachate of 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. Though the surface water bodies close to MSW are considered to be a pool of leachate based on majour ion chemistry, it was further confirmed by very high concentration of organic compounds (TOC - 380, COD - 18000 and BOD - 16000). The penetration of pollutants from these sources to pore water depends on many factors. Szymański et. al., (2018) in their experiment inferred that the propagation of pollutants contained in leachate filter through porous ground layer which depends on the mass of supplied pollutants, the intensity of supplied leachate, and layer thickness. Samadder et. al., (2016) in their study on closed municipal solid waste landfills located at Ranital of Jabalpur, Madhya Pradesh, India noted that the leachate generated from the landfills finds paths into the groundwater and surrounding surface water courses.

Contaminated groundwater: Groundwater samples showing signs of contamination were segregated to evaluate the chemistry of those waters. Samples having EC >3000 m S/cm were identified as highly contaminated which were distinctly displayed in *italics* in Tables 1 to 4. Few samples (3 to 5) in each sampling episode were found to have the abnormal concentration of certain analyzed parameters. The average values of all these samples (17) specify 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. The intensity of contamination can be further ascertained from the fact that none of the water samples were suitable for drinking uses as per the Requirement (Acceptable limit) category of Indian Standard Drinking Water-Specification (BIS 2012). Very limited samples were found suitable for drinking purposes when Permissible limit criteria were applied (Table 7). High contaminant content in water was also reflected in water quality indices (WQI, Asit and Surajit 2015). The mean WQI values for groundwater samples were very high in first three sampling sessions (ranging from 82 to 89) and were significantly reduced to 65 in post-monsoon 2012 (Tables 1 to 4). Classification of water based on WQI display very few samples belong to Excellent class whereas majority fall in Good class (Table 7). In case of surface water the mean WQI for all the sampled secessions was 170 and all most all belong to Poor class. The compliance to drinking water specifications check and indices derived from WQI calculations exhibit landfill leachate from MDY spinout contaminants through mass flux to vulnerable water source. Deshmukh and Aher (2016) inferred a high level of electrical conductivity in groundwater was attributable to the impact of a nearby landfill site. The high chloride concentration may be ascribed due to solid waste dumping which in turn was leaching from upper soil layers in dry climates and natural geochemical activities in the area (Sarla and Ravi 2012, Naveen et. al., 2018). An excess of chloride in water was usually taken as an index of pollution and considered as a tracer for groundwater (Loizidou and Kapetanios 1993). Conglian et. al., (2019) in their studies on the Regina landfill, Canada reported high Cl^-, TH values in groundwater of the Condie aquifer.

The extent of deterioration of the chemical quality of the groundwater in space and time has risen over the years. Hot spot was noticeable in fringe area of watershed at Rajiv Gandhi karmik nagar and Masjid Rajivgruhakalpa, where EC was >9000 m S/cm, TH >4000 mg/l, and Cl^- >3000 mg/l. These could be isolated or 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., (2020) in their study on Jawaharnagar municipal solid waste dumpsite opined that - the spatial maps of critical parameters like TDS, Cl^-, and NO_3^- indicated leachate contamination in groundwater wells approx. 2 km from the dumpsite. Domestic waste also contributes NO_3^- and Cl^- in its leachate (Pujari and Deshpande 2005). These ions mostly were of non-lithogenic origin, the influence of external physicochemical factors on water chemistry cannot be ruled out. It can be confirmed from low NO_3^- and high organic compounds content (TOC, COD, and BOD, Table 5) that most of the MSW contains domestic (kitchen) waste. The denitrification process along natural attenuation might be controlling the nitrate enrichment. The decrease in the summer season can be attributed to the lowering of the groundwater table wherein anaerobic condition was created and nitrate was partially converted to nitrogen (Lawrence et. al., 2001). Similarly, high Ca^{2+} and Na^+ (average was 354 and 425 mg/l respectively) content in many contaminated water samples can be accounted for aquifer matrix as the area was underlain by granite gneisses.

Contaminant dynamics: The garbage dumped on hill slopes slowly move down as sheet flow into water bodies present in the vicinity of MDY. The location of the dumping site near the top of a topographic high (recharge zone) has induced the permeation of leachate in the groundwater system along the slopes (Sanjay et. al., 2010). Contaminant transport was slow towards the water body on the north but its movement was rapid in the south due to high relief. The mass flux along with surface-runoff flow into downstream surface water bodies and accumulates in the low lying area of the watershed. The highly contaminated water from these tanks percolates into sub-surface strata based on aquifer hydraulics. Anomalous content of physiochemical and heavy metals in the three ponds of the landfill and their adverse effect on the groundwater and surface water was reported by Tawfiq et. al., (2019) in their research on landfill leachate system near Dengkil town, Malaysia. Sarala and Ravi (2012) noted in their studies on assessment of groundwater quality parameters in and around Jawaharnagar, Hyderabad that during the monsoon seasons the rainwater drains into the solid waste polluting the land leachate existing in the surrounding areas and the low lying areas. The tanks and streams in the propinquity of MSY act as point sources of pollutants (Selvakumar et. al., 2017). The random dumping of hazardous waste in the industrial area could be the main cause of contamination of the groundwater and soil spreading by rainwater and wind (Bhagure and Mirgane 2011). The resistivity values specify 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 Madyala stream made it preferential flow-paths for mass-flux transfer. Geophysical surveys also reveal the prevalence of lineaments and highly fracture zone both towards north and south of dumping site as well as the thickness of weathering zone was as high as 27 m near Irlagutta tank which promote plume propagation. These hydrological favorable sites of watershed and flux dynamics made them exceedingly vulnerable to pollution. Water samples from these areas demonstrate the enduring effect of effluence. Similar observations were made by Mor et. al., (2006), Paras et. al., (2007), Vandana et. al., (2011), Nagarajan et. al., (2012), Xiang et. al., (2019), (Han et. al., 2016), Przydatek and Kanownik (2019), Alam et. al., (2020) and Negi et. al., (2020).

Conclusions

The high concentration of many tested parameters including organic compounds in all four sampling episodes demonstrates that unprotected MDY was causing the impurity of both the surface and groundwater unabated. Noncompliance of many samples to drinking water specifications and high WQI values in several samples support the contention. Geophysical investigations corroborate that the influence of 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 support that MSW adversely affected distant but hydraulically connected aquifers. Various factors like soils, topography, and flow dynamics have largely controlled the migration of leachate to the groundwater system. Low and variable imprints of water quality deterioration certain areas can be accounted for feeble and uneven lateral and vertical flow of water in hard rock terrain due to heterogeneous fracture patterns which restricts the movement of contaminants. The presence of leachate was visible on the surface water bodies and the influence of contaminant plume on sub-surface water at vulnerable locations was very much evident in the form of very high ion content. The study warrants appropriate solid waste management to control migration of pollutants into the aquatic environment of the area.

Declarations

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Tables

Due to technical limitations, tables are only available as a download in the Supplemental Files section.

Figures

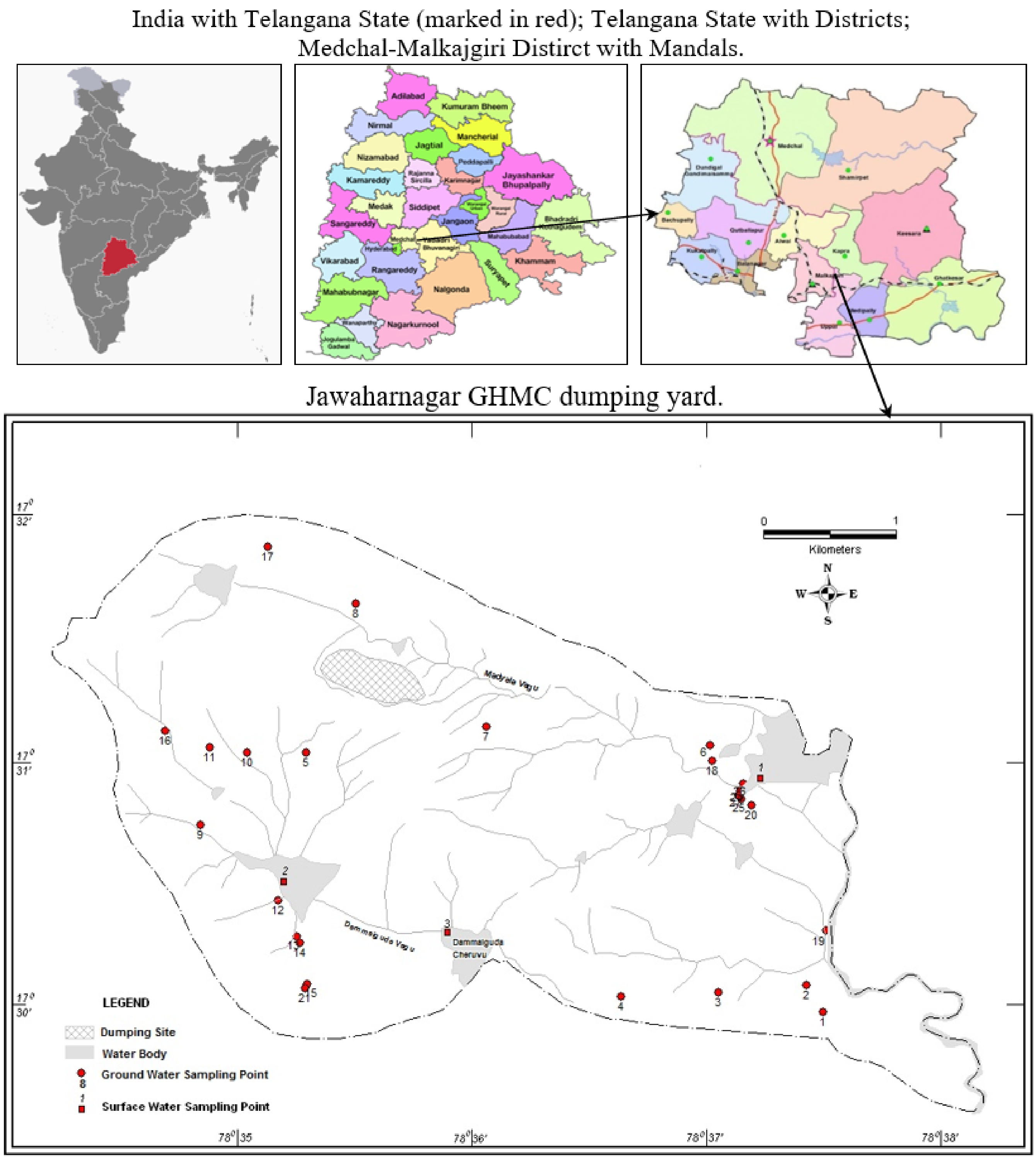

Figure 1

Key Map with Study area and samples locations. Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

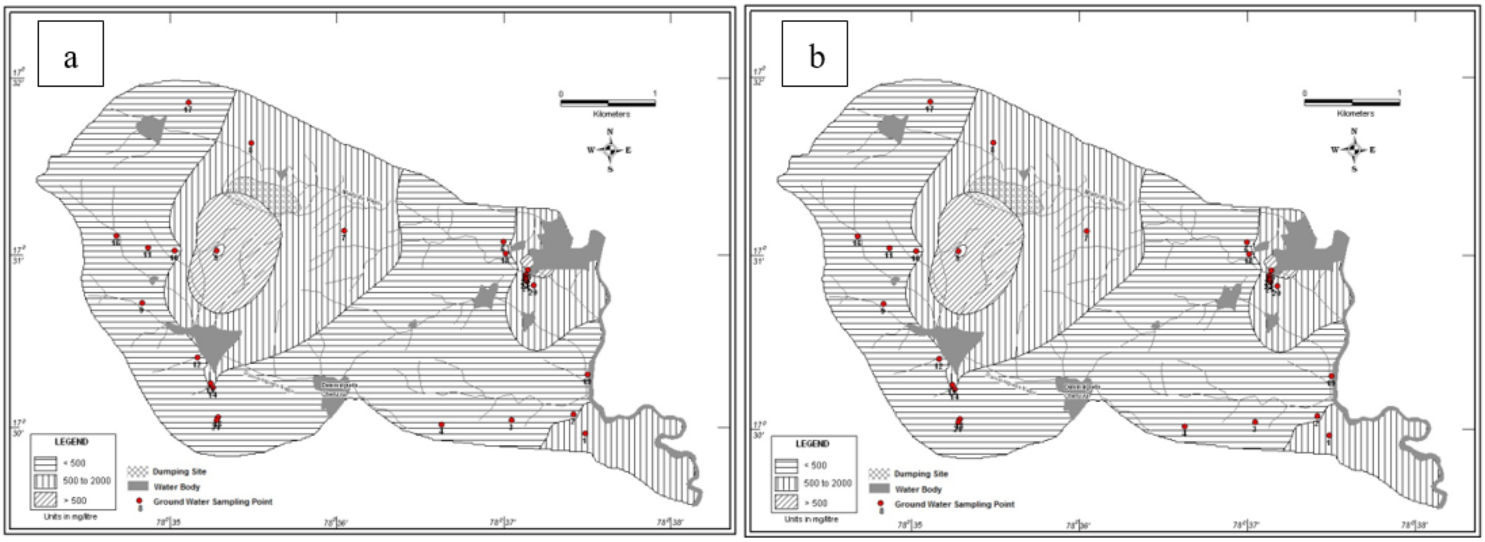

Figure 2

Spatial distribution of TDS in Pre-monsoon 2012 (a), Post-monsoon 2012 (b). Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

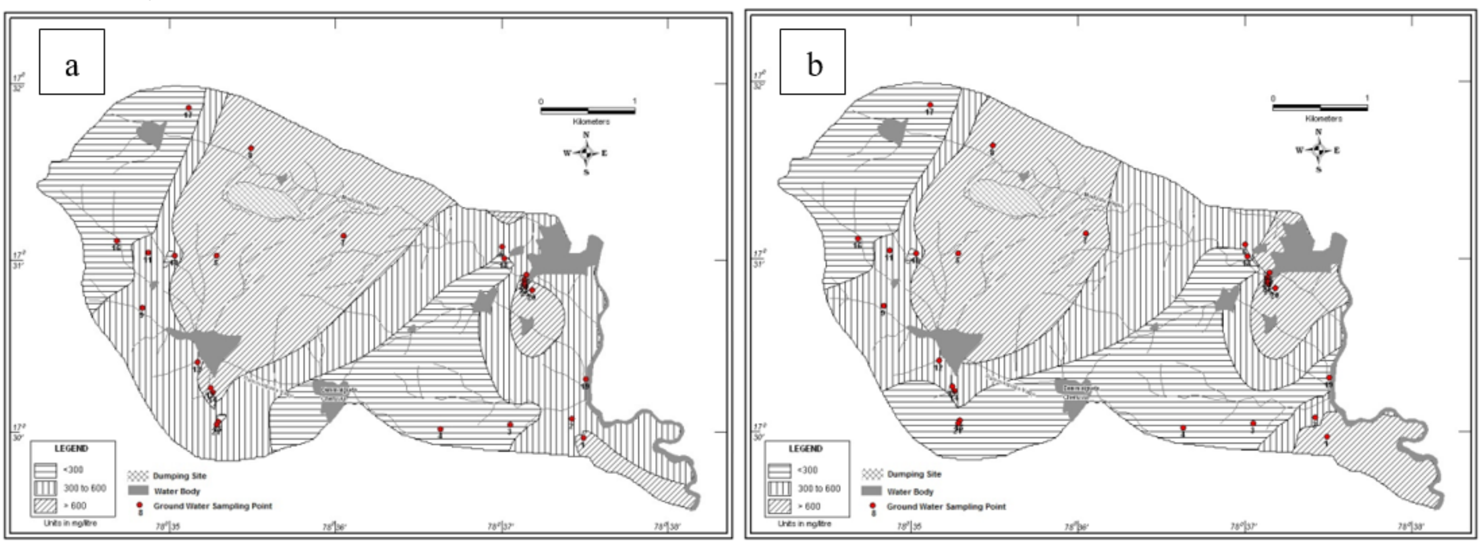

Figure 3

Spatial distribution of TH in Pre-monsoon 2012 (a), Post-monsoon 2012 (b). Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

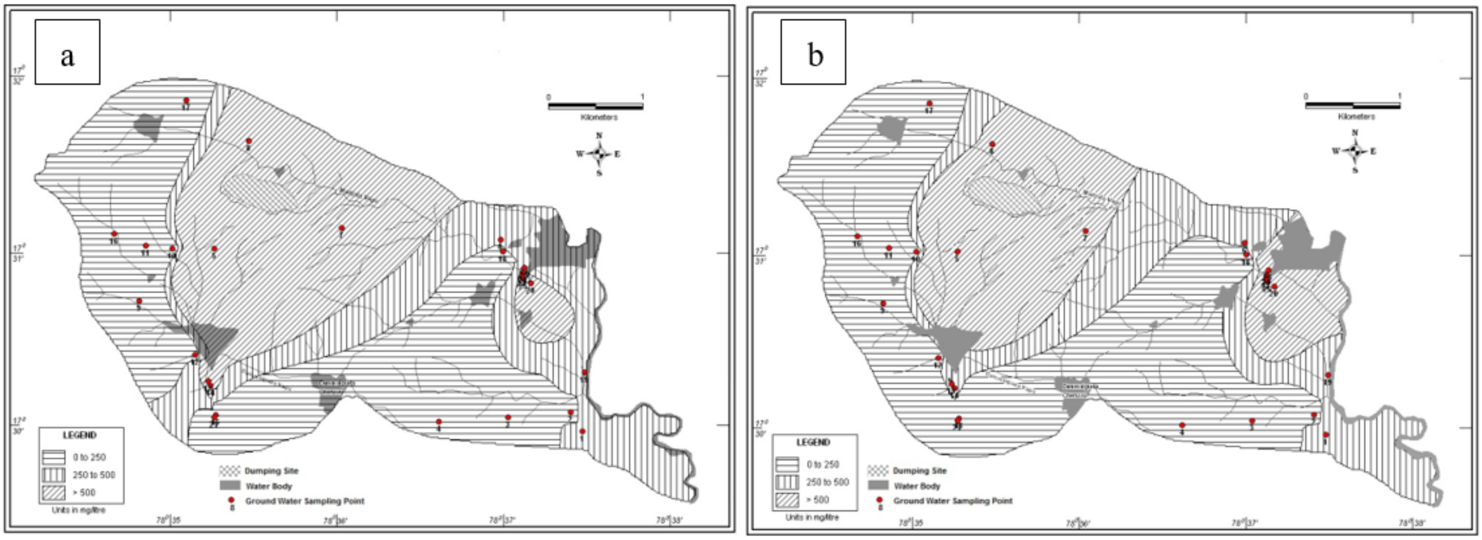

Figure 4

Spatial distribution of Cl in Pre-monsoon 2012 (a), Post-monsoon 2012 (b). Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

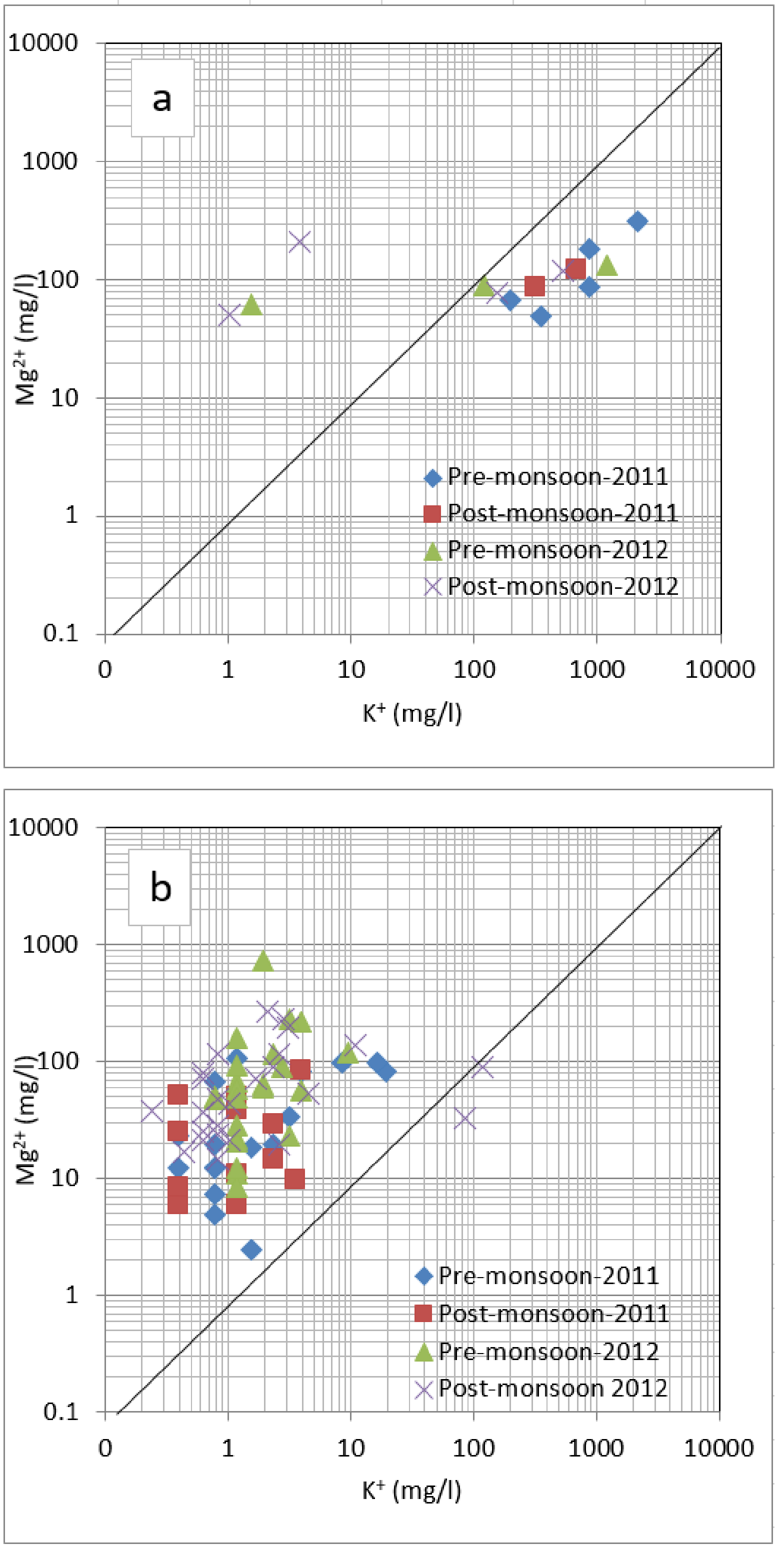

Figure 5

K+ vs Mg2+ plot for (a) surface water and (b) groundwater.

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- Table1Premon2011.xlsx
- Table2Postmon2011.xlsx
- Table3Premon2012.xlsx
- Table4Postmon2012.xlsx
- Table5.xlsx
- Table6.xlsx
- Table7.xlsx