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ORIGINAL RESEARCH ARTICLE



## Physicochemical assessment of leachate from Pokhara landfill site and its impact on the quality of Seti River water, Nepal

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### ABSTRACT

The management of municipal solid always poses serious environmental problems on land, air, and groundwater, especially in the case of developing countries. The characterization and assessment of leachates are necessary to understand the water quality in the urban region as well as has enormous importance in sustaining the livelihoods of people in the riverine environment maintaining the ecological balance. Landfill leachate contains thousands of complex components, which contaminate the nearby water bodies, and communities with several hazardous ingredients. The present study was conducted to assess the influence of landfill leachates on the quality of Seti River water. The samples were collected from four stations (Tatopani, Ramghat, Landfill, Below landfill, and Kotre). The samples were analyzed for pH, total hardness, dissolved oxygen, biochemical oxygen demand, turbidity, total dissolved solids, electrical conductivity (EC),  $\text{Cl}^-$ ,  $\text{NH}_3$ , and  $\text{PO}_4^{3-}$  by standard methods. The pH and EC were measured *in situ* whereas other parameters were analyzed in the laboratory adopting standard protocols. The physicochemical parameters of river water and that of leachates were compared to monitor the level of contamination. The research reveals the landfill to have insignificant pollution of water on matching the parameters with World Health Organization (WHO) guideline values. Regular monitoring of the quality of river water and sustainable management of solid waste is essential for the ecological quality and integrity of the environment in the region. Scientific information obtained by this study could contribute to policymakers for the sustainable management of water quality and landfill in the downstream and urban segments of the river basins.

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### INTRODUCTION

The management of solid waste is becoming a challenging issue for governmental, municipal, and local authorities in developing countries like Nepal due to unplanned urbanization, rapid generation of waste, improper management, and lack of public

awareness. The solid waste from municipal is a large collection of organic and inorganic matters containing a substantial group of specific compounds (Václavík *et al.*, 2016). Dumping of municipal waste over certain land portions is a common and one of the cheapest practices in many parts of the world (El-Fadel *et al.*, 1997; Longe and Balogun, 2010). Improper designing and

operation of landfills can cause adverse effects on the quality of surface and groundwater. The degree of deterioration depends on the composition and quality of leachate and the distance of the landfill site from the water sources (Słomczyńska and Słomczyński, 2004). Water moves through the huge mass of dumped solid waste and percolates into the bottom. As it comes out from the waste with innumerable inorganic and organic compounds, it is known as “leachate” and meets surface and groundwater. The major concern of any landfill site operation is the potential health risks caused by the use of leachate-polluted groundwater (Nagarajan et al., 2012). The chemical composition of leachate depends upon several factors like waste composition, degree of compaction, design and operation procedure of landfill site, the climate, absorptive capacity, temperature, geology, hydrology, amount of rainfall, age of the waste.

The leachate from municipal landfills is heavily loaded with different organic matters, inorganic components ( $\text{NH}_4^+$ ,  $\text{Ca}^{2+}$ ,  $\text{Mg}^{2+}$ ,  $\text{Na}^+$ ,  $\text{K}^+$ ,  $\text{Fe}^{2+}$ ,  $\text{SO}_4^{2-}$ ,  $\text{Cl}^-$ ), and heavy metals (Cd, Cr, Cu, Pb, Ni, Zn), and xenobiotic substances (Bhalla et al., 2012). As the leachate mixes with water bodies the physicochemical parameters like the concentration of chloride, nitrate, sulfate, ammonium, phosphate ions, phenol, Fe, Zn, chemical oxygen demand (COD), etc., increase indicating the deterioration of water quality (Mor et al., 2006). The continuous decaying of the municipal waste in the landfills emits greenhouse gases and increases nitrogen concentration in the leachate. In the primary phase of operation, leachate consists of large amounts of degradable organic substances and heavy metals whereas, at maturity, methanogenesis takes place resulting in lower biochemical oxygen demand (BOD), chemical oxygen demand (COD), methane, ammonia, and heavy metals (Jokela and Rintala, 2003). The harmful chemicals released from unregulated landfills leachate had caused contaminations to the underlying aquifers in many large cities. Denizens are becoming more aware of the degradation of groundwater quality. The poorly regulated solid disposal system has enforced the concerned authorities to undertake appropriate control measures at the landfills (Singh et al., 2009). Many scientific researchers have revealed substantial pollution on groundwater close to landfill sites. Water bodies lying near the landfills of Lahore city were found to have higher concentrations of pollutants than the Pakistan Standards and Quality Control Authority (PSQCA, 2004) and arsenic concentration over than World Health Organization (WHO) drinking water criteria (Muhammad and Zhonghua, 2014). The physicochemical parameters including EC, TDS,  $\text{Cl}^-$ ,  $\text{SO}_4^{2-}$ ,  $\text{NO}_3^-$ ,  $\text{Na}^+$ , &  $\text{Fe}^{2+}$ , etc., in the groundwater samples near different landfill sites of Tamil Nadu, India were moderately higher than the standard values. The result indicated the deterioration of water quality by the percolation of leachate to the aquifers (Nagarajan et al., 2012). The deterioration of water quality due to different natural and anthropogenic activities are posing serious implications on the lives and ecosystems, which has attracted attention all over the world (Thomas et al., 2014; Kumar et al., 2018; Singh et al., 2021). Pokhara city that lies in the foothills of Central Himalayas of Nepal, is emerging as a popular destination of tourism, the

center of rapid economic growth and urbanization (Adhikari et al., 2017; Paudel et al., 2019). The Seti River is a glacier-fed (glacier is the source of water different nutrient and water (Adhikari et al., 2019; Sharma et al., 2020) which flows from the catchment of the city. It is a part of RAMSAR Wetlands (No. 2257) and exhibits a pivotal role in the shaping of different economic and ecological activities like a supply of drinking water, irrigation, fishing, hydroelectricity, recreation, tourism, disposal and dilution of sewage, conservation of biodiversity, etc., (Paudel et al., 2017), ([www.ramsar.org](http://www.ramsar.org)). Management of solid waste is crucial to preserve and promote the natural magnificence of a rapidly growing city like Pokhara. This study will highlight the status of the landfill site in terms of its location and its impact on Seti River water. Preservation of its natural quality is urgent from the point of natural and environmental considerations. Contamination of the river brings many adverse effects on the health of the public, and the riverine ecosystem of the area. Therefore, it is imperative to elucidate the hydro-chemical variability of the river basin. This helps the policymakers and other stakeholders to ascertain the combined effect of natural and anthropogenic factors on the hydro-chemical dynamics of the Himalayan freshwater ecosystems.

Landfills have been the preferred choice of waste disposal in many cities. Poor management of landfills and lack of public awareness is posturing serious challenges to the municipals and the local communities. Nearby water bodies, flora, fauna, the local people, and ultimately the whole ecosystem are getting several adverse consequences from the landfills. Regular monitoring and decent management of solid waste are necessary for a clean city without a deteriorating environment. The level of pollution in river water bodies by landfill sites in Pokhara is not accessed scientifically. This study provides a new opinion and awareness towards the preservation of valuable water bodies by competent management of municipal waste. So, the main objective of this study is to evaluate the influence of leachate contamination from the Pokhara landfill site on Seti River water. The estimation of some of the physicochemical parameters such as pH, total hardness, dissolved oxygen, biochemical oxygen demand, turbidity, total dissolved solids, electrical conductivity (EC),  $\text{Cl}^-$ ,  $\text{NH}_3$ , and  $\text{PO}_4^{3-}$  of River water above and below the landfill site provides the level of pollution in the river. This study could contribute to adopting viable strategies for the sustainable management of municipal solid waste and preservation of riverine water quality and the environment.

## MATERIALS AND METHODS

### Study area

Seti river is located on the southern slopes of the central Himalayas originated from the base of Machhapuchhre and the Annapurna Himalayas. The river flows through high topographical variation via Pokhara valley and fuses into the Trisuli River (Figure 1). The climatic circumstances of the central part of the basin indicate sub-tropical to cool temperate, however the climatic variation in the northern part varies from temperate

to alpine with a high precipitation rate, approximately 3000 mm per year (Paudel et al., 2017). The sampling sites are located in the Pokhara metropolitan city, at the foothills of central Himalayas of Nepal (Figure 1) (Paudel et al., 2017). It is the largest metropolis of Nepal occupying an area of 464.24 sq. km. Pokhara valley lies in the Mahabharat range of Nepal between 83° 48' 11" E and latitudes 28° 4' 39" N (Rimal et al., 2015). According to Pokhara metropolitan city source, the population of the city is 402,995 (<https://pokharamun.gov.np/>). Pokhara landfill site (LFS) lies about 6 km outskirts of the main city in Bachhebuduwa range of ward no 18. It has been in operation since 2004 for the overall solid-waste management of the metropolitan. The site is constructed by cutting off the rigid rocks of the location and covers a total area of 10 hectares, with 4 hectares for landfilling, 1.5 hectares for leachate treatment, 3.75 hectares for a buffer zone, and 0.75 hectares for other necessary infrastructures (Adhikari et al., 2013). The land use/land cover of the study basin is indicated in Figure 1.

The solid waste of the Pokhara metropolitan is collected and transported to the landfill site every day. At first, the mixed waste is segregated into different sets. The recyclable materials are separated and circulated to the respective places and the remaining portions are dumped.

### Sampling and analysis methods

The samples were collected from four stations (Tatopani, Ramghat, Landfill, Below landfill, and Kotre) two lying above and two below the landfill site during the monsoon season of 2016.

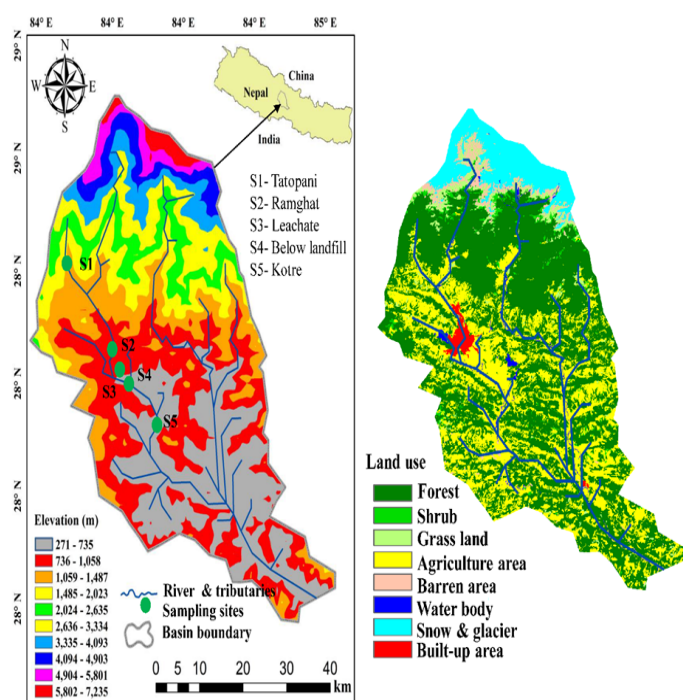


Figure 1. Location of sampling sites and land use of study area.

The leachate samples were collected randomly from the exhaust ponds. Samples were collected in clean plastic bottles and stored at 4°C in the laboratory. The TDS, EC, and pH values of all of the samples were tested *in situ* by using a digital equipment (HI-98129, HANNA, Romania) (Adhikari et al., 2019; Adhikari et al., 2020, 2021; Kaphle et al., 2021). The samples were tested for total hardness, turbidity, dissolved oxygen (DO), biochemical oxygen demand (BOD), total dissolved solids (TDS), Cl<sup>-</sup>, NH<sub>3</sub>, and PO<sub>4</sub><sup>3-</sup>. Standard chemicals and reagents were used which were from Fisher-scientific, SD fine, Sigma Aldrich, etc., companies. The experiments were carried out in the chemistry lab of Prithvi Narayan Campus, Pokhara, by adopting standard protocol (American Public Health Association, 1999).

The turbidity of water was measured by the turbidity meter of the HACH2100AN model. DO was determined by Winkler's iodometric method. The chloride content of water was determined by the argentometric titration method. Total hardness of water was determined by a titrimetric method using ethylenediaminetetraacetic acid (EDTA), BOD by using phosphate buffer, ammonia was determined by the phenate method, phosphate by stannous chloride method, and total dissolved solids by gravimetric method. The experiments involving volumetric titrations were performed in triplicates. The results were assessed with WHO guidelines for drinking water (Table 1)

Table 1. WHO guideline values of some physicochemical parameters of drinking water Source: (WHO, 2008).

Physicochemical parameters	Guideline value
pH	6.5 - 8.5
Turbidity	5 NTU
Conductivity	400 ms/cm
Total hardness	500 mg/L
Calcium hardness	75 mg/L
Magnesium hardness	50 mg/L
Chloride	250 mg/L
Sodium	200 mg/L
Sulphate	400 mg/L
Nitrate	10 mg/L
H <sub>2</sub> S	Not delectable
Iron	0.3 mg/L
TDS	500 mg/L
Ammonia	0.3 mg/L
Dissolved oxygen	5 mg/L
BOD	6 mg/L
Alkalinity	600 mg/L

**RESULTS AND DISCUSSION**

**Composition of municipal solid waste**

According to Pokhara metropolitan source, the city harvests approximately 150-170 tons of solid waste per day. The waste is collected from the city and transported to the site by adopting a private-public partnership (PPP) mechanism. The personnel equipped with proper safety measures segregate the waste into different fractions mechanically before dumping. The materials like plastics, papers, glass bottles, textiles, metals, batteries, etc., which can be recycled, are exported to the corresponding scrap dealers. The organic fraction which comprises about 65% of the waste (Adhikari et al., 2013), is dumped over the layers of accumulating zone and covered by gravel and soil layer using excavators daily. The seepage of the waste layers is allowed to pass through the Reed Bed treatment unit. The oozed fluid is subjected to a compost plant and exhausted as leachate. The leachate is diluted by surface water and allowed to flow towards the Seti River, which lies about 200 m away from the exhaust. These activities were monitored during the onsite field observation.

The segregation of waste in Chennai was found to be composed of biodegradable 64.4%, recyclable 10.8%, inert materials 24.4%, and hazardous 0.4% (Kurian Joseph et al., 2012). In Chandigarh, about 33.7% of the total municipal solid waste is disposed of through landfills, and other fractions are managed by recycling, composting, etc., (Gupta and Gupta, 2015). The solid waste of Chennai, India, contained about 60-70 % combustible materials like textiles, leaves, plastics, food waste, etc., and 30-40 % of non-combustible fraction comprised of metals and glasses, etc., collected at Perungudi dumping site (Mohan and Gandhimathi, 2009). The separation of the municipal solid waste into different fractions might be an efficient way of sustainable management. It reduces the operation cost for the administration of an exponentially increasing quantity of solid waste in the cities. Also, it inspires the solid waste management parties by turning “waste into money” from different recyclable materials properly.

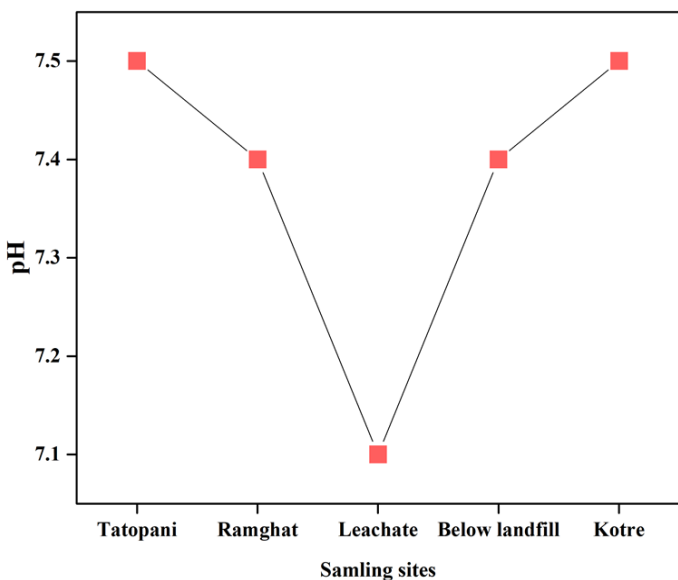


Figure 2. Variation of pH of river water.

**pH**

The pH of the leachate indicates the concentrations of acidic, basic substances and partial pressure of carbon dioxide in the landfill gas in contact with the leachate (Banar et al., 2006). The pH values of Seti River water ranged from 7.4 to 7.5 in different stations, which are in a normal permissible range indicating no sign of contamination by the leachate having a pH value of 7.1 (Figure 2). The pH value of the leachate is slightly lower than that of the Seti River might be due to the chemicals released from the leachate. At the initial years of operation, pH at landfills is generally around 5.5 and gradually increases above seven after the 10 years of operation. The pH value of the leachate reveals that the dumping site is in its methanogenic phase when the pH ranges from 7.0 to 7.8 (El-salam and Abu-zuid, 2015). A previous study reported the pH of the leachate 6.5 in 2013 (Adhikari et al., 2013) and is found slightly increased to 7.1 in our study. The heavy metal precipitation led to an increase in the pH of the leachate. This result coincides with the pH values higher than 7 in the landfills older than 10 years of operation (M. El-Fadel et al., 2002). In our study, there is no substantial effect of leachate composition on the pH of river water.

**Electrical conductivity and total dissolved solids**

The electricity conducting ability of water is due to the presence of different inorganic ions (Adhikari et al., 2019, 2021; Adhikari et al., 2019). The electrical conductivity is proportional to the concentration of inorganic ions, mainly high levels of different anions and soluble salts dissolved in water (Maiti et al., 2016). The WHO permissible limit of electrical conductivity (EC) is 400 µs/cm. The research reveals that the EC of river water lies within the permissible limit and is not affected by mixing the leachate. Our study shows that the leachate had high EC (Figure 3) but was not found to influence the trend of EC values of the river water.

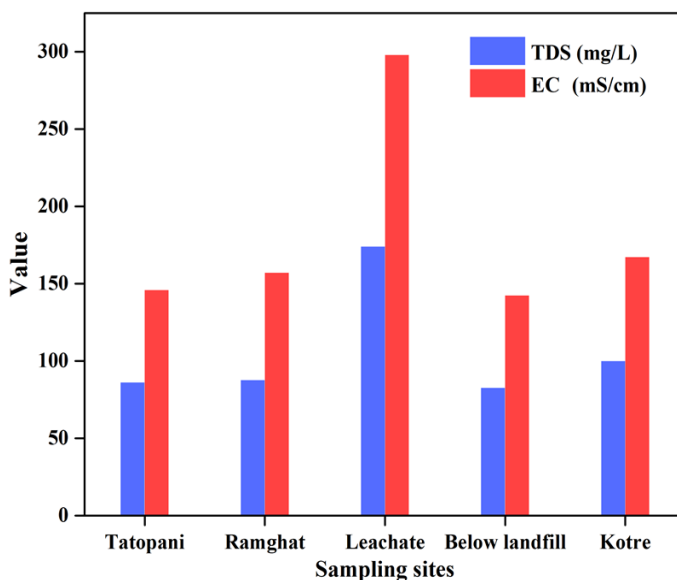


Figure 3. Variation of EC and TDS in the study area.

The total dissolved solids in water comprise mainly due to the presence of inorganic and organic matter. Its value reflects the extent of mineralization that changes the physical and chemical characteristics of the water body (Salami *et al.*, 2015). The TDS value of leachate is 174 mg/L and that of river water ranges from 82.6 mg/L at below landfill site and a maximum of 100 mg/L at Kotre station (Figure 3). The results are in agreement with the physicochemical analysis of leachates from ten different landfill sites of Jabalpur, India which had the TDS values ranging from the minimum of 410 mg/L to the maximum of 5211mg/L (Bundela *et al.*, 2012). The analysis of leachate samples of Lokoja municipal open landfills of Nigeria was found to contain high values of TDS of 5180.60 mg/L to 3071.80 mg/L. These values were expressively higher than that of the WHO standard of 2000 mg/L for the discharged wastewater into streams (Olaewaju *et al.*, 2012). In comparison to this, the Pokhara landfill can be regarded to be in a good condition of waste disposal.

### Total hardness

The hardness of water is mainly contributed by the presence of soluble chlorides, sulfates, and bicarbonates of calcium and magnesium. The WHO permissible limit of total hardness of water is 500 mg/L. The result shows that the river water lies within the limit and the values are not varying significantly. River and its tributaries flow across the same composition of soil and contain the same minerals. The value ranges from a maximum of 126.67 mg/L at Ramghat followed by 124.67 mg/L at below landfill site, 124.0 mg/L at Tatopani, and a minimum of 118.67 mg/L at Kotre station (Figure 4). The highest value was found at Ramghat, possibly due to the high concentration of Ca<sup>2+</sup> and Mg<sup>2+</sup> caused by the incineration of dead bodies in the area. The total hardness of the samples from around 500 m of the municipal solid waste dump side of Mayiladuthurai, India ranged from 312 – 536 mg/L and that of the samples from the non-dump side ranged from 139 – 428 mg/L. The results indicated the elevation of the hardness of nearby water bodies by the dump side (Sangeetha and Selvarajan, 2017). The total hardness of drinking water samples from Arbaminch town of Ethiopia

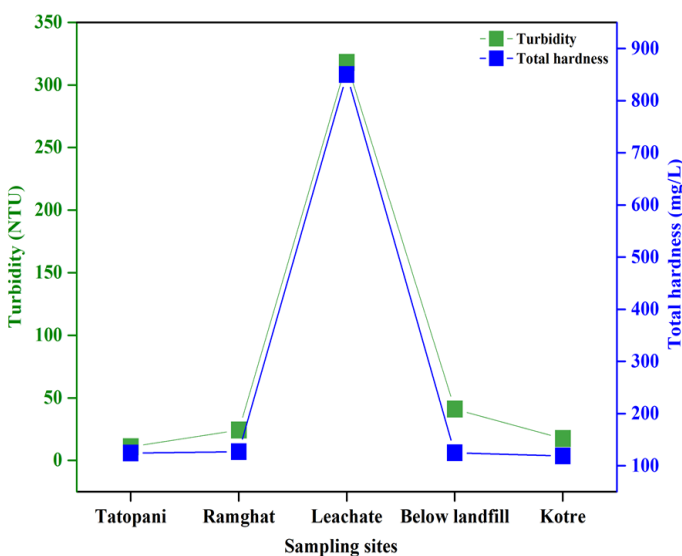


Figure 4. Total hardness and Turbidity of water at different stations.

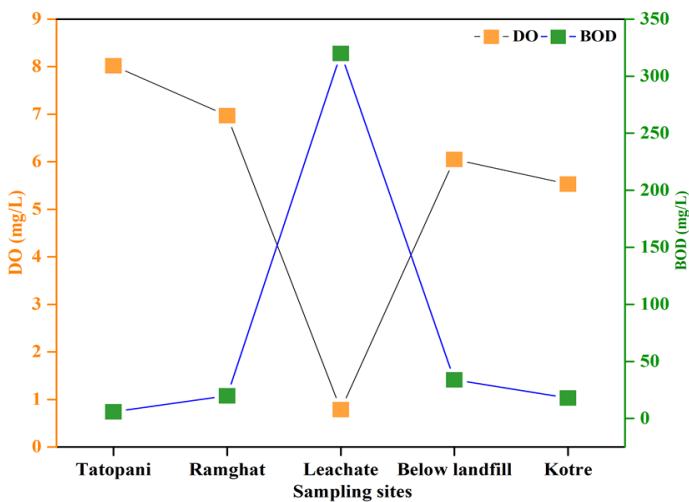
ranged from 119.2 mg/L to 135.11 mg/L and was categorized as hard water. Based on these criteria, Seti River water belongs to the moderate to hard water category (Reda, 2016). A higher value of total hardness of 850.0 mg/L is due to the presence of different types of calcium and magnesium salts in the leachate. As the hardness of Seti River water below and above the landfill site does not show a marked difference, the mixing of a small volume of leachate was not found able to disturb the total hardness of the huge water body in the river. If this landfill site runs for a longer time, it will deteriorates the quality of water of the river.

### Turbidity

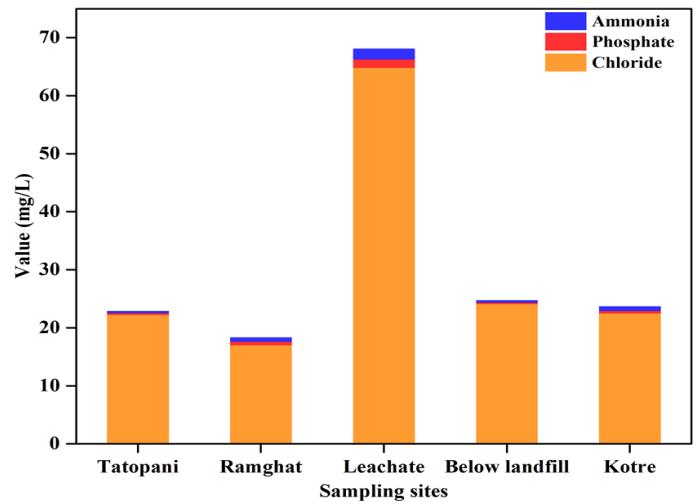
The turbidity indicates the abundance of insoluble silt, clay, fine organic matter suspended in water (Muhammad and Zhonghua, 2014). The leachate of the Pokhara landfill was found to have very high turbidity of 318 NTU (Figure 4). Seti River flows along with many insoluble suspended materials, due to the contrasting geology and land use of the watershed. The study revealed the turbidity ranged from the minimum value of 11.04 NTU at the Tatopani station to the maximum of 41.0 NTU at Ramghat station. All the samples are of lower-ranking from the WHO guideline value of 5 NTU. Seti River itself is found to be incompetent from the point of turbidity criteria according to the WHO standard. The result reveals that the Pokhara landfill has a more muddled discharge than that of a landfill from South Africa which had turbidity ranging from 12.78 NTU to a maximum of 295.5 NTU at different sampling stations (Edokpayi *et al.*, 2018).

### Dissolved oxygen and biochemical oxygen demand

The amount of dissolved oxygen (DO) measures the degree of pollution by organic matter, demolition of organic substances as well as the self-purification system of water. The WHO guideline value of DO is 5 mg/L and under this limit aquatic life does not tolerate. Similarly, water having a DO value below 2 mg/L may lead to death for most fishes (Olaewaju *et al.*, 2012). The leachate of the Pokhara landfill was found to have a pretty low DO of 0.79 mg/L (Figure 5) which is quite low to sustain aquatic life whereas river water is within the limit for the survival of aquatic life. Biochemical oxygen demand (BOD) is a measure of dissolved oxygen required by aerobic bacteria for the breakdown of organic material in a sample of water at a certain temperature and specified time. A higher value of BOD indicates the raised degree of pollution in the water body by organic pollutants. The presence of toxic chemicals inhibiting bacterial activity can inhibit the BOD value (Enujiugha and Nwanna, 2004). The BOD value of the leachate was 320 mg/L and that of the river at various stations ranges from 6 mg/L at Tatopani station to 34 mg/L at the sampling station below the landfill site (Figure 5). All the samples are above the limit of WHO guideline value for drinking water. As the river flows through the human settlement area, randomly exhausted organic solid waste in the river might have increased BOD. The results do not support any evidence of contamination of leachate on the Seti River. The



**Figure 5.** Dissolved oxygen and biochemical oxygen demand of water at different stations.



**Figure 6.** Concentration of chloride, phosphate, and ammonia.

change in physical and chemical components of groundwater close to the landfill sites of Poland was assessed within 2008-2014. The results revealed that the increased values of Cd, EC, and total organic carbon (TOC) indicated the degradation of water quality below landfills was due to the negative impact of leachate percolation. This contamination is a consequence of the lack of efficiency of the existing drainage system in 19-year of its operation (Przydatek and Kanownik, 2019). The disorganized dumping of the municipal solid waste at the sides of the Bishnumati River in Kathmandu has significantly degraded the quality of the river and shallow-well water with very high electrical conductivity, nitrate, nitrite, and chemical oxygen demand (COD) (Devkota and Watanabe, 2005). The impact of leachate from the Ramna landfill site of Varanasi, India, to the nearby groundwater bodies was evaluated. For instance, the BOD of leachate was 1335 mg/L and that of water samples of pre-monsoon and post-monsoon were 3.11 mg/L and 1.57 mg/L respectively. The study has suggested the possibility of contamination of different pollutants to the adjoining water bodies of landfills (Mishra et al., 2019). The BOD values of leachates from different Asian landfills have analogous to that of the Pokhara landfill. The BOD values of Payatas of Philippines (190 -1600 mg/L), Taiwan (16-312 mg/L), and Malaysia (87-1787 mg/L). The comparative analysis showed that the Payatas landfill had reached a stable state with low efficiency of biological treatment of the waste. Evaluation of physicochemical parameters of municipal and Payatas creeks have shown a higher pollution load during the dry season. Based on contaminated nature and a high degree of pollution caused by leachate in the Manila region, the study has suggested replacing the landfill site at an appropriate location with effective environmental control guidelines (Chounlamany et al., 2018).

#### Concentrations of chloride, phosphate, and ammonia

Chloride ion ( $\text{Cl}^-$ ) and phosphate ( $\text{PO}_4^{3-}$ ) ion easily interchange through an aqueous medium and their concentration greatly inhibits the water quality. So, their concentrations might be the tracer to validate the level of pollution. The presence of phosphate in the leachate might be generated from agricultural, domestic, detergents, and industrial effluents (Maiti et al., 2016).

The leachate of the Pokhara landfill had the concentration of chloride and phosphate ions 64.85 mg/L and 1.43 mg/L, respectively. Figure 6 shows that the concentrations of  $\text{Cl}^-$  at different stations varied from a minimum of 17.04 mg/L at Ramghat, 22.25 mg/L at Tatopani, 22.5 mg/L at Kotre to a maximum of 24.14 mg/L at just below the landfill. A bit larger value of  $\text{Cl}^-$  just below landfill might be due to the contamination of leachate passing into the river. These values are within the permissible limit of the WHO guideline value of 250 mg/L for drinking water. The result suggested no sign of deterioration in the chloride content of Seti River water by the leachate of the Pokhara landfills. The current study revealed the concentration of phosphate in river water fluctuated from 0.253 mg/L at below landfills to a maximum of 0.61 mg/L at Ramghat station. A relatively higher amount of  $\text{PO}_4^{3-}$  might be ascribed to the accumulation of excess domestic, hospital, and cremation waste at Ramghat station. Marked variation of physicochemical parameters of leachate from a particular landfill was observed at different seasons. The improperly managed landfills of Jammu, India, showed diverse concentrations of chloride ions with a maximum of 92.02 mg/L in winter and 66.8 mg/L at pre-monsoon sampling. The phosphate ions had the same type of variation with the concentrations of 43.2 mg/L at post-monsoon and 48.6 mg/L at winter sampling. The study concluded that the water bodies lying close to the landfill site were contaminated by leachate infiltration (Raina et al., 2019). The leachate from the Alexandria landfill of Egypt had the concentration of ammonia and phosphates as 321 mg/L and 0.37 mg/L (El-salam and Abu-zuid, 2015). Ammonia is an important pollutant exhausted by the decomposition of different wastes. A part of nitrogen might have been released with leachate as an ammoniacal compound by aerobic and anaerobic decomposition of solid waste (Maiti et al., 2016). The present study showed the concentration of ammonia as 1.85 mg/L for leachate. In the river water ammonia content ranged from 0.335 (Tatopani), 0.363 (below landfill), 0.71 (Ramghat) to 0.78 mg/L (Kotre). A higher concentration of  $\text{NH}_3$  might be due to the presence of an excess of biological waste from the human settlement area with random disposal of waste into the river.

## Conclusions and recommendations

The research shows that there is no noteworthy adulteration in the physicochemical parameters of the river. As the landfill site matures, its recycling efficiency will reduce and the waste materials will not be disposed of properly. On the other hand, the amount and variety of waste materials of the growing city will keep on increasing. It leads to the growth in the quantity of leachate flowing towards the river. The study recommends the necessity of some precautionary measures for the management of solid waste. Integrated, multisector approaches are necessary to develop safe and sustainable disposal of the waste without deteriorating the groundwater quality. Rigorous management and continuous monitoring of leachate and water quality for physicochemical and biological parameters are necessary. Furthermore, it suggests closing the matured landfill site and developing an alternative spot at a suitable place soon. A clear picture of water quality will be identified through long-term monitoring in the riverine basin as it is influenced by both natural and anthropogenic circumstances. Our data set will serve as the foundation for a future road map and in-depth investigation.

## Conflict of interest

The authors declare no conflict of interest

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## REFERENCES

- Adhikari, B., Manandhar, D. R., & Khanal, S. N. (2013). Study of leachate and waste composition at different landfill sites of Nepal. *Kathmandu University Journal of Science, Engineering and Technology*, 9(ii), 15–21.
- Adhikari, N. P., Adhikari, S., Liu, X., Shen, L., & Gu, Z. (2019). Bacterial Diversity in Alpine Lakes: A Review from the Third Pole Region. *Journal of Earth Science*, 30(2), 387–396. <https://doi.org/10.1007/s12583-018-1206-5>
- Adhikari, N. P., Adhikari, S., & Paudel, G. (2019). Bacterial Diversity in Aquatic Ecosystems over the Central Himalayas, Nepal: Progress and Future Perspectives. *Janapriya Journal of Interdisciplinary Studies*, 8, 200–211. <https://doi.org/10.3126/jjis.v8i0.27319>
- Adhikari, S., Zhang, F., Adhikari, N. P., Zeng, C., Pant, R. R., Ram, K., Liu, Y., Ahmed, N., Xu, J., Tripathee, L., Zhang, Q., Bhuiyan, M. A. Q., & Ahsan, M. A. (2021). Atmospheric wet deposition of major ionic constituents and inorganic nitrogen in Bangladesh: Implications for spatiotemporal variation and source apportionment. *Atmospheric Research*, 250, 105414. <https://doi.org/10.1016/j.atmosres.2020.105414>
- Adhikari, S., Zhang, F., Zeng, C., Tripathee, L., Adhikari, N. P., Xu, J., & Wang, G. (2019). Precipitation chemistry and stable isotopic characteristics at Wengguo in the northern slopes of the Himalayas. *Journal of Atmospheric Chemistry*, 76(4), 289–313. <https://doi.org/10.1007/s10874-020-09399-1>
- American Public Health Association. (1999). *Standard methods for the examination of water and wastewater* (L. S. Clesceri, A. Greenberg, & A. W. Eaton (eds.); Nineteenth). American Public Health Association, American Water Works Association, Water Environment Association.
- Banar, M., Özkan, A., & Kırkcıoğlu, M. (2006). Characterization of the leachate in an urban landfill by physicochemical analysis and solid phase microextraction-GC/MS. *Environmental Monitoring and Assessment*, 121, 439–459. <https://doi.org/10.1007/s10661-005-9144-y>
- Bhalla, G., Swamee, P., Kumar, A., & Bansal, A. (2012). Assessment of groundwater quality near municipal solid waste landfill by an aggregate index method. *International Journal of Environmental Sciences*, 2(2), 1492–1503. <https://doi.org/10.6088/ijes.00202030034>
- Bundela, P. S., Pandey, A. K., Jamaluddin, Awasthi, A. K., & Pandey, P. (2012). Evaluation of physicochemical parameter of municipal solid waste leachate at Jabalpur. *International Journal of Plant, Animal and Environmental Sciences*, 2(1), 223–226.
- Chounlamany, V., Tanchuling, M. A., & Inoue, T. (2018). Water quality and pollution loading of a river segment affected by landfill leachate and domestic waste. *International Journal of Environmental Studies*, 76(3), 1–17. <https://doi.org/10.1080/00207233.2018.1507874>
- Devkota, D. C., & Watanabe, K. (2005). Impact of solid waste on water quality of Bishnumati River and surrounding areas in Kathmandu, Nepal. *Journal of Nepal Geological Society*, 31, 19–24. <https://doi.org/10.3126/jngs.v31i0.253>
- Edokpayi, J. N., Durowoju, O. S., & Odiyo, J. O. (2018). Assessment of heavy metals in landfill leachate: a case study of Thohoyandou landfill, Limpopo province, South Africa. In H. E.-D. M. Saleh & R. F. Aglan (Eds.), *Heavy Metals* (pp. 219–231). IntechOpen. <https://doi.org/http://dx.doi.org/10.5772/intechopen.74009>
- El-Fadel, M., Bou-Zeid, B., Chahine, W., & Alayli, B. (2002). Temporal variation of leachate quality from pre-sorted and baled municipal solid waste with high organic and moisture content. *Waste Management*, 22, 269–282.
- El-Fadel, M., Findikakis, A. N., & Leckie, J. O. (1997). Environmental impacts of solid waste landfilling. *Journal of Environmental Management*, 50(1), 1–25. <https://doi.org/10.1006/jema.1995.0131>
- El-salam, M. M. A., & Abu-zuid, G. I. (2015). Impact of landfill leachate on the groundwater quality: A case study in Egypt. *Journal of Advanced Research*, 6(4), 579–586. <https://doi.org/10.1016/j.jare.2014.02.003>
- Enujiugha, V. N., & Nwanna, L. C. (2004). Aquatic oil pollution impact indicators. *Journal of Applied Sciences and Environmental Management*, 8(2), 71–75.
- Gupta, N., & Gupta, R. (2015). Solid waste management and sustainable cities in India: the case of Chandigarh. *Environment and Urbanization*, 27(2), 573–588. <https://doi.org/10.1177/0956247815581747>
- Jokela, J. P. Y., & Rintala, J. A. (2003). Anaerobic solubilisation of nitrogen from municipal solid waste (MSW). *Reviews in Environmental Science and Biotechnology*, 2(1), 67–77. <https://doi.org/10.1023/B:RESB.0000022830.62176.36>
- Kaphle, B., Wang, J. bo, Kai, J. lei, Lyu, X. miao, Paudyal, K. N., & Adhikari, S. (2021). Hydrochemistry of Rara Lake: A Ramsar lake from the southern slope of the central Himalayas, Nepal. *Journal of Mountain Science*, 18(1), 141–158. <https://doi.org/10.1007/s11629-019-5910-0>
- Kumar, V., Kumar, S., Srivastava, S., Singh, J., & Kumar, P. (2018). Water quality of River Ganga with reference to physico-chemical and microbiological characteristics during Kanwar Mela 2017, at Haridwar, India: A case study. *Archives of Agriculture and Environmental Science*, 3(1), 58–63.
- Kurian Joseph, Rajendiran, S., Senthilnathan, R., & Rakesh, M. (2012). Integrated approach to solid waste management in Chennai: An Indian metro city. *Journal of Material Cycles and Waste Management*, 14, 75–84. <https://doi.org/10.1007/s10163-012-0046-0>
- Longe, E. O., & Balogun, M. R. (2010). Groundwater quality assessment near a municipal landfill, Lagos, Nigeria. *Research Journal of Applied Sciences, Engineering and Technology*, 2(1), 39–44.
- Maiti, S. K., De, S., Hazra, T., Debsarkar, A., & Dutta, A. (2016). Characterization of leachate and its impact on surface and groundwater quality of a closed dumpsite - a case study at Dhapa, Kolkata, India. *Procedia Environmental Sciences*, 35, 391–399. <https://doi.org/10.1016/j.proenv.2016.07.019>
- Mishra, S., Tiwary, D., Ohri, A., & Agnihotri, A. K. (2019). Impact of municipal solid waste landfill leachate on groundwater quality in Varanasi, India. *Groundwater for Sustainable Development*, 9, 100230. <https://doi.org/10.1016/j.gsd.2019.100230>

- Mohan, S., & Gandhimathi, R. (2009). Solid waste characterisation and the assessment of the effect of dumping site leachate on groundwater quality: A case study. *International Journal of Environment and Waste Management*, 3(1/2), 65–77. <https://doi.org/10.1504/IJEW.2009.024700>
- Mor, S., Ravindra, K., Dahiya, R. P., & Chandra, A. (2006). Leachate characterization and assessment of groundwater pollution near municipal solid waste landfill site. *Environmental Monitoring and Assessment*, 118, 435–456. <https://doi.org/10.1007/s10661-006-1505-7>
- Muhammad, A. M., & Zhonghua, T. (2014). Municipal solid waste and its relation with groundwater contamination in Lahore, Pakistan. *Research Journal of Applied Sciences, Engineering and Technology*, 7(8), 1551–1560. <https://doi.org/10.19026/rjaset.7.431>
- Nagarajan, R., Thirumalaisamy, S., & Lakshumanan, E. (2012). Impact of leachate on groundwater pollution due to non-engineered municipal solid waste landfill sites of erode city, Tamil Nadu, India. *Iranian Journal of Environmental Health Science & Engineering*, 9(35), 1–12. <https://doi.org/https://doi.org/10.1186/1735-2746-9-35>
- Olarewaju, O., G., Sa'id, M. D., & Ayodele, J. T. (2012). Levels of some physicochemical parameters in leachates from open dumpsites in Lokoja, Kogi state, Nigeria. *Chemsearch Journal*, 3(2), 26–33.
- Paudel Adhikari, N., Liu, Y., Liu, K., Zhang, F., Adhikari, S., Chen, Y., & Liu, X. (2019). Bacterial community composition and diversity in Koshi River, the largest river of Nepal. *Ecological Indicators*, 104, 501–511. <https://doi.org/10.1016/j.ecolind.2019.05.009>
- Paudel, N., Adhikari, S., & Paudel, G. (2017). Ramsar Lakes in the Foothills of Himalaya, Pokhara- Lekhnath, Nepal: an overview. *Janapriya Journal of Interdisciplinary Studies*, 6, 134–147. <https://doi.org/10.3126/jjis.v6i0.19315>
- Przydatek, G., & Kanownik, W. (2019). Impact of small municipal solid waste landfill on groundwater quality. *Environmental Monitoring and Assessment*, 191(169), 1–14. <https://doi.org/https://doi.org/10.1007/s10661-019-7279-5>
- Raina, Y. M., Alam, P., & Raina, M. I. (2019). Study of the characteristics of leachate and its influence on groundwater quality near improper landfill site in Jammu City, India. *International Journal of Environment and Waste Management*, 23(2), 195–211.
- Reda, A. H. (2016). Physicochemical analysis of drinking water quality of Arbaminch town. *Journal of Environmental & Analytical Toxicology*, 6(2), 1–5. <https://doi.org/10.4172/2161-0525.1000356>
- Rimal, B., Baral, H., Stork, N., Paudyal, K., & Rijal, S. (2015). Growing City and Rapid Land Use Transition: Assessing Multiple Hazards and Risks in the Pokhara Valley, Nepal. *Land*, 4(4), 957–978. <https://doi.org/10.3390/land4040957>
- Salami, L., Fadayini, O., Patinvoh, R., & Koleola, O. (2015). Evaluation of Leachate Contamination Potential of Lagos Dumpsites Using Leachate Pollution Index. *British Journal of Applied Science & Technology*, 5(1), 48–59. <https://doi.org/10.9734/bjast/2015/11707>
- Sangeetha, S., & Selvarajan, G. (2017). Physico chemical analysis of groundwater near municipal solid waste dump site and non dump site -A comparative study around Mayiladuthurai, India. *Research Journal of Pharmacy and Technology*, 10(10), 3483–3488. <https://doi.org/10.5958/0974-360X.2017.00623.0>
- Sharma, B. P., Adhikari, S., Paudel, G., & Adhikari, N. P. (2020). Microbial Diversity in the Glacial Ecosystem of Antarctic, Arctic, and Tibetan Plateau: Properties and Response to the Environmental Condition. *Janapriya Journal of Interdisciplinary Studies*, 9(1), 231–250. <https://doi.org/10.3126/jjis.v9i1.35239>
- Singh, R. K., Datta, M., & Nema, A. K. (2009). A new system for groundwater contamination hazard rating of landfills. *Journal of Environmental Management*, 91(2), 344–357. <https://doi.org/10.1016/j.jenvman.2009.09.003>
- Singh, J., Kumar, V., & Kumar, P. (2021). Kinetics and prediction modeling of heavy metal phytoremediation from glass industry effluent by water hyacinth (*Eichhornia crassipes*). *International Journal of Environmental Science and Technology*, 1–12. <https://doi.org/10.1007/s13762-021-03433-9>
- Ślomończyńska, B., & Ślomończyński, T. (2004). Physico-chemical and toxicological characteristics of leachates from MSW landfills. *Polish Journal of Environmental Studies*, 13(6), 627–637.
- Thomas, J., Joseph, S., Thirvikramji, K. P., Manjusree, T. M., & Arunkumar, K. S. (2014). Seasonal variation in major ion chemistry of a tropical mountain river, the southern Western Ghats, Kerala, India. *Environmental Earth Sciences*, 71(5), 2333–2351. <https://doi.org/10.1007/s12665-013-2634-2>
- Václavík, V., Ondrašíková, I., Dvorský, T., & Černochová, K. (2016). Leachate from municipal waste landfill and its natural degradation—A case study of zubří, Zlín region. *International Journal of Environmental Research and Public Health*, 13(9). <https://doi.org/10.3390/ijerph13090873>
- WHO. (2008). *Guidelines for drinking-water quality* (3rd ed., Vol. 1). World Health Organization.