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Research Article

Physio-chemical characterisation of dumped solid waste

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ABSTRACT

Landfilling is the most common practice used for the disposal of solid waste since it is the cheapest method of municipal solid waste management. The present study aims to determine the physical and chemical characteristics of dumped solid waste collected directly from the Okhla landfill site (New Delhi, India) which has been declared as exhausted in 2018. These waste samples have been collected having ages beyond 20 years. Further, several laboratory tests were performed on the samples to investigate parameters namely physical composition, moisture content, density, optimum moisture content, pH, electrical conductivity, percentages of carbon (C), nitrogen (N), hydrogen (H), sulphur (S) and C/N ratio. The physical composition of samples was found to be substantially heterogeneous. The mean values for moisture content and optimum moisture content were observed as 10.03% and 22.27% respectively. Moreover, the mean of density, pH and electrical conductivity was obtained as 1323.88 kg/m^3, 6.44 and 3.06 mho/cm respectively. On the other hand, the elemental parameters C, H, N, S mean percentages were evaluated as 5.98%, 0.73%, 0.27% and 0.71%. Consequently, C/N ratio was evaluated as 23.46 for the samples. These results have also been compared with the MSW characteristics of Asian countries.

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INTRODUCTION

Dumped solid waste (DSW) mainly comprises wastes from households, commercial buildings, offices, institutions, parks, streets, construction, and demolition sites. Typical residential and commercial DSWs include clothing, disposable tableware, yard trimmings, cans, office disposable tables, paper, and boxes, whereas institutional and industrial DSWs contain restaurant trash, paper, classroom wastes, wood pallets, plastics, corrugated boxes, and office papers [1]. In India, rapid urbanisation, and the shift of population towards cities has contributed to higher DSW generation in metropolitan cities like Delhi, Mumbai, Kolkata, Bengaluru etc [2–4]. Moreover, more than 92% of these wastes are disposed of directly on open dumping sites in an unsecured manner [5, 6]. Therefore, waste management has become one of the strategic agendas of India's leading mission "Swachh Bharat Abhiyan". Accumulated waste not only affects the public health and environment but also hamper the industrial and socio-economic growth of the country [7, 8].

Delhi is a highly urbanized and closely populated metropolitan city that produces about 9000 MT (Metric Tonnes) of solid waste every day which is expected to reach 17000–25000 Tons per day due to rapid industrial development [9–16]. Also, according to Central Public Health and Environmental Engineering Organization [17] per capita municipal solid

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waste (MSW) generation in Delhi is about 700 g/day which is five times the national average. To have an efficient solid waste management system it is important to initially recognise the physical and chemical attributes of the waste [13, 18–22].

Across the globe, numerous studies have been presented on the physio-chemical characteristics of dumped MSW [22–30, 31]. In general, DSW comprises- recyclable waste (textiles, plastics, glass, metals etc), organic or compostable waste (leaves, wood, food, fruit and vegetable peels etc.), hazardous waste (batteries, medicine etc.) and soiled waste (diapers, syringe, sanitary napkins, pad etc Among these, Gomez et al. [22] reported 12% plastic, 16% paper and 48% organic waste in Mexico City. However, Zhou et al. [30] found 55.86%, 11.15%, 8.52%, 3.16%, 2.94% and 0.84% of food residue, plastics, paper, textiles, wood waste and rubber respectively in MSW in China. Chamem and Zairi [26] found organic waste components between 31–59%, paper 9–10%, textiles 12–16% and plastics, leather and rubber 7–11% in MSW of Gabes City. Saglam and Aydin [31] revealed that MSW generated from educational institutes in Istanbul contains about 36.4% organics, 24% paper, 14.4% plastics, 8.1% glass, 4.8% metals and 12.3% miscellaneous waste. Mushtaq et al. [32] reported a high percentage of organic waste between 10.3%–68.5%, tailed by recyclable waste 12.3%–15.30%, and inert waste 8.27%—9.10% respectively. Swales [33] reported that an average MSW sample contained 53.3% of organic matter, 14.7% of plastic, 13% of paper, 4.2% of glass, 2.7% of metal, 11.6% of others and 0.5% of household hazardous in Brisbane. Yildiz et al. [27] found that the moisture content of waste in Turkey, and Istanbul varies between 46–65%. Furthermore, the chemical characteristics of MSW include pH, electrical conductivity, carbon (C), nitrogen (N), hydrogen (H), Oxygen (O), sulphur (S), Phosphorus (P), Chlorine (Cl), C/N ratio etc. Hla & Roberts [29] performed the chemical analysis of MSW in Brisbane, Australia and measured the presence of C, H, N, O, S and Cl as 52.8%, 6.4%, 1.29%, 31%, 0.18% and 0.73% respectively. Zhou et al. [30] reported the percentages of C, H, O, N, S, Cl as 2.45%, 0.46%, 4.17%, 0.28%, 0.12% and 0.77% respectively in China. Gidarakos et al. [24] determined C, H and N content in MSW in Crete, Greece as 53%, 7.32% and 1.32% respectively.

On the other side, several works of literature from India on the physical and chemical characteristics of MSW have also been testified [6, 13, 34, 35]. The composition of MSW in Bangalore as reported by Ramachandra et al. [6] states that paper, metal, glass and organic content were about 12.69%, 1.67%, 0.65% and 81.96% respectively. Also, Mushtaq et al. [35] identified 12.3–15.3% recyclable waste followed by 10.3–68.5% organic waste in MSW collected from the region of North-western Himalayas. Thaitame et al. [36] observed 61% of organic waste and the remaining was inorganic waste in Sangamner City. It has been perceived that organic waste production is much higher in India (about 40–63% [12]), as contrasted to other developed countries [3, 20, 37].

Furthermore, the physical analysis of DSW has also been assessed by [3, 13, 35]. Kumar and Goel [3] reported 42% moisture content and 58% total solids (20% volatile solids and 80% fixed solid of total solids). Mushtaq et al. [35] found average moisture content varied between 47.6–52.40% in the region of Kashmir.

Also, the chemical analysis of DSW in India has been conducted by [13, 38]. Katiyar et al. [38] stated the following percentages of C, H, O, N, S, P and Potash in MSW collected in Bhopal- 26.6%, 5.9%, 47.7%, 1.1%, 0.98%, 0.84% and 0.93% respectively. Also, a C/N ratio equal to 26.6 was reported. Rana et al. [13] indicated the composition of C, O, H and N as 34.18%, 11.41%, 4.42% and 1.35% in Chandigarh MSW whereas, the same was observed as 33.8%, 10.2%, 4.2% and 1.53% in Mohali and Panchkula, it was found to be 31.9%, 11.1%, 4.2% and 1.1% respectively.

The composition of MSW changes with time. It has been testified that in a landfill it takes less than ten years for heavy metals and several decades for organic pollutants, organic carbon and nitrogen to get stabilised. These stable landfill wastes can be used successfully in various construction works such as subgrade road construction. Therefore, over the years, these physical and chemical analyses of DSW need to be conducted for the proper and efficient operation of waste management systems.

The present study aims to determine the physical and chemical characteristics of DSW collected directly from the Okhla landfill site (New Delhi, India) which was declared as exhausted in 2018. These waste samples have been collected having ages beyond 20 years. The physio-chemical analysis of waste is an essential objective and will serve as the guideline in deciding the waste management techniques by the government. The objectives of the present study are- (a) to collect the waste directly from the landfill dumping site, (b) to determine the components of waste in each sample by segregation, (c) to investigate the physical characteristics of waste samples, (d) to investigate the chemical characteristics of the waste samples.

Description of the Site

Okhla landfill site at Okhla Phase – I, New Delhi is situated close to ESIC hospital. The landfill was authorized in 1996 under the head of South Delhi Municipal Corporation (SDMC), extending over an area of 56 acres. The site received 2000 metric tons of waste per day and was announced exhausted in 2018. Despite this, in the year 2023, the landfill site is still receiving waste from the regions of south and central Delhi due to the unattainability of alternate dumping facilities. As a result of which the mountain of waste is still standing as displayed in Figure 1.

Nevertheless, the government is working in full swing to utilise the decomposed waste (>20 years) as composting material, fillers in road construction etc. The work presented here aims to determine the physical and chemical characteristics of stable DSW collected from the exhausted Okhla landfill site.

MATERIALS AND METHODS

Sampling of DSW

In this study, DSW of the Okhla landfill dumping site were collected eight times from different locations of the landfill.

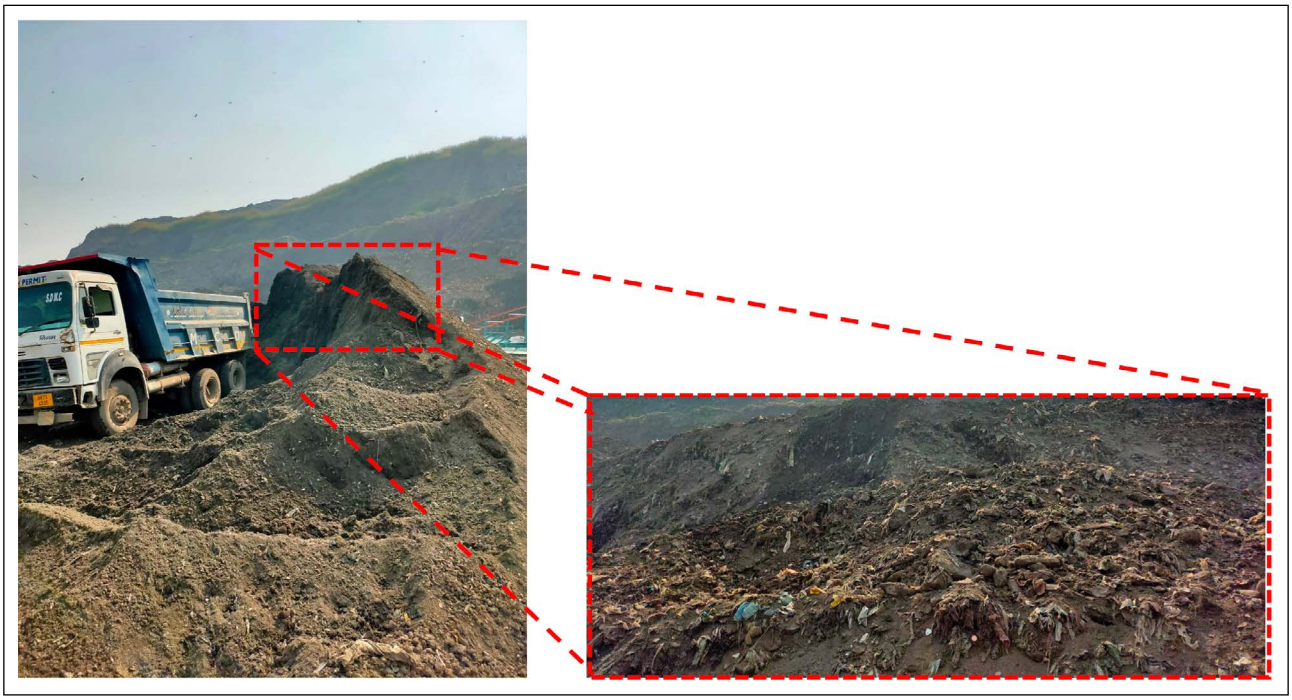

Figure 1. Waste dumped at Okhla Landfill site.

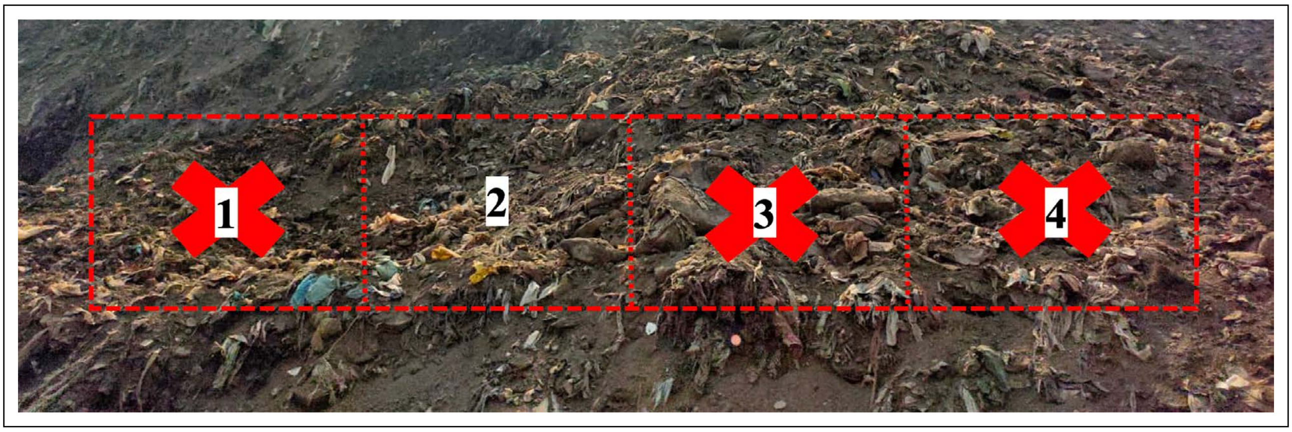

Figure 2. Quartering technique for sampling of waste.

The sampling of each eight samples was performed using the Quartering technique [29, 39–42]. In this technique 20kg of each sample was mixed thoroughly, spread on the ground and quartered approximately. Then one quarter was selected randomly without being biased as shown in Figure 2. These samples were instantly stored in 5kg plastic bags to inhibit any susceptible change in moisture level and carried to the laboratory. The total weight of the collected DSW was approximately 40 kg.

In the laboratory, these collected waste samples of each type were correctly weighed again and composite samples of different samples as per requirement were prepared for the physical and chemical analysis implying the same quartering technique.

Physical Analysis- Laboratory Testing

The physical analysis of DSW has been carried out by performing several laboratory studies. The physical analysis includes the determination of physical composition, moisture content, dry density and optimum moisture content (OMC). The procedures adopted for these tests have been discussed in the subsequent section.

Determination of Physical Composition

Each composite sample of DSW was spread evenly on a clean surface and different types of waste were hand-segregated and grouped into combustible and non-combustible waste categories. The segregated wastes were then weighed and their respective percentages in each sample type were evaluated.

Determination of Moisture Content, Dry Density and OMC

The moisture content of each eight samples was determined using the "Grab sampling without sorting" technique. Initially, 100g of a composite sample of each type was taken in triplicate and oven dried at 110°C for 24 hours. The sample was then cooled and the difference in

Table 1. Physical composition of waste samples I-VIII

Parameters	Waste sample							
	I	II	III	IV	V	VI	VII	VIII
Physical composition (% by weight)								
Combustible waste								
Fine waste (<20 mm)	95.00	94.00	93.00	95.00	48.76	68.79	73.07	31.74
Leaves	0.70	0.60	1.70	1.90	0.23	1.15	2.10	4.19
Textile	–	2.40	–	–	0.03	0.02	1.66	0.09
Wood straps	–	–	–	0.80	0.25	–	–	–
Broken tiles	–	–	–	–	0.20	3.69	6.38	–
Plastic	2.70	1.50	1.30	0.20	8.44	0.19	0.54	4.81
F.A.	1.10	1.50	3.10	2.10	42.07	26.08	16.22	51.58
Non-combustible waste								
Glass	–	–	0.90	–	–	0.05	0.007	5.62
Metals	0.50	–	–	–	–	–	–	1.94

the weight of the sample was recorded. The moisture content (ω_c) of the samples was calculated using Eq. 1;

$$\omega_c\,(\%) = \frac{\text{Difference in the weight of waste sample}}{\text{Initial weight of waste sample}} \times 100 \quad \text{Eq. 1}$$

The dry density of composite waste samples (I to VIII) having natural moisture content was determined according to the Standard Proctor Compaction procedure. A larger compaction mould with a 6-inch inside diameter, 6.1-inch height, with a volume of 1/10 cubic feet with a detachable collar was used. The initial weight of the mould was recorded (say, W_i). Thereafter, the waste sample was filled up to the rim of the mould in three layers, compacting each layer 75 times. A 5.5 lb hammer with a 2-inch face was made to fall from a height of 12 inches on each of the three layers of the sample to achieve the desired compaction. Finally, the weight of the mould along with the compacted waste sample was measured (say, W_f). A similar procedure was adopted for the remaining waste samples. The dry density (γ_d) of waste samples were calculated using Eq. 2.

$$\gamma_d\,(\text{km/m}^3) = \frac{(W_f - W_i)}{\text{Volume of the mould}} \quad \text{Eq. 2}$$

Chemical Analysis- Laboratory Testing

The chemical analysis of DSW has been carried out by performing several laboratory studies following the guidelines of BIS 9234 [43]. A similar approach to analysis has also been adopted by [42, 44]. Chemical analysis in the present study comprises of determination of pH, electrical conductivity (EC) and elemental analysis.

Determination of pH and EC

The pH of the pulverised waste samples was determined by mixing each sample in water to obtain a 1:10 solution. The solutions were allowed to stand for about 2 hours to ensure maximum dissolution of salts in water. Then pH meter was dipped in each sample and readings were noted [45]. EC of the samples was determined based on the based on the calibration of cell with standard 0.1 N KCl solution of conductivity 14.12 m mhos at 30°C.

Elemental Analysis

Elemental analysis establishes the quantities of carbon (C), hydrogen (H), nitrogen (N) and sulphur (S) exhibited in the sample. This evaluation is based on the combustion of samples in a devoted apparatus recognized as an Elemental Analyser. After the combustion compound gases having C, H, N and S elements are liberated and measured using gas chromatography.

RESULTS AND DISCUSSION

Physical Analysis

Physical Composition

The combustible category comprised nine types of waste namely, fine waste, leaves, textiles, wood straps, broken tiles, plastics and F.A (Table 1). In all the samples, fine waste (soil-like material with particle size <20mm) was found to be the major component. The percentage of fine waste varied between 93.00% to 95.00% in samples I-IV whereas, in samples V-VIII the same was obtained to vary between 31.74% to 73.07% by weight. The second major component was found to be F.A. whose percentage varied between 1.10% to 3.10% by weight in samples I-IV. However, its percentage in samples V-VIII was found to be between 16.22% to 51.58% by weight. The third major component was plastic found to vary between 0.20% to 8.44% by weight in samples I-VIII. The other subsequent component was leaves varied between 0.23%–4.19% by weight in samples I-VIII. The textile component was found in samples II and V-VIII with its percentage varying between 0.02%–2.40% by mass. Further, 0.20%–6.38% by weight of broken tiles were found only in samples V-VII. Moreover, wood straps were found to be 0.8% and 0.25% respectively in samples IV and V only.

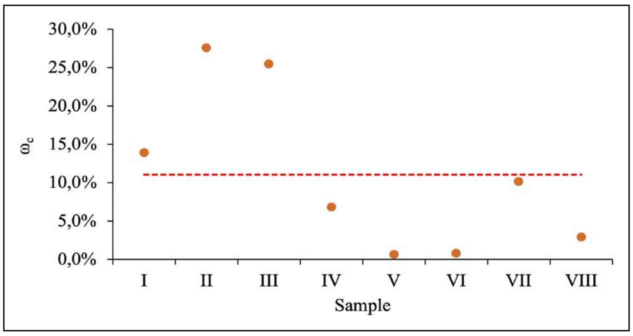

Figure 3. Moisture content in waste samples I-VIII.

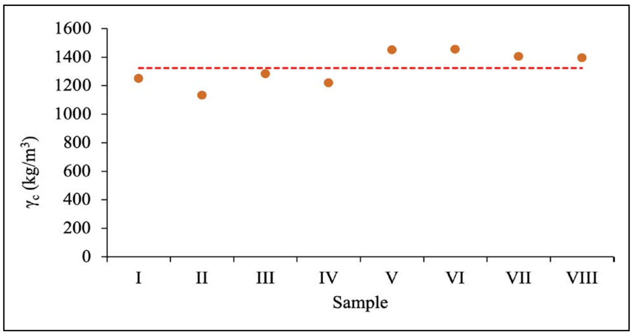

Figure 4. Density of waste samples I-VIII.

In contrast, the non-combustible category comprised metals and glass (Table 1). Metals were found only in samples I and VIII as 0.50% and 1.94% by weight respectively. Glass was found to be 0.90%, 0.05%, 0.007% and 5.62% in samples III, VI, VII and VIII respectively.

Moisture Content, Dry Density and OMC

The moisture contents in samples I-VIII were calculated using the relation given in Eq. 1 and were found as 13.90%, 27.60%, 25.50%, 6.80%, 0.61%, 0.79%, 10.15% and 2.91% respectively. The scatter plot illustrating the variation of moisture content in each sample is shown in Figure 3, depicting a mean value of 11.03%. Saluja et al. [46] also reported an average moisture content of 8.99 ±1.6% for a stabilised landfill site. In contrast, the moisture content in MSW across various cities in India is found to vary between 46–51% [4, 21, 47] and in Asian countries between 17–65% [3, 16, 19, 20]. This low percentage of moisture content in the present case is apparent due to the decomposition and compaction of the landfill site over time.

Using the Standard Proctors Compaction test the density of each sample was determined as mentioned in section 2.3.3. The dry densities evaluated using Eq. 2 are 1250 kg/m^3, 1132 kg/m^3, 1284 kg/m^3, 1219 kg/m^3, 1450 kg/m^3, 1456 kg/m^3, 1406 kg/m^3, 1394 kg/m^3 in samples I to VIII respectively describing the average dry density equal to 1323.88 kg/m^3 (Fig. 4). However, Hazra and Goel [48] stated the average density of MSW in Bhopal (India) as 600 kg/m^3. But then dry density was found to vary between 500–1500 kg/m^3 in China [49].

In samples I-VIII the OMC was obtained as 23.50%, 30.50%, 18.71%, 22.69%, 21.12%, 18.25%, 23.37% and 20% respectively. Thus, the average OMC in samples was found to be 22.27% as depicted in Figure 5. Further, Figure 6 illustrates the variation of moisture content versus dry density. The peak value of each curve indicates the OMC of the respective samples.

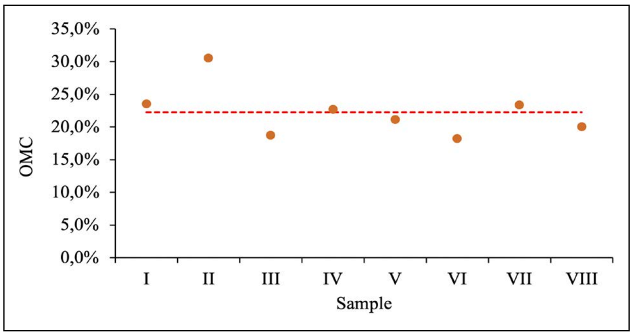

Figure 5. OMC of waste samples I-VIII.

OMC: Optimum moisture content.

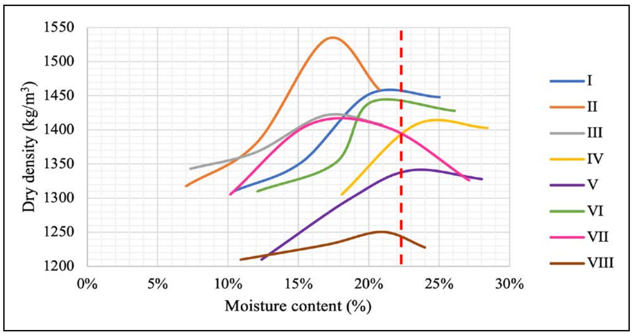

Figure 6. Variation of Dry density wrt moisture content for waste samples I-VIII.

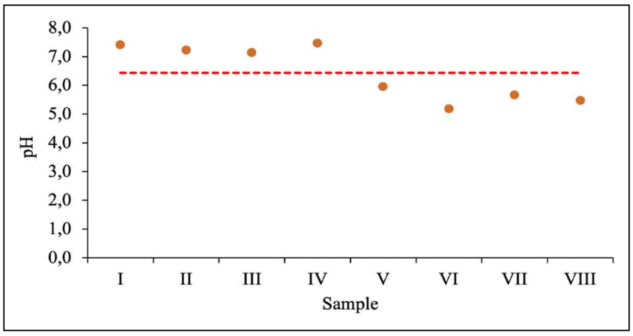

Figure 7. pH of waste samples I-VIII.

Chemical Analysis

pH and EC

The pH of samples I-VIII has been observed to vary between 5.18 and 7.47 as shown in a scatter plot (Fig. 7) indicating 6.44 as the mean value. Further, the EC of each sample I-VIII varied between 2.41–3.59 mho/cm as shown in Figure 8. The average EC of samples was found to be 3.06 mho/cm indicative of a great degree of mineralization in waste samples [50]. Also, Shanthi et al. [42] stated average pH and EC as 7.25 and 3.74 mho/cm for DSW samples of the Coimbatore (India) region.

Elemental Analysis

C and H contents are indicators of the level of oxidation in the waste samples. The percentage of C in I-VIII sam-

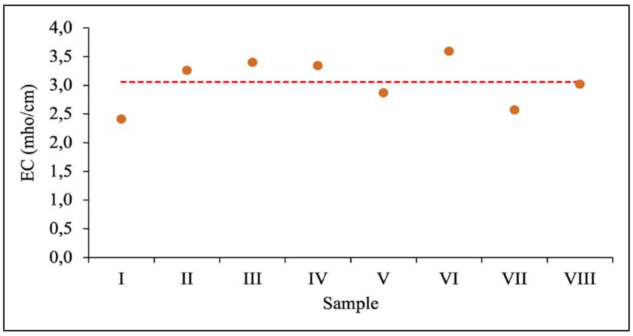

Figure 8. EC of waste samples I-VIII.

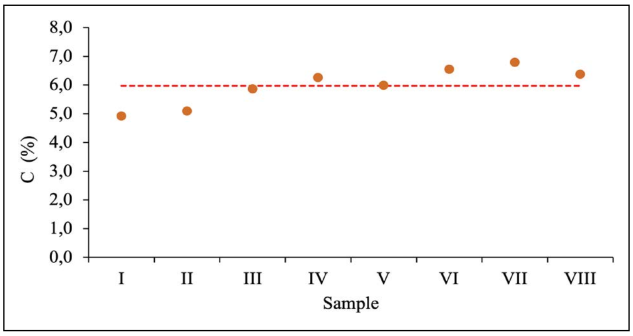

Figure 9. Carbon content of waste samples I-VIII.

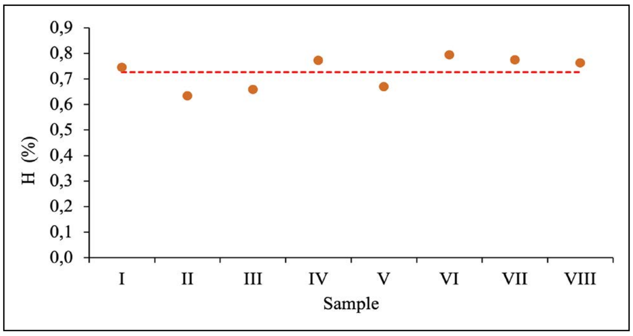

Figure 10. Hydrogen content of waste samples I-VIII.

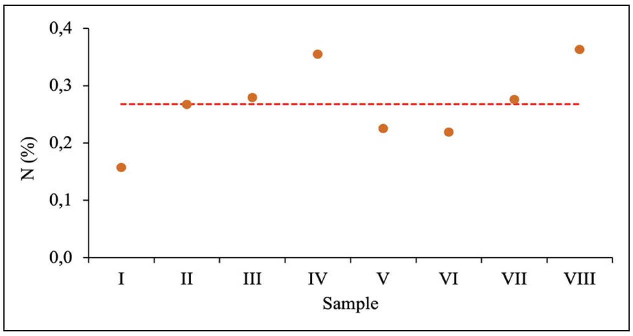

Figure 11. Nitrogen content of waste samples I-VIII.

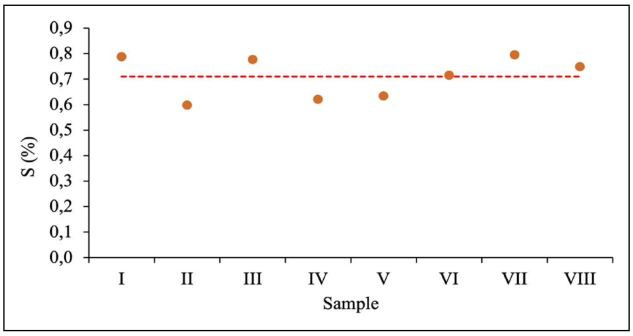

Figure 12. Sulphur content of waste samples I-VIII.

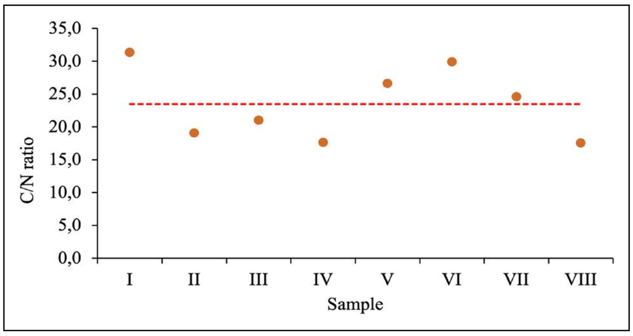

Figure 13. C/N ratio of waste samples I-VIII.

ples varied between 4.92% to 6.79% having a mean value of 5.98% as illustrated in Figure 9. However, H content in samples was found to be between 0.634% to 0.794% with a mean percentage of 0.73% as depicted in Figure 10. Trabelsi et al. [41] and Saluja et al. [46] reported C% as 6.82% and 3.5% respectively and H% as 1.07% and 0.478% respectively in the DSW sample of >20-year-old landfill.

N content in eight samples was found to vary in the range of 0.157% to 3.363% beside the mean percentage of 0.27% (Fig. 11). Likewise, Saluja et al. [46] indicated 0.13% N whereas, Trabelsi et al. [41] reported N content as 0.55% in stable MSW samples. Moreover, the mean S% of eight samples were observed as 0.71% only which varied in each sample between 0.598%–0.795% (Fig. 12). Tracing percentage of S (0.197%) has also been reported by Saluja et al. [46].

The C/N ratio is indicative of rate of biodegradation of waste in landfills and is inversely correlated. In general, the C/N ratio of DSW varies between 20–30 for maximum digestion by microbial action [51]. In the present study, the mean C/N ratio has been obtained as 23.46 (Fig. 13) which is less than 30, indicative of completely decomposed and stable waste samples [52]. Also, Trabelsi et al. [41] and Saluja et al. [46] reported C/N ratio of 12.4 and 36.56 respectively.

CONCLUSION

The present study aims to investigate the physio-chemical characteristics of DSW samples collected from an exhausted Okhla landfill site (about >20years old). The following are some of the major conclusions derived from the study.

i. In all the waste samples fine waste (soil-like material having particle size <20mm) was obtained to be the major constituent about 75%. The other combustible constituents were F.A. > leaves > textile > broken tiles > wood straps whereas, non-combustible constituents-metal and glass were found in traces.

ii. The average moisture content of samples was detected to be 11.03%. On the other hand, mean density and OMC were observed as 1323.88 kg/m^3 and 22.27% respectively.

iii. The pH and EC of the samples were determined as 6.44 and 3.06 mho/cm respectively.

iv. The chemical analysis revealed a good C/N ratio equal to 23.46 (<30) which indicates that the waste has been digested and decomposed effectively.

v. Hence, this decomposed waste can be effectively utilised for construction works such as subgrade in roads, brick manufacturing etc.

DATA AVAILABILITY STATEMENT

The author confirm that the data that supports the findings of this study are available within the article. Raw data that support the finding of this study are available from the corresponding author, upon reasonable request.

CONFLICT OF INTEREST

The author declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

USE OF AI FOR WRITING ASSISTANCE

Not declared.

ETHICS

There are no ethical issues with the publication of this manuscript.

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