# Characterisation and Migration of Microplastics (MPs.) from Leachate

**Saleh M. Abdullahi, Abubakar Halidu, Sanni J. Enewo and Usman H. Ahmed**
Department of Civil Engineering Technology, Federal Polytechnic Nasarawa (FPN)

**Corresponding Author:** Saleh Mamman Abdullahi
salehtawa@yahoo.com (+2348022545488)

DOI: 10.56201/ijemt.v9.no1.2023.pg69.82

***Abstract***
*SW are household refuse found within socioeconomic environment in the forms of biomass and non-decomposable materials, and general method of disposals are controlled and uncontrolled. However, control measures are through ISWM of recovery, recycle, reuse, reduce (4Rs) figure 1 of sustainable waste management system. Similarly, GHGs; Plastics and Leachate fluids are potential hazards in MSW sites which leads to negative environmental footprint. Leachate fluids provides for easy transportation of MPs. figure 2, as well as NPs. pollution of underground water reservoir, and subsequent pollution of available surface water and nearby soils through surface runoff. The consequential effect is general threat to biodiversity and the ecosystem. Methodological analysis of this research are as outlined in Figure 3 and 4 respectively. Furthermore, it can be deduced from this research, that plastic wastes is the second most largest form of waste stream found on most landfills as well as the physical environment, and in view of this, its negative effects cannot be over emphasized. However, its herein recommended that; there's the need to holistically invest in MSW renewable energy sources specifically, solids and leachate wastes to drastically reduce the prevalence of contaminating the air, environment as well as both surface and under-ground water bodies due to MPs, NPs. and leachate.*

***Keywords:*** *Municipal Solid Waste; Microplastics; leachate; Landfill Gas; and ISWM.*

## 1.0 Background

Solid Waste (SW) is accumulated refuse from regular human activities, and are generally discarded within human settlements and their immediate surroundings. Characterization revealed that the major components of SW are generally biomass materials in the forms of food waste, paper, and wood/vegetable wastes. Six (6) Nigeria cities (Abuja, Kano, Lagos, Maiduguri, Onitsha and Port Harcourt) as example generate an average of 54,507,577.000 kg (60,084.32 tons**)** of waste per day. SW disposal through intergraded solid waste management (ISWM), reduces the adverse environmental degradations, pollutions and the negative human health impacts in the environment, and when effectively managed, it will provide for socioeconomic supports, growths and enhanced quality to human life. The Engineering disciplines can diversify the country's economy to achieving greater pinnacle through effective SWM of recovery as replacement for: valuable resourced materials in the use of wastes as fuel for production, generation and provision of cheaper sustainable renewable energy for national development; and for land reclamation and support to agricultural enhancement; bioremediation of heavy metals and for Oil re-use or re-refining (Saleh Mamman Abdullahi UK MSc, Research work 2015).

Nigeria is having abundant SW disposed all around its rural and urban areas, leading to environmental degradation, pollutions and with adverse health implications. Hence, these wastes are resources for renewable energy and for economic development, which remains grossly untapped in Nigeria. This means renewable energy sources can adversely contribute to reducing the daily amount of GHGs we emit into the atmosphere, as well as reduces the expensive cost and the negative environmental effects from the use of finite resources/fossil fuels (non-renewable). Similarly, through integrated solid waste management (ISWM) hierarchical structure of recovery, recycle, reuse, reduce (4Rs) and preventive measure *Fig. 1* below, its eminent that volume of disposed wastes and carbon input leading to leachate and their respective negative effect will however be curtailed effectively.

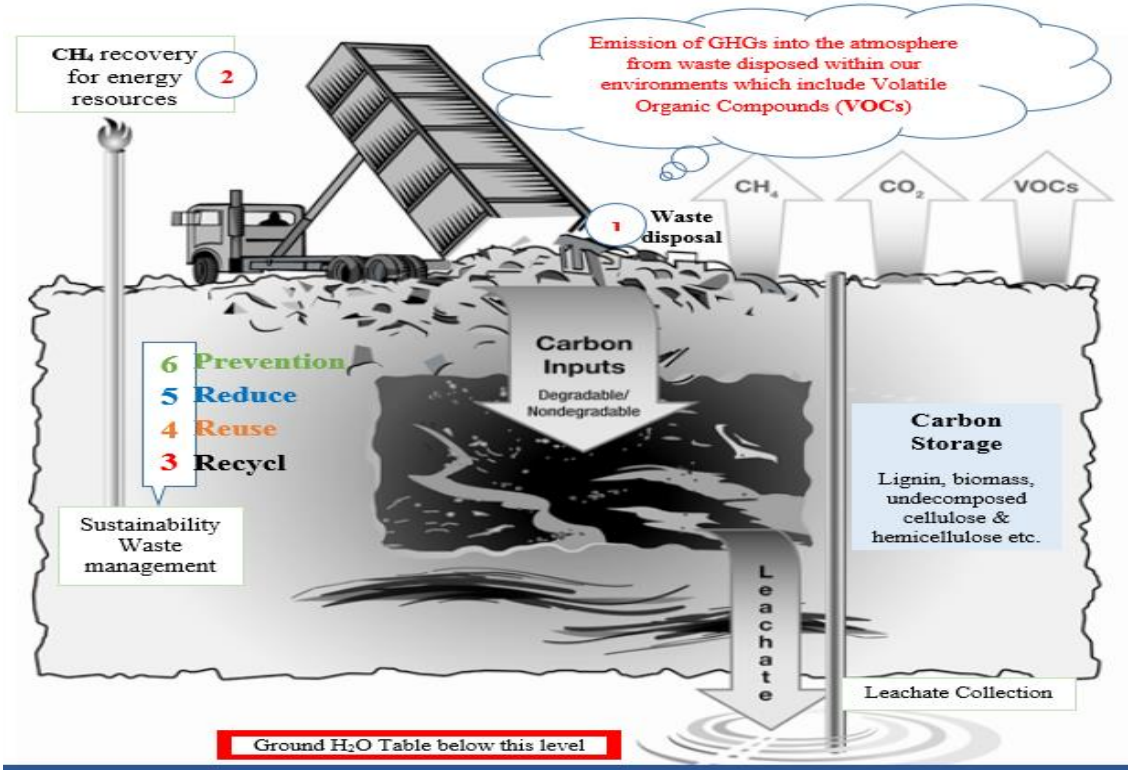


Figure 1: Waste disposal processes
**Source:** (Author UK MSc, Research work.)

### 1.1 By-Product of a Sanitary Landfill

1) **Landfill leachates:** Are permeated fluids originating from MSW which contains in it; extracts, of both saturated and unsaturated constituents with the probability of being potentially detrimental ecological system. (Warith, 2003) *Fig. 1*. Leachate fluids are potentially hazardous and poise immediate hazard, because it has the potentials of transporting pollutants which contribute immensely to subsequent pollution of the nearby soils, underground water reservoir as well as available surface water.
2) **Landfill Gas:** Are commonly present in municipal landfill sites. This includes among others; Ammonia ($NH_3$); Carbon dioxide ($CO_2$); Methane ($CH_4$); Nitrogen (N); Oxygen (O); as well as volatile organic compounds. These are products of decomposed biological constituents of MSW. The major contributor for landfill gases are basically $CH_4$ and $CO_2$ and originates from products of organically decomposable constituent wastes on landfills *Fig. 1*.

### 1.2 Problem Statement

1) Nigeria has no effective ISWM system hence, the adverse extent as well as effect of underground water pollution due to leachate infiltrations and percolations cannot be quantified, with little or no effort to examine landfill leachate and the characterization of its constituent pollutant,
2) The level of surface water pollution can be traced to surface runoff of metals, plastics and contaminants from the vast uncontrolled open dumping process which currently exist in Nigeria. However, countless numbers of rural communities' domestic water consumptions as well as animals depend on these water sources.

Nigerian ISWM problems are basically psychologically driven, lack of technological advancement, politically motivated with economical barriers. Leading to the combination for; insufficient financial backing, fragile judicial system to promulgate prudent policies and laws, scarcity of infrastructural and professional in the fields, enlightenment and awareness is lacking, ineffective disposal techniques and recovery process as the major source to ecological and carbon footprints leading to:

- Gross environmental degradation, pollution, and subsequently constitutes out breaks of rampant cases of diseases and devastating health effects on both human and animals;
- Refuse dup sites had become an environment for indiscriminate defecation by all ages of humans;
- Gross Leachate collections, which subsequently pollutes soil starter and underground aquifers (boreholes and open dug wells) hampered by noncompliance to managing and monitoring pollution of land, water and air quality;
- Global warming and the depletion of the Ozone layer, as a result of excessive release of toxic GHGs ($CO_2$, $CH_4$, VOCs etc.) in to the atmosphere;
- Sustainable management of both hazardous and non-hazardous wastes are lacking with little or no support for R&D on sustainable ISWM to generate power and energy in Nigeria;
- Absolute blockage of water channels and facilities, does pave ways for over-flooding within host communities and its environs; thereby, causing loss of billions of dollars annually.

The quest of managing these disposed wastes in Nigeria is by direct open burning, leading to the destruction of the Ozone layer and subsequently weakens the ambient strength of civil engineering structures such as bridges, culverts and other utility structures, [Author personal industrial research and development (R&D)].

### 1.3 Aim(s) & Objectives of this Research work are:

1) To come up with sustainable as well as viable laboratory approach to Evaluate and Characterise the Migration of Microplastics from Landfill Leachate in order to attaining current Best Practice Environmental Options (BPEO) of Solid Waste Management.

### 1.4 Significance and the Contributions of this research work to Knowledge will include among others:

1) To evaluate and characterise plastics as it exist in landfill leachate;
2) To promoting and providing bases for extensive R&D for researchers in the evaluation of leachate and its eminent and or potential effect to water course;

3) This research work will serve as reference and as an effective tool in global institutions of learning via reputable national and international journals, conferences, seminars, workshops etc.;
4) This research will provide a base document for government and policy makers, stakeholders of interest and concerned individuals, for adoptions to effective implementation for BPEO.

**2.0 Literature Review**

The terminology "Microplastics" (MPs.) in 2004 has been used by Thompson, to defining smaller particles of plastic contaminants which are found in most nautical environments but with much stresses on the fragmented sizes (Thompson et al. 2004). However, the various forms of shapes and sizes considered for defining MPs. were subsequently redefined globally by several researchers (Andrady 2011); (Arthur et al. 2008), and (Verschoor 2015). Similarly, it can be said that, among several and widespread definitions of MPs., that of "United States National Oceanic and Atmospheric Administration (NOAA)", proposed definition is said to be the most commonly used and which defines MPs. as all forms plastic fragments (particles) found within the environment which passes through 5 mm aperture of sieve mesh (less than 5 mm cross sectional area) excluding the various chemical compositions of the plastics.

However, recent innovations identifies a cluster of researchers associated to this field, postulated the cross sectional area and or diameters of MPs. to be 1 μm, with the view to characterise subsequent and or future data analysis, and hence postulated definition of Sub-microplastics (SMPs.) to be less than 1 μm and are known be Nano-plastics (NPs) (Hartman et al. 2019).

Several researches has outlined that particles of MPs. are universally evaluated and are identified in a wide arrays, based on sizes, polymer types, shapes, and their pollution concentration within the natural habitat such as on land, marine and freshwater bodies (Campanale C. et al 2019), including agricultural ecosystems (Rillig, M.C et al 2017), atmosphere (Prata, J.C. 2018) the food chains (Waring, R.H. et al 2018), to include water used for drinking (Pivokonsky, M. et al., 2018), as well as biota (Rezania, S. et al., 2018), including remote and an unexpected places or areas (Cook, T., 2019). There are MPs. which exist very thinly and are generally much smaller as veil, which can be dispersed though wind for several miles distances. Similarly some are harder and well compacted in a rocky forms (Corcoran P.L et al 2019).

Much of the disposed plastic wastes after resourceful recovery, are reused but subsequently in the long run they end up in most disposal sites and or landfill, and the volume of these wastes are estimated to be around 95 % of global disposed MSW generated. However, 79 % of the landfill wastes are estimated to be plastics, and hence this translates to the availability and abundancy of MPs. in landfills. (Zhou et al. 2014). With the aforementioned reasons, landfill sites serves as accumulative loading receptacle for macro to micro plastic material sizes (K. Duis, and A. Coors, 2016). It's eminent that waste management, structures in the forms of wastewater treatment facilities, including landfill sites, are prospective MPs. sources. Hence, it can be said that we are limited as to the knowledge as well as the understanding for the potential extents of landfill sites serving as reservoir basin for MPs. "(Ngo et al. 2019); Kazour et al. 2019); (Cowger et al. 2019) and (J.N. Hahladakis, et al, 2018)" as well as (L. Hou, 2020).

The presence of leachates in landfills, either treated and or otherwise, were known to be agents of environmental pollutions containing heavy metals as well as the presence of toxic substances, and are primarily available in both soil as well as underground water aquifers. Pollution of such underground water aquifers presents an enormous potential threat to the

existence of the ecosystem as well as end users of such local underground water resources. However, the existence of poisonous plasticizers in landfill leachates had been confirmed and were reported in some research works, and similarly established that landfill sites provide enormous ground for a substantial volume of plastics related pollutant "(Jonsson et al. 2003); (Asakura et al. 2004); (Baderna et al. 2011); (Kalanatarifard & Yang 2012); and (Wowkonowicz et al. 2013)" Furthermore, the occurrence of primary MPs. which exists within MSW as well as landfills, and subsequently reproduces to generating secondary MPs. aided to the result of containing larger volume of buried plastic wastes which provides for conducive and or much favourable environmental condition for progressively as well as for the incessant broken-down of macro-plastics (MAPs) to MPs. "(Ishigaki et al. 2004) and (Webb et al. 2013)" Current study has shown that, only just 3 ISI research papers as well as 2 resent reports evaluates the degree of MPs. in leachates collected from landfill site, with just focus mainly on the Europe as well as the Chinese. While in the year 2016, a researcher by name; "Kilponen" established evidently this first topic (J. Kilponen. 2016), which addressed MPs. levels in "Brook (M€at€ajoki brook) known to be a recipient of leachate from over than 30 years old-closed landfill site in Finland" (J. Kilponen. 2016).

However other relevant current medical research investigation highlights the present toxicity effects of MAPs as well as MPs. leachate in relation to aquatic ecosystem. It has reported to have said that; landfills leachate had been confirmed to inducing several forms of harmful, with negative effects on the life cycles of some aquatic species. Similarly, the report states that; the freshwater creatures recorded sub-lethal negative effects including decrease in the "Daphnids" productivity (Zimmermann et al. 2020), in accordance with (Bucci et al. 2021), it does increases the rate of "fathead minnow larvae deformities", increasing DNA division in "apoptotic germ cells of nematodes (Ficociello et al. 2021)" as well as "inhibitions of photosynthesis in microalgae (Luo et al. 2019; Luo et al. 2020)" Also stated sub-lethal effects in salty water creatures including "mussel embryo abnormalities (Silva et al. 2016)" similarly, "sea urchin embryo and larvae (Oliviero et al. 2019; Rendell-Bhatti et al. 2021)" as an abnormal developments as well as inhibition processes, there is also evolution decrease in "sea Urchin larvae (Cormier et al. 2021)", with also decrease in the distributions of "Barnacle Cyprids (Li et al. 2015)", as well as decreasing hunting evasion in fresh water Snails (Seuront, 2018). It has been outlined by (Lithner et al. 2009) that, plastics in leachates contributes immensely to the deaths of Daphnids in the marine system "(Dave and Aspegren, 2010); (Lithner et al. 2012); and (Zimmermann et al. 2020)". Similarly, this includes salty water Copepods as well as Barnacle Nauplii these as reported by "Bejgarn et al. 2015 and Li et al. 2015" Similarly, "Mussel embryos by (Silva et al. 2016)"

**2.1 Occurrence of MPs.**

In view of the above literature, it can now be generalised in summary that; MPs. exists in three (3) major forms within the environment namely, the atmosphere, land (soil) and the water bodies, while the interconnecting medium from atmosphere to water and to soil is through atmospheric transmission as well as dry and wet deposition processes. While the medium of propagation between soil and water is through surface runoff, wind, and precipitation (rainfall), and from water to soil, the medium of propagations are similarly tidal, flooding and wave forms. However these processes is said to be a cyclonic interphase *Fig. 2* below.

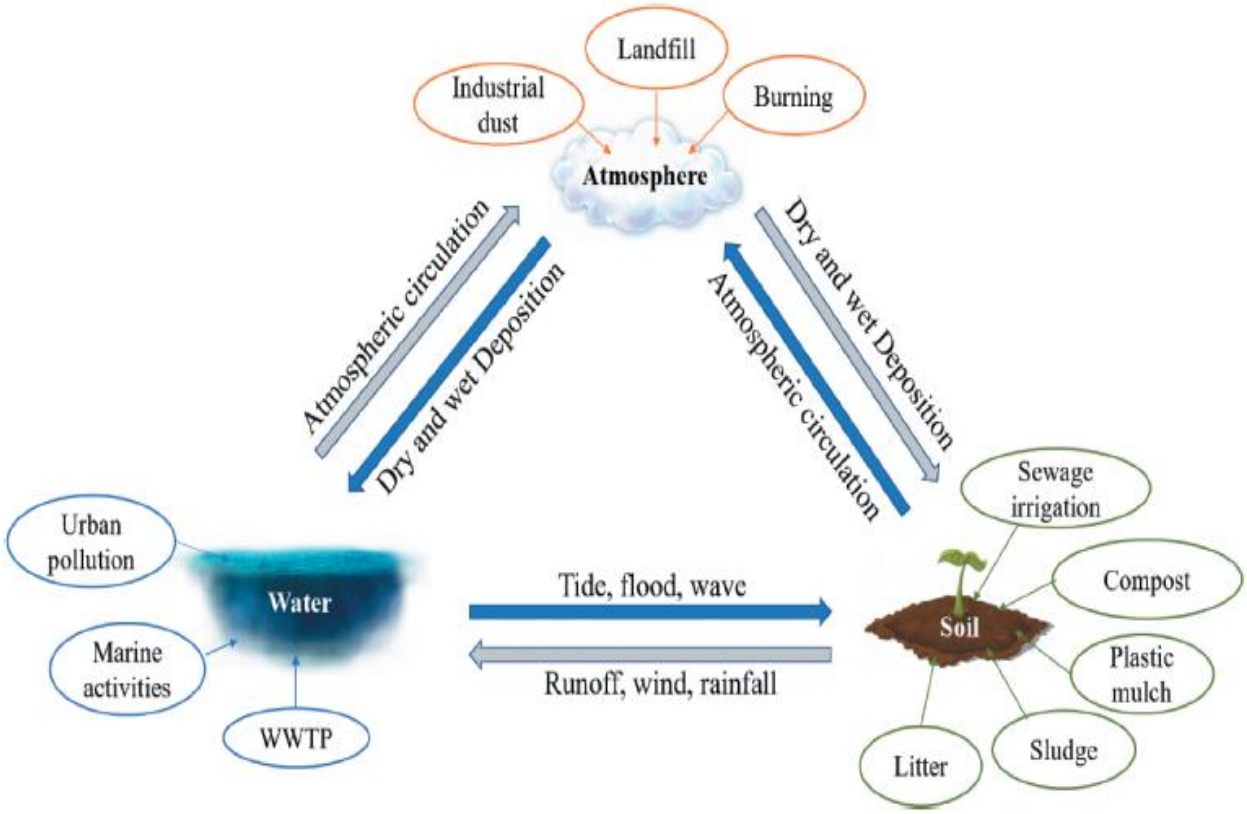


**Figure 2:** Cyclonic interphase of microplastics found in the environment.

## 3.0 Materials and Methods

### 3.1 Relevant Materials

The major relevant materials required for this research work will includes:

1) MSW landfill site with leachate management system residence in institution country *Fig. 4.* or;
2) Controlled waste disposal sites with leachate collection probes or ponds;
3) High-tech laboratory having digitalized FT-IR Routine Spectrometers; FT-IR Microscopes; Raman Microscopes; and Microplastics Finder (MPF).The MPF is a software that automatically analyses whole FT-IR images of microplastics samples within a few minutes.
4) Current versions Land-GEM software among other majors.

### 3.2 Proposed Method to be used for data Collection

The proposed method in respect to this research work, will be a combination of both quantitative as well as qualitative approaches (raw data collection from existing landfill site and or relevant authorities, analytical and numerical approach, computer base validation/simulations, current and relevant scholarly materials among others). This is with the view to increase the probability and the likelihood of exploring effectively with greater perfection characterisation of migrating microplastics from landfill leachate. The leachate raw samples will be collected from selected landfill leachate management plants (ponds) *Fig. 4*, and should be stored at lower temperature (Degree Celsius) for further conveyance to be analysed in the laboratory.

### 3.3 Authors Methodological Summary

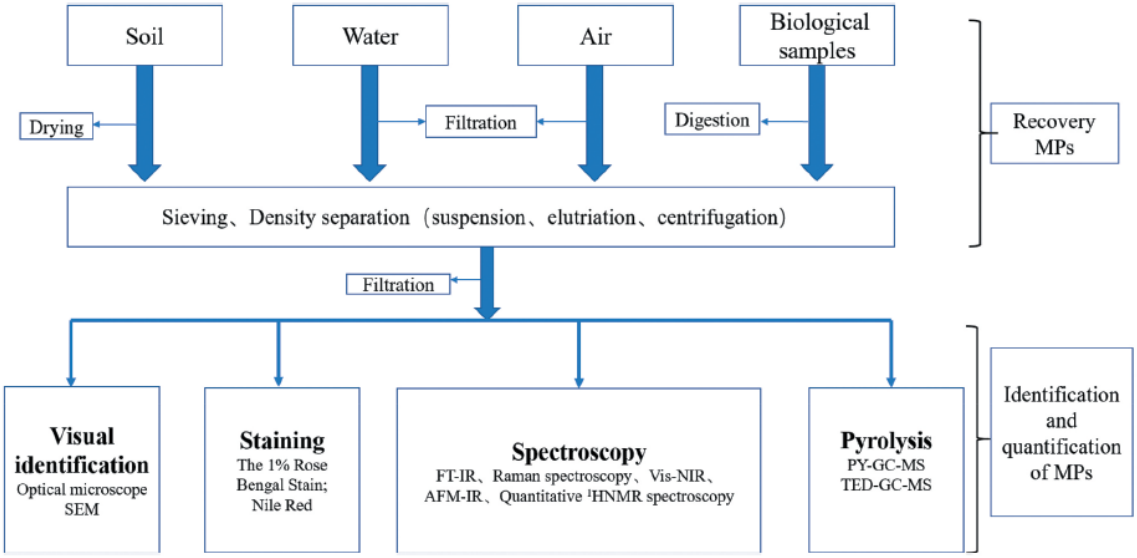


**Figure 3:** Laboratory analysis and methods of characterisation of MPs.

### 3.4 Construction process of MSW LFG and Leachate collection system

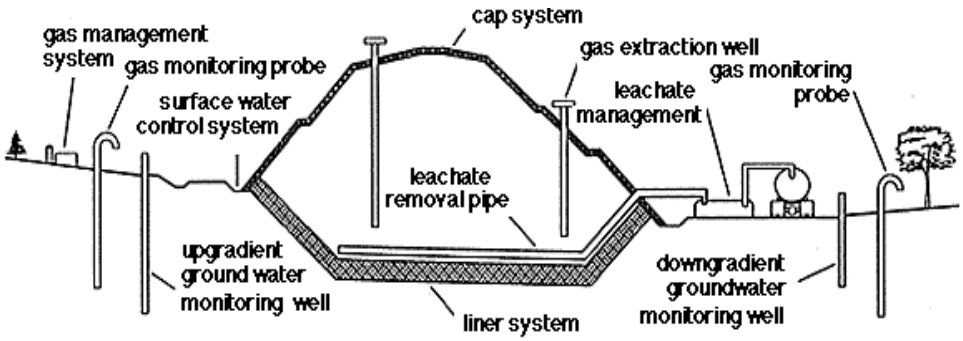


**Figure 4:** Cross section through MSW landfill structure.
**Source:** (Saleh Mamman Abdullahi UK MSc, Research work, 2015)

### 4.0 Results

**Table 1:** Characteristic MSW generation in six (6) Nigerian cities as at 2015

| Waste | Abuja | Kano | Lagos | Maiduguri | Onitsha | Port Harcourt |
|---|---|---|---|---|---|---|
| Glass | 03.000 | 02.000 | 03.000 | 04.000 | 09.200 | 13.500 |
| Metal | 03.400 | 05.000 | 04.000 | 09.100 | 06.200 | 17.200 |
| Paper | 25.300 | 17.000 | 14.000 | 07.000 | 23.100 | 12.400 |
| Plastic | 03.400 | 04.000 | 04.000 | 18.000 | 09.200 | 09.900 |
| Putrescible | 42.600 | 43.000 | 56.000 | 25.800 | 30.700 | 31.000 |
| Textile | 03.300 | 07.000 | - | 03.900 | 06.200 | 07.600 |
| Others | 19.530 | 22.000 | 19.000 | 31.300 | 15.400 | 08.400 |
| **Total (%)** | **100** | **100** | **100** | **100** | **100** | **100** |

**Source:** Compositions of Nigerian wastes. (Igoni et al., 2007; Ogwueleka, 2009; Ayuba et al., 2013 and Saleh Mamman Abdullahi UK MSc, Research work, 2015)

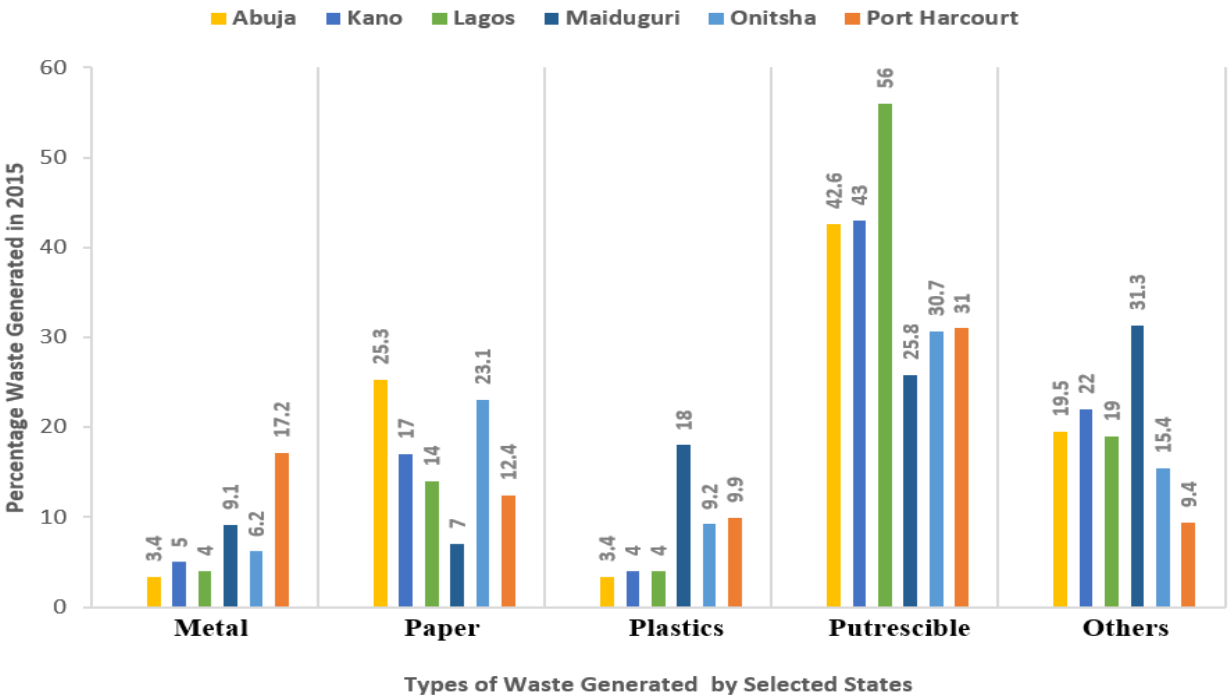


**Figure 5:** Year 2015 percentage of major wastes disposed on Six (6) cities landfills

From the results in *Table 1* above and *Table 2*, it can therefore be deduced, that six (6) major cities out of thirty six (36) cities in Nigeria were used as a reference to assess major waste forms generated on their respective landfill, and these were found to be Glass, Metals, Paper materials, Plastics, Putrescible (biodegradables), Textile materials and Others minor unclassified form of wastes are found on the waste disposal sites in Abuja, Kano, Lagos, Maiduguri, Onitsha and Port Harcourt respectively. Similarly, the result collected for the year ending 2015, putrescible waste forms the bulk of all wastes generated which are; 42.6, 43, 56, 25.8, 30.7 and 31% hence, this constitutes the highest form of wastes found in all the cities landfills. With the paper wastes being second on the table for having 25.3, 17, 14, 07, 23.1 and 12.4% respectively. So also, other form of unclassified wastes general are in third place, for having volume of wastes disposed on sump sites from these cities to be 18.5, 20, 15, 25.3, 15.4 and 08.8%, while plastic generated waste is fourth on the table list, this is also evident in waste generation trend as in *Fig. 5* above.

**Table 2:** Characteristic MSW generation in six (6) Nigerian cities as at 2021

| Waste | Abuja | Kano | Lagos | Maiduguri | Onitsha | Port Harcourt |
|---|---|---|---|---|---|---|
| Glass | 05.000 | 04.000 | 05.800 | 09.000 | 10.300 | 13.900 |
| Metal | 01.000 | 03.000 | 01.200 | 04.000 | 05.100 | 07.100 |
| Paper | 02.100 | 1.000 | 14.000 | 07.000 | 13.000 | 11.200 |
| Plastic | 28.740 | 23.000 | 28.000 | 24.400 | 19.300 | 20.900 |
| Putrescible | 29.600 | 40.000 | 36.000 | 25.600 | 30.600 | 31.000 |
| Textile | 04.300 | 09.000 | - | 03.800 | 06.300 | 07.100 |
| Others | 18.530 | 20.000 | 15.000 | 25.300 | 15.400 | 08.800 |
| **Total (%)** | **100** | **100** | **100** | **100** | **100** | **100** |

**Source: (**Authors R&D 2021)

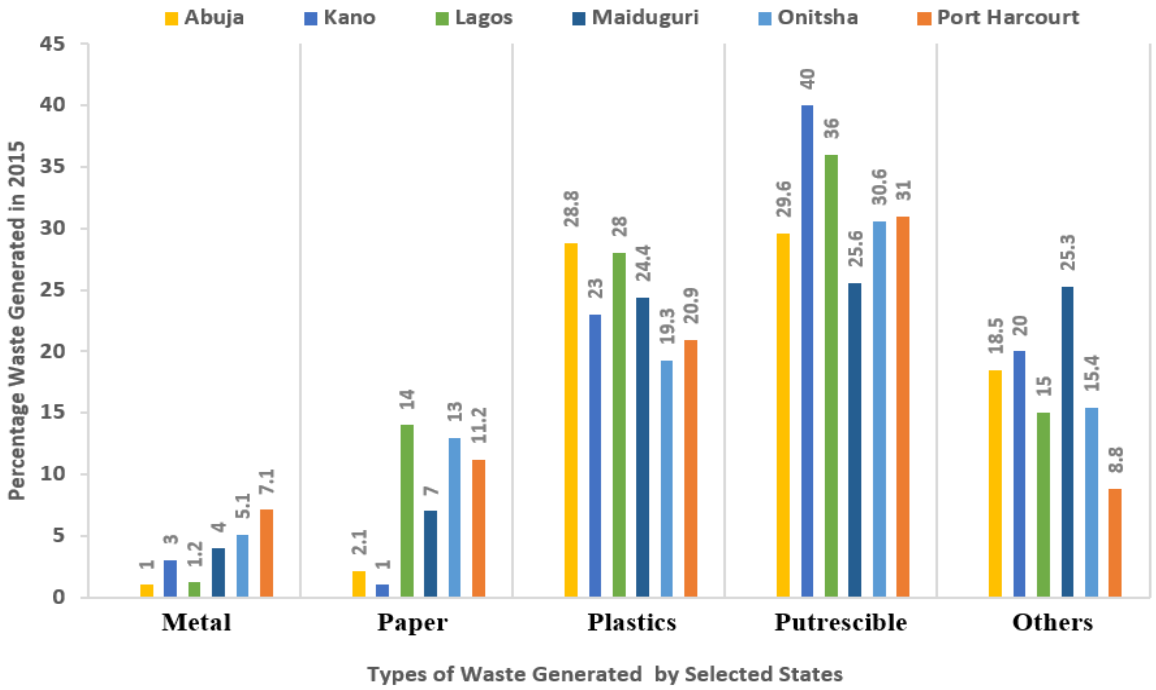


**Figure 6:** Year 2021 percentage of major wastes disposed on Six (6) cities landfills

Furthermore, result collected for the year ending 2021 shows decline in the volume of wastes generated for putrescible, but remain to be the leading waste volume found on the dump sites evident in *Table 2* above with respective volumes to be 29.6, 40, 36, 25.6, 30.6 and 31%. However, the volume of plastic waste recorded an increased volume across the cities for being second place highest volume of wastes generated as found from all the cities dumpsites in the preceding years, 2015 to 2021, with a difference of; 03.4% to 28.7% for Abuja; 04% to 23, 28% for Kano; and 04% to 28% Lagos; similarly 18 to 24.4% for Maiduguri; while 09.2% to 19.3% is for Onitsha and finally 09.9 to 20.9% is for Port Harcourt respectively. From this therefore, it can be said that plastic wastes are increasingly found in all the research landfill, and as it's physically seen littered all around the socio economic environment. This is so, because plastic containers as well as plastic barges are widely used much more than any other materials for both domestic and industrial uses, and in several cases, they end up on the landfills as MAPs and or MPs.

**Table 3:** Common plastic type and their residual end products found as waste on landfills

| Waste plastic | Available as |
|---|---|
| Poly-ethylene terephthalate (PET) | Drinking water bottles etc. |
| High Density Polyethylene (HDPE) | Carry bags, bottle caps, house hold articles etc. |
| Low Density Polyethylene (LDPE) | Milk pouches, sacks, carry bags, bin linings, cosmetics and detergent bottles |
| Poly propylene (PP) | Bottle caps & closures, wrappers of detergents, biscuit etc. |
| Urea formaldehyde | Electrical fittings, handles and Knobs. |
| Polyester resin | Casting, bonding fibbers (glass, Kevlar, carbon fibber) |

**Source: (**Authors R&D 2023)

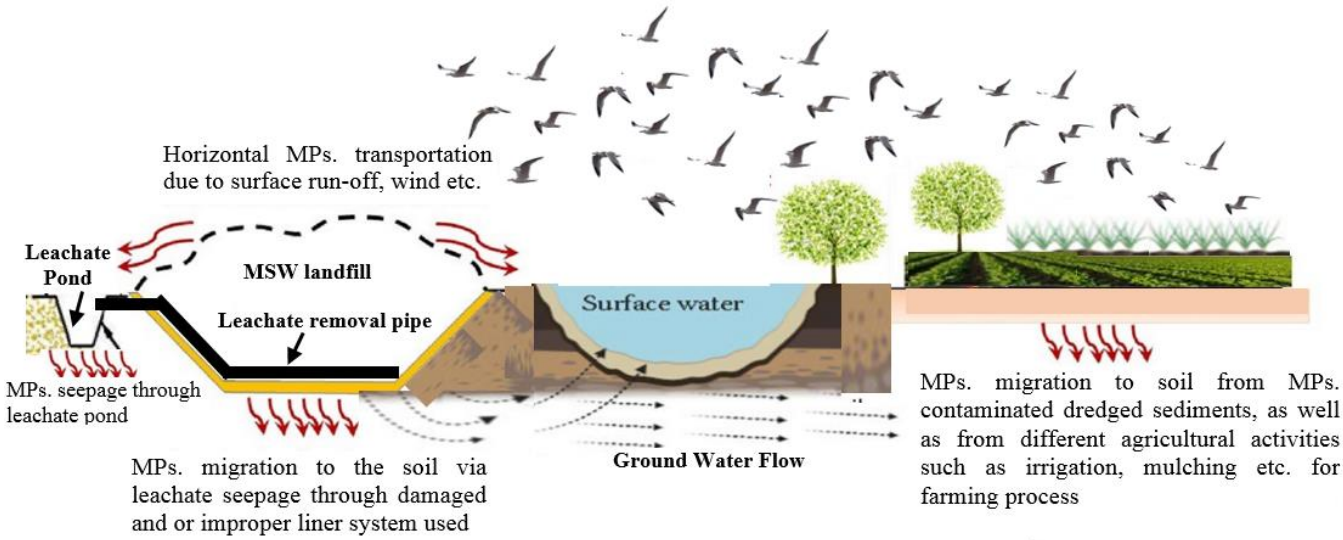


**Figure 5:** MPs. transportation from landfills (seepage, airborne, surface run-off, direct discharge from leachate pond).

**Source: (**Authors R&D 2023)

From *Table 3* above, there are about six (6) major characterisation of plastics commonly used in the manufacture of various plastic material, and at one point of the other such materials end up as wastes on the landfill sites as MAPs. and under certain pressure with time, **these MAPs. starts to breakdown to form MPs. as well as NPs., which subsequently migrates and or are transported from the landfills on to surface water bodies, soils and farmlands through wind abrasion, surface run-off or floods** *Fig. 5*. Similarly the same MPs. and NPs. migrates alongside with leachate via leachate removal pipes which are stored in the leachate interceptor ditch (pond) for collection to undergo treatment at leachate management facilities. However, landfill structures can experience leachate seepage through faulty and or damaged bottom liner, which subsequently gets to pollute the soil within the environment as well as contaminating the available groundwater table (flow) *Fig. 5* above.

Furthermore, both leachate and MPs. are eminent treat to both the existence of human, animal and the ecosystem at large, but when not properly and effectively managed. The conception of wastes on landfill require utmost safety as it undergoes different processes during and after disposal namely; as the waste is being disposed off, formation of MPs. and NPs. are formed under the actions of aerobic stage, to anaerobic stage, through acidification stage, then methanogenesis (biomethanation), with residual leachate containing heavy metals, organic pollutants, as well as the presence of pathogens, and resistance genes, from these super vectors are formed.

## 5.0 Conclusion

MSW refers to the different form of material waste that are dispose off on the landfills, while plastics are one of the constituent waste streams. Plastics are polymer material that can be moulded into different form and shapes under the influence of pressure as well as heat. Plastics on landfills can be found as MAPs, MPs., and as NPs. MPs. are less than 5 mm and or 1 μm by size distribution, and are products of varying chemical compositions, and are associated to several origin sources. The extensively use of plastics as well as its unreasonable disposal, has made MPs. wastes issue to be among current global environmental constrains, owing to its negative ecological threats to the coexistence of the ecosystem.

Furthermore, it can be deduced from this research, that plastic wastes is the second most largest form of waste stream found on most landfills as well as the physical environment, and in view of this, its negative effects cannot be over emphasized. However, landfill structures can experience leachate seepage through faulty and or damaged bottom liner, which subsequently migrates with different forms of MPs. as well as NPs. that gets to pollute the soil within the environment and subsequently contaminates the available surface and groundwater bodies, with which it comes in contact with. Similarly, several sturdies has been undertaking on landfill leachate, but with less focus to examine the characterisations, preventions and control strategies of MPs. as well as NPs. sediments in landfills leachate. Therefore, further sturdies is require to fill this research and or knowledge gaps.

## 6.0 Recommendation

This research work has the following fundamental recommendations as follows:

- The need to holistically invest in MSW renewable energy sources specifically, solids and leachate wastes to drastically reduce the prevalence of contaminating both surface and under-ground water bodies due to MPs, NPs. as well as leachate;
- To encourage and support for effective R&D's towards the utilization of environmental waste streams for renewable energy sources, to cut off the availability of indiscriminate wastes;
- To adopt the use of turning wastes to resources, converting poly-ethylene (PET, HDPE, LDPE etc.) to produce interlocking titles, pavement surfaces among others;
- Similarly, this research work is recommending its use as one of the reference and as an effective tool in global institutions of learning as baseline document for researchers, government, policy makers, stakeholders among other majors to initiate further research into the activities of MPs. and Leachate.

## References

Asakura, H., Matsuto, T. and Tanaka, N. (2004). The behavior of endocrine-disrupting chemicals in leachate from MSW landfill sites in Japan. Waste Manage. 24: 613-622.

Andrady, A.L. (2011). Microplastics in the marine environment. Mar. Pollut. Bull., 62: 1596-1605.

Arthur, C., Baker, J. and Bamford, H. (2008). The occurrence, effects, and fate of microplastic marine debris. Proceedings of the International Research Workshop on Microplastic Marine Debris, September 9-11, 2008, University of Washington Tacoma, Washington, USA, pp. 9-11.

Baderna, D., Maggioni, S., Boriani, E., Gemma, S., Molteni, M., Lombardo, A. and Benfenati, E. (2011). A combined approach to investigate the toxicity of an industrial landfill's leachate: Chemical analyses, risk assessment, and in vitro assays. Environ. Res., 111: 603-613.

Bejgarn S, M MacLeod, C Bogdal, and M Breitholtz. (2015). Toxicity of leachate from weathering plastics: An exploratory screening study with Nitocra spinipes. Chemosphere 132: 114-119.

Bucci K, J Bikker, K Stevack, T Watson-Leung, and C Rochman. (2021). Impacts to larval fathead minnows vary between preconsumer and environmental microplastics. Environmental Toxicology and Chemistry 00: 1-12.

Campanale, C.; Stock, F.; Massarelli, C.; Kochleus, C.; Bagnuolo, G.; Reierscheid, G.; Uricchio,V. (2019). Microplastics and their possible sources: The example of Ofanto river in Southeast Italy. Environ. Pollut. 113284

Cook, T. (2019) How are microplastics transported to Polar Regions? EOS 100.

Corcoran, P.L.; Moore, C.J.; Jazvac, K. (2014). An anthropogenic marker horizon in the future rock record. GSA Today 24, 4–8.

Cormier B, C Gambardella, T Tato, Q Perdriat, E Costa, C Veclin, FL Bihanic, B Grassl, F Dubocq, A Kärrman, KV Arkel, S Lemoine, F Lagarde, B Morin, F Garaventa, M Faimali, Xavier Cousin, M Bégout, R Beiras, and J Cachot. (2021). Chemicals sorbed to environmental microplastics are toxic to early life stages of aquatic organisms. Ecotoxicology and Environmental Safety 208: 111665.

Cowger, W., Gray, A.B., Eriksen, M., Moore, C. and Thiel, M. (2019). Evaluating wastewater effluent as a source of microplastics in environmental samples. In Karapanagioti, H.K. and Kalavrouziotis, I.K. (eds.), Microplastics in Water and Wastewater, IWA Publishing, London, UK, pp. 109-131.

Dave G, and P Aspegren. (2010). Comparative toxicity of leachates from 52 textiles to Daphnia magna. Ecotoxicology and Environmental Safety 73: 1629-1632.

Ficociello G, V Gerardi, D Uccelletti, and A Setini. (2021). Molecular and cellular responses to short exposure to bisphenols A, F, and S and eluates of microplastics in C. elegans. Environmental Science and Pollution Research 28: 805-818

Hartman, N.B., Hüffer, T., Thompson, R.C., Hassellöv, M., Verschoor, A., Daugaard, A.E., Rist, S., Karlsson, T., Brennholt, N., Cole, M. and Herrling, M.P. (2019). Are we speaking the same language? Recommendations for a definition and categorization framework for plastic debris. Environ. Sci. Technol. 2019, 53, 3, 1039-1047

Ishigaki, T., Sugano, W., Nakanishi, A., Tateda, M., Ike, M. and Fujita, M. (2004). The degradability of biodegradable plastics in aerobic and anaerobic waste landfill model reactors. Chemosphere, 54: 225-233.

Jonsson, S., Ejlertsson, J., Ledin, A., Mersiowsky, I. and Svensson, B.H. (2003). Mono-and diesters from o-phthalic acid in leachates from different European landfills. Water Res., 37: 609-617.

J. Kilponen. (2016). Microplastics and Harmful Substances in Urban Runoffs and Landfill Leachates: Possible Emission Sources to Marine Environment, Finnish Environment Institute Lahti University, Appl. Sci.

J.N. Hahladakis, C.A. Velis, R. Weber, E. Iacovidou, P. Purnell, (2018). An overview of chemical additives present in plastics: migration, release, fate and environmental impact during their use, disposal and recycling, J. Hazard Mater. 344 (2018) 179–199, https://doi.org/10.1016/j.jhazmat.2017.10.014.

Kalanatarifard, A. and Yang, G.S. (2012). Identification of the municipal solid waste characteristics and potential of plastic recovery at Bakri Landfill, Muar, Malaysia. J. Sustain. Dev., 5: 11.

K. Duis, and A. Coors, (2016). Microplastics in the aquatic and terrestrial environment: sources (with a specific focus on personal care products), fate and effects, Environ. Sci. Eur. 28 2–25, https://doi.org/10.1186/s12302-015-0069-y.

Kazour, M., Terki, S., Rabhi, K., Jemaa, S., Khalaf, G. and Amara, R. (2019). Sources of microplastics pollution in the marine environment: Importance of wastewater treatment plant and coastal landfill. Mar. Pollut. Bull., 146: 608-618

Krishnan K. J., Kalam A., Zayegh A., (2013) "H2 Optimisation and Fuel Cells Application on Electrical Distribution System and its Commercial Viability in Australia," Heat Transfer Engineering**,** a Taylor and Francis Journal 2013

L. Hou, D. Kumar, C.G. Yoo, I. Gitsov, E.L.W. Majumder, (2020). Conversion and removal strategies for microplastics in wastewater treatment plants and landfills, Chem. Eng. J. 406 126715, https://doi.org/10.1016/j.cej.2020.126715.

Li H, GJ Getzinger, PL Ferguson, B Orihuela, M Zhu, and D Rittschof. 2015. Effects of toxic leachate from commercial plastics on larval survival and settlement of the barnacle Amphibalanus amphitrite. Environmental Science and Technology 50: 924-931.

Lithner D, J Damberg, G Dave, and A Larsson. (2009). Leachates from plastic consumer products – screening for toxicity with Daphnia magna. Chemosphere 74: 1195-1200.

Lithner D, I Nordensvan, and G Dave. (2012). Comparative acute toxicity of leachates from plastic products made of polypropylene, polyethylene, PVC, acrylonitrile-butadiene-styrene, and epoxy to Daphnia magna. Environmental Science and Pollution Research 19:1763-1772.

Luo H, Y Xiang, D He, Y Li, Y Zhao, S Wang, and X Pan.( 2019). Leaching behavior of fluorescent additives from microplastics and the toxicity of leachate to Chlorella vulgaris. Science of the Total Environment 678: 1-9.

Luo H, Y Li, Y Zhao, Y Xiang, D He, and X Pan. (2020). Effects of accelerated aging on characteristics, leaching, and toxicity of commercial lead chromate pigmented microplastics. Environmental Pollution 257: 113475

Ngo, P.L., Pramanik, B.K. and Shah, K. (2019). Pathway, classification, and removal efficiency of microplastics in wastewater treatment plants. Environ. Pollut., 255: 411-431

Oliviero M, T Tato, S Schiavo, V Fernández, S Manzo, and R Beiras. 2019. Leachates of micronized plastic toys provoke embryotoxic effects upon sea urchin Paracentrotus lividus. Environmental Pollution 247: 706-715.

Pivokonsky, M., Cermakova, L.; Novotna, K.; Peer, P.; Cajthaml, T.; Janda, V. (2018). Occurrence of microplastics in raw and treated drinking water. Sci. Total Environ. 643, 1644–1651.

Prata, J.C. (2018). Airborne microplastics: Consequences to human health? Environ. Pollut. 234, 115–126. Int. J. Environ. Res. Public Health 2020, 17, 1212

Rendell-Bhatti F, P Paganos, A Pouch, C Mitchell, S D'Aniello, BJ Godley, K Pazdro, MI Arnone, and E Jimenez-Guri. (2021). Developmental toxicity of plastic leachates on the sea urchin Paracentrotus lividus. Environmental Pollution 269: 115744.

Rezania, S.; Park, J.; Din, M.F.M.; Taib, S.M.; Talaiekhozani, A.; Yadav, K.K.; Kamyab, H. (2018). Microplastics pollution in dierent aquatic environments and biota: A review of recent studies. Mar. Pollut. Bull. 133, 191–208.

Rillig, M.C.; Ingraa, R.; De Souza Machado, A. (2017). Microplastic Incorporation into Soil in Agroecosystems. Front. Plant Sci. 8, 1805.

Seuront L. (2018). Microplastic leachates impair behavioural vigilance and predator avoidance in a temperate intertidal gastropod. Biology Letters 14: 20180453.

Silva PPGE, CR Nobre, P Resaffe, CDS Pereira, and F Gusmão. (2016). Leachate from microplastics impairs larval development in brown mussels. Water Research 106: 364-370

Thompson, R.C., Olsen, Y., Mitchell, R.P., Davis, A., Rowland, S.J., John, A.W. and Russell, A.E. (2004). Lost at sea: Where is all the plastic? Science, 304: 838.

Verschoor, A.J. (2015). Towards a definition of microplastics: Considerations for the specification of physico-chemical properties. RIVM Letter Report 2015-0116, National Institute for Public Health and the Environment, Bilthoven, the Netherlands

Waring, R.H.; Harrisa, R.M.; Mitchell, S.C. (2018). Plastic contamination of the food chain: A threat to human health? Maturitas 115, 64–68.

Webb, H.K., Arnott, J., Crawford, R.J. and Ivanova, E.P. (2013). Plastic degradation and its environmental implications with special reference to poly (ethylene terephthalate). Polymers, 5: 1-18.

Wowkonowicz, P. and Baranski, A. (2013). Release of di (2-ethylhexyl) and dibutyl phthalates from municipal landfills in Poland. Przem. Chem., 92: 2345-2350

Zhou, C., Fang, W., Xu, W., Cao, A. and Wang, R. (2014). Characteristics and the recovery potential of plastic wastes obtained from landfill mining. J. Cleaner Prod., 80: 80-86.

Zimmermann L, S Göttlich, J Oehlmann, M Wagner, and C Völker. (2020). What are the drivers of microplastic toxicity? Comparing the toxicity of plastic chemicals and particles to Daphnia magna. Environmental Pollution 267: 115392