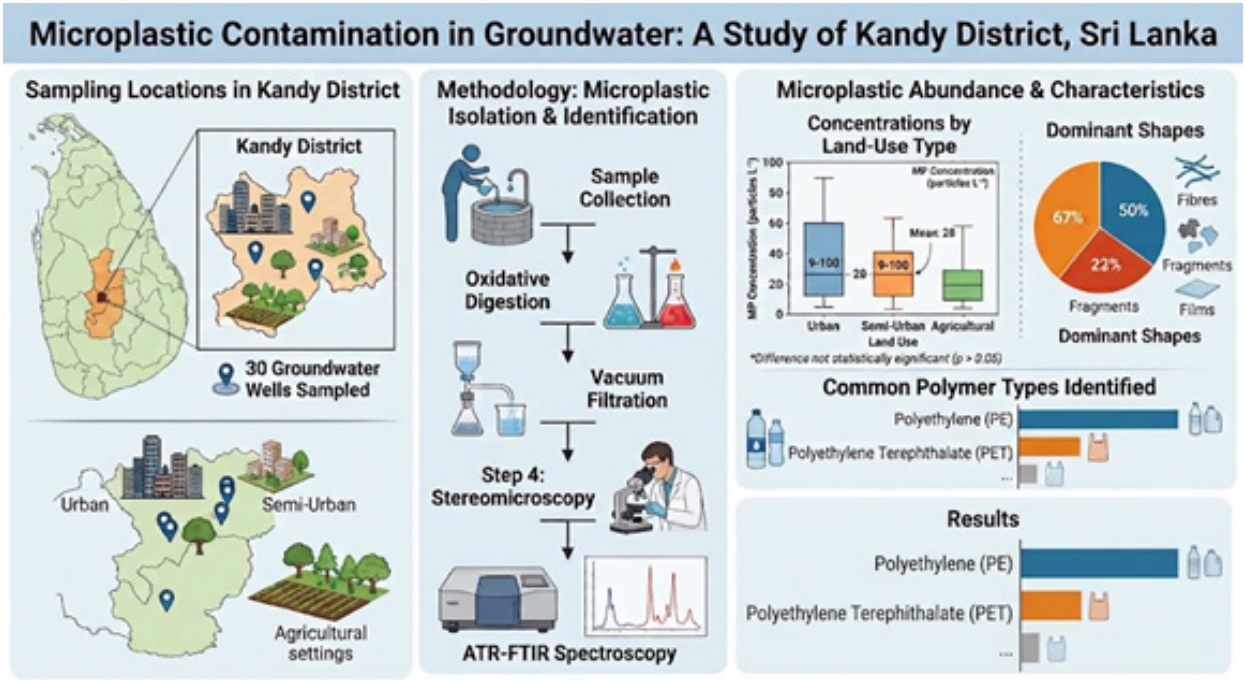
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SHORT COMMUNICATION

Occurrence and Characteristics of Microplastics in Dug-Well Groundwater of the Kandy District, Sri Lanka

A.Y. Chandrasiri, N.C.S. Ruklani, and H.M.S.P. Madawala

Graphical Abstract



Highlights

- Microplastics (MPs) were detected in all dug wells sampled across the Kandy District
- MP concentrations ranged from 9 to 100 particles L^{-1}, with urban wells showing higher contamination levels
- Fibers were the dominant MP shape, followed by fragments and films
- Polyethylene (PE) and polyethylene terephthalate (PET) were the dominant polymers identified by ATR-FTIR
- These preliminary findings highlight the vulnerability of groundwater resources in Sri Lanka to MP contamination and the need for routine monitoring

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SHORT COMMUNICATION

Occurrence and Characteristics of Microplastics in Dug-Well Groundwater of the Kandy District, Sri Lanka

A.Y. Chandrasiri[1], N.C.S. Ruklani[2*], and H.M.S.P. Madawala[2]

[1]*Department of Environmental and Industrial Sciences, Faculty of Science, University of Peradeniya, Peradeniya, Sri Lanka*

[2]*Department of Botany, Faculty of Science, University of Peradeniya, Peradeniya, Sri Lanka*

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Abstract

Microplastic (MP) pollution is an emerging environmental concern, yet groundwater systems remain inadequately studied, particularly in Sri Lanka. Groundwater, which remains under-researched, is the primary drinking water source for some rural and semi-urban areas in the country. This study aimed to evaluate the occurrence, abundance, and characteristics of MPs in groundwater across Kandy District. Thirty wells representing urban, semi-urban, and agricultural settings were sampled. Microplastics were isolated using oxidative digestion and vacuum filtration, identified by stereomicroscopy, and polymer types confirmed using ATR-FTIR spectroscopy. Microplastics were detected in all wells, with concentrations ranging from 9 to 100 particles L^{-1} (mean: 28 particles L^{-1}). Fibres were the dominant form, followed by fragments and films. Urban wells showed higher concentrations than semi-urban and agricultural wells, although differences among land-use categories were not statistically significant ($F = 1.05$, $p = 0.365$). Polyethylene and polyethylene terephthalate were the most common polymers identified. These preliminary findings demonstrate that groundwater in the Kandy District is vulnerable to MP contamination and emphasize the need for routine groundwater monitoring.

Keywords: Dug wells; Groundwater pollution; Kandy District Microplastics; Morphological types

INTRODUCTION

Plastic pollution has emerged as one of the most critical environmental challenges affecting ecosystems worldwide, particularly oceans, freshwater bodies, and soils. Over the past few decades, global plastic production and consumption have increased dramatically due to the material's durability, low cost, lightweight nature, and versatility (Bucknall, 2020). However, inadequate waste management practices, especially open landfill disposal, have resulted in the widespread release of plastic debris into surrounding environments, making landfills significant sources of microplastics (MPs) in freshwater systems.

Microplastics are generally defined as plastic particles smaller than 5 mm that occur in various environmental compartments, including oceans, lakes, soils, and freshwater systems (Thompson et al., 2009). They are broadly categorized as primary and secondary MPs. Primary MPs are intentionally manufactured in small sizes for use in products such as cosmetics, personal care items, and healthcare products, whereas secondary MPs originate from the fragmentation of larger plastic materials through processes such as ultraviolet (UV) radiation, weathering, wind, wave action, and biological activity. Secondary MPs are generally considered more abundant than primary MPs in most environmental compartments (Tibbetts et al., 2018; Samandra et al., 2022).

Microplastics originate from both terrestrial and marine sources, although approximately 80% are derived from land-based activities (Kosior & Crescenzi, 2020; UNEP, 2005), emphasizing the importance of terrestrial waste mismanagement in global MP pollution (Rashid et al., 2025). MPs can enter groundwater through multiple interconnected pathways, including surface runoff, atmospheric deposition, agricultural inputs such as compost and fertilizers, wastewater effluents, landfill leachate, sewage infiltration, and percolation through porous soils or fractured rock formations (Lee et al., 2024; Panno et al., 2019; Selvam et al., 2020). Although MP contamination has gained much attention lately as an emerging environmental concern, groundwater environments remain far less studied than marine and terrestrial environments (Hurley & Nizzetto, 2018; Lee et al., 2024). Global reviews on the topic of groundwater contamination by MPs have identified

**Corresponding Author's Email: sumudur@sci.pdn.ac.lk*
https://orcid.org/0000-0003-4330-6766

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this problem as a new area with possible implications for the quality of drinking water and human health (Lee et al., 2024; Rajan et al., 2024; Hoang et al., 2025). For instance, Lee et al. (2024) carried out a systematic review of 24 studies on groundwater MP contamination and concluded that MP contamination is wide-spread, from 0 to 6,832 particles L^{-1}, although groundwater has been explored considerably less than surface water and marine environments. Moreover, Hoang et al. (2025) pointed out that there is still insufficient knowledge about the transport and fate of MPs in groundwater and about the risks of groundwater contamination by MPs, especially in tropical environments. In the case of Sri Lanka, there are currently no studies on the occurrence of MPs in groundwater of dug wells in Kandy District.

In tropical regions, groundwater is a vital resource for drinking water supply and agricultural production, underpinning human well-being and economic development (Indika et al., 2022). In Sri Lanka, approximately 80% of the rural population depends on groundwater for household purposes (Herath & Ratnayake, 2007; Villholth & Rajasooriya, 2009). Groundwater utilization has expanded significantly, particularly in the dry zone, where dug wells (36.4%) and tube wells (3.2%) serve as major water sources (NWSDB Annual Report, 2017). However, the increasing prevalence of MP pollution, together with the lack of systematic monitoring, poses a growing threat to groundwater security. Exposure to MPs has been associated with potential adverse health effects, although many mechanisms remain under investigation (Prata et al., 2020; Minh-Ky et al., 2023).

The Kandy District, located in the central highlands of Sri Lanka, is both densely populated and ecologically significant, with widespread dependence on groundwater resources. High rainfall, steep topography, urbanization, and inadequate waste management infrastructure contribute to increased plastic waste accumulation and create favorable conditions for MP transport into aquifers. Despite these concerns, research on groundwater MP contamination in Sri Lanka remains extremely limited. Therefore, the present study aims to investigate MP contamination in selected dug wells within the Kandy District under different land-use settings. Specifically, the study evaluates the abundance, types, and physical characteristics of MPs and examines their distribution patterns and potential sources of contamination.

MATERIALS AND METHODS

Description of the Study area

The study was carried out in selected locations in the Kandy District, Sri Lanka. A total of 30 dug wells were selected from Kandy city and its surrounding suburbs (Figure 1). These wells (10 wells from each category) were classified into three categories urban (UR), semi-urban (SU), and agricultural (AG) based on the characteristics of their immediate surroundings, rather than the larger geographical area (Table 1).

Table 1: Classification of dug wells based on their immediate surroundings

Categories	Site IDs	Description of immediate surroundings
Urban (UR)	UR1-UR10	Dense residential and commercial features in close proximity to the well
Semi-urban (SU)	SU1-SU10	Mixed village settings with moderate residential activity
Agricultural (AG)	AG1-AG10	Wells located within or adjacent to paddy-cultivated fields

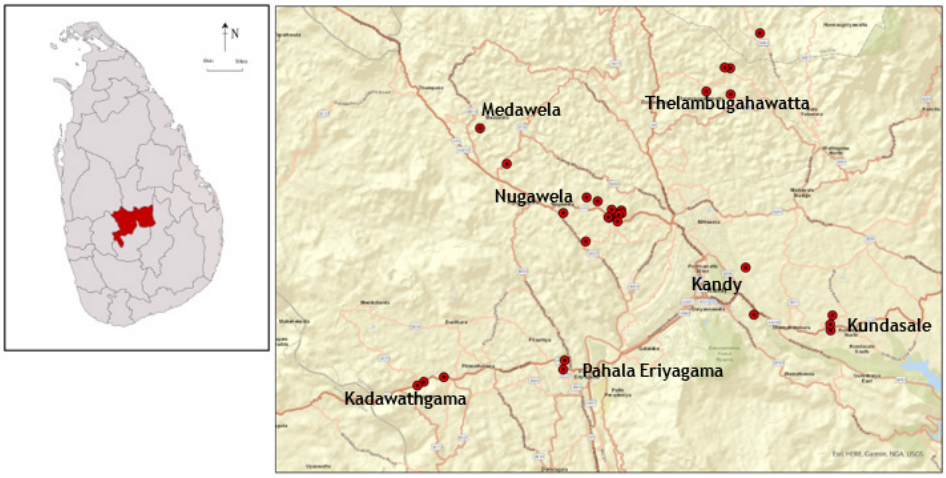


Figure 1: Geographic distribution of sampling locations in Kandy District, Sri Lanka. The inset map (left) highlights the study area within the country (red). The main map (right) shows the 30 dug wells sampled (red dots). Well categories (urban, semi-urban, agricultural) and corresponding well IDs are detailed in Table 1

Sample collection

All groundwater samples were collected in pre-cleaned 500 ml amber glass bottles, and water samples were collected approximately 5 m below the water surface where well depth permitted. All dug wells selected for the study were properly lined with bricks and cement along the interior walls. For each dug well, triplicate water samples were collected on the same day during each sampling event conducted between March and August 2025. The use of triplicate samples improved measurement reliability and reduced random analytical variability. Collected samples were immediately stored at 4°C prior to the analysis to preserve their physicochemical integrity and prevent chemical or biological changes.

Sample preparation and pre-treatment

Microplastics were isolated using oxidative digestion to remove organic matter that could interfere with MP detection. The samples were treated with a 30% hydrogen peroxide (H_2O_2) solution at 50 °C and incubated for 48 hours. Following digestion, the samples were filtered through 0.45 µm glass fibre filter paper using a vacuum filtration system. This filtration step limited the analysis to microplastic particles ≥0.45 µm; smaller particles (including nanoplastics) were not retained and were therefore not quantified in this study. The filter papers were then placed in a desiccator for cooling and preservation prior to subsequent quantification and identification.

Identification and characterization of Microplastics

Shape, color, and abundance

The color, shape (fibre, fragment or film), and abundance of MPs were recorded by examining the filter papers under a stereomicroscope. Recovered MPs were imaged and visualized using a Zeiss stereomicroscope equipped with an Axiocam 208 color camera. Image capture and processing were performed using Zen 3.1 (Blue Edition) software, which enabled detailed observation and accurate documentation of the MP particles.

Polymer identification and validation

Representative MP samples were analyzed using Fourier Transform Infrared Spectroscopy in Attenuated Total Reflectance mode (ATR-FTIR; JASCO FTIR 6700). The resulting spectra were compared with reference spectral libraries, including the JASCO polymer library and published reference spectra (Jung et al., 2018; Käppler et al., 2016; Primpke et al., 2018) to identify the chemical composition and determine the polymer types of the MPs. Peak assignments were further validated against published FTIR data for PET and PE (Liang et al., 2021; Hummel, 2002; Socrates, 2001).

Data Analysis

One-way analysis of variance (ANOVA) was done in order to compare the abundance of MPs across the three categories of dug wells. Post-hoc mean separation was performed using Tukey's test. All statistical analyses were done using the Minitab 22 software, with $\alpha = 0.05$ as the significance level. No tests of assumptions of normality and homogeneity of variances were done in this study.

RESULTS AND DISCUSSION

Microplastic abundance across dug wells

As shown in Figure 2, across all 30 dug wells sampled, total MP abundance ranged from approximately 9 to 100 particles L^{-1}, with a mean concentration of 28 particles L^{-1} (SD = 12.24). The highest MP abundance was recorded at UR5, a community dug well located close to a busy road (Kandy – Colombo road), which contained an average of 100 particles L^{-1}. In contrast, the lowest abundance occurred at SU8, with only about 9 particles L^{-1}.

There were significant differences in MP levels among individual dug wells (one-way ANOVA using Well_ID as factor: $F = 13.59$, $p < 0.001$), suggesting that MP levels are significantly different among individual wells. However, when wells were categorized according to their land-use, there were no significant differences among urban, semi-urban, and agricultural wells (one-way ANOVA using Category as factor: $F = 1.05$, $p = 0.365$). This suggests that while there are significant differences among wells in terms of MP pollution, land use does not significantly explain such differences. Though the concentrations of MPs were highly variable among the wells, the MP concentration did not differ statistically across all land-use types. It can thus be concluded that site-specific determinants such as the waste disposal system, condition of the wells, and proximity to highways, landfills, and agricultural sites have a greater influence on the MPs in groundwater than the land-use type itself. Such findings have been reported in previous studies concerning groundwater (Lee et al., 2024). Furthermore, the values are comparable to those reported in regional studies in South India (approximately 2–80 particles L^{-1}), indicating that groundwater in the study area experiences similar levels of MP contamination under mixed urban and agricultural influences (Natesan et al., 2021). MP presence in the samples from groundwater collected in Delhi, India, with the concentrations varied between 2 to 28 particles per litre (mean 14 ± 6.53 particles per litre), with obvious spatial variation in landfill, industrial, and residential areas (Tripathi et al., 2026). The higher mean concentration in Kandy urban wells (50 particles per litre; 9-100) compared with that in Delhi (14 particles per litre; 2-28) can be attributed to variations in the waste disposal practices (e.g., dumping and burning in Kandy), well types (dug wells in Kandy *vs.* tube wells in Delhi), hydrogeological regime (high precipitation and shallow aquifers in Kandy), and analytical techniques.

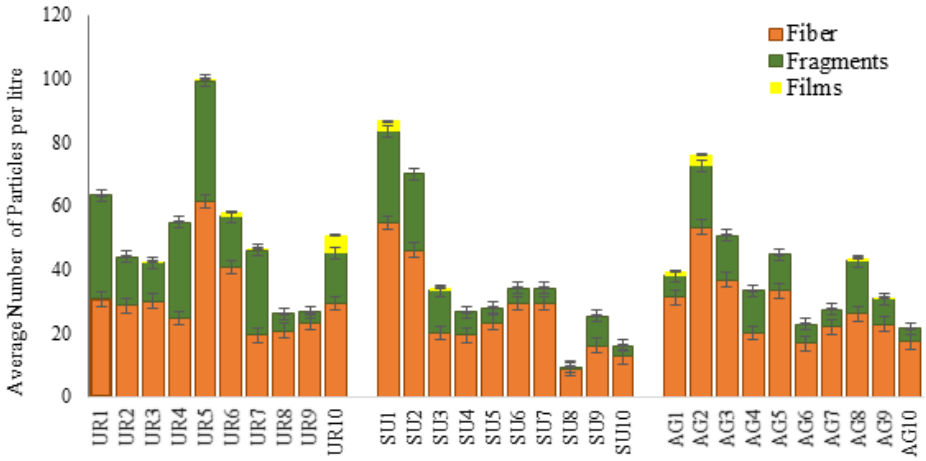


Figure 2: Average number of microplastic particles per litre in different dug wells, categorized by well type, Urban (UR1 – UR10), Semi-urban (SU1 – SU10), and Agricultural (AG1 – AG10). The data is presented in three categories: fibers (orange), fragments (green), and films (yellow). Error bars represent the Standard Error of the Mean (SEM). The averages are based on 3 samples (n = 3) for each dug well

Spatial distribution of MPs across dug well categories

Dug wells situated in urban surroundings exhibited the highest mean MP concentration (51.3 particles L^{-1}), followed by wells in agricultural surroundings (39.0 particles L^{-1}), while the lowest concentrations were observed in semi-urban surroundings (36.4 particles L^{-1}) (Figure 2).

Variations among individual wells despite no significant differences in land-use types indicate that individual site characteristics rather than general land use could be more important determinants of groundwater MP contamination. These factors include local waste disposal practices (open dumping, open burning, leaching from landfills), presence of point source contamination (traffic roads, markets, industry, etc.), well characteristics, land use at the immediate vicinity, surface contaminant migration to groundwater through the aquifer's hydro-connectivity, and atmospheric MP deposition. Within-category variations in this study (urban wells varying from about 10 to 100 particles L^{-1}) reinforce this interpretation. Lee et al (2024) made similar observations in their studies related to groundwater. Since this study applied 0.45 µm filter paper for sample preparation, we were only able to analyze MP particles that are >0.45 µm. Comparison with other studies must then be done cautiously since the particle size detection limit will greatly affect the results.

The elevated MP concentrations observed in urban wells are likely linked to the greater intensity of human activities and the accumulation of plastic waste in densely populated areas. In the Kandy District, the following particular local sources that may be responsible for the contamination of MP are: (i) The Kandy municipal waste dump which is fed with mixed plastic waste, which will generate MP-contaminated leachate that could contaminate wells in the vicinity (Fatta et al., 1999; Hui et al., 2020); (ii) The Kandy-Colombo road which is a major road in the area and hence has high traffic volume, and hence, MPs resulting from tire abrasion and plastic litter will contaminate roadside soil and ultimately groundwater (Hale et al., 2020); (iii) The Mahaweli river and its tributaries which receive untreated domestic wastewater that recharges shallow groundwater (Barchesi et al., 2021); and (iv) The open dumping and burning of plastic waste at various open sites both residential and commercial. This is a common practice in the study area (Li et al., 2021).

Agricultural wells exhibited intermediate MP concentrations, reflecting the widespread use of plastics in modern farming practices. Sources include the degradation of plastic mulch films, irrigation infrastructure, greenhouse coverings, and the application of compost or organic amendments containing plastic residues. Once introduced into agricultural soils, MPs may be transported downward through infiltration associated with rainfall and irrigation, potentially reaching groundwater (Hoang et al., 2025). Surface runoff, drainage networks, and nearby streamlets may further facilitate the transfer of MPs from agricultural lands into subsurface environments (Ma et al., 2020). Atmospheric deposition is a common process that could cause MP contamination in soils irrespective of their land use – whether urban, semi-urban, or agricultural (Manikanda Bharath et al., 2021; Zhang et al., 2025). In urban and semi-urban soils, the deposition of MPs from textiles and tire wear would be of importance because of the higher traffic and human presence (Hale et al., 2020). In agricultural soils, atmospheric deposition could be one of the factors contributing to soil MPs, alongside plastic mulches, irrigation systems, and composting (Zhang et al., 2025). In all cases, deposited MPs would accumulate in topsoil and might be transferred into groundwater through infiltration (Hoang et al., 2025).

Semi-urban wells recorded the lowest mean MP concentrations, although this difference was not statistically significant, likely reflecting lower population

densities, reduced waste generation, and less intensive land-use activities. Nevertheless, the presence of MPs in all sampled wells indicates that contamination is not restricted to heavily urbanized locations and may occur through regional transport pathways, atmospheric deposition, or hydrological connectivity between land-use types. From the above findings, it is apparent that the land use could affect MP contamination in groundwater, but the differences between the categories are not statistically significant. The site-specific factors could hence play a greater role than the general land use. Despite no statistically significant difference in concentrations among land uses, urban wells had the highest average MP concentration of 50 particles L^{-1}, and this could be attributed to factors specific to the Kandy District, including: (i) open dumping and burning of plastic waste, which is commonly done in residential and commercial areas in Kandy and contributes to the contamination of the surrounding soil; (ii) leachate of the Kandy municipal waste dump, which contaminates the neighboring wells; (iii) plastic and tire fragments on the road between Kandy and Colombo due to traffic; (iv) grey water and domestic wastewater discharges of households and businesses to the surrounding soils; and (v) shallow well construction in Kandy, where most dug wells are shallow and made of bricks and cement, which may have cracks that allow surface contamination to reach them (Panno et al., 2019; Indika et al., 2022). The highest MP concentration (100 particles L^{-1}) was measured in UR5, an excavated well near the Kandy-Colombo road, indicating the significance of the local point source over the broad land use category.

Characterization of MPs by shape and colour

Microplastics were grouped into three shape categories: fibres, fragments, and films since foams and pellets were absent from the samples. Results showed a clear dominance of fibre-type MPs across all categories of dug well samples (67%), followed by fragments (32%) and films (1%).

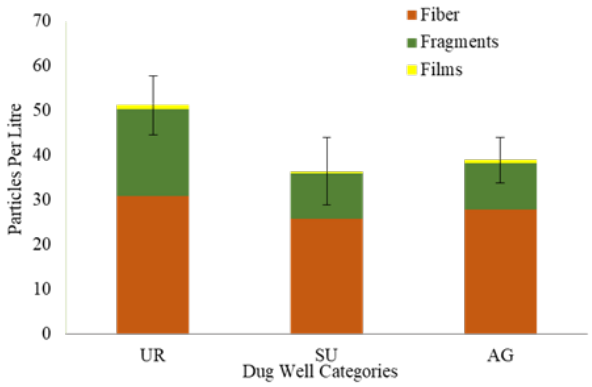


Figure 3: Stacked bar chart showing the average concentration of microplastic shapes (fibers, fragments, films) in groundwater from urban (UR), semi-urban (SU), and agricultural (AG) dug wells. Error bars represent the standard error of the mean (SEM; n = 3 per well)

Across all land-use types, fibre-type MPs were predominantly blue, followed by red and white, with black being minimal or absent. Fragment-type MPs showed greater variation, with red and yellow dominating in semi-urban and agricultural areas, while urban samples displayed a more balanced distribution among colours. Prevalence of blue and red fibres was evident in all three land uses, which could be due to the widespread use of synthetic textiles since laundry processes and effluents from grey water washing were witnessed near the wells at the time of sampling. Blue and red are the popular colours used in clothes and domestic textiles in the Kandy district area, and synthetic textile washing has been shown to be an important source of microfibres in the environment (Boucher & Friot, 2017). Fragment type MPs had more diversity in colours between land uses. Similar colours in fibres and fragments suggest common anthropogenic sources mainly household plastic products and textiles-related activities, although differences in colour proportions across dug-well categories also indicate not only shape-dependent sources but also their varying degradation processes (Manikanda Bharath et al., 2021).

Polymer Identification (FTIR Analysis)

The FTIR spectra of the representative samples exhibit characteristic absorption bands consistent with polyethylene terephthalate (PET) and polyethylene (PE) (Hummel, 2002; Jung et al., 2018; Käppler et al., 2016; Liang et al., 2021; Socrates, 2001) (Figure 5a and 5b).

Figure (a) shows a strong and sharp peak at approximately 1710 cm^{-1}, corresponding to the ester carbonyl (C=O) stretching vibration, a key diagnostic feature of PET. Additional absorption bands near 1230 cm^{-1} and 1091 cm^{-1} are attributed to asymmetric and symmetric C–O stretching vibrations of the ester linkage, confirming the polyester structure. Aromatic ring vibrations observed between 1400 cm^{-1} and 725 cm^{-1}, including aromatic C=C stretching and out-of-plane C–H bending modes, indicate the presence of terephthalate units. Collectively, these spectral features provide strong evidence for the identification of PET.

Figure 4(b) exhibits strong peaks at approximately 2913 cm^{-1} and 2850 cm^{-1}, which correspond to the asymmetric and symmetric stretching vibrations of methylene (CH_2) groups, which are characteristic of long, linear hydrocarbon chains typical of polyethylene (PE), particularly high-density polyethylene (HDPE). Additional diagnostic bands at 1470–1460 cm^{-1} (CH_2 bending) and 730–720 cm^{-1} (CH_2 rocking) further confirm the presence of crystalline polyethylene. The absence of other functional group absorptions supports the identification of PE microplastics. Overall, FTIR analysis revealed two dominant polymer types, polyethylene terephthalate (PET) and polyethylene (PE), among the analyzed samples. PE is widely used in packaging and agricultural applications, while PET is commonly associated with beverage bottles and synthetic textiles. These findings align with previous studies reporting PE and polypropylene (PP) as the most

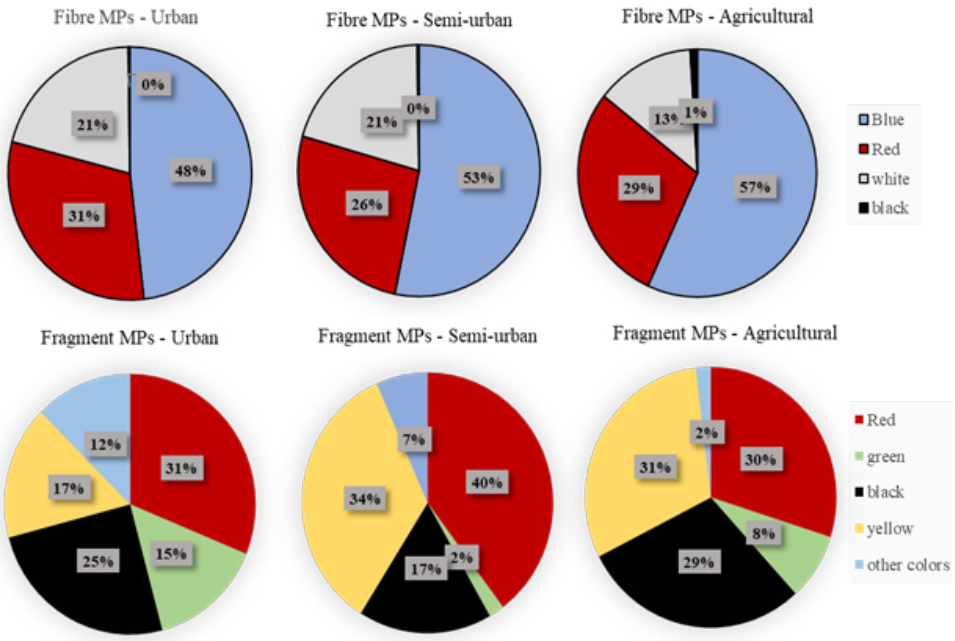


Figure 4: Percentage distribution of colour categories of fibre and fragment microplastics detected in dug wells located in urban, semi-urban, and agricultural surroundings in the Kandy District, Sri Lanka

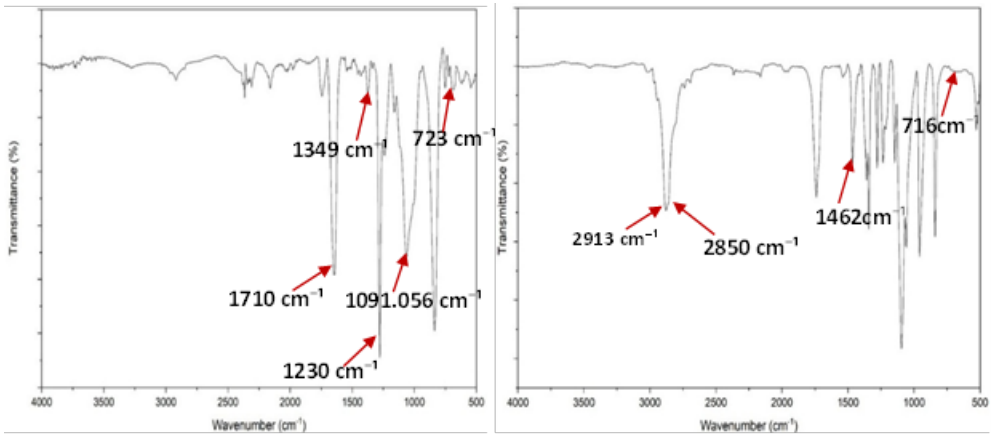


Figure 5: FTIR spectra of representative microplastic particles: (a) polyethylene terephthalate (PET) and (b) polyethylene (PE). Key diagnostic peaks are annotated. Spectra are representative of the dominant polymer types identified across the sampling sites

prevalent MPs in groundwater and other environmental compartments (Walker-Franklin et al. 2026), raising environmental concerns due to their high production volumes and ability to adsorb trace metals and contaminants (Colmenarejo et al., 2024). The hydrogeological factors were not quantified in the current study, such as well depth, depth to groundwater table, permeability of soil, or rate of infiltration. Thus, the actual pathways for the migration of MPs into the groundwater in the Kandy District could not be conclusively identified. It is hence important to understand that the concepts of percolation, infiltration, and hydrogeological connectivity outlined here are only preliminary in nature. Future studies should incorporate hydrogeological measurements; including well depth, depth to water table, soil permeability, and groundwater flow direction to better understand the mechanisms of MP transport into groundwater systems.

CONCLUSIONS

Microplastics were present in all dug wells (9 to 100 particles L^{-1}), with fibres as the most prevalent morphology. The prevalence of blue and red fibres indicates that synthetic textiles and laundry effluent are probably the primary sources of MP pollution, as synthetic fabrics and washing of clothes are common in the region. Open dumping and open burning of mismanaged plastic waste could be other possible sources of MPs, especially for fragments and films. Even though urban dug wells had significantly high average MP concentrations compared to semi-urban and agricultural dug wells, there was no significant difference between the three categories of dug wells. Variations between the sampled sites were higher compared to variations between the categories of dug wells. FTIR analysis confirmed the presence of common synthetic polymers, including PET

and PE. However, the absence of hydrogeological data (e.g., well depth, depth to water table, soil permeability) limits our ability to identify the specific transport pathways by which MPs enter groundwater. Overall, this the first reported assessment of groundwater microplastics in the Kandy District demonstrates that groundwater sources in the district are vulnerable to MP pollution, emphasizing the need for targeted monitoring, site-specific management interventions, and the development of effective strategies to mitigate groundwater contamination.

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DECLARATION OF CONFLICT OF INTEREST

The authors declare no conflict of interest.

FUNDING INFORMATION

The work was supported using resources available through existing research projects of the Principal Investigators.

AUTHOR CONTRIBUTION

Conceptualization: **N.C.S.R., H.M.S.P.M.;** Data curation and investigation: **A.Y.C.**; Statistical Analysis: **A.Y.C.;** Data Interpretation: **A.Y.C., H.M.S.P.M., N.C.S.R.;** Writing the original draft: **A.Y.C.,** Manuscript editing and reviewing: **H.M.S.P.M., N.C.S.R.**

DATA AVAILABILITY STATEMENT

The dataset generated during the current study are not publicly available, but are available from the corresponding author on reasonable request.

DECLARATION OF GENERATIVE AI AND AI-ASSISTED TECHNOLOGIES IN THE MANUSCRIPT PREPARATION PROCESS

During the preparation of this work, the authors used ChatGPT in order to assist with language editing and toning. After using this tool/service, the authors reviewed and edited the content as needed and take full responsibility for the content of the published article. Gemini AI was used to assist in the creation of the graphical abstract.

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