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Microplastic pollution in the surface water of Yele Mallappa Shetty Lake, Bengaluru: First report

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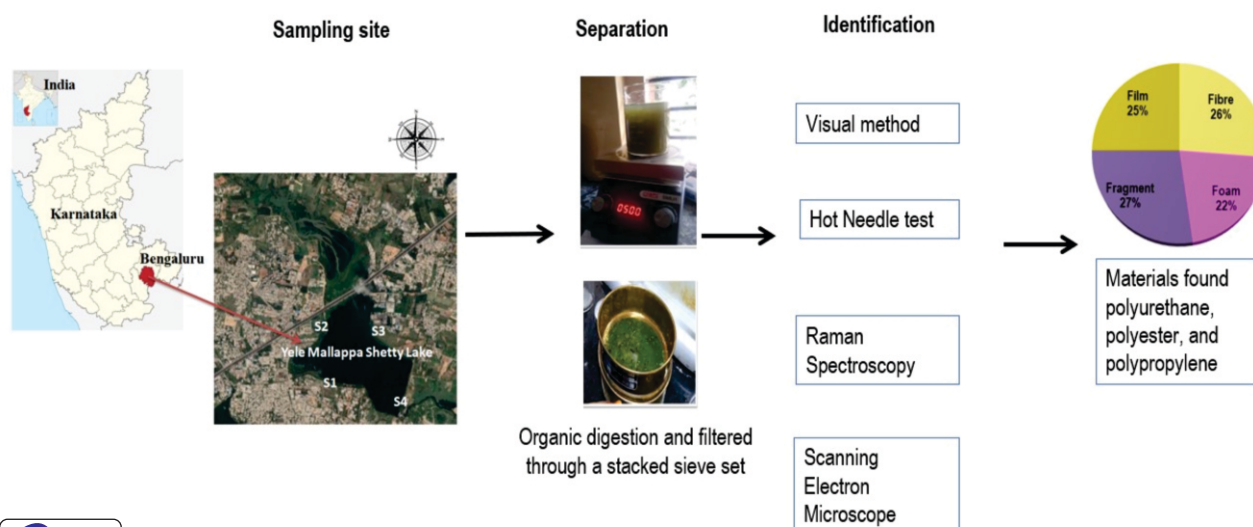
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Abstract

Aim: This study was conducted to identify and characterize microplastics in Yele Mallappa Shetty (YMS) Lake, Bengaluru.**Methodology:** Water samples were collected from four distinct entry locations to the lake and analysed for microplastic as per the methods adopted by the National Oceanic and Atmospheric Administration (NOAA).**Results:** Samples of three different microplastic foams—polyester, polyurethane, and polypropylene—were analysed using scanning electron microscopy (SEM), visual analysis, hot needle testing and Raman spectroscopy. The diameters of various components ranged from 0.2-3 mm, with the majority of the samples consisting of fibres (26%), fragments (27%), films (25%) and foam (22%). The mean concentration of microplastic recorded in the water sample was 10 ± 0.7 particles l⁻¹.**Interpretation:** Protecting wetland ecosystems is essential because they provide countless services, such as food and building materials, biodiversity, flood control, and groundwater recharge. This study provides valuable baseline data on microplastics in YMS lake for the first time.**Key words:** Bengaluru lake; Lake water, Microplastic pollution, Water pollution, Yele Mallappa Shetty Lake

Introduction

Over the past four decades, the worldwide production of plastic has increased from 50 to 370 million metric tons. Plastic pollution in the ocean today could be due to the \$600 billion global industry which contributes to approximately 8 million metric tons of plastic entering the oceans each year (Rouch *et al.*, 2021). Currently, 71% of plastic waste is absorbed directly by the environment (Dey *et al.*, 2021). Over time, non-degradable plastics in the environment erode and break down into nanoplastics and microplastics. In 2004, 20 µm microplastic particles have been identified as pollutants (Thompson *et al.*, 2004). In 2009, the National Oceanic and Atmospheric Administration (NOAA) defined microplastics as plastic particles less than 5 mm in size (Arthur *et al.*, 2009). Based on the SI units, microplastics are currently defined as ranging from 1 µm to 5 mm (Hartmann *et al.*, 2019). Recent studies suggest that microplastics are transported by wind, which could lead to deposition on land or in water bodies. Because of these plastic pollutants transport, source-sink dynamics are strongly affected in terrestrial and marine ecosystems (Van Colen *et al.*, 2021).

Microplastics are prevalent in diverse environments, including urban and rural settings, indoors and outdoors, spanning from soils to aquatic ecosystems, and even within the digestive tracts of vertebrates and invertebrates (Bank *et al.*, 2019; Zhang *et al.*, 2020). This indicates that plastic pollution is endangering aquatic animals, entering the food chain, and adversely affecting human health. Therefore, pollution of the entire aquatic ecosystem poses a significant threat to the health of both aquatic and terrestrial organisms. Lakes are inland bodies of water that do not exchange water directly with the ocean. In fact, lakes are a valuable water resource for agriculture, households, and livestock. However, the present study area in Bengaluru, one of fast-developing India's southern states, does not have perennial rivers to supply piped water. Hence, in 16th century, Kempegowda, the founder of Bengaluru, Wodeyar of Mysore and the British have built about 280 lakes throughout the city of Bengaluru. The lake water has been supplied for subsistence activities including agriculture, raising livestock and fishing, as well as for drinking, bathing and washing. These lakes have also influenced the microclimate and rejuvenated the groundwater (Thippiah, 2017). But today only 17 lakes remain while the rest have been encroached unauthorisedly, dried up, or leased to government agencies (Hamsa *et al.*, 2020) or used to dumping waste.

This study focuses on one of the largest lakes constructed by Yele Mallappa Shetty, a Bengaluru merchant in the 19th century to address the water crisis. Yele Mallappa Shetty Lake provides food and shelter for migratory birds and serves as a life support system for many organisms. The water in this lake has been polluted due to the increasing use of metal-based fertilizers, household cleaners and industrial chemical effluents. A study conducted to determine heavy metal accumulation in the water and gill tissue of *L. rohita* reared in Yele Mallappa Shetty Lake

indicates the presence of heavy metals (Noor *et al.*, 2016). In another study, it has been reported that irrigating with this lake water in and around Bengaluru causes the soils and crops to accumulate heavy metals above permissible levels, thereby rendering the crops unsuitable for consumption (Hamsa *et al.*, 2020).

Water quality assessment viz., temperature, pH, turbidity, TDS, etc., and chemical tests such as BOD, COD, dissolved oxygen, alkalinity, hardness and characters show that Yele Mallappa Shetty Lake is graded 'E' due to poor water quality index (Noor *et al.*, 2016). Henceforth, Chandan *et al.* (2014) have shown that the maintenance of Yele Mallappa Shetty Lake and taking care of drainage lines along with developmental activities is essential to prevent ground water contamination. In addition, studies indicate microplastics are emerging contaminants in aquatic ecosystems and it has been studied in different lakes around the world (Irfan *et al.*, 2020; Malla-Pradhan *et al.*, 2022). Apart from, a part from inorganic and organic pollutants, plastic pollution is becoming increasingly prevalent in the aquatic environments, which needs to be addressed and which help in finding mitigation policies. Therefore, the main objective of the study is to identify the microplastic pollutant present in the surface water of the lake and further characterize it to determine its source. This study could provide valuable baseline data on microplastic pollutants in Yele Mallappa Shetty Lake for the first time.

Materials and Methods

Study Area: Yela Mallappa Shetty Lake (13°01'24.6"N 77°43'45.2"E) lies in North-East of Bengaluru city, of Karnataka state, India (Fig. 1). It is one of the largest lakes in Bengaluru city spread over 260 acres constructed in the early 1900s (Reddy *et al.*, 2015). The urbanized area covers the town places like satellite town Yalahanka in the North; Hebbal in the south-east and Krishnarajapuram in the west within the Bruhat Bengaluru Mahanagara Palike boundary (Chandan *et al.*, 2014). Yele Mallappa Shetty Lake is a part of the Hebbel Valley watershed, surrounded by Medahalli on the east, Avalahalli and Veeranahalli in the west, Old Madras Road in the south and Doddabanhalli on the eastern side. The Old Madras Road slashes the Yele Mallappa Shetty Lake in half, severing this region's Raja Kaluve system. Through Hebbal, Nagavara, Kalkere, and Maragondanahalli, the link runs into Yele Mallappa Shetty Lake but is interrupted by the highway (Reddy *et al.*, 2015).

The lake has 5 inlets and the details are shown below: (a) Overflow of Rampura Lake is directly entering the lake through a natural ravine towards the north-western side of the lake, which is the major source of water to the lake. (b) Sewage/sludge from the Basavanapura residential area towards the western side of the lake is directly connected to the lake through stormwater drain which is the second major source of water to the lake. (c) Sewage/sludge from the village area of Virgonagar towards the eastern side. (d) Hirandahalli area towards the northern side of the lake is



Fig. 1: Map of the study area and photographs of sampling points, eutrophication location, and waste dumping sites.

also directly connected to the lake. (e) Sewage/ sludge from the Kurudusonnenhalli area towards the southern side of the lake is also directly connected to the lake through a stormwater drain. The lake has one weir and the outflow from the said weir finally joins South Pinakini River.

The paramount reasons for pollution of Yele Mallappa Shetty Lake are Sewage/ sludge flowing in the stormwater drains entering the said lake, rapid and large urbanization, changes in land use pattern, under capacity of sewers, encroachment of sewers, damages to the sewerage system and direct discharges from unauthorized layouts in newly formed 110 villages, effluent from a drug manufacturing company located in the south-west of the lake, entering the water leading to a substantial quantity of sewage flowing into the stormwater drains. Lake eutrophication made sample collection challenging at Yele Mallappa Shetty Lake, but during the month of August few locations were cleaned for immersion of Ganesha statues. Hence, surface water was collected in the 4th week of August 2022, the rainy season. A total of four samples were collected from the following locations (Fig. 1).

Sample 1 (S1): South Western part of the lake; Sample 2 (S2): Western part of the lake; Sample 3 (S3): North Eastern part of the lake and Sample 4 (S4): Southern part of the lake.

Sample collection method: Approximately 10 l of surface water was collected using a steel bucket at every sampling site (10 to 20 cm in depth). In order to collect microplastics, collected water samples were filtered through a stacked sieve set (4.5 mm and 45 microns). In the following step, double distilled water was used to wash the 45-micron sieve, and the contents were carefully transferred into a one-litre glass bottle. Two replicates of the sample from each site were collected and stored at 4°C.

Extraction of microplastics from the water sample: Microplastic extraction from surface water was performed using National Oceanic and Atmospheric Administration (NOAA) Guidelines (Sutton *et al.*, 2016) with a slight modification. In order to remove labile organic material, samples were processed via Wet Peroxide Oxidation (Masura *et al.*, 2015). Briefly, 20 ml of 30% H₂O₂ and 20 ml of Fenton's reagent were added and stirred using a magnetic

stirrer at 350 rpm for 45 min. After organic digestion, samples were filtered through a stacked sieve set (4.5 mm and 45 microns) and rinsed with deionized water into Petri dishes.

Identification of microplastics: The microplastic sample collected in glass petri dishes was observed under a stereomicroscope at 40X magnification. During the microscopic examination, the color of each microplastic particle was noted and their sizes were determined by calibrating the microscope under 100X. Based on their shape, microplastics were divided into 4 categories such as film, fibre, foam, and fragment (Gopinath *et al.*, 2020; Malla-Pradhan *et al.*, 2022). Microplastics were further identified according to the criteria described by Irfan *et al.* (2020). Microplastic abundance was calculated using the following formula after the morphological classification of particles (Gray *et al.*, 2018).

$$\text{Microplastic abundance} = \frac{(\text{Number of microplastics identified})}{(\text{sample size})}.$$

A hot needle test was performed to confirm whether the suspected particles were plastic or non-plastic (De Witte *et al.*, 2014). Following the protocol of Anifowoshe *et al.* (2022), plastic particles were selected randomly to check their chemical composition using Raman spectroscopy-LabRam (HR) UV system (spectral range 0–3000 cm^{-1} , 585 nm laser) at the Centre for Nano Science and Engineering (CeNSE), Indian Institute of Science, Bangalore. Raman spectra obtained were compared with the spectra of virgin plastics found in the Spectra Libraries of Plastic Particles (SLoPP) Microplastics Library and the chemical composition analysed using the KnowItAll software's spectral library (20.1.210.0) (Bio-Rad Laboratories, Inc). In addition, scanning electron microscopy (SEM) imaging was used to detect surface morphology of the selected microplastics found in the tested water sample. Microplastic particles were fixed on carbon tape separately and desiccated overnight before analysis. SEM (ULTRA 55) was used to characterize dry samples at the Centre for Nano Science Engineering (CeNSE), Indian Institute of Science. Ultra-high resolution scanning electron imaging coupled with material spectroscopy made up the ULTRA 55, representing the most recent advancement in GEMINI technology. An energy and angle selective Backscattered electron (EsB) detector based on SUPRA 55 was included in the ULTRA 55, and this detector included a filtering grid for improved image quality. With the EsB detector, boundaries, particles, and features could be imaged and measured more precisely because it is less susceptible to edge contrast and charge effects (Anifowoshe *et al.*, 2022).

Control of contamination: Contamination control measures were taken during laboratory analysis. The apparatus used were cleaned with deionized water. Glass bottles were used to store samples and plastic containers and other plastic apparatus were strictly not used throughout the experiments to avoid plastic contamination. The samples were covered with aluminium foil to minimize their exposure during processing and to prevent contamination. Petri plates used were examined under a stereomicroscope to find out airborne contamination. A blank which only contained deionized water was filtered through a

stacked sieve set (4.5mm and 45 microns) and the water was treated in a similar manner without the digestion process as mentioned above. Results indicated a negligible amount of contamination. Therefore, the background contamination was not subtracted from the total microplastic count.

Data analysis: GraphPad Prism (version 8.0) was used to analyze the microplastic abundance and the data were statistically analyzed by One-way ANOVA and Tukey's multiple comparison for post-hoc test. Statistical significance was at the level of $*p < 0.05$. ($p=0.0442$).

Results and Discussion

The morphology of microplastics identified in Yele Mallappa Shetty Lake was determined using a microscope. The microscopic examination of surface water revealed that the most abundant microplastics were fibre, foam, fragments and film (Fig. 2). This study clearly demonstrated that microplastic pollution was due to anthropogenic activities. It was found that the average concentration of microplastics in Yele Mallappa Shetty Lake was 10 ± 0.7 particles l^{-1} surface water. The highest abundance of microplastic was found at Site 1, due to heavy domestic waste disposal. Site 1 was a densely populated residential area and the lake was heavily polluted by sewage water and human activity. The second highest abundance of microplastic was observed at Site 2. The second sampling site was located in the Western part of the lake, facing highway. Algal growth was found at the third sampling site (Site 3), located in the Northeast corner of the lake, which received the most agricultural runoff, and had less abundance of microplastic compared to other sampling sites.

The fourth sampling site (Site 4) was lake outlet, located in the Southern part of the lake. Due to many industrial activities that discharged wastewater into the Lake, this sample had the third highest amount of microplastics (Fig. 3). The main types of microplastics observed in surface water were fibre (26%), fragment (27%), film (25%), and foam (22%). The microplastics were mainly produced from domestic waste, which contained synthetic fibres and packaging materials dumped directly into the lake. Microplastics found were color-classified and size-wise discussed (Fig. 4, 5). According to these data, domestic packing materials and laundry fibrous materials generated the majority of microplastics. Furthermore, 0.2 mm-sized materials were found in large quantities. A plastic piece will melt, curl, or break when subjected to a hot needle test, whereas a biological or organic substance will char (Lira *et al.*, 2020). Therefore, it is possible to differentiate between plastic pieces and organic matter by a hot needle test. The suspected particles were thus tested under a hot needle, and it was observed that the white foam had melted, curled, and changed its structure (Fig. 6) and the orange film had melted and broken (Fig. 7).

As a result, it was confirmed that the identified suspected particles were plastic. Further, the chemical composition of suspected visible particles, including white foam (MP1),

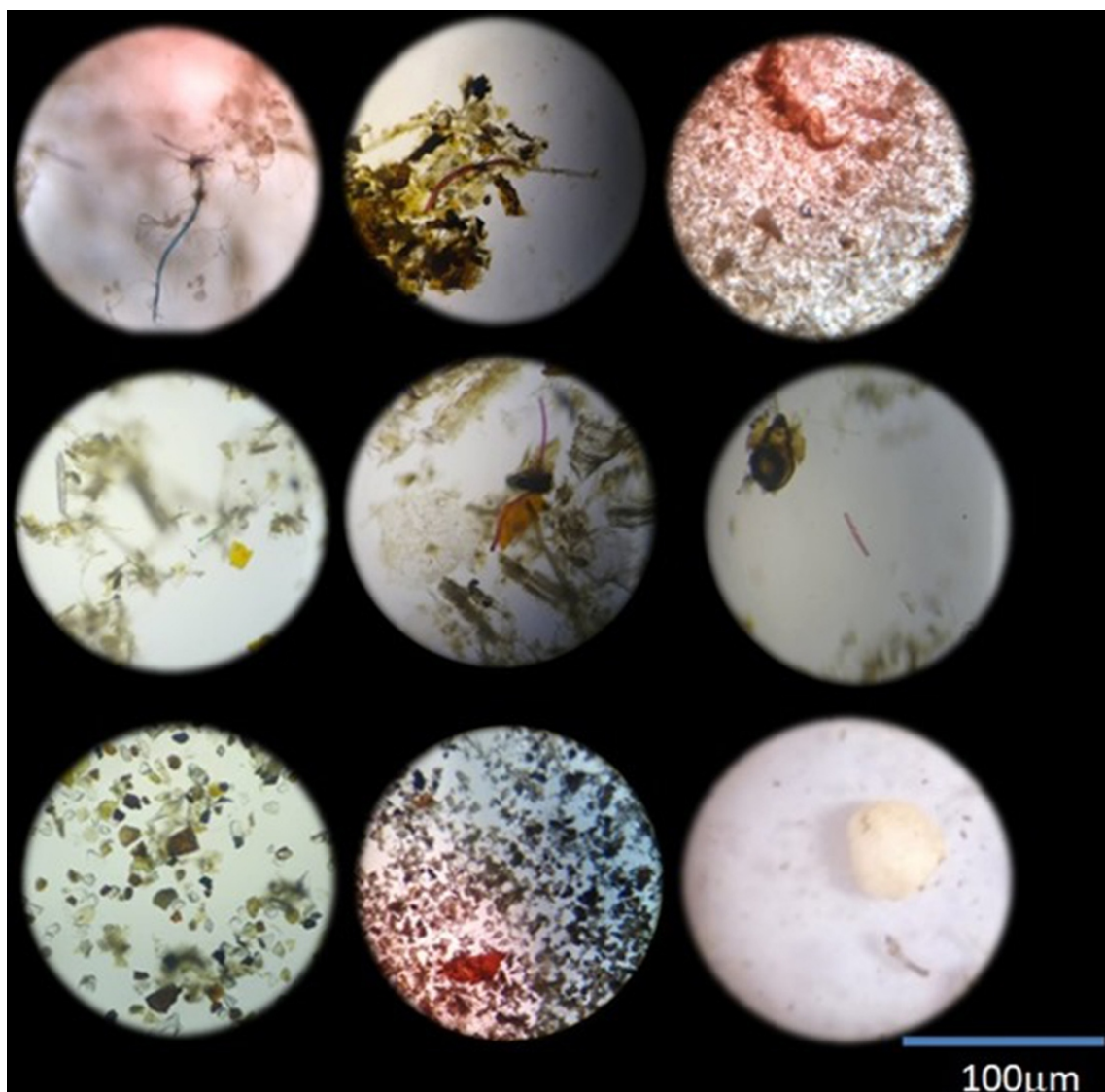


Fig. 2: Microscopic images of microplastic fibres, foam, fragments and film in water [40X].

transparent film (MP2), and red fibre (MP3) were determined using a reliable, robust, sensitive, and faster Raman spectroscopy. Both MP1 and MP2 showed bands at 1728 cm^{-1} and 1699 cm^{-1} (stretching vibrations of the carbonyl groups), wherein the bands could be attributed to ester and to urethane carbonyls, respectively. As well, the increasing band intensity at approximately 1612 cm^{-1} indicated N-H deformation vibrations of primary amines which were typically found between 1610 cm^{-1} and 1630 cm^{-1} (Bruckmoser and Resch, 2014) and the spectral regions between 1680 and 1620 cm^{-1} specified alkene groups. The significant band spans between 1265 - 1200 cm^{-1} indicated C-N and C-O of the amide group. Interestingly, in the case of MP1 intense band at 994 cm^{-1} indicated CH of aromatic ring bending.

This unique peak at 994 cm^{-1} (CCO) made a difference which could be polyurethane and henceforth, MP2 with only amide could be a polyamide of nylon type. However, the visual examination supported the fact that MP1, the white foam matched with polyurethane whereas MP2, the transparent film was shown to match with polyamide (Fig. 8).

These microplastic pollutants such as polyurethane and polyamide materials are expected to originate from inlet water of industries or domestic waste, which may contain electronic materials, carpets, artificial fabrics, adhesives, skateboards and elevators (Adetunji *et al.*, 2021). Moreover, polyurethane and polyamide are organic polymers typically formed by the reaction

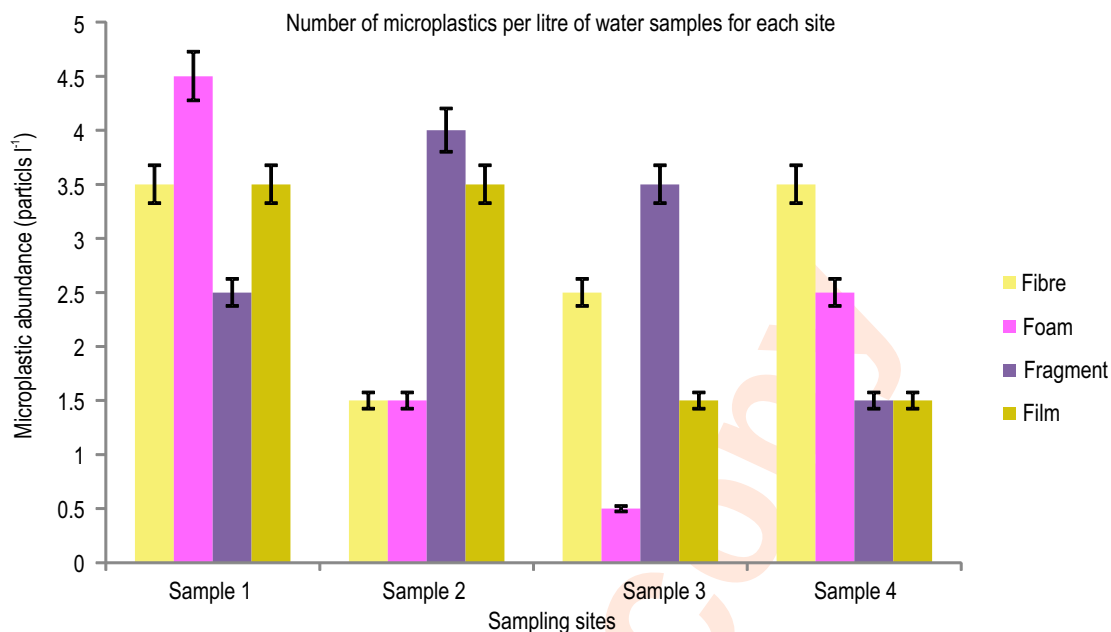


Fig. 3: Number of microplastics per litre of water samples for each site.

of diisocyanates with polyols and dicarboxylic acid with diamines (Luscombe *et al.*, 2021). There is growing evidence that these polymers when exposed to the environment produce hazardous products such as glycols and amines, which can be harmful to the respiratory system, skin, and may have an impact on aquatic animals (Zimmermann *et al.*, 2020; West *et al.*, 2022). Additionally, MP3's Raman spectrum showed main vibrations at 530, 809, 973, 1040, 1167, 1316, 1458, 1740 cm^{-1} . Vibration at 809 cm^{-1} was assigned to CH_2 rocking while stretching of C–C and C– CH_3 , and at 973 cm^{-1} had been assigned to CH_3 rocking and C–C stretching. The remaining bands were assigned as follows: 1040 band to stretching of C– CH_3 and C–C stretching and CH bending; CH bending, and C–C stretching; 1330 to CH bending and CH_2 twisting; 1458 to asymmetric bending of CH_3 and CH_2 bending (Andreassen 1999). Therefore, MP3 was shown to match with isotactic polypropylene (iPP), a commercial polypropylene fibre (Fig. 8).

Commercial polypropylene is predominantly isotactic (90–95%) and produced by Ziegler-Natta catalyst with head-to-tail priming of propylene monomer (Ariff *et al.*, 2012). It is used in a wide range of industries including packaging, textiles, automotive, and consumer products (Hossain *et al.*, 2024). Researchers have found that polypropylene particles exhibit cytotoxicity and can induce pro-inflammatory cytokines, such as IL-6 and TNF alpha, which are responsible for local immune responses (Hwang *et al.*, 2019). Thus, isotactic polypropylene identified in this study might have originated from either industrial effluent or domestic waste in the surrounding area and had been found to be toxic to humans as well as other aquatic organisms. Thus, the Raman analysis indicated that polyurethane, polyester,

and polypropylene were the main components present in the microplastics found in the tested water sample. Suspected microplastic particles were also analysed by SEM to determine their morphology and to detect different mechano-chemical distresses on their surfaces. The nanoscale crazes/cracks were observed (Fig. 8), which showed that markings were considered to be due to the oxidation and mechanical stress imparted on the surface of selected foam and fibres during course of time. Because of its vast potential to give unique insight into the micro and nanoscale worlds, scanning electron microscopy (SEM) is a formidable instrument in the fields of materials research, mining and geology (Dastbaz, and Ashrafzadeh, 2020). The widths of different components varied from 0.2 to 3 mm, with the bulk of the samples consisting of fibres (26%), fragments (27 %), films (25%) and foam (22%). However, the study showed that mechano-chemical distress and subsequent exposure of aged and weathered microplastics increased the pathogenic uptake efficiency as well as aiding adhesion to inflammatory cells as part of the foreign body response (Farr *et al.*, 2024).

As it is well known that urbanization led to the encroachment of water bodies and was the main reason for the pollution of important water bodies like lakes and rivers. It is evident that Yele Mallappa Shetty Lake was heavily polluted by plastic. Major microplastic pollutants found were fibres and fragments. Microplastics were mainly from the domestic waste, which contained synthetic fibres and packaging materials dumped directly into the lakes. It is essential that wetland ecosystems should be protected because of their countless services, which include freshwater supply, food and building materials, biodiversity, flood control and groundwater recharge.

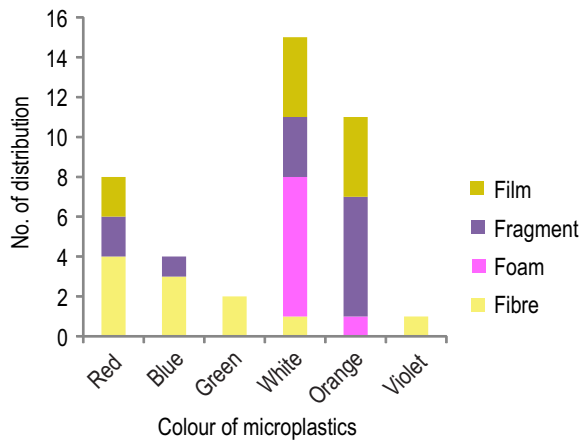


Fig. 4: Color classification of microplastic found in Yele Mallappa Shetty Lake.

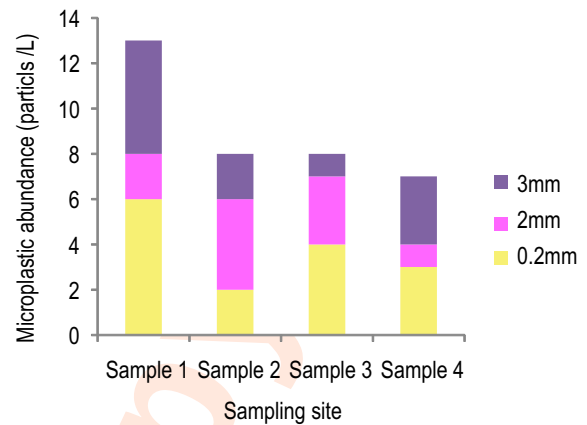


Fig. 5: Comparison of microplastics in Yele Mallappa Shetty Lake by size / Size distribution of microplastics.

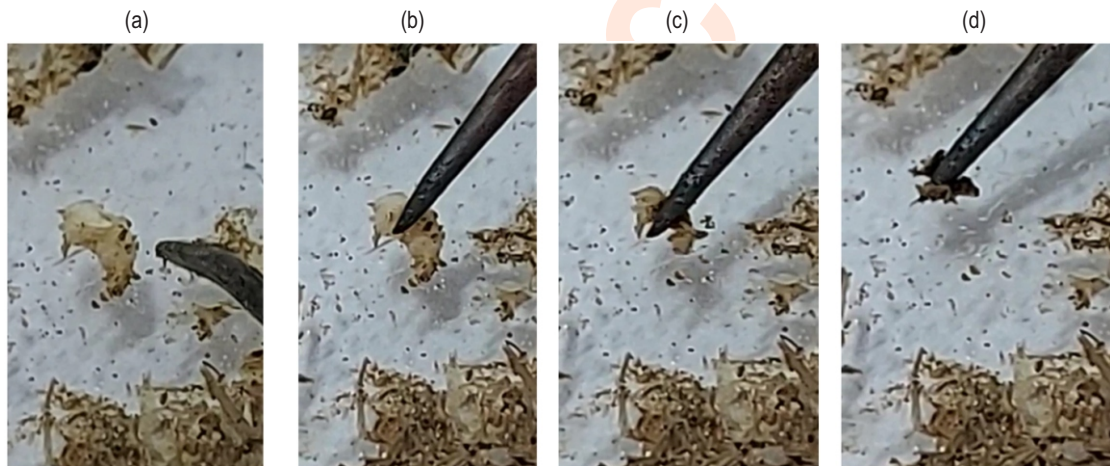


Fig. 6: Hot needle test of white foam: (a) Approach of hot needle on a white foam; (b) Hot needle in close proximity; (c) Hot needle melts the foam and (d) Final result – foam reacted and melted due to heat.

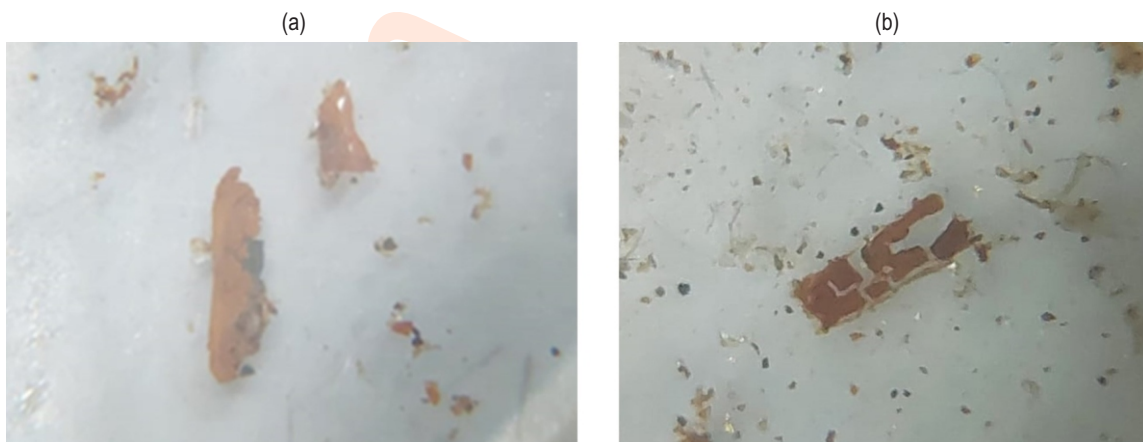


Fig. 7: Hot needle test of orange film; (a) film before melting and (b) film melted after hot needle test.

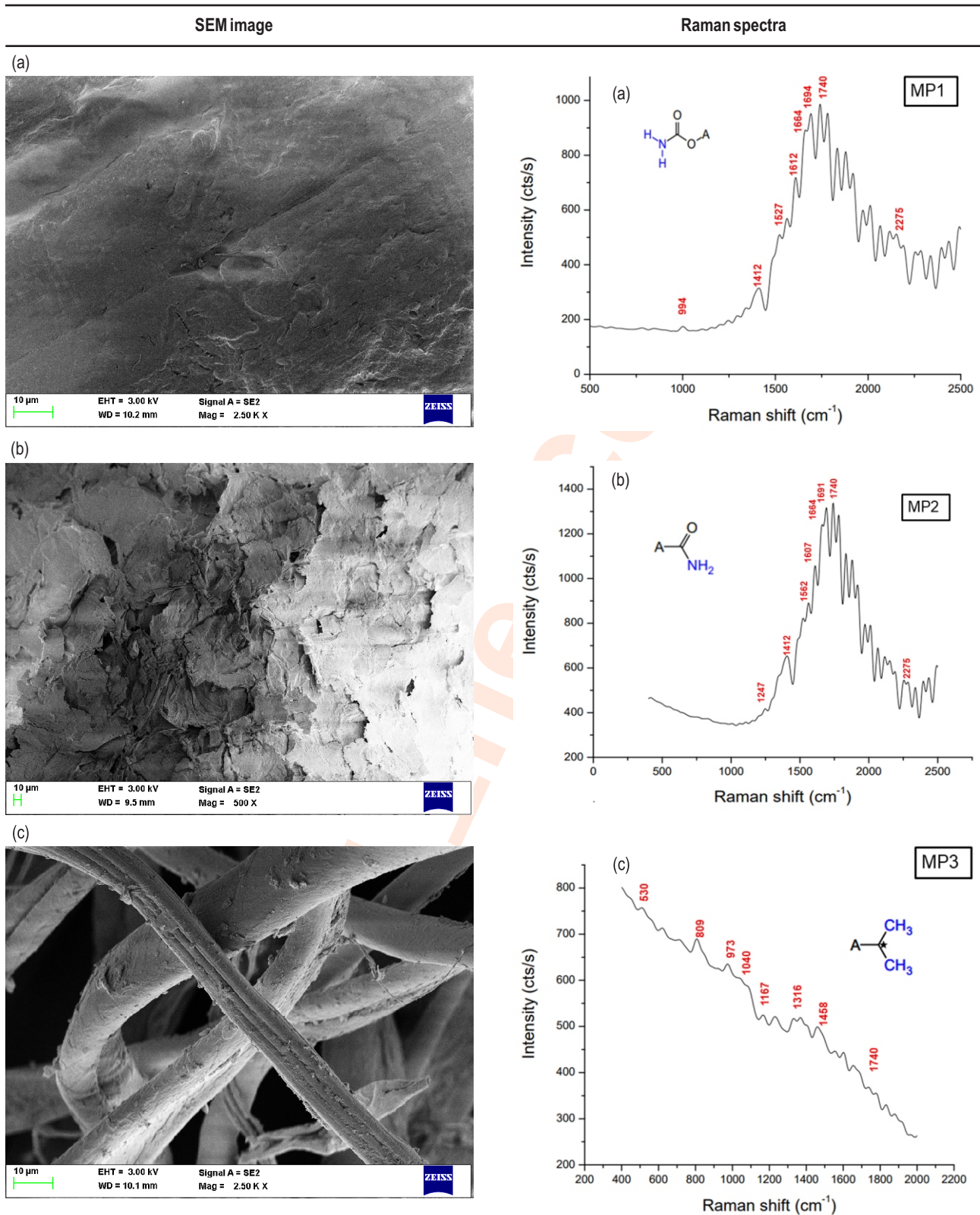


Fig. 8: SEM image and Raman spectra of microplastics found in Yele Mallappa Shetty Lake compared with Spectra Libraries of Plastic Particles (SLoPP) Microplastics Library showing functional group. (a) MP1, (b) MP2 and (c) MP3.

The major impacts of urbanisation include the loss of wetlands and green spaces, floods, declining groundwater tables, and the increase in carbon footprint due to heat islands (Ramachandra et al., 2016). However, UN Sustainability Goal 6 is to provide clean water and sanitation. It is therefore vital to prevent freshwater contamination as it will ruin the whole locality, including aquatic life, and lead to poor quality of life. Thus, this study clearly demonstrated the status of lake water quality and also the importance of keeping the lake water free from plastic pollution.

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Authors' contribution: **N.S. Kaviyarasi:** Formulation, preparation, presentation of the published work, coordination responsibility for the research activity planning and execution, specifically conducting research and investigation, writing the initial draft, formal analysis of the study data; **V. Prasanna:** Experiments such as organic digestion and visual detection performed during the research and investigation process; **S. Abitha:** Collection of water samples; research and investigation process, including experiments such as organic digestion and visual detection; **A.T. Anifowoshe:** Process of investigation, including Raman spectroscopy analysis of microplastics, revision of manuscript and formal analysis of study results.

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