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Research article

Influencing factors of microplastic generation and microplastic contamination in urban freshwater

Rutjaya Prateep Na Talang [a], Sucheela Polruang [b], Sanya Sirivithayapakorn [b,*]

[a] Environmental Modeling Consultant Center, Environmental Engineering Department, Faculty of Engineering, Kasetsart University, Bangkok, 10900, Thailand

[b] Environmental Engineering Department, Faculty of Engineering, Kasetsart University, Thailand

A R T I C L E I N F O

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Runoff
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A B S T R A C T

This research analyzes data on the microplastic (MP) contamination in the environmental systems (atmosphere, lithosphere, hydrosphere) and the levels of MPs in freshwater of cities with different levels of national income. This study investigates the influencing factors of MP generation, i.e., mismanaged plastic waste, untreated wastewater, number of registered motor vehicles, and stormwater runoff. The statistical correlations between the MP contamination in urban freshwater and the four influencing factors of MP generation are determined by linear regression. The results indicate that MPs are most abundant in aquatic systems (i.e., hydrosphere) and pose a serious threat to the human food chain. The regression analysis shows a strong correlation between mismanaged plastic waste and microfragment smaller than 300 μm in particle size in urban freshwater with high goodness-of-fit ($R^2 = 0.8091$). A strong relationship with high goodness-of-fit also exists between untreated wastewater and microfragment of 1000–5000 μm in particle size ($R^2 = 0.9522$). The key to mitigate the MP contamination in urban freshwater is to replace improper plastic waste management and wastewater treatment with proper management practices.

1. Introduction

Microplastics (MP) are so ubiquitous that they can be found even in the most remote places on earth [1–5]. It is even more disturbing that MPs are already found in human tissues, through the direct inhalation of the contaminated air and ingestions of MPs contaminated foods [4,6,7]. Evidence shows that MPs are more common in freshwater and marine food chains than in terrestrial food chains [8–13].

In the abiotic system (i.e., atmosphere, lithosphere, and hydrosphere), MPs in urban freshwater due to human activities are closely linked to the presence of MPs in the aquatic food chain [14]. According to OECD [15], UNEP [16], UN Environment [17], MPs in the ecosystems are primarily secondary MPs from the breakdown of larger plastic items. This fact highlights a direct link between the current MP problems and the use and disposal of plastics.

The production and consumption of plastics, especially single-use plastics, dates back to the early 1950s [18]. The degradation time of plastics into MPs varies greatly, depending on the environmental conditions, types, and morphology of the plastics [19–21]. The MPs found in the water samples taken from rivers reveal their two possible sources: degradation of mismanaged inland plastic waste

* Corresponding author.
E-mail addresses: rutjaya@gmail.com (R.P.N. Talang), fengslpo@ku.ac.th (S. Polruang), fengsys@ku.ac.th (S. Sirivithayapakorn).

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and MP-containing effluent, e.g., the synthetic microfibers from the laundry [22,23]. The finding indicates a relationship between the levels of MP contamination in freshwater (mismanage plastic waste) and improperly treated or untreated domestic wastewater.

Runoff plays an important role in transporting anthropogenic debris, including MPs, from inland sources to the aquatic systems [24]. According to [25–27], the particles from vehicle tires are the main source of outdoor atmospheric MPs, demonstrating a direct association with the number of motor vehicles. The land-based MPs and degraded plastic waste enter the river systems through wind and stormwater runoff and end up in the oceans [16,28,29]. The land-based plastic waste continues to degrade and becomes a long-term source of MPs in the ocean [4,16,30].

There is a growing awareness regarding the ubiquitous presence of MPs within the environment, particularly within human biological systems. Initial research suggests that *MPs could impact human health*, but evidence to quantify the health impact is very limited [16,17]. The precise threshold of MP concentration required to elicit adverse effects on human health, as well as the environmental concentration levels deemed harmful, remain undetermined. Established guidelines regarding the permissible levels of MP contamination within environmental systems are lacking [31]. However, a shift towards understanding the mechanisms driving MP generation is warranted. Analysing the relationship between influencing factors of MP generation and MP contamination facilitates targeted interventions aimed at mitigating MP proliferation, and therefore the potential for reducing human exposure to MPs is enhanced. This approach presents a pragmatic means of managing subsequent consequences arising from MPs. This directs the objectives pursued in this study, which include identification, characterization, and correlation analysis of the various factors that contribute to the generation of MPs in urban freshwater, and actionable policy recommendations to mitigate the MP contamination in freshwater are then proposed. The policy recommendations are based on the correlations between the MP contamination in urban freshwater and the influencing factors of MP generation (i.e., mismanaged plastic waste, untreated wastewater, number of registered motor vehicles, and stormwater runoff). In this study, the MPs are categorized by particle size (i.e., smaller than 300 μm, 300–1000 μm, and 1000–5000 μm) and MP type (i.e., microfiber and microfragment).

2. Materials and methods

Fig. 1 shows the overall research framework and methodology, consisting of three parts. The first part is concerned with the collection and analysis of data on: (a) the MP contamination in the environmental systems (atmosphere, lithosphere, hydrosphere), (b) the MP contamination in freshwater of 24 cities in 16 countries with different levels of national income: lower-middle, middle-income,

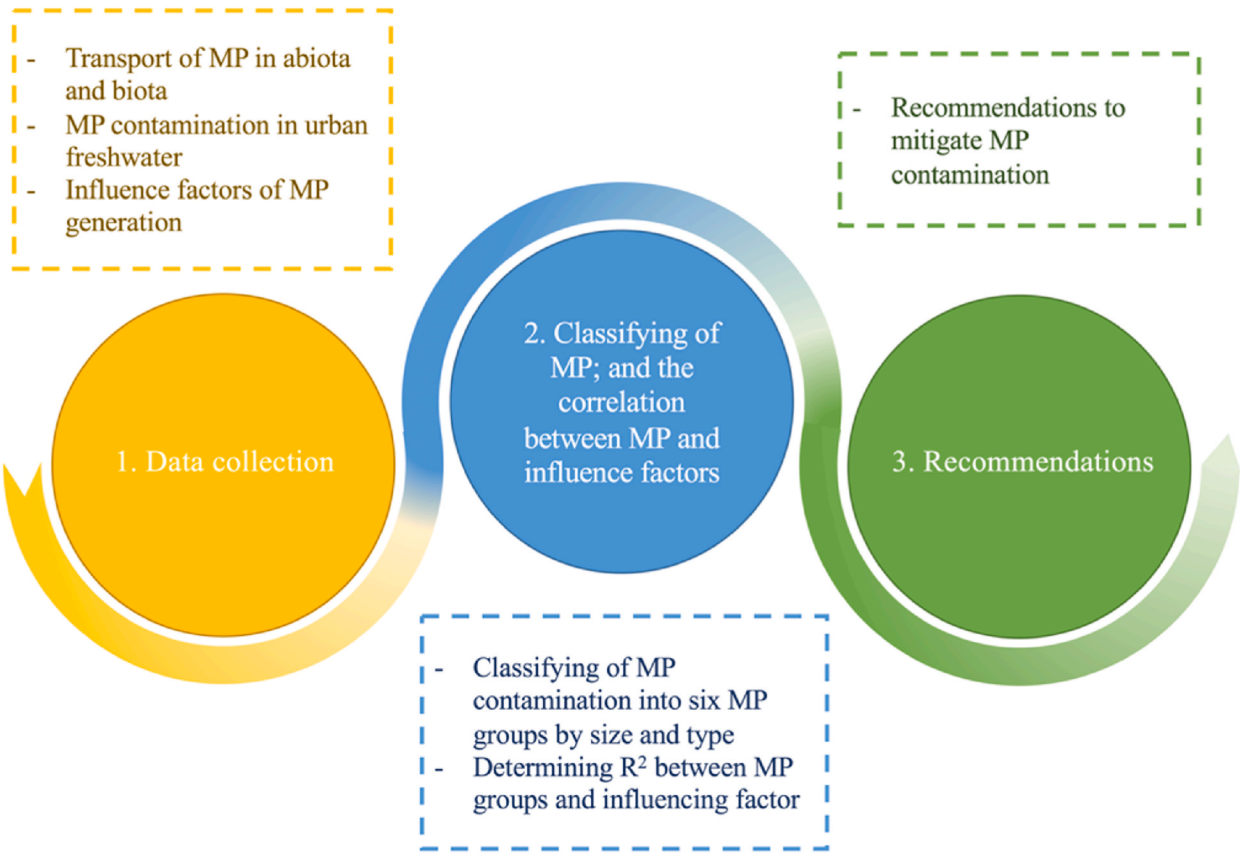

Fig. 1. The overall research framework and methodology of this research.

and high-income countries, and (c) the influencing factors of MP generation. The study data are from existing peer-reviewed publications and publicly available information from local government and international organizations. The contamination of urban freshwater with microplastics is pervasive across multiple cities and countries worldwide. But in this work, consideration is given to the completeness and reliability of the data, only datasets meeting stringent criteria for comprehensiveness being included in this study. The extensive dataset obtained from these 24 cities provides a solid foundation for analysis within the framework of our research. The second part deals with: (i) the classification of MPs by particle size (i.e., $<$300 μm (small), 300–1000 μm (medium), and 1000–5000 μm (large)); and by MP type (i.e., microfiber and microfragment); and (ii) the linear regression between the MP contamination in urban freshwater and the four influencing factors of MP generation (i.e., mismanaged plastic waste, untreated wastewater, number of registered motor vehicles, and stormwater runoff). The final part discusses policy recommendations and measures to mitigate MPs in urban freshwater.

2.1. Data collection

The data on the MP levels in the environmental systems and in freshwater of 24 cities of lower-middle, middle-income, and high-income countries, as well as data on the influencing factors of MP generation, are gathered from existing peer-reviewed publications and reports by local government agencies and international organizations. The relationships between the MP contamination in urban freshwater (by MP size and type) and the four influencing factors of MP generation are determined using linear regression analysis.

The influencing factors of MP generation (on an annual basis) include mismanaged plastic waste (lithosphere), untreated wastewater (hydrosphere), number of registered motor vehicles (atmosphere), and stormwater runoff (MP transport). The mismanaged plastic waste per capita of a given city is calculated by dividing the volume of mismanaged plastic waste by the population size of the city [32,33]. The untreated wastewater of a given city is calculated by multiplying the wastewater generation per capita [34] by the population size of the city [33], except for Taipei where the data are obtained from the Sewerage Systems Office [35] and Lee [36]. The number of registered motor vehicles of a given city is computed by multiplying the national vehicles per capita excluding two-wheelers [37] by the population size of the city [33]. The stormwater runoff of each city is calculated by using equation (1) [38].

$$Q = C \bullet i \bullet A \quad (1)$$

where Q is the stormwater runoff of runoff, C is the runoff coefficient, i is the mean annual rainfall from the World Meteorological Organization [39] of each city, and A is the area of each city [40,41].

2.2. Microplastic classification and correlations between microplastic contamination and the influencing factors

The data on MP contamination in urban freshwater are subsequently grouped into six MP groups by MP size and type combined.

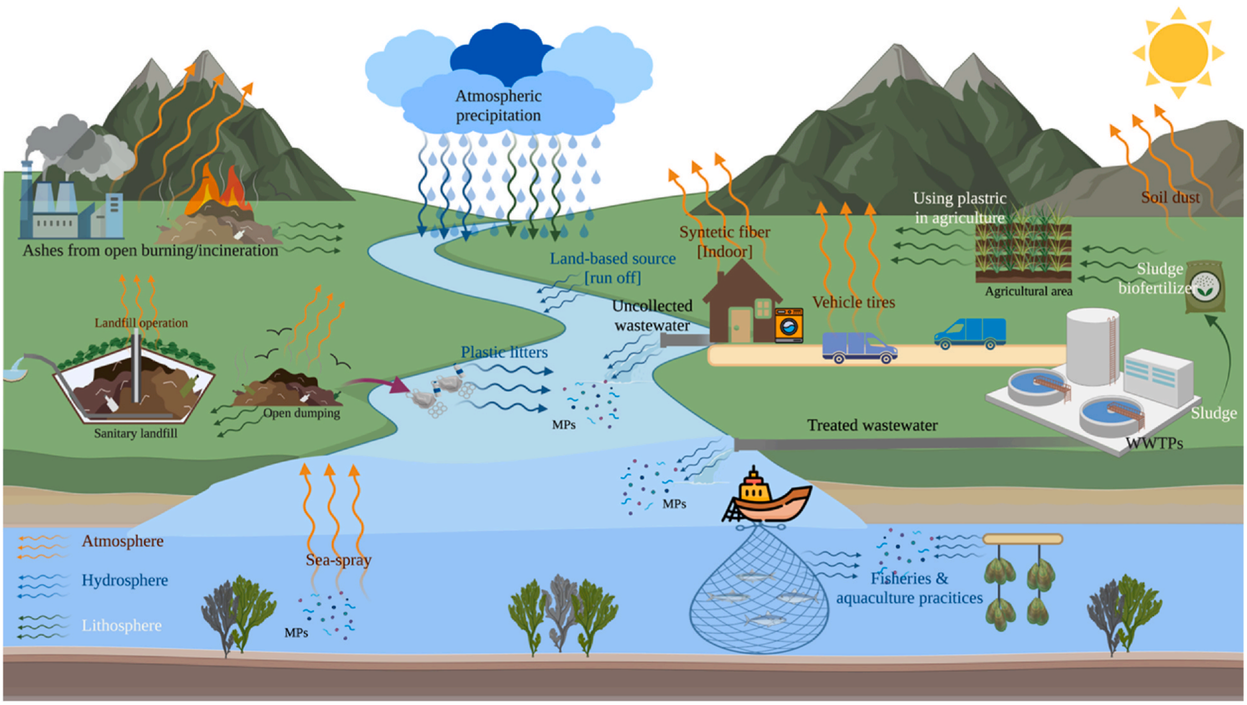

Fig. 2. Microplastics in the abiotic system.

The six MP groups are: smaller than 300 μm microfiber (small-MFiber), 300–1000 μm microfiber (medium-MFiber), 1000–5000 μm microfiber (large-MFiber), smaller than 300 μm microfragment (small-MFragment), 300–1000 μm microfragment (medium-MFragment), and 1000–5000 μm microfragment (large-MFragment). T-test is performed to test whether the test statistic follows a Student's t-distribution under the null hypothesis (H_0: $T_{calc} \leq T_{crit}$), where T_{calc} is the t-value of each MP group and T_{crit} is the t-value from the t-distribution table, given the 95 % confidence level. The data is rejected if T_{calc} is greater than T_{crit} ($T_{calc} > T_{crit}$) [42].

The linear regression relationships and the coefficients of determination (R^2) between the MP contamination in urban freshwater (by six MP groups) and the four influencing factors of MP generation are determined [43].

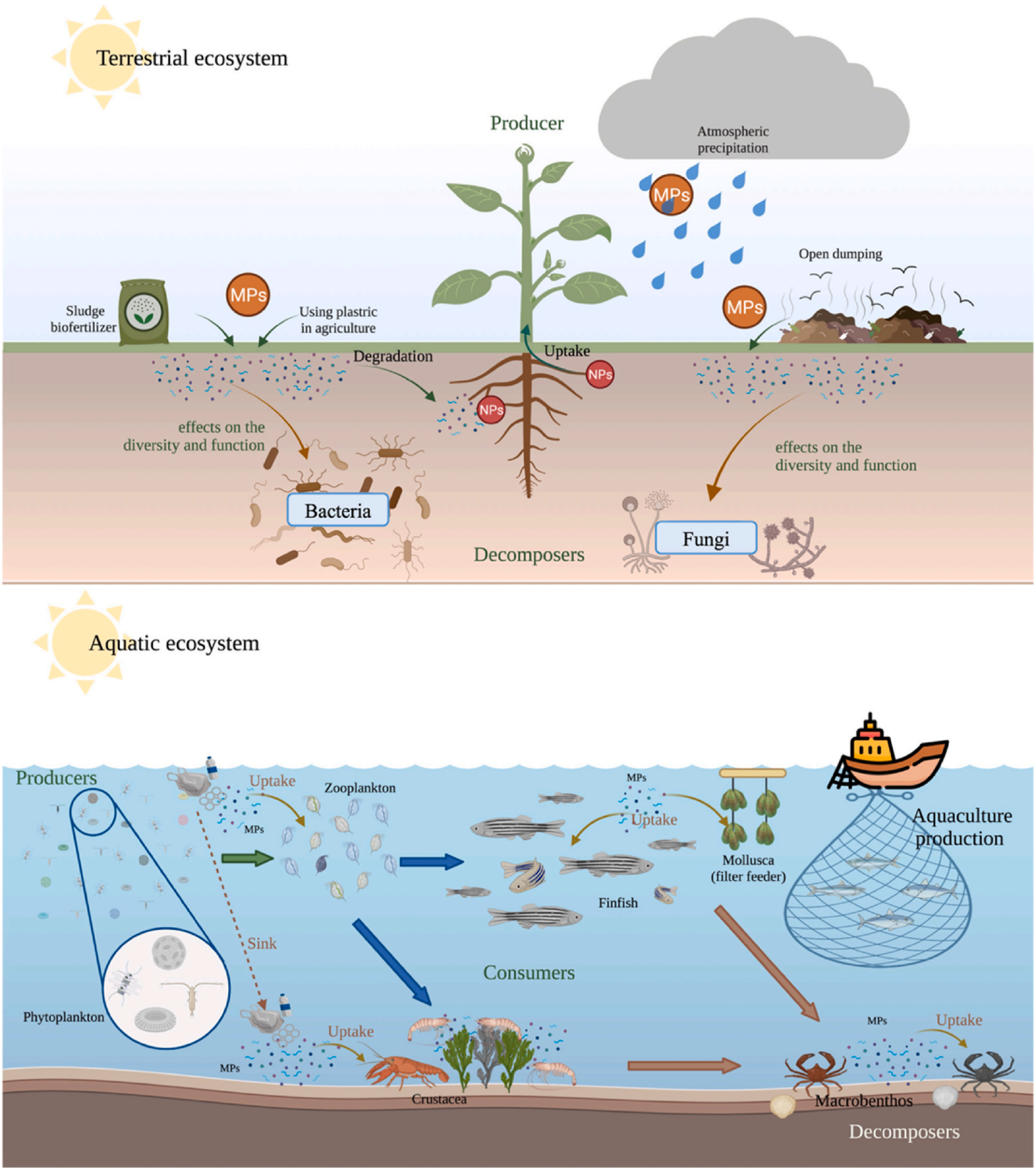

Fig. 3. Microplastics and nanoplastics (NP) in the biotic system.

2.3. Policy recommendations to mitigate microplastic contamination

In light of no established standards to limit the levels of MP contamination, this current research thus proposes actionable policy recommendations to mitigate the MP contamination in freshwater. The policy recommendations are based on the regression correlations between the MP contamination in urban freshwater and the influencing factors of MP generation (i.e., mismanaged plastic waste, untreated wastewater, number of registered motor vehicles, and stormwater runoff).

3. Results and discussion

3.1. Distribution and transport of microplastics

3.1.1. Microplastics in the abiotic system

Fig. 2 shows the sources of MPs in the abiotic system (i.e., atmosphere, lithosphere, and hydrosphere). Tables SI–1 in the supplementary information (SI) section tabulates the atmospheric, hydrospheric, and lithospheric MPs of different countries.

The reported atmospheric MPs range from 0 to 5700 MP/m^3 (Tables SI–1). The atmospheric MPs in China are dangerously high, with 5700 MP/m^3 in Beijing [44]. The atmospheric MPs in the environment, such as mountains, coastlines, snow, and glacier, are lower than those in urban areas, except for Hamburg, Germany [3]. The atmospheric MPs primarily originate from synthetic fibers, vehicle tires, sea spray, soil dust, and plastic waste (Tables SI–1). The MPs from vehicle tires are a major contributor of outdoor atmospheric MPs [6,26,45,46]. MPs in agricultural soil originate mainly from *plantation* in *plastic cover* (for weed and temperature controls) and from biological wastewater treatment sludge disposed of by open dumping or used as biofertilizers [47]. MPs in agricultural soil are released into the atmosphere along with soil dust. Open burning and incineration also contribute to atmospheric MPs [48].

The MPs found in agricultural soil are typically of fragments, films, and fibers [4] and increase with the passing of time [49]. The sources of lithospheric MPs include agricultural soil, atmospheric precipitation, and certain plastic waste treatment (Tables SI–1). Improper waste management practices, e.g., open dumping and open burning, contribute to the MP contamination in lithosphere, especially at or near the disposal site [16]. In comparison, proper waste management practices, e.g., landfill and incineration, release MPs of lesser degree [48,50].

The hydrospheric MPs originate from plastic litter, wastewater, fishery and aquaculture, atmospheric precipitation, and land-based sources through runoff [22] (Tables SI–1). Mismanaged plastic waste is disintegrated into MPs through the abiotic (physical and chemical) and biotic (biochemical) degradation processes [20–22]. The atmospheric MPs precipitated with rain, together with the land-based MPs, enter the aquatic environment and eventually the food chain primarily through the surface runoff [16].

3.1.2. Microplastics in the biotic system

Fig. 3 shows the MPs commonly found in the biotic system (i.e., the terrestrial and aquatic ecosystems) [17]. MPs have direct and indirect effects on the diversity and function of the biota in the terrestrial ecosystem, particularly plant growth [10,12,13]. Plants can absorb nanoplastics (1–1000 nm) through their cell wall [8,9]. MPs are also found in the guts and feces of grazing animals, e.g., sheep [11].

The MPs in the aquatic ecosystem can hinder the photosynthetic activity of phytoplankton [51–53]. Zooplankton can ingest MPs; and other consumers in the higher trophic level, such as molluscs (clams, mussels, and oysters), consume the MP-contaminated zooplankton (Tables SI–1). According to FAO [54], over 95 % of the marine aquaculture production in 2018 (30.76 million tons) were contaminated with MPs, threatening the aquatic food chain. The non-selective suspension and deposit feeders residing in the benthic zone (which serves as a sink for MPs) are also threatened by MPs in aquatic environments [55–58].

3.2. Microplastic contamination in urban freshwater

A strong link exists between the MPs from human activities and those in the aquatic ecosystem [16,59]. Table 1 presents the MP contamination in urban freshwater (the surface water of lakes, lagoons, canals, rivers, and estuaries) of 24 cities or metropolises in 16 countries with different levels of national income. The lower-middle-income countries under study are Bangladesh, India, Nigeria, Pakistan, Philippines and Vietnam; and the upper-middle-income countries include China, Malaysia and Thailand. The high-income countries being studied are Australia, China (Taipei), France, Japan, Netherlands, Portugal, South Korea and USA.

MPs with particle size larger than 300 μm (medium and large) are found in abundance in urban freshwater in the lower-middle-income and upper-middle-income groups of countries (Table 1). The urban freshwater in the upper-middle-income and high-income groups of countries is predominantly contaminated with MPs smaller than 300 μm in size (small), including China, France, Malaysia, the Netherlands, Portugal, South Korea, and the US. Specifically, the small MPs (2–120 μm) are most abundant in the Douro River in Portugal's Porto, Portugal (334000 MP per m^3) [60], while the Han River in Da Nang, Vietnam has the lowest MP contamination (2.7 MP per m^3), with 300–5000 μm (medium and large) particle sizes the dominant MPs [61]. Tables SI-2 to SI-7 present the *t*-test results associated with the six MP groups: smaller than 300 μm microfiber (small-MFiber), 300–1000 μm microfiber (medium-MFiber), 1000–5000 μm microfiber (large-MFiber), smaller than 300 μm microfragment (small-MFragment), 300–1000 μm microfragment (medium-MFragment), and 1000–5000 μm microfragment (large-MFragment).

The research parameters of MP contamination in freshwater of the 24 cities being studied differ in terms of the sampling period, water sample collection method, and MP analysis. As a result, the data on MP contamination in freshwater of 24 cities cannot be

Table 1
Microplastics contamination in downstream urban freshwater of cities of different levels of national income: lower-middle, upper-middle and high-income groups.

Location		MP in freshwater (MP/m³)								Water source	Size (μm)	Identified microplastic method
		Microfiber			Microfragment			Other (excluding microfiber & microfragment)	Total			
City	Country	Small (<300 μm)	Medium (300–1000 μm)	Large (1000–5000 μm)	Small (<300 μm)	Medium (300–1000 μm)	Large (1000–5000 μm)					
Lower-middle income group rowhead												
Dhaka	Bangladesh	Not studied	Not studied	613.35	Not studied	Unexplored	1022.85	2863.8	4500[a]	Lakes in city	1000–5000	FTIR- ATR
Kolkata	India	Not classified							1111[c]	Hooghly River	150–4560	FITC
Lagos	Nigeria	48.21	62.18	99.21	3.44	4.44	7.09	5.76	230.33[d]	Lagos Lagoon	100–5000	FTIR- ATR & μFTIR
Lahore	Pakistan	40.98	120.85	949.86	59.55	175.64	1380.49	153.37	2893.85[e]	Ravi River	50–5000	FTIR- ATR
Manila	Philippines	22.47	59.25	122.58	265.93	701.09	1450.53	783.15	3405[f]	Pasig River	250–5000	FTIR- ATR
Da Nang	Vietnam	Not studied	1.97		Not studied	0.73		Not reported	2.7[b]	Han River	300–5000	FTIR- ATR
Ha Noi		Not studied	39.60		Not studied	8.40		Not reported	48[b]	Nhue and Red Rivers	300–5000	
Ho Chi Minh City		Not studied	3.51		Not studied	0.39		Not reported	3.9[b]	Saigon River	300–5000	
Upper-middle income group rowhead												
Beijing	China	161.66			248.37			41.84	451.88[g]	Qing River	50–5000	FTIR
Chongqing		37650.04	29949.96	10415.00	Not reported	Not reported	Not reported	26985	105000[h]	Yangtze River	0.45–5000	μFTIR
Guangzhou		295.93	715.42	1203.39	69.14	167.14	281.14	5.45	2724[i]	Pearl River	20–5000	μFTIR
Kuala Lumpur	Malaysia	545.87	965.77	587.86	70.64	124.98	76.08	98.80	2470[l]	Klang River estuary	300–5000	FTIR- ATR
Bangkok	Thailand	Not classified							31.87[j,k]	Chao Phraya River	53–5000	FTIR- ATR
High income group												
Adelaide	Australia	4576			1081.60			742.40	6400[m]	Multiple freshwater streams	20–5000	Raman spectroscopy
Taipei	China	Not reported	Not reported	Not reported	Not studied	28.45		6.29	34.74[w]	Tamsui River	300–5000	FTIR
Paris	France	8772	1020	357	Not reported	Not reported	Not reported	9950	22400[t]	Seine River	25–1000	μFTIR
Osaka	Japan	Not classified							9.02[r]	Yamato River	100–5000	FTIR
Tokyo		Not classified							3.29[s]	Naka River	300–5000	FTIR
Amsterdam,	Netherlands	52953	36380.33		Not reported	Not reported	Not reported	11000	100333.33[n]	Canals in the City of Amsterdam	10–5000	FTIR

(continued on next page)

Table 1 (*continued*)

Location		MP in freshwater (MP/m^3)								Water source	Size (μm)	Identified microplastic method
		Microfiber			Microfragment			Other (excluding microfiber & microfragment)	Total			
City	Country	Small (<300 μm)	Medium (300–1000 μm)	Large (1000–5000 μm)	Small (<300 μm)	Medium (300–1000 μm)	Large (1000–5000 μm)					
Porto	Portugal	47000	Not studied	Not studied	283900	Not studied	Not studied	3100	334000[u]	Douro River	2–120	Manual measurement & Digital stereo-microscope
Seoul	South Korea	18.32	11.94	1.59	49.52	32.30	4.31	Not reported	117.98[v]	Han River	100–5000	FTIR
Chicago	USA	Not studied	10.57		Not studied	6.65		0.71	17.93[o]	Chicago River	330–2000	SEM
Los Angeles		Not classified							8891.5[p]	Los Angeles & San Gabriel Rivers	3–5000	FITC
New York		Not classified							3.92[q]	Raritan River and estuary	250–2000	FTIR- ATR

Note.
FTIR is a Fourier Transform-Infrared Spectroscopy.
FTIR- ATR is a Fourier Transform-Infrared Spectroscopy using Attenuated Total Reflection.
μFTIR is a Micro-Fourier Transform-Infrared Spectroscopy.
FITC is a Fluorescein isothiocyanate.
SEM is a Scanning Electron Microscope imaging.

[a] [62].
[b] [61].
[c] [63].
[d] [64].
[e] [65].
[f] [66].
[g] [67].
[h] [68].
[i] [69].
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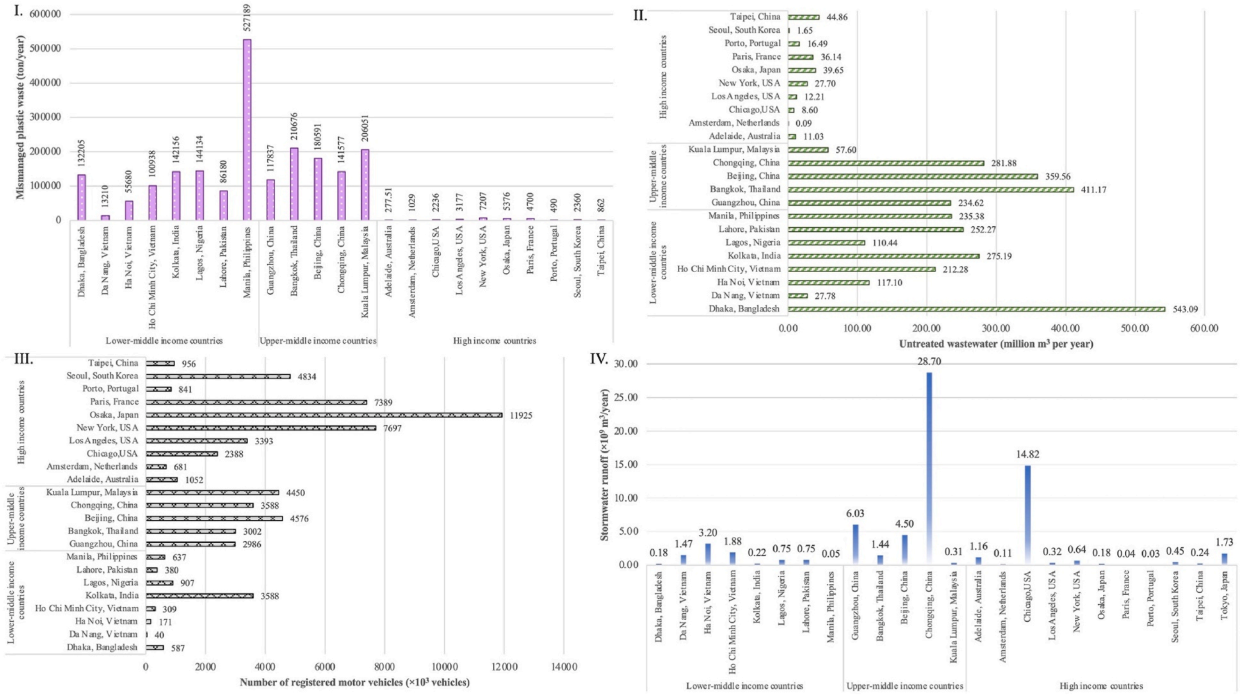

Fig. 4. The influencing factors of microplastic generation by city: (I) mismanaged plastic waste, (II) untreated wastewater, (III) number of registered motor vehicles, (IV) stormwater runoff.

compared directly, and the regression correlations of this study cannot be applied to predict the MP contamination in urban freshwater of other cities or metropolises, without some modifications. On the contrary, the relationships between the MP contamination in urban freshwater and the influencing factors of MP generation are used as basis for policy recommendations. The outcomes of this study can serve as a foundational framework for proposing policy interventions aimed at mitigating MP pollution in urban freshwater by prioritized focusing on the core influencing factors.

3.3. The influencing factors of microplastic generation

Fig. 4 presents the data (on an annual basis) of mismanaged plastic waste, untreated wastewater, number of registered motor vehicles, and stormwater runoff by the levels of national income: lower-middle-income, upper-middle-income and high-income countries. Mismanaged plastic waste and untreated wastewater in the lower-middle-income and upper-middle-income groups of countries are higher than in the high-income group. The city of Manila in the Philippines has the highest mismanaged plastic waste (527189.43 tons) while the city of Porto in Portugal the lowest (490.14 tons). The city of Dhaka in Bangladesh has the highest untreated wastewater (543.09 million m^3) while the city of Amsterdam in the Netherlands has the lowest untreated wastewater (0.093 million m^3).

The number of registered motor vehicles in the lower-middle-income and upper-middle-income groups are lower than in the high-income group. The megacity of Tokyo in Japan has the highest number of registered motor vehicles (23.3 million vehicles), while the city of Da Nang in Vietnam the lowest (40,480.48 vehicles). The stormwater runoff is closely related to the climate and land use of different areas. The high-income group of countries are also afflicted by MPs despite efficient plastic waste and wastewater treatment (Table 1 and Fig. 4). The finding suggests that the current waste and wastewater treatment systems are inadequate for the removal of MPs.

3.4. The regression analyses

Table 2 tabulates the coefficient of determinations (R^2) of the linear regression analyses between the MP contamination in urban freshwater (by six MP groups) and the influencing factors of MP generation (i.e., mismanaged plastic waste, untreated wastewater, number of registered motor vehicles, and stormwater runoff). The corresponding regression relationships and R^2 are graphically presented in Figures SI-1 to SI-6.

The results show high goodness-of-fit between mismanaged plastic waste and small-MFragment, $R^2 = 0.8091$ (Fig. 5), and between untreated wastewater and large-MFragment, $R^2 = 0.9522$ (Fig. 6), given that $R^2 \geq 0.7$ indicates a strong relationship [83]. The rest (Figures SI-1 – SI-6) indicate a weak relationship, with R^2 in the range of 0.0030–0.5526 (Table 2). As seen in Tables SI–1, the hydrospheric MPs (from untreated wastewater and landfill leachate) account for the largest proportion of MP debris in the abiotic system

Table 2
The coefficient of determinations (R^2) of the linear regression analyses.

MP group \ Influencing factors	Mismanaged plastic waste	Untreated wastewater	Motor vehicles	Stormwater runoff
small-MFiber	0.1380	0.1681	0.5526	0.0489
medium-MFiber	0.0600	0.0752	0.4891	0.0454
large-MFiber	0.0353	0.1713	0.0222	0.4655
small-MFragment	0.8091	0.1912	0.0882	0.0358
medium-MFragment	0.0477	0.5309	0.0184	0.2197
large-MFragment	0.0184	0.9522	0.3586	0.0030

[48,84–88], and could be attributed to mismanaged plastic waste and untreated wastewater.

3.5. Recommendations to mitigate microplastic contamination

In many countries, e.g., Canada, Columbia, European Union, New Zealand, Peru, Rwanda, Saint Lucia, Singapore, and Thailand, specific plastic products, the single-use plastic products in particular, are prohibited and/or restricted [89]. However, no country has imposed a ban on all plastic products due to the entailed negative effects on the economy [59]. A third of plastic waste in the lower-middle-income countries and one-fourth in the upper-middle-income countries are improperly treated (i.e., open dumping) [90–92]. The results reveal that mismanaged plastic waste has a strong relationship with the accumulation of microfragments smaller than 300 μm in particle size (small-MFragment) in urban freshwater (Fig. 5). To mitigate the MP pollution in freshwater, plastic items should be reused and recycled; and improper plastic waste management, especially open dumping, needs to be phased out and switched to proper treatment practices, e.g., landfill and incineration.

The research results also show that untreated wastewater has a strong relationship with the 1000–5000 μm microfragments (large-Mfragment) (Fig. 6). However, untreated wastewater has a weak relationship with the accumulation of microfibers of all sizes (i.e., small-MFiber, medium-MFiber, and large-MFiber), with R^2 in the range of 0.0752–0.1713. The finding is inconsistent with Hongprasith, Kittimethawong, Lertluksanaporn, Eamchotchawalit, Kittipongvises and Lohwacharin [84], Herzke, Ghaffari, Sundet, Tranang and Halsband [93], Šaravanja, Pušić and Dekanić [94] who reported that untreated wastewater mainly contains fibrous MPs

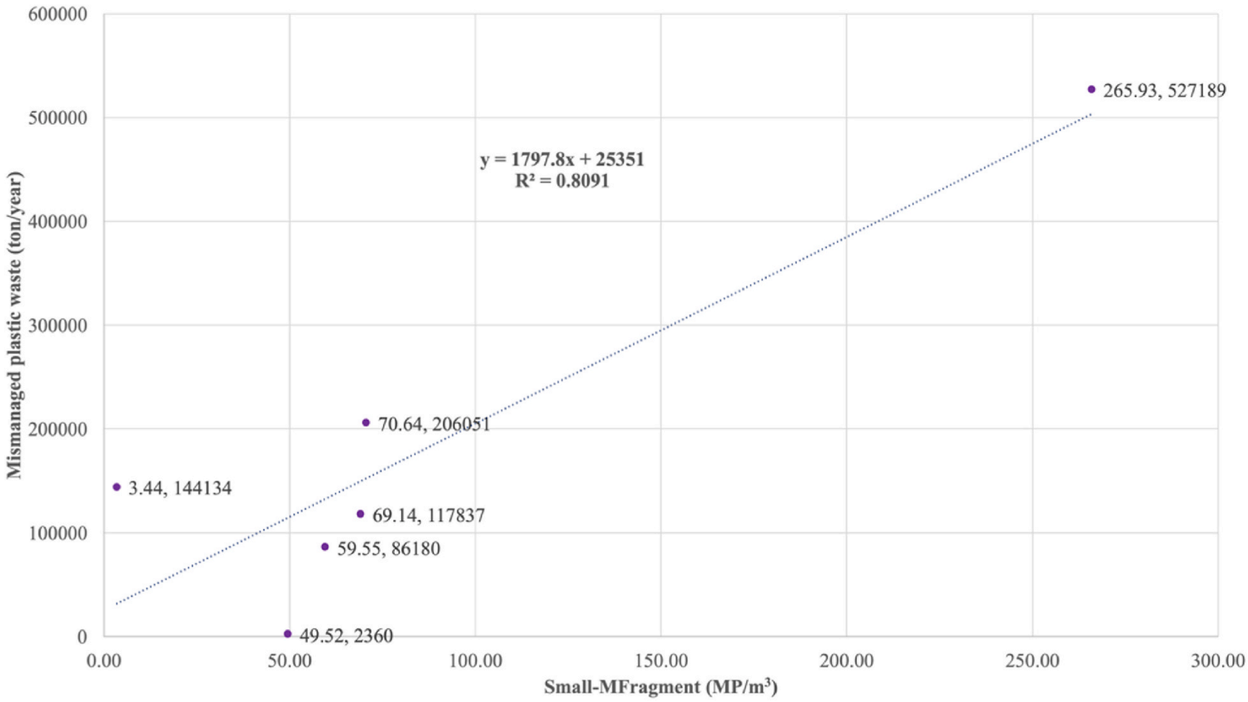

Fig. 5. The linear regression between mismanaged plastic waste and small-MFragment.

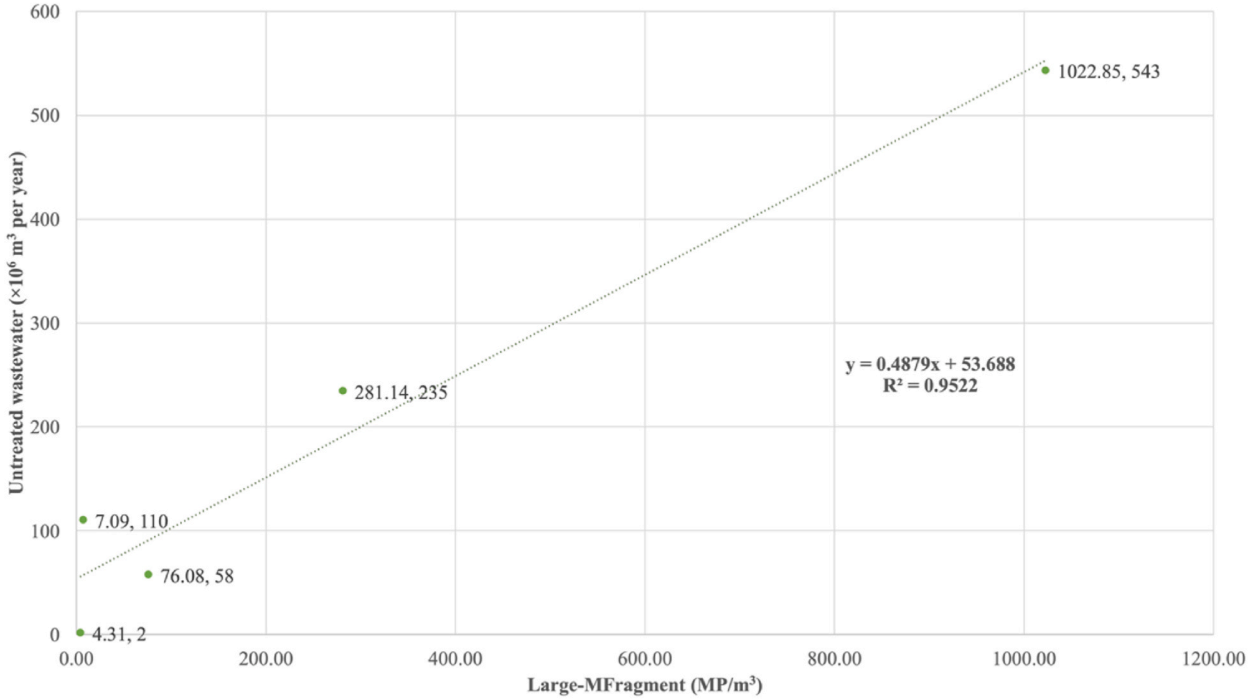

Fig. 6. The linear correlation between untreated wastewater and large-MFragment.

(microfibers). The inconsistency suggests that there are other influencing factors of MP generation, such as the degradation rates of plastics due to different physical, chemical and thermal processes; and the properties of synthetic fabrics [21,95]. Given the growing demand of synthetic fibers worldwide [96,97], the current plastic waste and wastewater treatment technologies are inadequate for removal of fibrous MPs prior to release into the environment. To reduce the MP pollution in receiving water bodies especially urban freshwater, the existing treatment systems should be augmented with at-source treatment technology to capture fibrous MPs, e.g., particle filters in a washing machine [98]. In addition, the synthetic fabrics need to become more environmentally friendly to reduce the MP contamination in the aquatic environment.

It should be noted that the quantitative analysis of the proposed control measures for the four influencing factors in this study lacks specification regarding the exact timeframe for observing enhancements. Consequently, the duration necessary for improvement and the corresponding reduction in MPs remain. Considering the findings, it is evident that further investigations are warranted to enhance the understanding of the influencing factors of MP generation and MP contamination. By refining the understanding of the polymer composition of MPs, identifying the types of products from which these MPs originate could lead to the formulation of targeted strategies aimed at mitigating MP proliferation by focusing on the regulation or elimination of specific plastic products. Moreover, it could underscore the necessity of implementing bans or restrictions on the production and usage of certain plastic materials contributing disproportionately to MP pollution. Fundamentally, thorough investigations into MP identification at a detailed level hold promise for accelerating the formulation of more impactful policy measures and management strategies to address MP pollution.

4. Conclusion

This research reviews and analyzes data on the MP contamination in the environmental systems (atmosphere, lithosphere, hydrosphere) and the levels of MPs in freshwater of 24 cities in 16 countries of different levels of national income. Linear regressions are analyzed between the influencing factors of MP generation, i.e., mismanaged plastic waste, untreated wastewater, number of registered motor vehicles, and stormwater runoff and the different MP size range (<300 μm (small), 300–1000 μm (medium), and 1000–5000 μm (large)) and MP type (microfiber and microfragment) found in the aquatic environment. The results reveal that MPs are most abundant in aquatic systems and pose a serious threat to the human food chain. The MPs smaller than 300 μm account for the largest proportion of the MP debris found in urban freshwater of high-income countries, while the MPs larger than 300 μm are predominant in the freshwater of countries of the lower-middle-income and upper-middle-income groups. Of particular interest is that MP contamination is rampant in freshwater of cities or metropolises, even with efficient environmental management. The regression analysis shows a strong relationship between mismanaged plastic waste and microfragment smaller than 300 μm in particle size ($R^2 = 0.8091$) and between untreated wastewater and microfragment of 1000–5000 μm in particle size ($R^2 = 0.9522$) in urban freshwater. To mitigate the MP contamination in urban freshwater, the improper plastic waste treatment and wastewater treatment needs to be phased out and replaced with proper management practices.

Data availability statement

The authors declare that the inventory data and the findings of this study are available within the article and in the supplementary information.

CRediT authorship contribution statement

Rutjaya Prateep Na Talang: Writing – original draft, Visualization, Resources, Investigation, Data curation. **Sucheela Polruang:** Writing – review & editing, Validation, Resources, Conceptualization, Methodology, Supervision. **Sanya Sirivithayapakorn:** Writing – review & editing, Conceptualization, Investigation, Resources, Validation.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

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