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Review Article

A Review of the Current Status of the Impact of Selected Microplastics on the Life-Cycle of Mosquitoes, Especially Vector Species

Gujju Gandhi[1], Ramesh Chandra[2], Shaukat Kamal[3]

[1]Scientist, National Environmental Engineering Research Institute (NEERI), (CSIR), Nagpur, Maharastra.
[2]Regional Office of Health & Family Welfare (NCVBDC), Kendriya Bhawan, Aliganj, Lucknow.
[3]National Centre for Disease Control (NCDC), Kitab Bhawan Lane, North Shri Krishna Puri,Patna, India.
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Corresponding Author:
Shaukat Kamal, National Centre for Disease Control (NCDC), Kitab Bhawan Lane, North Shri Krishna Puri,Patna, India.
E-mail Id:
shaukatkamal25@yahoo.in
Orcid Id:
https://orcid.org./0000-0002-3358-15724
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ABSTRACT

Microplastics (MPs) and nanoplastics (NPs) are worldwide pollutants affecting the environment - marine, freshwater aquatic or terrestrial/ aerial. The research findings from the globe remained confined to the marine environment, while toxicity has been reported in several freshwater aquatic and terrestrial organisms, the knowledge about how these pollutants can affect insects and other animals at the early developmental stage remains incipient and much have to be done in this direction. The findings have no consistency and hence, there is a need to investigate the ecological and potential public health implications on the life cycle of mosquitoes, particularly vector species.

Keywords: Microplastics, Nanoplastics, Vector-Borne Diseases, Environmental Pollutants, Mosquitoes

Introduction

With the advents of new technology and tools in the modern world, man has also modified or changed himself in accordance with the availability of the material required for daily needs. The modern world has become much more dependent on the use of material made from plastic since the later half of the 20th century, be it the daily use of bags for marketing, utensils for various purposes - drinks, eatables, transportation of material or storage replacing the readily degradable packaging or dispensing material, due to their low cost and more persistency.[1,2] Plastic is widely used globally due to the ease of manufacturing, low cost, stable chemical properties, and good water resistance, the production has been steadily increasing year to year. The plastic used generally includes polystyrene, nylon, polyurethane, and polypropylene, Accordingly, man has not only become adapted for such practices but has also opted to use plastic goods. Plastic has become an inseparable part of our daily life. The widespread indiscriminate, mismanaged and unsafe use/ disposal of a massive amount of household products made up of different plastic polymers has become a cause of environmental pollution in the world.[3–8] The COVID-19 pandemic enhanced the release of micro-plastic in the environment.[9–11] The European Environmental Agency reported in its research that the total quantity of terrestrial

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microplastics (MPs) found on the ocean floor is estimated to be around 14 million tonnes. It was also estimated that the use of microplastic has become a global problem on account of its accumulation in the environment because it is being released into the environment all over the world. These plastics are gradually decomposed/ fragmented by the physical, chemical and biological effects in the environment, but the process of decomposition takes a long time for complete decomposition of the plastics. Most of the plastics released in the environment constitute plastic debris with small-sized particles-microplastics (MPs). The small-sized plastic debris with a diameter of < 5 mm (1 µm to 5 mm) forms MPs, which are considered to be toxic and particles even smaller than 1 µm constitute nanoplastics (NPs).[12–17] There is direct entry of micro-sized plastic into the environment through domestic and industrial wastes/ effluents.[18] The accumulation of MPs in the physical[19,20] and biological environment,[21–23] has led to the open field of research for quantification of the MPs in different eco- systems and in living organisms, together with their impact on human and animal physiology.[24,25] Microplastic pollution has caused many hazards to marine life and has already produced widespread concern8 but MPs have been detected in freshwater organisms[26–28] and in food webs too.[29,30]

Vector-borne diseases (VBDs) not only affect human beings but also pose a major threat in tropical and subtropical countries including India, resulting in social distress and economic loss. VBDs are infections caused by pathogens/ parasites, and transmitted by hematophagous arthropod vectors (bedbugs, biting midges, black flies, fleas, kissing bugs, lice, mosquitoes,sand flies, ticks and mites). People suffer from a significant disease burden from these diseases in local and focal areas of India, which is reflected in the form of morbidity and mortality from malaria, dengue, chikungunya, Japanese Encephalitis (JE), Kala-azar, and lymphatic filariasis. Though India has made significant achievements towards the elimination of malaria, lymphatic filariasis and Kala-azar, visceral leishmaniasis, yetmany other arboviral diseases like dengue, chikungunya and Japanese Encephalitis have experienced area-specific increases in the past few years due to local and focal outbreaks in many parts of our country. Zika virus infection, Chandipura viral fever, CCHF fever, KFD and Scrub typhus are also adding to a public health concern in the regions. Though the diseases are zoonotic, but have more concern to human health perspective due to the high mortality caused by them. Among the hematophagous arthropod vectors, mosquitoes are the leading vectors for human infections, and both the vector as well as human host are exposed to the contamination of the MPs in the environment. A number of studies have been conducted on the presence of MPs in the environment related to vector mosquitoes and human beings.

An attempt has been made through the present article to make an in-depth review of various research on vector mosquitoes so that the inference drawn can be utilised for applying the tool in controlling the vector and consequently vector-borne diseases too.

Methodology

The literature on MPs was searched through journals available in the library and through the internet related to the impact of MPs on the aquatic (larva and pupa) and aerial/ terrestrial forms (adults) of vector mosquitoes. Both laboratory findings as well as natural habitat findings were reviewed. Additionally, those findingsrelated to the macro-plastic material were also kept on record, which supported the development of the vector and spread the dreadful diseases. The data available was critically analysed and reviewed and the inference drawn has been presented in this communication.

Salient Observations and Discussion

On perusal of the research work conducted with respect to the impact of MPs, which are common environmental pollutants, it was found that the pollution due to MPs was proliferating gradually in marine, freshwater and terrestrial environments, without any or with poor understanding of their biotic implications. Plastic pollution was first reported in the aquatic environment in 1972 and accordingly, the thrust remained towards the marine aquatic environment. Though some studies were conducted to assess and evaluate its toxicity on humans and the environment,[31] very little is known about its effects on insects, mainly the disease vector mosquitoes.

In recentstudies carried out so far, the uptake, ontogenic transference and effect of different concentrations (0, 50, 100 and 200 MPs mL^{-1}) and sizes (2 and 15 µm) of polystyrene MPs between aquatic and terrestrial life stages of Culex pipiens complex mosquitoes have been discussed. Both 2 and 15 µm MPs transferred from the aquatic larval to the terrestrial adult stage of Culex mosquitoes, and uptake correlated tightly with initial exposure concentration. However, neither the concentration nor size of MPs significantly influenced mortality rates between the aquatic larval and terrestrial adult stages. Thus, no impact of MPs was observed on the weight of emerging mosquito adults. It was also observed that the exposure of MPs does not affect mortality rates between life stages of freshwater Culex populations, which suggests that MPs do not impact nutritional uptakes, with unhampered development to adulthood. MPs were transferred ontogenically through organisms with complex life histories, presenting a potential pathway for dispersal of MPs into terrestrial environments i.e. facilitating subsequent dispersal of MPs aerially and between freshwater and habitats.[32] The high concentrations of MPs in habitats did not deter *C. pipiens* adults from ovipositing. Moreover, MPs can move readily through freshwater food webs via biotic processes such as predation, and reveal high potential for MP exposure and transference through ecosystems.[33] On the other hand, polyethylene microplastics (PE MPs) lead to biochemical changes predictive of nutritional impacts, as well as induce oxidative stress, redox state imbalance, and neurotoxicity in *Culex quinquefasciatus* larvae. The short exposure to PE MPs (5 days) at the environmental concentration of 4.24 x 106 particles m^{-3} induced changes, which suggest damage to energy metabolism such as reduced total proteins, total soluble carbohydrates, and triglycerides levels. In addition, increased thiobarbituric acid reactive species, in association with reduced total glutathione and DPPH radical scavenging activity (%) have suggested an imbalance between oxide-reducing agents and antioxidant defence system, induced by pollutants. On the other hand, increased acetylcholinesterase activity has suggested the neurotoxic effect of PE MPs. At last, PE MPs have accumulated in the larvae, and it may have been a triggering factor for the observed changes. Thus, observations confirmed the potential of *Culex quinquefasciatus* larvae to act as transporters of MPs in different ecosystems and how PE MPs can affect their development and lead to losses in different ecological functions of the species.[34] Therefore, the change in the impact of MPs may be attributed to the type of MPs, which remained polyethylene MPs in the later cases, and the species of the mosquitoes.

In another species of vector mosquito, *Aedes aegypti* completes metamorphosis and polystyrene (PS) MPs can pass from feeding aquatic larvae to non-feeding pupae and adults that fly to land. Two-micrometre of polystyrene (PS) microspheres were readily ingested by larvae, affecting the feeding behaviour of the larvae and with an increase in body weight without affecting the development and mortality of the mosquitoes. Thus, the blood-sucking vector mosquito, *Aedes aegypti* has no adverse effect of PSMPs on development and mortality and may participate in the circulation of MPs, carrying particles from aquatic to terrestrial environments.[35] Here again, the types of MPs and mosquito species are different and may have different behaviours. Similarly, in another study, a total of 1241 MPs belonging to polyethylene, polycarbonate, polypropylene, polystyrene, polyvinyl chloride and nylon with sizes ranging from 0.5 µm to 80 µm in diameter were isolated from the mosquito larvae of *Aedes aegypti*. Indeed all four stages of mosquito larvae feed on NPs and subsequently transfer them to non-feeding pupa and then to flying adult mosquitoes, further to the offspring. However, the NP exposure and accumulation did not affect the survival of mosquitoes, but altered the biochemical constituents, thereby delaying the development of mosquitoes. Notably, the female mosquitoes that emerged from the NP treatment group showed increased blood-feeding activity and increased starvation resistance capacity. The puzzling accumulation of NPs/ residues in different organs, especially in the salivary gland signifies that female mosquitoes could potentially inject polymer residues into humans and animals and carry particles from aquatic to terrestrial environments.[36] The findings of this study are in conformation with a previous study.[35] However, MPs consist of many types of polymers of plastic, with little or no impact.

The effects of polyethylene MPs, the most common MP documented in environmental samples, on the development and survival of the mosquitoes *Aedes albopictus* and *Culex quinquefasciatus* have been discussed ahead. In laboratory egg-laying and larval development container environments, similar to those used by both species in the field, a mix of 1–53 µm MPs at concentrations of 60, 600, and 6000 MP ml^{-1} increased early instar larval mortality in both species relative to control treatments. A significant difference was found in the response of each species to microplastic at the lowest microplastic concentration tested, with *Culex quinquefasciatus* survival equivalent to that in control conditions but with *Ae. albopictus* larvae mortality elevated to 37% within 48 h. These results differ from those of previous studies in which larvae were only exposed to MPs during the last aquatic instar stage and from which it was concluded that microplastic was ontogenically transferred without negatively affecting development. Increasing plastic pollutant concentrations could therefore act as selective pressures on aquatic larvae and ultimately influence outcomes of ecological interactions among mosquito vector populations.[37] It is obvious from these findings that all mosquito vector species may not behave in a similar manner and such factors responsible for developing the ability to withstand the species against adverse environmental conditions/ microplastic pollutants are of utmost need. In another study, no effect of MP exposure was observed on body size, development, and growth rate, when the wild-type first instar *Culex pipiens* and *Culex tarsalis* larvae were exposed to two 4.8–5.8 µm polystyrene microplastic concentrations (0 particles/ml, 200 particles/ml, 20,000 particles/ml) to evaluate the effect of MP exposure on body size, development, and growth rate. As such no effect of microplastics was found on any of the traits in either species. These results indicate microplastic exposures comparable to levels found in nature have minimal effects on these fitness-related traits. Future directions for this work include examining whether the effects of MP exposure are exacerbated when evaluated in combination with other common stressors, such as warming temperatures, pesticides, and food limitations.[38] The *Aedes* (Stegomyia) *aegypti* (L.) and (Stegomyia) *albopictus* (Skuse) mosquito larvae were fed 1 µm polystyrene MPs and examined the impacts of ingestion on adult emergence rates, gut damage, and fungal and bacterial microbiota. Results show that MPs accumulate in the larval guts, resulting in gut damage. However, little impact on adult emergence rates was observed. MPs are also found in adult guts post-emergence from the pupal stage, and adults expel MPs in their frays after obtaining sugar meals. Moreover, the effects of MPs on insect microbiomes need to be better defined. To address this knowledge gap, we investigated the relationship between MP ingestion and the microbial communities in *Ae. albopictus* and *Ae. aegypti*. The microbiota composition was altered by the ingestion of increasing concentrations of MPs.[39] The study on the effects of MP and NP ingestion on the survivorship and reproduction of two medically important mosquito species, *Aedes aegypti* (L.), and *Ae. albopictus* (Skuse) reflected that the larval and pupal survivorship were not significantly affected by particle size or concentration, but there was a reduction of *Ae. aegypti* pupal survivorship associated with the ingestion of 0.03 µm NPs. Results also suggest that ingesting 0.03 µm NPs reduced egg production in both mosquito species. However, there was little impact of 0.03 NP and 1.0 µm MP ingestion on adult survivorship and longevity. To further investigate the effects of MP ingestion on mosquito fitness, we also examined the effects of laboratory-generated MPs of varying shape, size, and plastic polymer type on *Ae. aegypti* immature and adult survivorship. The data suggests that the polymer type and shape did not impact *Ae. aegypti* immature or adult survivorship. These findings highlight the potential consequences and the need to investigate further the ecological and potential public health implications of MP and NP ingestion by mosquitoes.[40]

From the aforementioned observation, it is obvious that there is a big gap in the studies so far related to the freshwater breeding mosquito species and the opinion of difference is due to the fact that in one study, the microplastic type is different or collectively many polymers taken into account, at another place the species are different and environmental stress factors not considered in the study, likewise many more, which are not enabling us to find some considerate findings. There is a need to investigate the ecological and potential public health implications of MP and NP through mosquitoes. Overall, the microplastic has little to do with the vector species of mosquitoes but their macro forms are posing a threat to human health due to indiscriminate disposal of plastic wares/ articles in an open environment, enhancing the congenial breeding habitats of *Aedes* mosquito.[41] The proper disposal of such macro-plastic material can help us to minimise the risk of diseases like dengue, chikungunya, Zika virus and yellow fever.[42] Such acts on the part of the public will not only help in containing the disease at no delay but will also prevent its spread to other areas,[43] together with maintaining the cleanliness of the environment.

Conclusion

Through this in-depth review of the research findings from around the globe, it can be concluded that MPs' toxicity has been reported in several aquatic and terrestrial organisms. The knowledge about how these pollutants can affect insects at the early developmental stage remains incipient and much has to be done in this direction. The findings have no consistency and hence, there is an imminent need to investigate the ecological and potential public health implications of MP and NP through mosquitoes.

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