

Research article

Inapt management of menstrual hygiene waste (MHW): An urgent global environmental and public health challenge in developed and developing countries

Utptal Anand^a, Meththika Vithanage^b, Anushka Upamali Rajapaksha^{b,c}, Abhijit Dey^d, Sunita Varjani^e, Elza Bontempi^{f,*}^a Department of Life Sciences, Ben-Gurion University of the Negev, Beer-Sheva 84105, Israel^b Ecosphere Resilience Research Center, Faculty of Applied Sciences, University of Sri Jayewardenepura, Nugegoda, CO 10250, Sri Lanka^c Instrument Center, Faculty of Applied Sciences, University of Sri Jayewardenepura, Nugegoda, 10250, Sri Lanka^d Department of Life Sciences, Presidency University, 86/1 College Street, Kolkata 700073, West Bengal, India^e Gujarat Pollution Control Board, Paryavaran Bhavan, CHH Road, Sector 10A, Gandhinagar 382 010, Gujarat, India^f INSTM and Chemistry for Technologies Laboratory, Department of Mechanical and Industrial Engineering, University of Brescia, Via Branze, 38, 25123, Brescia, Italy

HIGHLIGHTS

- Menstrual hygiene waste represents an underestimated environmental problem.
- It is critical not only for women's health and dignity, but also for the environment.
- It cannot be still consider a problem relegated only to low-income countries.
- The menstrual hygiene waste generated from migrants is considered for the first time.
- Dedicated actions are proposed to solve knowledge gaps in this field.

GRAPHICAL ABSTRACT



ARTICLE INFO

Keywords:

Menstrual hygiene waste (MHW)
 Waste management
 Environmental pollution
 COVID-19
 Human health
 Sustainable development goals (SDGs)

ABSTRACT

Menstrual hygiene waste management has received lack of attention and hence it has been poorly investigated, mainly due to its association to social and cultural aspects of a natural process, that is often surrounded of entrenched stigma and taboos. Therefore, data about quantities and full lifecycle of the generated waste are often not available or suffer of large uncertainty.

However, this argument represents a relevant and critical issue, not only for the health of the women, their equality, and dignity, but also possible associated environmental concerns. This work highlights the necessity and the urgency to face the problems associated with menstrual hygiene waste, which cannot be still considered only relegated to low-income countries. It gives the dimension of the waste associated to migrants in the incoming areas, which is often neglected in sanitation program implementation. This work also describes the existing knowledge gaps and suggests some actions to implement in the next future.

* Corresponding author.

E-mail address: elza.bontempi@unibs.it (E. Bontempi).

In the pandemic context, menstrual hygiene needs urgent attention, also to understand the possible implication of this waste, generated for example in refugees' camps, in SARS-CoV-2 spread, and to prevent eventual unknown environmental issues connected with the reconvention of some factories from the production of menstrual hygiene products to facemasks manufacture.

1. Introduction

World Health Organization defines an adolescent as a person aged 10–19 years old (WHO, 1996). During this period, the child undergoes physical, psychological, and biological development and women's menarche marks the start of the reproductive phase of their lives, which is an important biological milestone. Most women reach menarche between the ages of 12 and 13 years old, which is consistent across populations. Although menstruation is a natural process, in several societies it is still surrounded by entrenched stigma and taboos, because it is regarded as dirty and unclean. This is generally coupled with a lack of knowledge about menstruation biological background and management, as well as shyness and embarrassment.

Menstruation wastes are the wastes that a woman generates during her reproductive years. They are produced during the menstrual cycle, also called menses, periods, or the monthly bleeding cycle (Swenson and Havens, 1987). Hormones regulate menstruation, and this process involves the endometrium, or uterine lining, gradually thickening and shed off during a period of 3–5 days, or even as long as 7 days. Mucus and vaginal secretions are also contained in the menstrual fluid, in addition to blood. Each woman experiences their menstrual flow differently and it can appear more or less at the beginning of menses, or it can vary throughout the menstrual cycle. Menstrual fluids usually have different colors, ranging from red to bright red and to dark brown to black. During hormonal imbalances, fibroids, polyps, and endometriosis, menstruation can flow more, and excessive bleeding can lead to anaemia (Goldstein and Lumsden, 2017).

Unfortunately, literature devoted to menstrual hygiene waste (MHW) is very limited, and the lack of suitable and comprehensive studies devoted to present and discuss the environmental problems associated with MHW management is evident. The experience of women (mainly adolescent girls), particularly the issues connected with managing menstruation, has dominated the discussions, with great attention to the implications connected with the gendered dimensions of sanitation-related psychosocial stress (Amiya et al., 2010; Sommer, 2013; Sommer et al., 2013; Sommer and Sahin, 2013; Mohammed and Larsen-Reindorf, 2020; Schmitt et al., 2021; Sahiledengle et al., 2022). Only few works report general considerations about possible environmental issues generated by MHW (Muralidharan, 2018; Bhagwat and Jijina, 2020). These works are devoted to studies only in societies with inequitable gender norms, showing that disposal of menstrual hygiene products is often improperly managed, with a consequent high danger that some products end up in the waterways and oceans (Pachauri et al., 2019). To have an idea about the importance of this problem, it is sufficient to report that the most common products purchased by Poles for war refugees from Ukraine (in March 2022) were personal hygiene products, with feminine hygiene products reaching 44% (source <https://marketingprzykawie.pl/>).

Therefore, several knowledge gaps exist about this task. For example, at the end of 2021 literature does not provide a reliable and affordable evaluation of the waste generated by menstrual hygiene products. The main cited data (Bharadwaj and Patkar, 2004) was published more than 16 years ago and estimates that a woman disposes 125–150 kg of sanitary waste along her life (ranging from pads, cloth pads, internal absorbents, and menstrual cups); then considering the global population women, the yearly world generated MHW may range between 250 to 300 millions of tons. However, no data are available about the amount of similar waste generated by women in crisis conditions, as for example by refugees and/or migrants. In addition, all the environmental and health

implications of MHW are still undisclosed. This can be also partially attributed to another fundamental knowledge gap: the lack of complete information concerning materials and manufacturing technologies of menstrual hygiene articles, which is mandatory to establish the most suitable technologies for MHW disposal. Finally, the establishment of the most suitable management strategies for these wastes among women living in precarious conditions remains a problem.

Figure 1 shows the number of refugees worldwide in 2017, by housing type. Accommodation types are classified as planned/managed camp, self-settled camp, collective center, reception/transit camp, and individual accommodation (private), as well as unknown if the information is not available. It is evident that unknown accommodation and situations with refugees living in camps and camp-like situations are more than half.

The main goal of this paper is to fill some of the existing literature knowledge gaps about MHW, specifically addressed to women living in refugees' camps. This was obtained by giving some realistic and quantitative dimensions of an urgency, that is often considered to be relegated only to low-income countries, showing that it also concerns the developed areas, as for example USA and Europe, where women in critical situations, that are homeless or in accommodation of a temporary nature, can be found. For this aim, for the first time, the female migrant's situation is considered, proposing an estimation of the generated MHW. This work also presents the possible environmental risks associated with MHW incorrect management, due to women living in refugees' camps, and suggests some dedicated actions that should be implemented. The problem needs urgent attention also considering the pandemic and the current virus resurgence due to SARS-CoV-2 variants, as better explained in the section 3.2.

2. Methodology

2.1. Bibliographic analysis

Literature only provides an estimation of the MHW generated in some countries (see for example Bharadwaj and Patkar, 2004). For this work, the Statista platform (<http://www.statista.com/>), which provides data about the market survey, has been considered. In particular, the reports that have been acquired are the following: “Feminine hygiene market” and “Menstrual protections and precariousness in France”. All the data concern 2021.

The relevant scientific papers for this work were selected by searching in the SCOPUS database only two terms “menstrual” and “waste” in the

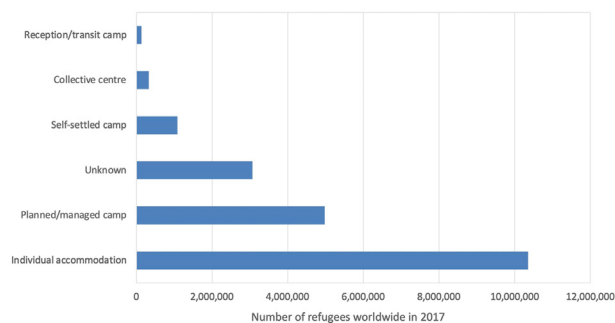


Figure 1. Number of refugees worldwide in 2017, by housing type (source UNHCR Global Trends – Forced Displacement in 2017).

keywords, title, and abstract. 93 documents resulted, showing an increased research interest in the last years, even if the annual number of published articles is still very low (see Figure 2). In addition, only 145% of papers concern environmental sciences, corresponding to only 23 studies which are relevant to the scope of this paper. Several articles present MHW disposal (unsuitable) procedures mainly in low- and middle-income countries (Robinson and Barrington, 2021). However, most of these works are based on survey results, addressed to understand the disposal practices, whereas the environmental implications due to the derived waste are essentially not presented and discussed. The first literature available considerations about the environmental sustainability of menstrual hygiene products have enhanced the advantages of using reusable disposal products (Hait and Powers, 2019) and proposed the use of biodegradable absorbents materials (Foster and Montgomery, 2021), also for women living in low- and middle-income countries. However, it is evident that this possibility cannot be considered in all the situations, as for example for migrants, generally living in poor hygienic conditions (as for example in camps). Poor menstrual hygiene can lead to reproductive tract infections, which can affect not only her current health but also her reproductive capabilities and well-being in the future. It was shown that particularly for women in low-income countries, the employ of reusable absorbents, instead of disposable pads, can be associated to urogenital diseases (Das et al., 2015). The proposition to use a reusable device must be coupled with the knowledge that it may be safe if it is correctly used (Das et al., 2015). As a result, proper menstrual-related information and habits are critical to adolescent girl's health and development. Unfortunately, a research survey (Ali and Rizvi, 2010) showed that in most developing nations there is a low attention to this crucial problem. Concerning some possible solutions to limit the environmental problems caused by MHW, some authors have suggested to reduce the mass of the adsorbent's products used for sanitary napkins, and to use more sustainable raw materials in producing menstrual hygiene products, as for example wood pulp for the absorbent (Hait and Powers, 2019), able also to guarantee less and cost-effective management.

The results of bibliometric analysis show that a more holistic study, involving the environmental impact of not suitable disposal of MHW, considering woman rights, opportunities, inclusivity, and health, also in critical situations, is mandatory. In particular, literature considering critical situations, as women that are homeless or in accommodation of a temporary nature, in rich countries is absent.

Humanitarian crises, that can be due to natural catastrophes (for example floods) or socio-political conditions (for example wars), exacerbate the problem of MHW management, given women's generally lack

access to safe disposal, producing a totally uncontrolled environmental emergency.

Population migration is a clear example. It represents a source of waste dissemination, for example in refugees' camps, that cannot be controlled and/or managed. However, most of the guidance devoted to managing an environment, sanitary, and humanitarian crisis is basically concentrated in the water, hygiene, and sanitation (Sommer et al., 2018) and does not incorporate the results coming from multidisciplinary knowledge needed for a comprehensive and effective analysis, evaluation, and response to the menstrual hygiene waste problem.

2.2. Menstrual hygiene waste generated by migrant women

Table 1 reports the average volume of paper used for feminine hygiene products (tampons and sanitary pads) calculated by using the market data provided by the Statista platform for 2021 (the data are evaluated considering only woman aged between 10 to 49 years). The 2021 average revenue is also provided. Mean world values and the corresponding data for two African states are reported as a comparison. France data allows to highlight the values corresponding to an industrialized EU country. As expected, the use of these products is much lower in low-income countries if the average value is considered as also the market revenue. The amount of annually generated MHW by female migrants, for the different destination regions, is estimated using the following approach. Statista platform shows that in France generally only 7.7% of women use sometimes washable sanitary towels and more than 65% employ single-use tampons and pads. To produce a suitable evaluation of the produced MHW in refugee' camps, it is reasonable to suppose the use of only disposable pads and tampons (and no other additional

Table 1. Average volume (kg) and revenue (\$) per women of paper used for feminine hygiene products (tampons and sanitary pads) in 2021. Data were extracted from the Statista platform (<http://www.statista.com/>) and normalised considering only woman with an age between 10 to 49 years.

	Average volume per woman (in Kg)	Average revenue per woman (\$)
Worldwide	1.4	19.7
Burundi	0.3	3.2
Burkina Faso	0.3	4.5
Southern Africa	1.3	17.3
France	1.8	30.6

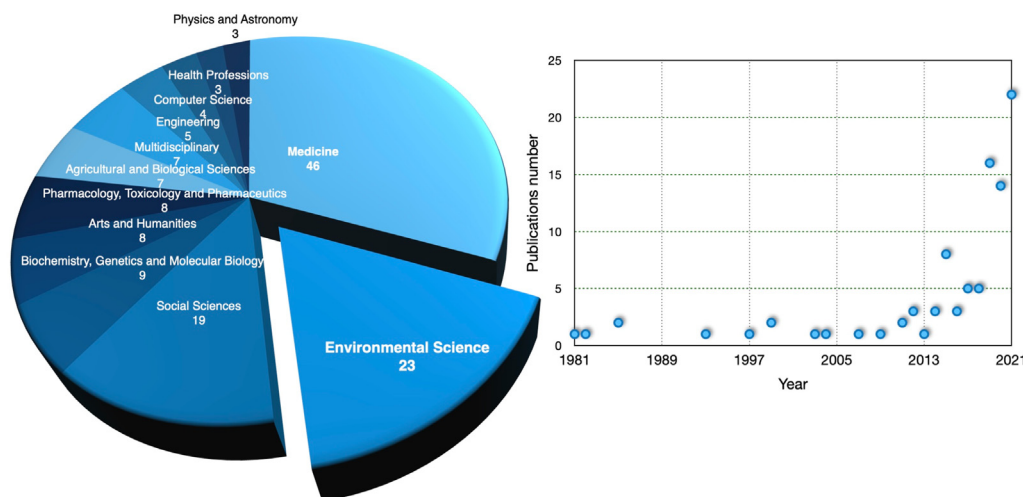


Figure 2. Scopus papers containing the terms “menstrual” and “waste” in the keywords, title, and abstract, represented by subject area and publication year, published from 1981 to 2021. The search was updated on February 2, 2022. In 2022 (at the moment) only two papers are published (not reported in this figure).

menstrual hygiene products) and the total waste mass of a single menstrual period can be assumed 0,139 kg (Sasidaran et al., 2021). This value is in accord with data about the amount of paper used for feminine hygiene products (tampons and sanitary pads) extracted from retail sales market analysis by Statista (see Table 1). Recent literature suggests a mass of 1,470 kg for a month (Velasco Perez et al., 2021); however this value corresponds to the French market data, then our proposed value can be considered more reliable if women in critical conditions are considered. It corresponds to a global amount of about 67 kg of sanitary waste along each woman life (considering the migrant condition), which is about 1/2 of the waste value generally proposed for a woman in the most cited literature (Bharadwaj and Patkar, 2004).

The geographical flux of female migrants (with an age between 10 to 49 years, then producing MHW) was evaluated considering their origin regions and their destination regions, using data extracted from the International Migrant Stock 2020 database (Migrant Stock, 2020).

Then, data about the waste generated in the incoming countries are obtained considering for the incoming female migrant a residence of a single month (then a single menstrual period) in a camp. It is evident that the residence period can be extremely variable. However, based on these data, more accurate evaluations may be done for single countries, with known migrant's residential time.

3. Results and discussion

3.1. Menstrual hygiene waste generated by migrants

Monthly hygienic menstruation products such as sanitary pads, tampons, and menstrual cups are required for women, girls, and transgender persons to live healthy and productive lives. Even though women's menstrual hygiene practices should be simple, a huge proportion of people lack sufficient hygiene knowledge or live in critical conditions. The Statista platform report highlights that in France more than 25% of the woman were affected by menstrual precariousness during their life, mainly connected to the instruments used for menstrual protection. 76% of French woman are convinced that menstrual precariousness is a public health issue.

The environmental and consequent human health implications of women's menstrual hygiene products need to be investigated and quantified in a comparative solid waste management/assessment of feminine hygiene products. A greater understanding of the impacts these products have and the processes or components that cause these effects can help discover areas where the product can be improved. These effects are also influenced by a woman's personal habits and rate of sanitary product use.

In particular, women's menstrual hygiene products can result among the major contributors to many environmental and human health issues in some critical conditions. For example, the generally lack of sanitation infrastructures for migrants living in camps, allows to suppose that this waste can be disposed in the environment.

Figure 3 shows the flux of female migrants, with an age between 10 and 49 years, in the last year (2020), which can be evaluated from their origin regions to their destination regions. Data were represented by a Sankey chart. The numbers of involved people are impressive, and all the continents are implicated in this humanitarian crisis, adding a sense of urgency.

From these data it is possible to estimate the produced MHW (see section 3).

Figure 4 shows the amount of menstrual hygiene waste, that can be annually generated by female migrants, considering the involved population reported in Figure 2, in the incoming regions, considering only one month of residence for each woman. This is the first time that these results are presented. Moreover, due to the choice to select a low weight and limited use of menstrual pads actual figures are expected to be higher, till to double values.

It is also important to highlight that several of the migration flows involve some months of movement, with also possible long time permanence in some areas. However, due to the lack of statistics, the temporal transition in different regions cannot be considered in the evaluation of the generated MHW and the eventual additional MHW due to women that are accounted as migrants in the previous year's cannot be estimated. In addition, despite that the assessment proposed in this work is very conservative, because only one month of permanence is considered, it shows that for several countries the amount of generated waste, that may result in high environmental contamination, cannot be neglected. For

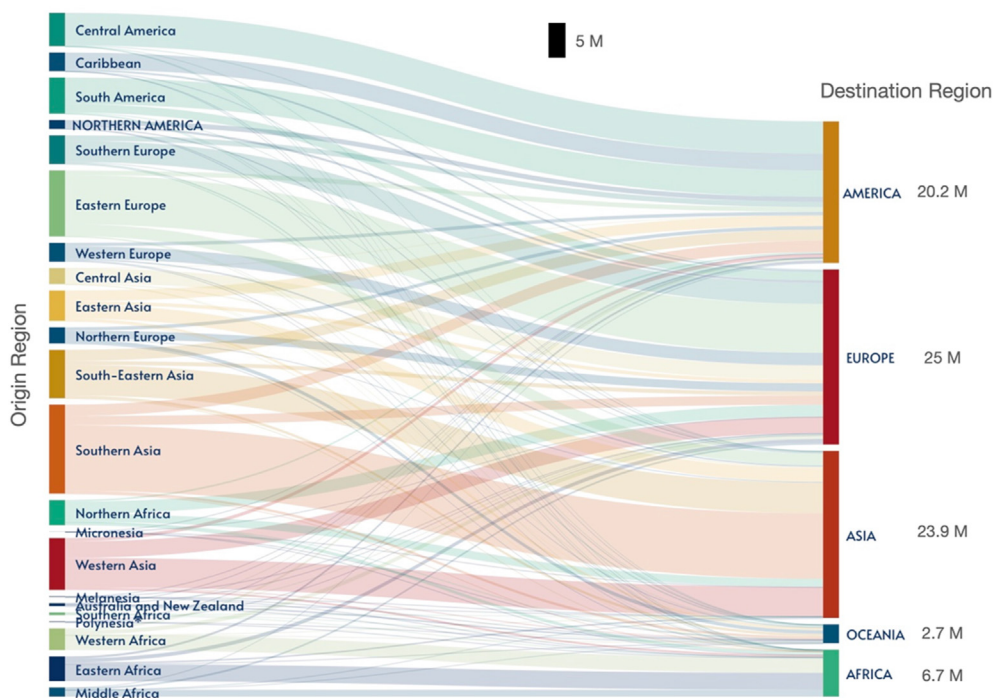


Figure 3. 2020 female (10–49 years) international migrant stock. Data were extracted from the International Migrant Stock 2020 database and represented by a Sankey chart showing the regions of destination and origin. Data are represented in millions (M).

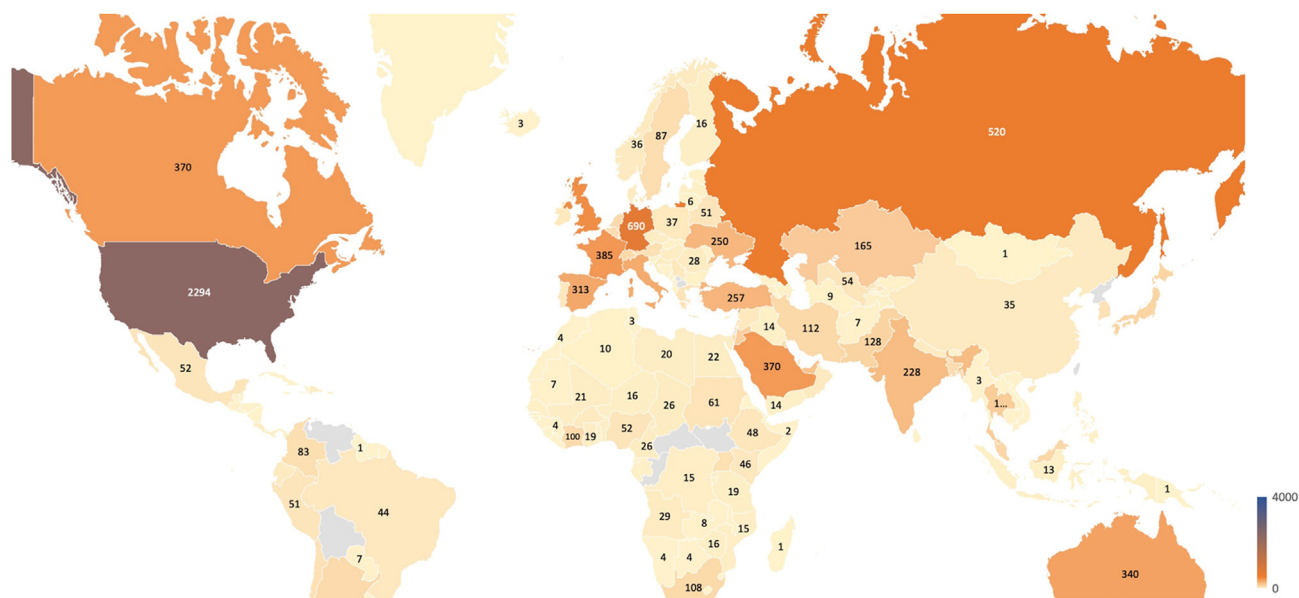


Figure 4. Amount (in tons) of menstrual hygiene waste, that can be annually generated by female migrants (considering the involved population reported in Figure 1) in the incoming regions. These results are obtained considering a residence of only a single month per migrant. The mass of a single waste was assumed 0,139 g in accord with ref (Sasidaran et al., 2021).

example, it results that the USA is the area most affected by this problem, with about 2300 tons of MHW. Europe, Germany, and France are the main involved countries.

3.2. Environmental concerns due to menstrual hygiene waste

The most diffused menstrual products are absorbents, like sanitary pads, tissue paper, and cloth, that can be also homemade (Elledge et al., 2018). Cloth pads are environmentally less polluting compared with disposable pads. However, their cleaning can be highly problematic in critical situations, as for example for women living in low- and middle-income countries, since it needs privacy and access to water. Then disposable pads are generally preferred, if available.

Environmental concerns derived from the uncontrolled disposal of menstrual hygiene waste can be associated with the materials used in their manufacturing and/or with the contained menstrual fluid.

Chemicals used in menstrual hygiene products are generally unregulated, with the consequence to be unchecked by governmental authorities' agencies. For example, in the USA neither the Food and Drug Administration nor the Environmental Protection Agency can monitor or require testing for the used materials. The consequence of the greater ingredient disclosure is that most menstrual hygiene products often contain residuals, as for example volatile organic compounds (Lin et al., 2020) and are realized by using low-cost materials (Woeller and Hochwalt, 2015), as petroleum-based plastics, like polyethylene and polyester, with high degradation times (around 500–800 years). Some of that, for example, acrylate (Sauder and Pratt, 2015), can release potentially toxic monomers or/and additives from the polymer network (Bettencourt et al., 2010). Other products contain pesticides, that can originate also from natural fibers as cotton (Kaur et al., 2018), like atrazine (Hait and Powers, 2019), pyrethrum, and procymidone (DeVito and Schecter, 2002), which can contribute to acute and chronic aquatic toxicity. Adhesive can contain hazardous chemicals like methylidibromo glutaronitrile. Some materials used for their fragrance and/or antibacterial activity contain chemicals like organochlorines. They can kill the microflora of the soil and delay the decomposition process (Kaur et al., 2018).

Finally, it is also important to highlight that combustion of sites where this waste is accumulated, may generate toxic air emissions, contain polychlorinated dibenzodioxins and other potentially dangerous

chemicals, and contribute to groundwater contamination as a result of leaching.

In addition, the current pandemic situation, with virus resurgence due to SARS-CoV-2 variants, involves completely unexplored implications of the consequence of uncontrolled dissemination of sanitary contaminated waste in the environment. In particular, the woman lower genital tract is exposed to different microorganisms, that can also result in microorganisms and/or endotoxin accumulation of in the menstrual fluid (Khan et al., 2010). Despite that it was shown that SARS-CoV-2 can survive several days outside the human body (Anand et al., 2021a, 2021b, 2021c, 2022; Iyer et al., 2021), no studies about the possible role of MHW in the transmission of the coronavirus disease-2019 (COVID-19) infection can be found in the literature. In particular, it was already reported that HIV virus may be transmitted by improper disposal of similar waste (Pachauri et al., 2019). Nonetheless, it is possible that MHW may represent a source of leaching of microorganisms and toxins into waterways (Pachauri et al., 2019). Indeed, SARS-CoV-2 infection cases have been confirmed in several refugee camps (Ismail et al., 2021).

3.3. Possible actions

Literature has already highlighted that reusable product, like the menstrual cup, could significantly reduce MHW being incinerated or sent to landfills (Blair et al., 2022). In particular, a menstrual cup is made from medical grade silicone rubber and may be sterilized and recycled. On the contrary disposable pads had a high impact on climate change and eutrophication and tampons strongly impact resource depletion (Hait and Powers, 2019). However, considering the Sustainable Development Goals (SDGs), it was recognized that reusable products are not suitable for people in the condition of homeless or in temporary accommodation (Vora, 2020). In these conditions indeed it is not possible to guarantee a suitable washing of these products. Then the attention must be devoted to disposable pads.

The data discussed in the two previous sections highlight that the examination of MHW environmental impacts is very urgent and that some actions are mandatory. As reported in section 2.1 limited actions have been already proposed for a better management of MHW: the adsorbent's mass reduction (Hait and Powers, 2019) and the use of more sustainable raw materials in their production (Hait and Powers, 2019).

Following the discussion of data reported in this work, it is possible to propose additional actions, devoted to disposable products. First, it appears that it is impossible to estimate environmental implications during and years after use, without dedicated studies to understand the MHW leaching of various elements (and/or pathogens) in the environment. Then dedicated research activities must be proposed and supported. The findings of these studies could have consequences for how menstruation products will be defined in future and how improvement actions will be planned in the domain of waste management. Second, the use of environment-friendly chemicals for the manufacturing of these products, to limit the possible soil, water, and air pollution effects, must be imposed. In this frame also the use of not mandatory treatments, as for example fragrance and bleaching agents, used only for aesthetic reasons, must be avoided. It would be an improvement to give also to the manufacturers the responsibility for waste generated by their products. This may be also supported by the creation of necessary legislation to advance the strategy, with defined roles and responsibilities and clear monitoring mechanisms. A code of practice for tampons safety has been already proposed by the Absorbent Hygiene Product Manufacturers Association. However, this is only an example of a voluntary subscription, that should be encouraged.

Third, the diffusion of the knowledge that a suitable management of menstrual hygiene waste must be considered a priority and not a taboo, must be promoted. In this frame, it is also mandatory to guarantee a smooth information flow that allows different groups of individuals, and specifically young women, to communicate the most suitable hygiene procedures. This may be achieved also by an increase in the coordination between political authorities and NGOs, and the promotion to support to long-term projects. Fourth, great attention must be devoted to developing suitable strategies for the management of MHW in refugee camps, where people can stay also for a prolonged time. In this frame it is fundamental to highlight that the attention is devoted to disposable pads, that should be addressed to landfilling or incineration (Blair et al., 2022), to avoid soil and/or water pollution.

Some projects (<https://sites.google.com/a/fater.it/recall-s/>, <https://diaperrecycling.technology>) have proposed solutions to manage all the absorbent hygiene products, that are the most challenging types of post-consumer waste because they are currently not recycled and usually disposed of via either landfill or incineration. The proposed practices are addressed technologies for the separation of this waste into its different constituents, to recover the different components into secondary raw materials (for example cellulose and plastic). The core processes generally involve thermal annealing in an autoclave, for waste sanitization. The output stream is then treated by mechanical processes to separate all the main components. In this way, cellulose, polyethylene and polypropylene plastics can be recovered and sent for recycling, for example after washing and drying. One of the main driving forces for the implementation of the proposed recovery strategies is the collection scheme, which must be able to separately collect MHW. In developed countries, for example, door-to-door waste collection systems have been implemented, making this opportunity available, and treating all the absorbent hygiene products in a single plant. Then this may be also considered for refugees' camps, but with some restrictions: this waste must be separately collected, and the treatments plants should be localized in the camp's proximity (to avoid long distances transport). Another possibility, mainly during the pandemic, may be the use of incineration or pyrolysis (Aldayyat et al., 2021), which allows to reduce the volume and improve the safety of MHW (Ducoli et al., 2021), resulting in more sustainable if compared to landfill (Blair et al., 2022). This procedure has already been promoted in India, where the amount of this MHW is significantly high (about 113,000 tons annually) (Sasidaran et al., 2021). However, it is extremely important to consider that menstrual hygiene waste can have high moisture (Sasidaran et al., 2021), then studies devoted to the understand the consequent environmental implications and the most suitable incineration conditions must be envisaged.

Finally, in the current pandemic situation, it is also urgent to consider that some factories originally producing sanitary hygiene products have been reconverted for facemask manufacturing. This may disclose in the next future serious health and environmental concerns associated to facemasks disposal, other than those already known caused by microplastics.

4. Conclusions

Apart from the significant physical and psychosocial impact that menstrual hygiene waste can have on adolescents, women's menstrual products management is a critical issue, globally. Despite that they can affect human and environmental health, resulting in an important part of diseases prevention and health promotion, several gaps in the knowledge exist. However, the problems associated with unsuitable waste management cannot be still considered relegated to low-income countries, due to the large extent of the population globally living in poor conditions, as for example migrants, in Europe camps.

Some actions such as promote additional research activities, reserve adequate financial resources, strive for equitable access, improve legislation, involve political commitments, use safe disposal treatments, and support dissemination would be critical to improve women's menstrual hygiene and a suitable treatment of the derived waste.

Filling the research gaps in the menstrual hygiene waste management and the connected environmental and health issues is an urgent priority. This is extremely important because the resulting implications will go beyond the involvement of SDGs 11, 12, 14, and 15, involving women dignity, health, and safety, supporting their valorisation and the achievement of their fundamental rights, in the frame of SDG 5.

Finally, it is important to highlight that even if this paper was specifically addressed to environmental concerns related to menstrual hygiene waste, it is also fundamental to remember that poor menstrual hygiene must be considered a source of vulnerability for women reproductive and urinary tracts, making the problem urgent mainly for people in critical situations.

Declarations

Author contribution statement

Utpal Anand & Elza Bontempi: Conceived and designed the experiments; Analyzed and interpreted the data; Wrote the paper.

Meththika Vithanage & Anushka Upamali Rajapaksha: Analyzed and interpreted the data; Wrote the paper.

Abhijit Dey & Sunita Varjani: Contributed reagents, materials, analysis tools or data. Wrote the paper.

Funding statement

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Data availability statement

Data included in article/supp. material/referenced in article.

Declaration of interests statement

The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.

Acknowledgements

All the authors are highly grateful to the authority of the respective departments and institutions for their support in carrying out this research. The authors also express their sincere gratitude to the unknown referee for critically reviewing the manuscript and suggesting useful changes.

References

- Aldayyat, E.A., Saidan, M.N., Al-Hamamre, Z., Al-Addous, M., Alkasrawi, M., 2021. Pyrolysis of solid waste for bio-oil and char production in refugees' camp: a case study. *Energies* 14 (13), 3861.
- Ali, T.S., Rizvi, S.N., 2010. Menstrual knowledge and practices of female adolescents in urban Karachi, Pakistan. *J. Adolesc.* 33 (4), 531–541.
- Amiya, R., Gupta, S., Habib, N., Whitesides, E., 2010. WASH and Women A Situation Analysis of Living and Working Conditions in the Tea Gardens of Dibrugarh District, Assam, India.
- Anand, U., Cabrerros, C., Mal, J., Ballesteros Jr., F., Sillanpää, M., Tripathi, V., Bontempi, E., 2021a. Novel coronavirus disease 2019 (COVID-19) pandemic: from transmission to control with an interdisciplinary vision. *Environ. Res.* 197, 111126.
- Anand, U., Adelodun, B., Pivato, A., Suresh, S., Indari, O., Jakhmola, S., Jha, H.C., Jha, P.K., Tripathi, V., Di Maria, F., 2021b. A review of the presence of SARS-CoV-2 RNA in wastewater and airborne particulates and its use for virus spreading surveillance. *Environ. Res.* 196, 110929.
- Anand, U., Bianco, F., Suresh, S., Tripathi, V., Núñez-Delgado, A., Race, M., 2021c. SARS-CoV-2 and other viruses in soil: an environmental outlook. *Environ. Res.* 198, 111297.
- Anand, U., Li, X., Sunita, K., Lokhandwala, S., Gautam, P., Suresh, S., Sarma, H., Vellingiri, B., Dey, A., Bontempi, E., Jiang, G., 2022. SARS-CoV-2 and other pathogens in municipal wastewater, landfill leachate, and solid waste: a review about virus surveillance, infectivity, and inactivation. *Environ. Res.* 203, 111839.
- Bettencourt, A.F., Neves, C.B., de Almeida, M.S., Pinheiro, L.M., e Oliveira, S.A., Lopes, L.P., Castro, M.F., 2010. Biodegradation of acrylic based resins: a review. *Dent. Mater.* 26 (5), e171–e180.
- Bhagwat, A., Jijina, P., 2020. A psychosocial lens on an indigenous initiative to address menstrual health and hygiene in indian villages. *Soc. Work. Publ. Health* 35 (3), 73–89.
- Bharadwaj, S., Patkar, A., 2004. Menstrual hygiene and management in developing countries: taking stock. *Junct. Soc.* 3 (6), 1–20. <http://www.mum.org/menhydev.htm>. (Accessed 10 January 2022).
- Blair, L.A.G., Bajon-Fernandez, Y., Villa, R., 2022. An exploratory study of the impact and potential of menstrual hygiene management waste in the UK. *Clean. Eng. Technol.* 7, 100435.
- Das, P., Baker, K.K., Dutta, A., Swain, T., Sahoo, S., Das, B.S., Panda, B., Nayak, A., Bara, M., Bilung, B., Mishra, P.R., 2015. Menstrual hygiene practices, WASH access and the risk of urogenital infection in women from Odisha, India. *PLoS One* 10 (6), e0130777.
- DeVito, M.J., Schechter, A., 2002. Exposure assessment to dioxins from the use of tampons and diapers. *Environ. Health Persp.* 110 (1), 23–28.
- Ducoli, S., Zacco, A., Bontempi, E., 2021. Incineration of sewage sludge and recovery of residue ash as building material: a valuable option due to as a consequence of the COVID-19 pandemic. *J. Environ. Manag.* 282, 111966.
- Elledge, M.F., Muralidharan, A., Parker, A., Ravndal, K.T., Siddiqui, M., Toolaram, A.P., Woodward, K.P., 2018. Menstrual hygiene management and waste disposal in low and middle income countries—a review of the literature. *Int. J. Environ. Res. Publ. Health* 15 (11), 2562.
- Foster, J., Montgomery, P., 2021. A study of environmentally friendly menstrual absorbents in the context of social change for adolescent girls in low-and middle-income countries. *Int. J. Environ. Res. Publ. Health* 18 (18), 9766.
- Goldstein, S.R., Lumsden, M.A., 2017. Abnormal uterine bleeding in perimenopause. *Climacteric* 20 (5), 414–420.
- Hait, A., Powers, S.E., 2019. The value of reusable feminine hygiene products evaluated by comparative environmental life cycle assessment. *Resour. Conserv. Recycl.* 150, 104422.
- Ismail, M.B., Osman, M., Rafei, R., Dabboussi, F., Hamze, M., 2021. COVID-19 and refugee camps. *Trav. Med. Infect. Dis.* 42, 102083.
- Iyer, M., Tiwari, S., Renu, K., Pasha, M.Y., Pandit, S., Singh, B., Raj, N., Krothapalli, S., Kwak, H.J., Balasubramanian, V., Jang, S.B., Dileep Kumar, G., Utpal, A., Narayanasamy, A., Kinoshita, M., Subramaniam, M.D., Nachimuthu, S.K., Roy, A., Valsala Gopalakrishnan, A., Ramakrishnan, P., Cho, S.G., Vellingiri, B., 2021. Environmental survival of SARS-CoV-2—a solid waste perspective. *Environ. Res.* 197, 111015.
- Kaur, R., Kaur, K., Kaur, R., 2018. Menstrual hygiene, management, and waste disposal: practices and challenges faced by girls/women of developing countries. *J. Environ. Public Health* 1730964, 1–9.
- Khan, K.N., Kitajima, M., Hiraki, K., Yamaguchi, N., Katamine, S., Matsuyama, T., Nakashima, M., Fujishita, A., Ishimaru, T., Masuzaki, H., 2010. *Escherichia coli* contamination of menstrual blood and effect of bacterial endotoxin on endometriosis. *Fertil. Steril.* 94 (7), 2860–2863.
- Lin, N., Ding, N., Meza-Wilson, E., Devasurendra, A.M., Godwin, C., Park, S.K., Batterman, S., 2020. Volatile organic compounds in feminine hygiene products sold in the US market: a survey of products and health risks. *Environ. Int.* 144, 105740.
- Mohammed, S., Larsen-Reindorf, R.E., 2020. Menstrual knowledge, sociocultural restrictions, and barriers to menstrual hygiene management in Ghana: evidence from a multi-method survey among adolescent schoolgirls and schoolboys. *PLoS One* 15 (10), e0241106.
- Migrant Stock 2020, 2020. United Nations Department of Economic and Social Affairs, Population Division. International Migrant Stock. <https://www.un.org/development/desa/pd/content/international-migrant-stock>. (Accessed 26 December 2021).
- Muralidharan, A., 2018. Management of menstrual waste: insights from India and Pakistan. Menstrual hygiene webinar series, Part 4: infrastructure solutions and menstrual hygiene. Available at: <https://vimeo.com/276271838>. (Accessed 30 December 2021).
- Pachauri, A., Shah, P., Almroth, B.C., Sevilla, N.P., Narasimhan, M., 2019. Safe and sustainable waste management of self care products. *BMJ* 365, 11298.
- Robinson, H.J., Barrington, D.J., 2021. Drivers of menstrual material disposal and washing practices: a systematic review. *PLoS One* 16 (12), e0260472.
- Sahiledengle, B., Atlaw, D., Kumie, A., Tekalegn, Y., Woldeyohannes, D., Agho, K.E., 2022. Menstrual hygiene practice among adolescent girls in Ethiopia: a systematic review and meta-analysis. *PLoS One* 17 (1), e0262295.
- Sasidaran, S., Kachoria, P., Raj, A., Ramalingam, S., Stoner, B.R., Sellgren, K.L., Grego, S., 2021. Physical properties of menstrual hygiene waste as feedstock for onsite disposal technologies. *J. Water, Sanit. Hyg. Dev.* 11 (3), 474–482.
- Sauder, M.B., Pratt, M.D., 2015. Acrylate systemic contact dermatitis. *Dermatitis* 26 (5), 235–238.
- Schmitt, M.L., Wood, O.R., Clatworthy, D., Rashid, S.F., Sommer, M., 2021. Innovative strategies for providing menstruation-supportive water, sanitation and hygiene (WASH) facilities: learning from refugee camps in Cox's bazar, Bangladesh. *Conflict Health* 15 (1), 1–12.
- Sommer, M., 2013. Structural factors influencing menstruating school girls' health and well-being in Tanzania. *Compare J. Comp. Int. Educ.* 43 (3), 323–345.
- Sommer, M., Sahin, M., 2013. Overcoming the taboo: advancing the global agenda for menstrual hygiene management for schoolgirls. *Am. J. Publ. Health* 103 (9), 1556–1559.
- Sommer, M., Kjellén, M., Pensulo, C., 2013. Girls' and women's unmet needs for menstrual hygiene management (MHM): the interactions between MHM and sanitation systems in low-income countries. *J. Water, Sanit. Hyg. Dev.* 3 (3), 283–297.
- Sommer, M., Schmitt, M.L., Ogello, T., Mathenge, P., Mark, M., Clatworthy, D., Khandakji, S., Ratnayake, R., 2018. Pilot testing and evaluation of a toolkit for menstrual hygiene management in emergencies in three refugee camps in Northwest Tanzania. *J. Int. Humanit. Action* 3 (1), 1–14.
- Swenson, I., Havens, B., 1987. Menarche and menstruation: a review of the literature. *J. Commun. Health Nurs.* 4 (4), 199–210.
- Velasco Perez, M., Sotelo Navarro, P.X., Vazquez Morillas, A., Espinosa Valdemar, R.M., Hermoso Lopez Araiza, J.P., 2021. Waste management and environmental impact of absorbent hygiene products: a review. *Waste Manag. Res.* 39 (6), 767–783.
- Vora, S., 2020. The realities of period poverty: how homelessness shapes women's lived experiences of menstruation. In: Bobel, C., Winkler, I.T., Fahs, B., Hasson, K.A., Kissling, E.A., Roberts, T.A. (Eds.), *The Palgrave Handbook of Critical Menstruation Studies*. Springer Singapore Pte. Limited, Singapore, pp. 31–47.
- Woeller, K.E., Hochwalt, K.E., 2015. Safety assessment of sanitary pads with a polymeric foam absorbent core. *Regul. Toxicol. Pharmacol.* 73 (1), 419–424.
- World Health Organization, 1996. Programming for adolescent health and development, 2. World Health Organization. WHO Technical Report Series No. 886.