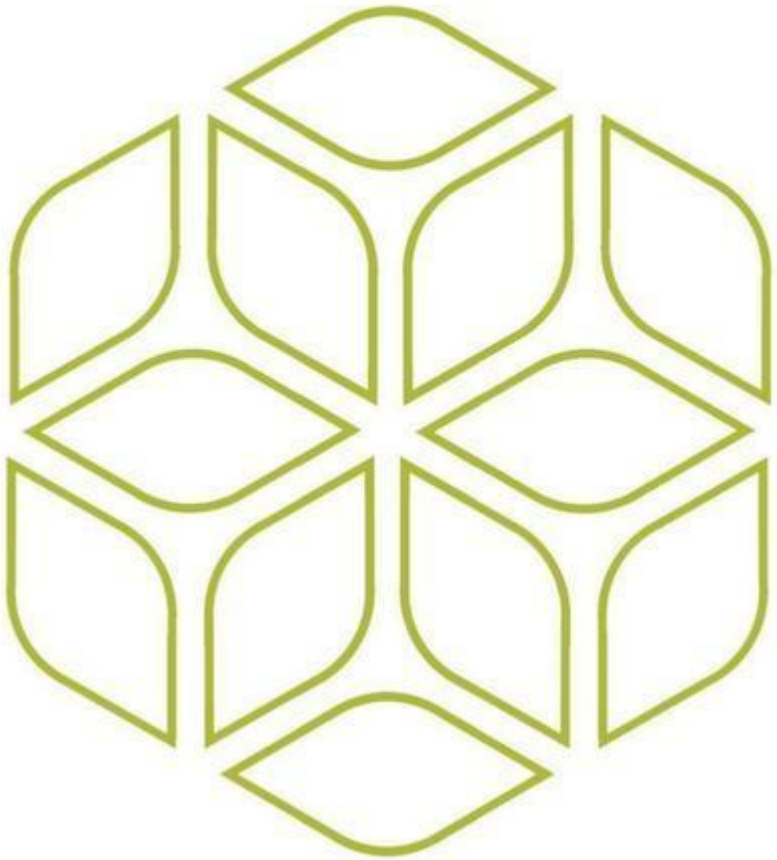

The impact of plastic pollution on urban flooding events:

Estimating the number of people impacted globally

Tearfund

May 2023

tearfund

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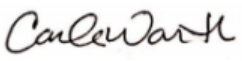
Signed	

Version control

File name	The impact of plastic pollution on flooding events
Version	Final Report
Date	15 May 2023
RF contract no.	5797

Acknowledgements

We would like to thank the stakeholders who were interviewed as part of this project and provided their insights and Fabrice Clavien for advice around study design and for review inputs. We would also like to acknowledge the invaluable contribution made by Guy Norman of Urban Research, who provided in-depth review and significant input to our statistical methodology, and the associated description of this in the text.

Limitations

This report has been produced by Resource Futures on behalf of Tearfund. Whilst Resource Futures has taken all due care to interpret and collate the information presented within the report, any third party relying on the results of the analysis shall do so at their own risk and neither Resource Futures nor Tearfund shall be liable for any loss or damages arising there from.

Contents

1 Introduction

1.1 Context

The accumulation of mismanaged plastic waste is a serious issue globally and is having severe negative impacts on biodiversity and the environment as well as on livelihoods and human health.

Between 2000 and 2019 plastic waste generation more than doubled[1]. Yet 2 billion people in low and middle-income countries (LMICs) do not have access to solid waste management, giving them little other option but to dump or burn their plastic waste. Only a small proportion of their waste is recycled or enters well-managed landfill sites[2]. Future projections show that quantities of mismanaged plastic waste will continue to increase globally under a business-as-usual scenario, with levels of mismanaged plastic waste being particularly high on the continents of Africa and Asia[3].

In addition, many LMICs are experiencing severe flooding as a result of climate change (which is causing an increase in extreme weather patterns), alongside rapid urbanisation and population increase[4]. As of 15 March 2023, cyclones, flooding and the lack of safe drinking water and sanitation have put 18 million people in Malawi at high risk of contracting cholera[5]. Recent flooding has impacted 11 districts and affected over 2 million people[6].

The two trends – mismanaged plastic waste and severe flooding in LMICs – are seemingly connected. As far back as 1988 it was reported that plastic bags blocking waterways were aggravating natural disasters, with devastating flooding events occurring during that year in Bangladesh, causing several deaths and two-thirds of the country to be submerged. In 1998 Bangladesh suffered further extreme flooding and it was estimated that 80% of this was as a result of polyethene bags blocking storm drains[7][8].

Since then, several research projects have increased our understanding of the extent of plastic-aggravated flooding (a term used in this report to describe flooding that is made worse by plastic pollution), specifically which regions globally are most at risk and what the human health impacts are. However, importantly, and to the best of our knowledge, no research paper has attempted to quantify how many people globally are currently at risk of plastic-aggravated flooding events.

With UN member states currently negotiating a global treaty on plastic pollution, the main objective of this report is to provide such an estimate (approximate as it may be), as well as summarise the state of

[1] OECD (2022) *Global Plastics Outlook: Economic Drivers, Environmental Impacts and Policy Options. https://www.oecd-ilibrary.org/environment/global-plastics-outlook_de747aef-en*

[2] The World Bank (2022) *Brief: Solid Waste Management.* https://www.worldbank.org/en/topic/urbandevelopment/brief/solid-waste-management

[3] Lebreton L., Andrady A. (2019) *Future scenarios of global plastic waste generation and disposal. https://www.nature.com/articles/s41599-018-0212-7*

[4] World Weather Attribution (2022) *Climate change likely increased extreme monsoon rainfall, flooding highly vulnerable communities in Pakistan,* https://www.worldweatherattribution.org/climate-change-likely-increased-extreme-monsoon-rainfall-flooding-highly-vulnerable-communities-in-pakistan/

[5] Reliefweb (2023) *UNICEF Malawi Humanitarian Situation Report No.1 for 1 January – 15 March 2023.* https://reliefweb.int/report/malawi/unicef-malawi-humanitarian-situation-report-no1-1-january-15-march-2023

[6] Interview with stakeholder in Malawi, March 2023

[7] UNEP (2018) *Single-Use Plastic: A Roadmap for Sustainability (Rev.2).* https://wedocs.unep.org/handle/20.500.11822/25496

[8] Ecospear (2018) *Bangladesh: world leader in banning plastic bags.* https://ecospearbd.com/bangladesh-world-leader-in-banning-plastic-bags/

current knowledge relating to plastic-aggravated flooding events and their negative consequences on human health.

It is important to note that the impacts described in this report are largely avoidable. Greater understanding of the links between plastic pollution, flooding, and health can thus shed light on important mitigating actions to avoid many of the health impacts altogether.

1.2 Scope

This study set out to research how plastic pollution is contributing to flooding events, what the associated human health impacts are, and to what extent it is getting worse. A key objective was to estimate how many people are at risk of plastic-aggravated flooding, highlighting in particular the severe impacts being experienced by people living in LMICs.

Flooding occurs when water overflows onto land that would typically be dry. This report examines both pluvial and fluvial plastic-aggravated flooding events, which can happen when a water body such as a river or lake overflows its normal boundaries (fluvial flooding) or when rainwater accumulates on saturated ground (pluvial flooding)[9].

Coastal flooding and marine litter have not been included in the scope of the research because coastal flooding occurs when water is pushed onshore due to sea level rise, tidal surges, and proximity to the marine environment. Urban drainage systems (or waterways) are thus less likely to be associated with the impacts of coastal flooding events. While coastal flooding and marine litter remain vital topics of research, literature on this subject has not been consulted for this report.

Rural flooding events have also not been included, as urban areas are considered more at risk due to their dense populations and increased plastic waste generation[10].

Small Island Developing States (SIDS) are also not included in this report. While many of these countries have significant and unique issues with plastic pollution, it is assumed that they experience mainly coastal flooding due to marine influences, and not pluvial or fluvial flooding, and thus not likely to be aggravated by plastic pollution blocking drains.

The scope of the research was thus focused on inland urban fluvial and pluvial flooding events in areas with dense populations and high levels of mismanaged plastic waste.

1.3 Approach

This research consists of a high-level desk-based literature review and a series of interviews with key stakeholders. Interviews were conducted with stakeholders who are based in countries that have experienced plastic-aggravated flooding events and/or who are specialists in the field of urban flooding and climate change.

Using the findings from the literature review and qualitative information provided by the stakeholders interviewed a methodology for a global statistic was developed to quantify the issue. This is presented

[9] Chen *et al* (2010) *An Analysis of the combined consequences of pluvial and fluvial flooding.* https://www.researchgate.net/publication/235694709_An_analysis_of_the_combined_consequences_of_pluvial_and_fluvial_flooding

[10] Lamond *et al* (2012) *The role of solid waste management as a response to urban flood risk in developing countries, a case study analysis.* https://www.witpress.com/Secure/elibrary/papers/FRIAR12/FRIAR12016FU1.pdf

in section 3.2 of this report. It was supplemented by additional desk-based research to develop an understanding of how many people face significant health risks as a result of plastic-aggravated flooding.

In conducting the research and interviews, a three-pronged approach was taken to analyse the link between plastic pollution, flooding, and health. We investigated:

1. The impact of plastic pollution on flooding
2. The impact of flooding on health
3. Future trends that are likely to make these impacts more severe

1.3.1 Literature review

The aim of the literature review was to identify relevant information in the public domain and to draw out as many quantified impacts as possible, building up a picture of the full impact of each of the categories of the three-pronged approach (e.g., causation of flood, impact, number of people impacted, human health impact etc). This research was also used to inform the stakeholder interviews to ensure they would address gaps and corroborate findings from the literature.

Freely available academic articles published in English were investigated and searched using Elsevier, Google Scholar, ScienceDirect and PubMed. Grey literature was also included in the literature review, with the databases of major international stakeholders such as the World Bank, UNDP, UN-Habitat, UNEP and Cities Alliance being used to identify relevant reports.

Contacts within Resource Futures' own networks were engaged to request any related work that could be shared. Any gaps in literature were noted to give a broad understanding of the research subject and where further work and information may be needed. Although thorough research was undertaken within the time frame, the literature presented in this report is not an exhaustive list and it is likely there are other relevant articles available should further research be undertaken.

1.3.2 Interviews with stakeholders

Resource Futures conducted interviews with five stakeholders. Four of the stakeholders were Tearfund employees based in urban locations in Juba, South Sudan; Jos, Nigeria; Lilongwe, Malawi and Kathmandu, Nepal. All four had witnessed increased flooding events in recent years and were keen to share their first-hand experience of plastic-aggravated flooding.

The fifth stakeholder was an academic expert identified through the literature review and is a worldwide leading expert on urban flooding, climate change, and sewer overflows.

1.3.3 Methodology for quantitative estimation of impacts

To estimate the global number of people at risk of plastic-aggravated flooding, and to identify the subset of that total judged likely to suffer significant negative health impacts (e.g., mortality, morbidity), we used the structured approach detailed in section 3.2. We note that this approach generates an approximate estimate: insufficient data is available for precise estimation. We note also that this is an estimate of current impact: we do not attempt to project quantitative estimation into the future, although we explore likely trends in section 2.3.

2 Understanding plastic-aggravated flooding and its impacts

This section presents an overview of current research understanding of plastic-aggravated flooding. Specifically, we investigate the evidence base around the extent plastic pollution is impacting flooding events, and how these flooding events are impacting human health.

First, the impact of plastic pollution on flooding events is described, looking specifically at the reasons why plastic pollution affects flooding events, and where these events are happening most frequently.

Next, the impact of flooding on human health is presented, including who is most impacted and what diseases are associated with flooding events.

Finally, future trends in population growth, waste production, urbanisation and climate change are also presented, to understand what could cause more severe flooding events in the future.

2.1 How plastic pollution is making flooding events more severe

Flooding is a common natural disaster which can impact high-, middle- and low-income countries alike. Drainage systems are used worldwide to assist with the removal of rain (and flood) water in urban areas. Plastic pollution can cause blockages to any drainage system[11], however, with rapid and unplanned urbanisation and development happening in many LMICs, these countries are at particular risk.

Plastic-aggravated flooding is caused by plastic pollution blocking drainage systems (and waterways), making flooding events more severe. The blocking of drainage systems by mismanaged plastic waste causes flood water to rise more quickly and to recede more slowly because water is unable

[11] Dinis *et al* (2021) *Disastrous flash floods triggered by moderate to minor rainfall events. Recent cases in Coastal Benguela (Angola).* https://www.mdpi.com/2306-5338/8/2/73

to drain away as it would under "normal" waste-free scenarios[12] [13] [14] [15] [16] [17] [18] [19]. This finding was corroborated by the stakeholder interviews.

Rapid urbanisation can lead to settlements/developments being built with poorly planned and maintained drainage systems as well as in geologically unstable areas such as riverbanks or other flood-prone land. This rapid development, combined with a lack of or poor solid waste management, leads to plastic waste entering and blocking drainage systems (and waterways)[20] [21] [22].

The available literature primarily focused on the increased intensity of flooding resulting from plastic pollution, but several sources were identified that also mention increased flood frequency as a result of plastic pollution. Given the mechanism described above, blocked drainage systems would likely give rise to both increased severity and increased frequency of flooding events[23] [24].

Cameroon, Nigeria, Democratic Republic of Congo (DMC), Ghana, India, Bangladesh, and Indonesia are just a few of the countries that have experienced more severe flooding events due to mismanaged plastic waste finding its way into drainage systems and reducing the serviceability of the drains[25] [26] [27] [28]

[12] Le Monde (2023) *Kinshasa drowns under a sea of plastic waste.* https://www.lemonde.fr/en/le-monde-africa/article/2023/01/09/drc-kinshasa-drowned-under-a-sea-of-plastic-waste_6010850_124.html

[13] Peters *et al* (2015) *Analysing Risk and Disaster in Mega urban Systems – Experiences from Mumbai and Jakarta.* https://www.researchgate.net/publication/273757678_Gerrit_Peters_Carsten_Butsch_Franziska_Krachten_Frauke_Kraas_Namperumal_Sridharan_Muh_Aris_Marfai_2015_Analyzing_Risk_and_Disaster_in_Megaurban_Systems_-_Experiences_from_Mumbai_and_Jakarta_GRF_Davos_

[14] Chen *et al* :(2010) *An Analysis of the combined consequences of pluvial and fluvial flooding.* https://www.researchgate.net/publication/235694709_An_analysis_of_the_combined_consequences_of_pluvial_and_fluvial_flooding

[15] Sarwar Ahmed (2005*) Impact of banning polythene bags on floods in Dhaka City by applying CVM and remote sensing*. https://www.researchgate.net/publication/251813921_Impact_of_banning_polythene_bags_on_floods_of_Dhaka_City_by_applying_CVM_and_remote_sensing

[16] Dinis *et al* (2021) *Disastrous flash floods triggered by moderate to minor rainfall events. Recent cases in Coastal Benguela (Angola).* https://www.mdpi.com/2306-5338/8/2/73

[17] Ayodele J. (2017) *Attitudes to Lagos residents to waste disposal as major cause to yearly flooding.* https://www.academia.edu/32054171/Attitudes_of_Lagos_Residents_to_waste_disposal_as_major_causes_to_yearly_flooding

[18] Sakijege T. (2019) *Repercussions of improved Municipal Solid Waste Management on Flood Risk Reduction: The Case of Dar es Salaam, Tanzania.* https://www.scirp.org/pdf/GEP_2019092516031010.pdf

[19] Hakuzimana (2021) *Break free from plastic: Environmental perspectives and lessons from Rwanda.* https://www.longdom.org/open-access/break-free-from-plastics-environmental-perspectives-and-lessons-from-rwanda-68106.html

[20] Ballesteros, Marife M. (2010) *Linking Poverty and the Environment: Evidence from Slums in Philippine Cities.* https://pidswebs.pids.gov.ph/CDN/PUBLICATIONS/pidsdps1033.pdf

[21] Dania Starovoytova (2016) *Consumer-Perception on Polyethylene-Shopping-Bags.* https://www.researchgate.net/publication/311306870_Consumer-Perception_on_Polyethylene-Shopping-Bags

[22] Dinis *et al* (2021) *Disastrous flash floods triggered by moderate to minor rainfall events. Recent cases in Coastal Benguela (Angola).* https://www.mdpi.com/2306-5338/8/2/73

[23] Mokuolu *et al* (2022), *Assessing the Effect of Solid Wastes on Urban Flooding: A case study of Isale Koko.* https://www.ajol.info/index.php/laujoces/article/view/240199

[24] Njoku *et al* (2015), *An Overview of Municipal Solid Waste Management in Developing and Developed Economies: Analysis of Practices and Contributions to Urban Flooding in Sub-Saharan Africa. https://www.researchgate.net/publication/279868600_An_Overview_of_Municipal_Solid_Waste_Management_in_Developing_and_Developed_Economies_Analysis_of_Practices_and_Contributions_to_Urban_Flooding_in_Sub-Saharan_Africa*

[25] Institute for Security Studies (2022) *Smuggling plastic is trashing Cameroon's environment.* https://issafrica.org/iss-today/smuggled-plastic-is-trashing-cameroons-environment

[26] Mokuolu *et al* (2022), *Assessing the Effect of Solid Wastes on Urban Flooding: A case study of Isale Koko.* https://www.ajol.info/index.php/laujoces/article/view/240199

[27] Dania Starovoytova (2016) *Consumer-Perception on Polyethylene-Shopping-Bags.* https://www.researchgate.net/profile/Diana-Starovoytova/publication/311306870_Consumer-Perception_on_Polyethylene-Shopping-Bags/links/58413a5a08ae61f75dd0aadd/Consumer-Perception-on-Polyethylene-Shopping-Bags.pdf

[28] Le Monde (2023) *Kinshasa drowns under a sea of plastic waste.* https://www.lemonde.fr/en/le-monde-africa/article/2023/01/09/drc-kinshasa-drowned-under-a-sea-of-plastic-waste_6010850_124.html

[29]. Bangladesh reported plastic-aggravated flooding events as far back as 1988. In 2002 a disastrous flooding incident in Mumbai occurred, killing over 1000 people as well as wildlife and livestock. This incident was attributed to plastic bags clogging storm drains and therefore preventing monsoon flood water from draining out of the city[30] [31]. These examples highlight that plastic-aggravated flooding is not a recent phenomenon.

However, a study in Isale Koko, Nigeria identified that disastrous flooding events only started to occur in 2014, highlighting the relatively recent occurrence of such events in this area[32]. Furthermore, according to recent reports in Malaysian media, from December 2021 to January 2022 Kuala Lumpur experienced flooding that was exacerbated by the presence of plastic pollution clogging drains. The Department of Irrigation and Drainage Kuala Lumpur (DIDKL) shared photos which showed an alarming level of plastic pollution blocking drains after a flash flood event (Figure 1). DIDKL appealed to the public to take note of the issues and to dispose of waste responsibly[33].

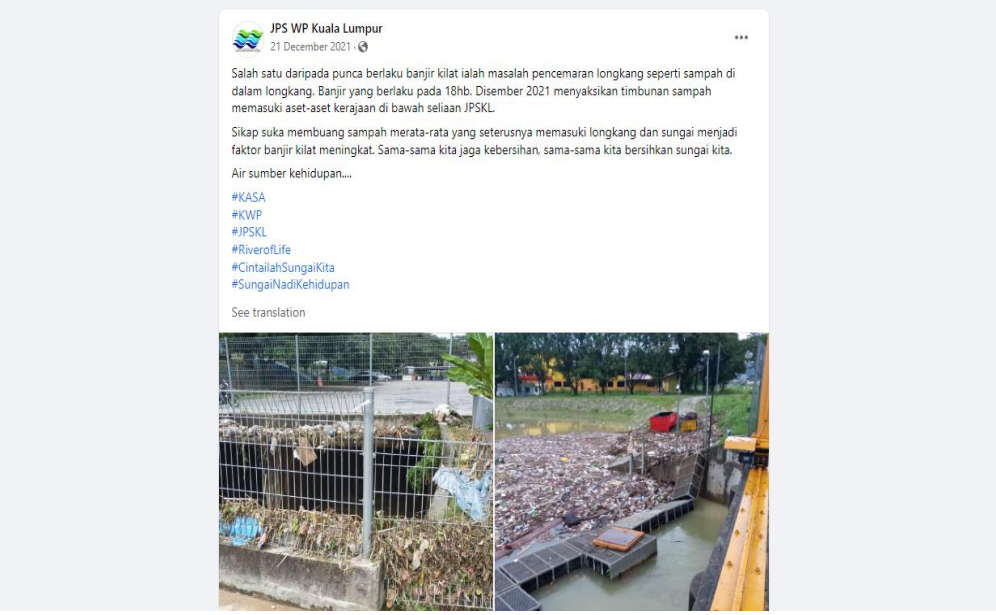


Figure 1: Government Department share images on Facebook of plastic pollution accumulation in drainage systems after a flash flood event in Kuala Lumpur, Malaysia on 22 December 2021[34]

Several peer-reviewed papers were identified where work had been undertaken to quantify the impact plastic pollution has on flooding events. The research undertaken by Honingh *et al* found that waste and debris were collecting at trash racks – man-made structures designed to collect river debris –in the

[29] Sarwar Ahmed (2005) Impact of banning polythene bags on floods in Dhaka City by applying CVM and remote sensing. https://www.researchgate.net/publication/251813921_Impact_of_banning_polythene_bags_on_floods_of_Dhaka_City_by_applying_CVM_and_remote_sensing
[30] UNEP (2018) *Single-Use Plastic: A Roadmap for Sustainability (Rev.2).* https://wedocs.unep.org/handle/20.500.11822/25496
[31] Dania Starovoytova (2016) *Consumer-Perception on Polyethylene-Shopping-Bags.* https://www.researchgate.net/profile/Diana-Starovoytova/publication/311306870_Consumer-Perception_on_Polyethylene-Shopping-Bags/links/58413a5a08ae61f75dd0aadd/Consumer-Perception-on-Polyethylene-Shopping-Bags.pdf
[32] Mokuolu *et al* (2022), *Assessing the Effect of Solid Wastes on Urban Flooding: A case study of Isale Koko.* https://www.ajol.info/index.php/laujoces/article/view/240199
[33] The Smart Local (2021) *JPSKL Says Garbage in Drains is a Cause of KL Flash Floods, Urges M'sians to Keep City Clean.* https://thesmartlocal.my/garbage-floods/
[34] JPS WP Kuala Lumpur (2021) Facebook 21 December 2021 [Accessed 16 May 2023]: https://www.facebook.com/JPSWPKL/posts/305061181633963

Cikapundung River in Indonesia[35]. It was identified that plastic pollution accounted for 34% of all material by weight, with plastic bags being the most abundant type of plastic present. This research also found that plastic pollution caught at trash racks caused blockages faster than other, more porous material (e.g., organic waste), especially after rain showers, due to the high floatability of the material. The study concluded that the accumulation of plastic pollution could potentially cause the water level to rise by one metre within the first hour based on river flow velocity typical of the rainy season of the area, therefore posing a significant flood risk to urban areas[36]. This study was undertaken in a river and did not look at plastics that could be blocking man-made drainage systems in urban areas.

In a further study by Mokuolu *et al*[37], urban drains were examined and through a series of reconnaissance surveys, it was identified that solid waste in drains was made up of 80% plastic and totalled 20% of the volume of the drain. The report concluded that solid waste in drains, and in particular plastic, was contributing to flooding events in Isale Koko, Nigeria[38].

All stakeholders interviewed stated that the presence of plastic pollution was contributing to more severe flooding events and spoke from first-hand experience of the devastation this had caused[39]. The stakeholder based in Juba, the capital of South Sudan, explained that currently 70% to 80% of the population of South Sudan could be at risk of severe flooding events due to plastic pollution mixing with other organic material reducing the serviceability of drainage systems[40].

The most commonly observed plastic items they had observed blocking drainage systems were plastic bottles, nylon threads from the fishing industry, plastic bags and plastic sachets[41]. Overall, although there are research papers (discussed above) that aim specifically to quantify and understand the role of plastics in flooding, it is evident that limited field studies have been undertaken to understand the important issue of the composition, quantity, and behaviour of plastic pollution in drainage systems. This suggests a lack of research interest (or funding) in this field, particularly when compared to the wealth of scientific research available on the impacts of plastic pollution on the environment.

The lack of or poor solid waste management is a major cause of plastic-aggravated flooding.

Several individual factors influence the levels of solid waste generation in a country, such as the level of economic development, population demographics, levels of industrialisation, the habits of the public and the local climate[42].

[35] Honingh *et al* (2020) *Urban River Water Level Increase Through Plastic Waste Accumulation at the Rack Structure.* https://www.researchgate.net/publication/339270704_Urban_River_Water_Level_Increase_Through_Plastic_Waste_Accumulation_at_a_Rack_Structure

[36] Honingh *et al* (2020) *Urban River Water Level Increase Through Plastic Waste Accumulation at the Rack Structure.* https://www.researchgate.net/publication/339270704_Urban_River_Water_Level_Increase_Through_Plastic_Waste_Accumulation_at_a_Rack_Structure

[37] Mokuolu *et al* (2022), *Assessing the Effect of Solid Wastes on Urban Flooding: A case study of Isale Koko.* https://www.ajol.info/index.php/laujoces/article/view/240199

[38] Mokuolu *et al* (2022), *Assessing the Effect of Solid Wastes on Urban Flooding: A case study of Isale Koko.* https://www.ajol.info/index.php/laujoces/article/view/240199

[39] Interviews with stakeholders from Nepal, South Sudan, Malawi, Nigeria and a specialist in Urban Flooding, March 2023

[40] Interview with stakeholder in South Sudan, March 2023

[41] Interviews with stakeholders from South Sudan, Nigeria, Nepal and Malawi, March 2023

[42] Njoku *et al* (2015), *An Overview of Municipal Solid Waste Management in Developing and Developed Economies: Analysis of Practices and Contributions to Urban Flooding in Sub-Saharan Africa.*

It has already been noted that increased urbanisation – and increased economic growth in particular – have led to, and will continue to lead to, an increase in solid waste generation in some regions globally and that solid waste management is often neglected in the urban planning process[43] [44] [45]. According to a study, around 90% of waste in Low-Income Countries (LIC) is currently disposed of in unregulated dumps or openly burned[46]. This means that unless waste management systems in LMICs, and LICs particularly, are rapidly improved, they will struggle to cope with the predicted increase in solid waste generation, with potential implications for human health, safety, the environment, and flood risk[47] [48] [49] [50].

Although there is evidence of a gradual increase in waste management infrastructure across the world, a recent report by Lebreton and Andrady found that, based on their projections, consumer demand for plastic on the continent of Africa, fuelled by population and economic growth, will outpace the gradual increase in waste management infrastructure, resulting in greater quantities of mismanaged plastic waste in the future[51].

An article by Cities Alliance, a global organisation focused on sustainable development, corroborated that poor waste disposal practices, such as those in unregulated or illegal dumpsites, are a major cause of flooding. The article explained that poor waste disposal practices in Bwaise, Uganda, were contributing to flooding events which were most apparent in areas with poorly maintained drainage systems[52]. Similarly, in Nigeria and Malawi informal waste disposal sites are often located in low-lying areas near slums and can pose a significant problem as plastic waste can be washed away during intense rainfall and enter drainage systems[53] [54].

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https://www.researchgate.net/publication/279868600_An_Overview_of_Municipal_Solid_Waste_Management_in_Developing_and_Developed_Economies_Analysis_of_Practices_and_Contributions_to_Urban_Flooding_in_Sub-Saharan_Africa

[43] Njoku *et al* (2015), *An Overview of Municipal Solid Waste Management in Developing and Developed Economies: Analysis of Practices and Contributions to Urban Flooding in Sub-Saharan Africa*.
https://www.researchgate.net/publication/279868600_An_Overview_of_Municipal_Solid_Waste_Management_in_Developing_and_Developed_Economies_Analysis_of_Practices_and_Contributions_to_Urban_Flooding_in_Sub-Saharan_Africa

[44] Lamond *et al* (2012) *The role of solid waste management as a response to urban flood risk in developing countries, a case study analysis*. https://www.witpress.com/Secure/elibrary/papers/FRIAR12/FRIAR12016FU1.pdf

[45] Lebreton L., Andrady A. (2019) *Future scenarios of global plastic waste generation and disposal.*
https://www.nature.com/articles/s41599-018-0212-7

[46] World Bank (2022) *Brief: Solid Waste Management.* https://www.worldbank.org/en/topic/urbandevelopment/brief/solid-waste-management

[47] World Bank (2022) *Brief: Solid Waste Management.* https://www.worldbank.org/en/topic/urbandevelopment/brief/solid-waste-management

[48] Sakijege T. (2019) *Repercussions of Improved Municipal Solid Waste Management on Flood Risk Reduction: The Case for Dar es Salaam, Tanzania.* https://www.scirp.org/pdf/GEP_2019092516031010.pdf

[49] Ayodele J. (2017) *Attitudes to Lagos Residents to waste disposal as a major cause to yearly flooding.*
https://www.academia.edu/32054171/Attitudes_of_Lagos_Residents_to_waste_disposal_as_major_causes_to_yearly_flooding

[50] Prof. C. I. N. Emelie (2020) *An Appraisal of the impact of waste and flood on environmental protection in Nigeria.*
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[51] Lebreton L., Andrady A (2019) *Future scenarios of global plastic waste generation and disposal.*
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[52]Cities Alliance (2020) *Uganda: Improving Waste Management for Flood Control*.
https://www.citiesalliance.org/newsroom/news/results/uganda-improving-waste-management-flood-control

[53] Interview with a stakeholder in Malawi, March 2023

[54] Prof. C. I. N. Emelie (2020) *An Appraisal of the Impact of Waste and Flood on Environmental Protection in Nigeria.*
https://www.nigerianjournalsonline.com/index.php/COOUJCPL/article/download/2026/1981?__cf_chl_tk=PxbrAfrALPEl8aL9QXi2bbFFidLroJx6nuuQToTfDJU-1683728569-0-gaNycGzNDCU

With informal settlements such as slums often lacking municipal services, residents living in these communities are at particular risk of flooding and are also less likely to be able to deal with the issue. Therefore, the control of mismanaged plastic waste, whether undertaken on a municipal level or a community level can significantly reduce flood risk[55] [56]. It was identified that in Nigeria, working in waste management is regarded as a low-status job with poor pay and this was resulting in absenteeism among waste workers, further contributing to waste build-up and more severe flooding events[57]. Two of the stakeholders, both based in sub-Saharan Africa, mentioned that lack of or poor solid waste management was a major cause of plastic-aggravated flooding[58]. The stakeholder based in Nepal explained that regions in Nepal are dry for eight months of the year and during this period, plastic pollution builds up in ditches and waterways due to the lack of solid waste management. During the wet season, heavy rains cause vast mobilisation of plastic pollution that makes its way into drainage systems causing significant blockages[59].

While these examples highlight the importance of solid waste management in reducing plastic-aggravated flood risks, a 2019 report focused on Dar es Salaam in Tanzania, identified that while a major contributing factor to flood risk, solid waste management is not the only driving force. The report found that big-picture thinking is required to reduce flood risk, including, but not limited to, community education and participation in waste removal, building better embankments, and avoiding construction on the edge of a water course[60]. This is particularly important to consider when understanding plastic-aggravated flood risk in poorly planned slum urban developments.

[55] Lamond *et al* (2012*) The role of solid waste management as a response to urban flood risk in developing countries, a case study analysis*. https://www.witpress.com/Secure/elibrary/papers/FRIAR12/FRIAR12016FU1.pdf
[56] Sakijege T. (2019) *Repercussions of Improved Municipal Solid Waste Management on Flood Risk Reduction: The Case for Dar es Salaam, Tanzania* https://www.scirp.org/pdf/GEP_2019092516031010.pdf
[57] Mokuolu *et al* (2022), *Assessing the Effect of Solid Wastes on Urban Flooding: A case study of Isale Koko.* https://www.ajol.info/index.php/laujoces/article/view/240199
[58] Interview with stakeholders in Malawi and South Sudan, March 2023
[59] Interview with stakeholder in Nepal, March 2023
[60] Sakijege T. (2019) *Repercussions of Improved Municipal Solid Waste Management on Flood Risk Reduction: The Case for Dar es Salaam, Tanzania.* https://www.scirp.org/pdf/GEP_2019092516031010.pdf

Figure 2 Plastic pollution overwhelming a stream in Democratic Republic of Congo, November 2022 [61]

Densely populated slums in South Asia and sub-Saharan Africa are likely to be experiencing the worst effects of plastic-aggravated flooding due to high levels of mismanaged plastic waste[62] [63]. Slums are highly populated, often poorly planned developments that lack stable living conditions. Other common characteristics include limited access to sanitation infrastructure, poor solid waste management and poor drainage systems[64]. In South Asia and sub-Saharan Africa, densely populated slums are often built near rivers and on flood-prone land with little to no embankments, putting these communities at high risk of plastic-aggravated flooding[65] [66] [67] [68] [69] [70].

[61] Tom Price / Bin Twinning (2022)
[62] Lamond *et al* (2012) *The role of solid waste management as a response to urban flood risk in developing countries, a case study analysis.* https://www.witpress.com/Secure/elibrary/papers/FRIAR12/FRIAR12016FU1.pdf
[63] World Bank Blogs (2022) *Flood risk already affects 1.81 billion people. Climate change and unplanned urbanization could worsen exposure* https://blogs.worldbank.org/climatechange/flood-risk-already-affects-181-billion-people-climate-change-and-unplanned
[64] Ahmed (2014) *Factors in building resilience in urban slums of Dhaka, Bangladesh.* https://www.sciencedirect.com/science/article/pii/S2212567114009988
[65] Njoku *et al* (2015), *An Overview of Municipal Solid Waste Management in Developing and Developed Economies: Analysis of Practices and Contributions to Urban Flooding in Sub-Saharan Africa.* https://www.researchgate.net/publication/279868600_An_Overview_of_Municipal_Solid_Waste_Management_in_Developing_and_Developed_Economies_Analysis_of_Practices_and_Contributions_to_Urban_Flooding_in_Sub-Saharan_Africa
[66] Interview with a stakeholder in Nigeria, March 2023
[67] Tearfund (2019) *No Time to* Waste. https://res.cloudinary.com/tearfund/image/fetch/https:/learn.tearfund.org/-/media/learn/resources/reports/2019-tearfund-consortium-no-time-to-waste-en.pdf
[68] Peters *et al* (2015) *Analysing Risk and Disaster in Mega urban Systems – Experiences from Mumbai and Jakarta.* https://www.academia.edu/54238399/Analyzing_Risk_and_Disaster_in_Megaurban_Systems_Experiences_from_Mumbai_and_Jakarta
[69] Kaburu *et al* (2019*) Anthropogenic factors that cause floods in Mukuru slums, Nairobi city county, Kenya.* https://ir-library.ku.ac.ke/bitstream/handle/123456789/22061/Anthropogenic%20Factors%20that%20cause....pdf?sequence=1
[70] Laryea *et al* (2010) *Proceeding of the West Africa Built Environment Research Conference.* https://centaur.reading.ac.uk/8192/1/Proceedings_of_WABER_2010_Conference_edited_by_S_Laryea,_R_Leiringer_and_W_Hughes.pdf#page=303

Pluvial flooding is becoming increasingly common in urban areas worldwide. One recent research paper stated that the increased flood risk in slums is due to the presence of densely packed developments, poor drainage systems and a lack of green spaces that allow flood water to naturally disperse. Unsustainable alterations to the natural environment (e.g., draining of wetlands and clearing of vegetation to make way for more urban development) means there is a lack of natural buffer zones to help mitigate the impacts of flooding. When this is coupled with unregulated dumping of plastic pollution in drains, it results in heavily disrupted storm water flow in slums causing the stagnation of flood water[71].

Those living in slums have limited access to basic services and communities' capabilities to bounce back from flooding disasters are impeded by poor economic conditions[72]. Four of the stakeholders interviewed corroborated the above findings and stated that slums are being severely impacted due to dense urbanisation and manipulation of natural buffers which is occurring due to rapid population growth within these areas, and they had experienced or knew of plastic-aggravated flooding events taking place in slum areas of Nepal, South Sudan, Malawi, and Nigeria[73].

Figure 3 Plastic accumulation in a river in Recife, Brazil, in 2022[74]

[71] Kaburu *et al* (2019) *Anthropogenic factors that cause floods in Mukuru slums, Nairobi city county, Kenya* https://ir-library.ku.ac.ke/bitstream/handle/123456789/22061/Anthropogenic%20Factors%20that%20cause....pdf?sequence=1

[72] Jobaer *et al* (2022) *Assessing urban poor resilience to natural disasters using analytic hierarchy process-based model: a case study on Khulna city.* https://www.researchgate.net/publication/365475285_ASSESSING_URBAN_POOR_RESILIENCE_TO_NATURAL_DISASTERS_USING_ANALYTIC_HIERARCHY_PROCESS-BASED_MODEL_A_CASE_STUDY_ON_KHULNA_CITY

[73] Interviews with stakeholders from Nepal, Malawi, Nigeria and South Sudan, March 2023

[74] Mocah Films/Tearfund (2022)

2.2 How plastic-aggravated flooding events are negatively impacting human health

A World Bank article stated that flooding is considered one of the leading climatic threats to people's livelihoods[75], highlighting the risk this natural disaster poses to human populations. Flooding events are affecting the health and well-being of people globally, and with the increased severity of flooding due to plastic pollution, the impact on humans is also likely to increase in severity.

People in urban poverty are most likely to be impacted by health-related issues due to flooding.

According to the World Bank, more than half of the global population now live in urban areas, and this is expected to increase to seven out of every ten people by 2050[76]. A recent UN report stated that current population growth is concentrated among the world's poorest countries, and mainly in sub-Saharan Africa. Billions of people live in urban poverty in poorly coordinated housing development in areas with under-provisioned drainage infrastructure and a lack of solid waste management services and as a result have a higher likelihood of experiencing negative health impacts following natural disasters[77] [78] [79] [80].

These areas have also been found to be geographically disadvantaged in the provision of emergency services compared to well-planned neighbourhoods[81]. In some slum areas, such as in Sierra Leone, houses are built on layers of waste, causing poor structural stability. This makes them vulnerable to flooding and at risk of being exposed to stagnated water, putting the residents at risk of disease[82].

All the stakeholders interviewed mentioned that those living in urban poverty –often in slums – are most impacted by flooding events. It was further mentioned that children, people with disabilities and elderly people are at particular risk, as they spend more time at home and may also have a lack of mobility, making it more challenging to escape flooding events[83] [84]. Children living in urban poverty

[75] World Bank Blogs (2022) *Flood risk already affects 1.81 billion people. Climate change and unplanned urbanization could worsen exposure* https://blogs.worldbank.org/climatechange/flood-risk-already-affects-181-billion-people-climate-change-and-unplanned
[76] The World Bank (2022) *Urban Development.* https://www.worldbank.org/en/topic/urbandevelopment/overview#:~:text=Today%2C%20some%2056%25%20of%20the,people%20will%20live%20in%20cities.
[77] United Nations (2022) *A World of 8 Billion*. https://www.un.org/development/desa/dpad/wp-content/uploads/sites/45/publication/PB_140.pdf
[78] Korah and Cobbinah (2016) *Juggling through Ghanaian Urbanisation: Flood Hazard Mapping of Kumasi.* https://pure.rug.nl/ws/portalfiles/portal/97537444/Korah_Cobbinah2017_Article_JugglingThroughGhanaianUrbanis.pdf
[79] Lamond *et al* (2012) *The role of solid waste management as a response to urban flood risk in developing countries, a case study analysis.* https://www.witpress.com/Secure/elibrary/papers/FRIAR12/FRIAR12016FU1.pdf
[80] Escobar Carias *et al* (2022) *Flood disasters and health among the urban poor.* https://onlinelibrary.wiley.com/doi/full/10.1002/hec.4566
[81] Korah and Cobbinah (2016) *Juggling through Ghanaian Urbanisation: Flood Hazard Mapping of Kumasi.* https://pure.rug.nl/ws/portalfiles/portal/97537444/Korah_Cobbinah2017_Article_JugglingThroughGhanaianUrbanis.pdf
[82] VSO (2018) *The homes built on plastic: Life in a Sierra Leone slum* https://www.vsointernational.org/news/blog/the-homes-built-on-plastic-life-in-a-sierra-leone-slum
[83] Interviews with stakeholders from Nepal, South Sudan, Nigeria, Malawi and urban flooding specialist, March 2023
[84] Escobar Carias *et al* (2022) *Flood disasters and health among the urban poor.* https://onlinelibrary.wiley.com/doi/full/10.1002/hec.4566

aged between four and 15 are twice as likely to ingest polluted flood water leading to enteric infections, compared to adults, and this is on average 40% to 50% higher during a monsoon season[85] [86].

The stakeholder based in Nepal mentioned that another demographic at risk of the health impacts of flooding are waste pickers, who often still work in flood water during flooding events and therefore have increased exposure to disease and other health impacts[87].

Flooding events pose both immediate and long-term dangers to human health. In the context of LMIC slums, it is likely that the major health impact of plastic-aggravated flooding is gastrointestinal infection including cholera and diarrhoeal disease. However, the health impacts of flooding are multiple and complex. The immediate impacts of flooding, as a direct result of flood water and damage to buildings, are well-documented and include drowning, trauma, hypothermia, electrocution, and carbon monoxide poisoning[88]. A 2018 global review[89] identified the following major categories of health impact, over timescales ranging from immediate to long-term:

- Gastrointestinal infections (faecal-oral including diarrhoeal disease, cholera, hepatitis A)
- Respiratory infections
- Skin infections, mostly but not exclusively bacterial
- Zoonoses (diseases transmitted by animals) and vector-borne diseases (including leptospirosis and mosquito-borne diseases)
- Impacts on existing chronic disease
- Accidental death and injury (including through drowning, electrocution and trauma)
- Mental health impacts

It is important to note that this was a global review (without a specific focus on LMIC slum communities), and that it does not attempt to assess the relative importance of the different types of impact. Data is not available to provide a detailed analysis of the mortality and morbidity impacts of plastic-aggravated flooding in LMIC slum communities, but it should be assumed that major impacts are likely to occur in all of the above categories.

The link between flooding and cholera is well-established[90] [91], and it is well-known that flooding of septic tanks and other centres of faecal contamination is a significant problem in LMIC urban communities[92]; people may be exposed to the contaminated floodwater directly, or through contamination of water supplies. The health impacts described above were widely corroborated by the

[85] Ballesteros (2010) Linking Poverty and the Environment: Evidence from Slums in Philippine Cities https://pidswebs.pids.gov.ph/CDN/PUBLICATIONS/pidsdps1033.pdf

[86] Berendes *et al* (2019) *Associational between open drain flooding and paediatric enteric infections in the MAL-ED cohort in a low-income, urban neighbourhood in Vellore, India* https://bmcpublichealth.biomedcentral.com/articles/10.1186/s12889-019-7268-1

[87] Interview with stakeholder in Nepal, March 2023

[88] Paterson *et al* (2018) *Health Risk of Flood Disasters.* https://academic.oup.com/cid/article/67/9/1450/4945455

[89] Paterson *et al* (2018) *Health Risk of Flood Disasters* https://academic.oup.com/cid/article/67/9/1450/4945455

[90] Schwartz BS *et al* (2004) *Diarrheal epidemics in Dhaka, Bangladesh, during three consecutive floods: 1988, 1998, 2004.* https://www.ncbi.nlm.nih.gov/pmc/articles/PMC1626162/

[91] Jorgensen *et al* (2016) *Dynamic modelling of health risks during wastewater influenced urban flooding* https://hal.science/hal-03322095/document

[92] Leandro J *et al* (2022) *Expected annual probability of infection: A flood-risk approach to waterborne infectious diseases. Water Research* https://www.sciencedirect.com/science/article/abs/pii/S0043135422005140

stakeholders interviewed in this research here: for example, the stakeholder in Nepal noted the association of hepatitis with flooding events[93].

The impacts of cholera in particular can be dramatic: a recent UNICEF report estimated that, from January to March 2023, 18 million people in Malawi were at high risk of contracting cholera due to cyclones, flooding and the lack of safe drinking water and sanitation[94]. During this time there were 53,226 reported cases of cholera in Malawi, with 1,634 deaths.

The stakeholder based in Malawi went on further to explain that recent flooding from cyclone Freddy (March 2023) had impacted 11 districts and affected over 2 million people, causing over 700 deaths. They indicated that there have been many flooding events in the last 12 months, and recovery from Cyclone Freddy has been compromised as a result[95].

The links between flooding and water-associated mosquito-borne diseases such as malaria and dengue are less clearly understood and may be dependent on highly specific local factors. However, the incidences of both diseases may certainly be increased by flooding[96] [97].

As well as disease impacts and accidental death and injury, high levels of post-traumatic stress have been reported in communities displaced due to flooding events and have been found to significantly increase adult depression-related symptoms as well as severe mental impairment and emotional functioning in children. This is reportedly due to their inability to understand the situation, acute feelings of helplessness, loss of attachments, and less experience coping with such types of situations[98]. The mental health impacts of flooding are not well understood and undoubtedly vary widely from context to context. However, they can be expected to have a major impact on well-being.

For a summary representation of the likely causal pathways linking plastic pollution to flooding and thence health, see Figure 6.

2.3 Future trends in climate, consumption, and urbanisation will make plastic-aggravated flooding events worse

From the research in sections 2.1 and 2.2 future trends were identified that are likely to make a region at higher risk of plastic-aggravated flooding and make the impacts of plastic-aggravated flooding worse.

Plastic usage and pollution is expected to rise and cause increased flood risk[99]. In 2015 it was estimated that between 60 and 99 million metric tonnes of mismanaged plastic waste were generated globally; this could triple by 2060 in a business-as-usual scenario, based on the projections by L.

[93] Interview with stakeholder in Nepal, March 2023
[94] Reliefweb (2023) *UNICEF Malawi Humanitarian Situation Report No.1 for 1 January – 15 March 2023. https://reliefweb.int/report/malawi/unicef-malawi-humanitarian-situation-report-no1-1-january-15-march-2023*
[95] Interview with stakeholder in Malawi, March 2023
[96] Boyce R *et al* (2016) *Severe flooding and malaria transmission in the Western Ugandan highlands: implications for disease control in an era of global climate change*. https://pubmed.ncbi.nlm.nih.gov/27534686/
[97] Tahir M *et al* (2020) *Devastating urban flooding and dengue outbreak during the COVID-19 pandemic in Pakistan*. https://pubmed.ncbi.nlm.nih.gov/33816368/
[98] Escobar Carias *et al* (2022) *Flood disasters and health among the urban poor.* https://onlinelibrary.wiley.com/doi/full/10.1002/hec.4566
[99] Emmerik, Schwarz (2019) *Plastic debris in Rivers https://wires.onlinelibrary.wiley.com/doi/full/10.1002/wat2.1398*

Lebreton and A. Andrady[100]. It is believed that this increase in mismanaged plastic waste will be disproportionally high on the continents of Africa and Asia[101]. In Africa, the growing middle class is creating a large consumer market for single-use plastic items. Shopping in supermarkets, with single-use plastic packaging, is now replacing the informal shops and markets that traditionally use less packaging[102]. Identifying an area that has a projected increase in consumer plastic usage and poor solid waste management is a key indicator of future risk from plastic-aggravated flooding. In Tearfund's report *No Time to Waste* it was estimated that every 30 seconds one person dies from diseases caused by mismanaged waste (including plastic), highlighting how increased plastic usage is creating a growing public health emergency globally.

Unplanned urban development and populations within slums are increasing throughout the world. Over 1 billion people globally live in slums and there has been a steady increase in this figure since 2018. It is estimated that by 2050 the global figure of people living in slums will reach 3 billion[103]. According to UN statistics, 80% of slum populations are concentrated in just three regions globally: Eastern and South-eastern Asia, sub-Saharan Africa and Central and Southern Asia[104]. The growth of slum populations is resulting in an increased number of unplanned developments being built on flood zones, further increasing the number of people at risk of natural disasters and plastic-aggravated flooding events[105].

[100] Lebreton L., Andrady A. (2019) *Future scenarios of global plastic waste generation and* disposal. https://www.nature.com/articles/s41599-018-0212-7
[101] Lebreton L., Andrady A. (2019) *Future scenarios of global plastic waste generation and* disposal https://www.nature.com/articles/s41599-018-0212-7
[102] Jambeck *et al* (2018) *Challenges and emerging solutions to the land-based plastic waste issue in Africa* https://www.sciencedirect.com/science/article/pii/S0308597X17305286
[103] Khan *et al* (2019) *Slum settlement problem and solution: A case Report of Karachi http://thesciencepublishers.com/biomed_lett/files/v5i1-7-BML20191008.pdf*
[104] UNstats (2018) *Make cities and human settlements inclusive, safe, resilient and sustainable* https://unstats.un.org/sdgs/report/2019/goal-11/#:~:text=The%20absolute%20number%20of%20people,Southern%20Asia%20(227%20million).
[105] Kaburu *et al* (2019) *Anthropogenic factors that cause floods in Mukuru slums, Nairobi city county, Kenya* https://ir-library.ku.ac.ke/bitstream/handle/123456789/22061/Anthropogenic%20Factors%20that%20cause....pdf?sequence=1

Figure 4 A river littered with plastic pollution, flowing through Haiti's capital city, Port au Prince[106]

Changing weather patterns are putting populations living in South and East Asia and sub-Saharan Africa at risk of flooding. Some of the regions already most severely impacted by flooding are located in tropical and subtropical regions that are likely to see an increase in extreme precipitation events due to climate change[107]. Africa is particularly vulnerable to the effects of climate change with changes in precipitation potentially causing increased and more intense rainfall events in certain regions[108]. Research articles have highlighted the fact that wet seasons, particularly in Africa, are getting more severe with the same amount of rainfall being concentrated in a shorter period of time. While the number of rainy days within a wet season are declining, the average rainfall per day is increasing, resulting in shorter wet seasons with increased and more intense rainfall[109] [110].

This fact was supported by the four stakeholders interviewed located in South Asia and sub-Saharan Africa who mentioned that weather events have become more severe in recent years, and they are witnessing more frequent flooding events[111]. The stakeholder based in South Sudan had noticed a significant increase in flooding events in the capital Juba in the last three years, with large swathes of urban areas having been subjected to severe floods[112]. They explained that with the removal of plastic pollution these floods would be largely avoidable as water would drain naturally into the Nile. In Angola, it was found that plastic-aggravated flooding events that occurred in 2017 and 2019 were

[106] Ruth Towell / Tearfund (2019)
[107] Eccles *et al* (2019) *A review of the effects of climate change on riverine flooding in subtropical and tropical regions* https://iwaponline.com/jwcc/article/10/4/687/69543/A-review-of-the-effects-of-climate-change-on
[108] Dunning *et al* (2018) *Later wet season with more intense rainfall over Africa under future climate change* https://journals.ametsoc.org/view/journals/clim/31/23/jcli-d-18-0102.1.xml
[109] Wang *et al* (2021) *Monsoons Climate Change Assessment* https://journals.ametsoc.org/view/journals/bams/102/1/BAMS-D-19-0335.1.xml
[110] World Weather Attributes (2022) *Climate change likely increased extreme monsoon rainfall, flooding highly vulnerable communities in Pakistan https://www.worldweatherattribution.org/climate-change-likely-increased-extreme-monsoon-rainfall-flooding-highly-vulnerable-communities-in-pakistan/*
[111] Interview with stakeholders from Nepal, South Sudan, Nigeria and Malawi March 2023
[112] Interview with stakeholder in South Sudan, March 2023

caused by moderate and even minor rainfall and that intense rainfall was not needed to trigger a plastic-aggravated flooding event[113]. More frequent and intense rainfall along with increased plastic pollution generation is a potentially dangerous combination and, as highlighted above, are both increasing.

Figure 5 A small boy outside a destroyed home in floodwater and plastic pollution, Central America[114]

Lack of policy implementation and lack of community awareness around plastic pollution and flooding are two important factors that could increase the risk of plastic-aggravated flooding. The stakeholder based in Nepal mentioned that while some countries may have policies in place aimed at reducing plastic usage and pollution, there is often a lack of implementation of these policies, due to other national priorities. This, coupled with a lack of public awareness of environmental issues, was resulting in policies not being enforced or followed[115]. However, this stakeholder did mention that after recent plastic-aggravated flooding in Bhaktapur in the Kathmandu valley, Nepal, residents were understanding the link between plastic pollution and severe flooding events, which is an encouraging step towards community-based mitigation measures.

Nigeria was also identified as a country where the implementation, prioritisation and enforcement of environmental policies was a challenge. While Nigeria implemented a plastic bag ban in 2019, the ban has so far been ineffective as the country lacks the resources to enforce such a policy as it is reportedly

[113] Dinis *et al* (2021) *Disastrous flash floods triggered by moderate to minor rainfall events. Recent cases in coastal Benguela (Angola) https://www.mdpi.com/2306-5338/8/2/73*
[114] D Membreno / EU Civil Protection and Humanitarian Aid (23/11/2020) https://cutt.ly/W6JPApH
[115] Interview with stakeholders based in Nepal, March 2023

overburdened in other areas [116] [117] [118]. However, a study conducted in Bangladesh found that the successful implementation of their plastic bag ban did reduce flood impacts, highlighting an example where successful policy implementation has worked to mitigate plastic-aggravated flood risk[119].

The lack of solid waste management policies and/or policy implementation, and the negative impact this has on the environment, is a crucial issue and is one of the main motivators for developing a globally binding plastic treaty.

Lack of community awareness regarding the importance of solid waste management and the link to plastic-aggravated flooding also appeared during the literature review and was supported by the stakeholder based in Nepal[120] as a factor that makes an area at higher risk of plastic-aggravated flooding. An article by Cities Alliance stated that one of the reasons that waste is ending up in drainage systems in Uganda is due to poor community awareness and education of the direct link between plastic pollution and flooding[121].

2.4 Summary of the problem

To summarise the main findings identified in sections 2.1, 2.2 and 2.3, the main causal pathways linking plastic waste, flooding and health have been displayed in Figure 6.

The causal pathway highlights the main health impacts that are being experienced by populations at risk of plastic-aggravated flooding. The next section will aim to quantify how many people are at risk of experiencing those health impacts.

[116] Emelie (2020) *An Appraisal of the Impact of Waste and Flood on Environmental Protection in Nigeria https://www.nigerianjournalsonline.com/index.php/COOUJCPL/article/download/2026/1981?__cf_chl_tk=iOaCsZqPFKrMfSnXuq9ei5kuMMJSXiL78wExT1JoN8Y-1683739446-0-gaNycGzNDHs*

[117] Adebiyi-Abiola *et al* (2019) *Cleaning up plastic pollution in Africa* https://www.science.org/doi/abs/10.1126/science.aax3539

[118] Mokuolu *et al* (2022), *Assessing the Effect of Solid Wastes on Urban Flooding: A case study of Isale Koko https://www.ajol.info/index.php/laujoces/article/view/240199*

[119] S. Ahmed (2005) *Impact of banning polyethene bags on floods of Dhaka city by applying CVM and remote sensing.* https://www.researchgate.net/publication/251813921_Impact_of_banning_polythene_bags_on_floods_of_Dhaka_City_by_applying_CVM_and_remote_sensing

[120] Interview with stakeholder based in Nepal, March 2023

[121] Cities Alliance (2020) *Uganda: Improving Waste Management for Flood Control* https://www.citiesalliance.org/newsroom/news/results/uganda-improving-waste-management-flood-control

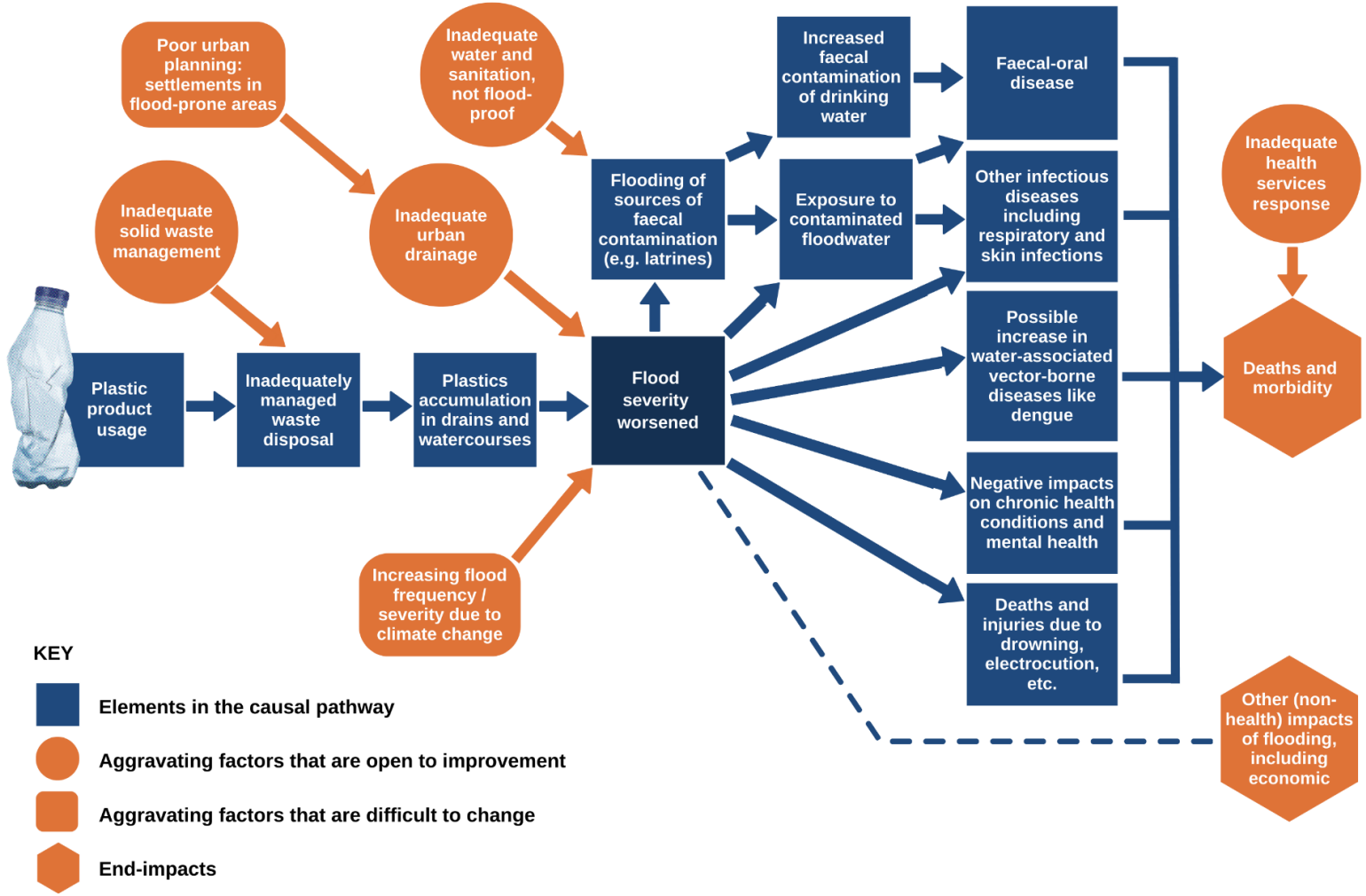

Figure 6 Summary of pathways linking plastic pollution, flooding, and health

3 Quantitative estimation of impacts

3.1 People impacted by plastic-aggravated flooding: top-line findings

Using the methodology described in section 3.2, we estimate that approximately **218 million people are at significant risk of plastic-aggravated flooding worldwide**[122]. This represents approximately 3% of the global population, equivalent to the entire population of Brazil. 74% of these people live in the East Asia & Pacific region or in the South Asia region. Approximately one-fifth (41 million) of these are infants, elderly people or people with disabilities, and so are at particular risk of negative health impacts.

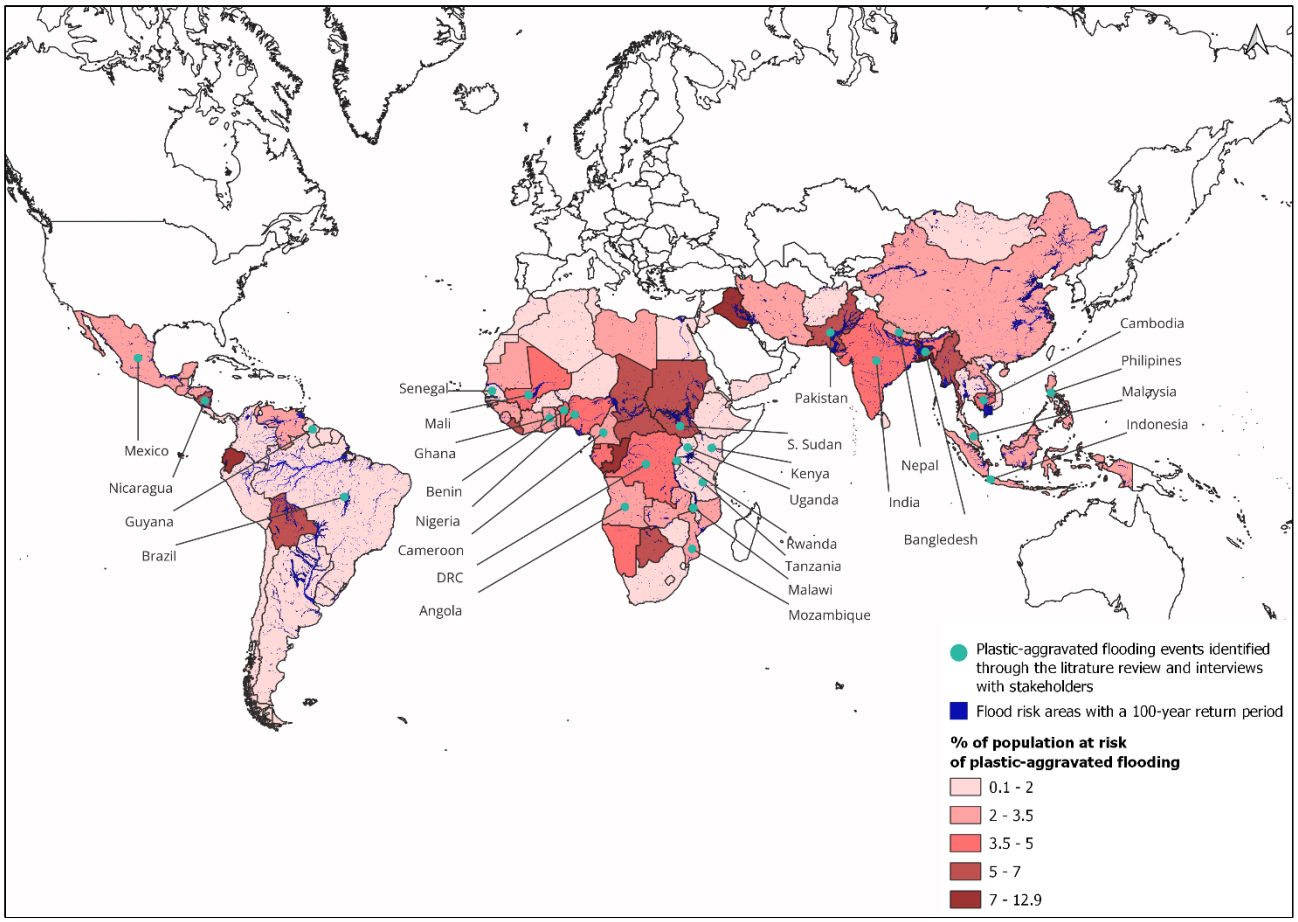

Figure 7 People at significant risk of plastic-aggravated flooding. This map has been overlaid with flooding events identified through the literature review and with data showing global flood risk areas with a 100-year return period [123] The green dots represent countries identified through the literature review and stakeholder interviews, they are thus indicative and not exhaustive of all countries experiencing plastic-aggravated flooding events.

[122] 1-*in-100 year floods with inundation depths over 0.15m (the 1-in-100 year flood being that which has a 1% chance of occurring each year; less severe but still potentially significant flooding events occur with higher frequency)*

[123] European Commission (2016) *Flood Hazard map of the world – 100-year return period* https://data.jrc.ec.europa.eu/dataset/jrc-floods-floodmapgl_rp100y-tif

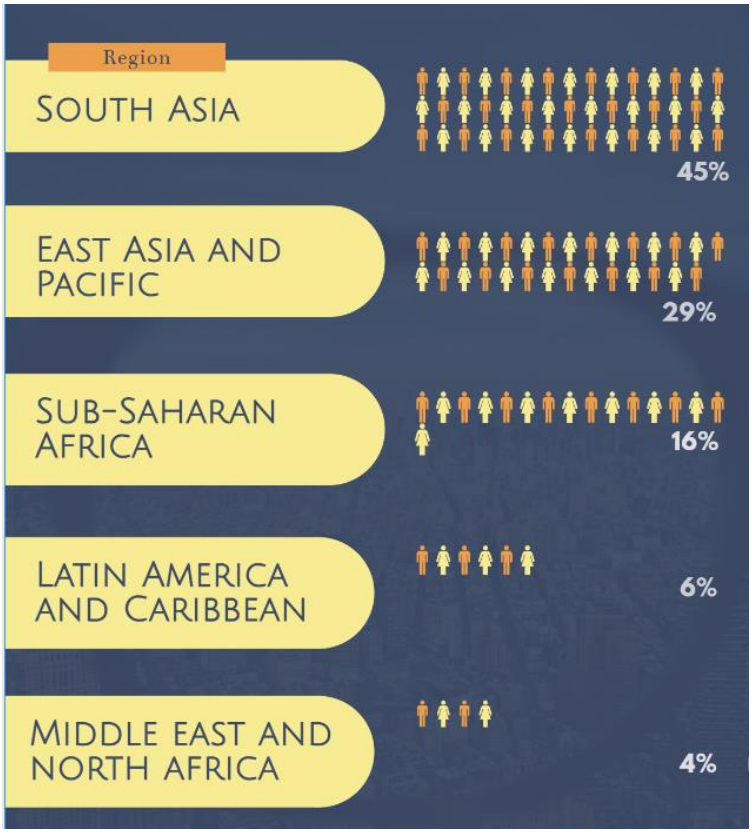

Figure 8: Proportion of total number of people affected by plastic-aggravated flooding (218 million), by region.

3.2 Estimation methodology

Our estimate of the number of people impacted globally by plastic-aggravated flooding is necessarily approximate: in view of the complexity of the casual chain (see Figure 6), insufficient data is available to generate an accurate high-certainty estimate.

Nonetheless, we have used a rigorous and conservative approach, and consider that 218 million is a realistic approximation to the number of people whose well-being is at significant risk through plastic-aggravated flooding. To obtain this estimate, we used a two-stage approach: first, identifying those countries in which plastic-aggravated flooding can be expected to have substantial impacts on well-being; second, estimating the proportion of total population in each country judged likely to suffer substantial impacts. This generated country estimates of population likely to be substantially impacted, which were added to obtain a global figure. To further estimate the number of people in each included country at particular risk of health impacts (and the corresponding global total), we conservatively considered that only infants, the elderly, and people living with disabilities are at particular risk of health impacts.

It is important to stress that our estimate conservatively considers only those living in urban slums in low- and middle-income countries (LMICs). This reflects the view – based on literature review, key informant interviews– that plastic-aggravated flooding is primarily an urban issue, and that substantial impacts on well-being will largely be seen in LMIC slum communities with poor drainage, poor waste management, and poor water and sanitation services.

3.2.1 Precise procedure

The precise procedure used was as follows:

Step 1

As a starting point, we used the study of Rentschler *et al.*[124] which estimated the population at significant risk of flood exposure in 188 countries globally, based on mapping of fluvial, pluvial, and coastal flooding events. These authors estimated that 1.81 billion people are exposed to 1-in-100 year floods with inundation depths over 0.15m (the 1-in-100 year flood being that which has a 1% chance of occurring each year). From Rentschler *et al.*'s list of at-risk countries, we carried forward only low- and middle-income countries (LMICs), on the assumption that plastic-aggravated flooding with significant impacts on well-being is largely a problem of LMICs (with often inadequate urban drainage, solid waste management, and water and sanitation services).

Step 2

We then further excluded all Small Island Developing States (SIDS), on the conservative assumption that in these countries, broadly speaking, flooding can be expected to be largely coastal, not pluvial/fluvial, and thus not necessarily likely to be aggravated by plastic waste blocking drains. (See also Step 4.)

Step 3

We then used published data on amount of mismanaged plastic waste[125] to exclude countries with mismanaged plastic waste less than 1 kg per capita per annum. This data was not available for 18 LMICs. However, we retained these countries, because very few of the LMICs for which data is available have mismanaged plastic waste less than 1 kg per capita per annum (available data: 70 LMICs have mismanaged waste and were included; 5 LMICs reportedly have well-managed waste, and so were excluded; 18 LMICs had no data available, but were included). As a sense check, we checked the mismanaged plastic waste per capita of the top 10 countries in our estimate (i.e., the 10 countries identified by us to have the largest total populations impacted by plastic-aggravated flooding), and all are above 6kg of mismanaged plastic waste per person per annum (with the exception of Indonesia, at 3kg per person per annum).

Step 4

Considering the 88 countries identified by the previous steps, we took the total population at risk of flooding in each country (as per Rentschler *et al.*) and subtracted populations judged likely to be affected primarily by coastal flooding, as opposed to pluvial/fluvial flooding, on the view that coastal flooding events are in general unlikely to be aggravated by plastic blockage of drains. Estimates of the number of people at risk of coastal flooding were in some cases obtained directly from Rentschler *et al.* (2022); where no such data was available, we conservatively subtracted the proportion of people living 10 km from the coast[126].

[124] Rentschler J., Salhab M., Jafino B. A. (2022) *Flood exposure and poverty in 188 countries* https://www.nature.com/articles/s41467-022-30727-4

[125] Ritchie H. and Roser M. (2022) *Plastic pollution* https://ourworldindata.org/plastic-pollution

[126] ResourceWatch (2010) *Populations in coastal zones* https://resourcewatch.org/data/explore/Populations-in-Coastal-Zones?section=Discover&selectedCollection=&zoom=3&lat=0&lng=0&pitch=0&bearing=0&basemap=dark&labels=light&layers=%255B%257B%2522dataset%2522%253A%2522995ec4fe-b3cc-4cf4-bd48-

Step 5

We then reduced the resulting figure by a factor corresponding to the urban proportion of the country's population. This reflects the assumption, outlined above, that plastic-aggravated flooding can be assumed to be largely an urban issue.

We note a potential methodological limitation here: it is not necessarily the case that the ratio of urban-to-rural flooding in Rentschler *et al.*'s data is the same as the national ratio of urban-to-rural population. To assess the validity of this step, we undertook a sense-check using a geographical information system called QGIS. Data from the European Commission Joint Research Centre Data "Catalogue on Flood Hazards of the World – 100-year return period"[127] was overlaid with Global Human Settlement Layer 2015[128] using urban centre populations. An overlap analysis was undertaken to show the number of urban centre populations that overlap with the flood hazard map. The resulting data was extracted for the eight countries identified by us to have the largest total populations impacted by plastic-aggravated flooding, namely Bangladesh, China, DRC, India, Indonesia, Iraq, Nigeria and Pakistan. In these key countries, this sense-check confirmed that our urban/rural split is acceptably accurate.

Step 6

We then further restricted our estimate to people living in slums, on the conservative view that significant direct impacts on health and other aspects of individual well-being are likely to be much more severe in slum communities (with typically poor drainage, solid waste management, and water and sanitation). The proportion of the urban population living in slums in each country was obtained from recent World Bank[129] and UN[130] data where available. Where World Bank and UN data were not available, the average percentage of the urban population living in slums in other in-scope countries in the same region was applied.

These six steps thus generated the total estimated number of people at significant risk of plastic-aggravated flooding in each of the 88 included countries, allowing summing to regional levels and global level. The full country-by-country data set is available from the authors on request.

Identifying those at particular risk of health impacts

In order to estimate the number of people at particular risk of negative health impacts, we simply reduced each country total by a factor corresponding to the proportion of that country's population (WHO data) who are infants (5 and under)[131], or elderly people (65 and over)[132,133] or living with disability (where we assumed that 2% of the population would be classed as people with disabilities).

b89d4e3ea072%2522%252C%2522opacity%2522%253A1%252C%2522layer%2522%253A%25222e533124-3258-4ec2-a777-beed1712d1a0%2522%257D%255D&aoi=&page=1&sort=most-viewed&sortDirection=-1

[127] European Commission (2016) *Flood Hazard map of the world – 100-year return period* https://data.jrc.ec.europa.eu/dataset/jrc-floods-floodmapgl_rp100y-tif

[128] European Commission (2015) *GHSL-Global Human Settlement Layer* https://ghsl.jrc.ec.europa.eu/ghs_fua.php

[129] The World Bank (2021) *Populations living in slums (% of urban populations)* https://data.worldbank.org/indicator/EN.POP.SLUM.UR.ZS?view=chart

[130] UN (2023) *Millenium Development Goals Indicators https://unstats.un.org/wiki/display/mdgs*

[131] World Bank (2021) *Population ages 0-14, total* https://data.worldbank.org/indicator/SP.POP.0014.TO

[132] World Bank (2021) *Population ages 65 and above* (% of total population) https://data.worldbank.org/indicator/SP.POP.65UP.TO.

[133] World Health Organization (2022) *Healthy life expectancy (HALE) at birth (years)* https://www.who.int/data/gho/data/indicators/indicator-details/GHO/gho-ghe-hale-healthy-life-expectancy-at-birth

This is clearly a highly simplified approach: but it's a conservative approach, and certainly includes what we can reasonably assume to be the most significant impact on mortality and morbidity, namely impact on infectious disease among infants. However, as summarised in Figure 6, the precise health impacts of plastic-aggravated flooding are wide-ranging and complex, and likely differ markedly from one location/event to another.

3.2.2 Sense-checking and limitations

Under Steps 3 and 5 above, we have noted an additional and specific sense-check. We also applied two more general sense-checks. First, we looked at those countries specifically identified in the literature or in stakeholder interviews as having experienced plastic-aggravated flooding. All these countries were LMICs with reported plastic waste mismanagement of more than 1 kg per capita per annum (where data were available). This supports the validity of our country inclusion/exclusion criteria. Second, we compared our estimate to Rentschler *et al.*'s estimates of the number of people in poverty experiencing significant flood risk[134]: out of the 1.81 billion people at risk of flooding globally, 780 million were identified as suffering the combined impacts of flooding and poverty (less than 5.50 USD per day). Our estimate of 218 million people at risk of plastic-aggravated flooding is thus around 28% of Rentschler *et al.*'s 780 million. Given that the 780 million includes rural and urban populations, whereas our estimate considers only urban, this seems broadly consistent.

As we have stressed above, this is an estimation based on best available data. Detailed data on impacts of plastic-aggravated flooding is not available, and neither is there sufficient data to allow detailed modelling of the complex causal pathways summarised in Figure 6. However, we have made multiple conservative assumptions and have applied various sense-checks, such that we consider the final estimate of 218 million people to be a realistic, and conservative, approximation. Nonetheless, we note several limitations of the approach used.

First, Rentschler *et al.*'s flooding data does not provide urban/rural splits, and our assumption that this split corresponds to urban-to-rural proportion in the national population is thus a simplification.

Second, our approach does not attempt to differentiate low-income urban populations in terms of the multiple specific factors which undoubtedly affect the link between plastic, flooding, and health in each location: factors like the precise pattern of plastic use and disposal, the precise pattern and nature of flooding events, the nature and "blockability" of the drainage system.

Third, we have included countries with mismanaged plastic waste greater than 1 kg per capita per annum, but we have not looked at possible differences between a location with 1 kg mismanaged plastic waste and (say) 3 kg mismanaged waste (although note that all of the top 10 countries by affected population have mismanaged plastic of greater than 3 kg per capita per annum).

Fourth, we have excluded Small Island Developing States and populations living within 10 km of the coast, but this is conservative, and likely excludes some people who suffer impacts of plastic-aggravated flooding.

[134] Rentschler J., Salhab M., Jafino B. A. (2022) *Flood exposure and poverty in 188 countries* https://www.nature.com/articles/s41467-022-30727-4

In short, there is currently insufficient data to ground a detailed understanding of the links between plastic pollution, flooding, and health impacts in any specific location. Nonetheless, it is clear from the literature and stakeholder interviews that such impacts exist on a large scale, and they can be approximated by approaches like those used here. There is an urgent need for more detailed empirical research into the human impacts of urban flooding, and the effects of plastic waste on those causal chains.

4 Conclusion

This research aimed to assess the contribution of plastic pollution to flooding and the related human health impacts. **The evidence gathered throughout this research demonstrates that plastic pollution in slums in many LMICs is making flooding events more severe by blocking drainage systems (and waterways), resulting in negative human health outcomes**, including gastrointestinal diseases such as cholera and diarrhoeal disease. While less well documented, it is likely that other significant health impacts are also affecting urban slum communities in LMICs, including mosquito-borne diseases such as malaria and dengue fever.

Drawing on the desk-based research and key stakeholder interviews, we developed a methodology for calculating a conservative approximation of the number of people at risk worldwide. This estimates that **218 million people are at significant risk of plastic-aggravated flooding events. And approximately 41 million[135] of these are infants, elderly people or people with disabilities, and therefore at even greater risk of negative health-related impacts.**

It is likely that this figure will increase in the future, with projected increases in mismanaged plastic, worsening climate change and increasing populations in slums.

Given the size of the problem and its importance to human health, the link between plastic pollution and flooding must be investigated further, particularly in the context of the global plastics treaty currently being negotiated. We note that further evidence and literature exist linking plastic waste, flooding, and human health and that more empirical estimates would be very useful; further investigation could corroborate our findings and provide a more detailed understanding of the impacts.

This would be directly in line with one of the core obligations proposed in UNEP's recent paper outlining potential options for elements towards an international legally binding instrument[136]. Core obligation 12 is about "protecting human health from the adverse effects of plastic pollution." UNEP suggest further that a potential option for control measures is to "conduct further research on the adverse effects of plastic and plastic pollution on human health." One such activity that would go far in aiding further understanding of the impacts of plastic-aggravated flooding could be to conduct field studies in an urban area of a LMIC in East Asia & Pacific region or in the South Asia region. The study

[135] *-in-100 year floods with inundation depths over 0.15m (the 1-in-100 year flood being that which has a 1% chance of occurring each year; less severe but still potentially significant flooding events occur with higher frequency)*

[136] United Nations Environment Programme (2023). *Potential options for elements towards an internationally legally binding instrument, based on a comprehensive approach that addresses the full life cycle of plastics as called for by United Nations Environmental Assembly resolution 5/14.* https://wedocs.unep.org/handle/20.500.11822/42190

could be focussed on identifying the risk of flooding as a function of the level of plastic mismanagement. These studies could then be supplemented to investigate what key factors – such as serviceability of drainage systems, accessibility to potable drinking water, waste services in informal settlements in flood-prone areas, etc. – would lead to reduced health outcomes because of plastic-aggravated flooding events.

High-quality plastic inventories are very important to address these issues generally. While the composition of plastic waste found on beaches receives much media attention, the composition of municipal (i.e., land) plastic pollution receives comparatively much less attention. This is problematic, as it has been demonstrated through this and other research that plastic pollution can block drainage systems, increasing flood risks. Understanding the main sources of plastic pollution in areas prone to plastic-aggravated flooding events will mean that targeted interventions can be developed to tackle or eliminate those problematic plastic items and avoid negative impacts associated with plastic-aggravated flooding.

This research demonstrates that the negative human health impacts caused by plastic-aggravated flooding are potentially very high and will undoubtedly impact marginalised communities in LMICs most. Nonetheless, it is important to consider the wider issues at play; while this research has identified that flooding can be aggravated by plastic pollution, this does not happen in isolation. There are wider contributing factors, particularly related to solid waste management, and any approach taken to mitigate or adapt to plastic-aggravated flooding events should therefore be similarly cross-cutting.

Appendix A – Interviews

A list of questions and topics was drafted to discuss with interviewees. The interview proforma was drafted in such a way as to aid in the analysis, e.g., asking interviewees to quantify impacts wherever possible. The questions were grouped into the three research categories:

1. the impact of plastic on flooding events
2. the impact of flooding events on health
3. contributing factors (e.g., climate change).

The interviews were aimed to supplement the literature review with first-person accounts of the impact plastic waste was having on flooding events. All interviews were conducted through Microsoft Teams. After the interviews had taken place, interview notes were combined into a single Excel sheet and key/impactful information was drawn out to include in the report.

Interviewee Occupation	Stakeholder location
Tearfund – WASH Technical Advisor	Juba, South Sudan
Tearfund – Environmental and Economic Sustainability Advisor	Kathmandu, Nepal
Tearfund – Advocacy Manager	Jos, Nigeria
Tearfund – Country Director for Malawi and Tanzania	Lilongwe, Malawi
Leading expert in urban flooding and climate change	Copenhagen, Denmark