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Viewpoint

Rising Water, Rising Risks: The Hidden Dangers of Emerging Contaminants in Climate-Intensified Storms

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The monitoring of contaminants of emerging concern (CECs) in diverse aquatic environments has been reported in many studies. However, the behavior and impact of these contaminants in urban runoff and floodwaters resulting from natural disasters remain a significant research gap. A recent extreme weather event across Gulf Cooperation Council (GCC) countries, comprising Bahrain, Kuwait, Oman, Qatar, Saudi Arabia, and the United Arab Emirates (UAE), raises questions about the fate, transport, and potential impacts of CECs in an otherwise arid region where they have been rarely monitored. Causing flooding and loss of life in Oman and UAE, this extreme weather event also led to sewage treatment plant failures, accumulation of urban runoff likely to contain chemical pollutants, and the potential for cross-contamination of treated water traversing distribution systems via cracked pipes. In this Viewpoint, we explore some of the potential impacts of urban runoff from unexpected storms and heavy rainfall in arid countries, which are increasingly common in our rapidly changing climate. We discuss the potential pathways of pollutants during these events and identify the hidden risks associated with CECs, which are unregulated and not typically monitored in water used for domestic or agricultural purposes. While highlighting the dangers of CECs, such as residues of pharmaceuticals and personal care products (PPCPs), tire-derived products, per- and polyfluoroalkyl substances (PFAS), and microplastics, we also include commonly regulated contaminants such as heavy metals and polyaromatic hydrocarbons (PAHs) resulting from industrial activities.

Flash Floods and Road Runoff Mobilize Chemical Contaminants in the Environment. On April 14 and 15, 2024, a majority of the GCC countries experienced an extreme weather event that generated the heaviest rainfall recorded in more than 75 years and caused extensive flooding and massive infrastructure disruption in heavily populated areas. The increasing incidence of extreme weather events like this one is attributed to anthropogenic global warming and the resulting climate change. If the Earth's temperature continues to increase at the present steep trajectory, the number of extreme weather events is projected to increase in turn.[1] The magnitude of the GCC storm was significant for an arid environment, with >250 mm (10 in.) of precipitation received within a 24 h span,[2] causing floods, blackouts, and interruptions in water supplies in many residential areas. While the obvious danger of flash flooding must be addressed, so too must urban planners, policy makers, and stakeholders attend to the hidden risks associated with contaminated flood waters. Heavy rains and flooding leach chemical contaminants that have accumulated over time on roads and construction sites. Once mobilized in water, these contaminants can be transported to environments that support fish and wildlife and also make their way into source water used for agriculture and domestic consumption, as illustrated in Figure 1. Because contamination of aquatic systems by flood waters and urban road runoff can include accumulated CECs, heavy metals, PAHs, and other unknown chemicals that may have long-term human and ecological impacts, such occurrences warrant investigation.

Heavy Rainfall and Poor Drainage Infrastructure Increase Pollution Risks. The design of drainage infra-

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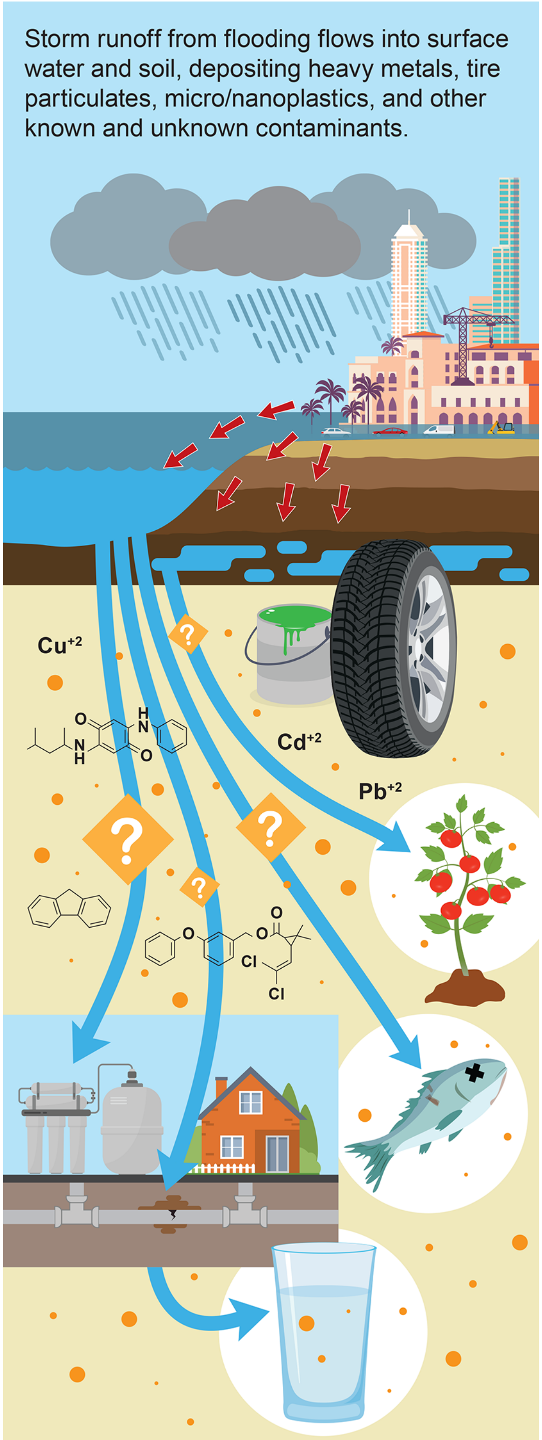

Figure 1. Storm runoff and floodwaters carry many environmental pollutants, including heavy metals, microplastics and nanoplastics, tire-derived products, pesticides, polyaromatic hydrocarbons, and other known and unknown contaminants of emerging concern (CECs). These chemicals can reach surface waters that support fish and wildlife or may be introduced to crop plants through irrigation. Polluted waters can also recontaminate treated water through intrusion of cracked underground pipes in aging distribution systems and may eventually reach domestic water supplies.

structure in most GCC countries has been informed by historic annual average rainfall, with minimal consideration given to what, heretofore, has been the remote possibility of heavy rainfall and flooding. Thus, unusually heavy episodes of rainfall such as that of April 2024 can cause untreated sanitary sewage overflows (SSOs) into nearby streams, with the potential for contaminating agricultural and domestic water sources. Sewage overflows may contain nutrients (e.g., nitrogen and phosphorus), heavy metals (e.g., mercury, cadmium, lead, and copper), pathogens (e.g., bacteria, viruses, and protozoa), helminths, residues of PPCPs, and chemicals that leach from consumer products (e.g., microplastics and PFAS). Several studies have provided evidence indicating that microplastics pose both physical and chemical risks in aquatic environments[3] and that PFAS (also known as forever chemicals) are bioaccumulative and cause numerous deleterious effects on humans and wildlife.[4] Diversion of SSOs, floodwater, and road runoff to less flooded areas, including nearby water bodies (e.g., ocean and estuaries), can result in the spread of these pollutants into areas that may potentially harm vulnerable wildlife and human populations. In addition to the contaminants in SSOs, pollutants associated with agricultural, municipal, and industrial activities (including construction and transportation) may include increased levels of heavy metals from paints and other construction materials, petroleum-related chemicals such as PAHs, pesticides and fertilizers, tire-derived products (e.g., 6PPD-quinone) that have been shown to be highly toxic to some fish species,[5] and many other unregulated chemicals that are considered CECs. Several of these CECs are not effectively removed in conventional wastewater treatment plants and have the potential to cause adverse environmental and human health effects in minute concentrations. Moreover, some PPCPs bioaccumulate in fish, with the potential for endocrine-disrupting effects, while others are taken up by crop plants destined for human and animal consumption.[6] Outdated drainage infrastructure can jeopardize ecosystems and human health.

Microplastics in Stormwater Facilitate the Spread of Pollutants into the Environment. The widespread presence of microplastics in wastewater can further amplify the dispersion of environmental pollutants. Microplastics act as carriers, adsorbing and transferring harmful pollutants such as polychlorinated biphenyls, PAHs, PPCPs, heavy metals, and pesticides.[7] Because of their hydrophobic nature, microplastics create an ideal environment on which microorganisms, including pathogens and antibiotic-resistant bacteria, can thrive in a biofilm layer known as the plastisphere.[8] Another risk associated with microplastics in stormwater is the environmental leaching of toxic additives, such as heavy metals, used to enhance polymer properties.[9] Stormwater has emerged as a major pathway for the migration of microplastics into receiving waters; it is expected to exacerbate the risks of CECs more than any other source because stormwater transports pollutants from urban areas to the surrounding environments. When microplastics come into contact with stormwater runoff, the leaching of pollutants may be compounded by turbulence, which makes it difficult to accurately assess the contribution of stormwater to microplastic pollution in surface waters. Due to the complex dynamics of microplastics in stormwater, including dispersion, weathering, and transport, our understanding of their behavior remains limited.[10] However, studies from various regions worldwide have indicated that stormwater contributes significantly more to microplastic pollution in surface waters than do effluents from wastewater treatment plants, highlighting the urgent need for further research.[11]

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Extreme Weather Events Could Lead to the Recontamination of Treated Drinking Water and Increased Occurrence of Disinfection Byproducts (DBPs). Water distribution pipelines are typically placed in subsurface areas under pavement. The presence of fissures and imperfections in water distribution pipe networks is well-known. During dry periods, leaks are a known reason for the loss of water loss the distribution network. Similarly, heavy rainfall and flooding can create the opposite problem for distribution pipes with integrity issues: contaminated water surrounding the pipe can enter fissures and cracks, thereby serving as conduits for pollutants.[12] Due to the high groundwater table during heavy rainfall, pollutants in flood-water and SSOs can remain in subsurface areas for extended periods of time, eventually entering into distribution networks through their fissures and imperfections. Of further concern, such distribution pipes contain residual chlorine from water disinfection, which has the potential to react with dissolved organic matter and the organic contaminants entering the fissures, resulting in the formation of DBPs. Though chlorination is crucial for inactivating microbial contaminants that enter the distribution network, some DBPs can be harmful to human health. During heavy rainfall, it is common practice to add extra chlorine to water treatment systems. The presence of excess chlorine increases the likelihood of probable reactions with organic precursors from stormwater, thereby increasing the likelihood that different types of DBPs will be formed,[13] including known trihalomethanes (THMs) and haloacetic acids (HAAs), as well as additional as yet unknown and unidentified DBPs. While THMs and HAAs are known as potent carcinogens and are regulated in many jurisdictions, there are many other types of DBPs documented in water supply systems with unknown health effects. Notably, there is a substantial knowledge gap about the identities of DBPs originating from stormwater, which has many contaminants from road runoff, with concomitant potential toxicities. Understanding the impact of these diverse groups of DBPs is crucial for effective environmental management and public health protection.

The Way Forward: Urgent Research for the GCC Region. Until recently, storm runoff has not been an issue in the GCC due the region's arid climate and scant rainfall. It is therefore unsurprising that the impact of chemicals in urban GCC runoff and SSOs is understudied; however, the April 2024 extreme weather event underscores why this must change. Many SSO contaminants are both stable and environmentally mobile via flood waters, with the potential to reach and contaminate domestic and irrigation water supplies. Given the likelihood that such weather events will occur more frequently, we advocate for proactive measures and consideration of the potential and largely unknown long-term effects of CECs on humans, fish, and wildlife. As first steps, we must (i) identify the pollutants in flood waters, as they will eventually end up in agricultural and domestic water supplies, and (ii) inform decision makers and stakeholders so that appropriate, proactive mitigation strategies may be implemented to protect human and environmental health. Because water reuse is important in arid regions, it is critical to understand the fate, transport, and impacts of CECs in flood waters containing a mixture of SSOs and road runoff, to prevent future long-term effects. These pollutants are not currently regulated, so the collection of baseline data is needed to enable development of predictive models that can project the potential of extreme events to contaminate water resources and domestic water supplies. Obviously, preparing the GCC for unprecedented heavy rainfall will require a redesign of drainage infrastructure, which will be a heavy and expensive lift. However, we must attend to the hidden dangers lurking in floodwater: unregulated chemical contaminants, both known and unknown, as well as their long-term effects. An ounce of research-driven prevention will doubtless be preferable to a pound of deferred "cure".

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Notes

The authors declare no competing financial interest.

Biography

Diana S. Aga is a SUNY Distinguished Professor and Henry Woodburn Professor of Chemistry at the University at Buffalo (UB). She also serves as Director of the UB RENEW (Research and Education in eNergy, Environment and Water) Institute. She obtained her B.S. in agricultural chemistry at the University of the Philippines at Los Baños (Philippines), her Ph.D. in analytical chemistry at the University of Kansas (USA), and postdoctoral training at the Swiss Federal Institute of Aquatic Science and Technology (Switzerland). She is an expert in chromatography and mass spectrometry (MS) for target and nontarget analysis (NTA) of organic contaminants and investigates the fate, transport, treatment, and toxicity of pollutants, including per- and polyfluoroalkyl substances (PFAS) and emerging contaminants such as pharmaceuticals and personal care products, in the environment. She is also conducting MS-based metabolomics and exposomics studies using high-resolution MS. Her research also includes evaluating the efficiencies of various biological, physical, and chemical treatment processes in removing emerging contaminants, antibiotics, and antibiotic resistance genes from wastewater treatment plants and in agroecosystems. Dr. Aga is recipient of various awards, including the National Science Foundation CAREER award, Humboldt Foundation Research Fellowship, Fulbright Fellowship, ACS Fellow, ACS AGRO Fellow, and ACS Schoellkopf Medal.

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