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Figure 1 | Flooding in Dhaka, Bangladesh. Tellman *et al.*[2] report that the proportion of the world's population that lives in flood-prone areas is increasing. Some of the biggest of these population increases have been in Dhaka.

Climate science

Fraction of population at risk of floods is growing

Brenden Jongman

Satellite imaging combined with population data shows that, globally, the number of people living in flood-prone areas is growing faster than is the number living on higher ground — greatly increasing the potential impact of floods. **See p.80**

Flooding of river and coastal systems is the most frequent and damaging climate-related hazard, affecting thousands of people and causing billions of dollars in losses each year[1]. The impacts often fall disproportionally on poor and vulnerable people, who have limited capacity to respond and recover from the shocks caused by floods. Over the past few decades, flood risk has increased globally because of a combination of climate-change-induced increases in the frequency and severity of floods, and because populations and economic activity have increased rapidly in hazard-prone areas (Fig. 1). On page 80, Tellman *et al.*[2] report a comprehensive assessment of nearly 1,000 large flood events that occurred between 2000 and 2018, and estimate the magnitude of the impacts. The findings aid our understanding of the underlying drivers of flood risk.

The authors combined a record of flood events with daily satellite observations to develop the Global Flood Database — a resource that stores the footprint of 913 large floods that occurred between 2000 and 2018, across all continents (except Antarctica). For each event, the authors then estimated the area inundated and the number of people living in that area, using geospatial data sets of population density for different years. This analysis improves our understanding of the spatial extent of major floods and, most importantly, allowed the authors to look at changes in population and socio-economic activities in areas prone to inundation.

Tellman and colleagues show that the population in flood-prone areas rose by an estimated 34.1% during the study period — an increase of between 58 million and 86 million people. By contrast, the global population grew by just 18.6% over the same period. The authors went on to calculate trends in expected flood exposure up to 2030 within the flood footprints identified in the study, using previously developed projections of flood extents and population exposure[3,4]. They found that the number of people exposed to floods is likely to continue to increase more quickly than the overall population in 59 countries, mostly in Asia and Africa.

Previous studies in this area relied on global flood models that use rainfall statistics and elevation models to map potential riverine and coastal flood zones[5]. Tellman *et al.* instead mapped an unprecedented number of validated events, including various flood types — such as those caused by dam breaks, local rainfall events and snowmelt — that had not been considered in the earlier analyses. As a result, the authors' estimate of the increase in the percentage of people exposed to floods globally is ten times higher than previous estimates.

As with all global assessments, the new work has its limitations. The flood events considered are still just a subset of all the floods that occurred during the study period. This is because the satellite observations capture only floods above a certain spatial extent and that were followed by a period of cloud-free weather, thereby allowing reliable optical detection. Furthermore, the spatial resolution of the satellite data and the use of global population models do not allow a detailed analysis of flood impact in urban areas. Given that the world is rapidly urbanizing and that urban disaster risk is an increasing concern, future studies should develop improved approaches for estimating global flood risk in cities.

The trends revealed in Tellman and colleagues' study might seem daunting, but there is also good news to be drawn from the statistics: the capacity of communities to manage and respond to floods has increased over time. Investments in flood protection, drainage infrastructure and early-warning systems, together with improved building standards, schemes for supporting flood-affected people and strengthened government policies enforcing risk-informed land planning, can both prevent floods and buffer the impacts when they occur[6]. The number of fatalities and extent of flood damage, relative to the number of people and economic assets exposed to floods, has declined globally over the past few decades[7].

As the global population grows and cities expand, natural ecosystems that once provided flood protection will also be under threat. Mangroves, coral reefs, dune systems and urban parks can damp flood waves, reduce peak flows and significantly reduce flooding and other climate-related hazards[8]. Investments in solutions that restore or construct ecosystems often provide a cost-effective way of reducing flood damage while improving biodiversity and providing other benefits[9]. Satellite technology can track changes in protective ecosystems[10], similarly to its use in monitoring flooding and population changes. However, even the best combination of infrastructure and nature-based approaches might be insufficient to deal with rising sea levels — the only option for some communities will be to manage their retreat out of flood-prone areas[11].

Understanding the links between climate change, socio-economic development and flooding is a big scientific challenge, but is essential for developing robust decision-support models that will enable policymakers to calculate and communicate the best mix of measures for future challenges. Tellman and colleagues' improved global estimates of risk are a crucial step in that direction.

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Immunology

Private protection at the brain's border

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At the outer border of the brain and spinal cord, immune cells have been observed that originate from the bone marrow of the adjacent skull and vertebrae. They reach this site through special bone channels, without passing through the blood.

Barriers around the brain and spinal cord of the central nervous system (CNS) protect neuronal cells from the changeable milieu of the bloodstream by controlling movement of molecules and cells between the blood and the CNS. These barriers also ensure that the CNS can be kept under surveillance by certain immune cells, but restrict the access of blood-derived immune cells and molecules to specific compartments at the border of the CNS[1]. Writing in *Science*, Cugurra *et al.*[2] and Brioschi *et al.*[3] report that the dura mater, a tissue layer around the outermost barrier of the CNS, sources a private immune protection from nearby bone marrow.

Encasing the brain and the spinal cord are three meningeal membranes[1,4] (Fig. 1). The outermost membrane, the dura mater, lacks a blood–brain barrier, and so the entry of blood-derived components, including immune cells, into this layer is unrestricted[1,4]. The arachnoid mater is attached to the inner surface of the dura mater. Between the arachnoid mater and the innermost meningeal layer, the pia mater, is the subarachnoid space, which contains cerebrospinal fluid (CSF) and resident immune cells that enter during embryonic development[5]. The arachnoid mater acts as a blood–CSF barrier between the dura mater and the subarachnoid space. The pia mater lies directly on top of the glia limitans, a thin layer of extracellular-matrix material and cell-protrusion endings at the surface of the CNS tissue[4]. The anatomy of the meningeal layers has been likened to the defences around a medieval castle, with two walls (the arachnoid barrier and the glia limitans) bordering a guard-patrolled moat (the subarachnoid space and its immune cells)[6].

The two new studies focused on different subsets of immune cells, namely, myeloid cells of the innate branch of the immune system (which recognizes stereotypical changes characteristic of infection)[2] and B cells of the adaptive immune system (which responds to and remembers specific foreign invaders)[3]. The authors attached the circulatory system of one mouse, in which these subsets of immune cells were fluorescently tagged, to that of a second, untreated, mouse, and made the surprising finding that fewer tagged cells than untagged cells were observed in the dura mater of the second mouse. This finding suggests that a considerable proportion of immune cells in the dura mater do not arrive from the bloodstream, but instead originate from the bone marrow in the skull and the vertebrae of the spine. This shortcut is made possible by the cells crawling along the outside