INSIGHTS

PERSPECTIVES

A boy wades in what is left from a kilometer wide affluent of the Rio Negro River, near Manaus, Brazil, as the region is hit by a severe drought.

PHOTO: BRUNO KELLY/REUTERS

ENVIRONMENTAL SCIENCE

Water scarcity is exacerbated in the south

The Southern Hemisphere has experienced a 20% drop in water availability in 20 years

By **Günter Blöschl**[1] and **Pedro L. B. Chaffe**[2]

Water availability the difference between precipitation and evaporation is expected to decrease in many regions of the world because climate change has modified the water cycle, more water will be abstracted by the growing population, and water pollution will continue to limit clean water (*1*). Estimates of changes in water availability are uncertain at continental and global scales because measurements of precipitation and evaporation tend to be indirect or only locally representative (*2*). On page 579 of this issue, Zhang *et al.* (*3*) report a study that combines streamflow observations of large river basins of the world with terrestrial precipitation data and satellite measurements of evaporation and water storage to show that water availability in the Southern Hemisphere has substantially decreased from 2001 to 2020. With their approach, the authors have improved the reliability of water availability estimates, which could help improve long-term water management.

Zhang *et al.* used a consistent method to validate ensembles of water availability estimates. For the Northern Hemisphere, the authors find no change in average water availability from 2001 to 2020, whereas for the Southern Hemisphere, water availability decreased by 70 mm per year, which corresponds to a reduction of about 20% over the entire period. This means that the global trend in water availability is brought about by changes in the Southern Hemisphere. Similarly, the year-to-year variability in water availability is mainly caused by changes in the south. According to the authors, in arid regions of the Southern Hemisphere, these changes are predominantly related to increased evaporation, whereas in humid regions in the south, they are mainly related to decreased precipitation. Both trends and the year-to-year variability of water availability are aligned with climate modes (long-term variations of the climate that are related to ocean processes), such as El Niño–Southern Oscillation (ENSO). ENSO can trigger droughts and floods in certain parts of the world. For example, in 2023, droughts hit Amazonia while, at the same time, Southern Brazil suffered floods.

The findings of Zhang *et al.* for the past two decades suggest future water management challenges in the Southern Hemisphere. Long-term water availability, as reflected in streamflow and groundwater recharge, is the base value against which to

[1]Institute of Hydraulic Engineering and Water Resources Management, Technische Universität Wien, Vienna, Austria. [2]Department of Sanitary and Environmental Engineering, Universidade Federal de Santa Catarina, Florianópolis, SC, Brazil. Email: bloeschl@hydro.tuwien.ac.at

assess planned water abstractions for irrigation, industry, and households while leaving water available for ecosystems. When water availability in streams and groundwater drops below water demand, drought conditions are felt by ecosystems and people. This was the case during 1996 to 2010 in Australia (*4*), 2013 to 2015 in South America (*5*), 2015 to 2018 in South Africa (*6*), and during several other droughts in the past two decades in the Southern Hemisphere.

The consequences of declining water availability over decadal scales are manifested in decreasing streamflow and groundwater levels in vast swaths of land. For example, substantially decreasing trends of streamflow have been observed in large parts of South America (*7*). Water availability fluctuations must also be considered at shorter timescales (months). In regions with seasonal rainfall, evaporation may quickly dry out the soil at the onset of the dry season, leading to flash droughts (*4*). Counterintuitively, in a drier climate, rainfall may be more concentrated in the wet season (*2*), leading to floods instead of groundwater replenishment. More droughts and floods represent an acceleration of the terrestrial part of the water cycle (faster storage and movement of water between land, ocean, and atmosphere), leading to increased ecosystem degradation through tree mortality and thus greater carbon dioxide emissions. This situation has been taking place in Amazonia (*8*), further intensifying climate change effects.

The impact of droughts and floods on humans have been enormous, affecting more than 3 billion people with damages exceeding $780 billion US dollars worldwide in the past two decades (*1*). Measures to mitigate their effects include construction of infrastructure, such as storage dams and diversions for irrigation; nature-based solutions, including enhancing infiltration of rainwater into the soil; and soft measures, such as water savings through crop choice and raising awareness. However, human response to water stress may have unexpected repercussions on the water cycle. In parts of South America, increased water use for agriculture has contributed 30% to rising drought trends of streamflow (*7*). More generally, water stress in semiarid regions globally may be amplified by greater irrigation demand under climate change (*2*).

Long-term feedbacks between humans and water in catchment areas may further exacerbate water shortages (*9*). Water reservoir construction tends to increase water demand, leading to the paradoxical effect that society becomes more vulnerable rather than more resilient. Examples of this are the 2015 to 2018 Cape Town drought (*6*) or even the water scarcity that hit the ancient Maya in the 9th century (*10*). In both cases, water consumption was far above natural water availability without reservoirs. Similarly, the construction of levees embankments built along river edges tends to increase vulnerability to large floods because citizens are enticed to move into flood plains (*11*). Comparative analyses of droughts and floods in different parts of the world have shown that societies reduce their vulnerability only if events of similar magnitudes have been experienced in the past (*12*). These long-term feedbacks are of particular interest in vulnerable parts of the Southern Hemisphere, where many countries are mid- to low-income, with limited technological and financial means that would help them overcome environmental crises.

There are water management challenges ahead brought about by reduced water resources in the Southern Hemisphere. Reduced water availability requires a shift from crisis response to long-term, proactive water management, as advocated in the Prague Statement of the International Association of Hydrological Sciences (IAHS) (*13*). This proactive water management needs to be aligned with global goals, such as the United Nations Sustainable Development Goals, while also drawing on the expertise of local citizens, hydrologists, and water managers. Strategies may rely on robust solutions under different possible futures that include long-term feedbacks of the coupled human-water system. These solutions may include diversifying water supply and flood protection systems and planning for flexibility in water use to reduce the potential impact of extreme events. ■

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BATTERIES

Solid electrolytes redefine ion conduction

A mechanism of ion transport in solid electrolytes can guide the design of lithium batteries

By **Anton Van der Ven**

Common lithium (Li)–ion batteries have profoundly transformed modern society by altering how energy is generated and consumed. Every charge and discharge cycle of a battery requires shuttling Li ions over large distances micrometers to millimeters. Commercial Li-ion batteries contain a liquid electrolyte to facilitate the rapid transfer of Li ions between the anode and the cathode, but there is a strong incentive to replace this with a solid electrolyte. Solid-state batteries promise to be safer and more compact than those with liquid electrolytes and could enable a substantial increase in the energy density of Li-ion batteries (*1*). However, ion transport through most solids is sluggish compared with that in liquids. On page 573 of this issue, Yu *et al.* (*2*) provide a detailed study on Li-ion transport optimization in the solid state, which will guide the development of a promising class of solid electrolyte batteries.

The fastest solid-ion conductors are metal sulfides and oxides, but those compounds that exhibit high Li-ion conductivities are susceptible to decomposition reactions when placed in physical contact with the cathode or anode (*1*). Moreover, many metal oxides and sulfides do not possess suitable mechanical properties to accommodate the cyclic stresses that solid-state batteries undergo as a result of volumetric changes of the cathode during cycling (*1*). This has spurred interest in solid electrolytes such as Li-metal-halides, e.g., Li_3MX_6 (where M is a metal and X is a halogen). These compounds adopt crystal structures that can conduct Li ions. Li-metal-halides are electrochemically more stable than their metal sulfide counterparts and are more

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