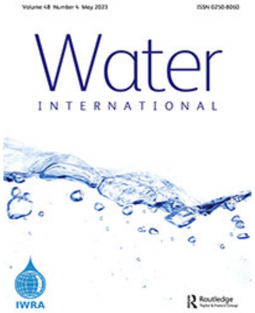

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VIEWPOINT

# Climate change is increasing global salt pollution

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## Background

Salination, or salinity pollution or salt pollution, of soils, surface water and groundwater is a global problem with regard to both agricultural/irrigation water and drinking water. Irrigation is the single-most widespread source of salt pollution: it accelerates salt pollution, reduces agricultural productivity and also poses health risks. Globally, it is estimated that 20% of total cultivated land and 33% of irrigated agricultural land is affected by high salinity/salt pollution (Shrivastava & Kumar, 2015). As explained below, climate change is increasing salt pollution.

Typical salts found in soils, surface water and groundwater are: sodium chloride (table salt); calcium chloride ('street salt' from road runoff); potassium chloride (muriate of potash); potassium sulphate (muriate of sulphate); calcium sulphate (gypsum); magnesium sulphate (Epsom salt); sodium bicarbonate (baking soda); and sodium sulphate (glauberis salt). These salts originate from the weathering of rock and soils, and from fertilizers and organic soil amendments. The surface runoff of these dissolved salts is the source of the salt content in oceans (in particular) and water bodies in general.

## The problem

Increased salts result from an interconnected suite of anthropogenic pressures such as irrigation, leaching of fertilizer, stormwater runoff and urban wastewater discharge (Damania et al., 2019). The most profound effect of salt pollution occurs in agricultural settings where soil evaporation and plant exhalation of water vapour (i.e., transpiration) are both high, and rainfall is low. Under these conditions, dissolved salt concentrations increase and are either absorbed by plants or evaporated into the atmosphere. The increased salts restrict water transfer to plant roots, resulting in stunted growth, lower quality plants and lower yield. Enough food is lost because of saline water each year to feed 170 million people – or a country the size of Bangladesh – every day for a year (Damania et al., 2019).

Moderate to severe salt pollution from irrigation, domestic wastewater and runoff from mines affects about one-tenth of all river stretches in Latin America, Africa and Asia (United Nations Environment Programme (UNEP), 2016). This condition makes using river water less desirable for irrigation and industrial applications. Globally, the largest salt-degraded agricultural lands include the Aral Sea Basin in Kazakhstan (primarily), the

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Indus Basin in India and Pakistan, the Yellow River Basin in China, the Euphrates Basin in Turkey, Syria and Iraq, the Murray–Darling Basin in Australia, California's San Joaquin Valley, and the Indo-Gangetic Basin.

The Indo-Gangetic Basin, fed primarily by the massive Indus, Ganges and Brahmaputra rivers (Figure 1), encompasses more than 250 million ha across Bangladesh, India, Pakistan and southern Nepal, hosting more than 750 million people and constituting over 100 million ha of agricultural land that accounts for 25% of global groundwater abstraction. Therefore, the Indo-Gangetic Basin has arguably one of the most important water supply systems on Earth (Fendorf & Benner, 2016). A total of 60%

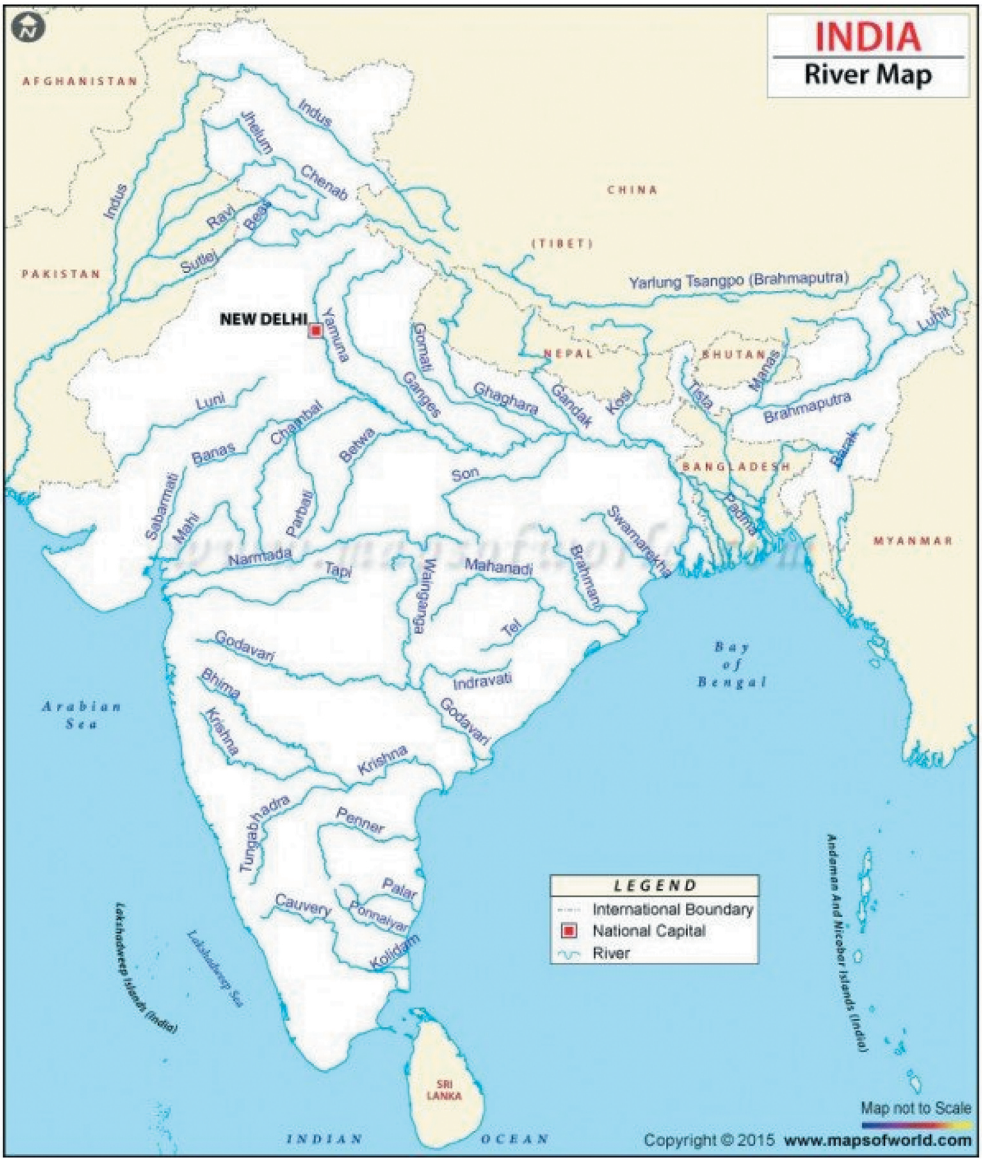


Figure 1. Map of the principal rivers of India. Source: https://www.mapsofworld.com, reproduced with permission.

of the groundwater in the basin's upper aquifers is contaminated by high concentrations of either arsenic or salt (Fendorf & Benner, 2016).

North-west India displays the elements of salt pollution noted above, but the area has compounding factors that exacerbate salt pollution. These factors include the presence and effects from an extensive canal irrigation network that introduces high salt surface water, and increased salt concentrations as a by-product of over-pumping of shallow groundwater. Both canal water and groundwater are the primary sources of irrigation. The state of Punjab in north-west India, north of the capital city of Delhi, is a major producer of wheat, rice and corn (maize), and groundwater withdrawals have significantly increased in recent years, and recharge has not restored the prior aquifer storage (Central Ground Water Board (CGWB), 2019).

Water quantity has been further depleted by waterlogging, which is the excessive distribution of surface water during irrigation. In this case, canals are conveying too much water into areas with shallow groundwater, resulting in standing water in the oversaturated area and offsite runoff of this water. Seepage from unlined canals also contributes to a raised water table and hence more waterlogging and wasteful runoff. Just as importantly, the soil pores in the root zone of a crop become saturated. This saturation impedes air circulation and restricts oxygen availability and increases carbon dioxide, all contributing to diminished crop productivity. This saturation also keeps excessive salts bound up in the root zone, further undermining crop yield.

Salt pollution is a challenge in South Africa, where there are a total of 19 catchment-based water management areas largely coincident with the country's major rivers (Figure 2). Each area has its own agency that manages the water resources and within these areas are water-user associations that oversee the day-to-day supply of irrigation water to the farms. These associations manage the water conveyance infrastructure; irrigation water is sourced from both surface water and groundwater. The most common salts are nitrate and sodium. Other salts include sulphates and chloride. Chloride is mostly due to improper management and treatment of domestic wastewater and fertilizers.

There has been an ongoing programme in South Africa to maintain reasonable water quality and manage salt pollution and the waterlogging of irrigated soils. Gypsum, sulphur or sulphuric acid are the most common soil amendments used to reclaim salt-rich soils, whereas gypsum, sulphuric acid and sulphur dioxide are used as water amendments. About 10–15% of the area under regular irrigation in South Africa has been significantly affected by waterlogging or salt pollution (Nell, 2017).

This is much lower than other countries such as Argentina (34%), Egypt (33%), Iran (30%), Pakistan (26%) and the United States (23%; Ghassemi et al., 1995). However, the salinity of South African surface waters are increasing due to mining; urban, industrial and agricultural developments; and the reuse of water resources (Nell, 2017). This is all the more concerning because according to the Food and Agriculture Organization (1995), only about 1% of South Africa's land area is suitable for irrigation.

River water is the primary source of salt pollution in soils in South African irrigation schemes. Irrigated agriculture is not only a recipient of deteriorated water quality, but also is a contributor to water quality deterioration documented in many rivers. An increase in salt pollution normally coincides with hydrologically dry years with below-average runoff and an increase in waterlogging during hydrologically wet years.


**Figure 2.** Map of the principal rivers of South Africa. Source: https://www.mapsofworld.com, reproduced with permission.

## Climate change and the increase of salt pollution

Climate change is causing many troubling phenomena associated with salt pollution:

### *Diminishing recharge*

North-west India and South Africa are examples of regions where the salt pollution problem is intensifying as the average global temperatures warms as a result of climate change. Globally, climate change is causing a decrease in the frequency of rainstorms. However, there is an increase in the intensity of the rainstorms, which commonly is lessening recharge to aquifers and increasing runoff in areas such as the Indo-Gangetic Basin, South Africa, Australia or areas in the Western United States, including California. Periods of drought are longer, which is likewise causing increased evaporation, a decrease in recharge and lowering of groundwater levels.

### *Salt content increases as groundwater levels drop*

The climate change-induced lowering of groundwater levels along with increased groundwater use for drinking and irrigation dries out more area in the near-surface unsaturated zone, which leads to higher salt concentrations. These resulting higher salt concentrations persist or worsen during more intense climate change-induced periods of drought. This is because under normal conditions, periodic rain events gradually leach excess salts and plants' root zones can then tolerate the salt concentrations.

### *Increasing temperatures and evaporation result in higher salt concentrations*

Evaporation and concentration of salts are increased by the recent year-over-year ambient temperature increases, particularly in summer. This phenomenon is particularly prevalent in arid and semi-arid regions, including India, South Africa, Australia and California, which has also led to unprecedented fires in Australia and California.

### *Increasing seawater intrusion and lowering water quality in coastal drinking water supplies*

Coastal areas are experiencing a rise in sea levels due to a combination of increased groundwater extraction and global warming that is causing melt-off of large ice masses and rising sea levels. Ocean temperatures are increasing, and this warmer water occupies more space. Low-lying coastal areas such as those in Bangladesh are increasingly being inundated with saltwater, gradually contaminating the soil with increased salt content. This inundation is exacerbated as the water levels of coastal drinking water wells drop where recharge is not keeping up with increased pumping, resulting in higher salinities.

### *Decreasing the size of snowpacks results in less runoff and less lowland recharge*

More intense precipitation events and less snowfall have caused less snowpack. Along with higher overall temperatures, this is resulting in seasonally earlier snowmelt and more runoff over a shorter period instead of the preferred gradual snowmelt that will feed rivers and serve lowland surface water users and also recharge lowland aquifers.

## Conclusions and recommendations

### *Salt pollution is a widespread problem that is being intensified by the effects of climate change*

Poor water quality leads to stunted growth or plant death because plants cannot survive the prolonged uptake of salt-rich water; or inundation of standing water in the root zone; or excessive concentrations of salts in the root zone. The following are a variety of approaches to mitigate salt pollution in a cost-effective manner.

### *Governmental bodies should consider implementing water quality monitoring and analytical testing*

Wholesale infrastructure changes are prohibitively expensive, so incremental changes, such as monitoring (periodic sampling and analytical testing), are methods to manage a large-scale problem. Periodic analytical testing (e.g., an annual programme of one sample during the rainy season and one during the dry months) is an efficient use of a nominal amount of funding to aid in the management and ultimately the improvement of water quality of irrigation water. The results can identify influent water of particularly poor quality from a given area and managers can redirect at least some of this water from canals, such as in north-west India. Once surface irrigation water reaches croplands, relatively low-cost improvements to drainage infrastructure can reduce waterlogging and lower salinity. Groundwater quality monitoring by sampling and analytical testing can also help reduce the use of particularly poor well water by curbing aquifer pumping in wells tapping low quality portions of an aquifer, or by installing some type of groundwater treatment system to improve water quality.

## 'Smart water' applications can provide cost-effective solutions

Water-scarce areas will benefit from a shift away from the use of basin irrigation (the variably controlled flooding of an area of irrigated land) as an irrigation technique in favour of more efficient systems such as drip irrigation. Mulching is a low-cost technique to reduce water consumption by reducing evaporation and thus lowering the amount of water consumed. It is the use of protective ground covering comprised of either organic materials such as leaves, straw, bark or wood chips, or inorganic material such as black plastic or geotextiles (landscape fabrics). Punjab practices a rice–wheat production system. Rice requires abundant water in the conventional irrigation approach, but wheat straw mulching can reduce the water requirement. For many arid to semi-arid agricultural areas where rice is a principal crop, efforts should be made to replace rice production with less water-intensive crops. For example, replacing rice with maize, different types of millet or sorghum could reduce irrigation water demand by 33% (Davis et al., 2018).

In South Africa, smart water interventions such as in-field subsurface drains have been employed to control flood water and waterlogging. Installation of sensors such as telemetric devices to monitor water supply have been used to address the salinity issue. In-field sensors have recently been used to verify salt content information collected from remote sources such as Landsat imagery or other satellites. Evidence presented in US case studies for California's San Joaquin Valley (SJV) and Minnesota's Red River Valley (RRV) demonstrates the utility of these sensor approaches in assessing soil salinity changes due to changes in weather patterns as a result of climate change. Changes in weather patterns have increased root - zone soil salinity, particularly in areas with shallow water tables (e.g., SJV and RRV), coastal areas with seawater intrusion (e.g., Bangladesh and the Gaza Strip on the eastern coast of the Mediterranean Sea), water - scarce areas potentially relying on degraded groundwater as an irrigation source (e.g., SJV and Murray - Darling River Basin in Australia), and arid lands such as Kuwait. Trends in salinization due to climate change indicate that the expansion of infrastructure and protocols to monitor soil salinity from field to regional to national to global scales are needed to provide information that can provide data that will ultimately increase crop yield.

### *Expanded pilot tests are needed to demonstrate how certain bacteria can enhance crop yield*

Indigenous bacteria in the near surface plant–soil environment have the ability to increase a plant's resistance to salinity stress (Shrivastava & Kumar, 2015). It is known that plants are colonized by both extra- and intracellular microorganisms. Rhizosphere (root-associated) bacteria can improve plant performance in stressed environments (Dimkpa et al., 2009). Some plant growth-promoting bacteria can stimulate plant growth and development by providing nitrogen, phytohormones, iron sequestered by bacterial-secreted compounds and soluble phosphate (Hayat et al., 2010). Bacteria may also indirectly promote plant growth in salt-rich soils by attacking pathogenic fungi that would otherwise cause soil-borne diseases (Lugtenberg & Kamilova, 2009). Biostimulation (i.e., providing nutrients to bacteria in the soil) may be an affordable and straightforward mechanism to scale this technology to a level that is beneficial to farmers challenged by salt pollution.

## Summary

It is incumbent on water practitioners to take the lead on educating policymakers on the negative economic impact of salt pollution, as it is real and measurable. Policy leaders would benefit from understanding how relatively low-cost solutions exist that can both increase agricultural output and improve water quality while addressing the negative effects that exacerbate salt pollution. These effects include the over-pumping of groundwater, or global temperature warming from the burning of fossil fuels. Too often practitioners and academicians and applied scientists put forth scientifically sound studies that are never presented plainly to the informed but non-scientific public. This results in missed opportunities between the scientific community and the general public, like two ships passing in the night.

## Disclosure statement

No potential conflict of interest was reported by the authors.

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