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Review Article

Groundwater Salinisation by Irrigation Practices in More Arid Regions

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Abstract

Irrigated agriculture in more arid regions substantially modifies the hydrological cycle. On permeable soils there is a progressive tendency for major long-term increases in the salinity of groundwater recharge, which is being further exacerbated by climate change. This process has received only scant attention and is analysed here. If not proactively managed it will gradually impact irrigation waterwell salinity, the productivity of agriculture itself, and can even lead to land abandonment.

Background to Concern

Groundwater resources provide about 40% of the water used for agricultural irrigation globally, with the proportion approaching 60% in both North America and South Asia. Thus irrigation with groundwater is of major importance for agricultural production and includes some highly profitable horticultural activity [1].

While the agricultural literature frequently refers to sustainability issues related to irrigation practices, these focus almost exclusively on the salinization of low permeability soils due to rising water-table with a consequent serious negative impact on crop yields [2-4]. The much more gradual, but equally serious, issue of salinisation of aquifer recharge (and eventually of groundwater resources as a whole) by irrigation practices on permeable soils in contrast has received very little attention.

Groundwater with electrical conductivity (EC) greater than 2, 000 µS/cm has been classified as moderately saline for use in crop irrigation [5]. There is no standard conversion from the readily-measured EC to TDS (total dissolved solids), since it varies somewhat with predominant salt type in solution, but a conversion factor of 0.65 is used here. Whilst it is feasible to irrigate with water of EC up to 5,000 µS/cm (3,250 mgTDS/L) for less sensitive crops (eg. onions), use on more sensitive crops (eg. some cereals) will impact growth and reduce productivity. Serious damage will occur to the most sensitive crops (including many vegetables, fruit trees and grape vines).

Making Irrigation More Efficient

There are various definitions of ‘irrigation efficiency but, in essence, the term is used to indicate the

percentage of irrigation water-supply which is actually transpired by the crop under cultivation, although ‘irrigation water-supply’ has variously been interpreted as that ‘abstracted from source’, 'delivered to field' or 'applied to crop'. The term has been widely cited in the agricultural literature for more than 50 years and is often central to the evaluation of how an irrigation system is performing and how it can be improved.

Clearly the purpose of agricultural irrigation is to increase crop production. The direct implication is that crop transpiration must also increase — because, for a given climatic condition and crop type (with just a few exceptions), biomass generation and food production exhibit a close-to-linear relation with crop transpiration [6].

From the farmer and irrigation engineer perspective, any water that does not contribute to crop production is considered a 'loss'. However, when looked at from the groundwater-body perspective the situation is very different, since a part of the farmer's 'water loss' is returned to underlying groundwater, and is thus not 'lost' to other uses. Moreover, a clearer distinction between the processes affecting water distribution and field application is also required. Thus, the term 'irrigation efficiency' can be the source of serious miscommunication and misunderstanding, and is potentially misleading [7].

Real water-resource savings, which result in more water being available for other uses (including environmental flows and/or for replenishing depleted aquifer storage), can only be achieved by reducing the size of the consumed fraction and/or the non-consumed non-recoverable fraction [8] and may be obtained through any combination of the following :

➢ reducing non-beneficial evaporation through more targeted irrigation

➢ reducing non-beneficial evaporation by use of plastic sheeting

➢ eliminating weeds and any other obvious sources of non-beneficial evapotranspiration

➢ switching to cultivation of less water-consuming crops with shorter growing season

➢ constraining or reducing the total irrigated area.

Process of Recharge Salinisation

Rain water has low total dissolved solids (TDS) and slightly acidic pH-with Cl and Na generally in the range 10–20 mg/L (although higher in coastal zones). On coming into contact with the land surface, rainfall acquires Ca and HCO3 and salinity commonly reaches 200–500 mgTDS/L in rainfall naturally recharging aquifers. Where irrigation is practiced on permeable soils, the dissolved salts in irrigation water are concentrated by evapotranspiration before soil leaching to groundwater, and irrigation returns are normally of the NaCl type. It will then be the vertical hydraulic conductivity of the vadose zone that controls the rate of downward penetration of return water and introduces a time-lag before any deterioration in groundwater quality first becomes evident.

The process can be evaluated using a salt-balance approach (Figure 1) and the relative annual salt- concentration factor (CF) for groundwater irrigation estimated on this basis, together with an indication of how this factor varies with irrigation water-use, field-application efficiency (α) and the crop-type and climatic regime.

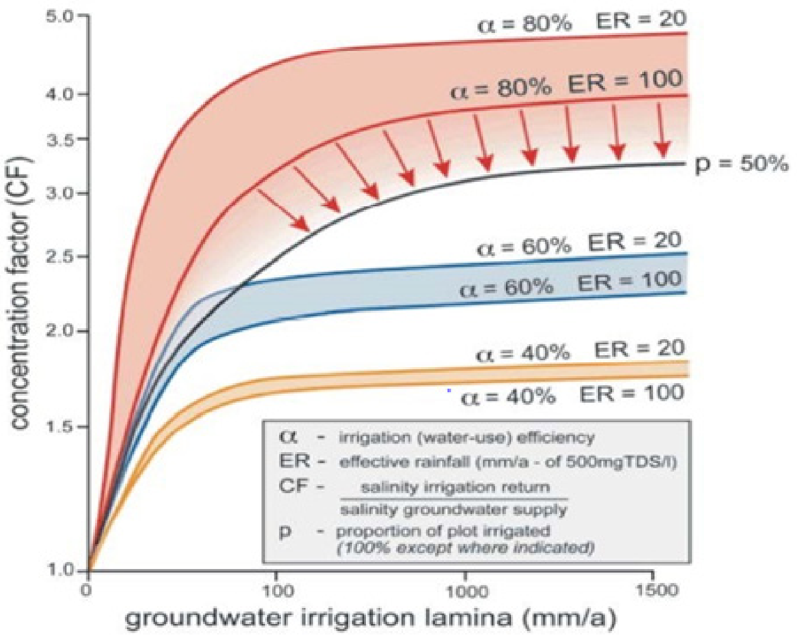

Figure 1: Variation of concentration of groundwater salinity by irrigation practices (large applications/annual lamina of groundwater as irrigation occur widely in more arid climatic regions and the resultant CFs of 2-5 will lead rapidly to serious increases of irrigation return-flow salinity).

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Irrigation return-flows from a wide variety of crops also often contain elevated concentrations of nitrate, resulting from excessive and/or ill-timed fertiliser applications. While this will cause a serious problem for potable water-supply provision, the co-presence of nitrate acts as a valuable tracer of the agricultural genesis of groundwater salinity [9].

Specific Cases of Recharge Salinisation

Mendoza-Argentina

The Carrizal Aquifer of Mendoza-Argentina comprises a thick Quaternary piedmont alluvial formation with a deep water-table (10-70m), occupying an arid Andean palaeo-valley between the present courses of the Mendoza and Tununyan rivers (Figure 2). The area has an average rainfall of about 180mm/a and groundwater recharge originates as seepage from a limited stretch of the bed of the Mendoza River.

During the 1990s the area was discovered to have an exceptional microclimate for export-quality viticulture and fruit production, which created a consumptive water demand of 3-4 mm/day during October–March (totalling 700–800mm/a). The area currently includes about 140 km2 of irrigated land, mostly served by a major expansion of groundwater use (from more than 600 waterwells), with pressurised ferti-irrigation, anti-hail nets and minimal tillage.

In the 1960s the salinity of shallow and deep groundwater was 1,170 and 650 mgTDS/L, but despite the introduction of a ‘groundwater-use restriction zone’ in 1997 surveys during 2003 revealed a marked salinity stratification down to 70m depth from 2, 860-1,960 mgTDS/L in an area extending progressively from the Mendoza River (Figure 2).

Nitrate levels of 20–60 mgNO3/L compared to <10 mgNO3/L at depth confirmed the agricultural origin of the salinity, The salinization has resulted in the substitution of onion and garlic for more profitable viticulture, with a corresponding fall in land values. Key management measures are urgently required, including diversion of more water from the Mendoza River into the Carrizal Valley during periods of peak flow for managed aquifer recharge and constraint on consumptive groundwater use by downward adjustment of the licenses for replacement waterwells.

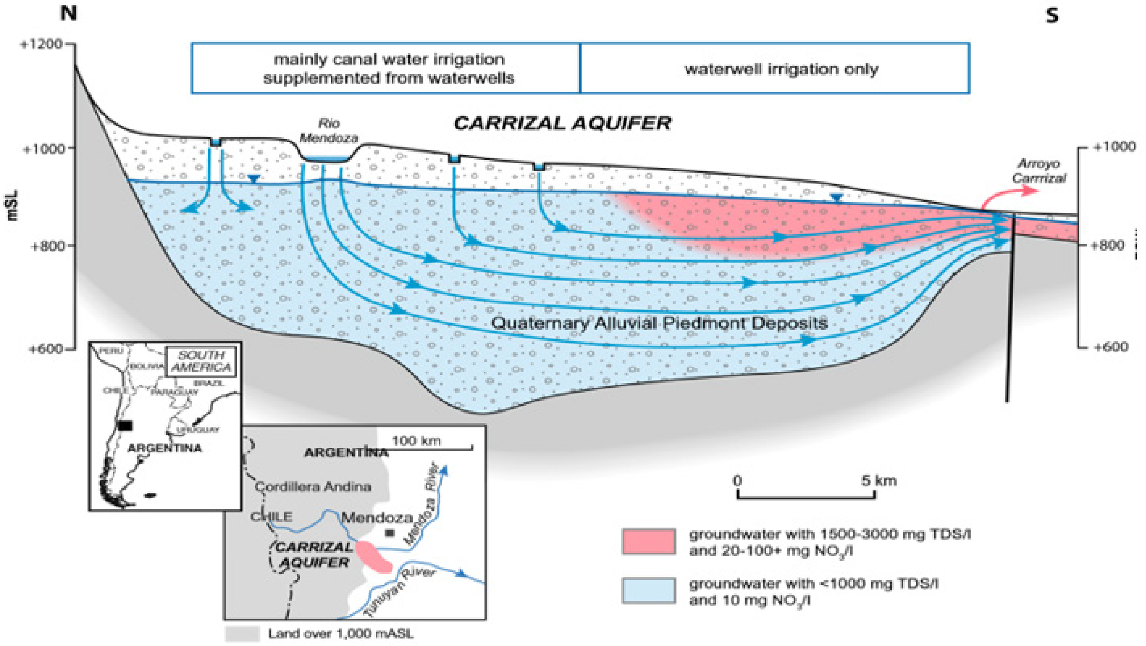

Figure 2: Hydrogeological cross-section of the Carrizal Aquifer of Mendoza-Argentina.

Almeria-Spain

The Campo de Dalias Aquifer of Almeria lies on a slightly elevated, arid coastal plain with an average rainfall of about 260 mm/a, and is largely underlain by a phreatic Pliocene/Quaternary alluvial outwash aquifer (Figure 3). It is situated on the southern flanks of the much wetter Sierra de Gador mountains formed by a Triassic dolomitic limestone aquifer which extends highly confined at depth beneath the plain. During 1965-85 groundwater irrigation expanded rapidly and today there are more than 1, 200 waterwells irrigating about 20, 000 ha (around 65%) of the land surface, which is covered by plastic greenhouses with ‘engineered soils’. using hydroponic cultivation to produce tomato, pepper, cucumber, egg-plant, courgettes, green beans, melon and water-melon for the export market.

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The intensive groundwater-based irrigation and extensive greenhouses have completely modified the local groundwater regime. The artificial well-drained soils allow excess irrigation to leach accumulated salts(with 75% of farmers applying 2 lamina of 30–60mm for this purpose), rainfall on greenhouses being directed to soakaways and large manure applications (2, 300-4, 600 kgN/ha on greenhouse construction and 600-1, 700 kgN/ha on each crop) leading to an increase of groundwater salinity down to 70m depth from <1, 200 mgTDS/L to 2, 000-4, 000 mgTDS/L. This has led to the abandonment of many waterwells in the shallow aquifer and use of the deep Triassic Dolomitic aquifer, resulting in recovery of the shallow water-table and the creation of a sizeable brackish-water lagoon (Figure 3).

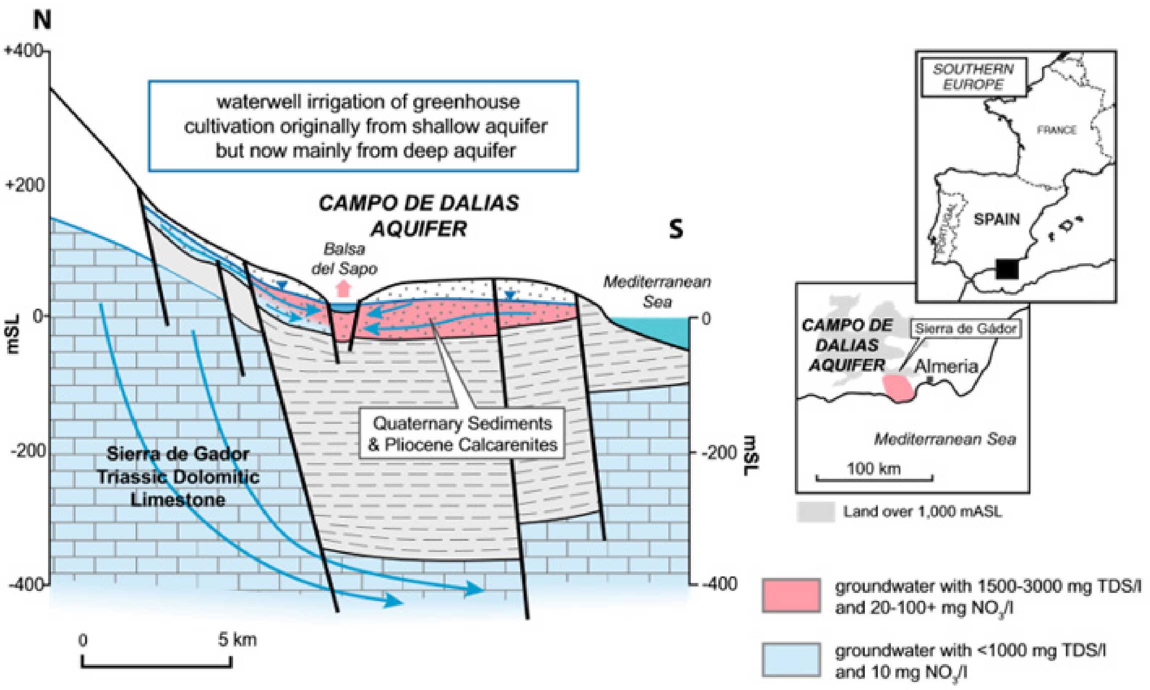

Figure 3: Hydrogeological cross-section of the Campo de Dalias of Almeria-Spain.

Elevated groundwater nitrate concentrations (100-400mg NO3/L) confirm the presence of saline irrigation-water returns in the upper aquifer and their stable isotope (15N and 18O) composition suggests that most is manure-derived [16]. The 'freshening-up' of the uppermost 25m of the shallow aquifer can be attributed to a reduction in irrigation return water salinity from use of the deep aquifer and to some artificial recharge from greenhouse drains.

Other Documented Sites

A few other examples of groundwater salinization by irrigated agricultural activity can be found in the published literature : Northern China [10], Iran [11] and Northeastern Algeria [12].

Concluding Remarks

The persistence and complexity of problems arising from the salinisation of groundwater recharge from irrigated agriculture in the more arid regions are such that they can only be properly addressed through integrated land and water management measures. The implementation of such measures will require a considerable effort on awareness-raising and capacity-building. Where groundwater is the primary source of irrigation water, the aquifer system will usually be the 'ultimate sink' for salinity accumulation. In such circumstances 'freshening-up' the groundwater system will require :

➢ reducing the overall consumptive use of groundwater by reducing annual cropping to conserve natural throughflow and drainage

➢ adopting greenhouse cultivation to reduce crop evapotranspiration

➢ down-sizing the groundwater-irrigated area by eliminating crops of lower market value

➢ increasing groundwater recharge by capturing local storm-water run-off to recharge lagoons.

Water resource agencies, in close collaboration with their agricultural counterparts, need to monitor and evaluate water and salt balances at local aquifer level to assess potential problems and to design appropriate management interventions. It is only through improved monitoring that negative trends can be identified early and adequate management interventions introduced.

Acknowledgements

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Conflict of Interest

No conflicts of interest.

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