



A simple method for determining the suitability of brackish groundwaters for irrigation

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Groundwater is becoming an increasingly popular resource for irrigation in the developing world but the method employed to measure a crucial factor that determines its suitability for use is expensive. The following article presents a simple and low-cost alternative technique.

The development of a successful and sustainable irrigation scheme in a rural community depends heavily on the quality of water available and the methods used to apply it to the land. Groundwater is often utilized for irrigation as it can be extracted on a simple and flexible basis; it may also be present in areas where surface water is scarce. Its quality can vary greatly, depending upon the type and quantity of dissolved salts it contains. The sustainable use of groundwater resources for irrigation is reliant on the effective measurement of these salts, ensuring it can be continuously applied to land without adverse environmental consequences.

Salinity and sodium hazards

The two most important water quality parameters for irrigation are:

- Specific electrical conductance (conductivity)
- Sodium Adsorption Ratio (SAR)

Conductivity measurements give a strong indication of overall salinity. High salinities limit the amount of water available for uptake by crop roots and can therefore reduce yields. The SAR is a measurement of the ratio of sodium (Na^+) ions to calcium (Ca^{2+}) and magnesium (Mg^{2+}) ions in milliequivalents per litre (meq l^{-1}). This is calculated using the following formula:

$$\text{SAR} = \frac{[\text{Na}^+]}{\sqrt{\frac{[\text{Ca}^{2+}] + [\text{Mg}^{2+}]}{2}}}$$

where $[\text{Na}^+]$, $[\text{Ca}^{2+}]$ and $[\text{Mg}^{2+}]$ refer to the concentration of sodium, calcium and magnesium ions respectively, in milli-equivalents per litre (meq l^{-1}).

SAR helps identify the 'sodium hazard' posed by a given sample of water. In particular, values of SAR in excess of 9 (see Table 1) indicate that there is a medium or high sodium, or low calcium plus magnesium content in the groundwater. If water with such a balance is applied to land it can cause the dispersion of soil colloids, destroying soil texture and permeability. The damage is irreversible and can occur to such an extent and over such a wide area that sufficient water cannot infiltrate to crop root zones. This produces conditions similar to drought. Prolonged exposure of soil to high SAR groundwaters can render large tracts of land useless for agriculture.

Money is the barrier

Conductivity can be determined in the field using an inexpensive conductivity meter, but SAR determination is far more costly.

Whilst the concentrations of Ca^{2+} and Mg^{2+} can be measured accurately

in the field using a hand-held titration device, Na^+ concentrations must be derived using either an ion selective probe (ISE meter) or an atomic absorption spectrophotometer (AAS). Both of these items are complex, delicate and very costly to purchase. Ion selective probes alone cost around US\$1600 (and off-the-shelf kits including an ISE meter are priced at around \$2300 at 2002 prices), and even second-hand atomic absorption spectrophotometers will typically cost more than ten times this amount. Furthermore, both ISE meters and AAS rigs are expensive to run, requiring reagent-grade calibration standards that are not readily available outside major cities. Add to this the fact that these items of equipment generally require maintenance and internal calibration by staff based in their country of origin, and the reasons for their lack of uptake in developing country conditions become obvious.

The heavy cost of SAR determination means that many irrigation schemes are developed without proper steps being taken to determine the salinity and sodium hazards at a given site. Where this gamble does not pay off, high conductivities and SARs will eventually lead to the failure of irrigation schemes and the irreversible destruction of agricultural land. Even where SAR was measured at the time an irrigation scheme was first commissioned, sustained pumping of wells can lead to significant changes in groundwater chemistry over time. It is therefore important to check conductivity and SAR at frequent intervals, which naturally

Table 1 The well-known Wilcox SAR classification scheme

SAR class	Range of values	Sodium hazard
S1	< 10	Low
S2	10–18	Medium
S3	18–26	High
S4	> 26	Very high

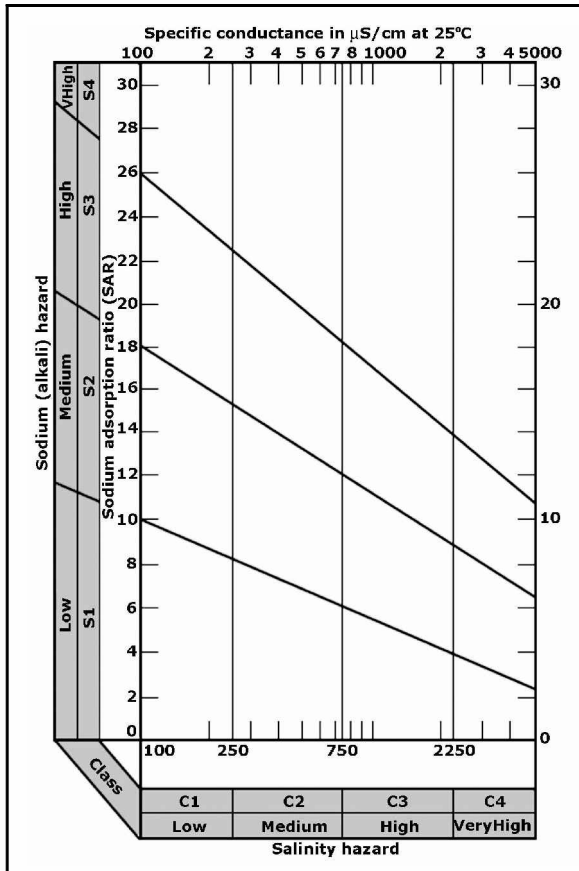


Figure 1 Wilcox diagram

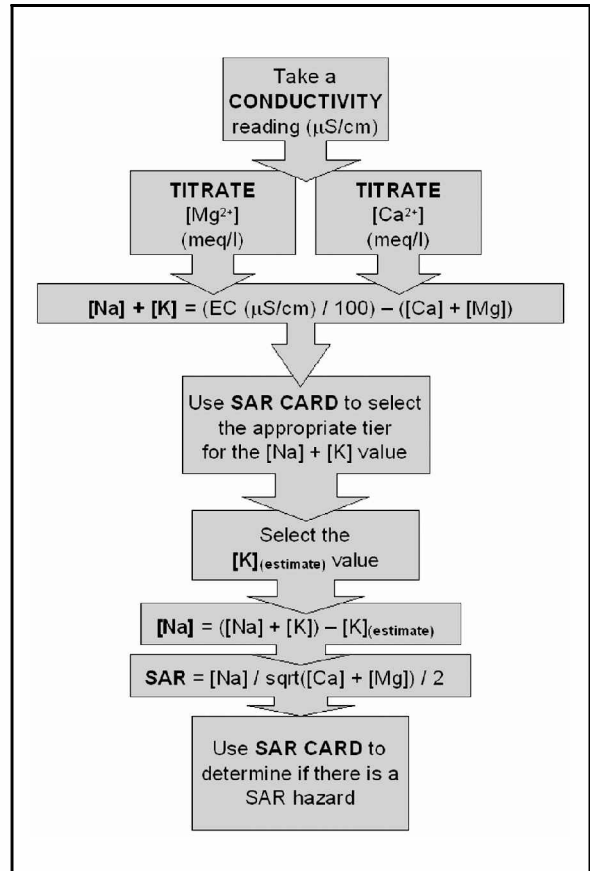


Figure 2 Flow diagram showing nine-step method

demands a simpler and cheaper method to approximate the SAR.

Study area

The Jericho district is an arid region located on the West Bank of the Jordan rift valley in Palestine. Irrigated agriculture is widely practised and there are over 60 wells and seven springs used to supply water for irrigation. Water quality varies greatly between individual wells and springs, and there are both low- and high-sodium groundwaters within a small area. Salinity is a problem in certain wells, which have had to be closed. The area was therefore ideal for testing the accuracy and flexibility of our new method for low-cost SAR determination.

Equipment needed for simple SAR determination

The equipment listed in Table 2 was selected on the basis that it:

- provides accurate results
- can be operated without a high level of technical expertise
- has low maintenance requirements
- is portable, robust and affordable.

Optional items of equipment can be chosen, at increased cost, which improve the overall ability to measure SAR accurately and to check for long-term changes in water quality. For instance, a hand-held titration kit (\$310) accurate to 1% can be substituted for the drop-count titration kit (which is accurate only to 5%).

Similarly, a further pH-temperature meter (costing \$280) provides the wherewithal to make sure that well waters being chemically tested are representative of the true groundwater.

The temperature can be monitored using a simple 1-litre container, through which part of the flow from the pump is diverted, and into which the conductivity and temperature/pH probes are placed. When the pH, temperature and conductivity all stabilize, it is safe to assume that the water being pumped represents the true hydrochemical composition of the

Table 2 Portable equipment for low-cost SAR determination

Item	Cost (US\$) at 2002 prices
Conductivity meter	\$366.00
Drop-count hardness titration kit for measuring [Ca ²⁺] and [Mg ²⁺]	\$127.00
1-litre container	\$ 3.50
Reagents (for 100 tests)	\$ 42.00
SAR card (developed by the authors)	\$ 0.00
Total	\$538.50

local groundwater, rather than the properties of the well casing.

Empirical determination of sodium concentration

In this study, an empirical method replaces the use of expensive ISE or AAS equipment for [Na⁺] determination. Our approach is based on the general relationship between electrical conductivity (EC, measured in micro-Siemens per centimetre), and dissolved ion concentration, shown in the formula below:

$$EC_{(\mu S/cm)} = ((Ca^{2+} + [Mg^{2+} + [Na^+] + [K^+]) \times 100_{(meq/l)})$$

The relationship generally holds true for conductivities up to 2000 μS . The formula above can be rearranged to:

$$[Na^+] + [K^+] = (EC_{(\mu S/cm)} / 100) - ([Ca^{2+} + [Mg^{2+}]_{(meq/l)})$$

Individual values of sodium [Na⁺] and potassium [K⁺] remain undetermined.

A hydrochemical study of 1370 groundwaters from regions of varying lithology and hydrochemical conditions was carried out to determine if a common ratio exists between sodium and potassium concentrations. The results of this study were split into five tiers (see Table 3).

Standard deviations were taken of the range of [Na⁺] + [K⁺] concentrations in each tier to determine how likely each tier was to return an accurate value of [K⁺]. This showed that tiers 1–3 are highly likely to return accurate estimations. Tiers 4 and 5 did not return such reliable standard deviations, but it is safe to assume that groundwaters containing [Na⁺] + [K⁺] cation ranges above 13.31 (meq/l) are highly likely to present a salinity hazard to the soil. The estimated value of [K⁺] can be used to calculate the approximate concentration of sodium using the formula below:

$$[Na^+]_{(approx)} = ([Na^+] + [K^+]) - [K^+]_{(estimate)}$$

The SAR card

The five-tier potassium concentration estimation (Table 3) and the relevant formulae have been printed on a wallet-sized, waterproof card for easy reference in the field. On the flip side of the card is a Wilcox diagram that is

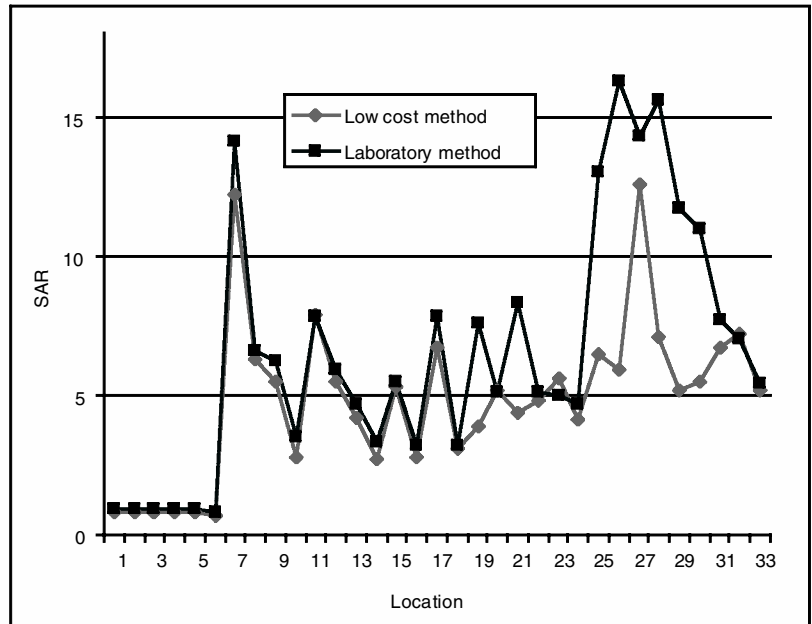


Figure 3 Plot comparing field and laboratory SAR results

used to classify the SAR of a groundwater to determine if it poses a hazard.

The empirical method to estimate [Na⁺] is incorporated into the nine-step method for calculating the SAR in the field once a sample has been taken (Figure 2).

Accuracy in the field

SAR readings for 33 groundwaters in the Jericho area were determined on site using the low-cost method. Samples of each groundwater were tested for the same parameters in the laboratory. Sodium was measured using an ion selective probe and the results of the two methods are compared in Figure 3.

Our low-cost method works best for groundwaters with low to medium conductivities (up to 3000 $\mu S/cm$). Above this value the relationship between laboratory and field results appears to deteriorate. This is of little conse-

quence, however, because groundwaters with such high values of conductivity should be treated with caution even without SAR determination.

Worldwide applicability

For an initial investment of less than \$600, an NGO or municipality can become fully equipped to carry out repeated SAR determinations. The cost of the apparatus employed in our method is under half that of a SAR determination kit incorporating an ISE meter, representing a saving of almost \$1500.

The affordable equipment used is robust and does not require specialist maintenance. It is not complicated and can be used by any NGO worker or agricultural developer with a basic knowledge of hydrochemistry.

The method can be widely applied to areas where there is a need to constantly monitor irrigation water quality in order to avert soil damage. Its application is not limited to groundwater; it can also be used on surface and wastewater sources.

About the authors

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Table 3 Five-tier system for the determination of potassium concentration [K⁺](meq/l)

Tier	[Na ⁺] + [K ⁺] range	Estimated [K ⁺] (meq/l)
1	0–2.67	0.08
2	2.67–6.21	0.21
3	6.21–13.31	0.45
4	13.31–35.70	0.92
5	> 35.70	0.69