GROUNDWATER SALINITY-origin, causes, impact and management

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Groundwater Salinity issues and management solutions
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Origin

The earth's land surface is 13.2×10^9 ha,
7×10^9 ha of this is arable,
1.5×10^9 ha is currently cultivated
0.34×10^9 ha (23%) are saline
0.56 × 109 ha (37%) are sodic

Worldwide, some ten million hectares of irrigated land is abandoned annually because of salinization, sodication and waterlogging

Massoud 1981

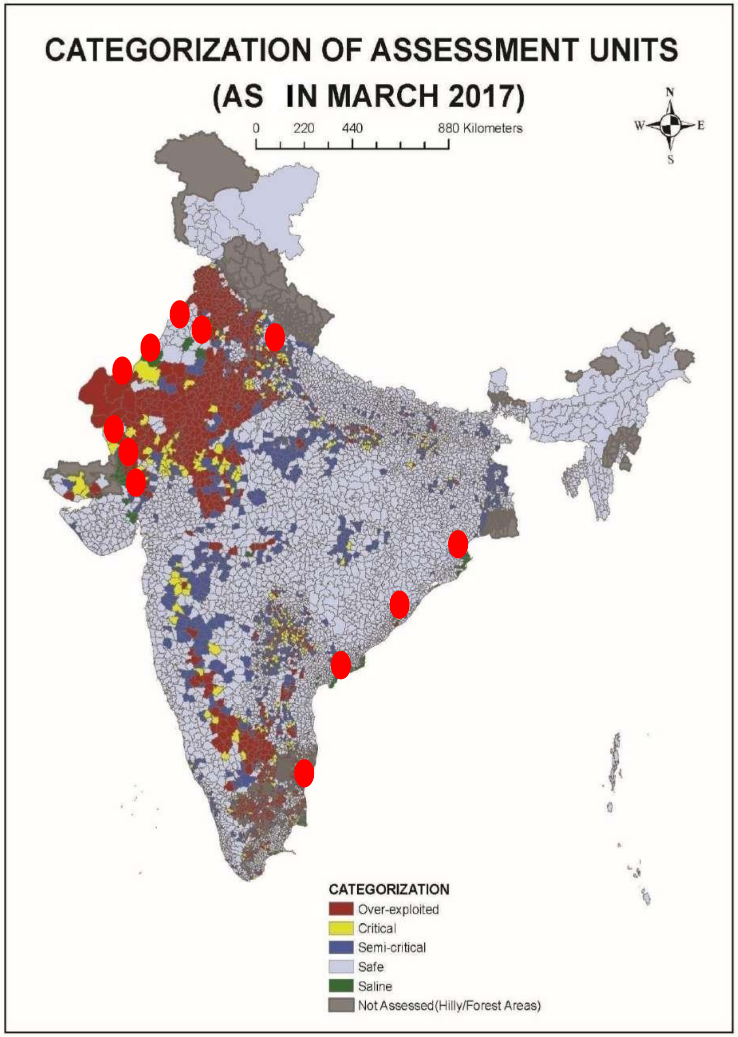
Origin

- Salinity problems occur under all climatic conditions
- Association between humans and salinity has existed for centuries and historical records show that many civilizations have failed due to increases in the salinity of agricultural fields, the most known example being Mesopotamia (now Iraq)
- Soil salinity is dynamic and spreading globally in over 100 countries; no continent is completely free from salinity
- Aral Sea Basin (Amu-Darya and Syr-Darya River Basins) in Central Asia,
- the Indo-Gangetic Basin in India,
- the Indus Basin in Pakistan,
- the Yellow River Basin in China,
- the Euphrates Basin in Syria and Iraq,
- the Murray-Darling Basin in Australia, and the San Joaquin Valley in the United States

- In the Indus plains of Pakistan and India, the practice of irrigation began about 2000 years ago during the Harapa civilization, but it is only recently that serious problems of salinity and sodicity are being encountered

Area	Saline soils	Sodic soils	Total	Percent
Australasia	17.6	340.0	357.6	38.4
Asia	194.7	121.9	316.5	33.9
America	77.6	69.3	146.9	15.8
Africa	53.5	26.9	80.4	8.60
Europe	7.8	22.9	30.8	3.30

Groundwater salinity distribution in India



CGWB 2017

GW Resources (Blocks)

Total – 6881

Saline – 100

Inland salinity:

Coastal salinity:

Impacts

Health

current recommendation for daily sodium set at <2 g/day (90 mmol/day) or sodium chloride <5 g/day (WHO 2003)

In a population drinking 2 l of water a day with a salinity level of 1 ppt, the sodium intake from water alone will be 0.6 g, which is approximately 30% of the daily WHO-recommended intake of 2 g (WHO 2003)

Hypertension (> a quarter of the world's adult population; leading cause of stroke and ischemic heart diseases globally –WHO, 2009),
Gastric cancer (one of the major cancers globally- Joossens et al., 1996)
Infant and Neonatal Mortality (George Joseph et al., 2019, WB group)

Agriculture/plantation crops

- Salinization may lead to changes in the chemical composition of natural water resources
- Degrading the quality of water supply to the domestic, agriculture and industrial sectors
- Poor soil structures particularly due to sodium, loss of fertile soils
- Less plant growth and yield,
- Taxonomic replacement by halotolerant species
- Loss of biodiversity
- Changes in local climatic conditions
- Collapse of agricultural and fishery industries
- Losses to infrastructure and ecosystems,
- Food insecurity

Groundwater salinity

More salinity in groundwater than surface water due to more exposure to soluble material from geological strata – less flow

Surface area of aquifer, mineral solubility and contact time
Salinity is inversely proportional to groundwater movement, generally increases with depth

Shallower depth- HCO_3
Deeper Depth – Cl
Precipitation also contains dissolved minerals –
it reacts with soil minerals and rocks

- **Type of mineral dissolved depends on**
- **chemical composition of rock**
- **physical structure of rock**
- **pH and redox potential**

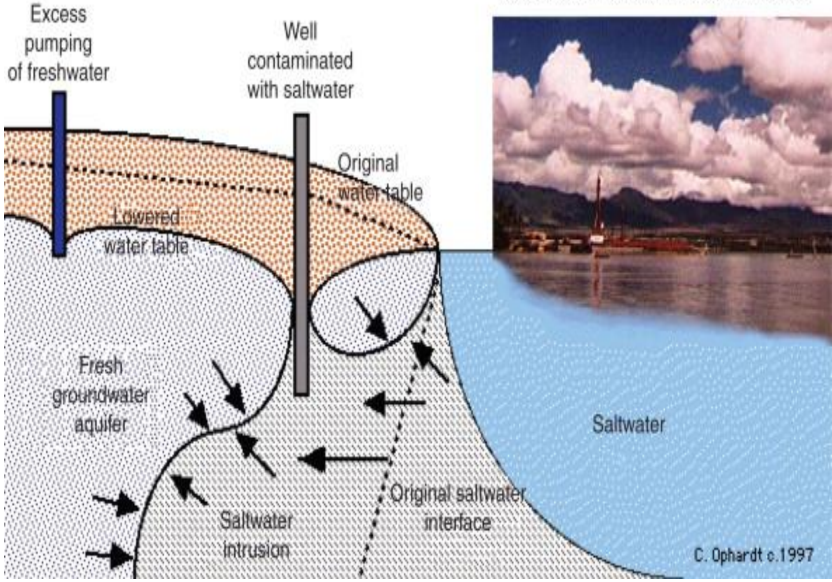
- **CO_2 assists in solvent action of water and results in downward movement**
- **Locally absorbed gases originating from magma contribute dissolved minerals to gw**

Salinity origin

- **marine origin-**

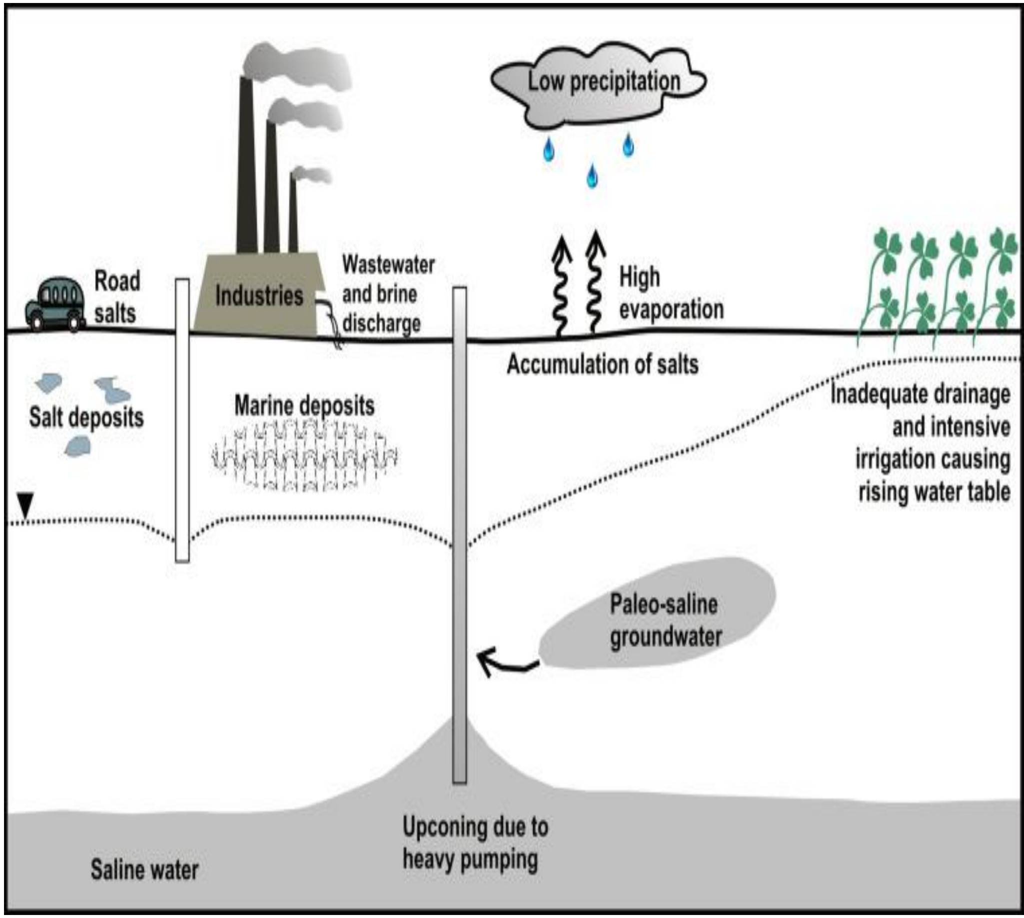
- **terrestrial origin**
- **mixed origin**

Saltwater intrusion in coastal areas



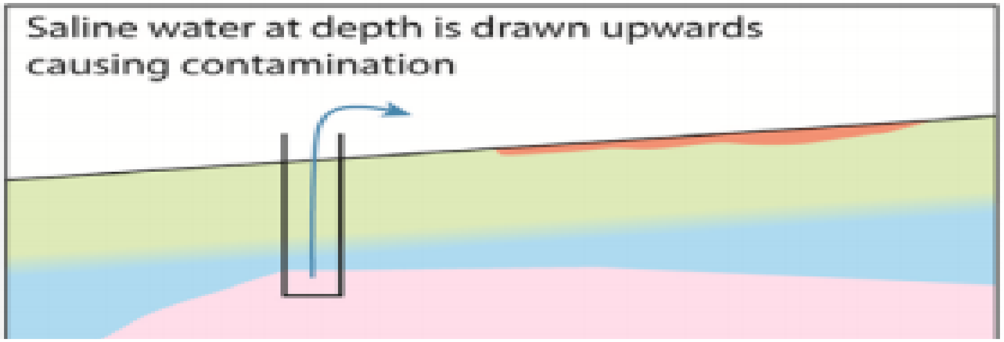
Types of Salinity

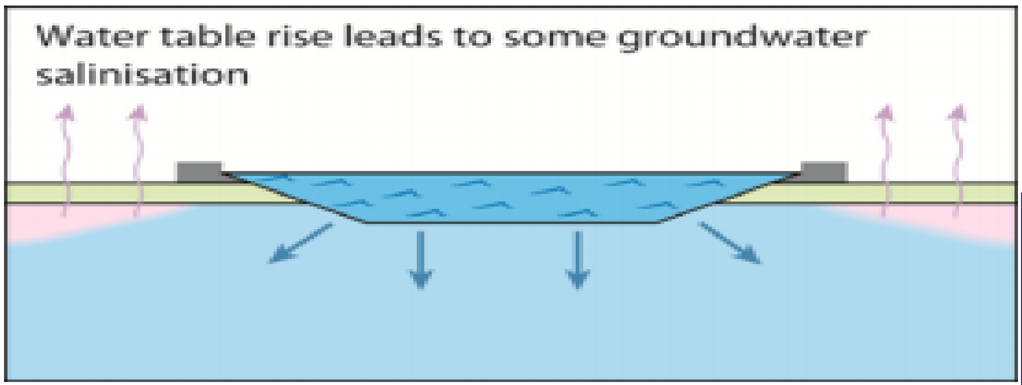
- **natural/primary salinity**
- **dryland/secondary salinity**
- **tertiary/irrigated salinity**

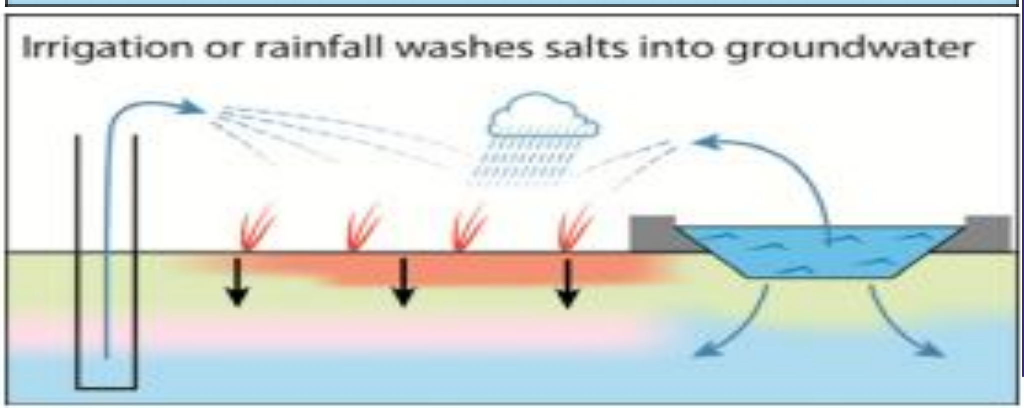


Mechanisms of salinity

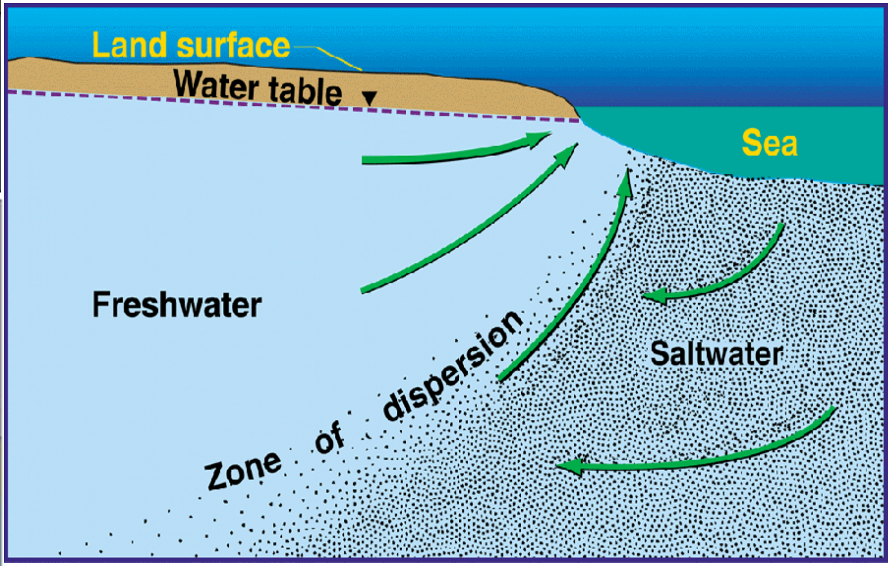
INLAND SALINITY







Coastal SALINITY



Salinity classifications

Salinity status	Salinity (grams of salt per litre)	Description and use
Fresh to marginal	< 0.5 - 1	Drinking and irrigation; apparent effects on ecosystem
Brackish	1 – 2	Irrigation certain crops only; useful for most stock
Saline to highly saline	2 – 35	Use for livestock with limitations
Brine	>35	Seawater; possible mining and industrial uses

Salinity Intrusion

Factors responsible for intrusion

- geological (in Indo-gangetic basin sedimentary region)
- meteorological processes,
- climate change effects (modifies meteorological variables like rainfall, temperature etc., impact by change in sea level, cause a global rise in atmospheric temperatures causing high evaporation thus intensifying risks of seawater intrusion),
- rise in sea level will also cause seawater to migrate upstream and inundate low-lying areas

Soil Salinity

Soil salinization is a major process of land degradation that decreases soil fertility and is a significant component of desertification processes in the world's dryland.

The accumulation of soluble salts in soil occurs when evaporation exceeds precipitation and salts are not leached (Arid areas) but remain in the upper soil layers in low-lying areas/poorly drained area

Natural soil salinization, referred to as "primary salinization," occurs in arid and semi-arid climatic zones. "Secondary salinization" is the term used to describe soil salinized as a consequence of direct human activities

SALTS

Salts are natural mineral components of soil that occur in various quantities throughout the landscape

Soil are classed as saline when these salts become present in quantities sufficient to adversely affect the growth and productivity of plants and animals.

CAUSES OF SOIL SALINITY

Salinization of soil results from a combination of evaporation, salt precipitation and dissolution, salt transport, and ion exchange

In shallow groundwater conditions, water and dissolved salts move by capillary action to the soil surface. When the water evaporates from the surface, the salts are left behind.

The salts present in soils can be easily mobilised and transported by the movement of groundwater, capillary rise and evaporation, and leaching and biological activity; Ultimately, this may lead to the accumulation or depletion of salts in different parts of the landscape

Land clearing and the introduction of wide-scale agricultural practices (in particular irrigation) has in many cases exacerbated these naturally occurring processes leading to the more rapid development of salt affected soils and water

Such radical changes in land use have resulted in considerable changes to the overall water balance

Salinity measurements

Water and soil salinity are measured by passing an electric current between the two electrodes of a salinity meter in a sample of soil or water

The electrical conductivity or EC of a soil or water sample is influenced by the concentration and composition of dissolved salts. Salts increase the ability of a solution to conduct an electrical current, so a high EC value indicates a high salinity level; more salts-higher conductivity

Can be measured at Practical Salinity Scales or parts per thousand i.e. grams in a litres of water

SI unit of conductivity is siemen (1/ohm) mS/cm or µS/cm at 25^0C

Measurement of EC can be computed for total dissolved solids (TDS) by applying a factor varying for the EC values

Salinity measurements

deciSiemens per metre (dS/m)	milliSiemens per centimetre (mS/cm)	microSiemens per centimetre (µS/cm)	electrical conductivity (EC)	parts per million (ppm*)
1	1	1000	1000	640
5	5	5000	5000	3200

Representation- Salinity measurements

EC_{se} is the electrical conductivity of a saturated soil extract

EC_a is the apparent electrical conductivity. It is a measure of bulk electrical conductivity of undisturbed soil in the field

It is measured with an electromagnetic instrument (EM38 and EM31) in a soil survey.

Agropedology 2008, 18 (2), 124-128

Measuring salinity with WET sensor and characterization of salt affected Soils

SURESH KUMAR, GOPAL KRISHAN AND S. K. SAHA

Agriculture and Soils Division, Indian Institute of Remote Sensing,
4, Kalidas Road, Dehradun- 248001, India.

Instruments/Equipments

Salinometer, salinimeter or salimeter – percentage of salt in a solution

Salinity refractometer:

Salinity Refractometer for Seawater and Marine Fishkeeping Aquarium 0-100 Ppt with Automatic Temperature Compensation

Salt meter:

Salt Meter is used for laboratory and *in situ* testing of the pH value, redox, conductivity, salt content, oxygen level and temperature of water

Aquaread

measurements of dissolved oxygen, EC and temperature

Instruments/Equipments

Salinity tester –
Measuring EC or salt content





Digital salinity meter

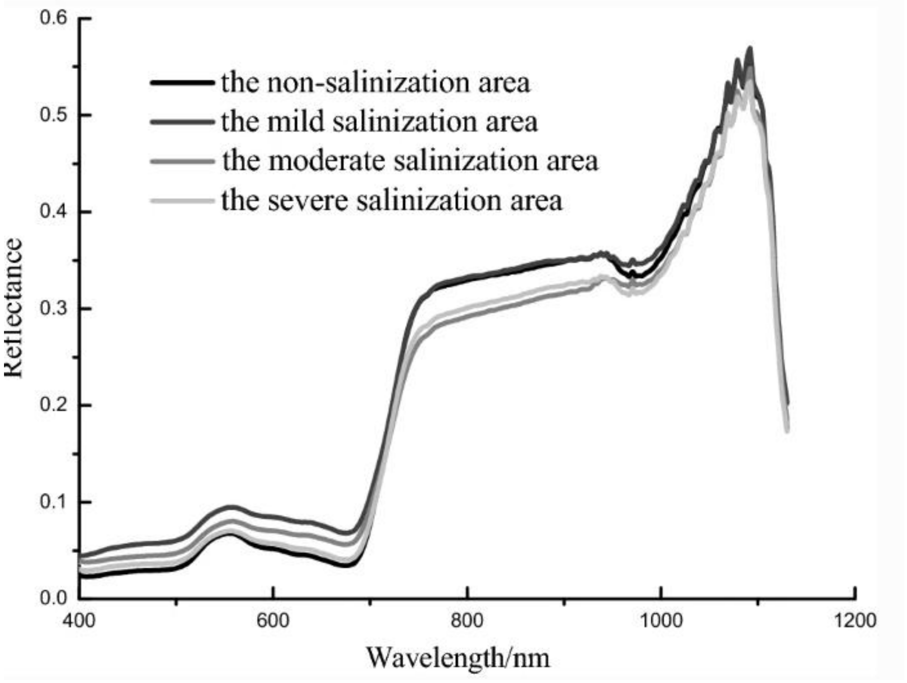
Microcontroller Based
Auto Ranging Facility
Auto Cell Constant Measurement
3½ Digit Display

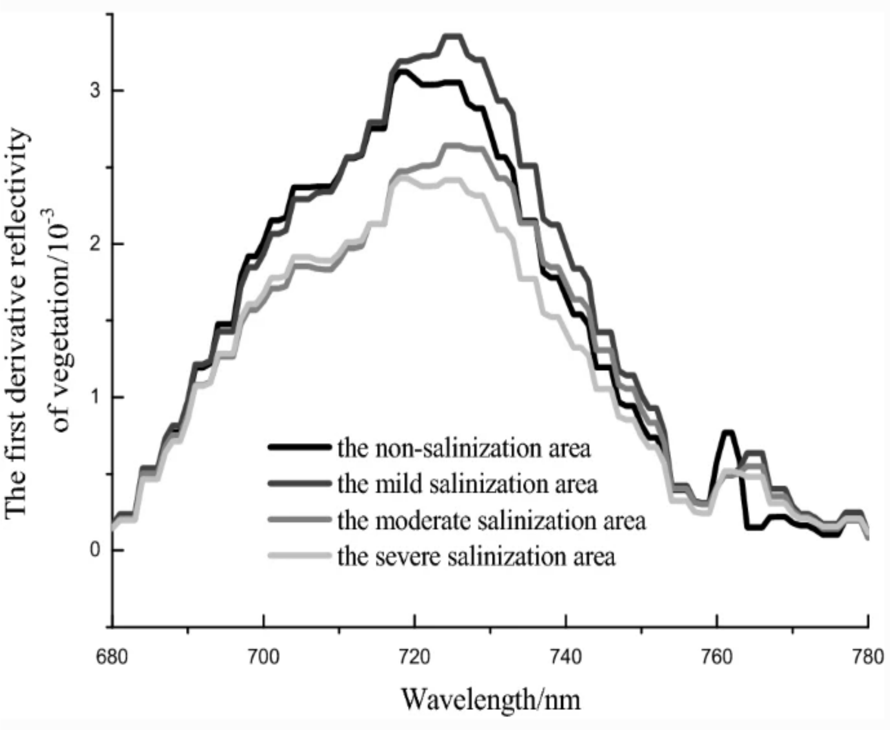
Salinity loggers
Long term high frequency monitoring

Remote sensing

Hyperspectral imaging

Hyperspectral remote sensing data sensing technology has achieved breakthroughs in modern technologies such as long-term dynamic monitoring of crop growth, crop species damage, and acquisition the agricultural information accurately





Hazem anf Gong, 2020

Salinity identification/ understanding

- Steadily increasing chlorides with time
- Cl/Br ratio is a reliable tracer (conservative) Sea water - ratio
- Waste water/sewage = 800
- Na/Cl ratios (<0.86 molar ratios of salt intrusion)
- Ca/Mg, Ca/(SO_4+HCO^3) = >1 sea water intrusion
- O&H isotopes can be used to describe process of saline and fresh water mixing (fresh water has depleted values and mixing should result in linear correlation) and residence times
- Boron isotopes: one of the process modifying chemistry of saline water intrusion is adsorption of K, B and Li onto clay minerals in host aquifers and are depleted in saline water associated with its intrusion

Salinity control and management measures

Soil Salinity
Reclamation and Management
Salt leaching
Scraping:
Flushing:
Leaching:

Salinity control and management measures

Quantity of water by leaching

The initial salt content of the soil, desired level of soil salinity after leaching, depth to which reclamation is desired and soil characteristics are major factors that determine the amount of water needed for reclamation

A useful rule of thumb is that a unit depth of water will remove nearly 80 percent of salts from a unit soil depth. Thus 30 cm water passing through the soil will remove approximately 80 percent of the salts present in the upper 30 cm of soil.

Salinity control and management measures

Water application method

Quantity of salts removed per unit quantity of water leached can be increased appreciably by leaching at soil moisture contents of less than saturation, i.e. under unsaturated conditions. In the field unsaturated conditions during leaching were obtained by adopting intermittent ponding or by intermittent sprinkling at rates less than the infiltration rate of the soil present in the upper 30 cm of soil.

25 cm of sprinkled water reduced the salinity of the upper 60 cm of soil to the same degree as 75 cm of ponded water.

Salinity control and management measures

Amendment

Whether an amendment (e.g. gypsum) is necessary or not for the reclamation of salt-affected soils is a matter of practical importance. Saline soils are dominated by neutral soluble salts and at high salinities sodium chloride is most often the dominant salt although calcium and magnesium are present in sufficient amounts to meet the plant growth needs. Since sodium chloride is most often the dominant soluble salt, the SAR of the soil solution of saline soils is also high.

Salinity control and management measures

Drainage

Irrigation is the most effective means of stabilizing agricultural production in areas where the rainfall is either inadequate for meeting the crop requirements or the distribution is erratic. Before the introduction to an area of large quantities of water through irrigation, there exists a water balance between the rainfall on the one hand and stream flow, groundwater table, evaporation and transpiration on the other.

Salinity control and management measures

Irrigation frequency

Modifying water management through appropriate irrigation practices can often lead to increased crop yields under saline soil conditions.

As the soil progressively dries out due to evapo-transpirational losses the concentration of salts in the soil solution and, therefore, its osmotic pressure increases making the soil water increasingly difficult to be absorbed by the plants. Thus infrequent irrigation aggravates salinity effects on growth.

On the other hand, more frequent irrigations, by keeping the soil at a higher soil moisture content prevent the concentration of salts in the soil solution and tend to minimize the adverse effects of salts in the soil.

Engineering measures

Surface drainage

Sub-surface drainage

Open ditches:

Mole drains:

Other sub-surface drains

Salinity control and management measures

Salinity Control structures:
effective in preventing upstream movement of tidal water through river channels

Recharge Techniques
augmenting the groundwater recharge

Management Techniques
long-term strategy

Salinity control structures

Tidal Regulators

Tail end Regulator

Tail end Regulators with Diaphragm Wall

Regulator cum Bridge

Salinity control structures

Lock cum Regulator

Inlet Sluice/ Control Sluice

Bandharas

Kharland Schemes

Salt Water Exclusion Dams (SWED)

Salinity control structures

Bunds/ Saline Embankment

Vented Cross Bars (VCB)

Nalla Plugs

Gully plugging in Forest Areas

5 Square Model

Recharge techniques

Check dams/ In-stream Structures

Recharge Tanks

Recharge Wells

Recharge Reservoirs/ Spreading Channels

Recharge Shafts

Afforestation

Shelterbelt Plantation

Management techniques

Scientific data collection, monitoring, assessment and modelling

Behavioural and Institutional Approaches

Water supply and demand management – Regulation/ limiting of Ground Water Extraction

Crop adaptation - Cropping pattern

Management techniques

Aquifer Storage and Recovery

ASR can first of all be approached as a storage technique where the aquifer is used as an underground reservoir.

Underground reservoirs do not occupy space, need only limited maintenance and losses due to evaporation are minimized and offer a good alternative to surface water reservoirs. Secondly, ASR can also be approached as a recovery technique.

Aquifers that are already salinized and rendered unsuitable for groundwater development can be (partially) recovered by flushing the dissolved salts from the groundwater system (this means both the groundwater itself and the aquifer material).

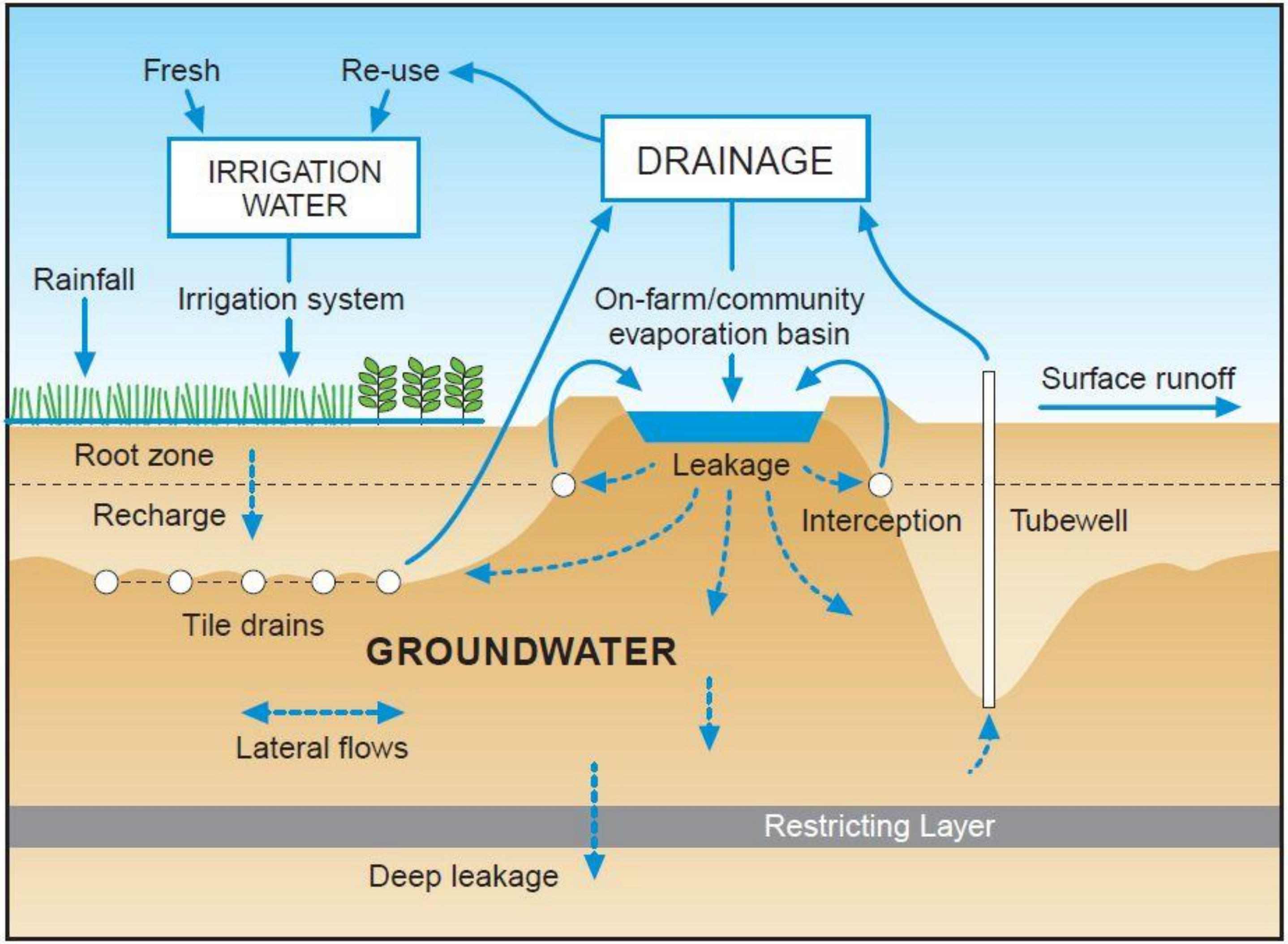
Flushing will need more than just one time the volume of the brackish or saline groundwater because of solutes transport retardation and may be a long-term process.

Management techniques

Plantations

Changes in vegetation can also change the water and salt balances in soil, the vadose zone, and shallow groundwater. Since deep tree roots can efficiently pump underlying shallow groundwater, afforestation of grasslands reverses the vertical flux of groundwater from the soil to the saturated zone. As a result, groundwater flows and discharges the aquifer through transpiration to the deep roots, leaving its salt load in the afforested stand.

Consequently, plantation reduces groundwater recharge and causes salinization of the soil and shallow groundwater.
Evidences for soil and groundwater salinization due to tree establishment on grasslands



Evaporation basins are often located within the zone of impact of the drainage systems. Install secondary (interception) drains near the basins to capture leakage. This more-saline water is usually stored in a separate cell within the evaporation basin, so that maximum evaporation rates are maintained in the main basin

Site selection for evaporation basin

- For an evaporation basin to be effective and have minimum leakage, construct it:
- well away from neighbour boundaries
- in soils with low permeability
- in flat areas (with little watertable slope)
- in areas with shallow groundwater
- in soils that allow recovery of leakage
- away from the influence of flood events – unless designed to be stripped – and surface water run-off
- where there is high groundwater salinity, so basin leakage will have a limited effect on the groundwater quality
- away from built infrastructure, which may be at risk from leakage and to avoid problems associated with visual pollution and odours
- with adequate space for the structure to be expanded if designed inflows are exceeded.

Engineering measures

Minimum flow in rivers

Reclamation of Land

Anti-sea erosion works

Desiltation of Lakes

Engineering measures

Desalination

A desalination plant turns salt water into water that is fit to drink. The most commonly used technology used for the process is reverse osmosis where an external pressure is applied to push solvents from an area of high-solute concentration to an area of low-solute concentration through a membrane. The microscopic pores in the membranes allow water molecules through but leave salt and most other impurities behind, releasing clean water from the other side. These plants are mostly set up in areas that have access to sea water.

Desalination has largely been limited to affluent countries in the Middle East and has recently started making inroads in parts of the United States and Australia. In India, Tamil Nadu has been the pioneer in using this technology

Desalination is an expensive way of generating drinking water as it requires a high amount of energy. The other problem is the disposal of the byproduct — highly concentrated brine — of the desalination process. While in most places brine is pumped back into the sea, there have been rising complaints that it ends up severely damaging the local ecology around the plant

Thank you

Questions ?