GROUNDWATER SALINITY-origin, possible remedial measures and management solutions

Gopal Krishan

Scientist – C

Groundwater Hydrology Division

National Institute of Hydrology, Roorkee- 247667, Uttarakhand, India

*Corresponding E-mail: drgopal.krishan@gmail.com

Groundwater Quality and Stable Isotope Characterization for Salinity Studies

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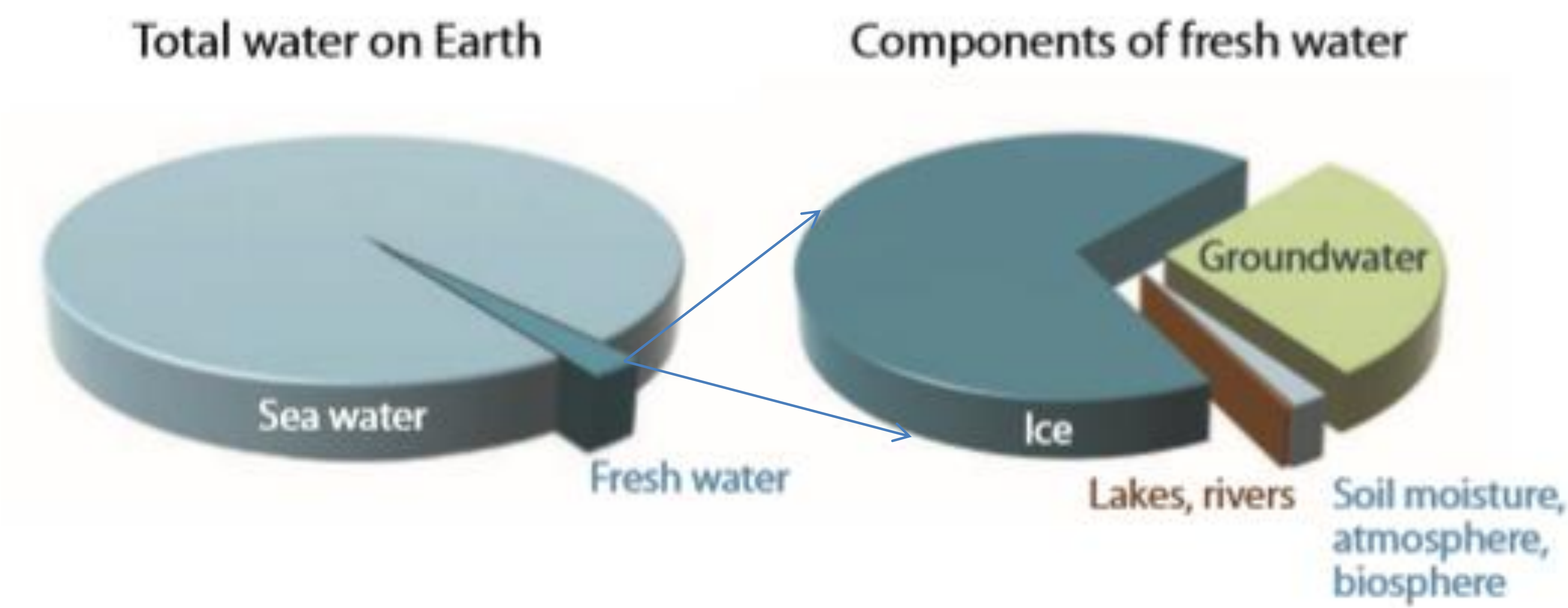
Organized by DRC, Kakinada

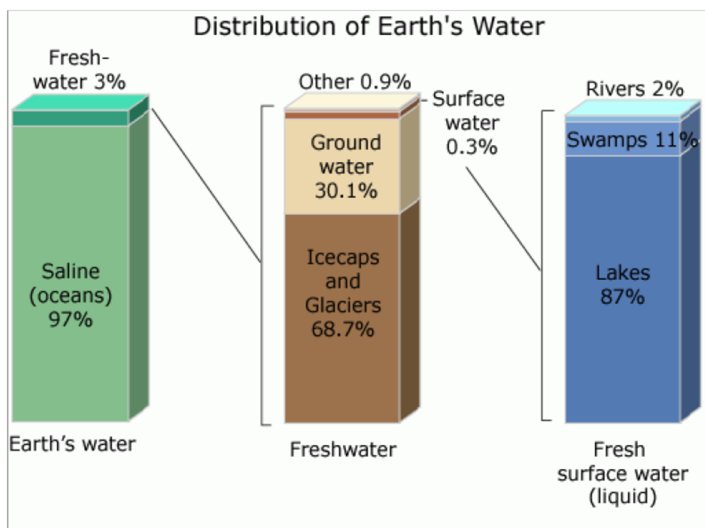
Origin

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

Shahid et al., 2018

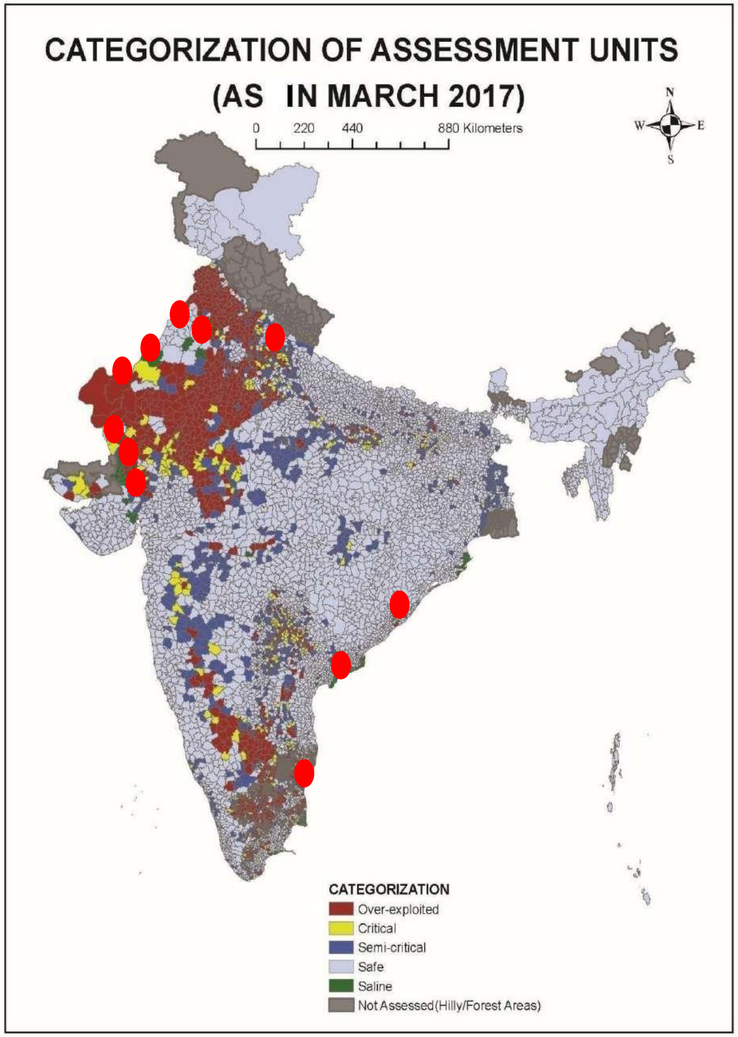


Shiklomanov and Rodda (2004)



10^3 km^3 (Mook (2000)

Groundwater salinity distribution in India



CGWB 2017

GW Resources (Blocks)

Total – 6881

Saline – 100

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)

In addition to sodium,
water also contain calcium (influences the bone, musculoskeletal and cardiovascular system development) and

magnesium (co-enzyme and relevant to lung function of the neonates and infants) peak around 1 mS/cm EC,
but their concentrations do not change after that level is reached with increasing level of EC

Ca- deficiency – gestational hypertension and prenatal mortality
Mg-deficiency – bronchial constriction and prenatal asphyxiation

Others- skin rashes, hair loss, diarrhea

Socio economic
Incomes
Livelihood
Migration
Health care costs

Salinity processes are natural processes closely linked with landscape and soil formation processes;

however, human activities can accelerate salinity processes, thereby further aggravating the land and water degradation of the affected region

Salinity is taken as a water issue when the potential use of water is limited by its salt content or its salt composition

It becomes a land use issue when the concentration of salt or sodium adversely affects plant growth, degrades soil structure or causes soil erosion.

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

Salinity

Concentration of salts in water;

contains significant amounts (referred to as "concentrations") of dissolved salts,
the most common being the salt we all know so well—sodium chloride (NaCl).

In this case, the concentration is the amount (by weight) of salt in water, as expressed in "parts per million" (ppm).

If water has a concentration of 10,000 ppm of dissolved salts,
then one percent (10,000 divided by 1,000,000) of the weight of the water comes from dissolved salts.

SI unit of conductivity is siemen (1/ohm) mS/cm or µS/cm

Saline water is not just in the oceans, it can be present in inlands also

Salinity origin

- **marine origin-** these are mostly found in coastal zone and may be of connate or intruded

- **terrestrial origin–**

(i) Natural (formations), these may be due to evaporation, dissolution, and at depth there may be semi permeable layers or salt filtering membrane

(ii) anthropogenic, irrigation and polluted groundwater

- **mixed origin**, these may be the mixing effect of any of above classes. Salinity may be of various degrees based on the concentration of salts which also decides the purpose of groundwater use.

Types of Salinity

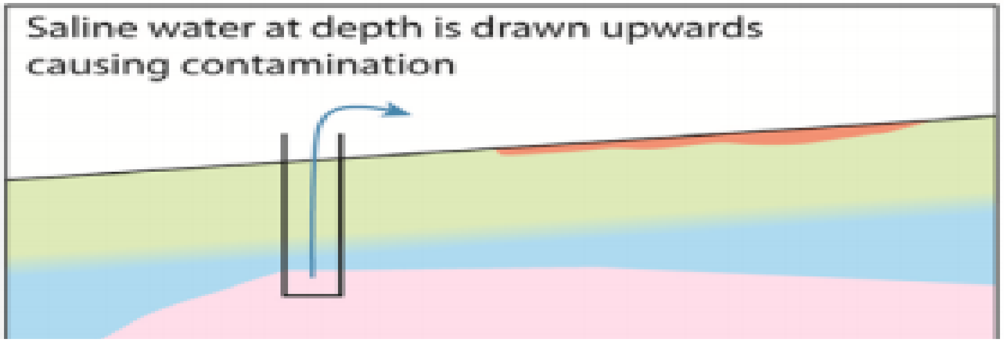
- **natural/primary salinity** caused as a result of dissolution of minerals (e.g. halite, anhydrite, carbonates, gypsum, fluoride-salts, and sulphate-salts) from bedrocks or accumulation of salts from rainfall built up over time, hence the residence time of these may be quite long ranging from thousands to million of years

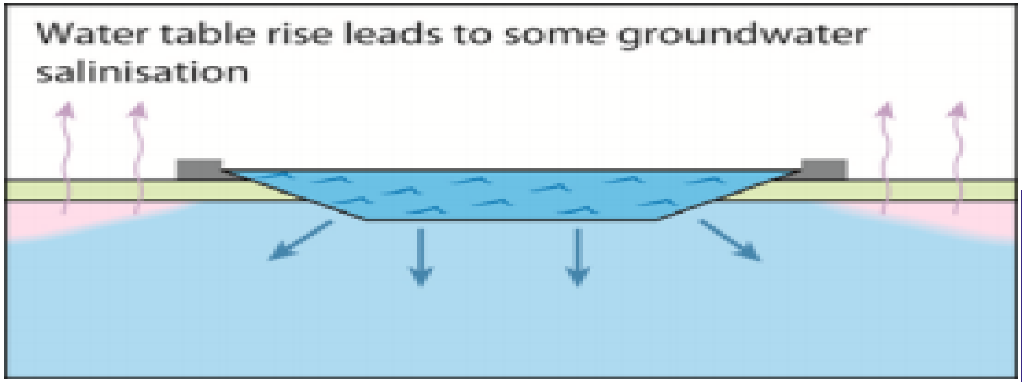
- **dryland/secondary salinity** caused due to rising water levels which bring salt to the surface or clearing of vegetation cause accumulation of salt in soil profile and in groundwater. In high rainfall areas the salts are percolated down while in arid and semi arid regions these remain on the surface

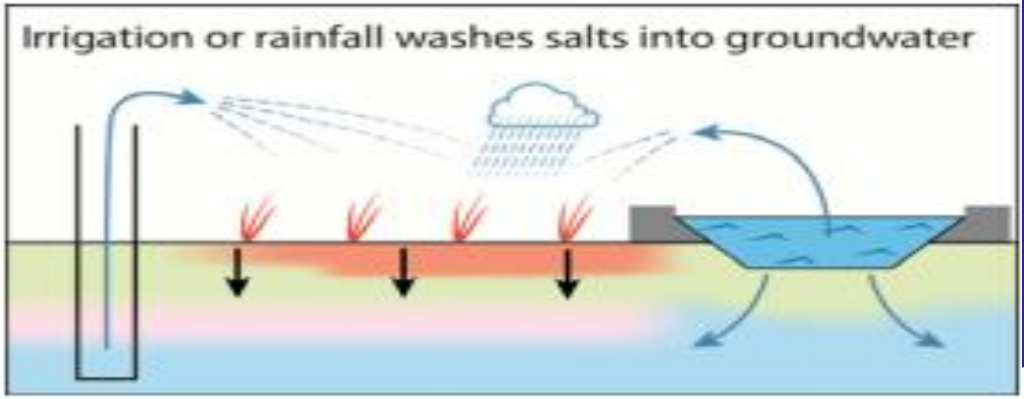
- **tertiary/irrigated salinity** caused as a result of repeated multiple irrigation of water where salts remain after evaporation and accumulate over time. These accumulated salts leech down to groundwater with rainfall.

Mechanisms of salinity

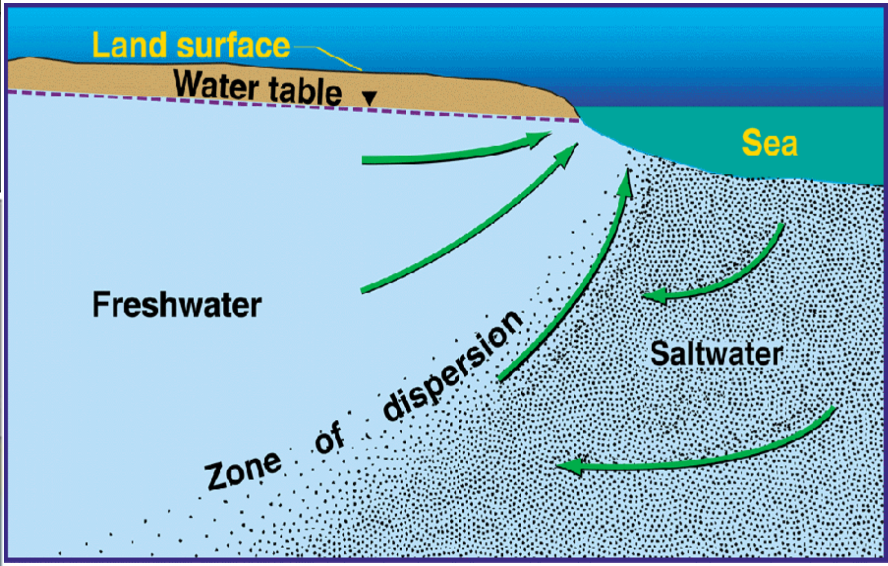
INLAND SALINITY







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

Intrusion of saline water to the fresh water

- degrades our fresh water resources

- causes loss to the socio-economy of the region.

Groundwater mobilises and carries the soluble salts through the regolith and mixes with the fresh water.

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 World Bank states that soil salinization caused by inappropriate irrigation practices affects about 60 million ha, or 24% of all irrigated land worldwide. In Africa, salinization accounts for 50% of irrigated land. Increasing soil salinization is occurring also in India, Pakistan, China, and Central Asia. Soil salinization is the first stage of environmental destruction caused by salinity and is interrelated with river and lake salinization

The accumulation of soluble salts in soil occurs when evaporation exceeds precipitation and salts are not leached but remain in the upper soil layers in low-lying areas

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

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

SOIL SALINITY- Coastal and inland

Coastal saline soils are different from inland saline soils in the sense that the inland soil salinity is due to secondary salinization from high water table conditions caused by the introduction of irrigation in arid and semiarid areas or it may also be due to natural conditions from dissolution of minerals.

The salinity problem in coastal soils arises during the process of their formation itself due to marine influence and frequent tidal inundation of the coast land with sea water and ingress of seawater along the estuaries, creeks, drains and rivers.

The repeated inundation with highly saline water renders the soil saline. The salinity of coastal soils varies with the season and is at its maximum in May. Salinity decreases with the onset of monsoon and is generally lowest during September in areas receiving rain from south-west monsoon.

Moreover, groundwater with high salt content is present at shallow depths in coastal areas because of low lying nature of these areas and their proximity to sea. These salts accumulate on the surface of the soil due to the capillary rise of saline groundwater during dry periods of the year.

SOIL SALINITY- Areas needing attention

Sundarbans of West Bengal- inundation of backwaters from sea
Delta areas of Krishna, Godavari and Cauveri,
Kari soils in Kerala -
Khar lands of Maharashtra (Ratnagiri and Thane)
Uttar Kannada district of Karnataka
Gujarat and Rann of Kachchh (Saurashtra region and in the districts of Ahmedabad, Amreli, Bharuch.
Khazan lands in Goa
East coast
Width of the saline zone tapers off towards Kanyakumari in Tamil Nadu.
West coast
the saline region is very narrow on account of the narrow width of Western Coastal Plains.

SOIL SALINITY- Impacts

Excessive salinity in soil leads to toxicity in crops, reduction in soil fertility, reduction of availability of water to plants by reducing the osmostic potential of the soil solution, and a significant change in the hydraulic properties of soil

Soil Salinity Class	Conductivity of the Saturation Extract (dS/m)	Effect on Crop Plants
Non saline	0 - 2	Salinity effects negligible
Slightly saline	2 - 4	Yields of sensitive crops may be restricted
Moderately saline	4 - 8	Yields of many crops are restricted
Strongly saline	8 - 16	Only tolerant crops yield satisfactorily
Very strongly saline	> 16	Only a few very tolerant crops yield satisfactorily

Soil	pH	ECe (dS/m)	ECe (mS/m)	SAR*
Normal or non-affected	6.5 – 7.2	<4	<400	< 13 – 15
Acidic	<6.5	<4	<400	< 13 – 15
Saline	<8.5	>4	>400	< 13 – 15
Saline-sodic (saline-alkali)	<8.5	>4	>400	> 13 – 15
Sodic (alkali)	>8.5	<4	<400	> 13 – 15

* SAR is the sodium adsorption ratio = comparative concentrations of $[Na^{+1}]$ / $[Ca^{+2}]$ + $[Mg^{+2}]$ in the soil solution

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

Representation- Salinity measurements

Salinity measurements are often reported with subscript abbreviations to indicate the origin of the sample tested and the method used to determine the salinity measurement. The method used will influence the accuracy of the results and confidence in interpretation. Common abbreviations and their descriptions are explained below

EC_w is the salinity of water - field or a laboratory

$EC_{1:5}$ is the first of three steps to estimate soil salinity (Ec_e)

It is determined by mixing 1 part soil with 5 parts distilled or deionised water. After mixing the sample and allowing the sediment to settle, the electrical conductivity of the solution is tested
An $EC_{1:5}$ can be performed in the field or a laboratory.

EC_e is the estimated amount of salt in the soil. It is estimated by multiplying the $EC_{1:5}$ value by an appropriate factor related to the soil texture of the sample. This can be determined in the field or a laboratory.

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

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

Salinity identification/ understanding

- **Steadily increasing chlorides with time**
- **Cl/Br ratio is a reliable tracer (conservative) Sea water - ratio is 297**
- **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

reclamation of saline soils refers to the methods used to remove soluble salts from the root zone

Salt leaching

Scraping: Removing the salts by mechanical means has had only a limited success. Although this method might temporarily improve crop growth, the ultimate disposal of salts still poses a major problem.

Flushing: Washing by flushing water over the surface to desalinize soils having surface salt crusts. Because the amount of salts that can be flushed from a soil is rather small, this method does not have much practical significance.

Leaching: Most effective procedure for removing salts from the root zone of soils. Leaching is most often accomplished by ponding fresh water on the soil surface and allowing it to infiltrate. Leaching is effective when the salty drainage water is discharged through subsurface drains that carry the leached salts out of the area under reclamation.

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.

Leaching curves relate the ratio of actual salt content to initial salt content in the soil (Sa/Sb) to the depth of leaching water per unit depth of soil (Dw/Ds)

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.

The amount of salts which move to the surface depend on the amount of salts present in the upper soil layers from where the water can flow upwards. Thus only a small fraction of salts move up during evaporation from the soil previously irrigated by sprinklers. In flooded soils, on the other hand, more salts move upward and accumulate in the soil surface.

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.

A higher cumulative intake when gypsum was applied. Application of an amendment, per se, might not be essential for either desalinization or desodication but could hasten the process by maintaining a higher infiltration rate by continuously supplying soluble calcium to the leaching water. Thus, the decision to use an amendment for the reclamation of saline soils having excess neutral soluble salts and a high SAR of soil solution (the so called saline-sodic soils) would depend on soil infiltration characteristics and the electrolyte level of the irrigation water.

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.

There are numerous instances throughout the world, where consequent upon the introduction of canal irrigation, the water table has risen considerably within 10 years to less than 2 m. Once the groundwater table is close to the soil surface, due to evaporation from the surface, appreciable movement of the groundwater takes place resulting in the accumulation of salts in the root zone.

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. Most plants require a continuous supply of readily available moisture to grow normally and produce high yields.

After an irrigation the soil moisture content is maximum and the salt concentration or the osmotic pressure of the soil solution is minimal: favourable for crop growth. 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. For these reasons crops grown in saline soils must be irrigated more frequently compared to crops grown under non-saline conditions so that the plants are not subjected to excessively high soil moisture stresses due to combined influence of excess salts and low soil water contents.

Engineering measures

Surface drainage

In surface drainage, ditches are provided so that excess water will run off before it enters the soil. However the water intake rates of soils should be kept as high as possible so that water which could be stored will not be drained off.

Sub-surface drainage

If the natural subsurface drainage is insufficient to carry the excess water and dissolved salts away from an area without the groundwater table rising to a point where root aeration is affected adversely and the groundwater contributes appreciably to soil salinization, it may be necessary to install an artificial drainage system for the control of the groundwater table at a specified safe depth.

Open ditches: **Open drainage ditches are advantageous for removing large volumes of either surface or subsoil water from land and for use where the water table is near the surface and the slope is too slight for proper installation of tile drains**

Mole drains: **The channels left by a bullet shaped device pulled through the soil, have been used successfully for shallow subsurface drainage of heavy clay soils in many, relatively humid parts.**

Other sub-surface drains **Any type of buried conduit with open joints or perforations that collect and convey excess water from the soil**

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
gated structure having a special arrangement for closing the gates

Inlet Sluice/ Control Sluice
at mouth of the creeks or sub creeks to control the saline ingress due to tidal effect in to the command area

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
Like recharge tanks more water spread area

Recharge Shafts
most efficient and cost-effective structures to recharge the aquifer directly. Water is put into the recharge shaft directly through pipes and the recharge is fast and immediately delivers the benefit

Afforestation
improve the rate of infiltration by formation of root channels and reduction in evaporation from land

Shelterbelt Plantation

viable technique for significantly reducing both the direct and indirect adverse impacts of salinity on plants and water resources along the coastline. It acts as barriers that diminish damage from salt-laden winds in coastal areas and provide shelter to coastal life. The 'bio-shield' formed by planting a vegetation belt along coastlines besides other such soft measures also help in absorbing/ dissipating the force of severe coastal storms and cyclones

Management techniques

Scientific data collection, monitoring, assessment and modelling

primary tools that hydrologists use to understand ground water flow and salt water movement in coastal aquifers. Data required for groundwater studies in coastal and deltaic areas, where saltwater intrusion plays a role, relate to records of geophysical surveys, hydro-geological parameters, water levels, groundwater quality, ecology, sea-level rise etc

Behavioural and Institutional Approaches

aimed towards ensuring sustained water quality and quantity over the long term

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

enforcing ground water legislation for future expansion of construction of wells farther inland, educating the farmers to reduce their present withdrawal to achieve ground water balance and adopting water saving practices viz. reduction of non-beneficial evaporative and leakage losses, increase of irrigation efficiency, a change to less water demanding production processes and land uses and to find alternative sources of water other than groundwater (surface water or re-use of waste water)

Crop adaptation - Cropping pattern

changed to manage salinity in soils and water, through introducing crops with lower water requirements; introducing salt tolerant and semi salt tolerant crops; incorporating Boron-resistant crops. Crop adaptation is accompanied by nutrients augmentation (in fertilizers) and soil quality improvement (e.g. adding gypsum sulphuric acid, and iron pyrite to reduce the negative effects of soil sodicity)

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.

The fresh water that is recharged may have various sources like harvested rainwater, river runoff, treated (desalinized) waste water, irrigation return flow and even seawater. Obviously, it only makes sense to recharge the freshwater when there are no alternative more urgent needs for that water.

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

protective embankments, surface and sub-surface drainage, leaching, adoption of suitable varieties of crops at various stages depending upon their salt-tolerance.

Anti-sea erosion works

seawalls, groynes, breakwaters/artificial headlands or offshore breakwaters influence coastal processes to stop or reduce the rate of coastal erosion which in turn will reduce the salinity ingress.

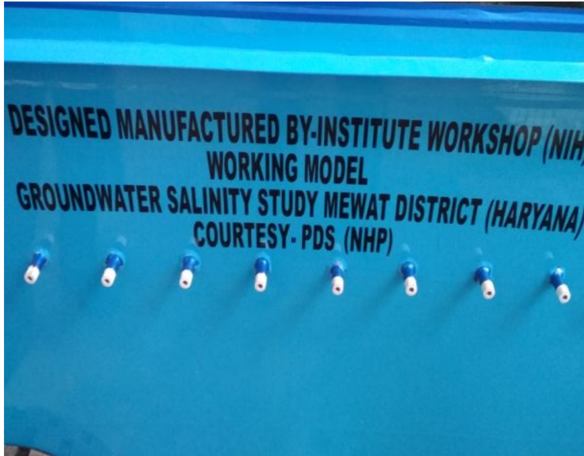
Desiltation of Lakes

The Lakes present along the coastal areas may be desilted to ensure that it is filled in by the fresh rainwater

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.


DESIGNED MANUFACTURED BY-INSTITUTE WORKSHOP (NIH)
WORKING MODEL
GROUNDWATER SALINITY STUDY MEWAT DISTRICT (HARYANA)
COURTESY- PDS (NHP)


Dulux
WeatherShield

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Identifying the seasonal variability in source of groundwater salinization using deuterium excess- a case study from Mewat, Haryana, India

G. Krishan[a,*], G. Prasad[a], Anjali[a], C.P. Kumar[a], N. Patidar[a], B.K. Yadav[b], M.L. Kansal[b], S. Singh[a], L.M. Sharma[c], A. Bradley[d], S.K. Verma[a]

[a] National Institute of Hydrology, Roorkee, Uttarakhand, India
[b] Indian Institute of Technology Roorkee, Uttarakhand, India
[c] Sehgal Foundation, Gurgaon, Haryana, India
[d] The University of Iowa, Iowa City, Iowa, 52242, USA

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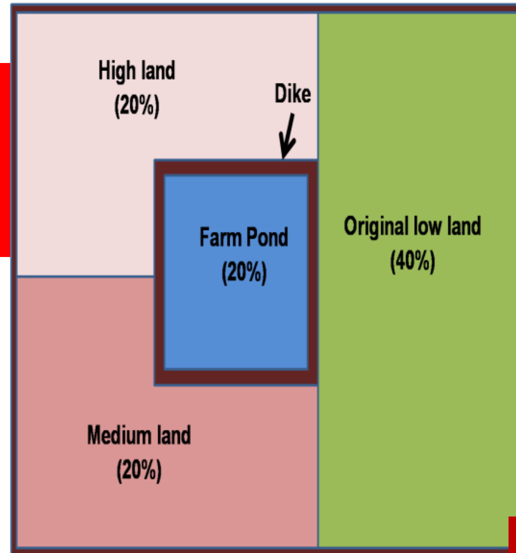
Understanding stable isotope systematics of salinity affected groundwater in Mewat, Haryana, India

Gopal Krishan[1,*], N C Ghosh[1], C P Kumar[1], Lalit Mohan Sharma[2], Brijesh Yadav[3], M L Kansal[3], Surjeet Singh[1], S K Verma[1] and Gokul Prasad[1]

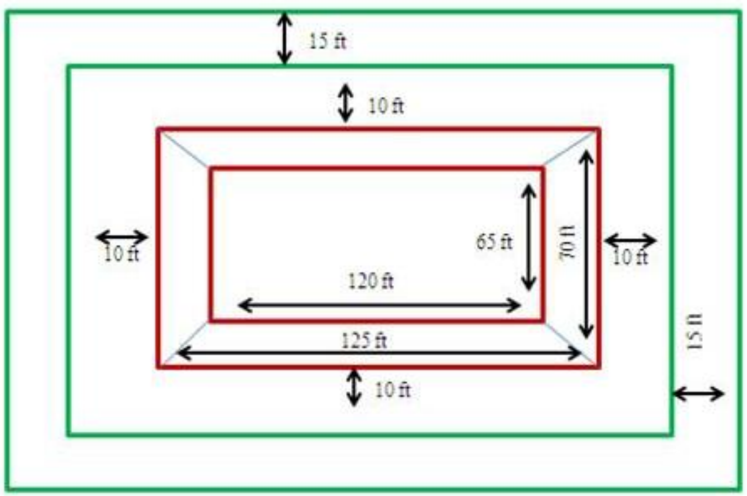
[1]National Institute of Hydrology, Roorkee, Uttarakhand 247 667, India.
[2]Sehgal Foundation, Gurugram, Haryana 122 003, India.
[3]Indian Institute of Technology, Roorkee, Uttarakhand 247 667, India.
*Corresponding author. e-mail: drgopal.krishan@gmail.com

Farm pond technique

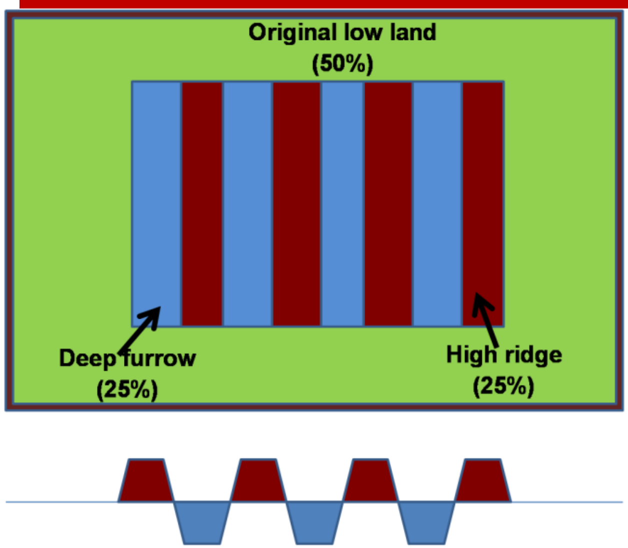


Restoring coastal delta by strengthening drainage channels

Brackishwater aquaculture



Shallow furrow and medium ridge



Cross section of deep furrow and high ridge

Thank you

Questions ?