INDIA WATER WEEK 2026 · SEMINAR PRESENTATION

Heliborne Based Geophysical Investigations for Assessing Submarine Groundwater Discharge

Insights from the Kalyanpur Block, Devbhoomi Dwarka District, Gujarat, India

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INTRODUCTION

SGD — A Critical, Underrepresented Coastal Process

Submarine Groundwater Discharge (SGD) the flow of water through continental margins from the seabed to the coastal ocean is a critical component of the **coastal water cycle, influencing freshwater availability, nutrient loading and nearshore ecology.**

Generally, SGD has been **quantified** using seepage meters, hydraulic-gradient approaches, radon/radium isotopes, thermal infrared imaging, ground-based resistivity, and numerical modelling but each is limited by sparse measuring points or inability to resolve continuous, high-resolution aquifer geometry at regional scale.

This study applies High-resolution **Heliborne TEM (HTEM),** integrated with **hydrogeological** and **hydrochemical data**, to estimate SGD along the coastal tract of **Kalyanpur Block, Gujarat** under the National Aquifer Mapping and Management (NAQUIM) programme, a CGWB–CSIR-NGRI collaboration.

STUDY OBJECTIVES

1. **Delineate resistivity zones for freshwater, brackish and saline domains**
2. Map preferential SGD pathways governed by structural / lithological controls
3. Assess spatial configuration of the freshwater–seawater interface
4. Estimate SGD along the coastline of the study area
5. Evaluate scalability of the integrated methodology for coastal groundwater management

STUDY AREA

Location & Physical Setting

Kalyanpur Block, Devbhoomi Dwarka District, lies on the western extremity of the **Saurashtra Peninsula**, Gujarat, its western margin directly contiguous with the Arabian Sea inherently susceptible to **seawater intrusion and SGD**.

The block is classified 'safe' for groundwater development (GWRE 2025), though coastal proximity introduces water-quality constraints beyond simple volumetric adequacy.

1,543 km²

Kalyanpur Block area

705 mm

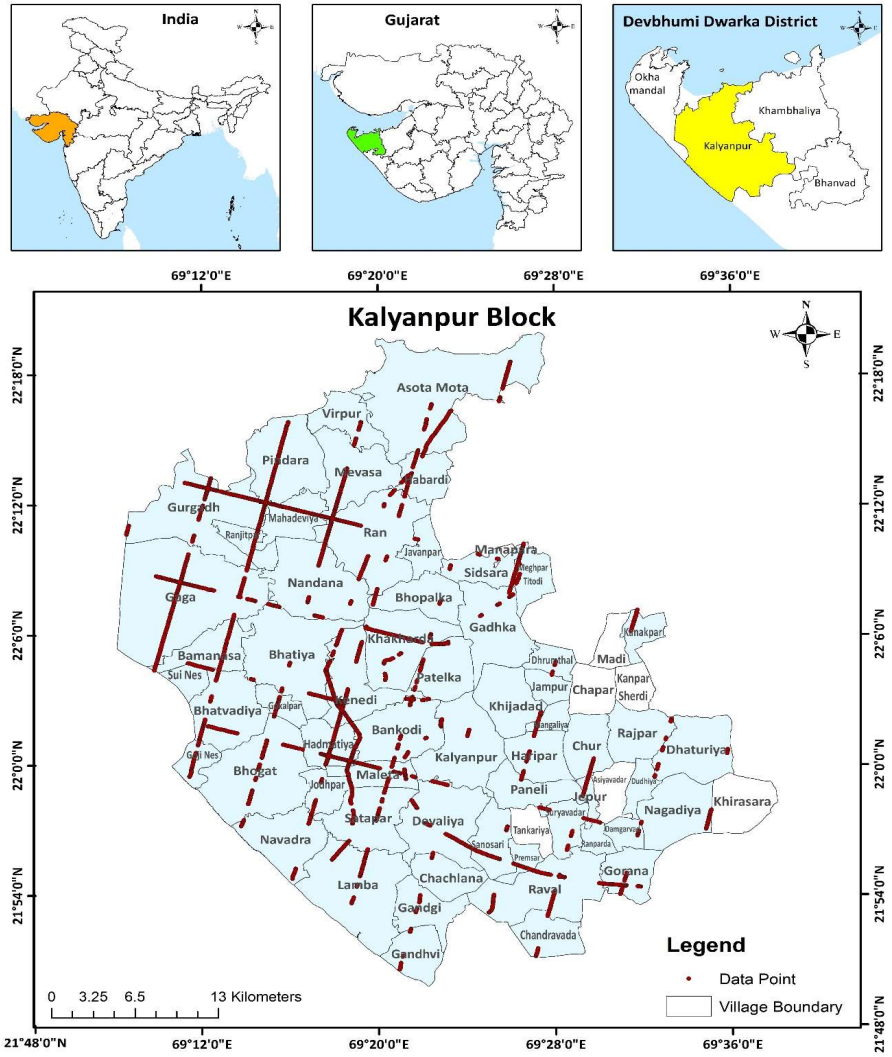
Mean annual rainfall (1991–2020)

Pediplain

Dominant landform, sloping W to Arabian Sea

'Safe'

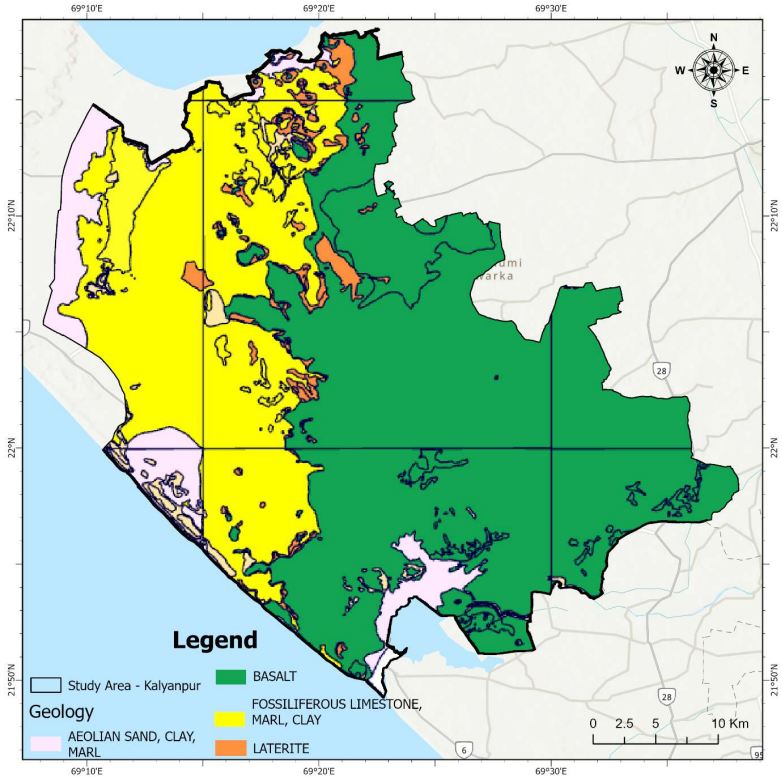
GWRE 2023 & 2024 development category



REGIONAL SETTING

Geological Framework

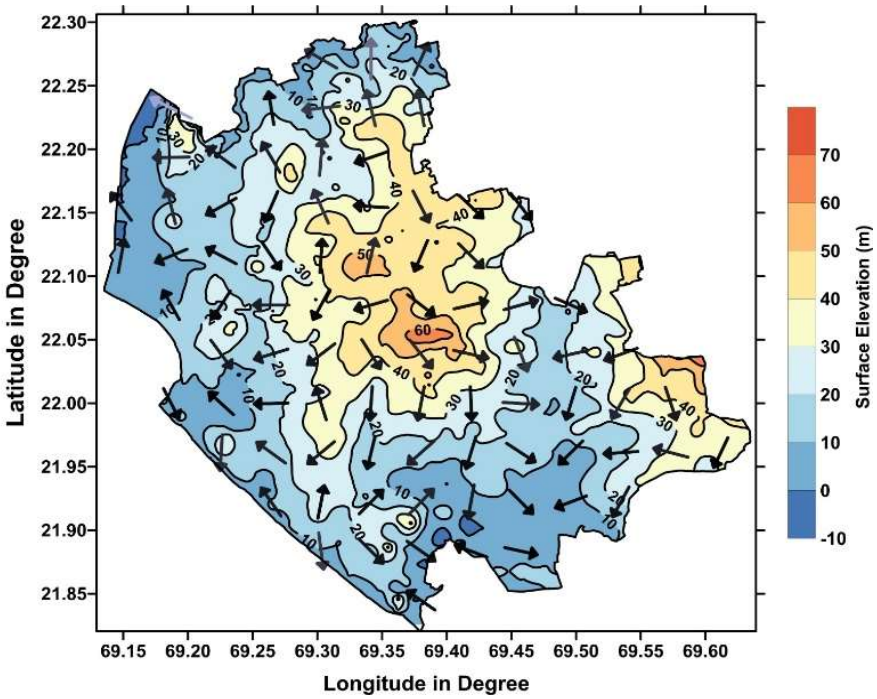
Formation	Age	Hydrogeological Character
Deccan Trap basalt	U. Cretaceous–L. Eocene	Basement; secondary porosity via weathering/fracturing; productive to 45–145 mbgl
Gaj Beds (limestone)	Middle Miocene	Shallow productive aquifer (20–25 mbgl); sea-water invaded 10–60 mbgl in coastal fringe
Dwarka Formation	M. Miocene–L. Pliocene	Predominantly clayey / poor aquifer; Kalyanpur Limestone Member enhances flow locally
Miliolite Series	Pleistocene	Good shallow phreatic reservoir; water levels ~5 mbgl
Alluvium	Recent–Sub-recent	Thin (<20 m) unconfined aquifer along coastal plains



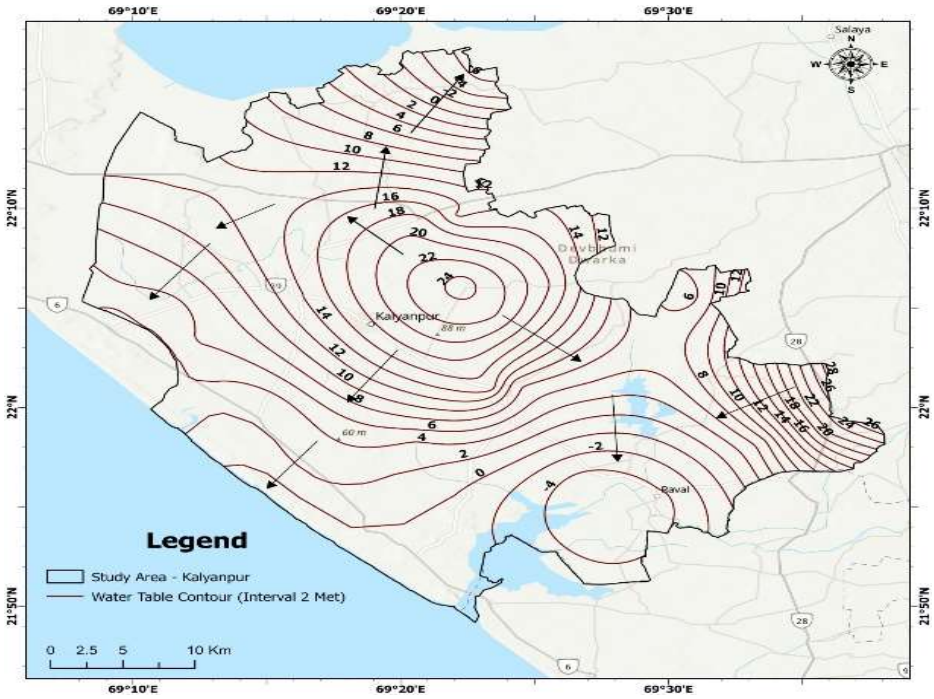
Geology of Kalyanpur Block (modified after Bhukosh, GSI; CGWB 2024)

HYDROGEOLOGICAL SETTING

Topography, Water Levels & Groundwater Flow



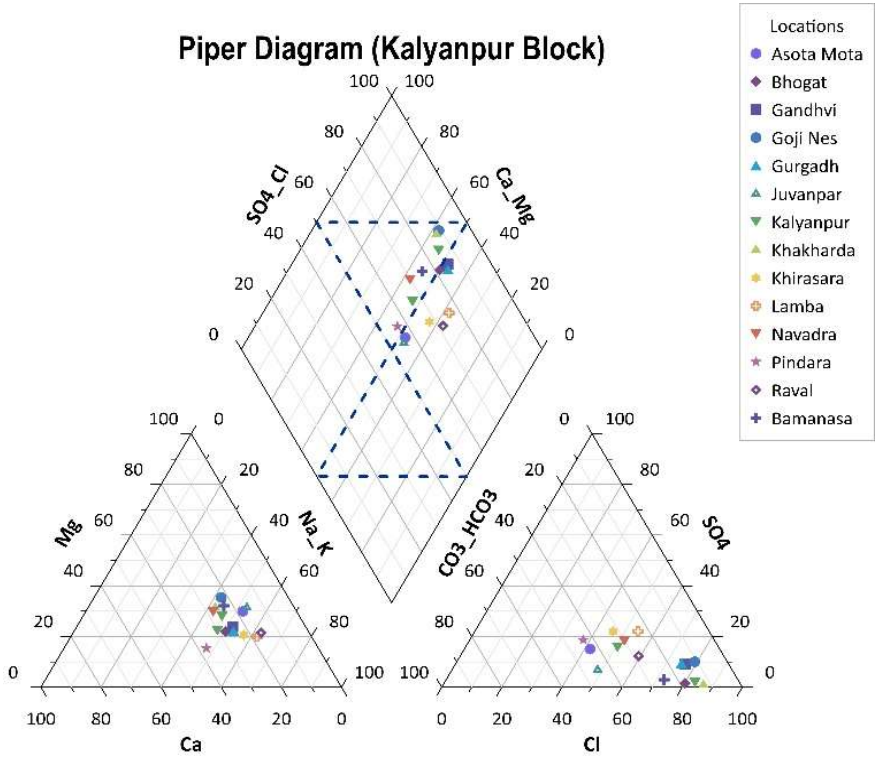
Surface elevation & inferred flow direction

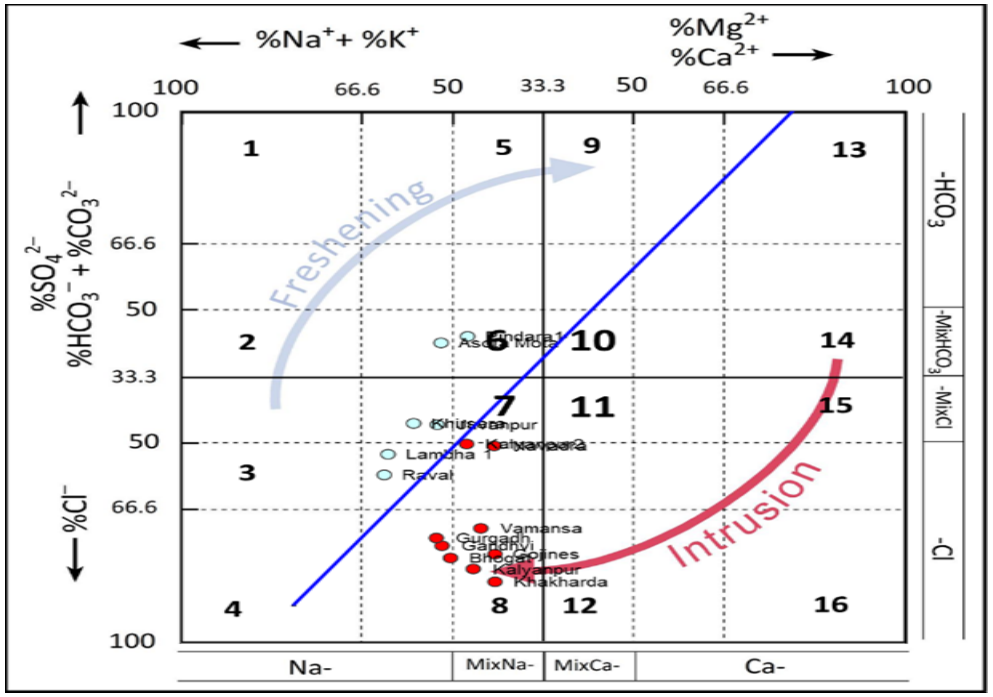


Water-table contours — flow converges toward the coast

Surface elevation ranges –10 to 70 m (msl); water-table elevation –1.4 to 31.5 m (msl), declining from the central/eastern interior toward the SW, W and N coasts. ~24% of 37 monitoring stations show post-monsoon water levels > 20 mbgl. Analysis of levels and flow direction identifies the south-western and northern coastal stretches as the primary zones of potential SGD.

Piper & Hydrochemical Facies Evaluation

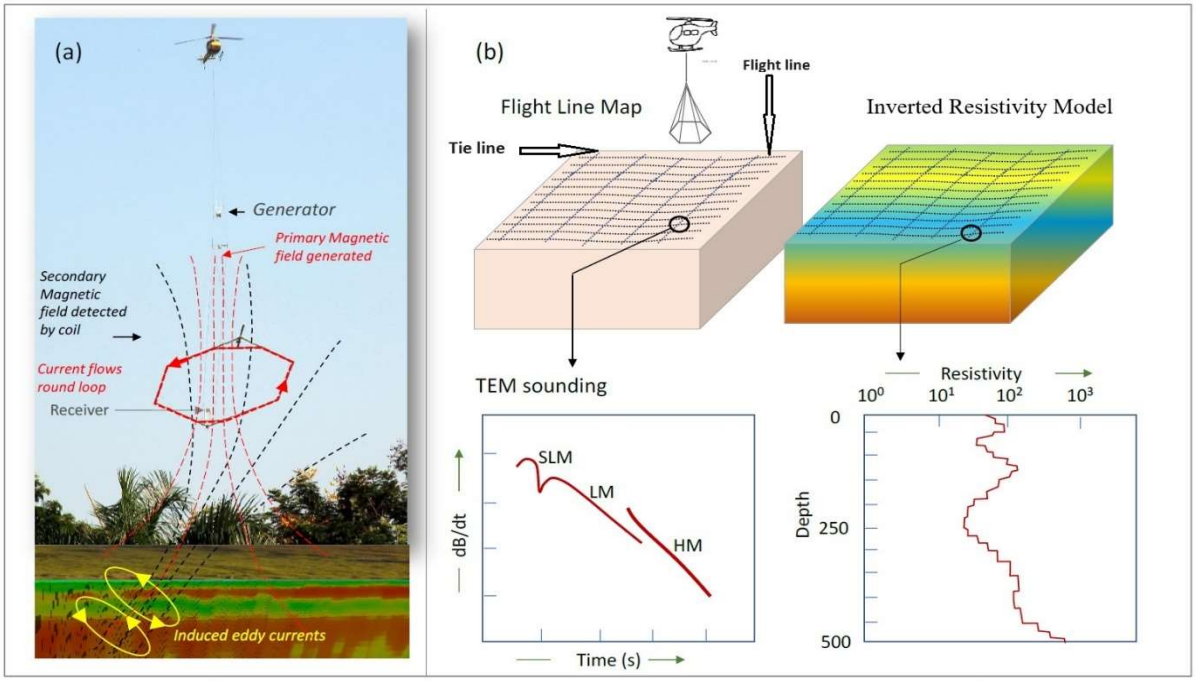




15 shallow (<50 mbgl) pre-monsoon 2025 samples; EC 923–5,902 µS/cm; ~50% Na–Cl facies. HFE-D: 9 of 15 samples (60%) show Na–Cl / MixNa–Cl saline-intrusion signatures; 6 (40%) show freshening (Na–MixHCO₃, MixNa–MixCl, Na–MixCl).

SURVEY METHODOLOGY

Heliborne TEM — Measurement Principle & Processing



Schematic map of (a) Heliborne TEM measurement showing primary and secondary field responses, and (b) Flight line pattern, dB/dt, and resistivity model

A helicopter-towed transmitter loop generates a primary magnetic field; induced eddy currents in subsurface conductors produce a secondary field measured by a receiver coil.

Dual-moment decay is inverted into a depth-wise resistivity model along each flight line.

Platform	SkyTEM-312 dual-moment TDEM
Low-moment	~3,000 Amp·m² — 5–50 mbgl
High-moment	~500,000 Amp·m² — 200–500 mbgl
Flight design	5 km spacing, 20 km tie-lines
Processing	LCI & SCI, Aarhus Workbench
Output	Mean Resistivity Maps, 10 m intervals, 0–200 mbgl

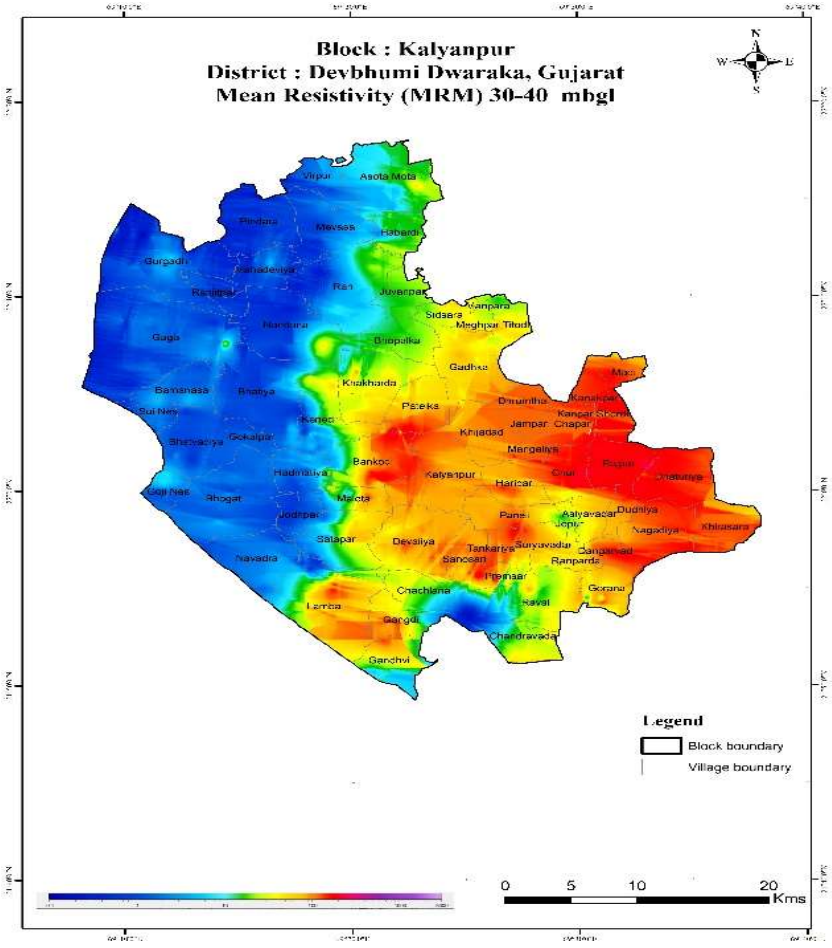


RESULTS

Subsurface Resistivity Classification

Zone	Resistivity	Significance
Freshwater aquifer	10 – 150 Ω·m	Principal potable source; primary horizon sustaining SGD
Brackish mixing zone	5 – 10 Ω·m	Fresh–saline interface, ~15–20 mbgl in weathered limestone
Saline / seawater zone	< 5 Ω·m	Sea-water invaded Gaj Bed limestone (15–60 mbgl)
Compact bedrock	> 150 Ω·m	Massive unweathered basalt; impermeable base

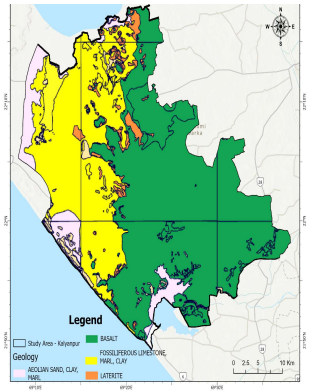
Productive weathered/fractured limestone zones (20–50 Ω·m) align with NNE–SSW basement lineaments — deep structural control on secondary permeability. 100–200 mbgl MRMs indicate productive fractured basalt suitable for borewells & managed aquifer recharge.

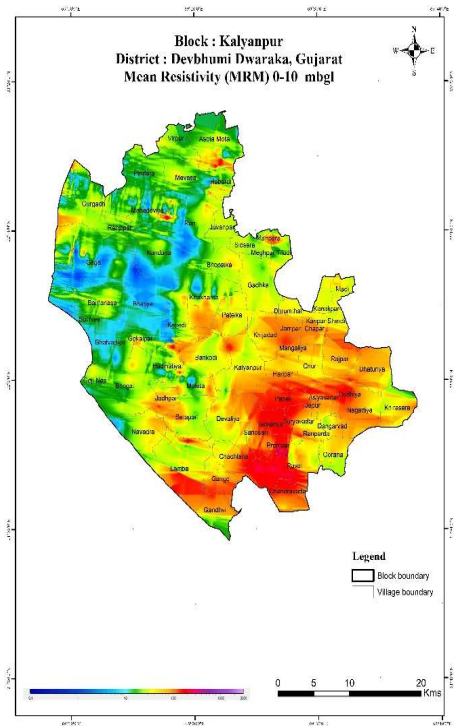


Mean Resistivity Map, 30–40 mbgl

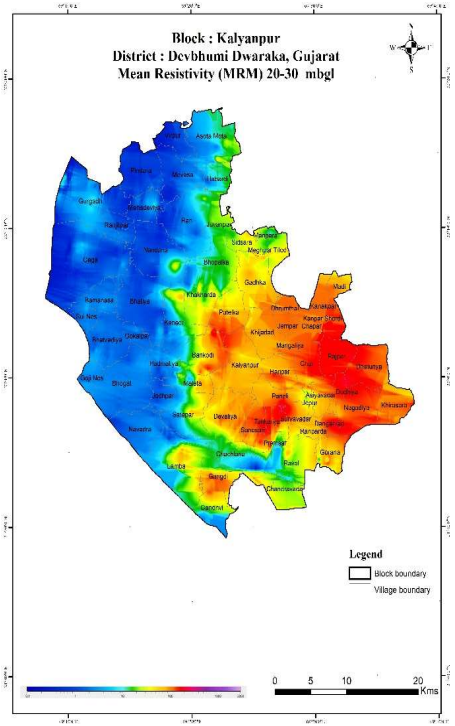
RESULTS

Depth-Resolved Mean Resistivity Maps

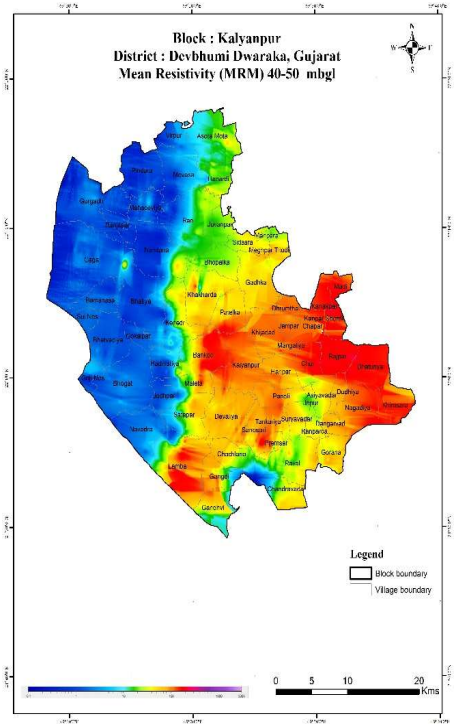




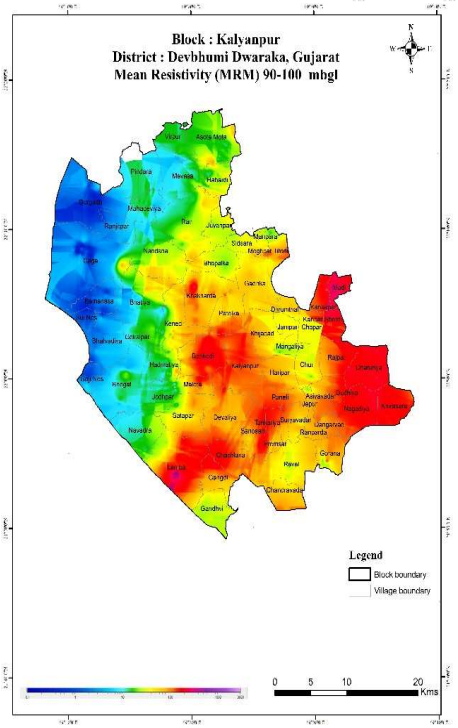
0–10 mbgl: variable near-surface resistivity; saline zones along western coast



20–30 mbgl: saline wedge at maximum lateral extent in Gaj Beds



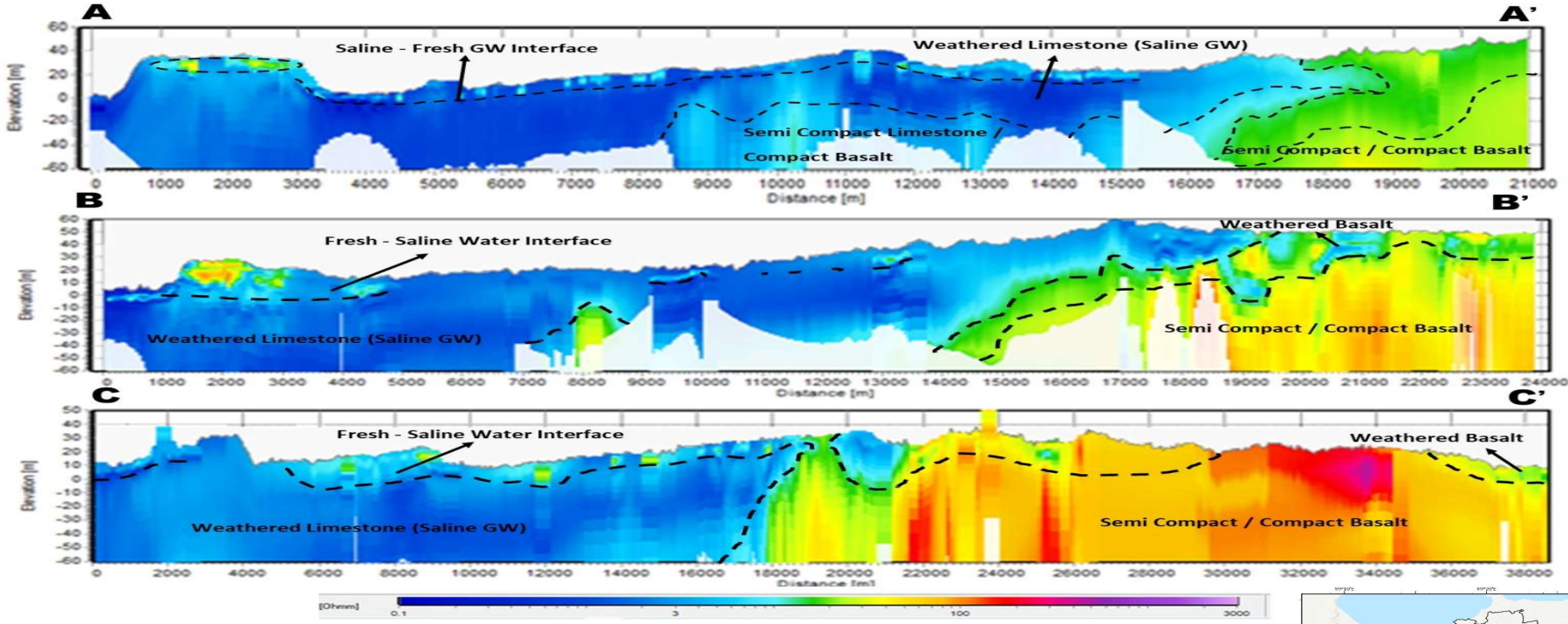
40–50 mbgl: fractured basalt productive zone begins to dominate

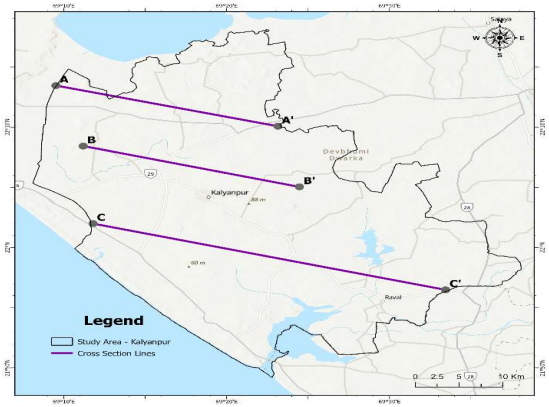


90–100 mbgl: high-resistivity corridors mark preferential SGD pathways

RESULTS

Freshwater–Saline Mixing Interface





Geoelectrical sections A–A′, B–B′, C–C′ (NW–SE) show freshwater lenses (~5 m thick, 10–40 Ω·m) overlying saline water (<5 Ω·m) in weathered limestone (interface at ~15–20 m), and a largely saline-free weathered basaltic aquifer (~20–50 m thick) remaining fresh throughout.

RESULTS

Identification of SGD Pathways

WEATHERED LIMESTONE AQUIFER

Freshwater overlies saline water along both coastlines; fresh–saline interface at ~15–20 m depth. Freshwater lens saturated thickness ~4–5 m constitutes the potential SGD zone.

~14 km

Lateral extent, N coast

~15 km

Lateral extent, SW coast

WEATHERED BASALTIC AQUIFER

Fresh throughout, no evidence of saline intrusion. Thickness ~20–50 m, thinning eastward. The saturated portion forms a significant, sustained pathway for SGD.

~3 km

Lateral extent, N coast

~13 km

Lateral extent, SW coast

SGD QUANTIFICATION

Method — Darcy's Law Approach

$Q = K \times b \times L \times i$

K = hydraulic conductivity · b = saturated thickness · L = aquifer length ⊥ flow · i = hydraulic gradient

K ≈ 5 m/day

Average lateral hydraulic conductivity assumed for both weathered limestone (0.0864–8.64 m/day) and weathered basalt aquifers

i = 0.0019 (N)

Hydraulic gradient, northern coast - 2 m over 1,016 m, normal to flow direction

i = 0.0006 (SW)

Hydraulic gradient, south-western coast - 2 m over 3,121 m, normal to flow direction

b ≈ 5 m / 25 m

Freshwater-saturated thickness - weathered limestone / weathered basalt, from HTEM sections

SGD QUANTIFICATION

Results — Estimated SGD by Coastline

Coastline	Aquifer	Thickness (b)	Length (L)	Gradient (i)	Q (m³/day)
Northern	Weathered limestone	~5 m	~14,000 m	0.0019	665
Northern	Weathered basalt	~25 m	~3,000 m	0.0019	712.5
South-Western	Weathered limestone	~5 m	~15,000 m	0.0006	225
South-Western	Weathered basalt	~25 m	~13,000 m	0.0006	975

Although the south-western coastline is longer within the study area, its estimated SGD is lower — primarily due to the lower hydraulic gradient (0.0006) relative to the steeper northern-coast gradient (0.0019).

1.38×10^3 m³/day

Total SGD — Northern coast

1.20×10^3 m³/day

Total SGD — South-Western coast

Seasonally variable with freshwater-lens thickness, hydraulic gradient, and related factors.

DISCUSSION

Implications for Coastal Groundwater Management

1

Aquifer geometry controls SGD

The weathered basaltic aquifer greater saturated thickness (~25 m) and largely fresh is the main SGD pathway; the limestone aquifer's contribution is capped by its thin (~5 m) freshwater lens.

2

Dynamic, vulnerable freshwater lens

Freshwater lenses overlying saline water at 15–20 m depth are dynamic and actively flowing seaward a limited, easily disturbed resource requiring regulated abstraction.

3

Gradient controls flux more than length

The steeper northern gradient (0.0019) yields higher SGD than the longer but gentler-gradient south-western coast (0.0006) length alone is a poor predictor of flux.

4

MAR site guidance from HTEM

Suitable MAR sites and tentative recharge/injection well depths have been identified within the weathered basaltic aquifer; ponds/check dams are likely more effective over limestone, where the freshwater column is thin.

CONCLUSIONS

Key Conclusions

- SGD along Kalyanpur's coastal tract is governed by aquifer geometry, structural controls and hydraulic gradients not a uniform coastal flux
- Weathered basaltic aquifer is the primary, sustained SGD pathway; weathered limestone contributes via thinner, shallower freshwater lenses
- A dynamic freshwater–saline interface persists at ~15–20 m depth, with seaward-flowing freshwater lenses on both coastal tracts
- Total estimated SGD: ~1.38 × 10^3 m^3/day (north) and ~1.20 × 10^3 m^3/day (south-west) gradient-controlled, not length-controlled
- The integrated HTEM + hydrogeology + hydrochemistry approach is a significant advancement over single-method SGD estimation
- Systematic HTEM coverage of India's other coastal aquifers is recommended to strengthen national coastal groundwater management

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Thank You

Questions & Discussion Welcome

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