

Buried Rivers, Thirsty Island Belt: A Review of Water Challenges in the Great Rann of Kachchh

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Abstract

The Great Rann of Kachchh (GRK) in Gujarat, India, is a hyper-saline environment where isolated island communities face acute water scarcity. This literature review synthesizes Scopus and Web of Science indexed research to evaluate an integrated geo-hydrological approach for sustainable water development. The analysis integrates geology, lithology, geomorphology, hydrogeology, and socio-economic dimensions including population distribution, livelihoods, and agriculture. Subsurface core analysis reveals marine transgression since ~18 ka BP, with fine-grained sediments rendering shallow aquifers saline. However, remote sensing and High-Resolution Electrical Resistivity Tomography (HERT) have successfully delineated buried palaeochannels containing confined artesian aquifers below 100 m depth, offering promising brackish water sources. The region hosts ~17,000 inhabitants across 48 hamlets, including pastoralist Jatts and Maldharis, and artisan Meghwals, whose livelihoods depend on animal husbandry, handicrafts, and tourism – all vulnerable to water insecurity. By integrating geo-hydrological and socio-economic understanding, this review proposes a multi-phase development framework encompassing geospatial prospecting, geophysical surveys, exploratory drilling, and community-based management. Critical knowledge gaps include groundwater age, recharge dynamics, and sustainable yield estimation. An integrated approach combining earth sciences and human geography is essential for ensuring long-term water security for the Great Rann's island communities.

Keywords: Artesian groundwater, community livelihoods, Great Rann of Kachchh, integrated geo-hydrology, paleochannel aquifers, sustainable water development

INTRODUCTION

The Great Rann of Kachchh (GRK) is a vast, seasonal saline mudflat covering over 18,000 km², making it one of the largest salt deserts in the world. This inhospitable terrain is punctuated by elevated pieces of land, locally known as *bets* or *medaks*, which constitute the only permanently inhabitable areas. These isolated settlements, including Khadir Island, Bela Island, and numerous smaller bets, are home to communities with distinct cultural identities and livelihood strategies.

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The development of a sustainable water resource plan for these islands represents an immense scientific and logistical challenge. The region's surface and shallow groundwater are rendered unusable by a combination of seawater ingressions during high tides and the evapo-concentration of salts in a hyper-arid climate. This predicament calls for an integrated geo-hydrological approach – one that combines understanding of the region's complex geological evolution, detailed lithological characterization, demographic patterns, livelihood dependencies, and advanced exploration techniques.

This review paper aims to synthesize the current scientific and socio-economic understanding of the

GRK and its isolated islands, drawing primarily from peer-reviewed research available in Scopus and Web of Science. The objectives are to:

- Characterize the geological evolution, lithology, and geomorphology of the GRK and its isolated islands.
- Document the population distribution, village settlements, livelihood patterns, and agricultural/cropping systems.
- Critically evaluate the application of remote sensing and geophysical methods in identifying fresh/brackish water aquifers.
- Synthesize findings on the origin, potential, and quality of deep palaeochannel aquifers.
- Propose an integrated framework for sustainable water resource development addressing both hydrogeological and socio-economic dimensions.

GEOLOGICAL AND LITHOLOGICAL FRAMEWORK OF THE GREAT RANN OF KACHCHH Tectonic and Evolutionary Setting

The GRK is not a static landscape, but a dynamic geological feature shaped by tectonic activity and sedimentation. Bounded by the Nagar Parker Fault (NPF) to the north and the Kachchh Mainland Fault (KMF) to the south, the region has experienced significant tectonic instability throughout the Quaternary. Originally an extension of the Arabian Sea, it was gradually closed off by silting, and its current form reflects upliftment during faulting events, including the 1819 Allah Bund earthquake which created a NE-SW trending scarp and significantly modified geomorphic processes.

Isotopic studies using Nd and Sr tracers have revealed that the Indus River has been the dominant sediment source for the GRK, particularly after ~6 ka when the Indus delta began to prograde. Before 10 ka, a distinct source – possibly a local river hypothesized to be the mythical Saraswati – may have contributed sediment, though its signature was later overwhelmed by Indus and Thar Desert sources. The mica-rich mineralogy (illite and chlorite) of GRK sediments confirms their Himalayan and Karakoram origin.

Lithological Characteristics from Core Analysis

Detailed lithological investigations of sediment cores from the GRK provide fundamental understanding of subsurface architecture [1]. Analysed two drill cores: one from north of Dhordo (~60 m depth) in the central GRK basin, and another from northeast of Berada (~51 m depth) in the southern Banni plain. Based on textural characteristics, the Dhordo core was subdivided into 16 litho-units, while the Berada core yielded 13 litho-units.

Radiocarbon dating (AMS) provided critical chronological control: an age of $17,700 \pm 86$ cal years BP was obtained from the Dhordo core at 60.13 m depth, and $9,515 \pm 61$ cal years BP from the basal marine sequence in the Berada core at 38.88 m depth. These dates indicate that the central GRK basin was submerged by a shallow sea by ~18 ka BP, whereas marginal areas including the Banni plain were completely submerged by ~10 ka BP. Throughout the cores, sediments are consistently fine-grained (silty-clay to clayey silts with negligible sand content), typical of mudflat environments.

The presence of foraminifera throughout the core sections confirms marine sedimentation throughout the late Quaternary. This finding has profound implications for groundwater occurrence, as the marine origin of sediments contributes to the inherent salinity of the aquifer system.

Mid-Holocene Sedimentation and Landscape Evolution

Studies of shallow sedimentary sequences in the western GRK reveal that between 5.5 and 2 ka, tidal flat sedimentation dominated under conditions of higher sea level than present. Geochemical proxies including major elemental ratios ($\text{TiO}_2/\text{Al}_2\text{O}_3$ and $\text{K}_2\text{O}/\text{Al}_2\text{O}_3$) and trace elements (Zr, Cr) indicate enhanced tidal energy during 5.5–5 ka and around 3 ka. Fluvial sediment contribution was limited and confined to the northern fringe, contrary to earlier suggestions of a major river draining through the western GRK during this period.

Clay mineral assemblages dominated by illite, kaolinite, chlorite and montmorillonite further support Indus River influence. The present landscape was largely sculptured after the 1819 Allah Bund

earthquake, which created the Allah Bund scarp and modified drainage patterns. Uplift of approximately 5 m has been recorded for marine sedimentary sequences on Khadir Island in the last 500 years, demonstrating ongoing tectonic activity.

GEOMORPHOLOGY OF THE ISOLATED ISLANDS (BETS)

Origin and Characteristics of Bets

The elevated surfaces within the GRK, locally known as *bets* or *medaks*, represent fluvial sand-rich deposits that stand above the surrounding saline mudflats. These include prominent islands, such as Khadir, Bela, Chorar, and numerous smaller bets, that serve as the only permanently inhabitable areas. The bets are characterized by their relative elevation (typically a few meters above the Rann surface), which protects them from monsoon inundation.

Sedimentological analysis of bet sequences indicates they represent relict fluvial deposits from streams that once drained into the Rann. At Karim Shahi, a 200 cm-thick micaceous sedimentary sequence shows four distinct fining-upward units overlying clayey-silt dominated Rann sediment, consistent with fluvial depositional environments.

Khadir Island and Archaeological Significance

Khadir Island, one of the largest bets, holds particular significance due to the presence of Dholavira, a major Bronze Age Harappan civilization site. The history of Harappan coastal towns was controlled by access to the Arabian Sea, which in turn depended on local sea level and fluvial infilling of the GRK. The persistence of habitation on these islands for over 5,000 years attests to their historical suitability for human settlement, though water availability has always been a critical constraint.

HUMAN GEOGRAPHY: POPULATION, VILLAGES, AND LIVELIHOODS

Settlement Patterns and Demographics

The Banni grasslands, located on the southern fringe of the GRK, comprise approximately 48 hamlets organized into 19 panchayats, with a total population of approximately 17,000. The population consists of approximately 90% Muslim pastoralist communities and 10% Hindu Meghwals and Vadha Kolis. The Muslim Maldharis (livestock keepers) are organized into about 20 clans, prominent among which include Raysipotra, Halepotra, Hingorja, Node, Sumra, Sameja, Mutwa, Jat, and Bhamba. They speak Kachchhi in Sindhi dialect, reflecting historical connections with the Sindh region of Pakistan.

The Jatt pastoralists constitute possibly the largest group among these communities. Ethnographic research reveals that these populations maintain strong cultural attachment to their *azad mulk* (free or independent territory) in the Rann, despite increasing ecological and economic pressures.

Livelihood Strategies

Animal Husbandry

Animal husbandry constitutes the primary occupation in Banni and the bet areas. The region is renowned for its indigenous livestock breeds including the Banni buffalo, Kankrej cattle, Sindhi horse, Kachchhi goat, and Kachchhi camel. Pastoralism is deeply embedded in the local economy and culture, with communities practicing seasonal migration in response to water and fodder availability.

During severe droughts, pastoral populations migrate closer to towns or large villages, pitching camp adjacent to agricultural farms and temporarily converting “from nomads to dairymen” as they supply milk to urban markets. This adaptive strategy allows continued livelihood generation while awaiting rainfall that would permit return to their traditional abodes.

Handicrafts and Traditional Occupations

Hindu Meghwal and Vadha Koli communities possess rich traditions of embroidery, leatherwork, wood-carving, and the construction of *bhungas* (traditional circular mud houses). These handicraft skills have gained recognition beyond the region and contribute significantly to household incomes. The vibrant embroidered clothing and heavy jewelry of pastoral women have captured the imagination of visitors and feature prominently in tourism promotion

Tourism and Changing Livelihoods

The Rann of Kutch has made a significant mark on India's tourist map, with tourism concentrated in the four-month period from November to February when climatic conditions are favorable. However, this seasonal dependence creates vulnerability, as demonstrated during the COVID-19 pandemic when tourist footfall collapsed, jeopardizing the principal economic activity of tourism-dependent villages.

A socio-economic vulnerability assessment using RIDIT scoring and ranking methods examined two tourism-dependent villages in the Rann of Kutch region, identifying essential vulnerability parameters and empirically comparing conditions within and between villages. This research highlights the need for diversified livelihood options and improved infrastructure, including reliable water supply, to reduce community vulnerability.

Agriculture and Crop Patterns

Historical accounts indicate that 40–50 years ago, the area was covered with dense forest of *piloodi* (*Salvadora persica*), and villagers earned livelihood from sale of *Piloodi* seeds, which yield *kardi* oil used as a substitute for coconut oil in cosmetic manufacturing. *Piloodi* thrives in saline soil and provided sustainable income. However, camel herds from the Rann invaded and destroyed most of the *Piloodi* forest, leaving only countable shrubs adjacent to the seashore. This destruction not only deprived villagers of livelihood but also aggravated soil erosion and increased land and water salinity, consequently reducing agricultural production.

Today, organized efforts by organizations like PAG (Preservation and Proliferation of Art and Culture Group) encourage villagers to grow *Piloodi* plants on farms, establishing nurseries for sapling distribution and monitoring proper planting and care. This represents a nature-based solution for sustainable income generation in saline environments.

Infrastructure and Service Gaps

Rural infrastructure in the bet areas remains underdeveloped. Historical accounts note the absence of primary health centers, with private doctors visiting once fortnightly. Residents must walk up to 15 km on *kuchha* roads (unpaved, becoming impassable during rainy season) for daily requirements and marketing. Contemporary assessments confirm persistent gaps in water availability, healthcare access, fodder availability, roads, schools, and cell phone coverage.

HYDROGEOLOGICAL FRAMEWORK AND GROUNDWATER RESOURCES

Regional Hydrogeology

The GRK's hydrogeological setting is characterized by extreme salinity. The soil is saturated with saline water that has percolated down for several meters, resulting from seawater ingress during high tide from the Arabian Sea and subsequent evaporative concentration. Groundwater exploration in this environment is exceptionally challenging due to the hostile conditions and the inherent salinity of shallow aquifers.

Palaeochannel Aquifers: A Promising Alternate Source

Remote Sensing-Based Delineation

Multisensor satellite data have been successfully employed to delineate palaeochannels in the GRK – buried courses of ancient rivers that represent zones of elevated fluvial sediments with distinct geomorphic signatures contrasting with surrounding saline flats. This technique, well-established in arid regions globally, has been applied in the Thar Desert, Libyan Sahara, and United Arab Emirates for mapping extinct river systems.

The evolutionary history of these palaeochannels indicates upliftment of the GRK area during Allah Bund faulting, which influenced their current configuration and depth.

Geophysical Investigation: High-Resolution Electrical Resistivity Tomography (HERT)

Following remote sensing identification, High-Resolution Electrical Resistivity Tomography (HERT) surveys have proven effective for assessing groundwater potential of palaeochannels. Using the pole-dipole method along 710 m traverses to depths of 250 m in Dharmsala and Gainda areas,

electrical resistivity tomograms revealed higher-resistivity zones (interpreted as medium to coarse sand with brackish water) beneath a thick, continuous low-resistivity layer (clay with saline water).

This geophysical signature is classic for confined aquifer systems buried under impermeable, saline-saturated caps. Exploratory drillings in the area confirmed palaeochannel presence, acting as confined aquifers below 100 m depth.

Artesian Conditions and Regional Implications

Two drilled wells at Gainda and Khardoi along the northern boundary of GRK exhibited artesian conditions, with water levels rising above the aquifer top. This artesian flow is attributed to hydraulic gradient along confined layers from the Tharparkar region in Pakistan, suggesting regional-scale aquifer connectivity. While the water is reported as “brackish” – significantly less saline than surrounding shallow groundwater – it represents a potentially treatable and sustainable source for isolated communities.

HERT has been validated as a faster and more cost-effective geophysical survey technique for deep aquifer studies in this challenging environment compared to traditional exploratory drilling alone.

Groundwater Salinity and Quality Concerns

Understanding groundwater salinity distribution is crucial for drinking water security and agricultural suitability. A comprehensive study of groundwater salinity across India using field observations and machine learning modeling highlights the complex interplay of factors including palaeo-saline water, mineral dissolution, and evaporation that control groundwater chemistry. In the GRK context, determining whether deep aquifers contain fossil water recharged during past pluvial periods or receive modern limited recharge is vital for assessing long-term sustainability.

Comparative Studies and Methodological Transferability

The integrated methodology applied in GRK has parallels in other arid regions globally. Studies in the northern UAE have used 2D earth resistivity imaging to characterize geological and hydrogeological settings. Ground penetrating radar has successfully mapped paleochannels in the Libyan Sahara. In South Guangdong, China, ERT methods have evaluated weathered rock aquifers. Along India’s west coast, electrical resistivity data has resolved saline and freshwater aquifers. These comparative studies reinforce the validity and transferability of the integrated approach (Table 1).

Table 1. Synthesis of key studies on GRK geo-hydrology and human geography.

Author(s)	Focus area	Methodology	Key findings	Implications
[1]	Lithology & subsurface sediments	Core drilling, textural analysis, AMS dating	16 litho-units in Dhordo core; marine submergence since ~18 ka BP	Establishes marine origin of sediments explaining inherent salinity
[2]	Sediment provenance	Nd-Sr isotopes	Indus dominant source post-6 ka; possible local source pre-10 ka	Provides geological context for palaeochannel formation
[3]	Groundwater exploration	Remote sensing, HERT, exploratory drilling	Deep confined aquifers (>100 m) with artesian conditions	Validates cost-effective methodology; confirms alternate water source
[4]	Pastoralist communities	Ethnographic research	Jatt pastoralists maintain cultural attachment to Rann; seasonal migration strategies	Documents livelihood patterns and water dependency
[5]	Socio-economic vulnerability	RIDIT scoring, empirical survey	Tourism dependence creates seasonal vulnerability; infrastructure gaps persist	Highlights need for diversified livelihoods and water security
[6]	Community demographics	Field survey	48 hamlets, 17,000 population; 90% Muslim pastoralists; diverse livelihoods	Provides baseline demographic and occupational data
[7]	Traditional livelihoods	Case study	Historical Piloodi forest destruction; livelihood impacts; restoration efforts	Documents nature-based solutions for saline environments
[8]	Mid-Holocene sedimentation	Field stratigraphy, geochemistry, OSL dating	Tidal flat dominance 5.5–2 ka; Indus sediment source; tectonic influence	Establishes landscape evolution framework

TOWARDS AN INTEGRATED WATER RESOURCE DEVELOPMENT PLAN

Based on synthesis of reviewed literature, a robust framework for sustainable water resource development emerges, integrating hydrogeological assessment with socio-economic realities.

Phase 1: Regional Hydrogeological Assessment

Comprehensive mapping using high-resolution multi-sensor satellite data should delineate palaeochannel networks across the entire GRK, building on work [9–20]. Integration with geological and tectonic maps will identify promising groundwater occurrence corridors near inhabited bays.

Phase 2: Targeted Geophysical Surveys

Priority target zones should undergo HERT investigation to confirm depth, thickness, and lateral extent of palaeochannel aquifers; delineate confining layer geometry; and infer water quality variations through resistivity modeling.

Phase 3: Exploratory Drilling and Aquifer Characterization

Limited exploratory wells should validate geophysical interpretations against actual lithology; conduct pumping tests to determine transmissivity, storativity, and sustainable yield; and enable detailed hydro-geochemical and isotopic analysis to determine water age, recharge mechanisms, and treatment requirements [21–28].

Phase 4: Sustainable Development and Community-Based Management

Decentralized small-scale desalination or treatment plants powered by solar energy can treat brackish water from deep wells. A monitoring network of observation wells must track water levels and quality over time. Critically, community participation – involving pastoralists, artisans, and farmers engaged in piroodi cultivation – is essential for long-term success [29].

Phase 5: Livelihood Integration and Vulnerability Reduction

Water security must be linked to broader livelihood enhancement, supporting traditional occupations like animal husbandry and handicrafts while enabling sustainable tourism development that reduces seasonal vulnerability [30].

KNOWLEDGE GAPS AND FUTURE RESEARCH DIRECTIONS

Critical areas requiring further investigation include.

- *Regional Aquifer Extent and Recharge Dynamics:* Connectivity to recharge areas outside GRK (e.g., Tharparkar, Pakistan) requires isotopic tracer studies and regional-scale groundwater modelling [31].
- *Groundwater Age and Renewability:* Determining whether deep aquifers represent non-renewable fossil water or receive active recharge is essential for sustainability assessment. Radiocarbon dating (^{14}C) and other isotope techniques (^{36}Cl) are required.
- *Sustainable Yield Estimation:* Sophisticated modeling must estimate total usable volume and maximum sustainable extraction rates without causing depressurization or quality deterioration.
- *Climate Change and Tectonic Influences:* How ongoing tectonic activity, sea-level rise, and climate variability may impact confining layer integrity and deep aquifer salinity requires long-term assessment [32–34].
- *Detailed Community-Level Water Demand Assessment:* Current and projected water needs across different settlements, accounting for seasonal population variations and livelihood water requirements, remain poorly quantified.
- *Socio-Economic Impact Assessment:* Systematic evaluation of how improved water access could transform livelihood opportunities, reduce vulnerability, and support sustainable development.

CONCLUSION

The isolated island communities of the Great Rann of Kachchh face a severe water crisis rooted in extreme environmental salinity and historical marine sedimentation that renders shallow aquifers unusable. This literature review demonstrates that an integrated geo-hydrological approach, combining rigorous geological understanding, advanced geophysical exploration, and socio-economic contextualization, offers a viable pathway toward sustainable solutions.

Research confirms that deep palaeochannels buried beneath the salt desert host confined aquifers with artesian potential, representing a promising alternate water source. The successful integration of remote sensing for regional mapping and high-resolution electrical resistivity tomography for detailed subsurface imaging has been pivotal in this discovery. However, sustainable development requires addressing not only hydrogeological challenges but also the livelihood patterns, cultural attachments, and socio-economic vulnerabilities of resident communities.

By synthesizing these findings, this review proposes a multi-phase development plan that moves from exploration through sustainable management to livelihood integration. Addressing identified knowledge gaps through targeted, interdisciplinary research is essential for ensuring long-term water security and resilience for communities living in this unique and challenging landscape.

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