

INNOVATIVE AND CLIMATE-RESILIENT
CONSTRUCTION MATERIALS FOR THE
REPUBLIC OF KARAKALPAKSTAN:
EVIDENCE FROM CEMENT-SECTOR
STATISTICS AND DURABILITY
REQUIREMENTS IN SALINE, HOT
CONDITIONS

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Abstract: *Karakalpakstan's construction sector operates under a distinctive combination of stresses: hot and dry summers, saline soils and groundwater conditions, and repeated exposure to dust–salt aerosols from the Aral Sea basin. These factors accelerate deterioration of conventional cement-based materials through moisture–salt cycling, sulfate attack, and cracking driven by thermal gradients. At the same time, Uzbekistan's cement output has expanded rapidly, implying both rising material demand and an opportunity to steer product development toward more durable and lower-carbon binders. This study combines national cement-sector statistics, official data on construction activity, and peer-reviewed durability and decarbonization literature to propose implementable innovation directions for Karakalpakstan. The results show strong national growth in cement production between 2023–2025 (January–July), while Karakalpakstan accounts for a measurable share of national construction works. Based on the evidence, the paper prioritizes blended cements and low-permeability concrete designs tailored to saline environments, including limestone–calcined clay cement (LC3), supplementary cementitious materials (SCMs), and enhanced quality assurance/quality control (QA/QC) systems. A practical*

municipal procurement and testing package is proposed to reduce lifecycle costs and increase service life in infrastructure and buildings.

Keywords: *construction materials; Karakalpakstan; salinity; sulfate attack; LC3; SCM; cement statistics; lifecycle durability*

Introduction

The Republic of Karakalpakstan is one of the territories most affected by the long-term environmental changes associated with the Aral Sea crisis. Wind storms transport large quantities of dust and salt from the dried seabed, creating chronic deposition and exposure conditions for infrastructure and the built environment. [5] In parallel, large areas of irrigated land in the broader basin are affected by secondary salinization, meaning that buildings, utilities and roads often interact with sulfate- and chloride-bearing soils and groundwater. [6]

For municipal and regional planners, these environmental realities translate into a practical question: which construction materials and specification systems deliver reliable service life with acceptable cost under saline and hot conditions? Conventional Portland cement concretes can perform well when properly designed and cured, but exposure conditions in arid saline regions require tighter control over permeability, cement chemistry, curing regimes, and protective detailing. Evidence from Uzbekistan-focused studies emphasizes that durability risks rise in harsh continental climates with salinity and temperature extremes, especially where construction quality is inconsistent. [9]

At the national level, the construction materials sector is expanding. Uzbekistan's investment portal reports a large cement industry footprint and notes that cement output reached 16 million tons

in 2024, with a reported total production capacity of 39.7 million tons per year. [3] Official statistics also show rapid year-to-year growth in cement production volumes for recent periods. [1,2] Such growth creates a window for innovation: new blended cements and durability-oriented mix designs can be scaled through standards, procurement, and quality systems.

The objective of this paper is to synthesize evidence and propose priority directions for innovative, climate-resilient construction materials in Karakalpakstan. The contribution is policy-ready: it links measurable national and regional construction indicators to a practical material selection and implementation framework for municipal planning.

Materials and Methods

The study follows a desk-based evidence synthesis design. National cement production indicators were compiled from publications of the National Statistics Committee of the Republic of Uzbekistan, including reported cement production in January–August 2024 and the year-by-year dynamics for January–July 2023–2025. [1,2] Sector-level industrial indicators (number of plants, capacity and 2024 output) were taken from Uzbekistan’s official investment portal. [3] To link materials demand to regional planning, official construction-works statistics for January–April 2025 were taken from the Statistics Committee’s press release, which provides a regional breakdown including Karakalpakstan. [4]

Environmental and durability requirements relevant to the Aral Sea region were grounded in authoritative and peer-reviewed sources: a World Bank assessment describing dust–salt storm transport and

impacts in the Aral Sea basin, [5] FAO guidance on saline soil conditions and management, [6] and technical literature on concrete durability under saline environments and soluble salt exposure. [9,10] Finally, innovation options were evaluated using the cement decarbonization and technology context from a Uzbekistan-specific study on cement plant decarbonization pathways. [8] For low-clinker binder options, the study references the peer-reviewed LC3 cement literature. [7]

Analytically, the paper uses descriptive statistics to report trends and regional shares, and a qualitative multi-criteria screening to identify priority material pathways for Karakalpakstan. The multi-criteria screening focuses on durability relevance in saline and hot conditions, potential for embodied-carbon reduction, and implementability (compatibility with existing plants and QA/QC capacity).

Results

Table 1. Uzbekistan cement sector snapshot (selected indicators for 2024). Source: [3].

Indicator	Value
Cement plants (count)	40.00
Total cement production capacity (million tons/year)	39.70
Cement output (million tons, 2024)	16.00
UzEx cement sales (million tons, 2024)	6.00
Employment (people, approx.)	13000.00

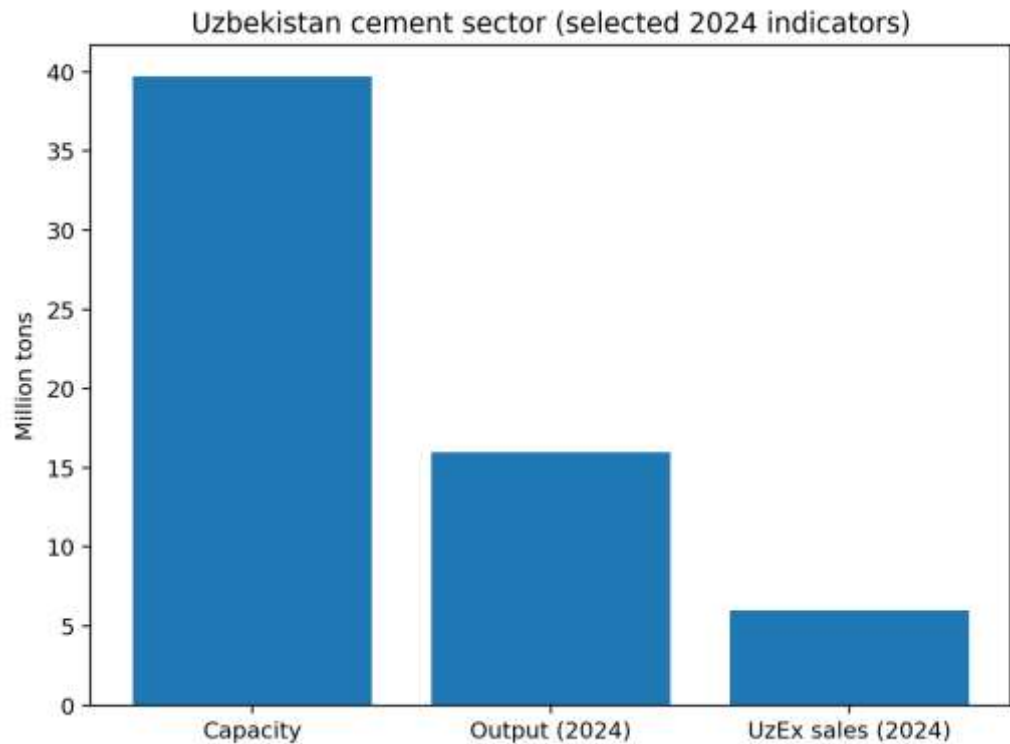


Figure 1. Selected cement-sector indicators in Uzbekistan for 2024 (capacity, output, and exchange sales). Source: [3].

Table 2. Cement production by large enterprises in Uzbekistan (January–July). Source: [2].

Year	Cement production (Jan–Jul, thousand tons)	Cement production (Jan–Jul, million tons)
2023	6817.600	6.818
2024	9078.900	9.079
2025	11344.400	11.344

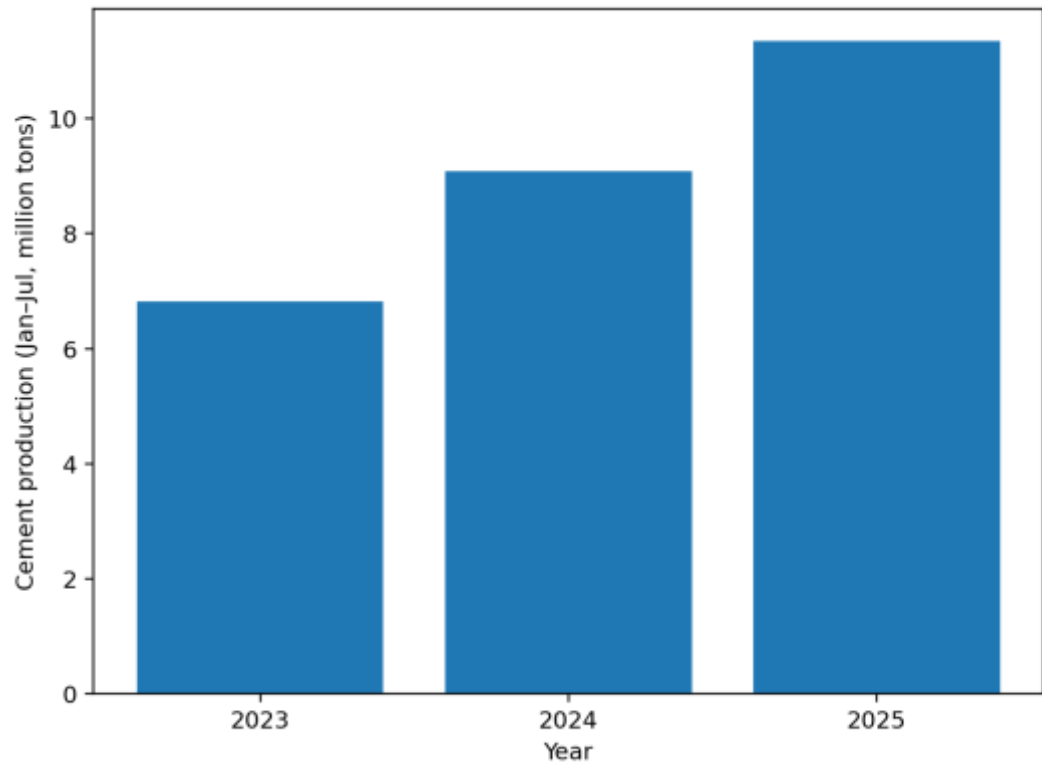


Figure 2. Cement production in Uzbekistan (January–July) for 2023–2025. Source: [2].

Official statistics report that cement production in January–July increased from 6.82 million tons in 2023 to 9.08 million tons in 2024 (a rise of approximately 33.2%), and further to 11.34 million tons in 2025 (a rise of approximately 25.0% over 2024). [2] In a related statistical release, the Statistics Committee reports 10.53 million tons of cement produced by large enterprises in January–August 2024, with 1.45 million tons produced in August alone. [1]

Combining the sector snapshot with output levels implies that, even with high production growth, national utilization of reported cement capacity remains moderate (output of 16 million tons versus capacity of 39.7 million tons corresponds to about 40.3% utilization, using the 2024

output figure). [3] This provides room for product differentiation and technology upgrades without immediate capacity constraints.

Table 3. Construction works completed in Uzbekistan and Karakalpakstan (January–April 2025). Source: [4].

Territory	Construction works (Jan–Apr 2025, billion soums)	Growth vs Jan–Apr 2024 (%)	Share of national total (%)
Republic of Uzbekistan	74026.00	110.30	100.00
Republic of Karakalpakstan	2761.60	106.10	3.73

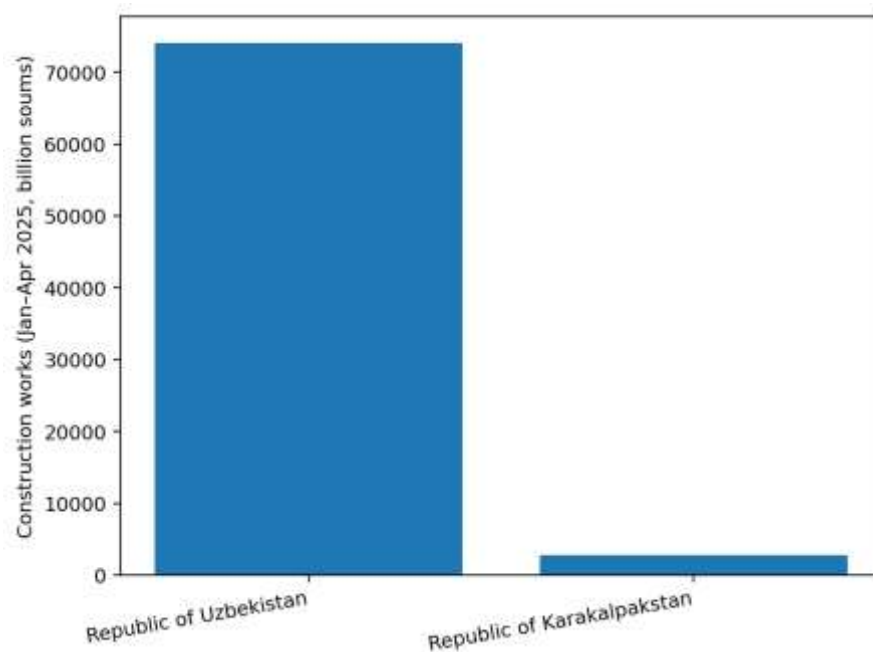


Figure 3. Construction works completed in January–April 2025: national total vs Karakalpakstan. Source: [4].

In January–April 2025, the volume of completed construction works in Uzbekistan reached 74,026.0 billion soums, while Karakalpakstan accounted for 2,761.6 billion soums, with positive growth compared to the

same period of 2024. [4] Although Karakalpakstan’s share of national construction works is below 5% for this period, the absolute scale is substantial and supports the case for region-specific material specifications and supply strategies.

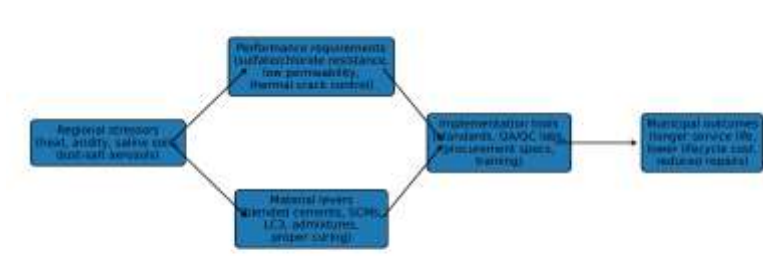


Figure 4. Material selection and implementation framework for Karakalpakstan (conceptual figure developed in this study).

Table 4. Qualitative screening of priority material pathways for Karakalpakstan (expert synthesis based on [6–10]).

Material pathway	Durability fit in saline/hot conditions	Embodied-carbon direction	Implementation notes
OPC-based concrete (baseline)	Medium (requires strict QC and detailing)	High CO ₂ baseline	Widely available; performance depends on permeability control
Sulfate-resisting cement / low C3A blends	High (for sulfate soils if permeability is low)	Similar to OPC unless blended	Needs correct cement selection + exposure-class specs
SCM-blended cement	High (improves permeability;	Lower CO ₂ via	Requires SCM quality control and

(e.g., fly ash/slag/pozzolan)	sulfate/chloride resistance)	clinker substitution	consistent supply
LC3 (limestone–calcined clay cement)	High (low permeability; good durability potential)	Lower CO ₂ (clinker reduction)	Compatible with existing plants; needs clay suitability and calcination control

Discussion

The statistics show that Uzbekistan's cement production has been rising rapidly in recent periods. [1,2] In parallel, sector information indicates substantial national capacity and a large number of plants, creating a practical opportunity to introduce blended products at scale rather than relying solely on traditional Portland cement. [3] For Karakalpakstan, the case for innovation is not only about reducing embodied carbon; it is also about lowering lifecycle costs in municipal assets exposed to salinity, high temperatures and dust–salt deposition.

Salinity and soluble salts influence concrete performance in multiple ways. They can increase risks of sulfate attack, contribute to efflorescence, and accelerate reinforcement corrosion when permeability and cover are inadequate. Recent Uzbekistan-relevant studies discuss how soluble salts in water and soil interact with concrete and maintenance conditions, reinforcing the importance of chemical testing and exposure-class specification. [10] More broadly, durability guidance for harsh continental climates in Uzbekistan stresses that construction quality and material choice must be treated as a system rather than as isolated parameters. [9]

Within this system, two innovation directions are especially implementable for Karakalpakstan. First, expand clinker substitution through SCM blending and LC3-type cements. LC3 research demonstrates that limestone–calcined clay blends can reduce clinker content while maintaining performance, and the approach has been widely discussed as a scalable low-carbon pathway. [7] Second, embed durability requirements into municipal procurement and QA/QC routines. In practice, municipalities can specify exposure classes, require permeability-related tests (e.g., water absorption and rapid chloride migration where relevant), and enforce curing protocols suited to hot climates.

A Uzbekistan-focused decarbonization study of cement plants emphasizes that clinker substitution is among the practical mitigation levers, alongside energy efficiency and waste heat recovery. [8] For Karakalpakstan, where construction needs intersect with climate resilience, blended cements can deliver a dual dividend: lower CO₂ intensity and improved durability through refined pore structure and lower permeability. However, benefits are contingent on consistent quality: variability in clay reactivity, SCM fineness, and mixing water salinity can negate gains. Therefore, a region-ready implementation package should include (I) routine chemical testing of mixing water and soils in project sites, (II) certification of SCM supplies, (III) training of batching-plant operators, and (IV) municipal inspection checklists.

Finally, the Aral Sea basin context means that dust–salt aerosols are not an abstract background condition; they are a continuing stressor with documented mass transport from the dried seabed. [5] This supports the practice of prioritizing protective detailing (adequate cover, crack

control, surface treatments) for exposed elements such as water reservoirs, canals, roadside structures, and public buildings.

Conclusion

This study linked national construction-materials statistics to the regional durability needs of Karakalpakstan and proposed priority innovation directions for climate-resilient construction materials. Official data show strong increases in cement production in Uzbekistan during 2023–2025 (January–July) and a significant national construction workload, with Karakalpakstan contributing a measurable volume of construction works. [2,4] Given saline soils, hot conditions, and dust–salt exposure from the Aral Sea basin, Karakalpakstan’s municipal and industrial stakeholders should prioritize: (1) blended cements and low-permeability concretes with clinker substitution (SCMs and LC3), (2) durability-centered procurement and testing routines, and (3) QA/QC strengthening across batching plants and on-site curing. These steps are feasible within current sector capacity and can reduce lifecycle costs by extending service life of buildings and infrastructure.

Future research should validate these pathways through field trials in Nukus and selected districts, including side-by-side durability monitoring of blended and conventional concretes under real exposure conditions and the development of region-specific performance specifications aligned with Uzbekistan’s standards system.

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