CLOSING THE MATERIAL LOOP

A value and trade chain assessment for Jaipur city

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The Centre for Science and Environment is grateful to the Swedish International Development Cooperation Agency (SIDA) for their institutional support.

Citation: Anumita Roychowdhury, Rajneesh Sareen, Mitashi Singh and Sayani Sen 2025, *Closing the Material Loop: A Value and Trade Chain Assessment for Jaipur City*, Centre for Science and Environment, New Delhi

Published by
Centre for Science and Environment
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1. Introduction—Unlocking circularity

It is now well understood and accepted that waste from construction and demolition (C&D) of buildings and infrastructure are not "waste." More than 90 per cent of this waste can be recycled and brought back as a resource to the construction sector itself.

Circularity is critical in view of the fact that India's construction industry is transforming rapidly with projections showing expansion at a compound annual growth rate (CAGR) of over 6 per cent from 2023 to 2033. The US $639–billion[1] industry is expected to nearly double to US $1.393 trillion by 2033, according to the India Construction Industry Research Report 2024–2033.[2] Contributing 9 per cent to the nation's GDP, this sector is set to become a cornerstone of India's economic growth, potentially accounting for up to 20 per cent by 2030.[3]

Urbanization and strategic government initiatives are fueling this growth. With the urban population set to exceed 40 per cent by 2030, India faces a pressing demand for 25 million affordable homes.[4] In response, the government is championing sustainable urban development through projects like 100 smart cities and 11 industrial corridors, positioning the construction industry as a driving force behind the nation's future.[5]

India will expand billions of square meters of space through various initiatives, including the Pradhan Mantri Awas Yojana (PMAY) and the Atal Mission for Rejuvenation and Urban Transformation (AMRUT), to develop affordable housing, commercial spaces, cold storage facilities, industrial corridors, smart cities, roads, and highways.

As a result of this growth, the demand for materials, waste generation and related emissions will increase sharply and correspondingly. This requires circular pathways to recover material from waste, reduce waste footprint and curb emissions from the sector.

This policy principle is well recognized in the rules and regulations for C&D waste management as notified by the Ministry of Environment and Forests and Climate Change (MoEFCC) as well as in the provisions of the Swachh Bharat Mission of the Ministry of Housing and Urban Affairs (MoHUA).

This emerging regulatory framework and related funding programmes are propelling cities to upscale C&D waste segregation, reuse and recycling for material recovery in the construction sector. This policy drive is designed to ensure that the waste is not dumped to destroy eco-sensitive areas including water bodies, ecologically fragile regions, green areas, and drainage channels while the recycled material can substitute and reduce demand for new virgin material.

An earlier review of this sector carried out by the Centre for Science and Environment (CSE) in its report 'Rubble Recast' has highlighted the potential of this initiative and assessed the steady expansion of the recycling efforts and related infrastructure in cities to enable robust circularity in the sector. With the support from the Government of India, cities are developing a cohesive ecosystem for the management of the C&D waste and setting up C&D recycling plants for material recovery. Already 34 recycling plants have become operational as of December 2024. These numbers are expected to double with more plants in the pipeline getting established.

This is a strategic shift towards formalizing material recovery and building an organised value and supply chain around the recycled products and resources. This is a shift from the traditional practice in which the informal sector segregates material of value from the dump and trades within a lower value chain. This has thus catalyzed well-established trading channels in used bricks, metal, wood, doors and windows etc that are recovered from the waste rubble. These are low end products but with a vibrant market and uptake.

This informal sector filters reusable material and markets them without much value addition. But it is unable to value add to the concrete and cement waste that is finally dumped in dump sites or are used for land reclamation. The informal sector does not have the capacity to make resource and technology out of these waste components.

Therefore, the new generation policies are creating opportunities for hi-tech recycling of concrete waste for value addition. A new recycling industry is growing with the support from the government that can invest in capital intensive recycling plants to produce a range of value-added products that can be further used by the construction industry.

To create a market, pull for these genre of circular products policy mandates is emerging at the central and state levels for adoption of recycled products in the new construction. The new construction need to use a specified percentage of building construction materials manufactured from recycled debris. The objective is to develop and promote new entrepreneurship and competition to recover resource from the waste.

There are several strong reasons for promoting this circularity and catalysing value chain around C&D waste.

Rise in material demand

India's material consumption has surged six-fold, from 1.18 billion tonne in 1970 to 7 billion tonne by 2015, according to the 2019 draft National Resource Efficiency Policy report. With the construction sector booming, demand for raw materials is expected to rise to nearly 15 billion tonne by 2030 and exceed 25 billion tonne by 2050, placing immense pressure on natural resources.[6] This growth will also lead to a substantial increase in construction and demolition (C&D) waste.

India's resource extraction rate—at 1,580 tonne per acre—is significantly higher than the global average of 450 tonne per acre, highlighting issues with low material productivity and poor circularity. While India imports key raw materials like sand, its recycling rate remains low, at just 20–25 per cent, as compared to 70 per cent in developed European countries, underscoring the need for greater efficiency and sustainability in resource use. [7]

Recycling of C&D waste can contribute towards material security and substitute virgin material.

Material recovery and material substitution to reduce resource footprint

Recycling C&D waste can reduce the use of natural aggregates and shrink the construction industry's carbon footprint. Studies have revealed that, in India, up to 30 per cent of recycled aggregates can replace natural ones in concrete and road-building, cutting carbon emissions by as much as 40 per cent. This shift helps to narrow the gap between supply and demand for raw materials in the construction industry.[8] Promoting circularity through the reuse and recycling of materials like recycled concrete aggregate (RCA), fly ash, and recycled steel not only reduces environmental impact but also supports India's ambitious goal of reaching net-zero emissions by 2070.[9]

Fly ash utilization from Thermal Power Plants (TPPs) is a successful example of circularity. Started in 1999, government policies required the use of fly ash bricks within a 50 km radius of TPPs, a mandate that expanded to 100 km in 2003. By

2020, the government had implemented a comprehensive policy framework aimed at achieving 100 per cent fly ash utilization, including the polluter pays principle for unused and legacy ash. Although coal remains a primary energy source, exacerbating fly ash management challenges, India's approach to converting fly ash into valuable products or integrating it into construction reflects a proactive strategy. Today, the cement sector leads in fly ash utilization at 25.05 per cent, followed by land reclamation (8.45 per cent), brick manufacturing (7.30 per cent), and ash dyke raising (6.07 per cent). This is indicative of a circular economy.[10]

Increasing emissions from construction sector

This heightened energy use is embedding substantial amounts of carbon in construction projects. The sector's energy intensity stems from two main factors—embodied energy, which is the total energy consumed throughout a building material's lifecycle; and operational energy,[11] which is the energy used during a building's daily use. Both types of energy contribute significantly to the sector's overall carbon emissions.

Currently, the construction sector is one of the largest global sources of carbon emissions, accounting for about 37 per cent of total emissions.[12] The industry traditionally relies on energy-intensive materials such as cement, steel, aluminium, and bricks—and require substantial energy to produce. Cement alone contributes approximately 8 per cent of global CO2 emissions due to the energy required to convert limestone into clinker.[13] Similarly, steel production is energy-intensive, relying on coal-based processes, while aluminium and brick manufacturing require high temperatures, further increasing emissions. If the current construction methods continue, embodied carbon could account for nearly 50 per cent of all emissions from new construction between 2020 and 2050.[14]

Despite advancements in building energy efficiency and the integration of renewable energy, emissions from new construction have risen by 1 per cent annually since 2010, primarily due to the high embodied energy of building materials. For example, in 2018, globally, the building sector accounted for 36 per cent of total primary energy use and 39 per cent of energy and process-related CO2 emissions, with 11 per cent coming from the production of materials like cement, steel, and glass. Every building contains numerous processed materials, each adding to the embodied energy and overall carbon footprint of the structure.[15]

While progress has been made to reduce the operational carbon footprint of buildings—such as emissions from heating, cooling, and lighting—by enforcing Energy Conservation Building Code (ECBC) guidelines, efforts to lower embodied carbon have not kept pace. Addressing embodied carbon is challenging because, unlike operational carbon, which can be managed through design and building management, embodied carbon is locked into the material supply chain. This supply chain spans multiple sectors and regions with varying regulations, and the lifecycle of building materials, from extraction to disposal, presents numerous points of carbon emissions that are difficult to control. India's buildings sector emits nearly 500 million tonne of CO2 in embodied carbon annually, a rate that if unabated could nearly double amid the growing urbanization.[16]

Policy determinants of C&D waste recycling

Correspondingly, the Construction and Demolition Waste Management Rules 2016 marks a significant step towards achieving a circular economy in India's construction industry. In addition to enforcing waste and dust management, this rule contributes to reduce the embodied carbon footprint of buildings by promoting the reuse of construction materials, which helps prevent waste from ending up in landfills or being illegally dumped. Government initiatives such as Swachh Bharat Mission 2.0 (SBM 2.0) and dedicated funding have accelerated this shift, yet challenges persist in maximizing material recovery from waste and facilitating trade of recycled materials.

As cities are taking baby steps to process C&D waste, the government aims not only to control pollution but also unlock the potential for circular growth. This process requires dedicated facilities, as well as integrated collection, transportation, and infrastructure, yet only 34 cities have established dedicated processing plants. In areas where formal C&D management systems are still evolving, the informal sector plays a vital role by collecting, sorting, and repurposing waste into reusable materials—often underappreciated.

Assessing real world circular economy in cities

Even as policies and regulations on waste recycling are taking shape and the cities are developing framework for implementation, it is necessary to do a reality check to understand how this market is evolving.

Centre for Science and Environment has been deeply involved with several state governments to provide knowledge support to develop C&D waste management rules. The most crucial link in this initiative is the closing of the waste loop to achieve a fully circular economy built on a thriving market for the recycled product. It is this market pull that can complete the circuit from the waste to resource.

Therefore, value trade chain assessment – how the material is recovered and sold in the market at different stages of the waste disposal -- is crucial to understand the potential, opportunities and the barriers.

Contexualising value trade chain

With growing capacity for recycling of C&D waste in cities and a range of value-added product from the waste increasing, developing a robust market in recycled products becomes critical to make circularity work.

Yet market development for recycled products is not confined to only products from the recycling plants. There is already a well-established informal trade in all usable waste that is generated from construction and demolition. It is necessary to understand this entire trade flow of the informal or semi-informal sector to reduce environmental and public health impacts at each stage of material trade chain and also design robust solutions for cities.

Such a mapping in each city will enable strong integration of the informal sector with the formal system as new formal systems and processes move to controlled operations -- similar to how other streams like electronic waste and municipal solid waste have transformed. For instance, sorting of municipal solid waste is now done by informal workers and ragpickers at state-of-the-art transfer stations. The ULB can mobilise human resource but the workers keep the profits. The processing takes place in facilities with appropriate safeguards. The C&D sector needs similar arrangements.

To assess this dimension, Centre for Science and Environment has carried out a deep dive assessment of the value trade chain of C&D waste in the city of Jaipur, the capital city of Rajasthan. This has assessed how the local trade chain works around C&D waste and how this trade chain can work for the uptake of the value-added products from the C&D recycling plant that has been established in the city.

This assessment takes a deep dive in the current material value and trade chain of Jaipur to understand the nature and quantum of materials this market is dealing with as the city establishes the first C&D waste recycling plant in Rajasthan.

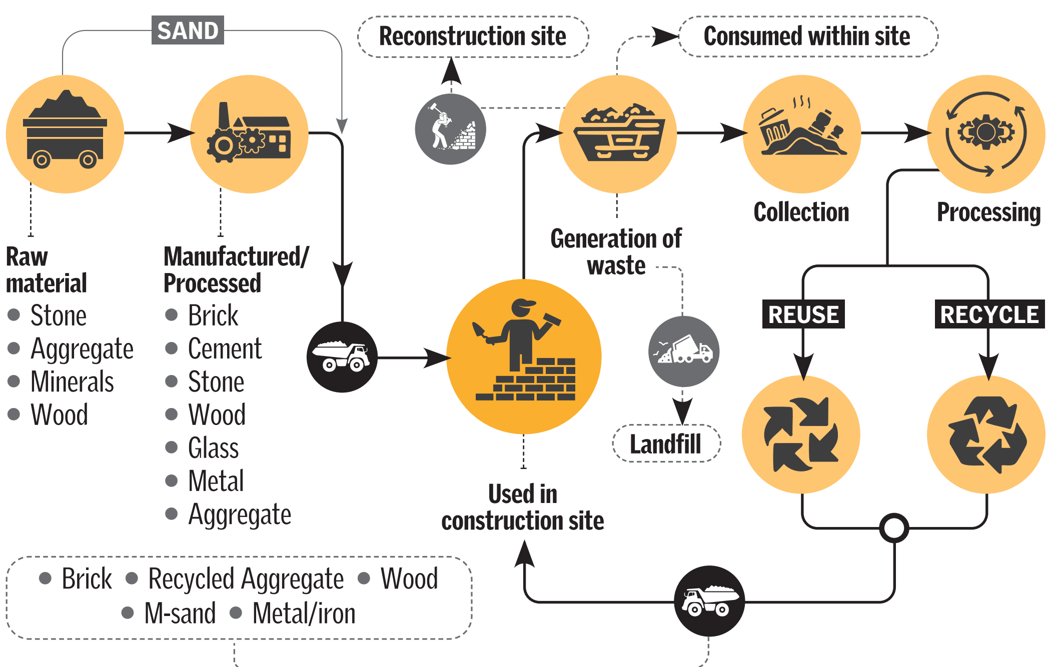
Another objective of this study is to estimate the potential to slash emissions by reducing dependence on virgin materials. Co-benefits include reduction of dust pollution and elimination of inefficiencies from mis-managed C&D waste and an unregulated informal material market. Overall this report aims to lay an economic foundation for maximum recycle and reuse of C&D waste materials and foster a safe circular economy.

2. The case of Jaipur

This report explores the construction sector's value chain through informal sector, to understand the opportunities for resource recovery and emission reduction throughout the trade and material flow. To analyse these potential gains, CSE conducted an in-depth study of Jaipur's construction ecosystem, examining key points in the value chain where improvements could lead to significant environmental benefits. A non-attainment city in Rajasthan, Jaipur is witnessing a rapid surge in industrial and construction activities, mainly due to its strategic proximity to the Delhi–Mumbai Industrial Corridor. Raw construction materials, including sand, cement, bricks, and aggregates, are in high demand to support a variety of projects, such as the construction of roadways, metro infrastructure, and commercial and residential complexes.

This report provides a comprehensive analysis and mapping of existing resource sources and the operational framework within the trade and value chain (see *Figure 1: Value and trade chain map of the construction sector*). A key aspect of

Figure 1: Value and trade chain map of the construction sector

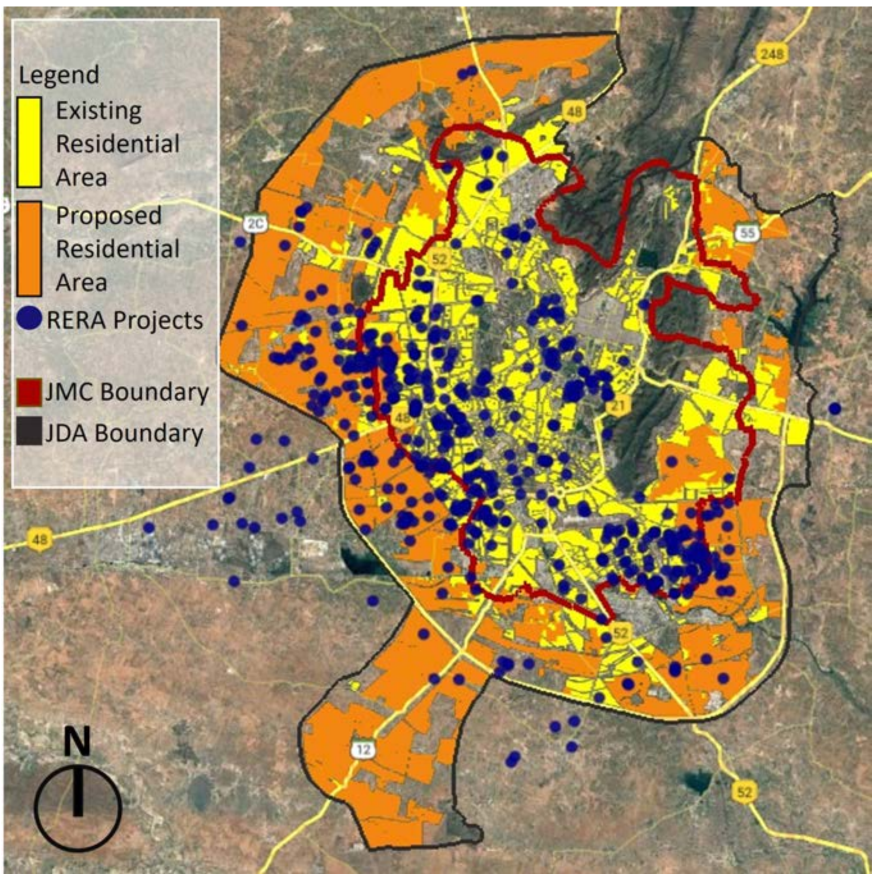


Source: CSE

this analysis is mapping the entry and exit points of materials, which is essential for optimizing recovery rates. In Jaipur, the informal workers help in material recovery at construction and demolition sites. However, the lack of formal recognition and inadequate infrastructure lead to inefficiencies and missed opportunities. By identifying and mapping these activities, the report aims to pinpoint critical hotspots for intervention to ensure that valuable materials are effectively recovered rather than wasted. Through this approach, the report seeks to highlight key areas for sustainable improvement in the construction sector's value chain.

Data reported in the Rajasthan Real Estate Regulatory Authority (RERA) database that, as of June 2024,[17] there are around 580 ongoing residential construction projects in Jaipur, primarily in the city's southern and southwestern areas (see *Map 1: RERA construction sites in Jaipur Development Area*). It also projects approximately 16.35 million square meters of new residential construction between

Map 1: RERA construction sites in Jaipur Development Area



Source: CSE

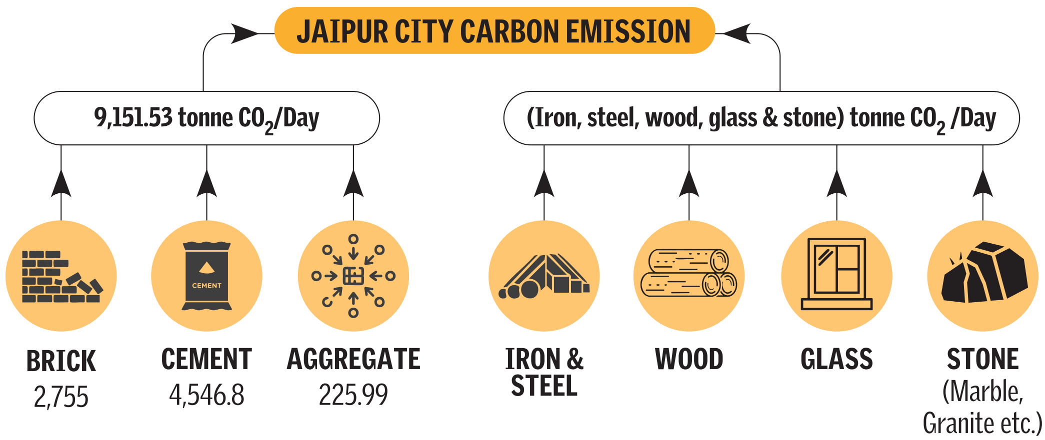
2023 and 2028. The RERA database only accounts for residential projects over 500 square meters and overlooks the numerous smaller residential buildings in cities like Jaipur. Additionally, redevelopment projects and smaller constructions will contribute further to the built area and increase material demand. As more projects are registered and constructed, the total construction area is expected to grow exponentially. From these RERA-registered projects alone, approximately 447 tonne per day (TPD) of C&D waste is anticipated, along with a substantial demand for construction materials.

However, the high demand for raw materials and the considerable C&D waste generated from sites have turned these areas into significant dust pollution hotspots. Additionally, the construction process itself is a major generator of dust and particulates, contributing to local pollution and health hazards. This is a critical concern as air pollution has become a major public health issue in Indian cities. Serious health issues linked to construction dust include lung cancer, silicosis, chronic obstructive pulmonary disease, and asthma.

Rajasthan's abundant mineral resources supply the construction materials from quarries in areas like Tonk, Kotputli, Bhilwara, Neem ka Thana, and Shambhupura—which are major dust pollution hotspots. The transport of these materials also contributes to dust emissions. In Jaipur, construction activities release harmful dust at every stage, including silica dust from materials like sand, stone, brick, concrete, and mortar, as well as dust from activities like tunneling, road milling, cement mixing, and demolishing old structures with toxic substances like lead and asbestos. Other forms of dust and particle emissions are from diesel engine exhausts, fugitive dust from loaded material, dust tracks of tyres, wearing and tearing of rubber tyres, and re-suspension of road dust.[18] The city's rapid development generates a large volume of C&D waste, adding to dust pollution around construction sites, material storage points, and disposal areas. The lack of adequate waste management facilities often leads to illegal dumping or the use of C&D waste for backfilling. This worsens pollution, especially in sensitive areas like wetlands and low-lying zones.

A field investigation conducted by the CSE for Jaipur city revealed that Jaipur consumes approximately 5,400 tonne of cement, 8,100 tonne of sand, 15,200 tonne of coarse aggregates, and 9.5 million bricks daily. Among these materials, cement is noteworthy due to its high embodied carbon, emitting 0.84 tonne of CO_2 for every tonne produced.[19] This equates to about 4,546.8 tonne of CO_2 emitted each day based on Jaipur's cement consumption, excluding emissions from transportation and other construction-related activities. Aggregates, which form 70 per cent of

Figure 2: Carbon emission of Jaipur city from material sources



Source: CSE

concrete's volume, release 9.3 kg of CO_2/tonne, resulting in around 226 tonne of CO_2 emissions daily from aggregate usage alone.[20,21] Brick production also significantly impacts the city's carbon emissions, releasing 200.4 kg of CO_2/m^3 [22], which totals over 4,378 tonne of CO_2 emitted daily in Jaipur. Combined with emissions from cement, bricks and aggregates, the city's construction activities generate over 9,151 tonne of CO_2 each day, increasing its carbon footprint (see *Figure 2: Carbon emission of Jaipur city from material sources*).

Given this substantial carbon output, it is important for Jaipur city to transition from traditional construction practices to a more sustainable approach. To address Jaipur's growing construction needs while tackling environmental challenges, there is a pressing need to move from a linear to a circular economy model. A significant percentage of materials, including concrete, iron, and wood, could be recovered and reintroduced into new construction projects. The recycling potential of these materials not only conserves resources but also reduces the demand for fresh raw materials, mitigating environmental degradation from mining activities. This shift will optimize the value and trade chain, enhancing resource efficiency and minimizing the environmental impact of the construction sector.

Jaipur's construction industry relies on a complex and dynamic flow of materials to meet the growing demands of its expanding urban landscape. From raw materials like sand, cement, and aggregates to finished products such as bricks and steel, the city's construction supply chain is integral to supporting various infrastructure projects. Understanding the sourcing and movement of these materials is crucial to identifying opportunities for sustainable development in Jaipur.

Flow of construction materials: Jaipur's construction industry supply chain

In the value trade chain, various materials play distinct roles. Raw materials like fine aggregates, coarse aggregates, bricks, stone timber, and metal ores form the foundation and are processed into intermediate materials such as cement and iron or steel beams. These intermediate materials are used to produce finished products, including pre-cut stone slabs and ready-to-use aggregates. Recycled materials, such as recycled concrete and reclaimed wood, contribute to sustainability by reducing the need for new raw materials. By-products and waste, like stone dust and metal shavings, need effective management to minimize environmental impact. Packaging materials ensure safe transport and delivery of products. Understanding these material types and their roles helps optimize efficiency and promote sustainability in the supply chain.

Aggregates

Jaipur's booming construction sector has also sky rocketed the demand for reinforced concrete (RC) structures, spurred by the adoption of new construction techniques. This surge has placed pressure on natural resources, especially for aggregates. Aggregates, comprising coarse materials like gravel and fine materials such as sand and manufactured sand (m-sand), are vital for concrete construction along with surface finishes. The coarse and fine aggregates are 60–75 per cent of the total volume of concrete structures.[23]

Extracted from quarries, these raw materials undergo processing before being distributed to construction sites. To ensure sustainable practices, it's crucial to adopt circular economy principles and explore innovative technologies. Understanding the trade chain of aggregates can help improve project efficiency and reduce reliance on natural resources.

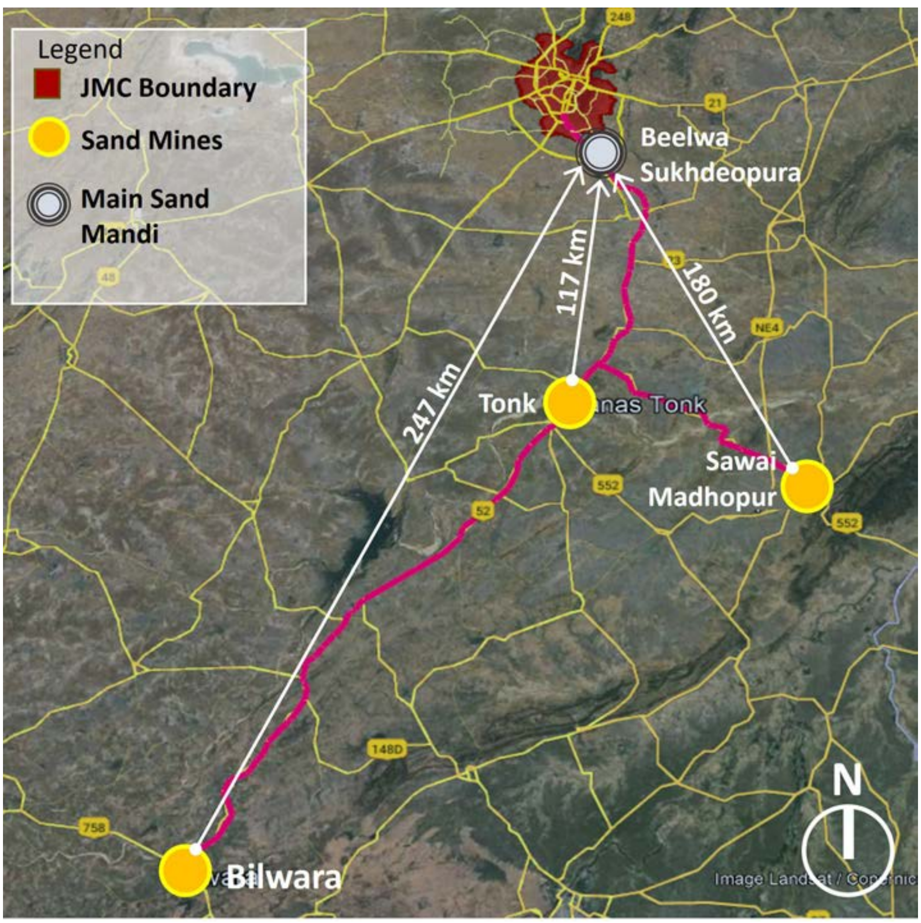
Fine aggregate: Sand

In Jaipur and its surrounding areas, river sand, commonly referred to as Bajri, is a major component used as fine aggregate in construction. This sand is primarily extracted from the Banas river and the Kothari river. Sand mining operations are concentrated along the Banas river near Tonk, about 117 km away from Jaipur. The Tonk is the main source of river sand for Jaipur (see Image: *Sand mine in Tonk*). Additionally, sand is sourced from Sawai Madhopur (along the Banas river) and Bilwara (along the Kothari river), located about 180 km and 247 km away from Jaipur, respectively (see *Map 2: Location of sand mines and main sand mandi near Jaipur city*). Transportation of the sand is carried out using vehicles such as tipper trucks and dumpers, with 16-wheeler dumpers typically transporting 25–35 tonne and tippers handling around 45 tonne per load.

Sand mine in Tonk

Source: South Asia Network on Dams, Rivers and People

Map 2: Location of sand mines and main sand mandi near Jaipur city



Source: CSE

Main sand mandi at Beelwa Sukhdeopura near Ring Road

Source: CSE

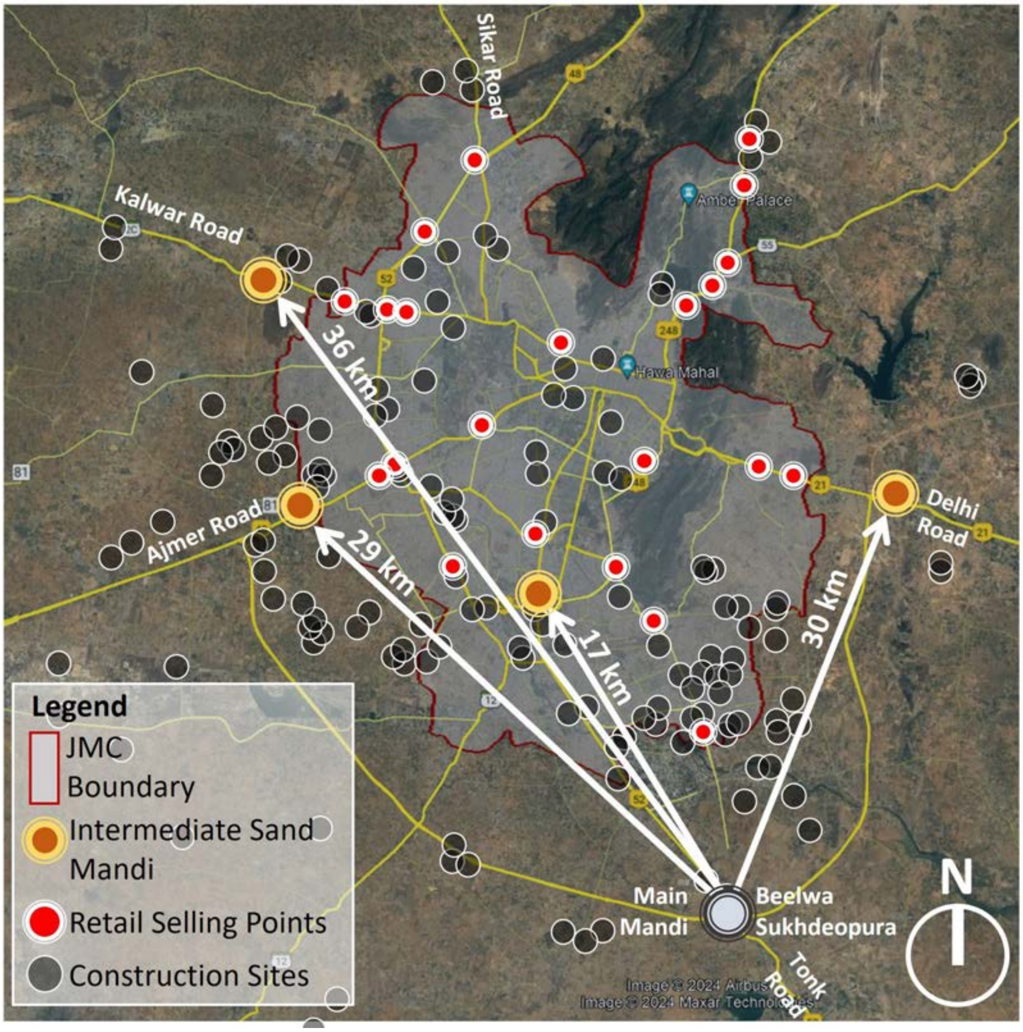
On an average day, around 8,100 tonne of sand is transported from sand mines to the central sand market or main bajri mandi at Beelwa Sukhdeopura, located about 25 km from Jaipur's city centre (see Image: *Main sand mandi at Beelwa Sukhdeopura near Ring Road*). This main bajri mandi, managed and operated by the informal sector, is strategically situated at the junction of Tonk Road and Ring Road, facilitating efficient distribution of sand to various construction sites. Its strategic location allows sand-laden vehicles to take direct routes to major construction sites and intermediate sand mandis, avoiding the congested city centre and ensure a smooth supply chain (see *Map 3: Location of construction sites along with intermediate sand mandis and retail sellers*).

The main bajri mandi's strategic location offers logistical advantages by optimizing transportation routes and maximizing vehicle loads. However, this distance often undermines the stringent enforcement of dust management regulations, leading to violations of the dust control rules specified in the Environment (Protection) Amendment Rules 2018. The lax measures increase fugitive dust pollution from uncovered vehicles and during sand loading and unloading. While the main mandi improves logistical efficiency, it also increases local dust pollution and deteriorates air quality in surrounding areas.

To curb pollution and enforce regulations, the administration should enhance vigilance and strictly enforce dust management rules, including introducing penalties. Balancing the benefits of efficient distribution with the need to safeguard environmental and public health requires prompt and effective action on dust management issues.

The sand trade in Jaipur involves a multi-tiered value chain, starting from sand mines and culminating in the delivery to construction sites. Daily, about 55–60 vehicles operate from the main bajri mandi starting at 3:00 a.m. Sand is extracted

Map 3: Location of construction sites along with intermediate sand mandis and retail sellers



Source: CSE

from mines and transported to the main bajri mandi at a cost of around Rs 1,100–1,200 per tonne. Dealers at the main bajri mandi resell the sand to intermediate mandi dealers for Rs 1,250–1,300 per tonne with a profit margin of Rs 30–50 per tonne. These rates fluctuate daily based on changes in demand and supply.

Besides the main mandi, Jaipur city features four intermediate sand mandis along the Ajmer Road, Kalwar Road, Delhi-Jaipur Road, and Gopalpura Chowk. Sand is transported from the main mandi to these intermediate mandis using mechanical and manual dumpers, as well as tracker trolleys. All intermediate mandis, except the one at Gopalpura Chowk, are located outside the city corporation limits to bypass

Intermediate sand mandis

Source: CSE

Retail selling points

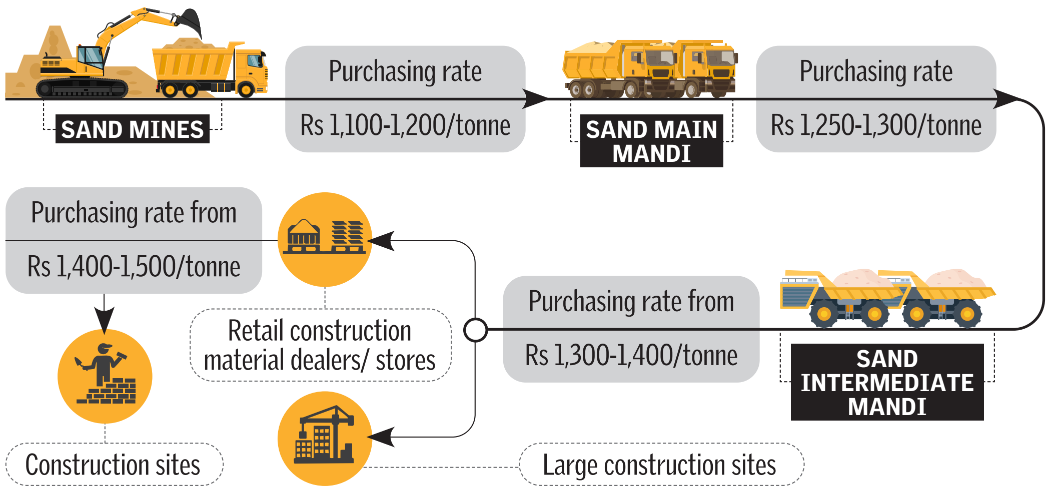
Source: CSE

daytime vehicle movement restrictions and adhere to regulatory requirements (see Image: *Intermediate sand mandis* and *Retail selling points*).

Retail store owners of construction material and large construction sites contractors acquire sand from these intermediate mandis at around Rs 1,300–1,400 per tonne. For smaller construction projects, such as individual buildings, sand is supplied by construction material dealers via tracker trolleys at prices of around Rs 1,400–1,500 per tonne. Within the city, small construction sites receive sand transported by trucker trolleys from local dealers (see *Figure 3: Trade chain of sand in Jaipur city*).

Jaipur's sand mandis, while essential for the construction industry, are a significant contributor to air pollution in the city. The constant movement of vehicles, particularly uncovered tractor trolleys, stirs up dust and particulate matter, leading to significant environmental and health impacts.

Figure 3: Trade chain of sand in Jaipur city



Source: CSE

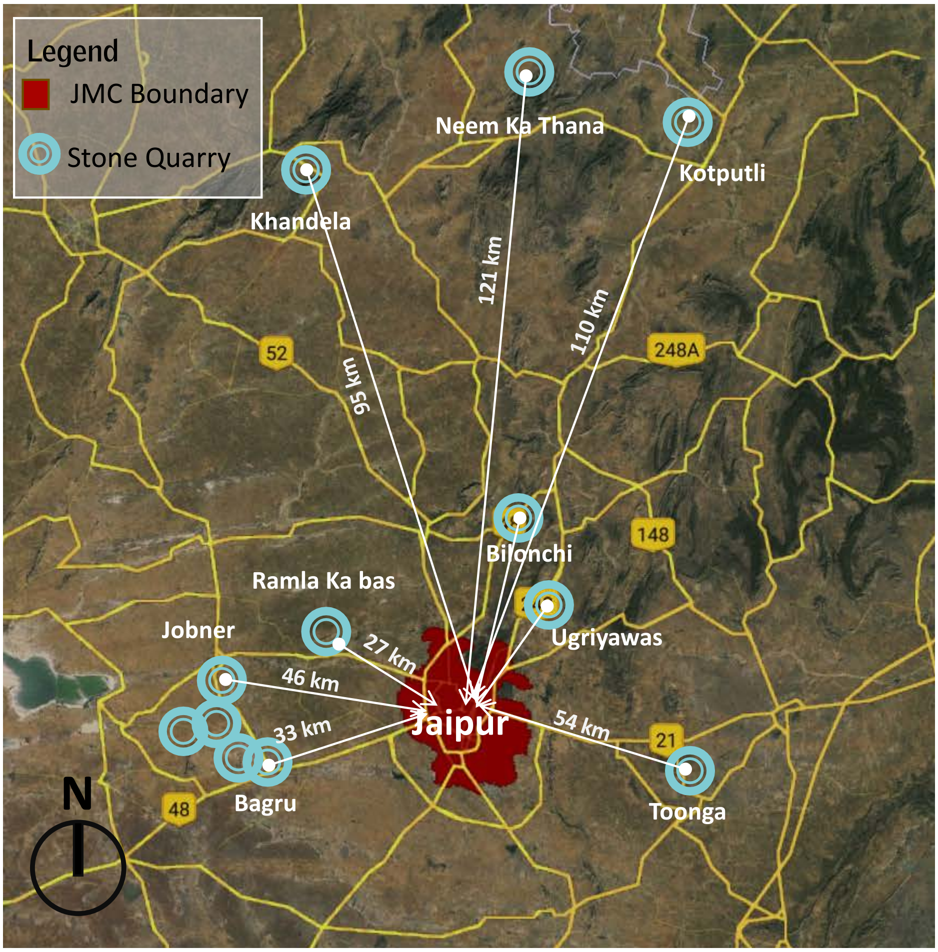
Coarse aggregates

Coarse aggregates, consisting of materials such as gravel and crushed stone, are vital for the strength and durability of concrete structures. Around 57 types of minerals including various building stones and coarse aggregates found in Rajasthan provide a significant source of raw materials for construction. These resources supply raw materials for the state's construction industry and contribute to the local and state economies by providing materials to various states.[24]

According to the CSE field investigation for this report, around 16,200 tonne of coarse aggregates are traded daily in Jaipur. Coarse aggregates like gravel, crushed stone, and manufactured sand (m-sand) are sourced from local quarries in areas such as Bagru, Jobner, Ugriyawas, Ramla Ka Bas, and Malhan—all within a 35-km radius of the city centre (see *Map 4: Location of stone quarry and crusher*). These quarries, located in the Aravalli region, play a crucial role in meeting the growing construction demands driven by rapid urbanization. However, the high demand for these materials raises concerns about exploitation of natural resources and the associated environmental impact. Unregulated quarrying contributes to land degradation, loss of biodiversity, and disruption of local ecosystems, calling for the urgent adoption of sustainable practices within the construction industry.

Moreover, the operations in these quarries, including stone crushing, exacerbates dust pollution, which further raises the levels of particulate matter ($PM_{2.5}$ and PM_{10}) in the air (See Image: *Stone crusher in Bagru*). Many stone crushers operate without proper compliance measures, creating health hazards for nearby residents

Map 4: Location of stone quarry and crusher



Source: CSE

Stone crusher in Bagru

Source: Google Earth

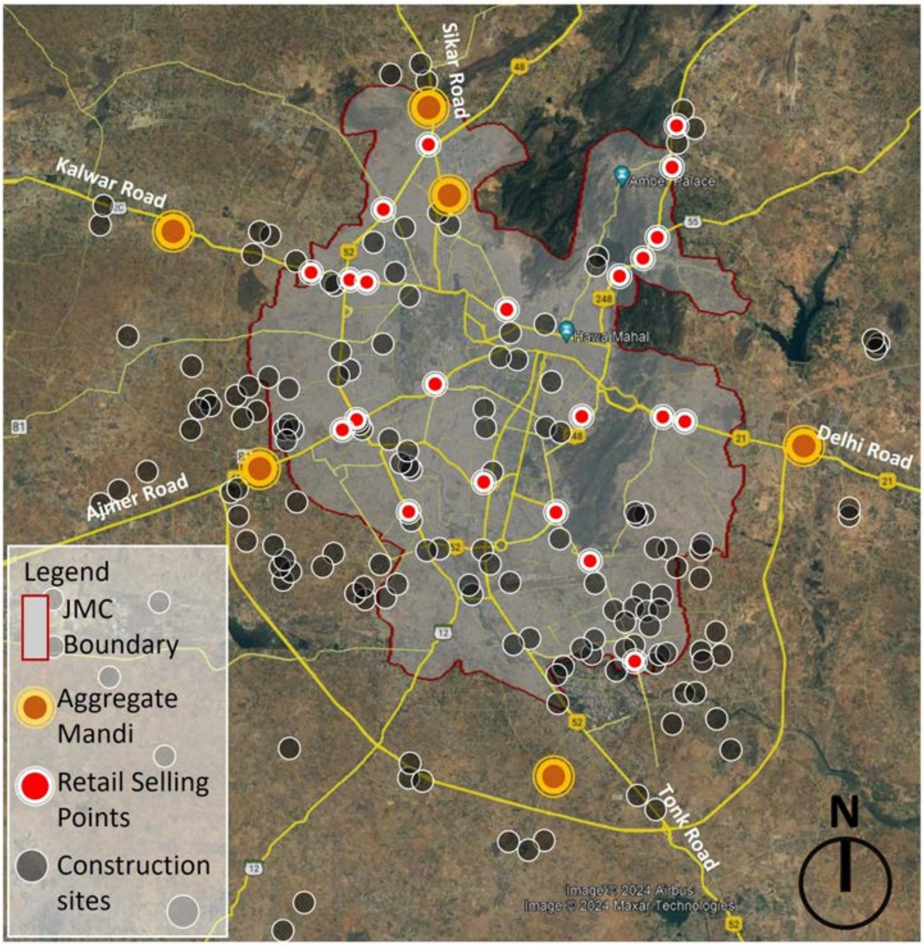
and workers.[25] The dust emitted from the crushing, transportation, and handling of aggregates worsens air quality and poses health risks to workers and nearby communities.

The transportation of aggregates from quarries and crushing units to construction sites or sand mandis significantly contributes to environmental degradation. These vehicles contribute greatly to emissions, including particulate matter and other pollutants, thereby intensifying the overall environmental impact.

Beyond the emissions from the vehicle engines, other sources of dust and particulate pollution include exhaust emissions from diesel engines, fugitive dust from uncovered or improperly loaded materials, and dust generated from the tracks left by vehicle tires. Additional dust is produced from the wear and tear of rubber tires and the re-suspension of road dust, which is stirred up by the constant movement of these heavy vehicles. Collectively, these factors contribute to the deterioration of air quality, posing environmental and health risks to the communities living near these transportation routes and industrial operations. This situation underscores the need for stricter regulatory enforcement and improved dust control measures to mitigate the environmental and health impacts of aggregate production in the region.

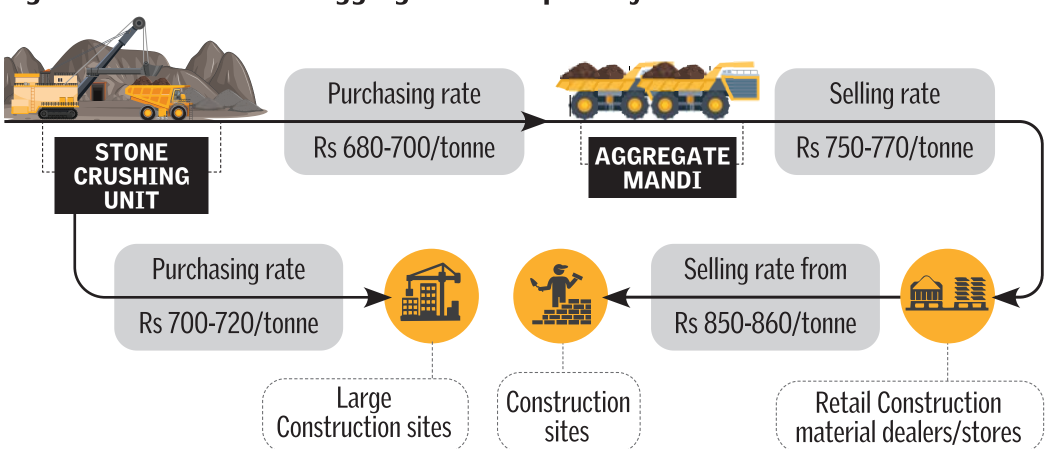
Aggregates are transported from stone crusher to various material mandis along Jaipur's outskirts, including Hatrod, Jaitpura, Bagrana, Ajmer Road, Sanganer, and Moredungri from crushers in areas like Bagru, Jobner, Mohlan, and Ramla Ka Bas (see *Map 5: Location of stone and aggregates mandis*). Aggregate supply and trade chain in Jaipur consists of several stages, each contributing to the final price of aggregates. At the outset, mandi dealers acquire aggregates from crushing units at prices ranging from Rs 680 to Rs 700 per tonne, depending on the quality and type of the aggregate. Then, they sell these aggregates to retailers at around Rs 750–770 per tonne, generating a profit margin of about 10–11 per cent, which translates to Rs 70 per tonne. Retailers purchase the aggregates from mandi dealers and resell them to end users at around Rs 850–860 per tonne. This resale price allows retailers to achieve a profit margin of around 10–14 per cent, or Rs 80–110 per tonne. The price of aggregates soars incrementally throughout the supply chain. From the crushing units to the mandi dealers, the price increases by around Rs 70–90 per tonne. From the mandi dealers to the retailers, the price increases by an additional Rs 80–90 per tonne. Overall, this results in a cumulative markup of about 25–28 per cent from the original purchase price at the crushing units to the final selling price to end users (see *Figure 4: Trade chain of aggregates in Jaipur city*).

Map 5: Location of stone and aggregates mandis



Source: CSE

Figure 4: Trade chain of aggregates in Jaipur city



Source: CSE

Material mandi (left) and a vehicle carrying aggregate (right)

Source: CSE

Retail store of aggregates

Source: CSE

For larger construction projects, aggregates are frequently acquired directly from crushers rather than through intermediary stages like mandi dealers and retailers. This direct procurement approach offers several advantages, including streamlined logistics, reduced costs, and better control over supply. Specialized vehicles, such as bulk carriers or dump trucks, are typically used to transport these aggregates directly from the crushers to the construction site or project location. However, this bypassing of the retail stage does not fully address the environmental issues associated with aggregate handling.

Retail stores and stockyards, which often store aggregates in open areas, also contribute to air pollution. In addition to storage practices, the handling and transport of aggregates are major contributors to dust emissions. Activities such as loading, unloading, and moving aggregates can generate airborne dust, especially in dry conditions. The operations of heavy machinery involved in these processes exacerbates particulate matter emissions.[26]

To address these environmental concerns, several measures can be implemented. Dust suppression techniques, such as using water sprays or dust suppressants on aggregate piles and during handling, can help reduce emissions. Covering stockpiles with tarps or other materials can protect aggregates from wind, further minimizing dust generation. Regular maintenance of transport vehicles and equipment, along with the use of dust control systems, can also ease emissions. Additionally, utilizing enclosed or partially-enclosed storage facilities can contain dust and lessen its environmental impact.

Stone

In addition to aggregates, the supply chain for stone slabs in Jaipur involves sourcing materials from various quarries that cater to specific construction needs such as flooring and cladding. Stone slabs are obtained from quarries located in Kalwar, Dadar, Sewadham, Kishangarh, Kota, and Achhojai. Marble slabs are sourced from Kishangarh, Udaipur, Makrana, Sumerpur, Nathdwara, Dewana and Krishnapura, while granite comes from quarries in Nimbiya, Kundwa, Kotra and Kanwera.

Stone slab retailers are primarily located on the outskirts of Jaipur in areas such as Mohanpur, Jagatpura (known for Kota stone), Vatika, Sanjay Nagar (Kalwar Road), Dadar, Sewadham and Hathod. These retailers purchase slabs from quarry dealers, with prices varying based on the size, quality, and type of stone. Cutting and grinding of these stone slabs are carried out in the Vishwakarma Industrial Area (VKI) in Jaipur to prepare the stones to meet construction requirements. Due to insufficient enforcement of dust control regulations at these processing sites and retail locations, substantial dust is produced during the cutting, grinding, and polishing of stones. This includes hazardous dust from cutting and drilling sandstone and granite, as well as from polishing activities, which releases crystalline silica particles in the air. Inhaling silica dust can cause serious lung conditions, such as scarring and silicosis—a potentially fatal disease.[27] This highlights the urgent need for stricter dust control measures and better enforcement of existing regulations to reduce the health and environmental hazards associated with stone processing in Jaipur.

Darika stone, imported from Dadar, is sold at local mandis at a cost price of Rs 2,500 per trolley, including transportation, and a selling price of Rs 3,200 per trolley, resulting in a markup of Rs 700 per trolley. This markup represents a significant profit margin for suppliers. Similarly, Chenai Stone, sourced from Sevadam, is traded at a cost price of Rs 2,000 per trolley and sold at Rs 2,800 per trolley, yielding a markup of Rs 800 per trolley.

For marble dealers, the cost price ranges at about Rs 100–200 per sq ft, while the selling price can vary from Rs 110—205 per sq ft. The markup in marble sales depends on the grade and quality of the marble, reflecting the profit margins achievable within this market segment. These pricing structures highlight the profit dynamics and financial margins in the stone trading market, where different materials offer varying opportunities for earnings based on their origin, quality and type.

Despite the financial benefits, the sector's lack of formalization and limited regulatory enforcement have contributed to dust pollution. To address these challenges, it is essential to implement stronger environmental safeguards and enforce dust control regulations more rigorously. Moreover, incorporating 2–10 per cent recycled aggregate materials in construction projects through tenders can further promote sustainability and reduce the industry's

Stone slab processing in Vishwakarma Industrial Area, Jaipur

Source: CSE

Stone slab material store (left); Fugitive dust formation during stone work at a site near Jaipur's airport (right)

Source: CSE

overall environmental footprint. By formalizing operations and prioritizing environmental responsibility, the sector can achieve a balance between profitability and sustainable practices.

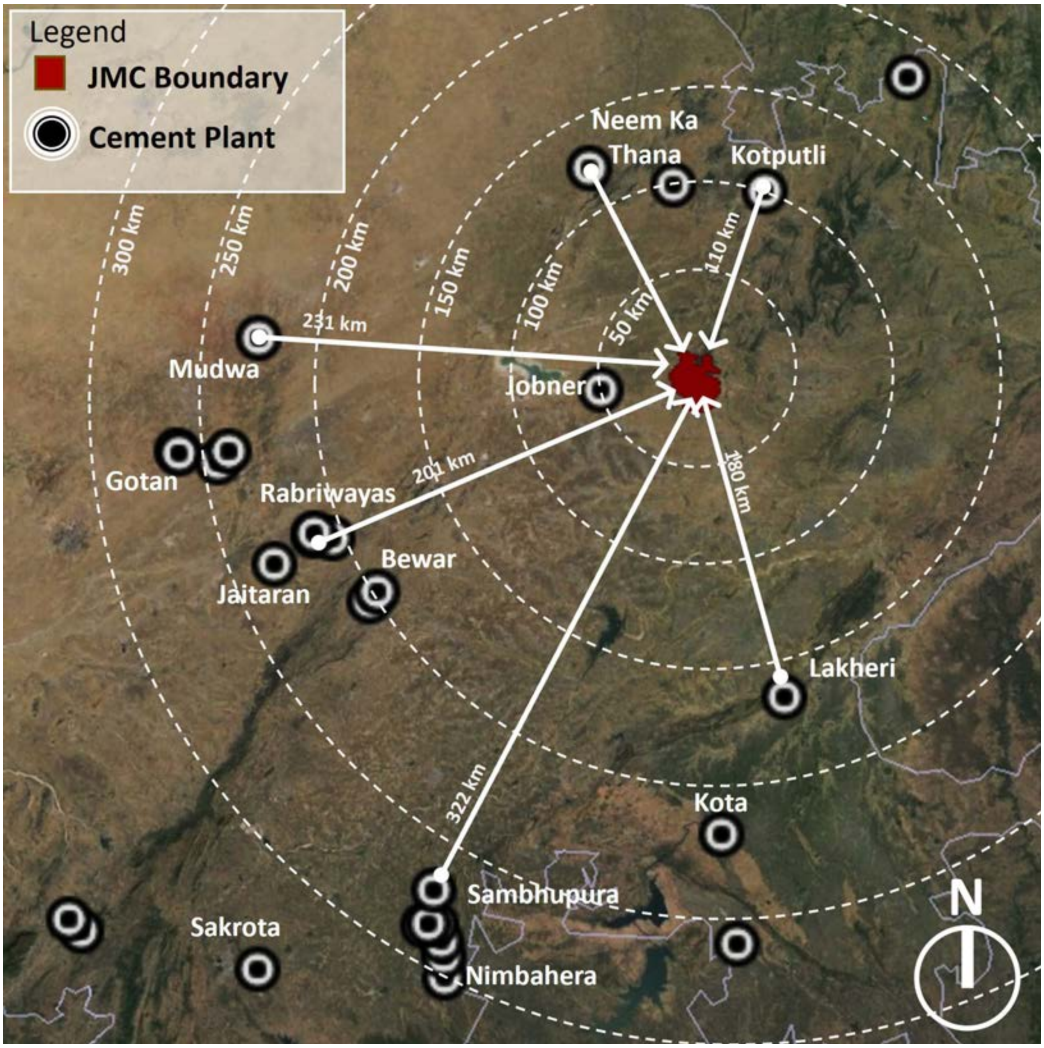
Cement

The cement industry contributes about 11 per cent of the input cost to the construction sector in India.[28] The production of lime clinker (CaO), the main component of cement, involves the calcination of limestone ($CaCO_3$), which releases CO_2. Combined with fossil fuel use in kilns, this makes cement production a significant source of greenhouse gas emissions.[29] Rajasthan, possessing about 26 per cent of the country's limestone reserves, significantly contributes to this cement manufacturing process. The state is home to 58 cement plants, which altogether produce over 125 million tonne of cement annually.[30]

The key stakeholders of cement manufacturing industry include Ultratech, ACC Lakheri, Ambuja, Shree Cement, India Cement, and Shriram. These companies operate several cement production facilities within a 200–km radius of Jaipur, spanning locations like Rabriwayas, Shambhupura, Kotputli, and Neem ka Thana (see *Map 6: Location of cement manufacturing plants in proximity of Jaipur city*). These plants are key nodes in the state's cement production network, each vital to the overall supply. Among these, Shree Cement's plant in Jobner, situated around 55 km from Jaipur, ensures a steady supply of cement for local construction projects. These companies ensure the efficient transportation of cement from their plants to Jaipur and surrounding areas. This logistical network supports the industry's supply chain by delivering cement to construction sites and retail outlets promptly.

According to the Jaipur Development Plan 2025, the Jaipur Development Authority (JDA) plans to establish 11 satellite towns and four growth centres within the development region, alongside expanding the city itself. This ambitious development plan will leverage approximately 1,596 km^2 of land available in the region, leading to a marked increase in cement demand. According to CSE field investigation in February 2024, Jaipur consumes around 5,400 tonne of cement daily from over 85 cement depots within the city limits, amounting to about 1.97 million tonne annually (see *Graph 1: Amount of cement trade from various depots and the number of depots of various cement production companies*). With the expected surge in urban development, this demand is projected to soar to 9.85 million tonne over the next five years.

Map 6: Location of cement manufacturing plants in proximity of Jaipur city

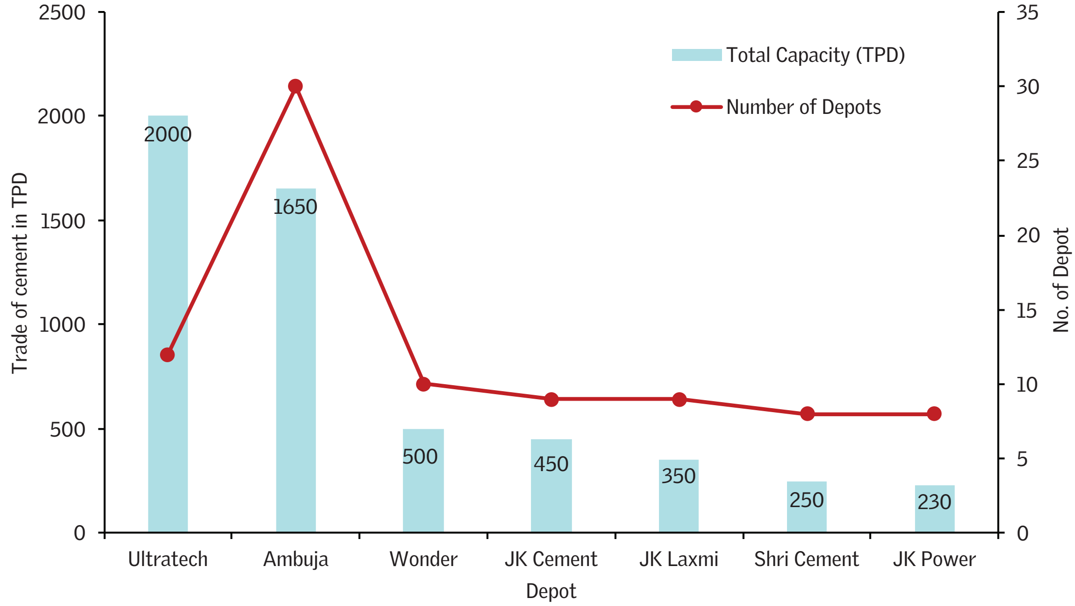


Source: CSE

Based on the daily cement trading database, CSE estimates in this study that 70 per cent of the cement traded is used for building construction, that is approximately 3,780 tonne or 75,600 bags of cement utilized daily for this purpose. Analysis of multiple Bills of Quantities (BOQs) indicates that about 0.4 bags of cement are needed for constructing 1 square foot (ft^2) of area. This usage translates to about 1.89 lakh ft^2 or 17,388 square metre (m^2) of construction daily (see *Figure 5: Estimation of C&D waste from cement consumption of the city*).

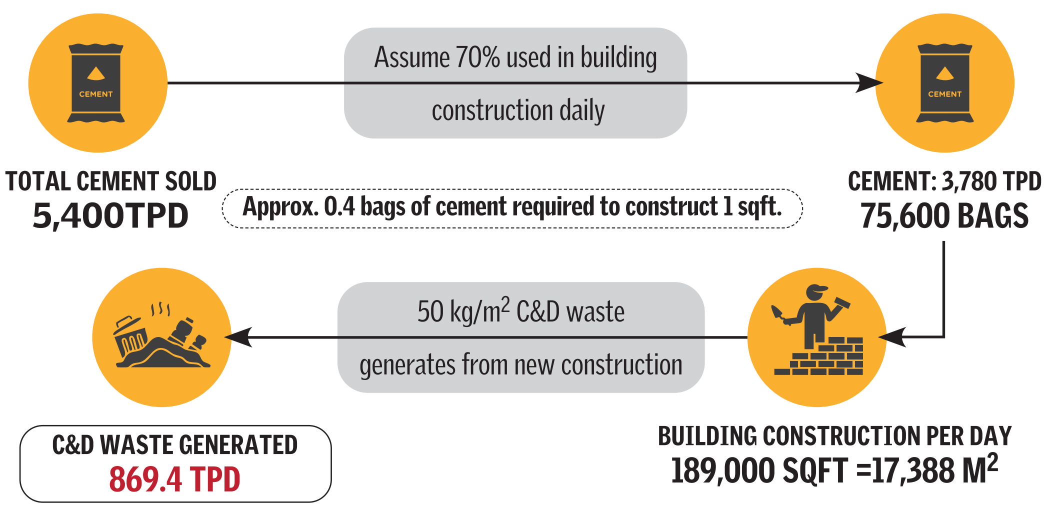
Additionally, with this level of construction activity, the city generates around 869.4 tonne per day (TPD) of C&D waste. This estimate follows the guidelines by

Graph 1: Amount of cement trade from various depots and the number of depots of various cement production companies



Source: CSE

Figure 5: Estimation of C&D waste from cement consumption of the city



Source: CSE

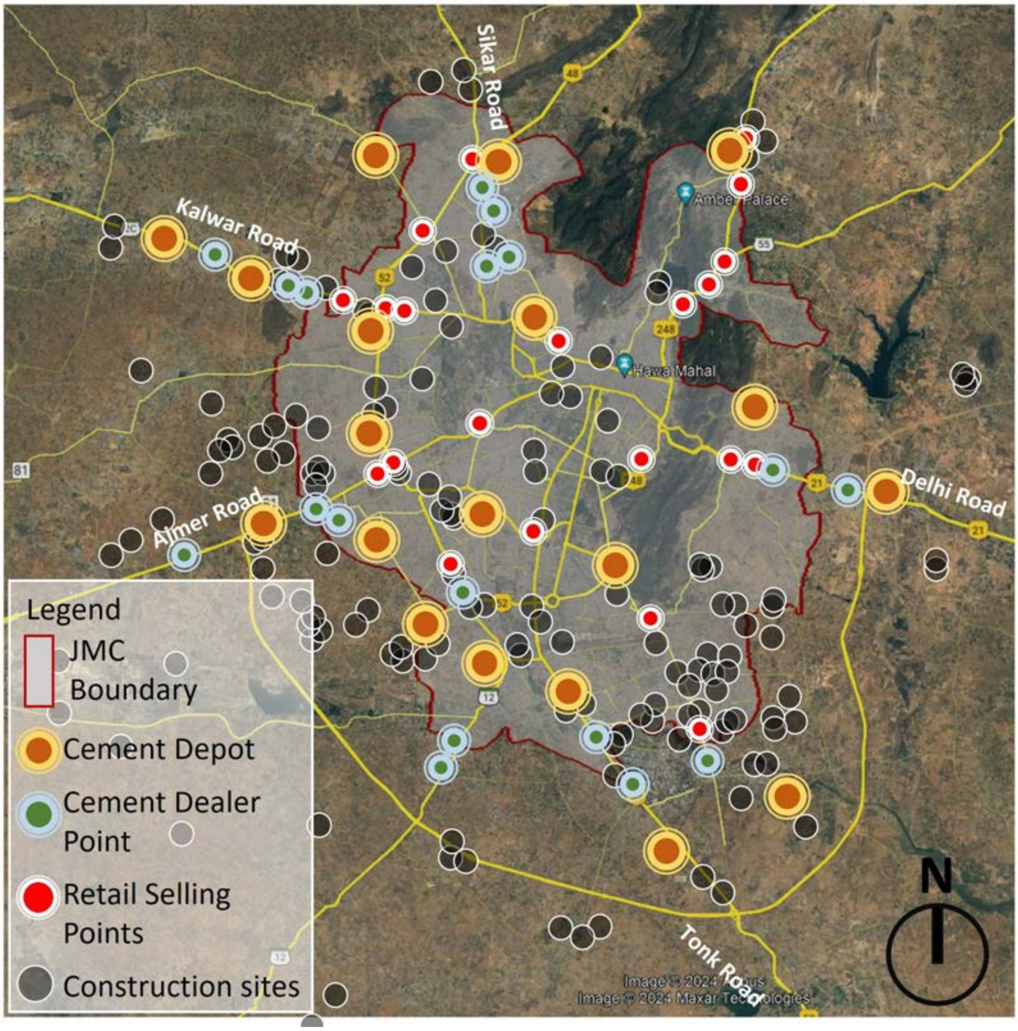
the Technology Information, Forecasting & Assessment Council (TIFAC), which suggests that new construction generates about 50 kg of C&D waste per square metre.[31] This amount of C&D waste far exceeds the capacity of the planned C&D waste processing facilities in Jaipur, creating a challenge for waste processing and disposal today as well as in the future. The mismanaged C&D waste is likely to be disposed through illegal dumping practices, contributing to severe environmental problems such as dust pollution, water contamination, and habitat disruption. The lack of enforcement and sufficient processing facilities means that the waste management system is unable to cope with the growing volume of C&D debris, leading to unregulated waste piling up in unauthorized locations and landfills.

Additionally, the cement industry in Rajasthan is a major contributor to greenhouse gas (GHG) emissions. As per the GHG Platform of India, Rajasthan's cement production emerged as the primary contributor to greenhouse gas emissions in 2018, emitting 16.67 million tonne of CO_2 equivalent. This constituted 54.51 per cent of the total emissions from the industrial sector in Rajasthan.[32] Clinker is the main ingredient in cement and the amount of CO_2 emitted from the cement manufacturing process is directly proportional to the amount of clinker produced. Currently, cement manufacturing relies heavily on carbon-intensive fossil fuels, which add to CO_2 emissions. Clinker production process accounts for 90 per cent of total CO_2-related emissions from manufacturing Portland cement. The remaining 10 per cent is from other sources, majorly electricity consumption.[33] Cement production, not only releases significant amounts of CO_2, but also emits other pollutants, such as particulate matter, that can severely degrade air quality.

The cement trading market in Jaipur is segmented into two primary sectors—large construction projects and individual builders, each with distinct procurement methods and pricing structures. Large-scale construction sites and builders typically source cement directly from cement plants through authorized dealers appointed by cement manufacturing companies. This approach allows them to secure bulk quantities at competitive rates, which generally range from Rs 280–285 per bag of cement suitable for RCC (Reinforced Cement Concrete).

In addition to large construction projects, major construction material dealers also source cement directly from plant operators. These dealers are strategically located in key industrial areas like Viswakarma Industrial Area, Kalwar Road, Sanganer, Bagru, and along Ajmer Road on the outskirts of Jaipur, which facilitate easier access to construction sites and efficient logistical management (see *Map 7: Location of cement depots, various dealer points and retail seller points*).

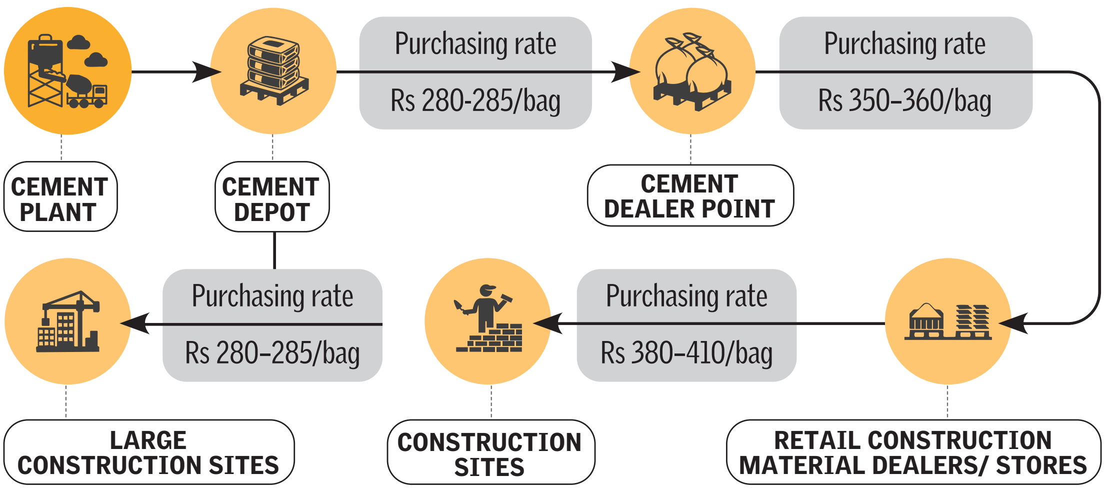
Map 7: Location of cement depots, various dealer points and retail seller points



Source: CSE

On the other hand, individual builders for smaller projects purchase cement through local dealers or retail sellers, who act as intermediaries between large construction material dealers and end users. Retail sellers buy cement at wholesale rates from large construction material dealers, typically between Rs 350–360 per bag, and sell it to the customer at retail prices ranging from Rs 380–410 per bag. This markup reflects the additional costs associated with smaller purchase volumes, storage, and transportation. Cement companies also maintain their own depots across the city to manage storage and distribution, ensuring a consistent supply and reducing lead times for deliveries to various projects (see *Figure 6: Trade chain of cement in Jaipur city*).

Figure 6: Trade chain of cement in Jaipur city



Source: CSE

Ambuja Cement depot near Sanganer

Source: CSE

Cement dealer doint and material retail seller shop

Source: CSE

This market segmentation underscores the price disparity between bulk and retail purchases, driven by the efficiencies of scale that large projects enjoy as compared to the additional costs faced by individual buyers. The strategic positioning of major dealers in industrial zones helps minimize congestion and streamline logistics, although it may increase transportation costs for inner-city projects as well as contribute to dust pollution.

As Jaipur expands, the rising demand for cement will increase emissions and strain waste management systems. Cement production across Rajasthan's plants will scale up rapidly to meet construction needs, leading to higher GHG emissions. To balance growth with environment preservation, the cement industry must adopt sustainable practices and cleaner technologies. Effective policy interventions, stricter regulatory oversight, and the promotion of greener alternatives are crucial to manage the environmental impact.

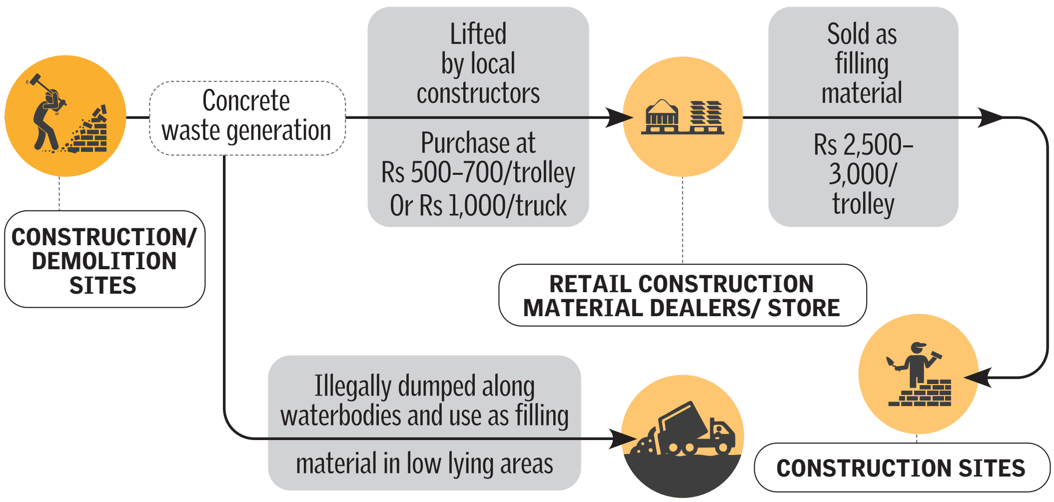
Enhancing C&D waste processing capacity, enforcing waste disposal regulations, and encouraging sustainable construction are vital to mitigating these effects.

Trade chain of concrete waste

Concrete waste, comprising cement and aggregates, constitutes a major portion of C&D waste. Its disposal practices have significant impacts on both environmental and urban landscapes. Typically, this waste often ends up in poorly managed landfill sites, adding to the growing challenge of urban space scarcity. The informal sector primarily manages this concrete waste in the city, which is often considered a nuisance by the urban local bodies and a challenge for formal waste management systems. Local material dealers have capitalized on this opportunity, creating a profitable business model by collecting, processing, and redistributing concrete waste that would otherwise be discarded or improperly disposed of. This informal system, while economically advantageous for those involved, remains unregulated and environmental risks.

For instance, in Jaipur, local material dealers typically purchase concrete waste directly from construction and demolition sites at very low rates, typically between Rs 500–700 per trolley or around Rs 1,000 per truck. For builders, this arrangement offers a convenient and cost-effective solution to clear their sites of concrete waste—an inevitable byproduct of construction activities. By removing debris at a nominal cost, dealers help builders maintain project timelines and site cleanliness without the need for formal waste disposal methods.

Figure 7: Trade chain of concrete waste



Source: CSE

Once acquired, the dealers resell the concrete waste at major marked-up prices, ranging from Rs 2,500–3,000 per trolley, primarily to other builders or for use in low-lying landfilling projects (see *Figure 7: Trade chain of concrete waste*). This marked-up resale price allows dealers to profit substantially from debris, which is essentially considered waste by the government. The process not only generates revenue for the dealers but also fills a gap in the market for cheap filling materials. However, this informal trading system is largely unregulated, leading to potential environmental impacts such as illegal dumping, contamination of land and water bodies, and increased dust and air pollution.

While the informal sector repurposes concrete waste, it operates outside environmental regulations, leading to issues like improper disposal and risks to soil and water quality. This lack of oversight can cause site instability and increased flood risks.

To address these challenges, formalizing the concrete waste trade is crucial. It is imperative to regulate these activities to ensure adherence to environmental standards, improve waste management practices, and enable better tracking of waste flows. This formalization would also foster sustainable urban waste management through incentives for recycling, the creation of licensed recycling facilities, and stricter disposal regulations. By integrating informal practices into a structured system, cities can turn environmental challenges into economic opportunities, promoting sustainability and improving urban quality.

Metal

Metal, especially iron and steel, is essential in the construction sector due to its strength, durability, and versatility. Steel or iron is primarily used to reinforce bars (rebars) in concrete, provides the necessary tensile strength to build robust and resilient structures like high-rise buildings, bridges, and large-scale infrastructure.

Iron forms the backbone of structural frameworks, beams, and columns, offering stability and support. Iron's recyclability also supports sustainable construction practices, reducing waste and environmental impact while contributing to the safety, longevity, and economic viability of infrastructure projects.

Trade chain of new metal

Iron and other metal industries are catering to the rapid urbanization of Jaipur. In Jaipur, various industrial areas like VKI, Jhotwara among others serve as key nodes in the iron supply chain. Dealers in iron rebars procure iron from local industries and then distribute it to retail sellers, effectively bridging the gap between production and end-use.

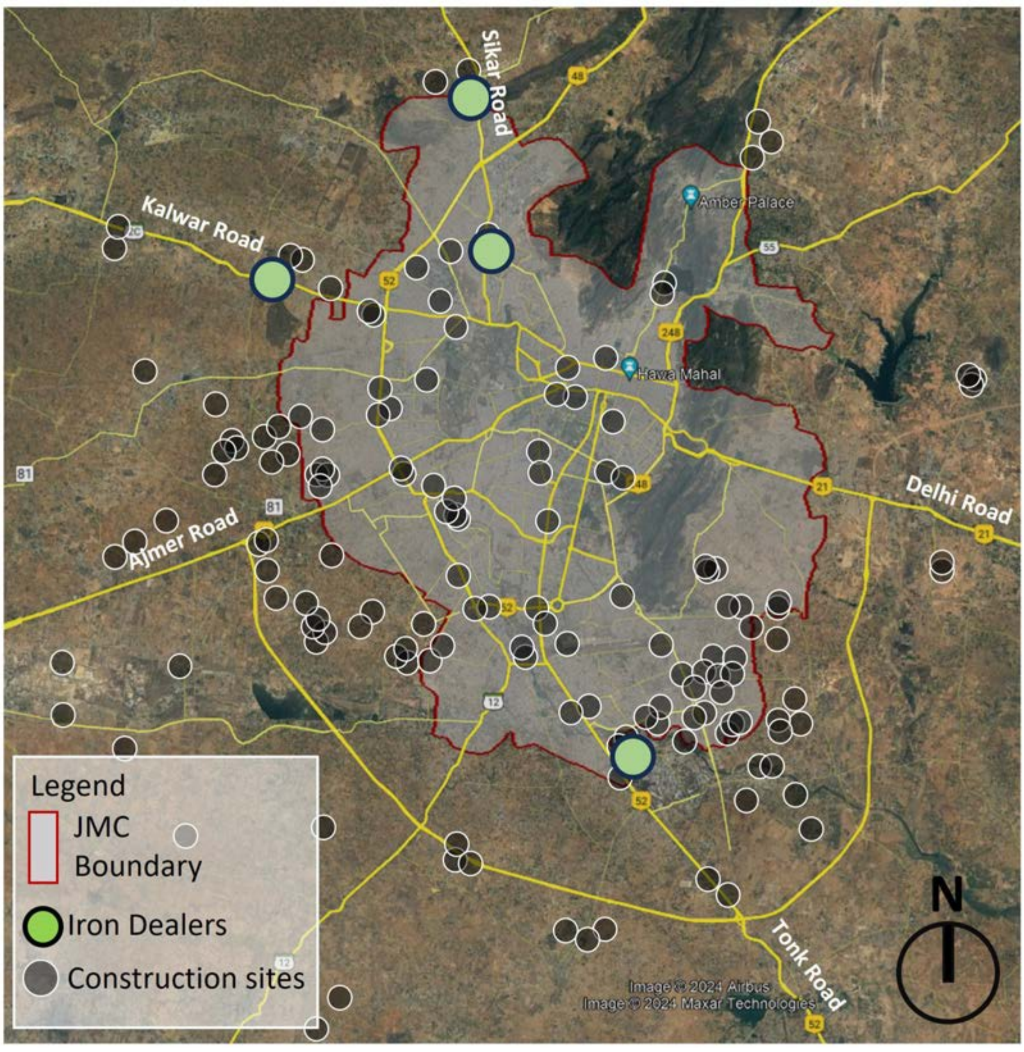
Iron prices fluctuate daily based on market demand and manufacturing costs. Dealers purchase iron at Rs 60–62 per kg. Then, they sell it to retailers at slightly higher rates at Rs 62–63 per kg. Retailers, who directly serve builders and construction projects, sell iron at Rs 70–75 per kg.

Iron dealer in Kalwar road

Source: CSE

The iron dealers are strategically located in key industrial zones such as VKI, Jhotwara, Bakrota, and Sitapur (see *Map 8: Location of iron and metal dealers in Jaipur*). These locations are facilitating the efficient distribution of iron, ensuring that the supply meets the burgeoning demands of Jaipur's construction industry. The trade chain in this sector demonstrates a clear markup progression from dealers to retailers, reflecting the costs associated with procurement, distribution, and retail. This structured approach ensures that the city's construction needs are effectively met while also highlighting the vital role played by various stakeholders in the iron supply chain.

Map 8: Location of iron and metal dealers in Jaipur



Source: CSE

Trading of metal scrapes

The value chain of iron scrap in Jaipur, through the informal sector, helps to establish a circular economy within the construction and metal industries, effectively reducing waste and promoting sustainability. Discarded iron rebars are initially collected by scrap dealers from construction sites and households, purchased at the rates of Rs 20–Rs 25 per kg. These dealers then sell the rebars to small-scale vendors at a markup, ranging from Rs 30–35 per kg.

The journey of the scrap continues as small-scale vendors sell the metal rebars to larger *loha* (iron) mandi dealers in areas like Sewaram Sector 35, where prices rise to Rs 38–40 per kg. At this stage, the iron scrap undergoes sorting and cutting into smaller pieces to prepare it for the next phase of the value chain. The processed scrap is then transported to foundry workshops in industrial hubs such as Bagru, Jhotwara, and VKI, where it is sold for about Rs 40–42 per kg. Here, the scrap is melted and recast into new products, thus, completing the recycling loop.

This entire process not only provides economic opportunities across multiple levels of the supply chain but also significantly reduces waste by reintroducing discarded materials back into the production cycle. By transforming scrap into valuable resources, this circular approach supports the sustainable development of Jaipur's construction and metal industries, mitigating the environmental impact of iron waste while driving the local economy.

Iron scrap dealers point in Jaipur

Source: CSE

Brick

Burnt clay bricks used in construction projects throughout Jaipur are sourced from various brick kilns located in both Rajasthan and Haryana. These brick kilns worsen air pollution through both stack and fugitive emissions, adversely affecting air quality and human health. Brick kilns in the region predominantly utilize Fixed Chimney Bull's Trench Kiln technology (FCBTK) and rely on coal and husk as primary fuel sources. In most brick kilns, stack monitoring is conducted to track emissions of pollutants like particulate matter (PM), sulphur dioxide (SO_2), and carbon monoxide (CO). Average concentrations in the stacks are 172ffl76 mg/Nm^3 for PM, 114ffl47 mg/Nm^3 for SO_2, and 484ffl198 mg/Nm^3 for CO. Emission factors per kg of fire bricks range at about 0.81–1.18 g for PM, 0.57-0.71 g for SO_2, and 2.07-2.80 g for CO. Corresponding emission factors per kg of coal used are 13–29 g for PM, 9–15 g for SO_2, and 40–56 g for CO_2.[34]

Rajasthan has 929 registered brick kilns, with Jaipur, Hanumangarh, and Sri Ganganagar districts serving as major hubs. Jaipur ranks third in the number of kilns in India.[35] This extensive use of outdated technology and polluting fuels has resulted in severe environmental degradation. Violations of particulate matter (PM_{10}) concentration limits are prevalent across most monitoring stations in these districts. According to global burden of disease estimates, Rajasthan has recorded over 65,000 deaths due to exposure to $PM_{2.5}$, with around 801 deaths specifically attributed to brick kilns as of 2018.[36]

Brick kilns emitting polluting smoke near Ugriyawas in Jaipur district

Source: CSE

In response to these issues, recent reports indicate that 90 per cent of brick kilns in the Alwar district have transitioned to zig-zag technology to mitigate pollution,[37] as mentioned in *Down to Earth*, CSE, March 2024. Additionally, nearly all kilns in Alwar have adopted biomass fuels in compliance with the Commission for Air Quality Management (CAQM) notification, aiming to reduce emissions and improve air quality in the National Capital Region (NCR).[38] These measures reflect an ongoing effort to address the severe environmental and health impacts associated with traditional brick kiln operations.

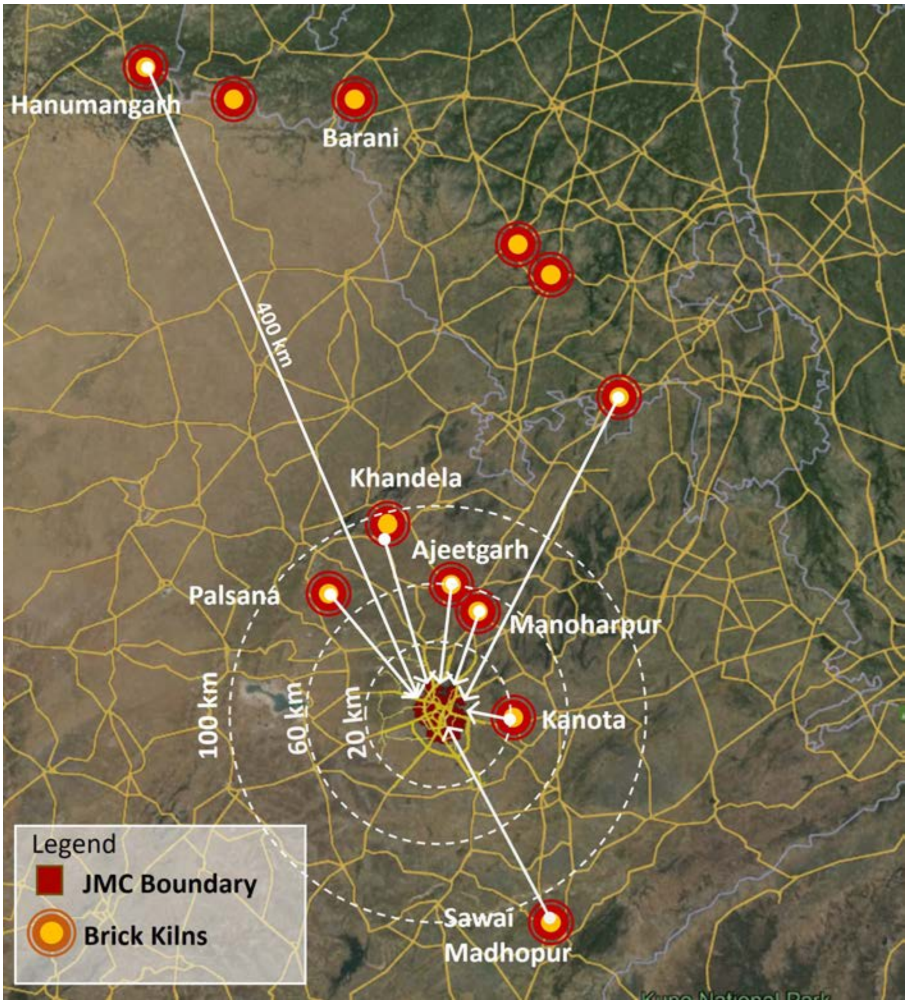
Trade chain of fresh bricks

Despite the issue of air pollution, the city requires bricks to build infrastructure and support the rapid development. To meet the construction requirements, about 9.5 million bricks are traded daily within Jaipur city. A significant portion of the bricks are supplied from several kilns located within a 20–100 km radius of Jaipur, such as Kanota, Ajeetgarh, Manoharpura, Khandela, and Palsana (see *Map 9: Location of brick kilns which supply bricks to Jaipur city*). Transportation of bricks from these nearby kilns to Jaipur is facilitated using manual dumper trucks and tractor trolleys. The pricing of bricks is determined by their quality and the distance they need to travel to reach the city.

For instance, Kanota, located 20 km from the Jaipur city, has about 18 brick kilns.[39] Due to its close proximity to the city, bricks sourced from Kanota kilns are the most cost-effective, priced at around Rs 3.50–4.50 per brick, along with economical transportation costs. In contrast, the first-class quality bricks are majorly sourced from the kilns of Ajeetgarh. Those Ajeetgarh bricks are priced at around Rs 4.50–5.0 per brick. Khandela bricks are priced slightly higher at around Rs 5–5.50 per brick. The most expensive bricks come from Hanumangarh, which is about 400 km away from Jaipur. With around 290 kilns, Hanumangarh produces high-quality bricks that command prices ranging at around Rs 5.50–Rs 6 per brick, reflecting both their superior quality and the higher transportation costs.

These bricks sourced from various kilns are purchased by dealers of eight brick mandis spread across the city, with most of them situated on the outskirts (see *Image: Brick mandi at Kalwar road*). These brick mandis are strategically positioned along highways or in close proximity to highways, facilitating efficient transportation and accessibility for both suppliers and buyers. This location choice ensures smoother logistics operations and reduces transportation costs, thereby optimizing the distribution process. Additionally, the proximity to highways enables easier access for heavy vehicles involved in the transportation of bricks,

Map 9: Location of brick kilns which supply bricks to Jaipur city

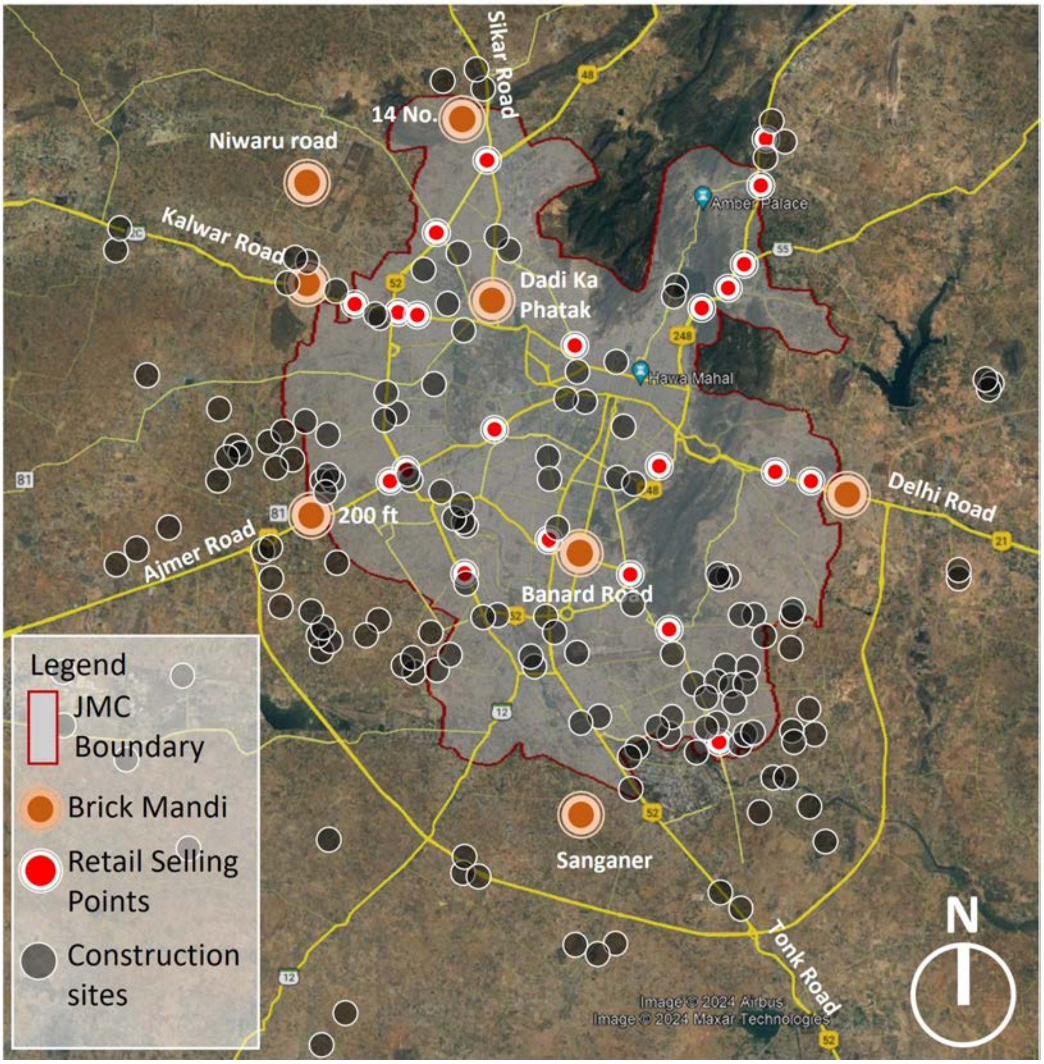


Source: CSE

Brick mandi at Kalwar road

Source: CSE

Map 10: Location of brick mandis and retail selling points

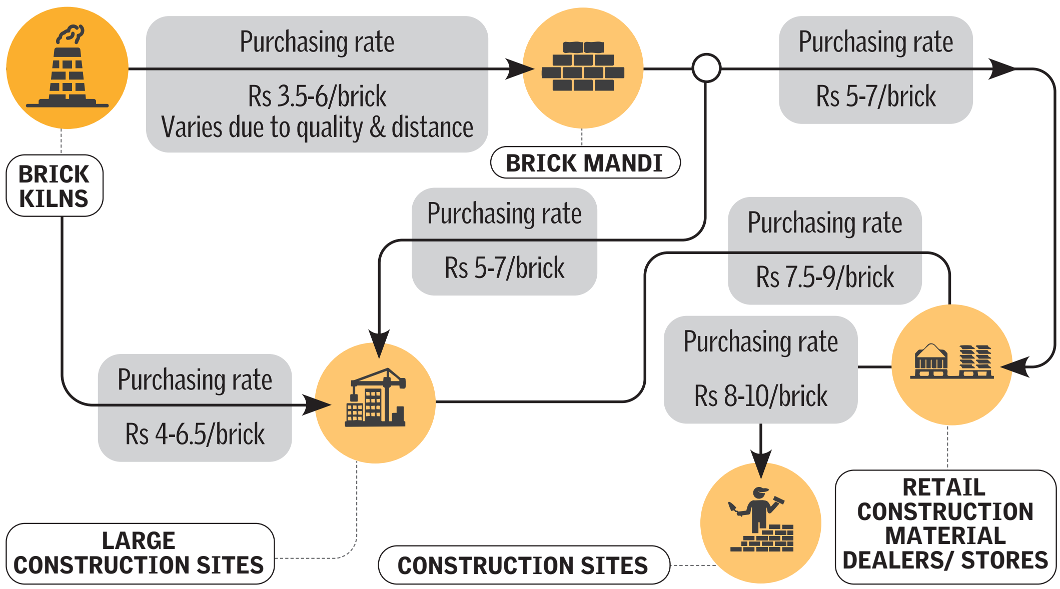


Source: CSE

further streamlining the supply chain (see *Map 10: Location of brick mandis and retail selling points*).

Brick mandi dealers typically purchase bricks at Rs 4–6 per brick and sell them at Rs 6–7 per brick, thereby securing a profit margin of about Rs 2–3 per brick. Builders buy directly from these mandis while local consumers seeking bricks for personal construction projects often purchase from retail stores, where prices range at about Rs 8–9 per brick. Brick brokers facilitate the supply chain by sourcing from kilns and delivering them to construction sites, often benefiting from the difference between their procurement and selling prices. This informal

Figure 8: Trade chain of brick in Jaipur



Source: CSE

trading network not only supports the city's construction needs but also operates with varying profit margins based on the quality and transportation costs of the bricks (see *Figure 8: Trade chain of brick in Jaipur*).

Trade chain of waste or used bricks

Brick mandi dealers as well as retailers also trade broken bricks, essential to the construction material supply chain. These broken bricks, while considered secondary due to their reduced quality, are valued for specific construction applications. Typically, broken bricks are used for purposes like brick soling beneath roads or as fill material.

The pricing of broken bricks varies depending on their source and intended use. Broken bricks from demolition sites are generally sold at Rs 400–500 per trolley. Dealers in brick markets sell these bricks to construction sites at higher rates at Rs 800–1,000 per trolley. Retail sellers, who offer these bricks directly to consumers, charge at around Rs 1,000–1,500 per trolley. Despite their lower quality compared to new bricks, broken bricks are a cost-effective option for various construction needs, providing an additional revenue stream for the informal sector of construction industry. This trade chain helps manage the waste generated from brick production and handling. By recycling these bricks, dealers contribute to

Broken bricks stored in brick mandi

Source: CSE

reducing construction waste and optimizing resource use in the industry. This practice also helps lower costs for builders while maintaining the efficiency of the brick supply chain.

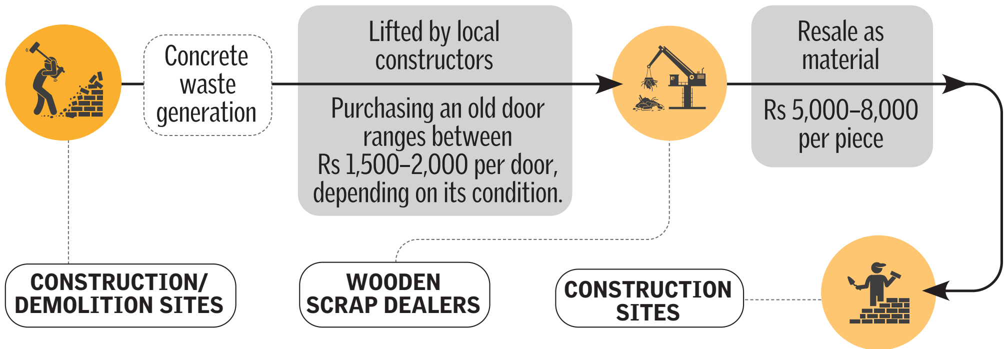
Trade chain of wooden scrap

Wooden elements such as doors, windows, cabinets, and planks are widely used for both functional and structural purposes in the construction industry. Wooden planks are commonly employed as shuttering material and for providing temporary support to structures during the construction phase. However, due to the inherent

Wooden scrape dealer in Ajmer Road

Source: CSE

Figure 9: Trade chain of wooden scrap in Jaipur



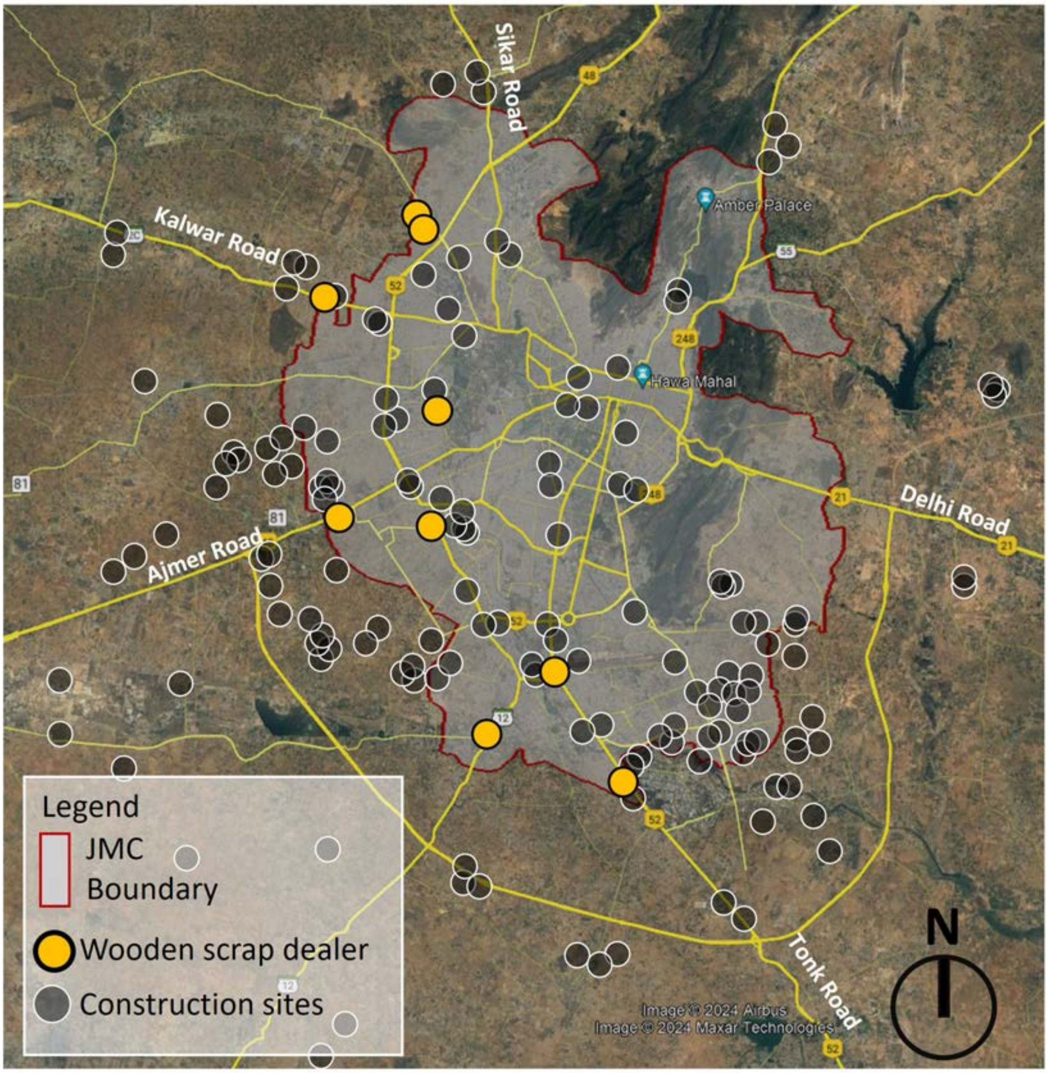
Source: CSE

material limitations of wood, these shuttering materials can typically only be reused four to five times before they are discarded. Similarly, during demolition or interior renovations, wooden components like doors and windows are often removed and considered as scrap.

The disposal and trade of wooden scrap are largely handled by the informal sector within cities like Jaipur. Scrap dealers play a pivotal role in this process, purchasing discarded wooden items from construction sites and households. The value of this scrap varies depending on the quality and type of the wood. For instance, old wooden doors may be purchased at Rs 1,500–2,000 per door. Skilled refurbishers often add value to these discarded items by repairing and restoring them, thereby extending their lifecycle. Once refurbished, these doors can fetch much higher prices, typically selling for rates at about Rs 5,000–6,000 per door in the secondary market (see *Figure 9: Trade chain of wooden scrap in Jaipur*).

Wooden scrap yards and refurbishing sites are dispersed throughout Jaipur, strategically positioned to facilitate the collection and resale of wooden materials (see *Map 11: Location of wooden scrap dealers in Jaipur*). This network not only supports a circular economy by reducing waste but also provides affordable alternatives to new wooden products for consumers. By salvaging and repurposing wooden materials, the informal sector effectively diverts waste from landfills, contributes to resource conservation, and offers an eco-friendly solution to meet the demand for construction materials. This practice highlights the potential for integrating sustainable methods within the construction industry, emphasizing the value of reusing and recycling materials to mitigate environmental impacts.

Map 11: Location of wooden scrap dealers in Jaipur



Source: CSE

3. Gap between formal and informal setup

The composition of C&D waste includes a wide variety of different materials. Concrete and masonry waste comprises 53–60 per cent of C&D waste.[40] These are often challenging to process and end up in landfills or are illegally dumped in low-lying areas or wetlands. To address this issue, mechanized processing is necessary to enable the reuse of these materials. Incorporating recycled concrete aggregates (RCA) into new concrete effectively reduces the depletion of natural resources and improves waste management practices.

The Indian Standard Code (ISC) 383:2016 requires the replacement of up to 20 per cent of natural coarse and fine aggregates with RCA in reinforced concrete.[41] This strategy not only lessens the environmental impact from natural resource extraction but also enhances circularity in the construction industry's value and trade chain.

Formal setup of the city

The Nagar Nigam Jaipur, Heritage has taken steps to address the growing issue of C&D waste by constructing a processing unit near Langariyawas with a capacity of 300 tonne per day (TPD) (see Image: *C&D waste processing plant in Langariyawas, Jaipur*). Additionally, the Nagar Nigam Jaipur, Heritage had already notified C&D waste by-laws in 2018 to promote efficient waste management and environmental protection. These regulations outline the responsibilities of waste generators, urban local bodies (ULBs), and service providers, emphasizing waste segregation, reuse, and recycling. Under the by-laws, waste generators are required to segregate their waste into five categories—concrete, bricks and mortar, soil, steel, and wood and plastics. This segregation allows for easier recycling and proper disposal. Generators can hand over the segregated waste to the ULBs and pay user charges, while bulk generators need to submit waste management plans for approval prior to construction, demolition, or remodeling activities.

To further promote circularity, the by-laws mandate that up to 40 per cent of waste must be reused on-site as aggregates. Additionally, the by-laws stipulate that recycled C&D waste products should replace 10–20 per cent of construction materials in municipal and government contracts, driving demand for recycled products and contributing to a circular economy.

C&D waste processing plant in Langariyawas, Jaipur

Source: CSE

The ULBs are responsible for developing a comprehensive city action plan, which includes the collection, transportation, and disposal of C&D waste, and ensuring the integration of C&D waste management into the building permission process. The JMC also enforces compliance through surveillance, promotes the use of recycled products in government projects, and offers incentives to encourage the adoption of recycled materials.

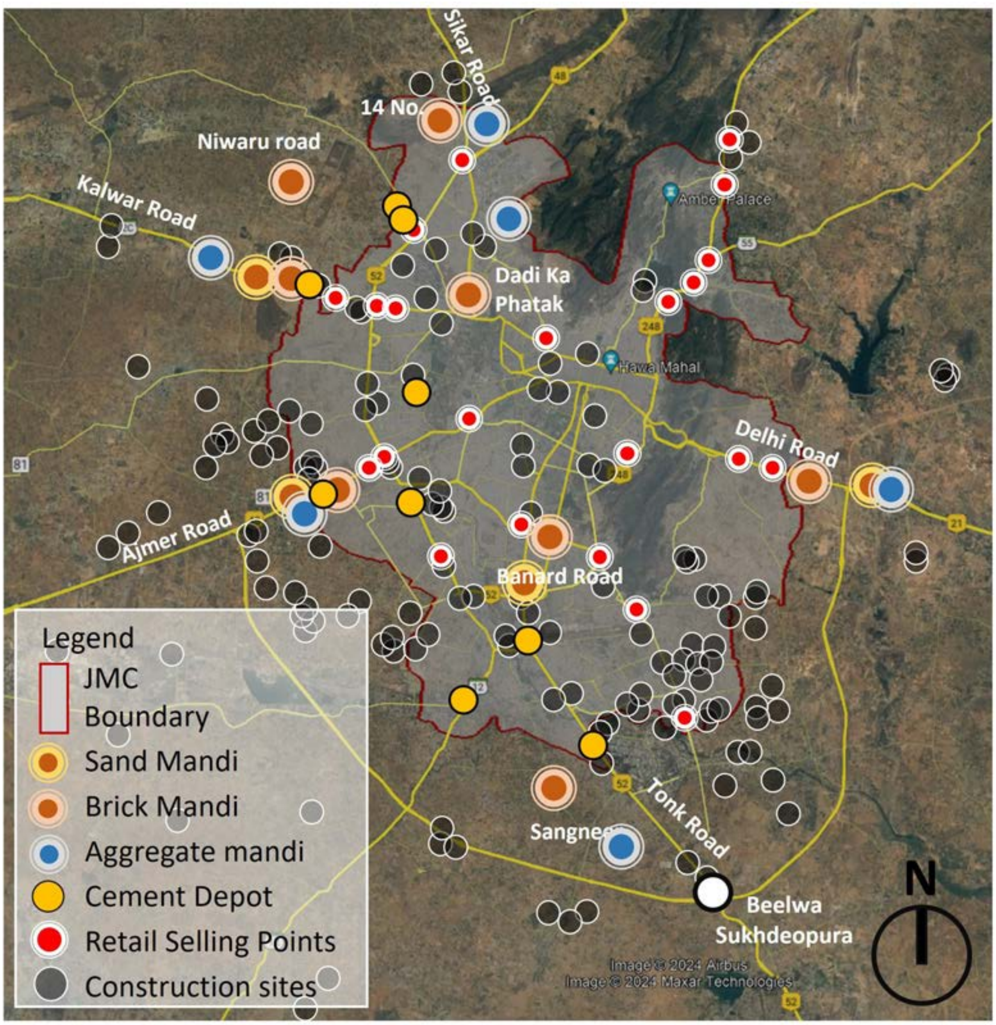
For processing the C&D waste, the ULB charges Rs 390 per tonne, and the city has proposed 11 collection points to facilitate efficient waste management. Once the dedicated C&D waste processing plant is operational, this fee will cover the collection, transportation, and processing of waste. Currently, waste generators pay a malba fee ranging from Rs 1,000 to Rs 10,000, depending on plot size, when seeking building permission, which is refundable if they handle waste disposal independently. The JMC offers C&D waste collection services through an on-call system, however, only a few waste generators adhere to this formal process.[42]

Despite various initiatives and rules, C&D waste management in Jaipur is currently largely managed by the informal sector, which offers lower transportation fees compared to the JMC. A field investigation conducted by CSE for this report in February 2024 revealed that a vast amount of C&D waste is being improperly discarded into water bodies, along roadsides, and on vacant lands around the city's perimeters. Additionally, waste from demolition activities often ends up at sanitary landfills through private contractors while informal sector workers transport it to various vacant areas using tractor trolleys. These improper disposal methods lead to severe environmental and health risks, such as land degradation, soil contamination, and groundwater pollution. Immediate action is required to address these issues to protect the environment and public health.

4. Areas of dust non-compliance

Major material markets, or mandis near Kalwar Road, Sanganer, Sikar, and Ajmer Road (see *Map 12: Location of various material mandis*) are strategically positioned along key transit routes, providing convenient access for construction activities in Jaipur. However, in an effort to increase profits, informal workers often overload trucks, leading to higher dust emissions and compromised operational safety standards.

Map 12: Location of various material mandis



Source: CSE

Material mandi without any dust control measures (left); illegal C&D waste dumping sites (right)

Source: CSE

These markets are major contributors of dust pollution as construction materials like sand and aggregates are often stored uncovered, allowing wind to disperse fugitive dust, and is exacerbated in windy conditions. Inadequate dust control during loading, unloading, and transport, without measures like water sprinkling or covering materials, further worsens air quality.

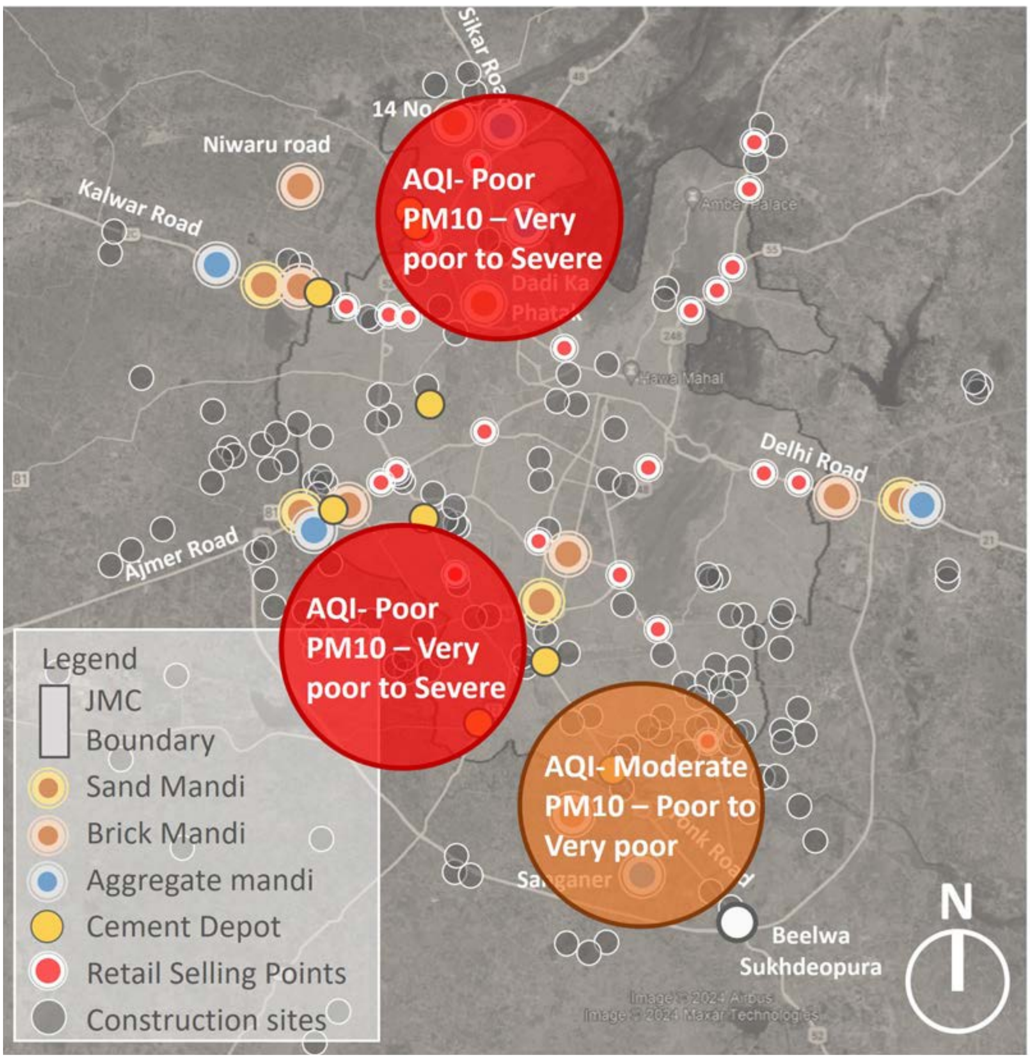
The movement of trucks, especially on unpaved or poorly maintained roads, generates additional dust, turning these areas into major sources of both linear and area dust emissions. This air pollution not only affects nearby residential areas but also contributes to environmental degradation, raising particulate matter (PM) levels and posing serious health risks, particularly respiratory issues. Additionally, informal workers dispose of waste in low-lying areas or near water bodies, which not only contaminates land and water but also poses significant risks to local ecosystems and public health.

According to the Rajasthan State Pollution Control Board (RSPCB), the Air Quality Index (AQI) near Ajmer Road and Sikar Road is rated as 'Very Poor to Severe' (see *Map 13: AQI of Jaipur*). The lack of effective dust control highlights the urgent need for better regulations and enforcement to ensure more sustainable construction practices in these areas.

Since these mandis are outside the jurisdiction of Jaipur Nagar Nigam (Greater), these market areas fall under a different regulatory framework, allowing more flexible approaches. This flexibility presents both challenges and opportunities. On one hand, the reduced oversight often leads to unsafe practices like overloading trucks, increasing dust emissions and undermining operational safety. On the other hand, it offers an opportunity for the government to tailor regulatory interventions that are responsive to the specific conditions of these areas.

The government can leverage this flexibility to implement a targeted monitoring that strengthens the enforcement of environmental regulations. By collaborating

Map 13: AQI of Jaipur



Source: Rajasthan State Pollution Control Board with key stakeholders such as the Public Works Department (PWD), the Jaipur Development Authority (JDA), the National Highways Authority of India (NHAI), and the Rajasthan Industrial Development and Investment Corporation (RIICO), the government can establish an integrated and effective regulatory framework in the state.

This cooperative approach allows different agencies to pool resources, expertise, and authority, ensuring that construction practices are not only economically viable but also environmentally sustainable. This approach will enable the government to promote infrastructure development while mitigating the negative impacts on air quality, safety, and public health.

5. Way forward

As Jaipur is developing its C&D waste management ecosystem, there are several opportunities to not only unlock circularity by maximum recycling and reuse but also to curb dust pollution and carbon emissions substantially.

Value trade chain assessment critical for better estimations

Current quantifications of C&D waste are based on actual waste generation in cities. This generation is a very small fraction as the informal sector processes about half of the C&D waste according to this study. Of the remaining half, which is mostly concrete, a big fraction is used in backfilling. The final residue that is disposed of at dumpsites or unauthorized areas is what forms basis for these quantifications. A study of construction value trade chain and cement consumption under it can help arrive at more realistic numbers. This estimate is crucial for the knowledge of urban local bodies in their process to select a concessionaire for C&D waste management. This helps in better negotiation of concessionaire fee and making an informed decision.

A well-structured circularity can also enable appropriate estimations of C&D waste that is necessary to plan and size the formal recycling plants. Current estimations are based on collected waste which in most cases is an underrepresentation. For instance, Jaipur has a 300 TPD C&D waste facility but estimation based on cement consumption take this number upwards of 850 TPD. Better estimations provide better negotiation opportunity to urban local bodies on the concession agreement to manage C&D waste.

Jaipur has recently established a processing facility with this exact capacity after it has gone through multiple attempts at selecting concessionaire. This was mainly due to the uncertainty assured, continuous and quality waste feed to the plant. This estimation is important as only energy intensive mixed and concrete C&D waste is processed at the recycling facilities.

The investigation shows that there is a minimum 300 tonne per day (TPD) threshold for economic feasibility of a C&D waste recycling plants in India. Plants smaller than this need support in the form of viability gap funding or public-private partnership. As many cities under Swachh Bharat Mission (SBM) 2.0 are tier 1 towns and smaller, they need clear estimations and a strategy to ensure that majority of C&D waste is recycled with appropriate safeguards. Value trade chain assessments can facilitate that.

There are also examples like Chandigarh that has achieved break-even point with a 150 TPD government-run recycling system. A key catalyst here is the public ownership and intent. Municipal Corporation of Chandigarh is responsible for primary and secondary collection of waste, its processing and uptake of the recycled products. This brings to the table maximum collection, efficient recycling, processing in a controlled environment and an enabling mechanism to ensure that all recycled products are taken up for use. Along with these, clear roles and responsibilities, and accountability become essential parameters for maximizing system efficiency and least damage to the environment and public health.

Improve collection efficiency and maximize recycling and integrate informal sector

A strong interface between formal and informal system that is already recycling materials with low processing requirement. In Jaipur about half of the waste does not reach to the ULB but enters the informal value trade chain which operates without any safeguards. An emerging good practice in Hyderabad involves authorized informal workers in primary collection who work with the ULBs. They respond to collection requests raised by generators and transfer the waste to the plant operator at designated collection points. The workers keep the profit and operate with appropriate safeguards. This has proven to have better collection efficiency. Similar solutions can be replicated. Also one of the learning is that a single agency responsible for primary and secondary collection performs better in collection than multiple agencies deployed for the same task. This ensures maximum waste reaches the plant for processing.

Integrate informal sector for C&D waste management and material handling with proper health and environmental safeguards

The material supply chain in Jaipur is a big contributor to dust pollution. Improper handling, transportation and storage practice wherein sand, aggregates, and other materials are frequently left uncovered, allowing wind to displace loose material and generate fugitive dust. Toxic materials handled by the informal sector which mainly works without safety equipment pose severe public health threat as well as environmental concern when released into the ambient air. In response, Jaipur has been ensuring construction materials are transported in covered vessels, creating green buffers along traffic corridors, repairing potholes, paving road shoulders, constructing water fountains at major traffic intersections among other measures under its Micro Action Plan. Such measures need to be expanded to the material markets. This includes recognition of the market, vendors, transporters to bring them under regulatory purview and create framework for accountability and compliance. Examples like Hyderabad and Delhi show that this is possible. In Delhi, as informal sector is appointed for solid waste handling and sorting local state-of-the-art sorting facilities and compactor stations. This provides the ULB with staff, the workers keep the profits and operate in a safeguarded and compliant environment. Same needs to be applied to the C&D waste and material supply chain.

Build guidance on recycled products, possible applications and potential markets

The three-tier informal material market system identified in this assessment is a crucial setup to push uptake of recycled C&D waste products in Jaipur. The material suppliers are the ones who must sell recycled products to ensure high uptake other than government orders made to the plant. These suppliers need to be informed on the emerging recycled products. There is a lot of exploration around the application and use of recycled products, however, recycling plants generally begin with production of aggregates of different sizes. With more feed coming in, the processing transitions to value added products like concrete bricks, floor tiles, paver blocks, bollards, manholes, etc. The primary buyer of these products are government bodies like ULBs, metro rail corporations, public works department, among others, and the private sector is picking up with a demand for concrete blocks. A mapping of such buyers, their requirements ahead of production can demonstrate potential market, set targets and provide a push to increase recycling. Testing, standardization and inclusion of these products in Schedule of Rates will further absorption.

Huge potential to reduce carbon emissions in construction trade chain

The recently established C&D waste management ecosystem brings a great opportunity to process large volume of concrete and masonry waste which previously went unrecovered. This waste can replace large amounts of river sand and aggregates and slash emissions substantially. This study shows if 20 per cent of the daily consumption of fresh aggregates in Jaipur were replaced with RCA as recommended in IS 383, this would result in 12 per cent less emissions. Replacing around 50 per cent clay bricks with fly-ash bricks will further bring it down by 9 per cent. Emission reduction from cement can be in the range of 47 per cent if 35 per cent fly-ash is added to it. With these very possible scenarios, daily emissions from the construction sector can be substantially reduced. These replacements must be prioritized for a circular economy.

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Jaipur is establishing a construction and demolition (C&D) waste ecosystem including a waste processing plant of 300 tonne per day (TPD) capacity. This is a great opportunity to reduce the demand for virgin materials when the city is booming with construction. CSE estimates that Jaipur requires at least 5,400 tonne of cement, 8,100 tonne of sand, 15,200 tonne of aggregates, and 9.5 million bricks while it generates 447 tonne of C&D waste. With proper recycling practices, Jaipur can slash daily CO_2 emissions from the construction sector by 27 per cent.

This study underscores that recycling holds the key in reducing the carbon footprint of the construction sector. It brings the entire construction value and trade chain under lens and highlights several ways to reduce virgin material extraction, increase reutilization of C&D waste, formalize traditional practices and overall foster greening of the construction sector.

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