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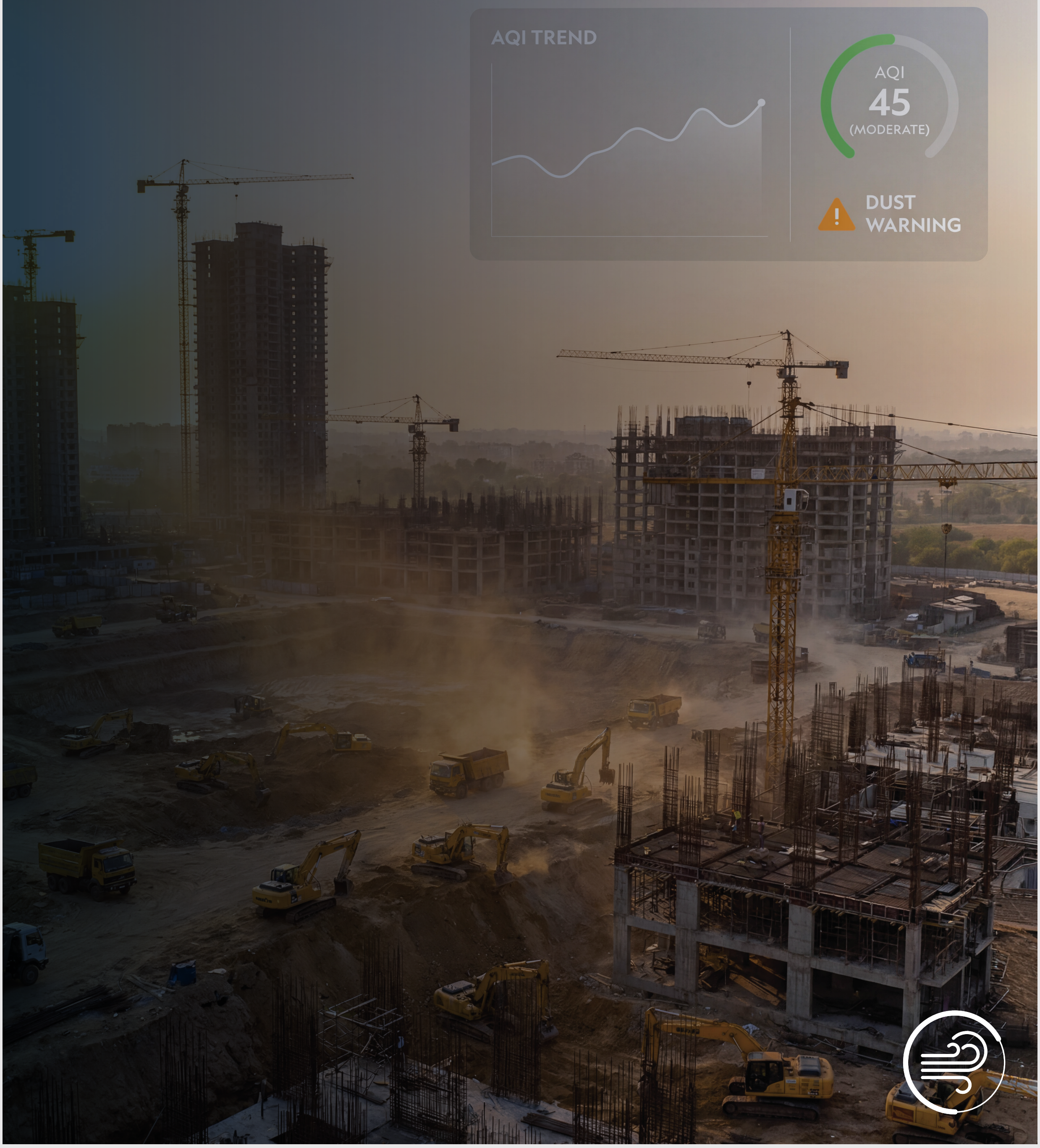
FROM COMPLIANCE MONITORING TO PROCESS INTELLIGENCE: IMPROVING CONSTRUCTION OPERATIONS WITH PM_{10} DATA

By Priyanka Gounder, Rutu Bhanusali



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EXECUTIVE SUMMARY

Construction is one of the largest sources of particulate pollution worldwide, and this reality is especially evident across India, where an unprecedented building boom is colliding with rising urban air pollution. Of all the pollutants a construction site produces, PM_{10} (coarse particulate matter up to 10 µm in diameter) is the most characteristic, heavily regulated, and directly tied to the physical activities occurring on site.

Indian regulation already requires construction sites in polluted cities to monitor PM_{10} and $PM_{2.5}$ and keep them within national thresholds. Yet on the vast majority of sites, that data does one job: it sits in a compliance report. It is collected to prove a site was watched, not to change what the site does. This is the central gap this paper addresses.

The argument is simple. Real-time PM_{10} data is not just a compliance artifact, but an operational signal. When a site can identify, in real-time, which activities spike dust and when weather conditions are carrying it off-site, that same data can drive scheduling, trigger dust suppression, protect workers, and hold contractors accountable. The challenge is not a lack of monitoring technology, but the need to use the data effectively. Realizing that shift requires acknowledging both the capabilities of real-time data and its shortcomings, and weighing the investment against the operational cost of inaction.

This whitepaper sets out why PM_{10} matters at construction sites, what the current monitoring landscape in India looks like, and, at its core, a practical framework for turning PM_{10} readings into better, safer, more compliant construction operations.

INTRODUCTION

India is building at a pace few countries have ever matched. Metro lines, expressways, airports, tunnels, commercial towers, and millions of housing units are under construction across the country. Construction contributes a significant share of national economic output and employs tens of millions of people. It is, by any means, an engine of the country's growth.

Construction and demolition activity is consistently identified as a leading contributor to particulate pollution in Indian cities. It is frequently cited alongside vehicular traffic and industrial emissions as one of the top sources of dust that pushes urban air past safe limits for months at a time. In the National Capital Region and other large cities, construction dust is a recurring trigger for emergency restrictions, including outright bans on building activity during the worst pollution episodes.

Among the pollutants construction generates, PM_{10} is the signature. It is the coarse fraction of particulate matter, dust thrown up by excavation, demolition, material handling, cutting, and the movement of heavy vehicles over unpaved ground. Unlike the finer $PM_{2.5}$, which travels far and lingers, much of PM_{10} settles closer to the source[1], which is precisely why it is so tightly coupled to what is physically happening at a given site at a given moment. Demolition spikes it; a water truck passing over a dry haul road kicks it up; a still, low-wind afternoon lets it accumulate. Since the relationship between activity and emission is so direct, PM_{10} data carries actionable information about the construction process itself. Sites measure dust to satisfy regulators, not to run the site effectively.

UNDERSTANDING PM_{10} AT CONSTRUCTION SITES

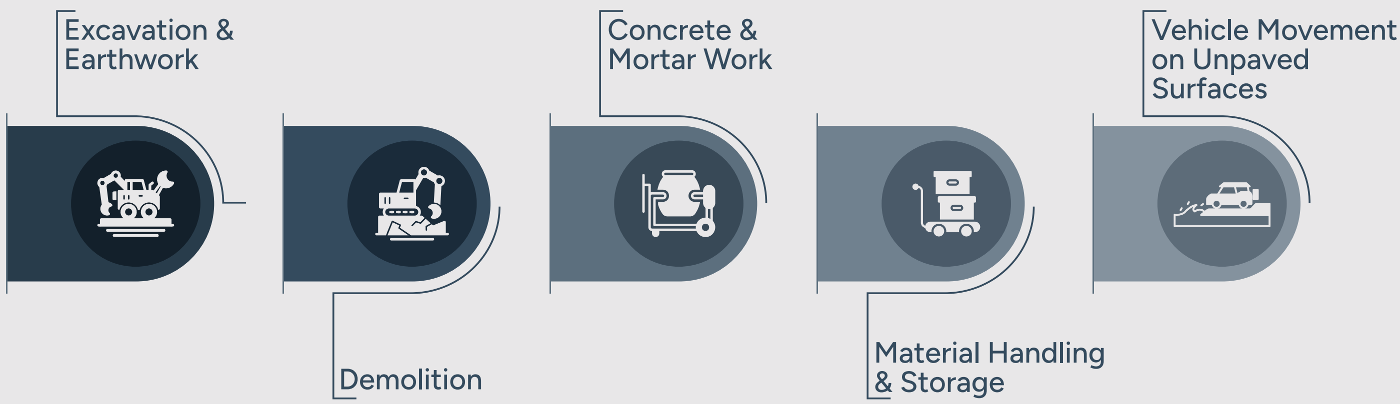
(1). What is PM_{10} and Why it Matters?

PM_{10} refers to particulate matter with an aerodynamic diameter of 10 µm or less, roughly a seventh the width of a human hair. At construction sites, the dominant source of PM_{10} is mechanically generated dust: material crushed, scraped, cut, dropped, or driven over. This distinguishes it from $PM_{2.5}$, which is more often a product of combustion.

The health implications are well established. Particulate exposure is linked to cardiovascular, respiratory, and skin diseases, and elevated mortality rates across a range of conditions. Particles in the PM_{10} range can be inhaled into the airways, making sustained exposure a genuine occupational hazard for construction workers and a nuisance and health concern for communities living near active sites. Because of these risks, air quality standards worldwide set explicit PM_{10} limits: the World Health Organization has recommended a PM_{10} limit of 20 µg/m³ as an annual average and 50 µg/m³ over 24 hours[2].

(2). The Activities That Generate PM_{10}

Not all construction work pollutes equally. Decades of site studies converge on a clear hierarchy of dust-generating activities. The earthwork and foundation phase, excavation, earth moving, and material handling, is repeatedly identified as the single largest source of particulate emission across a construction project's life[2]. Beyond that, the major recurring PM_{10} sources are:



1. **Excavation and Earthwork:** Digging, cut-and-fill, and soil handling that exposes and disturbs fine material.
2. **Demolition**: The breaking of concrete and masonry, one of the most intense short-duration dust events on any site.
3. **Concrete and Mortar Work:** Mixing and cutting operations. Site measurements of concrete and mortar-mixing activities have recorded extremely high localized PM_{10} peaks, with mortar mixing producing readings of several hundred micrograms per cubic meter at the point of work[3].
4. **Material Handling and Storage:** Loading, unloading, transferring, and open stockpiles that are resuspended by wind.
5. **Vehicle Movement on Unpaved Surfaces:** Trucks and plant driving over dry haul roads are a dominant source of fugitive dust, often the largest single PM10 contributor on road and infrastructure projects[4].

(3). How PM_{10} Levels Vary By Activity, Time, and Weather?

Crucially for site management, PM_{10} is not just a function of what is being done; it is strongly shaped by time period and underlying conditions. Studies of construction sites have found that wind speed, temperature, and the intensity of construction activity together show a strong statistical relationship with PM_{10} levels[5], with wind speed being the strongest single driver[6].

The mechanism is intuitive: low wind speeds prevent dust from dispersing, so particles remain suspended near the site longer and concentrations rise. Higher activity intensity, more machines, and more movement drive emissions up in parallel. The practical implication is that the same activity can produce very different PM_{10} outcomes depending on time. Excavation on a breezy morning behaves differently from excavation on a still, dry afternoon. A site that understands these patterns can work with them rather than against them, and that is exactly what real-time data makes possible.

(4). Reference Limits

Two reference points anchor any discussion of construction PM_{10} in India:

Standard	24-hr PM_{10} Limit	Annual PM_{10} Limit
WHO Air Quality Guideline (µg/m³)	50 µg/m³	20 µg/m³
India NAAQS (CPCB)	100 µg/m³	60 µg/m³

India's National Ambient Air Quality Standards set the PM_{10} limit at 100 µg/m³ over 24 hours and 60 µg/m³ as an annual average[7]. Under the Construction and Demolition framework, these particulate standards must be met at the site's outer boundary[8] .Cities that exceed the annual limits are subject to mandatory dust-mitigation rules.

THE CURRENT MONITORING LANDSCAPE IN INDIA

(1) What the Rules Require?

India has built a substantial regulatory scaffold around construction dust over the past decade. The key instruments include:

- The Construction & Demolition Waste Management Rules, 2016, impose duties on waste generators, contractors, and local authorities and require site-level plans to manage dust and debris[9].
- CPCB's Guidelines on Environmental Management of C&D Wastes and on dust mitigation, which specify on-site controls such as water sprinkling, green netting around scaffolding and stockpiles, wheel-washing at entry and exit points, and covered transport of materials[8].
- The Environment (Protection) Amendment provisions that make dust-mitigation measures mandatory for cities exceeding NAAQS particulate limits, and require developers to measure PM_{10} and $PM_{2.5}$ and monitor the effectiveness of their control measures.
- The Graded Response Action Plan (GRAP) in the National Capital Region, under which construction activity faces escalating restrictions, and, in the most severe stages, outright bans, as air quality deteriorates.
- Oversight bodies, including the Commission for Air Quality Management (CAQM) and State Pollution Control Boards, whose inspection teams and flying squads audit sites for compliance.

Recent updates have tightened this further, extending dust-control logging requirements to smaller sites, mandating display boards, and raising penalties for non-compliance. The direction of travel is unambiguous: monitoring obligations on construction sites are increasing, not easing.

(2) What is Monitored vs. What is Acted Upon

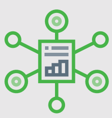
Here is the disconnect. The regulatory machine is designed to answer one question: Is this site within limits? And it answers it with periodic readings, logbooks, and inspection reports. That satisfies the regulator. But it leaves the far more valuable question unanswered: what should this site do differently, right now, to bring dust down?

A compliance reading taken to file away after the fact cannot tell a site manager that the excavation starting in 20 minutes will push the boundary monitor over the limit, or that the wind has dropped. Dust is now accumulating, or that one particular contractor's operation is responsible for a disproportionate share of the day's emissions. The data needed to answer those questions is the same PM_{10} data already being collected. What is missing is its use as a live operational input rather than a retrospective record.

(3) What's Mandatory vs. What's Best Practice

NAAQS Limits

CPCB C&D Guidelines



GRAP Framework

WHO Guidelines

IAQM Methodology

Every standard carries a different legal weight, and mixing them up leads sites to either over-invest in the wrong controls or under-invest in the ones that actually carry penalties.

- The NAAQS PM_{10} limits and CPCB's C&D dust-control measures are binding wherever they apply; monitoring and reporting are not optional, and non-compliance is enforceable.
- GRAP restrictions in the NCR are binding but conditional: they are triggered by regional air quality, not site-specific performance, which means a citywide trigger can still shut down a well-run site.
- WHO guidelines, by contrast, are not legally enforceable in India; they function as a stricter voluntary benchmark for sites aiming beyond bare compliance.
- International frameworks like the IAQM methodology are reference models, useful for structuring a dust-risk assessment, but carry no regulatory force in India whatsoever.

Each new standard should first be classified into one of these four categories, since this determines whether it directly shapes the monitoring plan or merely informs it.

(4) The Cost of Inaction

Treating PM_{10} data as paperwork rather than process intelligence carries real costs:

- **Construction bans and stop-work orders:** When city air quality breaches GRAP thresholds, construction is among the first activities to be halted, delaying projects regardless of whether any individual site was a major contributor.
- **Penalties and reputational exposure:** Non-compliance now attracts significant fines and scrutiny from inspection squads, NGT complaints, and residents.
- **Project delays:** Reactive shutdowns and rework disrupt schedules far more than planned; data-informed dust management would not.
- **Worker health and liability:** Sustained exposure to high PM_{10} is an occupational hazard, with the attendant duty-of-care and liability implications for employers.

Each of these penalties is, to some extent, avoidable if the data already on hand is used to anticipate and manage dust rather than merely document it.

(5) Weighing The Investment

The financial case of this argument is straightforward, even without accurate numbers. A multi-point PM_{10} monitoring deployment, boundary units, activity-zone monitors, dashboard, and threshold-based alerting represent fixed, initial, and recurring costs. Against that is the value of avoiding a single stop-work order, which can cost more in lost labour, idle equipment, and schedule disruption than the monitoring investment itself. A single GRAP-triggered shutdown or a single NGT complaint typically exceeds the cost of a full monitoring season. The comparison is not between monitoring and no monitoring; since monitoring is already mandated on most sites of any scale, it is passive versus active monitoring. The marginal cost of adding thresholds, alerts, and a response protocol on top of infrastructure that is already required and already installed is small relative to the cost of the next reactive shutdown it could prevent.

HOW PM_{10} DATA CAN DRIVE PROCESS IMPROVEMENT

This is the heart of the matter. Below are five concrete ways real-time PM_{10} data can change how a construction site is run, not in theory, but as direct operational levers.

(1) Activity scheduling based on real-time thresholds

Because PM_{10} is highly sensitive to weather and activity intensity, the timing of high-emission work can be optimized based on real-time conditions. If boundary readings are already elevated and the wind has dropped, the site can defer the most dust-intensive task, a major excavation pass, or a demolition pour, until conditions improve or suppression is in place. Rather than running a fixed schedule blind to air quality, the site sequences its dustiest work for the moments when the air can carry it safely, and the boundary has headroom. This is the difference between hitting a limit by accident and managing toward it deliberately. In practice, this shows up as a live dashboard view: the current PM_{10} boundary plotted against the threshold line, with a wind-speed overlay, allowing a site manager to make the call in seconds rather than interpreting raw numbers.

Fixed Schedule → Excavation at 2pm → Boundary breach → Stop-work

(2) Identifying high-emission activities and phases

Continuous monitoring builds a fingerprint of the site. Over days and weeks, the data reveal which activities, crews, and phases produce the highest PM_{10} emissions. This turns vague intuition (demolition is dusty) into specific, quantified knowledge (this demolition method on this material raised boundary PM_{10} by X for Y minutes). That knowledge lets a site target its interventions where they matter most, rather than spreading suppression efforts evenly across activities that pollute unequally. Over time, this becomes a simple ranked view: activities and crews sorted by their average PM_{10} contribution, turning weeks of raw readings into a one-glance priority list for where suppression and scheduling changes will have the most effect.

(3) Triggering dust suppression measures

The most immediate application is closing the loop between a reading and a response. When a monitor detects PM_{10} levels approaching the threshold, it can trigger suppression, water spraying, misting cannons, or anti-dust barriers at the right place and time. This matters because suppression has an optimal operating window. Research on water-based dust suppression has found that intermittent water supply under low wind conditions[10] can achieve the highest particulate suppression rates, meaning a data-triggered, well-timed spray is not only more effective at controlling dust but also more sparing with water than blanket, scheduled spraying. Data-driven suppression is both cleaner and more resource-efficient. Operationally, this is a threshold-crossing event on the dashboard, a reading moving from green to amber, that fires an automated trigger to the suppression system and logs the timestamp, with no manual intervention required to start the response.

(4) Worker protection decisions

Real-time PM_{10} data is an occupational-health tool as much as an environmental one. Localized monitoring near active work, concrete cutting, mixing, and demolition lets a site make exposure-based decisions: rotating crews out of high-dust zones, timing the dustiest tasks to limit cumulative exposure, escalating respiratory PPE when readings demand it, and verifying that engineering controls are actually working. Given that point-of-work activities like mortar mixing can generate PM_{10} readings many times the ambient limit, monitoring exposure where workers actually stand, not just at the boundary, is a meaningful safety upgrade. This typically appears as a separate zone-level view alongside the boundary dashboard, showing point-of-work readings near concrete cutting, mixing, or demolition, so a safety officer can measure exposure where workers actually are, not just what the boundary monitor reports.

(5) Contractor accountability through data trails

On large sites with many subcontractors, PM_{10} data creates an objective, time-stamped record of who generated what. This transforms contractor management. Dust-control obligations can be written into contracts and then verified against data rather than asserted. A continuous log shows whether suppression was running when it should have been, attributes emission spikes to specific operations, and gives the principal contractor a defensible evidence trail, useful both for internal accountability and for demonstrating diligence to regulators. This is usually surfaced as a filtered log view, emissions data segmented by zone or work order, so a spike can be traced back to the specific contractor and activity responsible, rather than appearing as an unattributed site-wide reading.

A FRAMEWORK FOR PM_{10}-BASED CONSTRUCTION MANAGEMENT

Turning the principles above into practice does not require reinventing the site. It requires a structured, four-step approach that layers operational intelligence onto monitoring infrastructure.

- **Deploy monitoring at the right locations and heights:** Effective management starts with representative data. That means placing monitors at the site boundary (where compliance is assessed), near major dust-generating activities (where the action occurs), and accounting for prevailing wind direction to capture impacts downwind. Sensor height should reflect both the workers' breathing zone and the boundary-compliance requirement. Poor placement produces data that is technically present but operationally inoperable.

- **Set site-specific PM_{10} thresholds and alert levels:** A single national limit is the floor, not the whole picture. Sites should set a hierarchy of thresholds, an early-warning level that prompts attention, an action level that triggers suppression, and a critical level tied to the regulatory limits. Thresholds can be tuned to the site's phase and sensitivity of surroundings (a site next to a hospital or school warrants tighter triggers).

- **Map alerts to predefined operational responses:** This step converts data into action. Each threshold should correspond to a pre-agreed, documented response: at the early-warning level, check and increase suppression; at the action level, activate misting and pause the highest-emission task; at the critical level, halt dust-intensive work and notify the site manager. When responses are predetermined, the reaction to a spike is immediate and consistent rather than improvised.

- **Log, report, and review for continuous improvement:** The data trail feeds two loops. The short loop is compliance reporting, automated, defensible records for regulators. The long loop is a process improvement: a periodic review of the site's PM10 history to identify which activities, methods, and conditions drove emissions, and to refine scheduling, suppression, and thresholds for the next phase. Over a project's life, this review cycle is what turns a monitored site into a genuinely better-run one.

The progression across these four steps is the progression this whitepaper argues for in miniature: from measuring dust to responding and learning from it.

WHERE THE FRAMEWORK FALLS SHORT

This framework is not without real limitations, and a credible monitoring strategy accounts for them rather than assuming perfect conditions. Sensors deployed in active construction environments are subject to drift due to dust accumulation, vibration, and weather exposure; readings degrade gradually rather than failing outright, making regular calibration a genuine operational requirement, not a formality. Source attribution is more challenging on sites with multiple contractors or construction nearby, as boundary dust spikes may originate off-site, and distinguishing these requires either source-specific zone monitoring or careful interpretation, not just a single boundary reading.

The downwind-monitoring logic that underpins real-time alerting also assumes a relatively stable wind direction during the relevant work window; on sites where wind shifts mid-shift, the monitor assumed to be downwind may no longer be the one capturing the actual plume, which can produce false reassurance as easily as a false alarm. None of these limitations undermines the case for real-time monitoring. Still, they do mean the framework works best as a structured decision-support tool operated with informed judgment, not as a fully automated system that can run unattended.

A Typical Implementation Timeline

Standing up this framework is faster than sites often assume, since most of the underlying monitoring infrastructure is already mandated and frequently already installed. Deploying and calibrating boundary and activity-zone monitors and establishing a reliable baseline typically take one to two weeks. Setting site-specific thresholds and alert levels, tuned to the project phase and surrounding sensitivity, generally takes another 1 to 2 weeks of observing baseline conditions before tiers can be set with confidence.

Integrating alerts with operational response, connecting threshold triggers to suppression systems, dashboards, and a documented response protocol for site teams, is the longest phase, usually taking three to six weeks, since it involves training site staff and testing the response loop under real conditions. In total, a site moving from passive compliance monitoring to an active process-intelligence setup should expect a five-to-ten week runway, considerably shorter than the typical delay caused by a single GRAP-triggered shutdown.

STANDARDS AND REGULATORY FRAMEWORKS

Any PM_{10}-based construction management programme should be built with the relevant standards in view. The principal reference points are:

- **CPCB Construction & Demolition guidelines:** India's Central Pollution Control Board sets out environmental management requirements for C&D activity, including specified dust-control measures and the requirement that particulate standards be met at the site boundary.
- **NAAQS particulate limits:** The National Ambient Air Quality Standards define the PM_{10} limits (100 µg/m³ over 24 hours and 60 µg/m³ annually) against which site compliance is assessed.
- **GRAP-based construction restrictions:** In the NCR, the Graded Response Action Plan imposes tiered restrictions on construction as air quality worsens, up to full activity bans in severe episodes.
- **WHO PM_{10} guidelines:** The World Health Organization's recommended limits (50 µg/m³ over 24 hours and 20 µg/m³ annually) represent the health-based benchmark. They are considerably stricter than national standards, a useful target for sites aiming beyond bare compliance.
- **International references:** Frameworks such as the US EPA's ambient standards and structured construction-dust assessment guidance (for example, the IAQM methodology used in the UK, which classifies sites by dust-impact risk and matches mitigation to that risk) offer well-developed models for risk-based dust management that can inform Indian practice[11].

REAL-WORLD APPLICATION

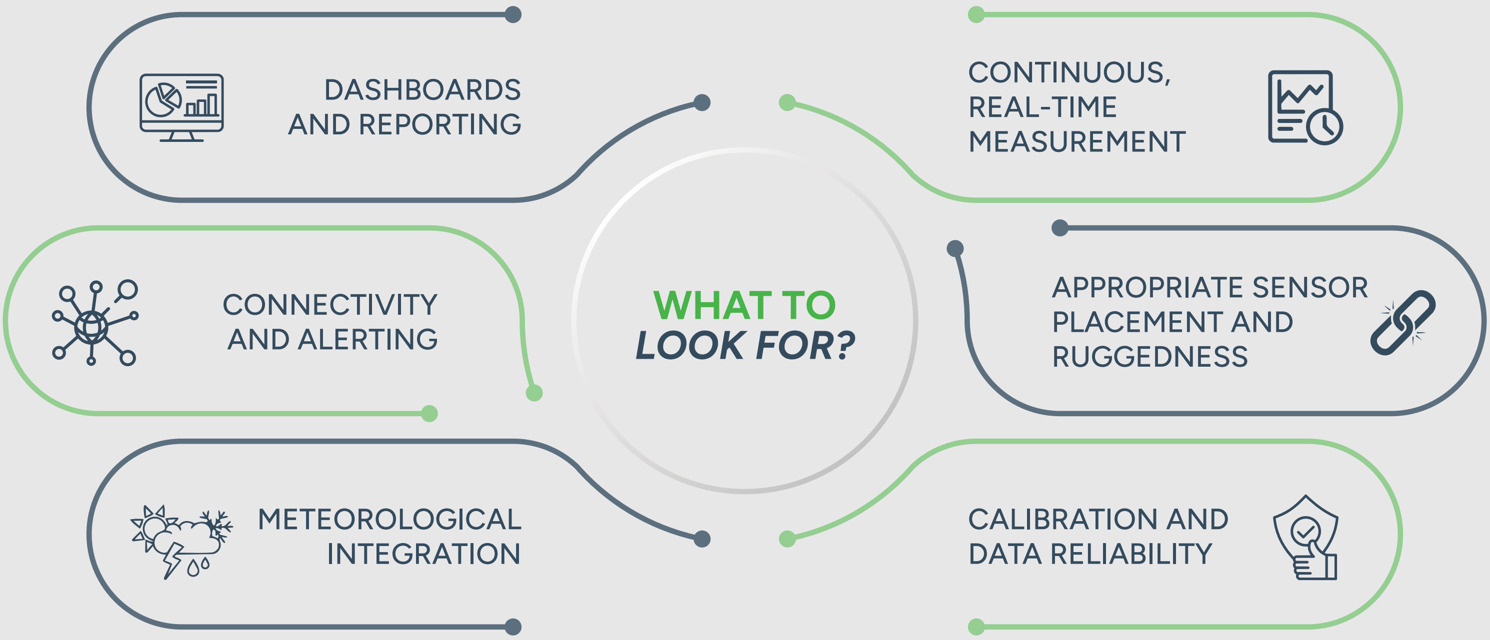
To make the framework concrete, consider how it plays out in a single sequence on an active site. A mid-morning excavation pass begins on the eastern edge of a large urban site. Within minutes, the boundary monitor downwind of the dig registers PM_{10} climbing past the early-warning threshold and rising toward the action level. Because the response is predefined, no one has to debate what to do: the alert automatically triggers the suppression system, and water spraying is activated along the active face and the adjacent haul road. Crucially, conditions are right for it: the wind is light, so intermittent spraying efficiently suppresses the dust.

Within the next interval, the downwind reading falls back below the action threshold, and the excavation continues without breaching the boundary limit. The entire event- spike, alert, suppression, recovery is time-stamped and logged, available later both as compliance evidence and as one more data point about how this site's excavation behaves.

That short loop, detect, alert, suppress, recover, log, is the framework working as intended. No inspector had to catch the spike after the fact. No stop-work order was triggered. The dust was managed in real time, the water was used efficiently, and the site automatically produced a defensible record. Repeated across every shift and every dust-generating activity, this is what the shift from compliance monitoring to process intelligence looks like in practice. Large Indian infrastructure projects, major tunneling and metro works in cities like Mumbai and Delhi operating under strict dust-control regimes, are exactly the settings where this kind of continuous, responsive management delivers the most value.

TECHNOLOGY CONSIDERATIONS

The framework is only as good as the monitoring system underneath it. When evaluating a PM_{10} monitoring solution for construction, the following capabilities matter most:



(1) Continuous, real-time measurement

Process intelligence depends on a live data stream, not periodic manual sampling. The system must report continuously so that spikes are caught as they happen.

(2) Appropriate sensor placement and ruggedness

Construction is in a harsh environment: dust, vibration, and weather. Monitors must be built to withstand it and be flexible enough to deploy at boundaries, near activities, and at multiple heights.

(3) Calibration and data reliability

Decisions and compliance evidence rest on the data's trustworthiness. Reliable calibration and quality assurance are non-negotiable for both regulatory defensibility and operational confidence.

(4) Meteorological integration

Because wind and weather so strongly shape PM_{10}, a system that captures wind speed, wind direction, and other meteorological parameters alongside particulates gives far richer, more interpretable data.

(5)Connectivity and alerting

Data must flow in real time to where it is acted upon: dashboards, mobile alerts, and ideally automated triggers to suppression systems. Threshold-based alerting is what closes the loop between reading and response.

(6) Dashboards and reporting

Clear visualization for live site decisions, plus automated compliance reporting to satisfy regulators with minimal manual effort.

A Note on Instrumentation

Oizom's environmental monitoring systems are designed for exactly this kind of deployment. Polludrone's continuous ambient monitor measures PM_{10} and $PM_{2.5}$, along with other pollutants and meteorological parameters, making it well-suited for boundary- and site-wide construction monitoring. At the same time, compact dust-monitoring units such as Dustroid can be positioned closer to specific high-emission activities. Paired with a real-time dashboard and configurable threshold alerts, this kind of system provides a continuous data stream, meteorological context, as well as automated alerting that the framework in this paper depends on, turning raw PM_{10} readings into a usable operational signal.

CONCLUSION

PM_{10} data is only valuable if it changes behavior. A reading filed away to prove a site was watched has done only a fraction of the work it could. The same data, used live, can schedule the dustiest tasks for when the air can handle them, trigger suppression at the optimal moment, protect the most exposed workers, and hold every contractor on site to an objective standard.

For Indian construction, this shift is no longer optional. Regulations are tightening, enforcement is sharpening, and the cost of reactive shutdowns and penalties is climbing. The sites that thrive will be the ones that get ahead of dust rather than chase it, and treat their monitoring not as a tick-box but as a source of intelligence for building better.

The infrastructure to do this already exists. Monitoring is already, in many cases, mandated and in place. What remains is the decision to use it differently: to move from compliance monitoring to process intelligence. Construction sites that make that move will be cleaner, safer, and more efficient, and, multiplied across a country building as fast as India, that is how the construction boom becomes compatible with breathable cities.

Smarter construction is cleaner construction. The data to get there already exists on every monitored site; the only missing step is reading it in real time rather than after the fact.

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MEET THE AUTHORS

HELLO,
I AM PRIYANKA GOUNDER

With a background in Environmental Engineering, I work as a Technical Content Writer at Oizom who turns complex air quality and sustainability topics into clear, actionable insights.

HELLO,
I AM RUTU BHANUSALI

With a background in environmental sciences, I work as a Research Partnership Coordinator at Oizom's Environment team. Focusing on building academic collaborations and coordinating research partnerships in the air quality monitoring domain.

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