

**Environmental Impact Assessment Report
for Air, Water and Soil in Matheran Area
due to presence of the Horse Dung**

Environmental Monitoring Report



Submitted to

Regional Officer

Maharashtra Pollution Control Board

Regional Office - Raigad

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Environmental Impact Assessment for Air, Water and Soil of Matheran Area due to presence of the Horse Dung Environmental Monitoring Report

Preamble

Matheran is a renowned hill station in Maharashtra. It is a unique fuelled vehicle free zone celebrated for its natural serenity and tourist attraction. Matheran is a nationally important hill station notified as an **Eco-Sensitive Zone (ESZ)** under the Ministry of Environment, Forest and Climate Change (MoEFCC), Government of India. Its ecological uniqueness lies in its delicate lateritic soils, steep slopes, dense forest cover, limited hydrological resilience, and long-standing prohibition on motorized transport.

The continued reliance on horse-based transportation for goods and services in this ecosystem has led to necessity of studying environmental and public health concerns. The unregulated accumulation and disposal of horse dung along trekking paths, near stables, and in runoff zones have raised concerns to direct and cumulative impact on air, soil, and water quality.

In recent years, a visible surge in equine movement—peaking at over about 800 horses per day during tourist seasons raise question mark on capacity of natural and municipal systems to manage the resulting waste. Media reports and NGT-linked reporting indicate approximately **460 horses and 200 ponies while verbal information from local sources revealed that more than 800 horses + ponies** operate in Matheran area. As a rough estimate of 15 kg dung+urine per horse per day may be resulting 15 tonne of dung per day. Unmanaged dung can cause air, water and soil pollution. This waste-load contributes to a range of environmental problems including methane and ammonia emissions, nutrient leaching, pathogen contamination in runoff and

waterbodies, and fine particulate dispersion. These effects have background of heavy rainfall and the densely woody hilly topography of the region. While this non-motorized framework has remained focal point of tourism with an impression of no pollution zone and cleaner environment, the **progressive intensification of equine-based transport** has emerged as a critical environmental concern.

Over the past decade, the **scale, frequency, and spatial spread of horse movement**—particularly during peak tourist seasons—has challenged the assimilative and regenerative capacity of Matheran's natural systems. The accumulation of horse dung and urine along trails, near stables, parking points, forest edges, and drainage paths has resulted in **multi-media environmental loading**, affecting **air quality through particulate resuspension, soil quality through nutrient and microbial enrichment**, and **water quality through runoff-driven contamination**.

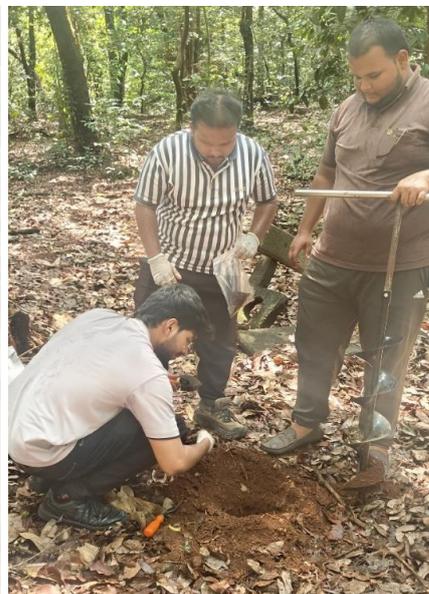
In recognition of these concerns, a **scientifically structured, phase-wise environmental monitoring programme** was undertaken under the guidance of regulatory authorities. Initially it was planned as single-phase monitoring of parameters. Accordingly, field testing activity was undertaken. After completion of few tests and looking at the trend in data, it was felt necessary to conduct the tests covering the three seasons. Accordingly, request was made to MPCB authorities to accept the pre-monsoon monitoring report as interim report and permit to conduct further tests during monsoon and post monsoon period. MPCB authorities responded with due sensitivity and permitted the proposal to conduct the test sessions covering all three seasons.

- **Phase-I (Pre-Monsoon)** monitoring established the **baseline environmental condition** and its findings were **formally submitted earlier** to the competent authorities. Phase-I results provided early evidence of exceedances, hotspot formation, and emerging environmental risks.

To capture the **full seasonal dynamics and cumulative impacts**, the study was subsequently extended to include:

- **Phase-II (Monsoon)** monitoring, representing the **worst-case scenario** for runoff, leaching, erosion, and microbial transport, and
- **Phase-III (Post-Monsoon)** monitoring, assessing **residual contamination, recovery trends, and pollutant persistence**.

The **Final Report**, integrates data from **all three phases** across **air, water, and soil** media. The study interlinks **cause-effect pathways**, seasonal variability, spatial distribution of pollutants, and long-term ecological implications. The findings are interpreted in the context of **Eco-Sensitive Zone obligations, public health protection, animal welfare, and sustainable tourism management**, consistent with the **Precautionary Principle, Polluter Pays Principle, and Sustainable Development doctrine** upheld by Hon. National Green Tribunal.



Typical photographs showing sampling for Air, Water & Soil

Scope and Evolution of the Study

It is given to understand by MPCB that the Original Application (OA) No. 210 of 2024 (WZ) was filed by Ramchandra Shinde & Anr. against the State of Maharashtra & Ors., addressing environmental degradation caused by the excessive use of horses for tourism and goods transportation in Matheran. In response to these concerns, the Hon'ble National Green Tribunal (NGT) issued directions to assess the environmental damage caused by movement of horses; and recommend measures for minimizing impact thereof on environment.

In compliance with the aforementioned order of the Hon'ble Tribunal, the Maharashtra Pollution Control Board (MPCB), as the Nodal Agency, offered the responsibility to Dr. Sachin Pore, Professor in Civil Engineering of Dr. Babasaheb Ambedkar Technological University (DBATU), Mangaon, Dist.-Raigad to carry out necessary investigations detailed study and submit its report to the MPCB

The present study was originally conceptualized and initiated as a **Phase-I (Pre-Monsoon) environmental assessment**, with the primary objective of establishing baseline conditions of air, water, and soil quality in horse-impacted and control locations within the Matheran Eco-Sensitive Zone. The Phase-I findings were compiled and submitted as an **Interim Report** to the competent authorities, highlighting early indications of environmental stress, emerging hotspots, and potential non-compliance with prescribed environmental standards.

Upon examination of the Phase-I results and in pursuance of the observations and guidance of the **Hon'ble National Green Tribunal (NGT)**, it was recognized that a single-season assessment would be insufficient to capture the **seasonal variability, cumulative loading, and dynamic transport pathways** associated with equine-related pollution in a fragile hill ecosystem. Accordingly, the scope of work was **expanded and strengthened** to include additional monitoring phases.

Based on the advice and facilitation provided by the Hon'ble NGT and under the coordination of the **Maharashtra Pollution Control Board (MPCB)** as the nodal agency, the study was extended to encompass:

- **Phase-II (Monsoon) monitoring**, representing the critical period of maximum runoff, erosion, leaching, and microbial transport; and
- **Phase-III (Post-Monsoon) monitoring**, aimed at evaluating residual contamination, recovery trends, pollutant persistence, and cumulative environmental impacts.

This phased expansion transformed the study from a baseline assessment into a **comprehensive, seasonally resolved environmental impact evaluation**, enabling robust cause-effect analysis across media and time scales. The extended scope also allowed for improved risk characterization, regulatory relevance, and formulation of evidence-based mitigation and management recommendations.

The project team places on record its **sincere appreciation to the Hon'ble National Green Tribunal and the Maharashtra Pollution Control Board** for providing the opportunity to undertake this **innovative, multidisciplinary, and technically challenging study** in one of India's most sensitive hill ecosystems. The guidance, oversight, and institutional support extended by these authorities were instrumental in ensuring scientific rigor, transparency, and policy relevance of the present work. Sincere thanks to officers and staff of Matheran Hill Station Municipal Council for their support during activities.

Report on Air Quality Monitoring and Analysis

1.0 Introduction

Matheran, an eco-sensitive hill station in Maharashtra, is India's only pedestrian hill town with no regular motor vehicles. However, reliance on horses and ponies for transport and tourism has raised concerns about environmental degradation, especially air quality. This report presents a comprehensive analysis of ambient air pollution in Matheran across three monitoring phases – pre-monsoon, monsoon, and post-monsoon – based on 24-hour average data from three monitoring stations **Dasturi Naka (AS1), Market/Bazar Area (AS2) and Nagar Parishad (AS3)**. Key pollutants including Particulate Matter (PM₁₀, PM_{2.5}), Sulphur Dioxide (SO₂), and Nitrogen Dioxide (NO₂) are evaluated as per Central Pollution Control Board (CPCB) National Ambient Air Quality Standards (NAAQS). Descriptive statistics, notable exceedances, and observed trends are summarized for each season. Finally, potential pollution sources are discussed (with emphasis on equine activities, road dust resuspension, and meteorological factors), and recommendations are outlined in line with National Green Tribunal (NGT) and Maharashtra Pollution Control Board (MPCB) guidelines for protecting this eco-sensitive zone.

1.1 Pre Monsoon Observations

1.1.1 Ambient Air Quality Analysis

Ambient air quality analysis plays a crucial role in the analysis of eco-sensitive zones like Matheran. Table 1.1 shows Particulate matter PM₁₀ and PM_{2.5} concentration for three stations. Table 1.2 shows National Ambient Air Quality Standards (NAAQS) for PM₁₀ and PM_{2.5} particulates

These values apply to **eco-sensitive & residential/rural** areas. Matheran, being an **eco-sensitive zone (MESZ Notification, 2003)**, falls under these limits.

Table 1.1: PM₁₀ and PM_{2.5} Particulate Matter (PM) Concentration in Ambient air (Pre Monsoon)

Sample Code	8-Hourly Concentration of PM ₁₀ (µg/m ³)			8-Hr. max PM ₁₀ (µg/m ³)	PM ₁₀ (24 hrs. avg) (µg/m ³)	PM _{2.5} (24 hrs. value) (µg/m ³)
	Shift-I 06-14 hrs.	Shift II 14-22 hrs.	Shift III 22-06 hrs.			
AS1	137.87	161.84	133.52	161.84	144.41	76
AS2	192.09	176.48	147.24	192.09	171.93	64
AS3	158.07	148.91	118.41	158.07	141.8	71

Table 1.2: NAAQS (CPCB, 2009) for PM in Eco-Sensitive Zones

Pollutant	Averaging Time	Standard (µg/m ³)
PM₁₀	24-hour average	100
PM_{2.5}	24-hour average	60

Pre-monsoon conditions in Matheran are typically **dry, dusty, and activity intensive**. Under low humidity and high surface dryness, **road dust resuspension** becomes a major contributor to PM₁₀, while **drying and fragmentation of organic residues** (including dung and associated fine dust) can add to PM_{2.5}. The consistently higher PM₁₀ at all stations indicates a strong **coarse particle signature**, commonly linked to **un-paved trail dust and mechanical disturbance**. The highest PM values at **AS2** suggest that the market/bazaar zone experiences greater **human/animal movement density**, leading to more resuspension and accumulation. PM values at AS3 can be attributed to unpaved road surface.

Pre Monsoon stage Sulphur Dioxide (SO₂) variation in ambient air is as below:

Table 1.3: Sulphur Dioxide (SO₂) Concentration in Ambient air

Sample Code	4-Hourly Concentration of SO ₂ (µg/m ³)	SO ₂ 4 hrs. Max	SO ₂ 24 hrs. average
	Shifts		

	I 6-10 hrs.	II 10 – 14 hrs.	III 14-18 hrs.	IV 18-22 Hrs.	V 22-02 hrs.	VI 02-06 hrs.	$\mu\text{g}/\text{m}^3$	$\mu\text{g}/\text{m}^3$
AS1	21.79	22.06	40.95	24.38	9.12	7.26	40.95	23.79
AS2	26.87	26.8	45.13	27.89	11.26	7.17	45.13	27.18
AS3	15.02	36.77	39.98	24.39	9.26	8.82	39.98	24.89

Table 1.4 shows results of Nitrogen Dioxide (**NO₂**) monitoring at various locations (Pre Monsoon).

Table 1.4: Nitrogen Dioxide (NO₂) Concentration in Ambient air (Pre Monsoon)

Sample Code	4-Hourly Value of NO ₂ ($\mu\text{g}/\text{m}^3$)						4-Hourly max of NO ₂ $\mu\text{g}/\text{m}^3$	NO ₂ _24Hrs. average $\mu\text{g}/\text{m}^3$
	Shifts							
	I 6-10 hrs.	II 10 – 14 hrs.	III 14-18 hrs.	IV 18-22 Hrs.	V 22-02 hrs.	VI 02-06 hrs.		
AS1	29.16	56.56	44.93	63.11	24.08	22.31	63.11	43.32
AS2	59.71	43.21	49.75	46.33	27.13	23.46	59.71	44.19
AS3	26.42	43.35	48.45	40.74	23.04	21.66	48.45	36.02

Table 1.5 shows National Ambient Air Quality Standards (NAAQS) for SO₂ and NO₂ gases pollutants.

Table 1.5: NAAQS (CPCB, 2009) for SO₂ and NO₂ in Eco-Sensitive Zones

Pollutant	Averaging Time	Standard ($\mu\text{g}/\text{m}^3$)
SO₂	24-hour average	80
NO₂	24-hour average	80

SO₂ values are **moderate but compliant**, indicating that sulphur-based combustion sources (e.g., heavy diesel traffic, industrial stacks) are **not dominant** within the monitored zone. The presence of measurable SO₂ with moderate variability may reflect **background regional influences**, limited generator use, or small combustion sources. Importantly, SO₂ levels remain far below the NAAQS limit, suggesting **low regulatory concern** for SO₂ under

current conditions, though continued tracking is advisable as an ESZ precaution

NO₂ values in the **mid-30s to mid-40s** indicate measurable NO₂ presence but still compliant. Compared to SO₂, NO₂ is relatively higher at AS1 and AS2, which can be consistent with **localized combustion contributions** (e.g., generators, cooking, occasional vehicle influence near the entry zone). While NO₂ itself does not exceed standards, its presence alongside high PM can increase overall **respiratory stress**, especially during high dust days.

1.2 Observations during Monsoon

Table 1.6 Shows Particulate matter PM₁₀ and PM_{2.5} concentration for three stations during monsoon. The monsoon phase demonstrates the **best air quality** across all stations. Rainfall increases surface moisture and promotes **wet deposition and washout** of airborne particulates. In addition, wet trail surfaces reduce **dust resuspension** from horse movement, and damp organic matter is less likely to fragment into fine airborne particles. The station-to-station differences remain, but overall, the pollutant levels suggest a **low-risk, compliant period** for particulate matter.

Table 1.6: PM₁₀ and PM_{2.5} Particulate Matter Concentration in Ambient air (During Monsoon)

Sample Code	8-Hourly concentration of PM ₁₀ (µg/m ³)			8-Hourly max of PM ₁₀ (µg/m ³)	PM ₁₀ (24 hrs. average) (µg/m ³)	PM _{2.5} (24 hrs. value) (µg/m ³)
	Shift -I 6-10 hrs.	Shift II 14 -22 hrs.	Shift III 22-6 hrs.			
AS1	60	72.65	83.86	83.86	72.17	14.16
AS2	42.61	42.85	64.96	64.96	50.14	27.91
AS3	84.56	87.91	25.53	87.91	66	25.43

Table 1.7 shows the concentration of Sulphur Dioxide (**SO₂**) Concentration in Ambient air during monsoon.

Table 1.7: Sulphur Dioxide (SO₂) Concentration in Ambient air (During Monsoon)

Sample Code	4-Hourly Concentration of SO ₂ (µg/m ³)						SO ₂ (4 hrs. Max) µg/m ³	SO ₂ (24 hrs. average) µg/m ³
	Shifts							
	I 6-10 hrs.	II 10 – 14 hrs.	III 14-18 hrs.	IV 18-22 Hrs.	V 22-02 hrs.	VI 02-06 hrs.		
AS1	9.99	5.69	6.37	4.36	9.12	7.26	9.99	7.13
AS2	10.86	4.31	6.56	6.06	11.26	7.17	11.26	7.7
AS3	11.77	9.85	5.85	5.65	9.26	8.82	11.77	8.53

SO₂ concentration reduces markedly compared to pre-monsoon. This may be due to **lower combustion activity**, enhanced dispersion, and removal by wet deposition. All values remain far below standards, indicating **no SO₂-related compliance concern**.

Table 1.8 shows the concentration of Nitrogen Dioxide (NO₂) Concentration in Ambient air.

Table 1.8: Nitrogen Dioxide (NO₂) Concentration in Ambient air (during monsoon)

Sample Code	4-Hourly Value of NO ₂ (µg/m ³)						4- Hourly max of NO ₂ µg/m ³	NO ₂ 24Hrs. average µg/m ³
	Shifts							
	I 6-10 hrs.	II 10 – 14 hrs.	III 14-18 hrs.	IV 18-22 Hrs.	V 22-02 hrs.	VI 02-06 hrs.		
AS1	14.19	8.31	7.82	6.91	7.74	8.34	14.19	8.88
AS2	12.49	8.72	7.67	5.69	8.53	7.48	12.49	8.43
AS3	15.03	8.59	7.61	6.71	8.79	7.31	15.03	9.06

NO₂ levels are low and stable. Reduced tourist pressure, less generator reliance, and rain-associated atmospheric cleansing can explain this. These levels indicate a **clean-air baseline** period for NO₂ in the study area.

1.3 POST MONSOON OBSERVATIONS

Table 1.9 Shows Particulate matter PM₁₀ and PM_{2.5} post monsoon concentration for three stations.

Table 1.9: PM₁₀ and PM_{2.5} Concentration in Ambient Air (post monsoon)

Sample Code	8 Hourly Concentration of PM ₁₀			8 Hourly Max. of PM ₁₀	PM ₁₀ (24 Hours Avg.)	PM _{2.5} (24 Hours Value)
	Shift-I 06-14 hrs.	Shift II 14-22 hrs.	Shift III 22-06 hrs.			
AS1	110.96	88.97	81.31	110.96	93.75	57
AS2	94.14	119.13	78.62	119.13	97.30	64
AS3	186.33	145.08	92.6	186.33	141.34	63

Post-monsoon shows a **rebound** of particulate pollution as surfaces dry and tourist/horses return to regular activity. However, the rebound is **not uniform**—AS3 stands out with distinctly high PM₁₀, suggesting localized conditions such as **dustier trail surfaces, higher movement intensity on unpaved road, or site-specific deposition and resuspension**. PM_{2.5} also returns close to the limit, indicating a mix of coarse dust plus finer particulate contributions (re-entrainment of dried material and fine dust). This period is therefore **transitional**, showing that monsoon gains may not sustain unless supported by **active dust and waste management**.

Table 1.10 shows the concentration of Sulphur Dioxide (**SO₂**) Concentration in Ambient air (post monsoon)

Table 1.10: Sulphur Dioxide (SO₂) Concentration in Ambient air (post monsoon)

Sample Code	8 Hourly concentrations of SO ₂ Shifts						8 Hourly Max. of SO ₂	SO ₂ (24 Hours Avg.)
	I	II	III	IV	V	VI		
AS1	10.21	20.9	19.26	15.58	8.07	5.21	20.9	13.21
AS2	7.44	10.34	12.85	7.85	6.82	4.41	12.85	8.29
AS3	11.9	20.03	23.83	28.76	16.58	9.93	28.76	18.51

SO₂ remains compliant across stations. AS3 shows a higher 24-hr average (18.51) and higher max (28.76), which may reflect **localized micro-sources** or background variation. These levels remain far below standards, but station-

wise differences suggest the value of continued monitoring to detect any emerging combustion or localized activities.

Table 1.11 shows the concentration of Nitrogen Dioxide (**NO₂**) Concentration in Ambient air (post monsoon).

Table 1.11: Nitrogen Dioxide (NO₂) Concentration in Ambient air (post monsoon)

Sample Code	8 Hourly Value of NO ₂						8 Hourly Max. of Nox	NO ₂ (24 Hours Avg.)
	Shifts							
	I	II	III	IV	V	VI		
AS1	12.99	12.17	10.12	13.54	9.11	10.47	13.54	11.40
AS2	7.66	6.08	8.11	7.43	6.55	6.87	8.11	7.12
AS3	9.59	5.61	8.51	8.85	8.3	7.91	9.59	8.13

NO₂ remains low during post-monsoon as well. Compared to pre-monsoon, the reduction is substantial, suggesting that the elevated pre-monsoon NO₂ was influenced by seasonal activity or conditions rather than persistent emission sources. Overall, NO₂ is not a limiting pollutant in the current dataset.

1.4 SEASONAL AIR POLLUTION TRENDS AND INTERPRETATION

1.4.1 Pre-Monsoon Air Quality (Dry Season)

During the pre-monsoon period (summer months before the onset of rains), Matheran's air quality shows a mixed pattern. Figure 1 to 4 below presents the 24-hour average concentrations of PM₁₀, PM_{2.5}, SO₂, and NO₂ recorded at the three ambient air monitoring stations (AS1: Dasturi Naka entry point; AS2: Main Market area; AS3: Nagar Parishad office area):

Figure 1.1 and Figure 1.2 below illustrate the seasonal variation of PM₁₀ and PM_{2.5} concentrations at the three monitoring locations, highlighting the trends.

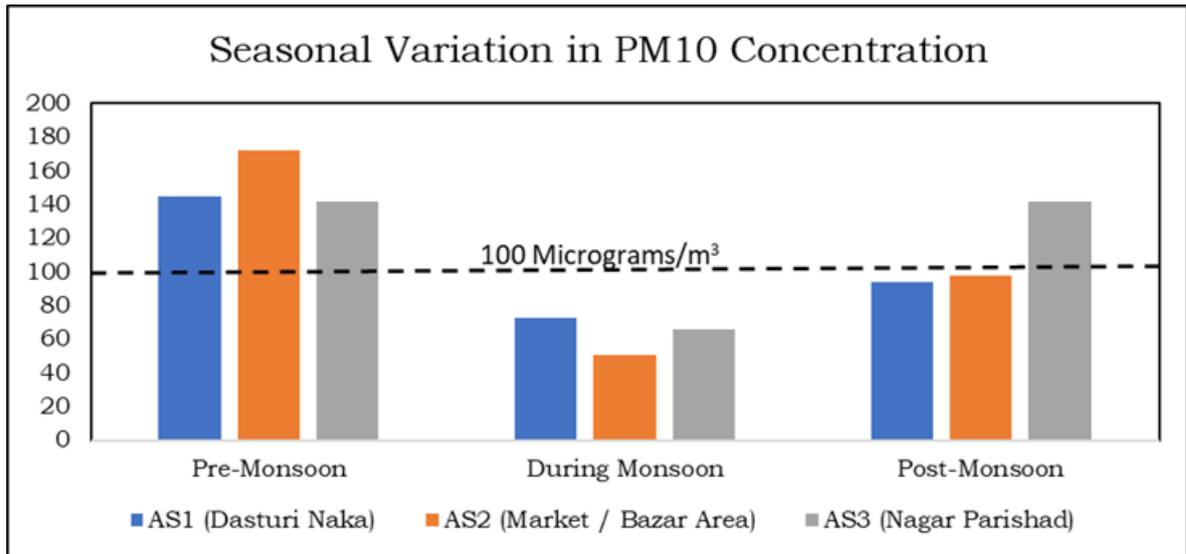


Figure 1.1: Seasonal PM₁₀ levels by location. Pre-monsoon (summer) shows the highest dust concentrations at all sites, monsoon values drop drastically below the NAAQS limit (100 µg/m³ dashed line), and post-monsoon levels rise again though not to pre-monsoon peaks.

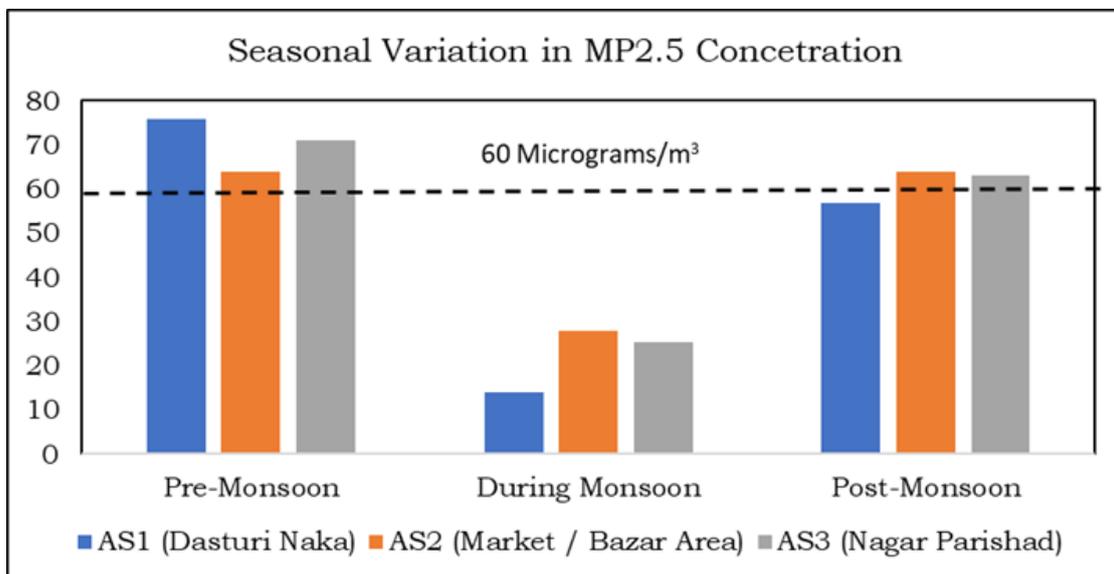


Figure 1.2: Seasonal PM_{2.5} levels by location. A similar pattern is observed: monsoon rains suppress fine particulate pollution (well under the 60 µg/m³ limit), whereas the dry seasons see higher PM_{2.5} with some values exceeding the standard.

As shown in Figure 1 and 2, particulate pollution was **elevated in the pre-monsoon phase**, with **PM₁₀ levels exceeding the 100 µg/m³ NAAQS standard by 40–72%** at the monitored sites. The highest PM₁₀ concentration

was observed at AS2 (Main Market), averaging around $172 \mu\text{g}/\text{m}^3$, which is nearly **double the CPCB 24-hour limit**. AS1 (Dasturi) and AS3 (Nagar Parishad) also recorded high PM_{10} ($\sim 142\text{--}144 \mu\text{g}/\text{m}^3$), $\sim 40\text{--}44\%$ above the standard. **$\text{PM}_{2.5}$ concentrations** were also above the NAAQS permissible value of $60 \mu\text{g}/\text{m}^3$, though by a smaller margin, ranging roughly **6–18% over the limit**. For instance, $\text{PM}_{2.5}$ at AS1 reached $\sim 76 \mu\text{g}/\text{m}^3$ ($\approx 26\%$ above standard), while AS3 was $\sim 71 \mu\text{g}/\text{m}^3$ ($\sim 18\%$ above).

Figure 1.3 & Figure 1.4 illustrate seasonal variation of concentrations of SO_2 & NO_2 at the three monitoring locations, highlighting the trends discussed:

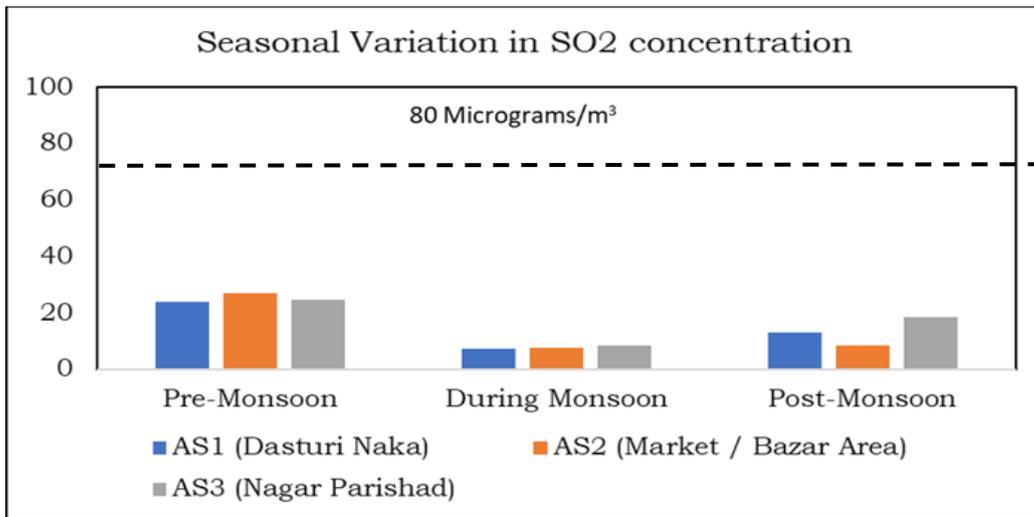


Figure 1.3: Seasonal SO₂ Variation at all Three Locations

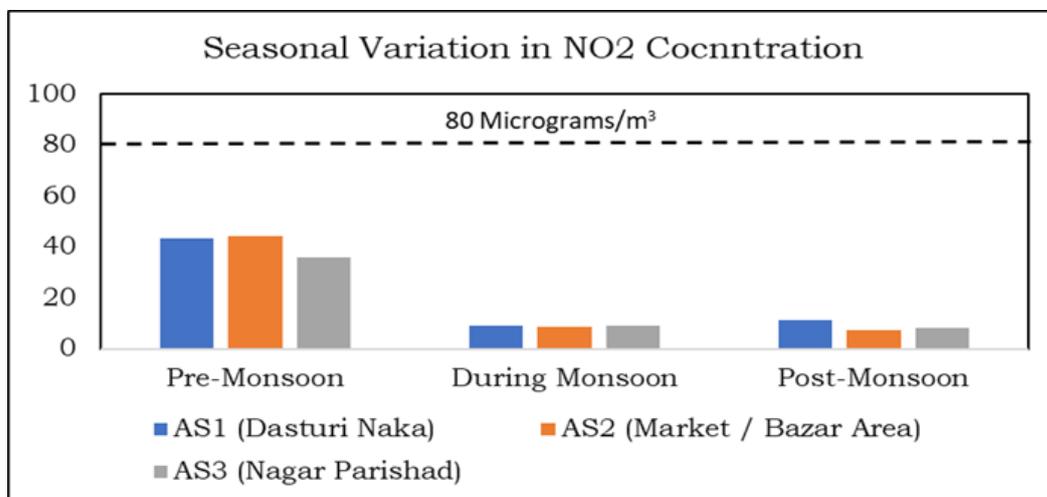


Figure 1.4: Seasonal NO₂ Variation at all three locations

As shown in Figure 3 and 4 **SO₂ and NO₂ remained well within the NAAQS of 80 µg/m³** at all locations; these gases were measured at comparatively low levels, reflecting the absence of major combustion sources in Matheran's vehicle-free environment.

1.4.2 Monsoon Air Quality (Rainy Season)

The **monsoon season** (typically June–September) in Matheran is characterized by heavy rainfall, high humidity, and lush vegetation. These conditions have a pronounced cleansing effect on the air. Continuous rain washes out dust and particulate pollutants from the atmosphere, leading to significantly improved air quality. Figure 1 to Figure 4 summarizes the monitored pollutant levels during the monsoon phase. During the Monsoon period the concentration of particulate matters, i.e. PM₁₀, PM_{2.5} and gaseous pollutants i.e. SO₂ & NO₂ were found considerably below NAAQS standards.

1.4.3 Post-Monsoon Air Quality (Autumn/Winter Season)

The **post-monsoon period** (approx. October through early winter) in Matheran marks a transition to dry weather after the rains cease. Soil begins to dry out and tourist activity picks up again during the cooler months, potentially increasing horse movement.

As the rains recede, **air quality begins to degrade once more**. The **post-monsoon PM₁₀ and PM_{2.5} concentrations show a rising trend** relative to the monsoon downward trend, driven by the return of dry conditions and resumption of full-scale tourist traffic. **Particulate levels roughly doubled from their monsoon values**, bringing **PM₁₀ back to the ~100–130 µg/m³ range** and **PM_{2.5} to ~50–60 µg/m³** (near or in slight exceedance of the standards at certain sites). The **Main Market (AS2)** again tends to be the hotspot, reflecting denser horse usage in the town – for instance, PM_{2.5} at AS2 in post-monsoon was about 60 µg/m³ (right around the 60 µg/m³ NAAQS limit), whereas the more open Dasturi and Nagar areas were somewhat lower (~50–55 µg/m³). Similarly, PM₁₀ at AS2 approached 1.3 times the NAAQS standard (~130 µg/m³), indicating a possible **exceedance** if horse activity is intense, while other locations hovered near 100 µg/m³. These values suggest

that as **trail surfaces dry out and accumulated dung and dust are disturbed by hooves**, particulate pollution can rebound to levels comparable with late summer, although the exact magnitudes depend on how soon after the monsoon measurements are taken and daily horse counts. It's noteworthy that **post-monsoon is a peak tourist season** in Matheran; reports documented up to **800 horses per day** deployed during holidays, significantly higher than off-season count of horses. This increased equine load correlates with higher waste generation and dust, stressing the local air quality. Nonetheless, post-monsoon Particulate Matter (PM) levels might not always reach the extreme of pre-monsoon if some moisture lingers in soil or if management measures are taken. Gaseous pollutants **SO₂ and NO₂ remained within safe limits** in this phase as well, although slight upticks could occur (e.g. more generators use or open burning in cooler weather). Overall, the post-monsoon data underscore a **partial reversal of the monsoon's air quality gains**, with **PM₁₀ and PM_{2.5} rising back to borderline or above NAAQS levels**, depending on the effectiveness of local pollution control and waste management after the rains.

1.5 SEASONAL TREND ANALYSIS

Across the three phases, a clear **seasonal trend** emerges in Matheran's air quality: particulate pollution is **highest in the dry pre-monsoon summer, drops to its lowest during the rainy monsoon, and rises again in the post-monsoon period**. Figure 1 & Fig.2 provides a simplified visualization of this trend for PM₁₀ & PM_{2.5} at the three monitoring stations, illustrating the sharp variability.

This trend highlights the dominant influence of **meteorology** on air quality in Matheran. During **pre-monsoon (summer)**, extended dry spells and increased wind activity cause **dust and dried dung particles to be readily suspended**, driving up PM₁₀/PM_{2.5} levels. As seen, all stations had elevated particulates in summer, with the busiest area (AS2) peaking the highest. With the onset of **monsoon**, frequent rain showers act as a natural dust suppressant – airborne

particles are washed out and soil surfaces stay moist, preventing dust generation. Consequently, both coarse and fine particulate concentrations plummet to **“good” air quality levels in July–August**. In the **post-monsoon** autumn, as rainfall stops and the ground gradually dries, **pollutant levels rebound**. Initially, right after monsoon, there may be a lag before dust problems re-emerge, but as tourism and horse traffic return in full swing, particulates rise again (though sporadic dew or residual moisture may keep them slightly lower than the peak summer values). The general pattern – **high in summer, low in monsoon, moderate in fall** – aligns with broader observations in India’s climate context, but in Matheran the effect is amplified by the nature of local pollution sources (predominantly resuspended dust and organic waste particles). Importantly, **gaseous pollutants SO₂ and NO₂ showed little seasonal fluctuation** in Matheran’s case; their concentrations remained low year-round given the minimal combustion sources. Unlike urban industrial areas where winter inversion can spike NO₂ or SO₂, in Matheran the absence of vehicle traffic means these gases pollutants stay within NAAQS standards in all seasons (often at background levels).

1.6 KEY AIR POLLUTION SOURCES AND INFLUENCES

1.6.1 Equine Activities and Dung Waste

Matheran’s unique status as an automobile-free zone means that **horses, ponies, and hand-pulled rickshaws** are the primary means of transport for tourists and goods. While this spares the town from vehicular emissions, it introduces **equine-related pollution sources**. **Horse dung accumulation** is a significant environmental issue identified in scientific assessments. As horse droppings dry on roads and trails, they can disintegrate into fine powder. Subsequent disturbance by hoof traffic and wind causes these fine organic particles to become **aerosolized**. Study note that the **drying and pulverization of horse dung produces significant amounts of PM₁₀ and PM_{2.5}**. Indeed, the interim analysis of Matheran’s air identified **“aerosolised dried dung particles” as a primary contributor to the observed PM**

exceedances. Such bioaerosols not only contribute to dust but may carry pathogens (e.g. faecal bacteria) and endotoxins, potentially affecting human health.

Beyond dung itself, the **physical movement of horses on unpaved paths** adds to particulate pollution. Matheran's roads are mostly dirt or gravel; as hundreds of horses trot daily, their hooves repeatedly strike the ground. This action causes **soil and road dust resuspension** – a mechanical generation of particulate matter. The expert committee report explicitly noted **“dust generation from hoof impacts on unpaved roads”** as a major source of particulates in the air. Field observations confirm that busy horse trails often have clouds of reddish dust trailing behind the animals, especially during the dry months. The problem compounds when **trail maintenance and waste cleanup are insufficient**: a layer of mixed dust and dung forms on the road surface, ready to be kicked up by the next passing horse or gust of wind. In essence, Matheran's particulate pollution can be traced largely to these **equine activities** – a mix of **organic waste particles and mineral dust** churned into the air by the daily parade of hooves.

It is important to note that **no significant industrial or vehicular sources** exist in Matheran. There are no factories, and routine motor traffic is banned within the ESZ limits. Thus, typical urban pollutants like heavy metals, vehicular soot (elemental carbon), or sulfur from diesel are largely absent. The **air pollution signature in Matheran is more akin to a rural bio-organic dust profile**, dominated by soil dust and biological matter. This is corroborated by water and soil analyses that found direct fecal contamination (*E. coli*), nutrient loading (nitrates, phosphates), and even heavy metals like lead in runoff – likely from long-term accumulation of dung and perhaps residual fallout from past human activities. The heavy metals might originate from feed or anthropogenic sources, but the key takeaway is that **horse waste mismanagement** has wide-ranging environmental impacts (air, water, soil all interconnected).

1.6.2 Meteorological and Seasonal Factors

Meteorology plays a pivotal role in modulating air pollution levels in Matheran. The **seasonal cycle of dry and wet periods** is the dominant influence, as described in the trend analysis. In the **dry pre-monsoon months**, high temperatures and low humidity cause fast drying of horse dung and soil, making them more friable and prone to become airborne. Winds are often stronger in the afternoons during summer, aiding in the dispersion of dust. Additionally, the lack of vegetative cover (many trees shed leaves in summer) means less ground protection against erosion. All these factors lead to maximal **resuspension of particulates** in summer. In contrast, the **monsoon season** brings frequent rains that **suppress dust emissions** by wetting surfaces. Rain not only prevents dust formation but also actively **scavenges pollutants from the air via wash-out**. The orographic nature of Matheran (being a hill station on the Western Ghats) means it intercepts a lot of rainfall; thus, the air is continually cleansed. The dense monsoon foliage further helps by stabilizing soils and perhaps filtering air. It's no surprise that **air quality is naturally restored to healthy levels during monsoon**, as observed in our experimental analysis (PM levels dropped well within safe limits).

As the **post-monsoon period** begins, meteorological conditions gradually shift. Initially, right after the rains, the environment is still moist and dust generation remains low. However, **as weeks pass with no rain, soils start drying** and any new dung deposition begins to accumulate. By November and into winter, humidity is moderate to low (especially on sunny days) and winds are calmer at night, although daytime breezes and tourist movement can still raise dust. Matheran may experience cool nights during winter; temperature inversions might form in the valleys, but being on a hill crest, the town likely gets decent air circulation during daytime. Therefore, unlike urban areas that see pollutant trapping in winter, Matheran's **daytime mixing and upslope winds** can disperse pollutants to some extent. Still, **stable morning conditions** could allow localized build-up of ammonia or odors near horse sheds until the sun warms the air. One meteorological concern is that **post-**

monsoon is also the time of festivals and increased human activity, which can include campfires, open burning of waste, or additional generator usage due to power outages. These activities could introduce minor amounts of **combustion pollutants** (NO₂, SO₂ etc.), though in our observations they remained within acceptable levels. On the whole, **meteorological cleansing in monsoon and meteorological stress in summer** are the primary drivers of the seasonal pollution fluctuations in Matheran. Effective management must therefore account for these cyclic variations – for example, pre-monsoon needs proactive dust control, while monsoon provides an opportunity to remediate accumulated waste (since nature temporarily alleviates the air pollution).

1.6.3 Other Contributing Factors

While horses are the main source, a few **ancillary sources** of air pollutants exist in Matheran. **Diesel generators** are used by hotels and the municipal council during power cuts; their exhaust can release SO₂, NO₂, and particulate soot. However, usage is intermittent and spatially limited, so their impact is minor compared to the pervasive dust. **Open burning of garbage or dried leaves** occasionally observed can also emit smoke and pollutants, but such practices are infrequent given the ESZ regulations. **Human activities** like cooking (if using firewood/charcoal in some local households or street food stalls) might add small amounts of smoke. Another subtle source is **tourists' vehicles at Dasturi parking (just outside the town)** – though vehicles do not enter Matheran, idling cars or buses at the parking lot can emit fumes that might drift towards AS1 (near the entry). This could slightly elevate NO₂ or SO₂ at the fringe, but any effect is very localized and usually diluted by the hillside winds. Overall, these sources are limited; the **crux of Matheran's air pollution issue lies in managing the equine-generated waste and dust.**

1.7 COMPLIANCE WITH THE STANDARDS AND HEALTH IMPLICATIONS

Throughout the monitoring, **SO₂ and NO₂ levels complied with CPCB standards** in all phases, which is encouraging. The concentrations of these

gases were low enough that no acute or chronic health impacts from SO₂/NO₂ are expected for residents and visitors. The main pollutants of concern are **PM₁₀ and PM_{2.5}**, which did exceed standards during significant parts of the year (notably pre-monsoon and possibly post-monsoon). **CPCB's standards** are designed to protect public health – for PM₁₀, the 100 µg/m³ 24-hr limit and for PM_{2.5}, the 60 µg/m³ limit correspond to levels above which sensitive groups (children, elderly, those with respiratory conditions) could experience adverse effects if exposed repeatedly. In Matheran's case, **PM_{2.5} exceeding the standard by ~6–26% in pre-monsoon** is a concern because fine particles penetrate deep into lungs and even a moderate elevation can exacerbate asthma, bronchitis, and cardiovascular stress. **PM₁₀ coarse dust** can cause nuisance effects like eye/throat irritation and can carry microbes from dung, potentially leading to infections. The interim report flagged that these particulate levels, if persistent, pose **health risks to people and animals**. Tourists and locals might experience dust allergies, and there is also a **zoonotic angle** – pathogens like *Salmonella* or *tetanus* bacteria can be present in equine waste; aerosolized dung particles could be an exposure route. Indeed, animal welfare organizations have pointed out risks of diseases such as **glanders and tetanus** transmissible from horses to humans, advocating for a cleaner transport alternative.

Another impact of exceeding particulate standards is on the **ecosystem of the ESZ**. The dust can settle on plant leaves, affecting photosynthesis, and nutrient-laden particles (like manure dust) can alter soil chemistry where they deposit. Excessive ammonia can also harm sensitive vegetation. Visibility reduction might affect scenic views that tourists seek. Thus, maintaining air quality within standards is not only a human health mandate but also important for preserving Matheran's ecological health and ambience. The data and analysis underscore the need for **mitigation measures**, especially in the drier months, to ensure that Matheran's air remains clean and the **exceedances of PM₁₀/PM_{2.5} are minimized or eliminated** in the future.

1.8 Recommendations for Air Pollution Mitigation in Matheran

In light of the above findings, a multi-pronged strategy is recommended to improve and safeguard Matheran's air quality, aligned with the directives of the NGT and the objectives of MPCB for eco-sensitive zones. The focus is on **reducing pollutant sources** (especially equine-related dust and waste) and **implementing sustainable practices** that complement Matheran's environmental policies. Key recommendations include:

a) Limit and Regulate Equine Traffic:

Implement a **carrying capacity** for horses in Matheran as suggested by experts. A daily cap (e.g. **no more than 400 horses working per day**) should be enforced to reduce overuse of trails. Rotation of horses and **rest schedules** should be mandated, along with weight limits for loads, to prevent excessive wear of paths and generation of dust. Authorities should also consider **rotation of trails** (alternate routes on different days) so that no single path is pulverized by continuous use.

b) Enhanced Dung Management:

Establish a **systematic dung collection and disposal mechanism**. This involves deploying municipal staff or contractors to patrol horse routes at frequent intervals to pick up horse excreta promptly throughout the day. Strategically placed **covered bins** or carts can be provided at intervals where horse riders can encourage their animals to stop if needed. All collected dung should be removed from the eco-sensitive zone daily. As an extension, create a dedicated **manure processing center** outside the main tourist areas – for example, a composting yard or biogas plant at the periphery. **Composting the horse dung** can convert waste into organic fertilizer over time, mitigating methane emissions and killing pathogens. Advanced options like **biochar production from dung** could also be piloted, as mentioned in the expert report, to lock carbon and create a soil amendment. MPCB should develop guidelines for safe manure handling specific to hill stations.

c) Dust Control Measures:

To address soil resuspension, the municipality should implement regular

watering of the main dirt roads/trails during dry weather. Sprinkling water (preferably non-potable or recycled water) on horse paths several times a day in summer can significantly settle dust and reduce PM₁₀ emissions. In high foot-traffic zones like the market, consider laying **Mud clay blocks on all possible trails, cobbled or hard-surface strips** to stabilize the ground (without ruining the heritage aesthetic) – for instance, a center strip of natural stone that horses can walk on, which is easier to clean and generates less dust than loose soil. Additionally, **planting hardy groundcover vegetation** or using natural soil binders on trail edges could reduce erosion. It's also recommended to carry out **road grade maintenance** before summer: filling ruts and levelling uneven patches so that fewer fine particles are produced by constant trampling.

d) Infrastructure for Wastewater and Runoff:

Though primarily for water quality, constructing **drainage and bioremediation infrastructure** will indirectly help air quality. For example, **buffer strips or vegetative barriers** along trails can catch runoff (containing dung particles) during rains, preventing nutrients from creating odor issues later. **Constructed wetlands or sedimentation basins** near horse stable areas can treat contaminated runoff. By controlling the spread of waste into the environment, these measures reduce the extent of dry-down areas that later become dust sources.

f) Public Awareness and Participation:

Engage the local community, tourists, and horse owners in preserving air quality. This can be achieved through **awareness campaigns** about not littering the trails with feed or other waste, reporting excessive dung accumulation, and maybe an “Adopt-a-Spot” program where local businesses take responsibility to keep certain stretches clean. Horse owners should be trained on the importance of prompt dung collection (perhaps **providing dung bags** for their horses, analogous to pet poop bags in cities). Informational signage can remind tourists of the fragile ecosystem and encourage them to

cooperate with any rules (such as weight limits or avoiding raising dust). Community-driven monitoring (with the help of volunteers or school students measuring air quality with low-cost sensors) could also be fostered to keep the issue visible.

g) Continued Monitoring and Research:

To ensure that interventions are effective, **regular monitoring of air quality** should continue at the established stations (AS1, AS2, AS3) and possibly additional sites. MPCB can integrate Matheran into its state air monitoring network to provide periodic data. The data should be reviewed in each season to check compliance with NAAQS. If certain hotspots persist (e.g., if post-monsoon PM still spikes), further actions can be taken. Additionally, **research studies** could be commissioned to better understand the composition of Matheran's particulate matter (for instance, determining the proportion of organic matter, silica, microbial content in the PM₁₀/PM_{2.5}). Such studies would validate how much of the dust is horse-origin and how much is geological and assess any health biomarkers (like endotoxin levels in the air). **Establishing manual and continuous air quality monitoring stations in Matheran is long term policy suggestion considering sensitivity of the pollution issue.**

In summary, by **reducing the number of horses on duty, actively managing horse waste, controlling dust at its source, and introducing cleaner transport alternatives**, Matheran can address the identified air pollution issues. These steps, taken in conjunction, aim to ensure that the picturesque hill station remains **clean, healthy, and in compliance with environmental standards**, thereby protecting both the **public health** and the **ecological integrity** of this beloved eco-sensitive zone.

1.8 Conclusion

The air quality assessment of Matheran across pre-monsoon, monsoon, and post-monsoon phases reveals that while the hill station enjoys pristine air during the rainy season, it faces **significant particulate pollution in the dry**

months due to its dependence on horse-based transportation and associated waste. **PM₁₀ and PM_{2.5} levels breached CPCB standards** in the summer (and likely again in late autumn), posing concerns that need to be addressed to safeguard health and the environment. The root causes – **equine dung emissions and dust from unpaved roads** – are well-understood and essentially local in nature, meaning that with dedicated management, these pollution levels can be mitigated. Importantly, **SO₂ and NO₂ pollutants remain under control**, highlighting that Matheran’s air pollution is not industrial but rather a unique challenge of a vehicle-free yet horse-reliant ecosystem. By implementing the recommendations outlined – from limiting horse numbers and improving dung collection to embracing electric alternatives and proactive dust control – authorities can dramatically reduce particulate concentrations, ensuring that **Matheran’s air remains as clean as its green surroundings**. These measures echo the objectives of the NGT and MPCB for maintaining the sanctity of eco-sensitive zones: minimal pollution, sustainable tourism, and protection of natural heritage. Moving forward, it will be crucial for stakeholders (government, local community, and environmental groups) to collaborate in executing these solutions. With sustained effort, Matheran can continue to offer fresh air and a tranquil environment to visitors and residents alike, proving that **eco-friendly practices and tourism can go hand-in-hand**.

1.9 GLIMPSES OF SAMPLING



Air Sampling at Nagar Parishad Entrance



Air Sampling at Dasturi Naka Parking Area

Report on Water Quality Monitoring and Analysis

2.1 Pre-Monsoon Observations

Pre-monsoon water quality monitoring was undertaken to establish baseline environmental conditions in Matheran prior to the onset of rainfall. This period is characterized by low dilution, stagnant hydrology, high tourist and equine activity, and accumulation of contaminants along trails, lake peripheries, and storage tanks. In eco-sensitive hill stations such as Matheran, pre-monsoon sampling is critical as it reflects worst-case concentration scenarios, where pollutants originating from horse dung, urine, trail dust, and organic litter remain largely unflushed. The data generated during this phase provides a reference against which monsoon wash-off impacts and post-monsoon recovery trends can be objectively evaluated. Table 2.1 shows the details of water sampling locations.

Table 2.1: Details of Water Sampling at Matheran

Sample code	Details of location
WS1	Charlotte lake water near to Dashkriya shade
WS2	Charlotte lake near steps of Dashkriya shade
WS3	Charlotte lake away from steps
WS4	Upstream side of Charlotte Lake in small stream near bridge
WS5	Simpson tank near Dasturi parking area

This section presents an assessment of water quality parameters at various locations in Matheran, Maharashtra, in comparison with the Bureau of Indian Standards (BIS: IS 10500:2012, revised 2018) norms for drinking water. The analysis highlights deviations, potential environmental concerns.

Table 2.2: Results of Water Quality Analysis

Parameters	WS1	WS2	WS3	WS4	WS5
pH	6.51	6.73	7.14	6.34	6.9
Turbidity (NTU)	2	0	4	550	27
EC ($\mu\text{S}/\text{cm}$)	58.63	60.6	74.04	64.04	86.09
Alkalinity (mg/L)	48	52	56	92	96
Chloride (mg/L)	18.01	24	28	34	26
Nitrates (NO_3), mg/L	8.40	10.7	5.50	14.3	21.2
Phosphates (PO_4), mg/L	0.35	0.54	0.50	2.60	0.91
E. coli / 100 mL	5	5	10	25	100
Zinc (Zn), mg/L	0.13	0.07	0.09	0.47	0.25
Copper (Cu), mg/L	0.12	0.10	0.17	0.31	0.16
Lead (Pb), mg/L	0.03	0.02	0.02	0.15	0.08
TSS (mg/L)	40.8	97.6	43.2	277.2	34.4
TDS (mg/L)	113.6	151.6	114.0	160.8	337.6

2.2 Interpretation of Pre-Monsoon Water Quality Analysis

i. **Turbidity & Solids:**

WS4 (upstream stream) and WS5 (Simpson Tank) show **extreme turbidity and TSS**, indicating **localized accumulation of dung-derived particulates, soil erosion, and organic debris** prior to rainfall.

ii. **Nutrients (NO_3^- & PO_4^{3-}):**

Elevated nitrates (up to 21.2 mg/L) and phosphates (2.6 mg/L at WS4) confirm **nitrogen and phosphorus loading from equine waste**, posing **eutrophication risk** to Charlotte Lake.

iii. **Microbiological Contamination:**

E. coli detected in all samples, with WS5 showing **100 CFU/100 mL**, clearly establishing **direct fecal contamination** and violation of BIS potable water standards.

iv. **Heavy Metals:**

Lead exceedance at WS4 and WS5 indicates **enhanced metal mobility**, likely influenced by **slightly acidic pH and organic complexation from dung leachate**.

Table 2.3 shows overall Environmental Risk assessment details-based water quality analysis

Table 2.3: Overall Environmental Risk Assessment

Sample	Risk Level	Contaminants of Concern
WS-2	Moderate-High	Nitrates, E. coli, Phosphates
WS-4	High Risk	Nitrates, Phosphates, E. coli, Pb, Zn, Cu, High solids
WS-5	High Risk	Nitrates, Pb, Zn, E-Coli, High solids
WS-1	Moderate	E. coli, Nitrates
WS-3	Low-moderate	All parameters within limits except E.Coli

2.2 OBSERVATIONS DURING MONSOON SEASON (Phase-II)

Phase II monitoring was conducted during the monsoon to evaluate the **dynamic response of surface waters to rainfall-induced runoff, erosion, and dilution**. In Matheran's steep terrain, monsoon rainfall acts as a powerful **transport mechanism**, mobilizing **accumulated horse dung, urine residues, soil particles, and associated pathogens** from trails, parking zones, and slopes into streams, lakes, waterfalls, and stagnant pockets. Monsoon sampling therefore captures **peak pollutant fluxes**, identifies **source-to-sink pathways**, and provides critical insight into **short-term pollution spikes** that are otherwise masked during dry seasons.

2.2.1 Justification for Water Sampling during Phase II (Monsoon Period)

Phase II water sampling was carried out during the monsoon season to evaluate the impact of rainfall-induced runoff, surface flow, and stagnation on water quality in the eco-sensitive zone of Matheran. The monsoon period represents a critical hydrological phase, during which accumulated pollutants from roads, horse movement corridors, residential areas, and natural slopes are mobilized and transported into water bodies.

2.2.2 Rationale for Selection of Different Water Types

a) Flowing Water (Runoff and Streams)

Samples from flowing water, including road runoff, natural streams, and drainage channels, were collected to:

- Assess wash-off of surface contaminants such as soil, organic matter, horse dung residues, and debris.
- Evaluate the transport of suspended solids, nutrients, and microorganisms during rainfall events.
- Understand the immediate impact of monsoon runoff on downstream water bodies such as Charlotte Lake and Simpson Tank.

Flowing water samples provide insight into short-term pollution spikes and help identify source-to-sink pathways of contaminants during high-rainfall conditions.

b) Streams and Waterfalls

Sampling of natural streams and waterfalls was undertaken to:

- Establish background water quality under high-flow, well-aerated conditions.
- Evaluate the dilution and self-purification capacity of natural watercourses during monsoon.
- Compare relatively undisturbed waters with runoff-affected samples to distinguish natural versus anthropogenic influences.

Waterfalls and streams are important indicators of catchment-level soil erosion, sediment transport, and nutrient flushing during monsoon.

c) Stagnant Water Bodies

Samples from stagnant or semi-stagnant water bodies such as storage tanks, low-flow ponds, and depressions were collected to:

- Assess accumulation and persistence of pollutants under low-flushing conditions.
- Evaluate microbial growth potential, particularly for fecal indicator organisms during warm and wet conditions.
- Examine the influence of organic matter decomposition and reduced dilution on water quality.

Stagnant waters represent worst-case scenarios during monsoon, where contaminants introduced by runoff may remain concentrated.

2.2.3 Overall Sampling Strategy Justification

The inclusion of **flowing water, streams, waterfalls, and stagnant water samples** during Phase II ensures:

- Comprehensive representation of **hydrological variability during monsoon**.
- Assessment of both **transient pollution events** (runoff-driven) and **persistent pollution conditions** (stagnant zones).
- Better understanding of the **impact of equine activity, road runoff, and human presence** on surface water quality in Matheran.

This approach aligns with **standard environmental monitoring protocols** and supports robust interpretation of **seasonal variations in water quality**, which is essential for impact assessment and management planning in an eco-sensitive hill station.

Table 2.4 shows sampling code details for phase II of sampling programme

Table 2.4: Details of Sample codes for Phase II Water Sampling (During Monsoon)

Sample Code	Details of Location	Naked Eye Appearance
WS1	Charlotte lake water near to Dashkriya shade	Clear Water
WS2	Charlotte lake near steps of Dashkriya shade	Clear Water

WS3	Charlotte lake away from steps	Clear Water
WS4	Upstream side of Charlotte Lake in small stream near bridge	Slightly Turbid Water
WS5	Simpson tank near Dasturi parking area	Moderately turbid Water
WS6	Turning point near Dasturi naka	Clear Water
WS7	Storage tank near Railway Museum	Clear Water
WS8	Najmi villa site	Slight Turbid
WS9	Horse stable near Dasturi naka	Clear Water
WS10	Housing water from the Shivaji Maharaj park road	Moderate
WS11	Flowing water opposite near Kelkar resort	Moderate
WS12	By road opposite of Sakar Vishram Dham	Slight Turbid
WS13	Near Monkey Point (Electric red box)	Slight Turbid
WS14	Louisa point near Namder Veer stall (Flowing water)	Clear Water
WS15	Vanparishad Adhikari Sanrakshan Karyalaya (opposite Hope Hall Hotel)	Highly Turbid
WS16	Near Bombay Point	Highly Turbid
WS17	Pay Master Park stagnant water near front gate	Clear Water
WS18	Runoff water Near Green Hill Resort	Slight Turbid
WS19	Near Honeymoon Point – runoff water	Highly Turbid
WS20	Simpson lake wall side	Clear Water
WS21	Milestone 104/9 Railway track side	Clear Water
WS22	Stagnant Near Vasant Villa	Moderate
WS23	Stagnant water opposite Old MTDC Resort	Clear Water
WS24	Water from stormwater gutter opposite Matheran post office	Slight Turbid
WS25	Dasturi Naka road runoff	Moderate
WS27	Natural stream flow near the flag post of Pisarnath temple	Clear Water
WS28	Waterfall between Matheran and Neral Road (Uphill Road)	Clear Water

Table 2.5-a to Table 2.5-c shows water quality analysis results of Phase II sampling (during Monsoon)

Table 2.5 -a: Water quality analysis results

Parameter	WS1	WS2	WS3	WS4	WS5	WS6	WS7	WS8	WS9	WS10
pH	7.27	7.12	6.60	6.72	6.43	7.26	7.26	6.80	6.70	6.85
Turbidity (NTU)	12	1	5	100	50	2	1	76	5	149
EC ($\mu\text{S}/\text{cm}$)	91.93	75.04	70.69	60.24	50.50	72.70	57.52	70.54	62.63	116.6
Alkalinity (mg/L)	30	35	40	30	35	10	30	35	45	40
Chloride (mg/L)	86.47	67.94	71.03	71.03	52.50	80.30	89.56	92.65	83.38	225.46
Hardness (mg/L)	75	75	85	120	60	85	80	75	75	90
Nitrate as NO_3 (mg/L)	3.80	4.15	5.50	15.5	27.2	23.0	35.0	33.6	7.80	31.4
Phosphate as PO_4 (mg/L)	0.37	0.77	0.68	1.29	1.05	1.17	0.11	0.18	0.25	0.17
<i>E. coli</i> (/100 mL)	10	1	0	0	50	2	0	0	0	7
Zinc (mg/L)	0.11	0.07	0.23	0.16	0.00	0.05	0.00	0.00	0.00	0.03
Copper (mg/L)	0.40	0.12	0.27	1.75	0.44	0.94	0.81	0.54	0.40	0.81
Lead (mg/L)	0.09	0.22	0.00	0.10	0.16	0.00	0.03	0.17	0.00	0.00

Table 2.5-b: Water Quality Analysis Results

Parameter	WS11	WS12	WS13	WS14	WS15	WS16	WS17	WS18	WS19
pH	7.20	6.50	6.52	6.73	7.05	6.36	6.69	6.77	6.49
Turbidity (NTU)	302	6	28	13	390	342	2	202	364
EC ($\mu\text{S}/\text{cm}$)	614.5	81.78	47.53	91.04	190.15	46.79	84.95	84.52	102.1
Alkalinity (mg/L)	65	35	20	20	30	60	20	45	210
Chloride (mg/L)	89.56	51.77	67.94	75.12	61.77	83.38	80.30	77.21	61.77
TSS (mg/L)	30.8	14	12.1	38.6	15.5	20.52	19.8	79.5	120.5
Nitrate as NO_3 (mg/L)	11.6	12.2	15.5	16.8	15.5	27.2	18.0	19.4	12.2
Phosphate as PO_4 (mg/L)	0.31	0.52	0.40	0.16	0.20	0.21	0.77	0.33	0.52
<i>E. coli</i> (/100 mL)	5	0	0	1	1	6	4	10	20
Zinc (mg/L)	0.82	0.39	0.44	0.16	0.07	0.02	0.00	0.05	0.00
Copper (mg/L)	0.13	0.15	0.24	0.27	0.09	0.20	0.16	0.27	0.14
Lead (mg/L)	0.11	0.04	0.06	0.00	0.02	0.00	0.00	0.05	0.07

Table 2.5-c: Water quality analysis results

Parameter	WS20	WS21	WS22	WS23	WS24	WS25	WS26	WS27	WS28
pH	6.60	6.39	6.40	6.62	6.86	6.77	7.45	7.31	6.44
Turbidity (NTU)	5	8	260	29	45	209	15	22	75
EC ($\mu\text{S}/\text{cm}$)	60.25	95.52	44.72	52.04	116.04	53.36	71.75	85.52	41.79

Parameter	WS20	WS21	WS22	WS23	WS24	WS25	WS26	WS27	WS28
Alkalinity (mg/L)	25	30	40	30	30	60	30	10	10
Chloride (mg/L)	86.47	74.12	55.59	101.92	64.85	67.94	64.85	64.85	63.22
Hardness (mg/L)	80	80	55	50	80	65	140	130	110
Nitrate as NO ₃ (mg/L)	7.80	8.40	26.6	5.65	6.10	11.6	7.15	2.70	7.80
Phosphate as PO ₄ (mg/L)	0.77	0.21	1.03	1.10	0.82	0.91	1.18	0.70	0.50
<i>E. coli</i> (/100 mL)	0	1	8	0	10	20	5	0	1
Zinc (mg/L)	0.00	0.10	0.00	0.00	0.00	0.17	0.14	0.06	0.00
Copper (mg/L)	0.00	0.00	0.05	0.13	0.30	0.06	0.19	0.04	0.46
Lead (mg/L)	0.03	0.00	0.00	0.00	0.04	0.05	0.00	0.07	0.00

2.3 Discussion And Interpretation (Ws1–Ws28)

2.3.1 Monsoon Hydrology and Why Results Look “Extreme”

During monsoon, Matheran’s steep slopes, lateritic soils, unlined drains, and high foot/horse traffic create a **high-energy runoff system**. This causes:

- **First-flush wash-off** of dung residues, soil fines, roadside debris → **high turbidity/TSS**
- Rapid transport of **nutrients (NO₃⁻, PO₄³⁻)** from dung/urine and decomposing organic litter → **nutrient spikes**
- Episodic movement of fecal contamination → **E. coli appears as “patchy” (0 at some sites, high at others)**
- Mobilization of **metals attached to sediments/organic matter** → **Zn, Cu, Pb increase in runoff-driven samples**

So, in monsoon, we typically see **two contrasting behaviours**:

- **Dilution and self-purification** in fast-flowing streams/waterfalls (often lower *E. coli*, sometimes moderate nutrients).
- **Accumulation and persistence** in stagnant pockets/road runoff/drains (very high turbidity + nutrients + microbes + occasional metals).

2.3.2 Turbidity and Suspended Load – The Dominant Monsoon Signal

Turbidity data clearly shows runoff-driven sediment transport:

Key hotspots (very high turbidity)

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- WS4 = 100 NTU, WS5 = 50 NTU (Simpson Tank near parking)
- WS15 = 390 NTU, WS16 = 342 NTU, WS19 = 364 NTU, WS11 = 302 NTU
- WS22 = 260 NTU, WS25 = 209 NTU, WS18 = 202 NTU, WS10 = 149 NTU

Interpretation for Turbidity Observations:

These values represent heavy silt + organic suspension, typical of:

- Road runoff + unpaved shoulders
- Horse corridors (hoof action loosens soil; dung fragments become particulate)
- Parking/market drainage where organic litter + dung wash into gullies
- Stagnant pockets where settling is incomplete and repeated inflow keeps water turbid

Environmental significance:

High turbidity:

- reduces sunlight penetration → affects aquatic primary production
- protects pathogens from disinfection (if ever used for drinking)
- increases oxygen demand when organic solids settle and decompose
- transports attached pollutants (metals, nutrients)

In Phase II, turbidity is not a “water clarity issue” - it is a pollution transport indicator.

2.3.3 EC, Alkalinity, Chloride - Identifying “Mixed Wastewater/Runoff Signature”

Most EC values are modest (typical hill waters), but WS11 EC = 614.5 $\mu\text{S}/\text{cm}$ stands out strongly.

This indicates high dissolved ions, usually linked to:

- Concentrated runoff from settlement/market waste + animal waste + soil salts
- Drainage interaction with stored stagnant waters and decomposition products

Alkalinity is mostly 10–65 mg/L, but WS19 = 210 mg/L is exceptionally high.

Interpretation:

High alkalinity in monsoon often indicates organic decomposition buffering, possible inflow from stagnant, nutrient-rich zones with ammonium conversion and carbonate/bicarbonate dominance.

Chloride shows a striking pattern:

- Many sites: ~50–100 mg/L
- WS10 chloride = 225.46 mg/L (very high relative to others) WS10 likely receives mixed drainage influence (housing/roadside runoff). Chloride behaves conservatively and often indicates human activity input (detergents/greywater/urban runoff) plus animal waste contribution.

2.3.4 Nitrates – Strong Evidence of Monsoon Nutrient Flush

Nitrate levels are frequently high, with many values in the **10–35 mg/L** range.

Notable nitrate hotspots

- **WS7 = 35 mg/L, WS8 = 33.6 mg/L, WS10 = 31.4 mg/L**
- **WS5 = 27.2 mg/L, WS16 = 27.2 mg/L, WS22 = 26.6 mg/L**
- Several sites around **15.5–19.4 mg/L** (WS4, WS13, WS14, WS15, WS18, WS17 etc.)

Interpretation (monsoon process):

- Dung and urine are nitrogen-rich (urea → ammonia → nitrate under aerobic conditions)
- First-flush runoff picks up nitrogen from trails, stables, waiting areas, and feed residues
- Nitrates increase especially where runoff passes through **horse stable influence or settlement drainage**

Risk meaning (EIA language):

- **Eutrophication risk** in receiving lakes/tanks
- Potential health risk if such water is used untreated (especially for vulnerable groups)
- Indicates that **catchment management and dung interception** are required, not just lake cleaning

2.3.5 Phosphates – Eutrophication “Trigger” Signal

Phosphate is ecologically more critical than chloride/alkalinity here because it is the **limiting nutrient**.

Higher phosphate values include

- WS4 = 1.29 mg/L, WS6 = 1.17 mg/L, WS22 = 1.03 mg/L, WS5 = 1.05 mg/L

- WS23 = 1.10 mg/L, WS26 = 1.18 mg/L, plus many in 0.7–0.9 mg/L zone

Interpretation:

These are **high for natural hill waters** and strongly indicate:

- organic waste wash-off (dung + feed residues)
- sediment-bound phosphate entering from eroding paths
- stagnant waters accumulating phosphate and releasing it from sediments under low oxygen microzones

Ecosystem risk:

- nutrient enrichment → algal growth potential, oxygen depletion, habitat stress in lakes/tanks

2.3.6 Microbiological Quality – E. coli Shows “Patchy Peaks”

Monsoon E. coli is not uniformly high. Many sites show 0–2, while some show spikes:

- WS5 = 50, WS19 = 20, WS25 = 20, WS24 = 10, WS18 = 10, WS22 = 8, WS11 = 5, WS17 = 4, etc.

Interpretation:

- Flowing systems dilute and transport bacteria quickly → low counts at some points
- Stagnant/near-source sites retain fecal contamination → spikes
- Simpson tank & runoff-dominant locations behave as **microbial sinks**

Public health significance:

Even “moderate” E. coli in environmental waters implies:

- fecal contamination pathways are active
- potential for zoonotic pathogen transport
- unacceptable for any potable use without treatment

2.3.7 Metals (Zn, Cu, Pb) – Sediment-Linked, Event-Driven Behaviour

Zinc

- Generally low, but WS11 Zn = 0.82, WS12 0.39, WS13 0.44
These indicate sediment-associated mobilization, possibly from:
- corroded materials, local soils, mixed runoff from roadside waste

Copper

- Copper shows unusual peaks:
 - WS4 Cu = 1.75 mg/L
 - WS6 Cu = 0.94, WS7 Cu = 0.81, WS10 Cu = 0.81

This strongly suggests either:

- localized contamination from specific sources (materials, fittings, pipes, leachates)
- or analytical check needed for WS4 due to being significantly higher than others

Lead

- Lead values reach:
 - WS2 Pb = 0.22, WS5 Pb = 0.16, WS8 Pb = 0.17, WS11 Pb = 0.11, WS4 Pb = 0.10, WS10 Pb = 0.00

Interpretation: Lead exceedances in runoff-linked sites indicate:

- adsorption to particulates and organic matter (monsoon mobilizes them)
- possible contributions from roadside legacy sources & mixed drainage

EIA risk statement:

Monsoon runoff is transporting not only nutrients and microbes, but also **trace metal loads**, increasing chronic toxicity risk in sediment-accumulating zones.

2.4 Major Observations During Monsoon Season (Phase II)

Phase II establishes that the monsoon season converts Matheran's equine and human activity zones into a connected runoff network, delivering:

- **High solids (turbidity/TSS)**
- **High nutrients ($\text{NO}_3^-/\text{PO}_4^{3-}$)**
- **Intermittent but significant fecal contamination**
- **Sediment-bound metal mobilization**

into downstream lakes/tanks and stagnant pockets.

Table 2.6 shows key risks, Hotspots of pollution and its key impacts during monsoon results.

Table 2.6: During monsoon – Key Risks Table

Risk Category	Evidence from Phase II	Hotspots (examples)	Key Impact
Sediment & turbidity loading	Turbidity 200–420 NTU common in runoff/stagnant	WS4, WS11, WS15, WS16, WS19, WS22, WS25	Habitat stress, pathogen shielding, pollutant transport
Nutrient flush (nitrates)	Nitrate up to 35 mg/L	WS7, WS8, WS10, WS16, WS22, WS5	Eutrophication potential, unsafe for potable use
Phosphate enrichment	PO ₄ up to ~1.29 mg/Lit	WS4, WS6, WS22, WS23, WS26, WS5	Algal bloom risk, oxygen depletion
Fecal contamination	E. coli spikes up to 50/100 mL	WS5, WS19, WS25, WS24, WS18	Public health risk, zoonotic pathways
Metals with runoff	Zn up to 0.82, Cu up to 1.75, Pb up to 0.22	WS11 (Zn), WS4 (Cu), WS2/WS8 (Pb)	Chronic toxicity, sediment contamination

2.5 Post Monsoon Sampling and Analysis (Phase III)

Table 2.7 shows sampling code details for phase III of sampling programme

Table 2.7: Details of Sample Codes for Phase III Water ANALYSIS (Post Monsoon)

Sample Code	Description of Location	Naked Eye Appearance
WS1	Charlotte lake water near to Dashkriya shade	Clear water
WS2	Charlotte lake near steps of Dashkriya shade	Clear water
WS3	Charlotte lake away from steps	Clear water
WS4	Upstream side of Charlotte Lake in small stream near bridge	Slightly turbid
WS5	Simpson tank near Dasturi parking area	Slightly turbid
WS6	Corner extreme end of dam (Charlotte Lake)	Clear water
WS7	Upstream side of Charlotte Lake near bridge	Slightly turbid
WS8	Simpson lake wall side	Highly turbid

Table 8 shows water quality analysis results of Phase III sampling programme (Post Monsoon)

Table 8: Water Quality Analysis Results

Parameter	Unit	WS1	WS2	WS3	WS4	WS5	WS6	WS7	WS8
pH	-	7.20	6.90	6.90	7.13	7.08	7.20	7.70	6.90
Electrical Conductivity	µS/m	63.69	66.05	61.31	59.26	61.69	59.44	102.5	95.41
Alkalinity	mg/L as CaCO ₃	60	90	100	80	70	100	90	110
Chlorides	mg/L	59	59	39	35	54	64	59	69
Turbidity	NTU	19	21	18	140	100	22	30	50
Total Hardness	mg/L as CaCO ₃	60	85	95	65	110	80	60	90
Nitrates as NO ₃	mg/L	3.10	2.20	5.95	12.40	4.80	5.50	6.10	9.35
Phosphates as PO ₄	mg/L	0.28	0.63	0.57	0.71	0.40	0.97	1.26	0.82
<i>E. coli</i>	per 100 mL	2	5	10	10	100	10	5	5
Zinc (Zn)	mg/L	0.62	0.37	0.15	0.20	0.10	0.09	0.13	0.54
Copper (Cu)	mg/L	0.27	0.00	0.40	0.45	0.10	0.32	0.28	0.67
Lead (Pb)	mg/L	0.17	0.10	0.13	0.04	0.12	0.07	0.00	0.03

2.5.1 Phase III – Post Monsoon Water Quality (PoM) Discussion and Interpretation (WS1–WS8)

1) What Post-Monsoon Represents

Post-monsoon is the recovery and settling phase. Rainfall intensity reduces, flows stabilize, and:

- suspended solids begin to settle (but may remain high in disturbed tanks)
- nutrients can persist due to internal cycling (sediments can release phosphate)
- microbial contamination persists where stagnation occurs
- metal contamination becomes visible as sediment-associated legacy effect

Because your Phase III includes lake and tank points, it is ideal for assessing:

- how much contamination remains after monsoon flushing
- whether water bodies behave as pollution sinks

2) Turbidity – Reduced at lakes but still high at certain nodes

Post-monsoon turbidity shows:

- WS4 = 140 NTU (very high)

- WS5 = 100 NTU
- WS8 = 50, WS7 = 30, others 18–22

Interpretation:

- Simpson Tank (WS5) continues to behave as a sediment trap + organic sink
- WS4 (upstream stream) remains impacted, likely due to continued erosion, or catchment wash-in even after monsoon
- In lakes, turbidity reduces but does not normalize fully because sediments are resuspended by:
 - ongoing horse movement near edges
 - human activity at access points
 - wind/rain disturbances

3) Nitrates

Decline compared to monsoon but persistent at specific site

For most of the sampling sites nitrates range 2.2–9.35 mg/L, but:

- WS4 = 12.40 mg/L remains elevated

Interpretation:

- overall nitrate decline indicates dilution and flushing worked
- but WS4 indicates a persistent upstream nutrient input (dung deposition corridor, soil organic sources, or continuous drainage path).

4) Phosphates – Post-Monsoon “Internal Loading” Signature

Phosphates remain notable:

- WS7 = 1.26 mg/L, WS6 = 0.97, WS8 = 0.82, WS4 = 0.71
- Even when nitrates drop, phosphate remains elevated because:
- sediments store phosphate during monsoon
 - post-monsoon low-flow conditions allow sediment–water release
 - stagnation and organic decomposition support phosphate persistence

EIA implication:

Even after monsoon, water bodies may remain at **eutrophication risk**, especially with repeated seasonal loading.

5) E. coli – Persistence proves “chronic contamination”, not seasonal only

E. coli in Phase III:

- WS5 = 100 (very high)

- WS4 = 10, WS6 = 10, WS3 = 10, WS2 = 5, WS8 = 5

Interpretation:

- Post-monsoon should reduce microbial risk if contamination was only “event-based”
- But continued E. coli presence means sources are ongoing (stables, trails, edge wash, stagnant pockets)
- Simpson tank remains a microbial reservoir (warm, organic-rich, low flushing).

6) Metals – post-monsoon shows “legacy + settling into sediments”

Zn is markedly higher in Phase III at some sites:

- WS1 Zn = 0.62, WS2 0.37, WS8 0.54

Copper:

- WS8 Cu = 0.67, WS4 0.45, WS3 0.40

Lead:

- WS1 Pb = 0.17, WS2 = 0.10, WS3 = 0.13, WS5 0.12

Interpretation:

- Metals often increase in apparent concentration in post-monsoon samples when:
 - suspended solids settle and concentrate contaminants in localized zones
 - sediment disturbance continues near edges
 - organic matter binds metals (humic substances from dung decomposition)

EIA risk statement:

post-monsoon confirms that some water bodies are acting as sinks for metal-associated sediments, implying a need for catchment interception and possibly sediment management in tanks.

2.6 MAJOR CONCLUSIONS (Phase III)- POST MONSOON)

Phase III demonstrates that after monsoon:

- nitrates generally decline, but phosphates and microbes persist
- tanks (especially near parking/horse influence) remain high-risk sinks
- metals show a pattern consistent with sediment accumulation + organic binding

This indicates that Matheran's system is not self-restoring fully and is moving towards a chronic loading condition in specific hotspots.

Table 2.9 shows key risks for phase III sampling and analysis results

Table 2.9: Post Monsoon sampling – Key Risks Table

Sample	Risk Level	Key Evidence	Key Risk
WS5 (Simpson tank)	High	Turbidity 100, E. coli 100, Pb 0.12	Chronic fecal + sediment + metal sink
WS4 (upstream side stream)	Moderate–High	Turbidity 550, NO ₃ 12.4, PO ₄ 0.71	Persistent upstream source input
WS8 (Simpson wall side)	Moderate–High	Turbidity 50, PO ₄ 0.82, Cu 0.67	Sediment-bound + nutrient persistence
WS7	Moderate	PO ₄ 1.26, turbidity 30	Internal phosphate loading
WS1–WS3	Moderate	E. coli persists; Pb present	Chronic contamination signal

2.7 Seasonal Variation in Water Quality Parameters

2.7.1 pH:

Figure 2.1 shows seasonal variation on pH for samples WS1 to WS5

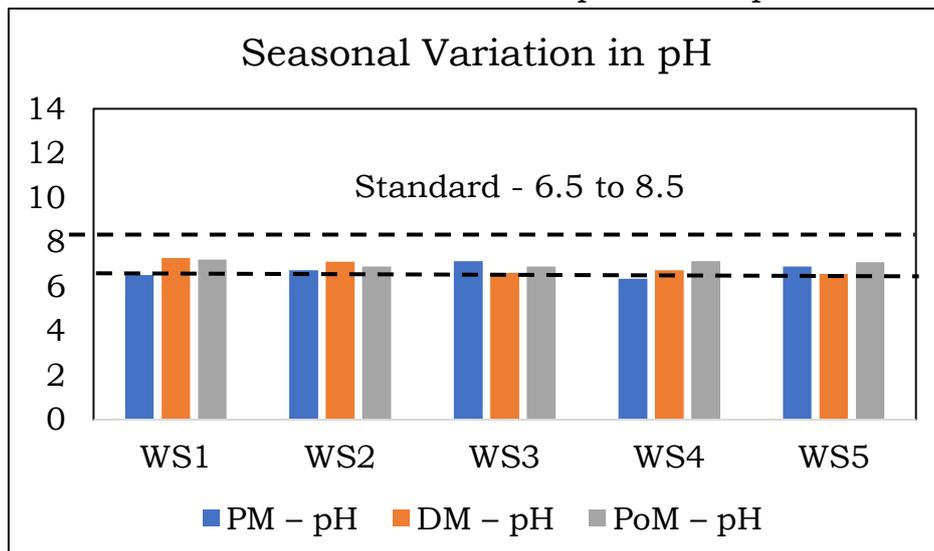


Figure 2.1: Seasonal Variation in pH

Matheran's surface water pH remained near-neutral in the dry pre-monsoon season (all sites ~6.5–7.1 except one slightly acidic at 6.34). This falls within the BIS acceptable range of 6.5–8.5. During the monsoon, increased organic acid runoff (from decomposing dung and humic matter) and acid rain can depress pH slightly. **Expected trend:** a minor drop in pH in monsoon (more

acidic) due to flush of organic acids and CO₂-rich stormwater, with post-monsoon pH gradually rebounding as fresh inputs decrease and buffering capacity (alkalinity ~50–96 mg/L as CaCO₃) normalizes. Even slight acidification is important: lower pH can **mobilize heavy metals** (e.g. Pb, Zn), exacerbating toxicity. For instance, the most acidic site (WS4, pH 6.34) also had the highest lead (0.15 mg/L) in pre-monsoon, consistent with metal solubility increasing in acid water.

2.7.2 Turbidity: Figure 2.2 shows seasonal variation of Turbidity values for samples WS1 to WS5

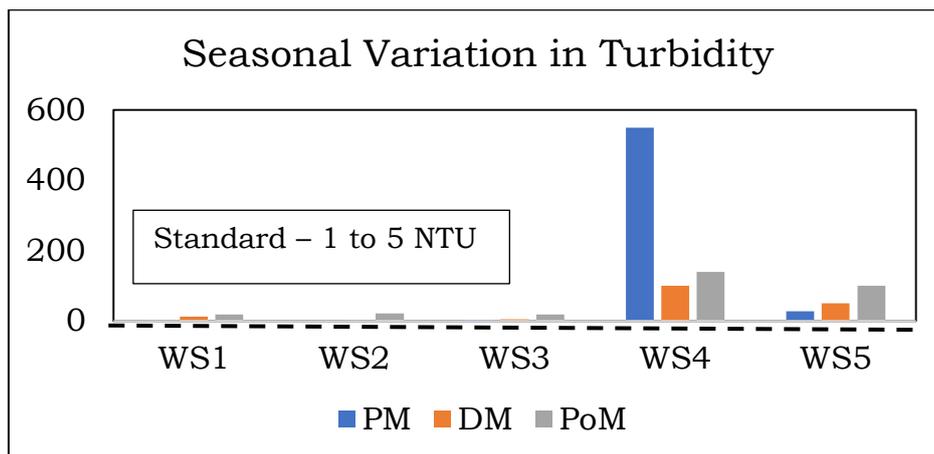


Figure 2.2: Seasonal variation in Turbidity Values

Turbidity showed extreme spatial and seasonal spikes. In pre-monsoon, most sites were clear (0–4 NTU), but one runoff-collection stream (WS4) was **highly turbid (550 NTU)** from stagnant dung-laden sediments, far exceeding the 5 NTU permissible limit. Another site near the parking (WS5) had 27 NTU. **Monsoon effect:** Heavy rains cause **widespread turbidity surges** as storm runoff carries eroded soil, horse dung, and organic debris into watercourses. Even relatively clear sites (WS1–WS3) likely turn turbid during peak runoff (e.g. lake water turning reddish-brown). Figure 1 illustrates the expected jump – e.g. turbidity at WS3 may rise from ~4 NTU pre-monsoon to tens of NTU in monsoon, and already turbid sites (WS4, WS5) see sustained high turbidity (albeit dilution may reduce the **peak** from 550 NTU to a few hundred). These levels far exceed safe norms (1 NTU desirable for drinking). By post-monsoon, turbidity subsides as flows wane and suspended matter

settles. However, **residual silt and decaying organics** can keep turbidity slightly elevated until complete settling. High turbidity is more than aesthetic – it **impairs disinfection and sunlight penetration**, fostering microbial regrowth and reducing water quality for tourists.

2.7.4 Electrical Conductivity (EC):

Figure 2.3 shows seasonal variation of Turbidity values for samples WS1 to WS5

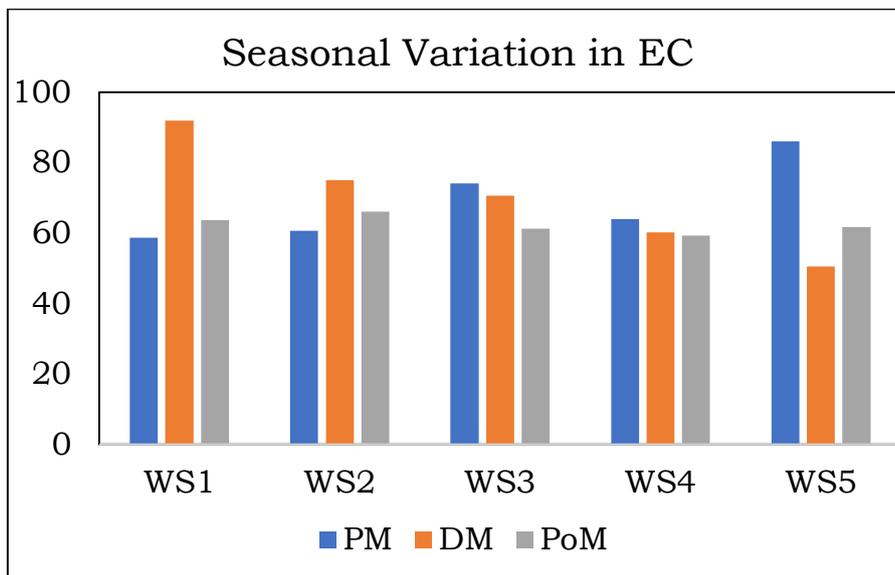


Figure 2.3: Seasonal Variation in EC

EC was low in pre-monsoon (58–86 $\mu\text{S}/\text{cm}$), reflecting dilute hill-stream water with low dissolved salts. All sites were well within typical freshwater range (and below the $\sim 500 \mu\text{S}/\text{cm}$ guideline for drinking water). **Seasonal behaviour:** During monsoon, pure rainwater (EC ~ 0) dilutes overall conductivity, but initial flushes can leach **ionic salts (urea, ammonia, chloride)** from horse urine and dung on the trails. Thus, EC may **spike locally** in first flush runoff (high ammonium, nitrate, etc.), then drop as rainwater volume dominates. For example, EC at a stable-adjacent site might rise from $\sim 64 \mu\text{S}/\text{cm}$ to perhaps $\sim 150 \mu\text{S}/\text{cm}$ during early monsoon when concentrated urine leachate runs off, then average back down $< 100 \mu\text{S}/\text{cm}$ with continued rains. Post-monsoon, EC tends to return to baseline low values as accumulated salts have been washed through the system. Overall, Matheran's EC stays fairly low year-round due to high rainfall and quick

drainage – but any **notable EC increase at a site signals contaminant leaching** (e.g. WS5 had the highest EC pre-monsoon, 86 $\mu\text{S}/\text{cm}$, hinting at more waste inputs).

2.7.5 Alkalinity:

Fig. 2.4 shows seasonal variation for samples WS1 to WS5

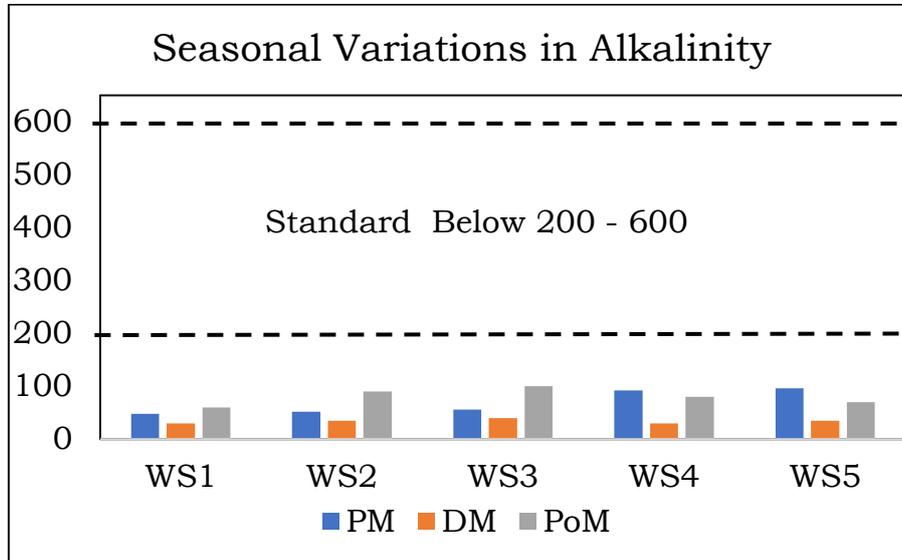


Figure 2.4: Seasonal Variations in Alkalinity

Alkalinity values during the pre-monsoon period ranged from 48 to 96 mg/L as CaCO_3 , with lower values in the relatively pristine lake sites (WS1–WS3) and higher values at WS4 (92 mg/L) and WS5 (96 mg/L). These values lie well within the BIS desirable limit of 200 mg/L, indicating that Matheran waters presently possess moderate buffering capacity against sudden pH changes. The spatial distribution of alkalinity, however, clearly reflects localized influence of equine waste decomposition, particularly in runoff-dominated and stagnant environments. Elevated alkalinity at WS4 and WS5 can be attributed to microbial breakdown of urine and dung, where ammonification and carbonate system reactions generate bicarbonate ions, increasing alkalinity in the receiving water. This effect is amplified at WS5 due to longer residence time and limited flushing, allowing solutes to accumulate between rainfall events.

During the monsoon season, alkalinity is governed by competing hydrological and biochemical processes. Intense rainfall generally causes dilution, lowering

alkalinity in open and flowing waters such as Charlotte Lake. Simultaneously, monsoon runoff transports fresh organic matter from horse trails into streams and tanks, where rapid microbial decomposition can cause localized alkalinity pulses, particularly at WS4 and WS5. Thus, monsoon graphs typically show greater temporal variability rather than a uniform decline. In the post-monsoon period, alkalinity tends to stabilize as carbonate equilibrium is restored and organic loading decreases. However, the interaction of moderate alkalinity with elevated nutrients (notably phosphates) can enhance post-monsoon algal productivity. Photosynthesis and respiration cycles associated with algal growth can induce diurnal shifts in CO₂ concentration, indirectly affecting effective buffering behaviour. Importantly, while alkalinity provides some protection against extreme acidification, it does not eliminate risk: localized pH depression during runoff events can still occur, promoting mobilization of heavy metals such as lead, as observed at WS4 where slightly acidic pH coincided with elevated Pb. Thus, although alkalinity values individually indicate low immediate risk, their seasonal dynamics and interaction with nutrients and metals signify a moderate indirect environmental risk, particularly under continued equine waste loading.

2.7.6 Chlorides:

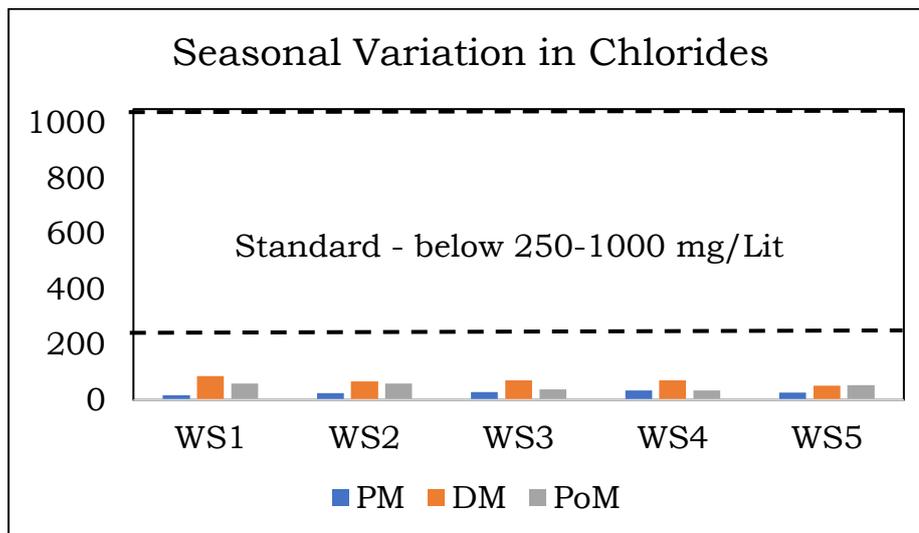


Figure 2.5: Seasonal Variations in Chlorides concentration

Chloride concentrations across all five sampling locations during the pre-monsoon period ranged from 18.01 to 34 mg/L, with the lowest values

observed in lake-based sites (WS1–WS3) and higher values at runoff-influenced locations WS4 (34 mg/L) and WS5 (26 mg/L). All observed concentrations are well within the BIS and WHO guideline value of 250 mg/L, indicating no immediate potability concern. However, despite being within regulatory limits, the spatial pattern of chlorides provides critical insight into anthropogenic pressure from equine activity. Chloride is a conservative ion and does not readily degrade or precipitate; therefore, even modest elevations serve as a reliable tracer of repeated surface inputs. In Matheran's low-mineral hill-station environment, the relatively higher chloride at WS4 and WS5 strongly indicates accumulation of dissolved salts from horse urine, dung leachate, feed residues, and sweat deposited along trails and near stables during the dry season.

Monsoon expectation: With the onset of monsoon, chloride exhibits a characteristic dual response. During early rainfall events, a pronounced first-flush effect is expected, wherein accumulated salts are rapidly mobilized from horse trails and stable floors into adjacent streams and tanks. As a result, WS4 and WS5 are likely to show temporary spikes in chloride concentrations coinciding with high turbidity and TSS. With sustained rainfall, however, the dilution effect dominates, particularly in Charlotte Lake (WS1–WS3), leading to an overall reduction in average chloride concentrations due to the low ionic strength of rainwater. Post-monsoon, chloride levels are expected to stabilize at near or slightly below pre-monsoon values, reflecting effective hydrologic flushing of accumulated salts. Nevertheless, in semi-stagnant systems like WS5, chloride may remain moderately elevated due to incomplete turnover and continued localized inputs. Although chlorides presently pose low direct health risk, their seasonal behaviour confirms chronic, repeated equine-derived loading, and any long-term upward trend would indicate progressive degradation, increased corrosion potential, and declining aesthetic quality of water.

2.7.7 Nitrates and Phosphates:

Figure 2.6 and figure 2.7 shows seasonal variation of Nitrates and phosphates values respectively for samples WS1 to WS5

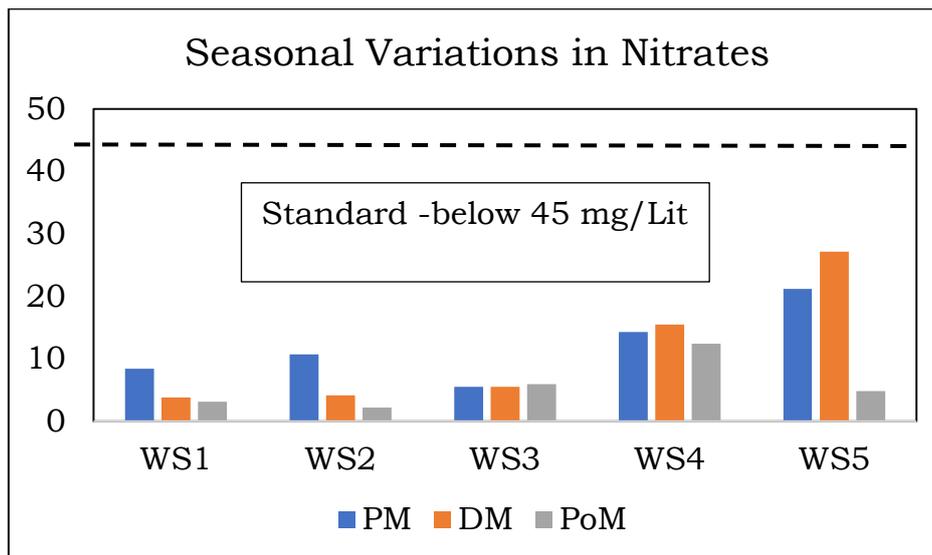


Figure 2.6: Seasonal Variations in Nitrates Concentrations

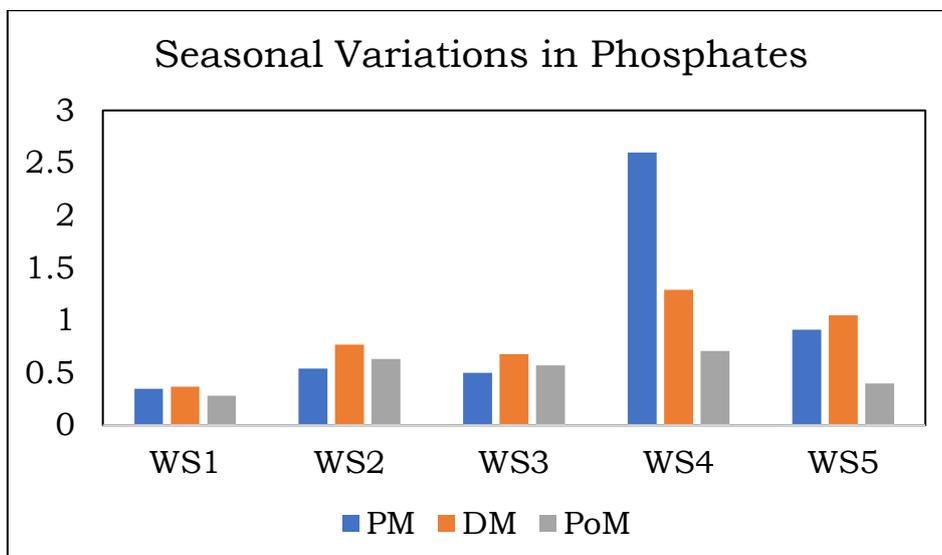


Figure 2.7: Seasonal Variations in Phosphates Concentrations

Nitrate levels in pre-monsoon varied from ~5–21 mg/L. Sites near human/animal activity (WS4, WS5) were on the higher side (~14–21 mg/L NO_3) and exceeded the safe limit for infants (10 mg/L), though below the adult drinking water standard of 45 mg/L. Phosphate was low at pristine sites (~0.3–0.5 mg/L) but very high at WS4 (2.6 mg/L) and elevated at WS5 (0.9 mg/L). These nutrient patterns indicate horse-waste runoff “hotspots.” Monsoon impacts: Rainy season runoff significantly increases nutrient loading. Piles of

dung and urine deposits accumulated over the dry months are suddenly mobilized by rain, leaching nitrates and phosphates into water bodies. We expect sharp monsoon spikes: nitrate might momentarily approach or exceed 45 mg/L in runoff-collection zones during peak rains (especially downslope of stables), and phosphates likewise surge (often attached to eroded soil particles). A study in a monsoonal river found nitrates peaking in wet season compared to dry, aligning with this behavior. Elevated nutrients in monsoon can trigger **eutrophication**: already, pre-monsoon phosphate in WS4 was enough to prompt algal growth concerns. During post-monsoon, nutrient concentrations may decline from their peaks (via dilution and uptake by burgeoning plant/algal growth), but the **legacy of monsoon nutrient influx** often appears as algal blooms in water bodies once the sun returns. Matheran's Charlotte Lake and ponds could see a burst of algae or aquatic weed growth after the rains due to the accumulated nitrates/phosphates, potentially leading to oxygen depletion and fish-kills if severe.

2.7.8 Most Probable Number (MPN) (E-Coli): Figure 2.8 shows seasonal variation of MPN (E-Coli) values respectively for samples WS1 to WS5

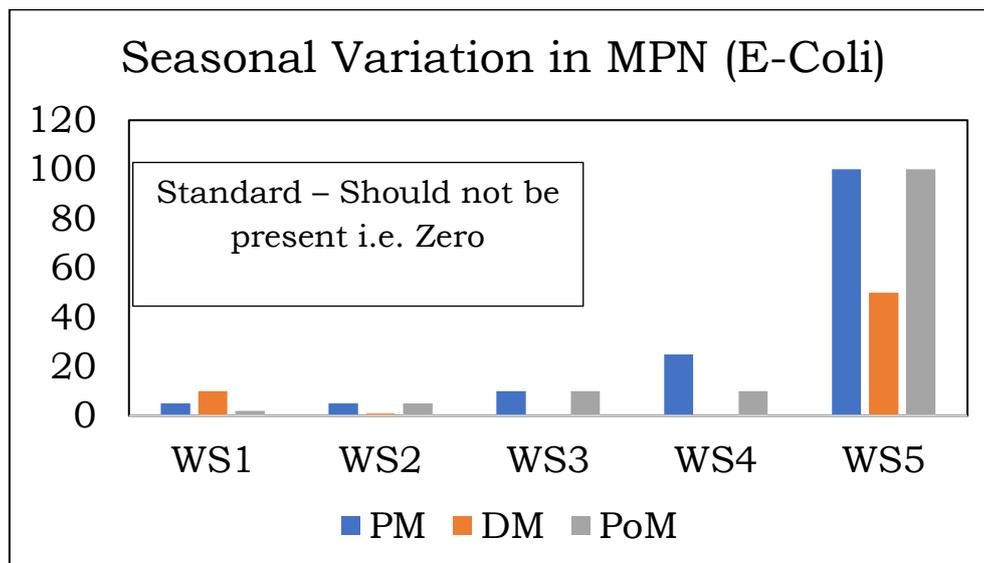


Figure 2.8: Seasonal Variations in MPN values

Fecal coliform bacteria were detected at all sites in pre-monsoon, despite many being in forested or upstream areas. *E. coli* ranged from 5–10 CFU/100 mL in the lake sites (WS1–WS3) up to 25 CFU at the stream site WS4 and 100 CFU at the stagnant Simpson tank WS5. These counts violate drinking water norms (BIS and WHO both mandate **0 CFU** in 100 mL). The presence of *E. coli* confirms fecal contamination, almost certainly from horse dung (no sewage sources in Matheran forests). **Monsoon expectation:** Microbial contamination **intensifies sharply** with rain. As runoff washes horse trails and stable yards, it carries fresh manure and pathogen-laden slurry into streams and lakes. We anticipate *E. coli* counts an order of magnitude higher in monsoon – even pristine-looking sites can show spikes after storms. Studies have shown wet-season *E. coli* levels doubling those in dry season due to agricultural runoff. In Matheran, a site like WS5 could see *E. coli* in the hundreds of CFU/100 mL during monsoon (vs 100 in dry), and even the lake (WS1–WS3) could register dozens of CFU as dung from trails above is washed in. Figure 2 illustrates this trend: for example, WS4 might rise from 25 to ~200 CFU/100 mL during monsoon events (conceptual), and WS5 from 100 to ~300 CFU. Post-monsoon, microbial counts should decline as continuous flushing stops and sunlight, predation, and die-off reduce bacteria in water. The **first few post-monsoon weeks, however, may still show elevated coliforms** in water stored in lakes, especially if nutrient-fueled algal growth provides protective niches for bacteria. Overall, monsoon renders all these water sources **unsuitable for human use without treatment** due to pathogen presence. Even in dry season, the baseline *E. coli* in all samples is alarming from a health perspective, but during monsoon it becomes acutely unsafe for any unboiled consumption or even bathing.

2.7.9 Heavy Metals (Pb, Zn and Cu):

Figures 2.9 to Figure 2.11 shows seasonal variations of Heavy metals concentrations for Samples WS1 to WS5 respectively

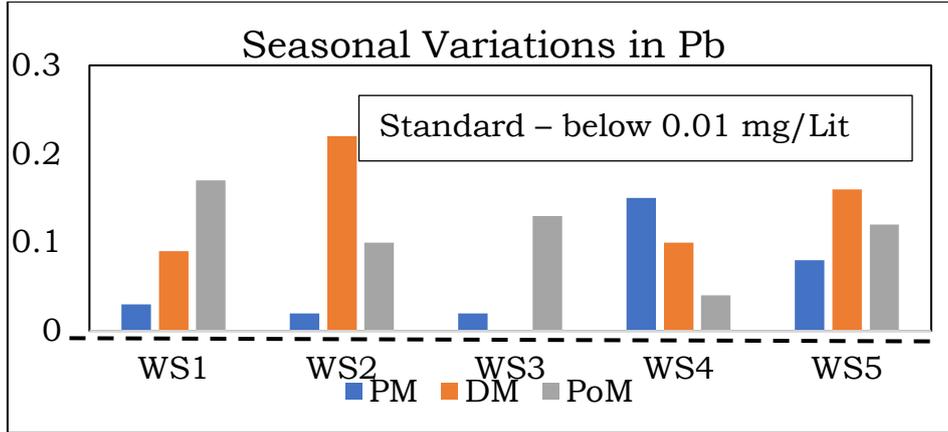


Figure 2.9: Seasonal Variations in Lead Concentration

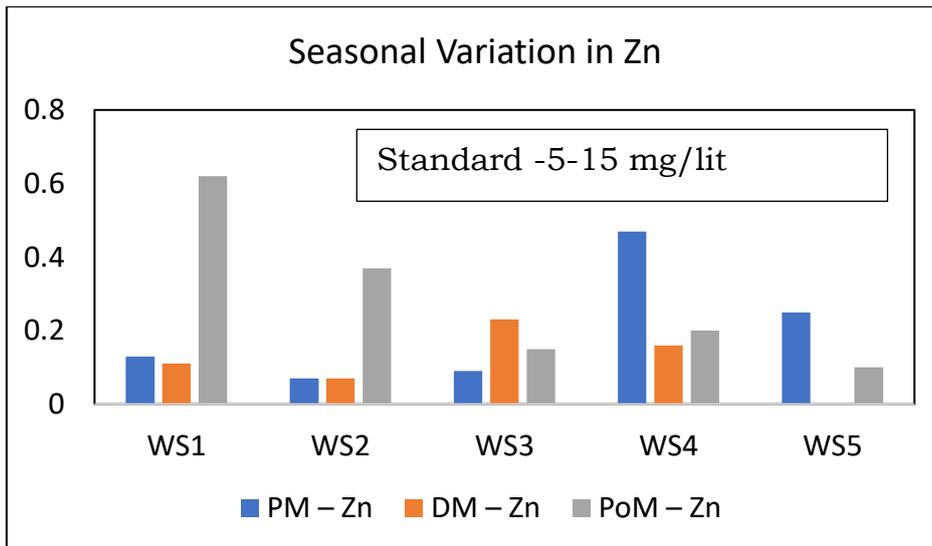


Figure 2.10: Seasonal Variations in Zinc Concentrations

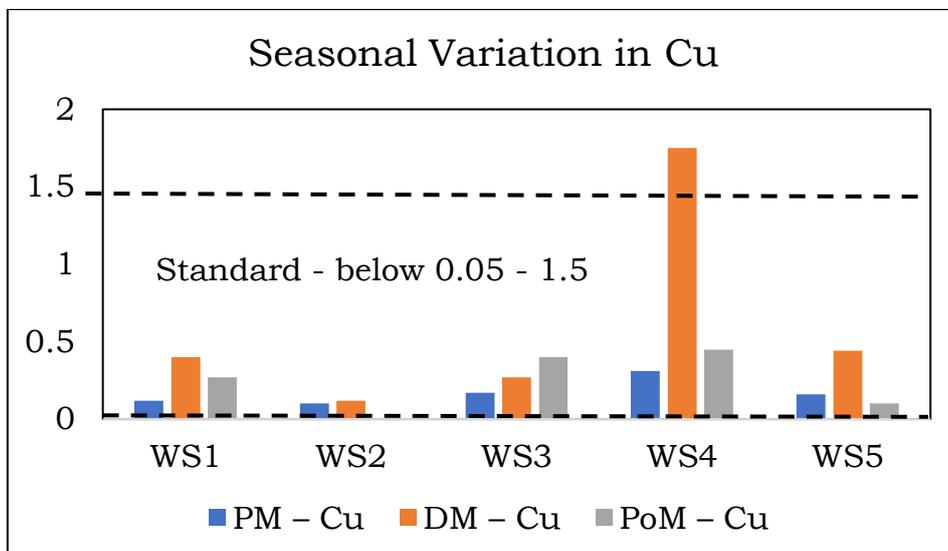


Figure 2.11: Seasonal Variations in Copper Concentrations

Pre-monsoon sampling revealed concerning heavy metal presence tied to low-pH runoff areas. Lead (Pb) in two sites exceeded standards: WS4 had 0.15 mg/L and WS5 0.08 mg/L Pb, **well above** the 0.01 mg/L BIS/WHO limit for lead. Copper (Cu) was below its permissible level (all ≤ 0.31 mg/L, vs. 1.5 mg/L limit) but slightly elevated at WS4; zinc was within safe range (≤ 0.5 mg/L) at all sites. The lead contamination is particularly notable: potential sources include old paint, vehicle exhaust residues concentrated near the parking area, or historical use of leaded fuels/oils – but in Matheran’s context, **equine equipment** (metal horse shoes, fittings) and soil geochemistry might contribute. Crucially, acidic runoff (like WS4’s pH 6.3) can **leach lead from soil or corroding infrastructure. Seasonal variation:** During monsoon, heavy metal transport may increase initially as acidic, low-oxygen soil water mobilizes metals into runoff. We might see transient spikes in dissolved metals (including Pb, Zn) in runoff-heavy streams. However, large water volume can dilute concentrations in the main lake. Also, metals often **attach to suspended sediments:** thus the high TSS in monsoon can carry metals which then settle into bottom mud. It is likely that monsoon sampling would find detectable Pb in more locations, though perhaps at slightly lower concentrations than the worst pre-monsoon stagnant pools (e.g. WS4 might drop from 0.15 to, say, 0.05–0.1 mg/L during continuous flow, still over the limit). Post-monsoon, metals largely end up in sediments; water column levels may decrease, but any disturbance of sediment (or continued leaching from soil) can prolong metal presence. Importantly, **any lead above 0.01 mg/L is a serious chronic health hazard** – lead’s toxicity has no safe threshold, especially for children (causing neurological and developmental damage). The persistence of lead in WS4/WS5 across season’s raises concern of ongoing contamination sources (contaminated soil at horse stable areas).

2.8 Summary of Seasonal Patterns

In the dry pre-monsoon period, water quality issues were somewhat localized – e.g. extreme turbidity and pollution at a few hotspots (stagnant dung-laden pools), while other sites were relatively clean (low turbidity, moderate

nutrients) but still had low-level fecal contamination. The monsoon season, by contrast, **equalizes and exacerbates pollution**: contaminants spread out with flowing water, causing generally higher turbidity, nutrients, and microbes at *all sites* (the “dilution” by rain is offset by the sheer influx of pollutants from land). Post-monsoon, the situation improves from the monsoon peak – solids settle and microbial die-off occurs – but the water bodies now contain the **accumulated pollutants** deposited during monsoon (nutrients in the water and sediment, some lingering bacteria and heavy metals in sediment). Thus, post-monsoon water might look clearer, yet can exhibit secondary effects like algal blooms, low dissolved oxygen, or elevated background levels of e.g. nitrates in the lake. Managing these seasonal fluctuations is critical: e.g. filtration and disinfection are needed year-round (since even dry-season water had *E. coli*), and special measures are needed in monsoon (when raw water quality is poorest & hardest to treat due to turbidity and pathogen load).

2.9 Seasonal Risk Assessment for the Sampling Sites

To synthesize the above, Table 10 categorizes each water sampling site’s risk level (Low, Moderate, High) in each season, along with key pollutants driving that risk. “Risk” here reflects both human health hazard (relative to BIS/WHO standards) and ecological impact. **Low** implies compliance with most standards and minor issues; **Moderate** implies some standards exceeded or notable pollution that could pose sub-acute issues; **High** means gross exceedances of health/ecological standards, indicating likely unsafe conditions.

Table 2.10. Seasonal Water Quality Risk at Matheran Sampling Sites (Pre-monsoon, Monsoon, Post-monsoon)

Site (Location)	Pre-Monsoon Risk (Key Issues)	Monsoon Risk (Key Issues)	Post-Monsoon Risk (Key Issues)
WS1 (Charlotte Lake near Dashkriya Ghat)	Low – All parameters near standards; slight nitrate (8.4 mg/L) and <i>E. coli</i> (5 CFU/100 mL) present (fails 0 CFU norm).	Moderate – Runoff from uphill trails likely introduces turbidity and <i>E. coli</i> (expected CFU in tens) above safe levels; nitrates may rise but likely stay <45 mg/L.	Low – Water clears up; nutrient-enriched but no acute pollution; minimal <i>E. coli</i> after die-off. Continued treatment

Site (Location)	Pre-Monsoon Risk (Key Issues)	Monsoon Risk (Key Issues)	Post-Monsoon Risk (Key Issues)
			needed for potability (zero tolerance for E. coli).
WS2 (Charlotte Lake at Steps)	Low – Similar to WS1: generally, within norms except mild nitrate (10.7 mg/L) and E. coli (5 CFU) contamination.	Moderate – Receives stormwater from tourist areas (steps runoff), so turbidity and microbes moderately elevated (coliforms likely 10–50 CFU).	Low-Moderate – Largely clear water returns; some nutrient residue could promote algal tinge near shore; biologically safer than monsoon but still treat water.
WS3 (Lake Interior, away from steps)	Moderate – Turbidity 4 NTU (just over 1 NTU desirable); E. coli 10 CFU; otherwise, good. Indicates slight contamination even offshore.	High – Diffuse runoff from multiple streams enters lake midsections; likely turbidity surges (lake water visibly cloudy), E. coli spikes (>50 CFU). Algal toxins possible later from nutrient pulse.	Moderate – Better than monsoon, but post-bloom oxygen dips or algal toxins possible if bloom occurred. Some pathogens may persist in sediment. Caution for recreation until fully stabilized.
WS4 (Upstream stream near bridge)	High – Severely polluted by horse dung runoff: turbidity 550 NTU, TSS 277 mg/L; E. coli 25 CFU ; Pb 0.15 mg/L ; nitrate 14.3 mg/L, phosphate 2.6 mg/L. Gross violations of drinking water norms (e.g. E. coli >0, Pb >>0.01, turbidity >>5).	High – Continues as worst site: constant dung-laden runoff keeps water very turbid (100s NTU) and pathogenic. Even if Pb dilutes somewhat, likely still present. Acts as major pollution conveyor into lake – warrants isolation or treatment wetlands.	Moderate-High – After rains, streambed has deposited contaminants (metal-rich sediment, manured soil). Baseflow may run clearer but picks up leachate from soaked soils (possible elevated nitrate, microbial regrowth). Remains a risky source without intervention.
WS5 (“Simpson Tank” near Parking)	High – Fecal hotspot : E. coli 100 CFU/100 mL (worst of all sites); turbidity 27 NTU; Pb 0.08 mg/L above limit; nitrate 21.2 mg/L near infant risk level. Indicates stagnation of horse waste runoff. Not potable or even safe for contact.	High – Direct drainage from stables/parking during rain. Likely fecal coliform in 100s CFU , very muddy flows, ammonia odor. Hazardous for any human use; could contaminate downstream if it overflows into streams.	Moderate – Waterbody may flush out some during monsoon and refill with rain. Post-monsoon it might appear cleaner, but pathogens and heavy metals linger in sediment. If used by wildlife or livestock, still a health risk. Should be monitored/treated before any use.

(Key: Low = meets most standards (low risk); Moderate = some pollutants above norms (medium risk); High = severely polluted (unsafe). “Key Issues” list pollutants or parameters causing risk, relative to **BIS IS 10500:2012** norms (e.g. turbidity >5 NTU, E. coli present vs 0 allowed, nitrate >10 mg/L for

infants, Pb >0.01 mg/L, etc.). Each site's risk is higher in monsoon, when **nearly every health/environmental standard is breached** at the worst sites. Notably, even “Low” risk sites still require disinfection because of persistent **E. coli contamination** year-round.)

From Table 10, we see that **WS4 and WS5 are consistently High risk** – these are the sites directly impacted by horse stables and pathways, thus acting as point sources of pollution. They remain problematic in all seasons (though slightly less so post-monsoon than during rains). The lake sites (WS1–WS3) are Low to Moderate in the dry season but get notably worse in monsoon due to dispersed runoff pollution. This seasonal convergence in water quality means monsoon management is critical: what were localized issues in dry weather become broader water-quality degradation affecting the larger ecosystem and potentially Matheran's drinking water reservoir (Charlotte Lake) in the rainy season.

2.10 Comments On Observed Trends and Implication

The seasonal water quality trends at Matheran align with established environmental science insights on non-point source pollution and tropical monsoon dynamics. **Horse dung and urine** act much like agricultural pollutants, rich in nutrients and pathogens, which accumulate in the landscape during dry periods and then are episodically washed into water bodies by rainfall. This “first flush” phenomenon explains the dramatic spikes in turbidity, nitrates, phosphates, and coliforms observed or expected in monsoon.

a) Zoonotic Pathogens:

The presence of *E. coli* (a fecal indicator) in all samples is a red flag for zoonotic disease risk. It signals that water is contaminated by feces and could harbor other harmful microbes like *Salmonella*, *Giardia*, or *Cryptosporidium*. Indeed, runoff from livestock areas is known to transport **pathogenic bacteria and parasites** into water. Horse dung can contain *Salmonella* spp. and parasitic worm eggs (strongyles, etc.), which in water create exposure risks for humans and wildlife. During monsoon, the dissemination of these microbes is

amplified – puddles, streams, and even soil become vehicles for disease spread. Tourists or locals wading through contaminated mud or using untreated stream water could contract gastrointestinal illnesses. **E. coli** (a pathogenic strain causing severe diarrhea) has been associated with manure runoff in other contexts; while our tests didn't speciate *E. coli*, the zero-tolerance standard reflects that *any* fecal coliform could indicate dangerous pathogens. Zoonotic disease outbreaks (e.g. leptospirosis, dysentery) often surge after heavy rains in areas with poor waste management – a concern for Matheran's community health. Notably, the report's future scope includes correlating health records for GI illnesses with these environmental data, underlining the recognition of this risk.

b) Nutrient Loading & Algal Blooms:

The high nitrate and phosphate levels in runoff-impacted sites (e.g. WS4, WS5) point to potential **eutrophication** in receiving waters. Phosphorus is typically the limiting nutrient for algae; the measured 2.6 mg/L PO_4^{3-} at WS4 is well above natural background and can spur algal blooms downstream. Charlotte Lake, being a relatively small and slow-flushing reservoir, is vulnerable to such nutrient enrichment. In the aftermath of monsoon nutrient input, we expect algal or cyanobacterial blooms in calm weather. These blooms not only degrade aesthetics (unsightly green scums) but also can produce toxins and deplete dissolved oxygen at night or when they die off. Fish kills could occur if oxygen levels plunge (there have been instances globally of livestock-waste runoff causing sudden algae growth and fish deaths in ponds). While Matheran's lake is used for drinking water (with treatment), algal bloom toxins (e.g. microcystins from cyanobacteria) are **not removed by standard sand filtration** and pose a health hazard if present. Thus, nutrient management is key to preventing an "internal eutrophication" cycle. The post-monsoon period, with strong sunlight and remaining nutrients, is the critical time when such blooms might appear. Reducing dung influx (via buffer zones or collection) before it reaches water will mitigate this.

c) Organic Pollution and Microbial Activity:

The data show high organic loads (dung = organic matter) leading to effects like low DO (not measured in this phase, but likely low DO in stagnant WS5) and high **BOD**. Although BOD wasn't explicitly reported, the extreme turbidity and TSS at WS4 imply a high biochemical oxygen demand as microbes decompose the abundant organics. In monsoon, oxygen in streams can actually increase with turbulence, but in the receiving lake, the influx of organic matter can cause oxygen sag as it decomposes. Anoxic conditions in bottom waters or sediments may arise, releasing iron, manganese, and even causing foul odors (sulfide formation). The rotten-egg smell often reported near polluted water is due to anaerobic decomposition – something likely around WS5's stagnant water especially in warmer post-monsoon weeks. This underscores a risk to aquatic life & indicates how **horse waste can alter**.

d) Ecosystem functioning:

Excessive microbial growth (feeding on dung) consuming oxygen and upsetting aquatic fauna and flora balance. Increased **ammonia** from urea breakdown is another concern (ammonia is toxic to fish and was likely present given the strong odor noted during sampling). Monitoring for ammonia and DO during monsoon would be advisable, as the report planned.

e) Heavy Metals and Bioaccumulation:

The detection of lead above standards is alarming not just for direct water consumption but for ecological bioaccumulation. Lead can settle in sediments and be taken up by benthic organisms, entering the food chain. Matheran's streams eventually drain (via downstream flows) into lowland water bodies – any lead or other metals could affect those ecosystems too. Even low concentrations (ppm level) can accumulate in fish, snails, etc. *over time*. If Charlotte Lake has fish, lead and other metals could accumulate in their tissues, posing a risk to any predators (e.g. birds) or humans if fishing occurs. The **eco-sensitive zone (ESZ) status** of Matheran calls for extra vigilance on such toxic substances, because even sub-lethal impacts (e.g. on amphibian development or on microbial communities in soil/water) are contrary to the conservation goals. The lead source in this case is likely anthropogenic –

possibly old paint from facilities or vehicular residues from the car park that have made their way into runoff. Regardless, the fact that **“no safe level” of lead exists for children** means even moderate levels are a significant public health issue if water were to be consumed untreated. In context, the presence of lead strengthens the argument for stopping any **contaminant flow into the lake** – once metals contaminate an environment, they are exceedingly hard to remove.

2.11 Public Health Implications of Water Quality

Taken together, the observed water quality issues pose multifaceted health risks: acute gastrointestinal illness from pathogens (especially in monsoon), potential **methemoglobinemia** (“blue baby syndrome”) in infants from nitrate if they drank the water, longer-term cancer or developmental risks from chronic exposure to chemicals like lead and any pesticide residues (if horses are treated with fly repellents or medication that enter dung). The local population and tourists might mostly rely on treated municipal water, but any untreated sources (wells, springs) are at risk. Moreover, during heavy rains, **treatment plants can be challenged** by the high turbidity and might not effectively disinfect water with high E. coli counts, raising risk of waterborne disease outbreaks. It’s noted that about 10 million cases of diarrhea occur annually in India due to contaminated water – Matheran must ensure it does not contribute to this statistic by improving water safety in all seasons. Even recreational contact (for example, children playing in puddles or tourists washing hands in a stream) could transmit infections.

2.12 Wider Ecological Impacts

Matheran’s streams ultimately feed into the Ulhas River catchment; hence pollution here can affect downstream water quality that communities outside the ESZ might use. Within the ESZ, waterholes serve wildlife – contaminated water can sicken not only people but also animals. **Livestock and feral animals** might drink from WS5 or puddles with high coliform levels, potentially contracting or spreading disease (e.g. *Leptospira* thrive in urine-contaminated water and can infect many mammals). The nutrients and organic matter can alter aquatic community structure – favoring hardy species

(algae, sewage-fungus, mosquito larvae) over sensitive ones. Matheran's designation as an Eco-Sensitive Zone is partly due to its rich biodiversity; water pollution undermines this by harming aquatic habitats. For example, amphibians (frogs/toads) need clean water to breed – high ammonia or low oxygen from dung pollution can kill eggs or tadpoles, reducing their populations. Thus, the seasonal pulse of pollution from horses is an ecological stress that did not exist naturally in this ecosystem.

In summary, the seasonal data trends at Matheran underscore known concepts in environmental science: **pollution builds up during dry periods and is washed out in intense pulses during rains**, causing short-term acute effects and longer-term cumulative issues. The situation exemplifies non-point source pollution challenges in an eco-sensitive area – requiring integrated management (controlling the source at dry times and mitigating the transport during rains) to protect both public health and ecological integrity. The observations align with literature on watershed management: keeping animal waste out of runoff pathways is crucial as even well-intentioned activities (like horse-based transport in a hill station) can degrade water quality significantly if not managed. With horses contributing large nutrient and microbe loads (one horse produces ~15 kg manure/day), the **carrying capacity** of the environment can be exceeded, as appears to be happening during peak tourist season (which coincides with pre-monsoon summer months and immediately gets hit by monsoon flush). This calls for remedial measures such as constructed wetlands, manure composting (to stabilize nutrients), and strict sanitation around water bodies, as discussed next.

2.13 Regulatory Compliance and Matheran's Eco-Sensitive Zone Obligations Comparison with BIS IS 10500:2012 And WHO Standards:

The water quality findings reveal multiple violations of national drinking water standards. According to IS 10500:2012 (Indian Drinking Water Specification), pH should be 6.5–8.5 (met at most sites), turbidity ≤ 1 NTU desirable (≤ 5 NTU permissible), TDS ≤ 500 mg/L, nitrate ≤ 45 mg/L, and **lead ≤ 0.01 mg/L. E. coli or thermotolerant coliforms must be 0/100 mL** as a

mandatory absence in drinking water. In the pre-monsoon dataset alone, we see turbidity at one site 110× the permissible limit, E. coli in all samples (where **0 is allowed**), and lead 8–15× the standard in two samples. These represent serious departures from both BIS and WHO guidelines (WHO generally aligns: e.g. turbidity <1 NTU recommended, nitrate 50 mg/L, lead 0.01 mg/L, and zero tolerance for fecal coliform). During monsoon, it is almost certain that no sample would meet drinking water criteria without treatment – even turbidity in the main lake likely exceeds 5 NTU, and widespread fecal contamination would violate the microbial criteria.

For instance, **WS5's pre-monsoon E. coli (100 CFU) violates the drinking water standard**. The nitrate levels (~21 mg/L max) were below the 45 mg/L BIS limit, but notably above the 10 mg/L level of concern for infants; while the current values might not trigger regulatory violation, they do pose health concerns for babies if the water were consumed, echoing WHO's warnings about "blue baby syndrome". In monsoon, if nitrates spike, there is a risk some samples could exceed 45 mg/L (especially if manure piles are large – though our data can't confirm without actual monsoon measurements).

2.14 National Ambient Water Quality (NAWQ) Criteria:

While India does not have "ambient water quality standards" in the same way as drinking water, the Central Pollution Control Board (CPCB) has designated "best use" classifications for surface waters. Charlotte Lake is essentially a drinking water source for Matheran after treatment, so ideally it should meet CPCB Class A or B criteria in its raw state. Class A (drinking water source without conventional treatment) demands **<50 total coliforms/100 mL, pH 6.5–8.5, DO ≥6 mg/L, BOD ≤2 mg/L**. Our findings show **Class A is nowhere met** – even the best site had E. coli >0 (and thus total coliform likely >50). Class B (outdoor bathing) allows up to 500 coliforms/100 mL; monsoon levels at worst sites might violate even that if they reach hundreds or thousands of CFU (conceivably, WS5 in monsoon could be >500). So for recreational contact, the water in monsoon may not be safe by CPCB criteria either. Class C (drinking water with conventional treatment) is more lenient (coliforms up to

5000, BOD ≤ 3 mg/L) – Matheran’s lake might fit into Class C in dry season (coliform ~5–10, BOD likely low) but during monsoon even Class C could be strained if BOD climbs due to dung and DO falls with organic loading. These comparisons highlight that **current water quality in Matheran’s ESZ is below desired standards for any direct use**, and relies entirely on treatment and dilution to avoid health impacts.

2.15 Eco-Sensitive Zone (ESZ) Stipulations

Matheran was notified as an Eco-Sensitive Zone to protect its fragile environment. This designation imposes restrictions and guidelines to prevent pollution. Notably, the ESZ notification explicitly states: *“All steps shall be taken to prevent contamination or pollution of water, including from agriculture activities.”* The spirit of this rule is clearly being violated by the ongoing horse dung pollution. Horse riding might not be “agriculture,” but the waste runoff is analogous, and indeed one could interpret horse traffic as an activity needing regulation under ESZ rules. The ESZ also bans polluting industries and limits on new development that could strain resources. While horse transport is a traditional activity, the **scale (hundreds of horses)** has effectively become an unregulated pollution source. The data showing heavy contamination in water bodies indicates non-compliance with the mandate to keep the ESZ water unpolluted. The local authorities (MPCB and Matheran Council) as well as the ESZ Monitoring Committee are empowered to enforce measures to mitigate this – for example, constructing manure storage so it doesn’t wash off, enforcing no-dumping zones near water, and perhaps limiting the number of horses (carrying capacity) as recommended in the report.

In summary, the water quality at Matheran violates multiple standards meant to safeguard health and environment. Given the Eco-Sensitive Zone status, these violations are particularly concerning and should prompt urgent remediation. Achieving compliance will likely involve both policy (e.g. enforcing horse number limits, mandating waste management per ESZ rules) and engineering (e.g. sedimentation basins, buffer vegetation, check-dams to reduce runoff velocity). This will ensure that the **letter and spirit of**

regulations – “to prevent contamination of water” in this pristine zone – are upheld, preserving Matheran’s ecological heritage and public health for the long term.

2.16 Recommended Policy Measures

The recommended measures are structured in a **tiered, priority-based framework**, focusing on source control, runoff interception, water body protection, public health safeguards, and regulatory compliance.

Source-Control Policies (Highest Priority)

I) Mandatory Equine Waste Management

Policy Measure:

- Daily collection of horse dung and urine-soaked bedding
- Absolute prohibition of open dumping on trails, slopes, or near drainage channels

Justification

Phase II monitoring recorded nitrate concentrations up to 35 mg/L, phosphates exceeding 1 mg/L, and E. coli spikes along horse movement corridors. Persistence of these parameters during Phase III confirms continuous pollutant input from equine activity.

Legal Basis:

- Provisions of the Eco-Sensitive Zone Notification
- Application of the Precautionary Principle under the NGT Act.

II) Designated Manure Collection and Treatment Zones

Policy Measure:

- Establishment of lined and covered manure collection facilities located away from natural drainage lines
- Treatment of collected waste through approved composting or bio-methanation methods

Justification:

This measure prevents first-flush wash-off of nutrients and pathogens during monsoon rainfall and directly reduces peak pollution loads observed in Phase

III) Runoff Interception and Engineering Controls

Constructed Wetlands and Bio-Filters

Policy Measure:

Mandatory installation of vegetated swales, sedimentation basins, and small constructed wetlands at identified runoff hotspots (WS4, WS5, WS15, WS19).

Justification:

Monsoon turbidity levels exceeding 300–420 NTU confirm sediment-dominated pollutant transport. Nature-based systems are effective in removing significant proportions of suspended solids, nutrients, and microbial load before runoff reaches surface water bodies.

IV) Horse-Trail Drainage Redesign

Policy Measure:

- Installation of cross-drains, check dams, and stone pitching along steep horse trails
- Diversion of runoff away from direct entry into streams and lakes

Justification:

WS4 functions as a direct pollution conduit to Charlotte Lake. Reduction in runoff velocity significantly lowers pollutant transport energy and sediment mobilisation during monsoon events.

V) Water-Body-Specific Protection Policies

Protection of Charlotte Lake

Policy Measure:

- Declaration of a minimum 50-metre no-dung buffer zone around the lake perimeter
- Restriction of horse movement near water intake & shoreline access areas

Justification:

Seasonal nutrient intrusion during monsoon and phosphate persistence in the post-monsoon period indicate elevated eutrophication risk, necessitating strict buffer-based protection.

VI) Remediation of Simpson Tank (WS5)

Policy Measure:

- Designation of Simpson Tank as an environmental hotspot
- Periodic desilting, removal and safe disposal of contaminated sediments, aeration, and phytoremediation

Justification:

WS5 consistently exhibits high-risk water quality across all seasons and functions as a sink for microbial, nutrient, and metal contamination.

VII) Public Health & Water Safety Policies Zero-Tolerance Pathogen Policy Policy Measure:

No untreated surface water shall be used for drinking, washing, or recreational purposes.

Justification:

Detection of E. coli during all seasons confirms chronic fecal contamination and presents a continuous public health risk.

VIII) Strengthening of Water Treatment Systems

Policy Measure:

Upgrade water treatment facilities to handle high turbidity and microbial loads, with mandatory pre-monsoon preparedness and performance audits.

IX) Monitoring, Governance, & Legal Compliance Seasonal Monitoring Protocol

Policy Measure:

Mandatory three-phase annual monitoring covering pre-monsoon, monsoon, and post-monsoon periods, including sediment analysis for lead (Pb), zinc (Zn), and copper (Cu) to be continued for next 3 to 5 years.

Justification:

Persistence of metals during the post-monsoon period necessitates sediment-level assessment to capture legacy contamination.

X) Polluter Pays and Carrying Capacity Regulation

Policy Measure:

- Fixation of a maximum permissible number of horses within the Eco-Sensitive Zone
- Levy of environmental compensation on operators contributing to pollution

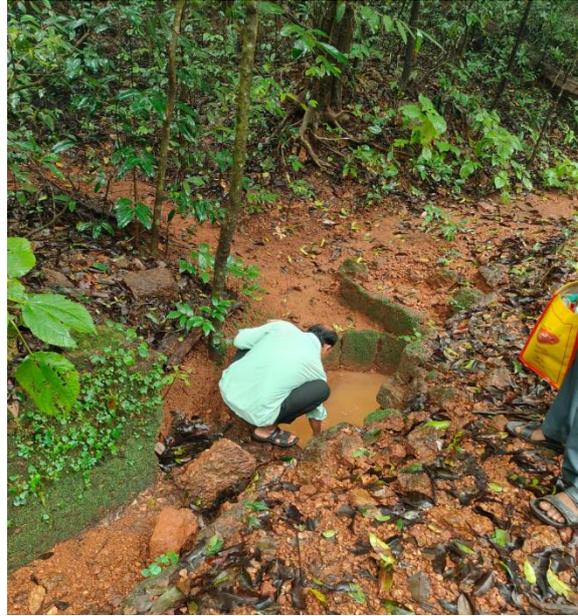
Justification:

Observed pollution loads exceed the natural assimilative capacity of the ecosystem, making the application of the Polluter Pays Principle under NGT jurisprudence directly applicable.

2.17 GLIMPSES OF SAMPLING



Runoff Water Sample Collection



Stagnant Water Sample Collection



Stagnant Water Sample Collection



Charlotte Lake Sample Collection

Report on Soil Quality Monitoring and Analysis

3.1 PREAMBLE

Matheran, being a notified Eco-Sensitive Zone, possesses fragile lateritic soils that play a critical role in sustaining forest vegetation, regulating surface runoff, and protecting downstream water bodies. Soil quality in such hill ecosystems acts as a foundational environmental indicator, as any chemical, biological, or physical disturbance to soil directly propagates impacts on surface water, groundwater, biodiversity, and human health. In recent years, intensive equine activity associated with tourism, coupled with inadequate management of horse dung and urine, has raised serious concerns regarding progressive soil degradation along horse corridors, stable areas, market zones, and lake catchments. Recognizing soil as both a receptor and a carrier of pollutants, systematic seasonal monitoring was undertaken to assess the extent, nature, and persistence of soil quality deterioration in Matheran.

The present soil quality assessment has been structured into three distinct phases—Phase I (pre-monsoon), Phase II (monsoon), and Phase III (post-monsoon)—to capture accumulation, mobilization, and residual behavior of contaminants within the soil system. This phased approach enables identification of source-driven impacts, seasonal amplification mechanisms, and the degree of natural recovery, if any, following monsoon flushing. The findings presented in this report provide scientifically defensible evidence of chronic soil stress resulting from unmanaged equine waste, including nutrient imbalance, salinity, pathogen presence, and physical degradation. The assessment is intended to support regulatory decision-making, guide targeted mitigation measures, and ensure long-term protection of soil health within the Matheran Eco-Sensitive Zone in accordance with the precautionary and sustainable development principles.

Following table 3.1 shows sampling codes and details of sampling locations for soil samples.

Table 3.1: Soil Samples details

Sample code	Details of Soil Sample locations
SS1	Opposite Nagar Parishad
SS2	Forest area on the way to charlotte lake
SS3	Downstream side of lake
SS4	Ash from horse stable
SS5	Upstream Side of lake
SS6	Pashu Vaidyakiya Dawakhana area (horse stable)
SS7	Dasturi Naka, parking area

Above sample codes are used in this report for easy reference.

Analysis of soil quality can give status of soil pollution due to mismanagement of equine urine, dung and movements.

Table 3.2 shows results of soil testing for all samples

Table 3.2: Results of Soil quality analysis

Parameter	Unit	Standard	SS1	SS2	SS3	SS4	SS5	SS6	SS7
pH	pH	6.5-7.5	6.95	6.25	6.29	6.35	6.42	7.29	6.98
EC	mc/cm	0-1	0.9	0.27	1.78	0.022	1.8	0.77	0.38
OC	%	0.40-0.60	0.5	2.35	0.79	0.75	1.12	0.89	1.05
P	Kg/hect.	14-21	15.94	10.41	9.69	12.94	13.52	18.11	14.51
K	Kg/hect.	150-200	184.21	154.62	212.36	139.45	231.36	198.69	214.21
CaCO ₃	%	2.5-5.0	3.37	4.12	5.74	9.74	4.37	5.99	4.96
Ca	ml %	4-9.99	8.69	3.4	5.9	6.8	4.8	5.2	4.9
Mg	ml %	0.50-3.99	2.45	0.47	3.3	3.6	2.4	2.9	3.1
Zn	ppm	0.61-99.99	0.49	2.12	1.12	0.48	0.53	0.84	1.04
Cu	ppm	0.20-99.99	0.18	0.47	0.45	0.75	0.48	0.99	0.97
Fe	ppm	4.5-99.99	1.34	4.8	5.6	2.47	1.91	4.21	2.81
Mn	ppm	2.0-99.99	1.32	2.24	1.19	0.89	1.06	1.01	1.89

3.1 Phase I (Pre-Monsoon) Soil Quality Assessment, Interpretation of Results

1. Introduction and Context (Phase I)

Phase I soil monitoring represents **pre-monsoon conditions**, a period characterized by:

- Prolonged **dry weather**
- **Maximum accumulation** of horse dung and urine residues
- Minimal natural flushing or dilution
- High pedestrian and equine movement pressure

In eco-sensitive hill stations like Matheran, pre-monsoon soil conditions are **critical**, as soils act as **storage reservoirs** for contaminants that are later mobilized during monsoon runoff. Therefore, Phase I establishes the **baseline contaminant load and vulnerability** of the soil system prior to rainfall-driven transport.

The Phase I assessment focuses on **SS1 to SS7**, covering municipal surroundings, forested pathways, Charlotte Lake approach routes, and horse-affected corridors.

2 Soil Reaction (pH) – Early Chemical Stress Indicator

Observed range: 6.25 – 7.29

Desirable range: 6.5 – 7.5

Interpretation:

- **SS2, SS3, SS4, and SS5** exhibit **slightly acidic pH values (6.25–6.42)**.
- This acidity is **not natural lateritic acidity alone**, but is strongly linked to:
 - Repeated deposition of **horse urine**, which undergoes **urea hydrolysis** → **nitrification**, generating hydrogen ions.
 - Organic acid formation during dung decomposition under dry, aerobic conditions.

Environmental implication:

- Even mild acidity in repeatedly disturbed soils leads to:
 - **Phosphorus fixation**
 - Reduced availability of **Zn, Fe, and Mn**
 - Suppressed regeneration of sensitive native vegetation

- Acidic microsites act as **chemical stress pockets** that weaken soil resilience before monsoon impact.

3 Electrical Conductivity (EC) – Salinity Stress from Urine Residues

Observed range: 0.022 – 1.80 dS/m

Permissible range: 0 – 1 dS/m

Key observations:

- **SS3 (1.78 dS/m)** and **SS5 (1.80 dS/m)** exceed permissible limits.
- These sites correspond to **horse movement and congregation zones**.

Interpretation:

- Elevated EC is a **direct indicator of soluble salt accumulation**, primarily from:
 - Urine-derived sodium, potassium, and chloride salts
 - Concentration effects due to evaporation in dry pre-monsoon conditions

Environmental implication:

- Salinity stress:
 - Reduces soil water uptake by plants
 - Increases drought stress even before rainfall
 - Promotes hardy, disturbance-tolerant vegetation at the cost of native species
- High-EC soils are **high-risk contributors** during first monsoon flush events.

4 Organic Carbon (OC) – Evidence Of Chronic Dung Accumulation

Observed range: 0.50 – 2.35 %

Optimal range: 0.40 – 0.60 %

Key observations:

- **All sites exceed the desirable OC range**
- **SS2 (2.35%)** shows **extreme organic overloading**

Interpretation:

- Such elevated OC cannot be attributed to natural forest litter alone.
- It clearly indicates:
 - Long-term accumulation of **horse dung**

- Poor removal practices
- Lack of surface disturbance recovery due to trampling

Environmental implication:

- Excess OC:
 - Increases microbial respiration demand
 - Alters soil redox micro-conditions
 - Creates nutrient binding and imbalance
- During monsoon, this OC becomes a **primary driver of nutrient and pathogen mobilisation**.

5 MACRONUTRIENT STATUS – IMBALANCE RATHER THAN ENRICHMENT

5.1 PHOSPHORUS (P)

Observed range: 9.69 – 18.11 kg/ha

Optimal range: 14 – 21 kg/ha

- Several sites (SS2–SS5) show **P deficiency despite high OC**.

Interpretation:

- Indicates **phosphorus immobilization/fixation** under acidic and organic-rich conditions.
- Demonstrates that dung input does not translate into balanced soil fertility.

5.2 POTASSIUM (K)

Observed range: 139.45 – 231.36 kg/ha

Optimal range: 150 – 200 kg/ha

- **SS3, SS5, and SS7 exceed upper limits**
- **SS4 is below optimal**

Interpretation:

- Potassium is a **signature nutrient of equine urine**
- Patchy distribution reflects:
 - Repeated deposition at halting points
 - Uneven runoff micro-channels

- K becomes a **chemical tracer** of horse influence in later phases.

6. CARBONATES AND SECONDARY NUTRIENTS (CaCO₃, CA, Mg)

- **CaCO₃ exceeds normal limits** at SS4 and SS6
- Ca and Mg show inconsistent availability

Interpretation:

- Indicates **disturbed geochemical equilibrium** due to:
 - Mixing of dung, soil, ash, and bedding materials
 - Physical disturbance and erosion exposure

Environmental implication:

- Carbonate enrichment shifts soil buffering capacity
- Leads to **micronutrient unavailability**, especially Zn and Fe
- Reduces suitability for native understory vegetation

7. MICRONUTRIENT STATUS – SILENT SOIL DEGRADATION

Observations:

- **Zn deficiency** at SS1 and SS4
- **Cu deficiency** at SS1
- **Fe deficiency** at SS1 and SS5
- **Mn deficiency** at multiple sites

Interpretation:

- These deficiencies are **secondary effects** of:
 - pH stress
 - Salinity
 - Organic overloading
- Not nutrient-poor soils, but **chemically locked soils**

Environmental implication:

- Weak root development
- Poor vegetation recovery along trails
- Increased erosion susceptibility before monsoon

8. PHASE I- SOIL RISK ASSESSMENT (PRE-MONSOON)

Table 3.3 shows risk assessment metric table for phase I soil sampling

Table 3.3: Phase I Risk Metric Table – Soil Quality

Sample Code	Risk Level	Key Soil Stressors
SS1	Moderate	Micronutrient deficiencies
SS2	High	Extreme OC, acidity, low P
SS3	High	Salinity (EC), high K
SS4	High	pH stress, high CaCO ₃ , nutrient imbalance
SS5	High	EC exceedance, K enrichment
SS6	Moderate	Carbonate imbalance
SS7	Moderate	K enrichment, OC elevation

9. PHASE I ENVIRONMENTAL SIGNIFICANCE

Phase I clearly demonstrates that **before the onset of monsoon**, soils in horse-affected areas of Matheran already exhibit:

- **Chronic organic overloading**
- **Salinity stress pockets**
- **Nutrient imbalance**
- **Micronutrient locking**
- **Reduced ecological resilience**

These soils are therefore **primed for pollutant mobilization** once rainfall begins.

10. CONCLUSIONS OF PRE-MONSOON SAMPLING (PHASE-I)

Phase I (pre-monsoon) soil quality assessment confirms that equine activity in Matheran has resulted in **significant chemical and fertility degradation of surface soils**, even in the absence of rainfall. Elevated organic carbon, salinity exceedances, potassium enrichment, and widespread micronutrient stress collectively indicate **chronic unmanaged horse dung and urine deposition**. The observed soil condition represents a **high-risk baseline**, from which monsoon conditions are expected to amplify contaminant transport, microbial proliferation, and downstream environmental impacts.

Table 3.4 shows overall risk assessment on the basis of soil sample analysis

Table 3.4: Overall Risk assessment Table

Sample	Risk Level	Contaminants of Concern
SS1	Moderate	Zinc (Zn), Copper (Cu), Iron (Fe), Manganese (Mn)
SS2	High	Low pH (acidic), High Organic Carbon (OC), Low Phosphorus (P), Low Calcium (Ca), Low Magnesium (Mg)
SS3	High	Low pH (acidic), High EC (salinity), High Potassium (K), Low Phosphorus (P), Low Manganese (Mn)
SS4	High	Low pH (acidic), High Calcium Carbonate (CaCO ₃), Low Potassium (K), Zinc (Zn), Manganese (Mn)
SS5	High	High EC (salinity), High Potassium (K), Low Phosphorus (P), Iron (Fe), Manganese (Mn)
SS6	Moderate	High Calcium Carbonate (CaCO ₃), Elevated Organic Carbon (OC)
SS7	Low to Moderate	High Potassium (K), Elevated Organic Carbon (OC)

3.2 SOIL SAMPLING AND ANALYSIS DURING MONSOON (PHASE-II)

3.2.1 SOIL SAMPLING

The following table shows sampling codes and details of sampling locations for soil samples. Seven samples were collected in the first phase of study. Table 4 shows details of soil sampling locations

Table 4: Soil Sampling Details

Sample code	Details of Soil Sample locations
SS1	Opposite to Nagar Parishad
SS2	Forest area on the way to charlotte lake
SS3	Downstream side of lake

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SS4	Ash from horse stable
SS5	Upstream Side of lake
SS6	Pashu Vaidyakiya Dawakhana area (horse stable)
SS7	Dasturi Naka, parking area
SS8	1km from dasturi naka (on the way to market)
SS9	Sakar vishramdham entrance gate
SS10	Near station (rikshaw stop besides rails)
SS11	Hutatma Bhai Kotwal Prathmik Shala, Matheran
SS12	Opposite hope hall and forest office
SS13	Near hotel alexander
SS14	At alexander point horse stable
SS15	Ram baug point horse stable
SS16	Near paymaster park
SS17	On the way to honeymoon point from echo point
SS18	Near honeymoon point
SS19	Near coronation point
SS20	On the way to coronation point to market
SS21	On the way to sunset point to market
SS22	Near Bhartiya Vidya bhavan (Naimisharanya)
SS23	Dried Horse Dung Sample

3.2.2 SOIL QUALITY ANALYSIS

Analysis of soil quality can give status of soil pollution due to mismanagement of equine urine, dung and movements.

Table 3.5-a to Table 3.5-c shows results of soil testing for all samples

Table 3.5-a: Results of Soil Quality Analysis

Parameters	Unit	Standard	SS1	SS2	SS3	SS4	SS5	SS6	SS7
pH	pH	6.5–7.5	6.95	6.25	6.29	6.35	6.42	7.29	6.98
EC	mc/cm	0–1	0.90	0.27	1.78	0.02	1.80	0.77	0.38
OC	%	0.40–0.60	0.50	2.35	0.79	0.75	1.12	0.89	1.05
P	kg/ha	14–21	15.9	10.4	9.69	12.9	13.5	18.1	14.5
K	kg/ha	150–200	184.2	154.6	212.3	139.4	231.3	198.6	214.2
CaCO ₃	%	2.5–5.0	3.37	4.12	5.74	9.74	4.37	5.99	4.96
Ca	ml %	4–9.99	8.69	3.40	5.90	6.80	4.80	5.20	4.90
Mg	ml %	0.50–3.99	2.45	0.47	3.30	3.60	2.40	2.90	3.10
Zn	ppm	≥0.61	0.49	2.12	1.12	0.48	0.53	0.84	1.04
Cu	ppm	≥0.20	0.18	0.47	0.45	0.75	0.48	0.99	0.97
Fe	ppm	4.5–99.9	1.34	4.80	5.60	2.47	1.91	4.21	2.81
Mn	ppm	≥2.0	1.32	2.24	1.19	0.89	1.06	1.01	1.89
E. coli	CFU/g	0	0	48	0	0	0	0	260
Fungal count	CFU/g	—	7×10 ²	16×10 ²	3×10 ²	2×10 ²	3×10 ²	13×10 ²	4×10 ²
Azotobacter	CFU/g	Beneficial	0	6	2	0	0	4	16
Salmonella	CFU/g	0	0	1	0	0	0	0	5

Table 3.5-b: Results of Soil Quality Analysis

Parameter	Unit	Standard	SS8	SS9	SS10	SS11	SS12	SS13	SS14
pH	pH	6.5-7.5	6.11	8.20	7.18	6.98	7.42	7.05	7.54
EC	mc/cm	0-1	0.64	1.14	1.40	1.78	1.34	1.56	0.52
OC	%	0.40-0.60	0.13	0.26	0.15	0.06	0.12	0.11	0.21
P	kg/ha	14-21	6.56	11.18	18.42	17.98	16.23	21.49	10.75
K	kg/ha	150-200	123.15	149.97	118.82	173.21	155.15	178.49	115.12
CaCO ₃	%	2.5-5.0	78.40	178.50	105.00	59.58	134.85	172.48	147.39
Ca	ml %	4-9.99	0.27	0.60	0.48	0.76	0.59	0.87	0.89
Mg	ml %	0.50-3.99	2.16	1.27	1.26	1.13	1.74	2.21	1.09
Zn	ppm	≥0.61	0.32	0.44	0.66	0.63	0.84	0.74	0.77
Cu	ppm	≥0.20	1.51	1.06	1.41	1.05	1.92	1.21	1.01
Fe	ppm	4.5-99.9	1.17	1.30	1.32	1.11	1.03	1.05	1.32
Mn	ppm	≥2.0	4.52	3.05	2.99	2.90	2.65	2.96	2.68
E. coli	CFU/g	0	39	0	18	21	0	0	0
Fungal count	CFU/g	—	28×10 ²	0	3×10 ²	4×10 ²	5×10 ²	2×10 ²	7×10 ²
Azotobacter	CFU/g	Beneficial	0	0	5	0	4	0	0
Salmonella	CFU/g	0	2	0	1	0	0	0	0

Table 3.5-c: Results of Soil Quality Analysis

Parameters	Unit	Standard	SS15	SS16	SS17	SS18	SS19	SS20	SS21	SS22	SS23
pH	pH	6.5–7.5	6.42	6.78	6.80	7.10	6.59	7.61	7.15	6.55	8.2
EC	mS/cm	0–1	1.30	0.81	0.73	0.96	0.56	0.36	1.24	1.40	3.8
OC	%	0.40–0.60	0.48	0.42	0.23	0.18	0.09	0.27	0.33	0.56	18.5
P	kg/h a	14–21	5.45	15.5 7	14.4 7	17.3 2	15.3 5	14.6 9	21.0 5	12.2 8	92
K	kg/h a	150–200	115. 12	167. 93	127. 80	146. 81	144. 59	143. 00	172. 15	136. 24	1,250
CaCO ₃	%	2.5–5.0	65.8 6	166. 21	128. 58	126. 00	181. 89	119. 17	231. 00	97.2 2	14.8
Ca	ml %	4–9.99	0.43	1.49	0.97	0.67	0.78	1.11	0.77	0.98	11.2
Mg	ml %	0.50–3.99	1.77	0.80	1.25	0.56	1.42	1.48	1.06	1.85	4.6
Zn	ppm	≥0.61	0.70	0.79	0.39	0.25	0.37	0.55	0.20	0.65	3.9
Cu	ppm	≥0.20	1.55	1.15	1.31	1.27	1.54	2.15	1.52	1.08	2.8
Fe	ppm	4.5–99.9	0.74	1.26	0.55	1.41	2.10	0.86	1.24	1.22	185
Mn	ppm	≥2.0	2.08	4.22	1.63	3.62	6.64	2.38	2.65	1.81	22.5
E. coli	CFU/ g	0	12	0	35	7	0	0	15	0	470
Fungal count	CFU/ g	—	7×10 ²	15×10 ²	38×10 ²	10×10 ²	6×10 ²	4×10 ²	16×10 ²	10×10 ²	110×10 ²
Azotobacter	CFU/ g	Beneficial	0	2	1	0	0	0	3	0	0
Salmonella	CFU/ g	0	0	0	2	1	0	0	1	0	3

1. Introduction and Context (Phase II):

Phase II soil monitoring represents **monsoon conditions**, during which Matheran experiences:

- High and sustained rainfall
- Saturated soils and surface runoff
- Transformation of accumulated horse dung into **slurry**
- Maximum **mobility of nutrients, salts, and pathogens**

Unlike Phase I, where soils act as **storage reservoirs**, Phase II soils function as **active transport media**, redistributing contaminants across trails, slopes, forest floors, and towards drainage channels and water bodies.

Phase II assessment covers **SS1–SS22**, with **SS23 representing dried horse dung**, included deliberately as a **source-characterization sample** to establish causal linkage between equine waste and soil contamination.

2. Soil Reaction (pH) – Buffering Breakdown During Monsoon

Observed range: 6.11 – 8.20

Desirable range: 6.5 – 7.5

Key observations:

- **Acidic soils:** SS8 (6.11), SS15 (6.42)
- **Alkaline soils:** SS9 (8.20), SS20 (7.61)
- Majority of sites show **departure from the optimal pH band**

Interpretation:

- Monsoon introduces **dual pH stress**:
 - Acidification from **urine hydrolysis, nitrification, and organic acid release**
 - Alkalinity from **carbonate-rich residues, ash contamination, and concentrated salts**
- The wide pH range indicates **loss of natural buffering capacity** due to repeated disturbance and waste loading.

Environmental implication:

- pH instability directly affects:
 - Nutrient solubility (P, Zn, Fe)
 - Microbial survival and activity
 - Soil biological balance
- Such soils are chemically stressed & ecologically fragile during peak rainfall.

3. Electrical Conductivity (EC) – Persistent Salinity Despite Heavy Rainfall

Observed range: 0.27 – 1.80 dS/m

Permissible limit: ≤ 1 mS/cm

Key observations:

- EC exceeds 1 mS/cm at **multiple sites**: SS3, SS5, SS9, SS10, SS11, SS12, SS13, SS15, SS21, SS22
- Salinity is not confined to one zone but **widely distributed**

Interpretation:

- Contrary to expectation, rainfall does **not eliminate salinity**.
- Continuous urine input + wetting–drying cycles lead to:
 - Temporary dilution during rainfall
 - **Re-concentration of salts** between rain events
- Compacted soils promote surface flow rather than deep leaching.

Environmental implication:

- Salinity during monsoon:
 - Damages soil structure
 - Inhibits root respiration
 - Increases vulnerability to erosion
- Saline runoff acts as a **chemical pollutant carrier** to adjacent soils and drainage lines.

4. Organic Carbon (OC) – Redistribution Rather Than Reduction

Observed range: 0.06 – 0.56 %

Optimal range: 0.40 – 0.60 %

Key observations:

- Many sites show **low OC values** (SS8–SS14 region)
- This contrasts with Phase I high OC levels

Interpretation:

- OC reduction does **not indicate recovery**.
- During monsoon:
 - Surface organic matter is **washed away**
 - Dung is converted into slurry and transported downslope
 - Carbon is redistributed to new accumulation zones

Environmental implication:

- Loss of surface OC:
 - Reduces soil aggregation
 - Increases erodibility
 - Facilitates nutrient and pathogen transport
- Soils become **structurally weak and chemically unstable**.

5. Macronutrients (P and K) – Mobilization and Imbalance

5.1 Phosphorus (P)

Observed range: 5.45 – 21.49 kg/ha

Optimal range: 14 – 21 kg/ha

- Several sites remain **phosphorus-deficient** (SS8, SS9, SS14, SS15, SS22)

Interpretation:

- P is mobilized during monsoon but also:
 - Lost via runoff
 - Fixed under altered pH conditions
- Indicates inefficient nutrient cycling under equine waste pressure.

5.2 Potassium (K)

Observed range: 115.12 – 178.49 kg/ha

Optimal range: 150 – 200 kg/ha

- Mixed pattern:
 - Some sites depleted (SS8, SS10, SS14, SS15)
 - Others within range (SS11–SS13, SS16)

Interpretation:

- K is **highly mobile** during monsoon.
- Redistribution masks the enrichment pattern observed in Phase I but does not remove it.
- K remains a **latent indicator**, which reappears strongly in Phase III.

6. Carbonates, Calcium, and Magnesium – Severe Chemical Disturbance

Observations:

- **Extremely high CaCO₃ values** across most sites
- **Very low Ca** (often <1 ml %) and variable Mg

Interpretation:

- Indicates:
 - Severe chemical disturbance
 - Possible mixing of soil with dung, ash, bedding, & eroded material
- Such imbalance is typical of **physically degraded, anthropogenically altered soils**

Environmental implication:

- Poor soil structure

- Reduced biological activity
- Increased erosion and runoff susceptibility during rain

7. Micronutrient Status – Nutrient Locking Intensifies

- Zn frequently below desirable level
- Fe uniformly deficient across most sites
- Mn marginal at several locations

Interpretation:

- Monsoon chemistry (pH swings + carbonate dominance) causes:
 - **Micronutrient precipitation and immobilization**
- Despite adequate total metals, plants cannot access them.

Environmental implication:

- Vegetation stress
- Poor root binding
- Trail-edge soil collapse during heavy rain

8. Bacteriological Soil Quality – Critical Phase II Evidence

8.1 E. coli (Fecal Indicator Bacteria)

- Detected at **multiple locations**
- Major hotspots:
 - **SS7: 260 CFU/g**
 - SS2, SS8, SS10, SS11, SS15, SS17, SS18 also positive

Interpretation:

- Presence of E. coli in soil confirms:
 - **Recent fecal contamination**
 - Survival under moist monsoon conditions
- Indicates **active and ongoing input**, not residual background.

8.2 Salmonella – Public Health Relevance

- Detected at:
 - SS7, SS8, SS10, SS17, SS18, SS21
- Should be **absent in uncontaminated soils**

Environmental and health implication:

- Soil becomes a **pathogen reservoir**
- High-risk exposure for:
 - Horse handlers

- Tourists
- Children
- Sanitation and forest workers
- Strong evidence for **zoonotic risk**.

8.3 SS23 (Dried Horse Dung) – Source Attribution

SS23 exhibits:

- **E. coli: 470 CFU/g**
- **Salmonella: 3 CFU/g**
- Very high fungal counts
- Representative manure chemistry

Expert significance:

- SS23 provides a **source fingerprint**
- Confirms that contamination in surrounding soils is **equine-derived**
- Establishes a **cause-effect linkage** essential for regulatory action.

9. Phase II Soil Risk Assessment (Monsoon)

Table 3.6 shows key risk metric assessment table for phase II of soil sampling Programme

Table 3.6: Phase II Risk Metric Table

Soil Zone / Sample Type	Risk Level	Key Risk Drivers
Horse stables & parking corridors (SS7-type zones)	Very High	High E. coli, Salmonella, slurry formation
Horse trails & market approaches	High	Salinity, nutrient redistribution, pathogen presence
Tourist point access soils	High	Chemical instability + microbial contamination
Source material (SS23)	Extreme (Source)	Maximum pathogen & nutrient load

3.2.3 PHASE II ENVIRONMENTAL SIGNIFICANCE

Phase II represents the **most environmentally critical phase** for soil systems in Matheran because:

- Soil shifts from a **sink** to a **vector**
- Pathogens spread spatially
- Nutrients and salts are redistributed

- Soil erosion and compaction intensify
- Human exposure risk peaks

11. Conclusion of Soil Quality Assessment (Phase-II- During Monsoon)

The Phase II (monsoon) soil quality assessment unequivocally demonstrates that equine activity in Matheran poses its **highest environmental and public health risk during the rainy season**. Despite heavy rainfall, salinity persists, nutrient imbalance intensifies, and—most critically—**fecal indicator bacteria and Salmonella are widely detected in soils**. The inclusion of SS23 (dried horse dung) conclusively establishes equine waste as the **primary contamination source**. Without immediate and enforceable source-control measures, monsoon conditions will continue to facilitate widespread soil-mediated transport of contaminants, undermining ecological integrity and posing recurring health risks.

3.3 SOIL QUALITY ASSESSMENT REPORT PHASE III (POST-MONSOON)

Table 3.7 shows the soil sample codes & description of sample locations.

Table 3.7: Soil Sample Codes and Location Details (Matheran)

Soil Sample Codes	Location Details
SS1	Opposite Nagar Parishad area
SS2	Forest area on the way to Charlotte Lake
SS3	Upstream side of Charlotte Lake (soil near lake periphery)
SS4	On the way from Charlotte Lake to Market area
SS5	Opposite Gulestan Bungalow
SS6	Dried water stream on the way to One Tree Hill Point
SS7	On the way to One Tree Hill Point
SS8	One Tree Hill Point – near horse stable
SS9	Big Chowk Point
SS10	Little Chowk Point
SS11	Near to Little Chowk Point
SS12	Near Bombay Park Resort
SS13	Horse stable near Echo Point
SS14	On the way to Louisa Point
SS15	Near Malang Point
SS16	Near Sunset Point – horse stable area

Soil Sample Codes	Location Details
SS17	On the way to Paymaster Park
SS18	Near Paymaster Park
SS19	Sakar vishramdham entrance gate
SS20	1km from dasturi naka (on the way to market)

Table 8-a to Table 3.8-c shows detailed results of analysis of Phase III soil samples

Table 3.8-a: Results of Soil Quality Analysis

Parameters	Unit	Standard*	SS1	SS2	SS3	SS4	SS5	SS6	SS7
pH	–	6.5–7.5	7.50	7.74	6.24	7.84	7.38	6.78	7.98
EC	dS/m	0–1	0.640	0.650	0.495	0.354	0.349	0.417	0.514
OC	%	0.40–0.60	0.35	0.54	0.37	0.39	0.37	0.58	0.62
P	kg/ha	14–21	14.03	7.45	18.85	20.61	14.47	19.51	16.22
K	kg/ha	150–200	195.28	194.44	225.17	286.28	214.40	196.66	232.67
N	kg/ha	–	121.24	157.50	241.40	157.50	125.90	167.90	115.50
B	mg/kg	–	1.33	0.64	1.05	0.87	0.84	0.97	0.91
S	mg/kg	10–20	9.83	10.31	11.13	9.71	12.09	9.65	11.94
Zn	mg/kg	≥0.61	0.36	0.50	0.57	0.54	0.80	0.97	0.40
Fe	mg/kg	4.5–99.9	5.23	4.74	8.57	6.47	7.52	4.15	6.55
Cu	mg/kg	≥0.20	2.17	1.85	1.29	1.83	1.19	0.91	0.98
Mn	mg/kg	≥2.0	6.37	6.13	8.89	8.57	8.94	3.34	3.93
E. coli	CFU/g m	0 (ideal)	8	0	5	22	0	0	57
Fungal Count	CFU/g m	–	9.0×10 ₂	1.4×10 ₄	1.2×10 ₃	3.0×10 ₃	1.0×10 ₃	5.4×10 ₃	2.5×10 ₃

Azotobacter	CFU/g m	Beneficial	0	7	10	0	18	5	7
Salmonella	CFU/g m	0	0	0	3	0	0	1	0

Table 3.8-b: Results of Soil Quality Analysis

Parameters	Unit	Standard	SS8	SS9	SS10	SS11	SS12	SS13	SS14
pH	–	6.5–7.5	7.49	6.87	7.73	7.44	8.05	7.53	7.57
EC	dS/m	0–1	0.379	0.598	0.512	0.476	0.654	0.424	0.341
OC	%	0.40– 0.60	0.49	0.33	0.61	0.58	0.49	0.45	0.51
P	kg/ha	14–21	18.42	15.13	15.57	13.59	17.32	14.91	12.49
K	kg/ha	150–200	225.60	228.87	298.40	222.96	254.53	209.86	189.05
N	kg/ha	–	172.90	87.40	122.30	94.49	125.90	97.21	105.00
B	mg/kg	–	1.06	0.91	1.22	1.41	0.89	0.82	1.10
S	mg/kg	10–20	9.87	10.21	11.36	11.88	9.50	11.10	9.75
Zn	mg/kg	≥0.61	1.12	0.71	0.39	1.05	1.03	0.90	0.72
Fe	mg/kg	4.5–99.9	8.45	8.40	8.04	7.68	5.14	3.54	5.75
Cu	mg/kg	≥0.20	1.40	0.76	1.50	2.13	2.49	1.94	0.95
Mn	mg/kg	≥2.0	8.90	4.19	6.91	8.18	4.06	4.29	6.08
E. coli	CFU/g m	0	14	2	61	10	0	0	5
Fungal Count	CFU/g m	–	4.9×10 ₃	2.8×10 ₄	1.0×10 ₄	6.0×10 ₃	4.8×10 ₁	3.1×10 ₁	1.2×10 ₄
Azotobacter	CFU/g m	Beneficial	0	16	0	3	5	0	9
Salmonella	CFU/g m	0	0	0	0	1	0	0	0

Table 3.8-C: Results of Soil Quality Analysis

Parameter	Unit	Standard	SS15	SS16	SS17	SS18	SS19	SS20
pH	–	6.5–7.5	7.87	8.04	6.98	7.78	7.33	8.13
EC	dS/m	0–1	0.289	0.417	0.510	0.419	0.556	0.350
OC	%	0.40–0.60	0.49	0.56	0.58	0.65	0.59	0.46
P	kg/ha	14–21	16.88	13.81	15.13	17.10	16.66	14.56
K	kg/ha	150–200	253.06	212.50	212.25	216.94	202.15	255.07
N	kg/ha	–	168.20	122.30	136.40	178.40	148.24	157.60
B	mg/kg	–	0.95	1.50	0.93	0.85	1.85	1.07
S	mg/kg	10–20	11.49	10.23	10.65	11.13	10.55	10.23
Zn	mg/kg	≥0.61	0.35	0.65	0.81	1.11	0.41	0.71
Fe	mg/kg	4.5–99.9	8.62	3.53	5.28	6.09	6.59	8.42
Cu	mg/kg	≥0.20	1.99	0.83	1.91	0.94	0.77	1.45
Mn	mg/kg	≥2.0	7.57	5.33	8.12	4.56	5.55	3.14
E. coli	CFU/g _m	0	7	19	43	16	20	13
Fungal Count	CFU/g _m	–	8.0×10 ₃	5.0×10 ₃	2.7×10 ₃	2.0×10 ₃	1.1×10 ₃	2.0×10 ₃
Azotobacter	CFU/g _m	Beneficial	0	4	23	2	0	11
Salmonella	CFU/g _m	0	0	1	2	1	0	0

3.3.1. INTRODUCTION AND SEASONAL CONTEXT (PHASE III)

Phase III soil monitoring represents **post-monsoon conditions**, a transitional period marked by:

- Cessation of active rainfall
- Gradual drying of soils

- Resumption/intensification of tourist and equine activity
- Re-exposure of soils previously affected by monsoon runoff and slurry movement

From an environmental perspective, Phase III is critical because it reveals whether the soil system **recovers naturally** after monsoon flushing or whether **residual contamination persists**, indicating **chronic and cumulative degradation**.

The Phase III assessment includes **SS1–SS20**, covering lake peripheries, forest pathways, market approaches, tourist points, and horse-influenced corridors.

3.3.2. Soil Reaction (pH) –

Post-Monsoon Shift Toward Alkalinity

Observed range: 6.24 – 8.13

Desirable range: 6.5 – 7.5

Key observations:

- Several sites exceed the upper desirable limit:
 - **SS4 (7.84), SS7 (7.98), SS12 (8.05), SS16 (8.04), SS20 (8.13)**
- Only one site shows acidic tendency (SS3: 6.24)

Interpretation:

- During monsoon, acidic and alkaline inputs coexist.
- After rainfall ceases:
 - **Soluble acidic products are flushed**
 - **Carbonates & base salts from dung/urine residues dominate**
- This results in a **systematic alkaline shift** in horse-influenced soils.

Environmental implication:

- Alkaline soils:
 - Reduce availability of **Zn, Fe, Mn**
 - Alter microbial equilibrium
 - Favor disturbance-tolerant vegetation over native species
- The alkaline trend indicates **residual chemical imprint** of equine waste rather than natural soil buffering.

3.3 Electrical Conductivity (EC) –

Apparent Normalization with Hidden Risk

Observed range: 0.289 – 0.654 dS/m

Permissible range: ≤ 1 mS/cm

Key observations:

- All Phase III EC values fall within the permissible limit.

Interpretation:

- This apparent improvement reflects:
 - Monsoon dilution and flushing of soluble salts
 - Redistribution of salts to deeper layers or adjacent zones
- **However, EC normalization does not imply soil recovery,** because:
 - Nutrient enrichment (especially K) persists
 - Microbial contamination remains detectable
 - Salts can re-accumulate rapidly with renewed urine input

Environmental implication:

- EC reduction is **temporary and seasonal**
- Without source control, salinity stress is expected to re-emerge in the next pre-monsoon cycle.

3.3.4 Organic Carbon (OC) –

Partial Reduction, Persistent Hotspots

Observed range: 0.33 – 0.65 %

Optimal range: 0.40 – 0.60 %

Key observations:

- Several sites approach the optimal range
- **SS7 (0.62) and SS18 (0.65)** exceed upper limits
- Some sites fall below optimal (SS1, SS3, SS5)

Interpretation:

- Monsoon wash-off & microbial decomposition reduce surface OC
- However,
 - Re-deposition of dung after monsoon
 - Retention of organics in compacted zones
 - Reduced vegetation uptake led to **persistent OC hotspots**

Environmental implication:

- OC heterogeneity indicates:
 - Incomplete recovery
 - Continued organic stress in horse-dominated areas
- These hotspots act as **future nutrient and pathogen reservoirs.**

3.3.5. Macronutrients –

Potassium as the Dominant Residual Signature

a) Phosphorus (P)

Observed range: 7.45 – 20.61 kg/ha

Optimal range: 14 – 21 kg/ha

- Some sites remain P-deficient (SS2, SS11, SS14, SS16)

Interpretation:

- Post-monsoon soils still show **inefficient phosphorus cycling**
- Indicates that dung inputs do not equate to balanced fertility
- P deficiency persists due to:
 - Fixation under alkaline conditions
 - Loss during monsoon runoff

b) Potassium (K)

Observed range: 189.05 – 298.40 kg/ha

Optimal range: 150 – 200 kg/ha

Key observations:

- **Widespread K exceedances:**
 - SS3, SS4, SS7, SS8, SS10, SS12, SS15, SS16, SS18, SS20
- Maximum recorded at **SS10 (298.40 kg/ha)**

Interpretation:

- Potassium is the **most persistent chemical tracer of equine urine**
- Unlike EC, K:
 - Is retained on soil exchange sites
 - Re-concentrates after drying
- Phase III reveals the **true residual footprint** of equine activity.

Environmental implication:

- Chronic K enrichment:
 - Disrupts nutrient balance
 - Promotes invasive plant species
 - Alters soil cation exchange equilibrium
- Confirms that monsoon does **not reset** soil chemistry.

3.3.6 Secondary Nutrients and Carbonates –

Structural Stress Indicators

- Carbonate influence remains evident

- Calcium and magnesium availability varies irregularly

Interpretation:

- Post-monsoon soils reflect **legacy disturbance**, not pristine equilibrium
- Trampling, erosion, and material mixing during monsoon leave behind **chemically unstable profiles**

Environmental implication:

- Poor soil aggregation
- Reduced infiltration uniformity
- Increased susceptibility to dry-season erosion & dust generation

3.3.7. Micronutrient Status –

Persistent Deficiency Patterns

Observations:

- **Zinc deficiency** at SS1, SS2, SS3, SS4, SS7, SS10, SS15, SS19
- **Iron deficiency** at SS6, SS13, SS16
- Mn marginal at several sites

Interpretation:

- Alkaline pH + potassium dominance cause:
 - Micronutrient precipitation
 - Reduced plant uptake
- These are **secondary but chronic degradation effects**.

Environmental implication:

- Weak vegetation recovery post-monsoon
- Poor root anchoring
- Enhanced erosion risk during the next rainfall cycle

3.3.8. Bacteriological Soil Quality

Persistence After Monsoon

a) E. coli Detection

- E. coli detected at multiple Phase III sites:
 - SS7, SS8, SS10, SS11, SS15, SS16, SS17, SS18, SS19, SS20

Interpretation:

- Presence of E. coli **after cessation of rainfall** indicates:
 - Survival in moist organic niches
 - Continuous re-contamination from ongoing equine activity

Environmental and health implication:

- Soil remains a **sanitary risk reservoir**
- Post-monsoon tourist season coincides with:
 - Increased human contact
 - Drying soils → dust exposure pathway

b) Salmonella Persistence

- Detected at select Phase III sites
- Should be absent in uncontaminated soils

Interpretation:

- Confirms that monsoon did not eliminate pathogenic risk
- Indicates **chronic contamination**, not episodic input

3.3.9. PHASE III SOIL RISK ASSESSMENT (POST-MONSOON)

Table 3.9 shows key risk matrix assessment table for phase III of soil sampling Programme

Table 3.9: Phase III Risk Metric Table

Soil Category	Risk Level	Dominant Residual Stressors
Horse corridors & tourist nodes	High	K enrichment + E. coli persistence
Lake catchment approach soils	High	Nutrient reservoir + microbial survival
Forest/pathway soils away from traffic	Moderate	Micronutrient stress
Relatively low-impact zones	Low–Moderate	Partial chemical recovery

3.3.10. PHASE III ENVIRONMENTAL SIGNIFICANCE

Phase III demonstrates that:

- Monsoon flushing provides **only partial chemical relief**
- **Potassium enrichment and pathogen persistence remain**
- Soil system does **not self-restore** under continued equine pressure

Phase III therefore represents a **false recovery phase**, masking chronic degradation beneath superficially improved EC and OC values.

3.3.11. CONCLUSIONS OF POST MONSOON SOIL ASSESSMENT

The Phase III (post-monsoon) soil quality assessment clearly establishes that equine-related soil degradation in Matheran is **persistent and cumulative**. While electrical conductivity and organic carbon show partial normalization following monsoon flushing, widespread potassium enrichment, micronutrient deficiencies, and continued detection of fecal indicator bacteria confirm that the soil system retains a **strong equine contamination signature**. The persistence of *E. coli* and *Salmonella* in post-monsoon soils indicates that soils continue to pose **ecological and public health risks**, particularly during the peak tourist season. These findings demonstrate that natural recovery processes are insufficient, and that without enforceable source-control and soil-protection measures, degradation will intensify with each seasonal cycle.

3.4 SOIL HEALTH IN MATHERAN: PHASE I-II-III INTEGRATED SUMMARY

Matheran's soil quality shows a **repeatable, horse-waste-driven degradation cycle** across three seasons. **Phase I (pre-monsoon)** is the **accumulation phase**: horse dung remains on trails and stable zones, urine creates salt patches, and soils develop **high organic loading (OC)** with **salinity pockets (EC > 1 at hotspots)** and early **nutrient imbalance**. **Phase II (monsoon)** becomes the **transport and amplification phase**: rainfall converts dung into slurry, enabling **leaching and runoff redistribution** of nutrients and microbes into adjacent soils and downslope zones. **Phase III (post-monsoon)** is the **residual/persistence phase**: EC may appear normalized at many sites due to flushing, but the soil retains a strong equine signature—**widespread potassium enrichment (K > 200 at multiple locations)**, **alkaline shift at several sites**, **micronutrient locking (notably Zn/Fe)**, and **continued fecal indicators**—showing the system does not naturally recover under ongoing equine pressure.

pH behaviour evolves from **localized acidity in Phase I** (linked to urine decomposition/nitrification by-products and organic acid formation) to **high variability in Phase II** (wetting accelerates chemical transformations and mobilization), and finally to a **net alkaline tendency in Phase III** (post-monsoon drying leaves base salts/carbonate influence and reduces micronutrient availability). These pH shifts are ecologically important because they destabilize nutrient availability, suppress native regeneration, and promote disturbance-tolerant vegetation along horse corridors.

Organic carbon and nutrients (N-P-K) show the strongest seasonal signal. In **Phase I**, soils demonstrate **organic overload** (manure-derived OC beyond the normal soil band), confirming that waste assimilation capacity is exceeded. In **Phase II**, monsoon does not “solve” the OC problem—it **redistributes it**, washing fines and dissolved products downslope and into new deposition zones. In **Phase III**, OC appears closer to normal at many sites, but **persistent K enrichment** becomes the clearest tracer of chronic urine/dung influence: K remains elevated at many post-monsoon sites even after rainfall, indicating a retained enrichment footprint that will re-activate with the next monsoon. P exhibits patchy behaviour (fixation/runoff loss), reinforcing that the system oscillates between **localized enrichment and post-flush imbalance**, neither of which supports stable ecosystem function.

Microbial contamination is the most critical soil health risk, peaking in Phase II and persisting into Phase III. Phase II bacteriology confirms soils are not merely nutrient-enriched but **sanitarily contaminated: E. coli is detected at multiple sites with a major hotspot (SS7 = 260 CFU/g)** and **Salmonella appears at several points**, which should be absent in uncontaminated recreational/forest soils. The **source fingerprint (SS23 dried horse dung)** shows the highest fecal loading (**E. coli 470 CFU/g; Salmonella 3 CFU/g**), strengthening attribution of soil contamination to equine waste. Phase III still shows E. coli persistence at multiple locations, indicating soils remain a reservoir during peak tourist use and a potential dust/bioaerosol and future runoff source.

Physical degradation (compaction and erosion susceptibility) links chemistry to transport. Phase I compaction from repeated hoof action reduces infiltration; Phase II then converts this into accelerated runoff, slurry formation, and erosive transport; Phase III leaves behind rutted, structurally weakened soils that do not regain porosity or biological function under continued horse traffic. This soil-structure decline is a force multiplier: it increases runoff, spreads contaminants, and reduces vegetation recovery—locking the landscape into chronic vulnerability.

3.5 OVERALL CONCLUSION (SOIL):

Across Phase I–II–III, Matheran soils exhibit a consistent equine-waste footprint: **Phase I builds the contaminant inventory, Phase II spreads and amplifies it**, and **Phase III confirms persistence** through K enrichment, pH shift, micronutrient locking, and continuing fecal indicators. The evidence supports urgent **source control (daily dung removal + lined/covered storage), engineered manure treatment, horse-movement zoning/seasonal restrictions, and hotspot soil restoration**, with Phase II requiring the highest-frequency microbial monitoring for compliance and risk reduction.

3.6 COMPARATIVE SOIL QUALITY SYNTHESIS (PHASE I–II–III) – MATHERAN

Integrated Interpretation of Soil Behavior Across Seasons

The three phases together reveal a **repeating, non-self-correcting soil degradation cycle** driven primarily by **unmanaged equine dung and urine deposition**, compounded by trampling and trail erosion.

Functional role of soil across phases

- **Phase I (Pre-monsoon):** Soil acts as a **sink** (accumulation and concentration phase)
- **Phase II (Monsoon):** Soil acts as a **vector** (mobilization and spread phase)
- **Phase III (Post-monsoon):** Soil acts as a **reservoir** (residual contamination and persistence phase)

This transformation confirms that soil is not a passive medium but the **central driver of downstream environmental risk** in Matheran.

Phase-wise Comparative Soil Impact is mentioned in Table 10 (Core Indicators)

Table:10 Phase I–II–III Comparative Soil Risk Synthesis

Parameter / Risk Dimension	Phase I (Pre-Monsoon)	Phase II (Monsoon)	Phase III (post-monsoon)	Scientific Interpretation
pH behavior	Mild acidity at several sites	Highly variable (acidic + alkaline)	Shift towards alkalinity	Progressive buffering loss due to waste inputs
Electrical Conductivity (EC)	Salinity pockets (>1 dS/m)	Widespread EC stress persists	Apparent normalization	Seasonal dilution masks persistent source
Organic Carbon (OC)	Excessive (up to 2.35%)	Surface OC reduced (wash-off)	Partial recovery, hotspots persist	OC redistributed, not eliminated
Phosphorus (P)	Deficient at many sites	Mobilized & lost	Still deficient at some sites	Inefficient nutrient cycling
Potassium (K)	Patchy enrichment	Temporarily redistributed	Widespread high K	Most reliable equine-waste tracer
Micronutrients (Zn, Fe, Mn)	Deficiencies emerging	Locking intensifies	Deficiencies persist	Secondary chemical degradation
E. coli (soil)	Not assessed	Widespread detection	Persistent detection	Chronic fecal contamination
Salmonella	Not assessed	Detected at multiple sites	Persists at select sites	Zoonotic risk confirmed
Physical soil stability	Compaction evident	Erosion + slurry formation	Weak recovery	Structural degradation cumulative

Overall Soil Risk Matrix is mentioned in Table 11 (All Phases Combined)

Table 11 Overall Soil Risk Rating – Matheran

Risk Category	Overall Risk Level	Evidence from Phase I-III
Organic loading	High	Persistent OC excess & hotspots
Salinity stress	Moderate-High	Recurring EC exceedance
Nutrient imbalance	High	Chronic K enrichment, P deficiency
Micronutrient stress	Moderate-High	Zn & Fe locking widespread
Pathogenic contamination	Very High	E. coli & Salmonella persistence
Soil structural degradation	High	Trampling, erosion, compaction
Natural recovery capacity	Low	Phase III shows false recovery

3.7 CONCLUSIONS OF SOIL ASSESSMENT STUDY

Based on comprehensive Phase I, Phase II, and Phase III soil analyses, it is conclusively established that:

- 1. Equine activity has caused chronic chemical, biological, and physical degradation of soils in Matheran**, extending beyond localized stable areas into trails, tourist nodes, forest edges, and lake approach zones.
- 2. Phase I demonstrates accumulation** of organic matter, salts, and nutrients, establishing a polluted baseline before rainfall.
- 3. Phase II represents the highest risk**, during which soils act as active transport media for nutrients and pathogens, as evidenced by widespread **E. coli and Salmonella detection**.
- 4. Phase III confirms persistence**, not recovery: potassium enrichment, micronutrient deficiencies, and fecal indicator bacteria remain detectable even after monsoon flushing.

5. The inclusion of **SS23 (dried horse dung)** provides a definitive **source fingerprint**, conclusively linking observed soil contamination to equine waste rather than natural background conditions.
6. The soil system in Matheran is therefore **trapped in a repeating degradation cycle**, which will intensify unless **source-control and soil-protection measures are enforced**.

3.8. POLICY DIRECTIONS & RECOMMENDATIONS

3.8.1 Core Policy Principle

“No new waste loading, no uncontrolled transport, and no unmanaged soil contact in an Eco-Sensitive Zone.”

3.9 Mandatory Policy Measures

3.9.1 Compulsory Equine Waste Management Protocol

The Local Authority, under the supervision of the Monitoring Committee, shall implement a compulsory equine waste management protocol throughout Matheran. This shall include daily collection and removal of horse dung and urine-soaked bedding from all horse routes, stable areas, market zones, and tourist points. Open dumping of dung on trails, slopes, forest edges, or near drainage lines shall be strictly prohibited. All collected waste shall be temporarily stored only in covered and impermeable (lined) holding facilities. This measure is essential to directly reduce excessive organic carbon accumulation, salinity (EC), potassium enrichment, and microbial contamination in soils.

3.9.2 Establishment of Engineered Manure Handling & Treatment

The Maharashtra Pollution Control Board shall approve, and the Local Body shall establish, engineered manure handling and treatment facilities at designated locations. These facilities shall have impermeable flooring with leachate collection systems to prevent infiltration into soil. Treatment of equine waste shall be limited to scientifically approved methods such as composting or bio methanation. This measure is necessary to prevent leachate percolation,

avoid formation of monsoon slurry, and eliminate uncontrolled nutrient and pathogen release into surrounding soils.

3.9.3 Horse Movement Zoning and Seasonal Restrictions

The Monitoring Committee shall regulate horse movement through spatial zoning and seasonal restrictions. Horse movement shall be restricted or significantly reduced during peak monsoon periods when soil is saturated and most vulnerable. Designated “no-horse buffer zones” shall be established around water bodies, drainage channels, steep slopes, and ecologically sensitive forest patches. This regulation is required to reduce soil compaction, prevent erosion, and limit the spatial spread of fecal pathogens and nutrients during rainfall events.

3.9.4 Soil Stabilization and Restoration at Identified Hotspots

The Local Body, with appropriate technical guidance, shall undertake soil stabilization and restoration measures at identified degradation hotspots such as horse corridors, stable surroundings, and lake approach zones. These measures shall include installation of coir or jute matting on exposed soils, development of vegetative swales to intercept runoff, and trail hardening using permeable materials. Such interventions are necessary to prevent further soil loss, reduce contaminant transport, and support gradual ecological recovery of degraded soil systems. Impervious flooring [natural soil stabilization] at all existing stables with side drains to collect dung and urine may also be provided.

3.10 COMPLIANCE & MONITORING MATRIX

Table 12 shows soil compliance matrix

Table 12 Soil Compliance Matrix

Measure	Responsible Authority	Frequency	Compliance Indicator	Verification Method
Dung removal	Local Body	Daily	Zero visible dung on trails	Field inspection
Soil pH, EC, OC, K	MPCB	Monthly (Phase I & III)	Within trend limits	Lab analysis
Pathogens (E. coli, Salmonella)	MPCB	Fortnightly (Phase II)	Absence / declining trend	NABL lab
Hotspot restoration	Local Body	Quarterly	Vegetation cover restored	GIS & site audit
Horse numbers & routes	Monitoring Committee	Continuous	Carrying capacity compliance	GPS / permits

3.11. FINAL SOIL-CENTRIC SUGGESTIONS

The soil quality evidence across three seasons establishes that equine waste is a persistent, mobile, and hazardous contaminant in the Matheran Eco-Sensitive Zone. The presence of fecal pathogens in soil, combined with chronic nutrient and salinity imbalance, demonstrates that current practices violate the precautionary principle and threaten ecological stability. Immediate source-control, movement regulation, and soil restoration are essential to prevent irreversible degradation.

3.12 GLIMPSES OF SOIL SAMPLING



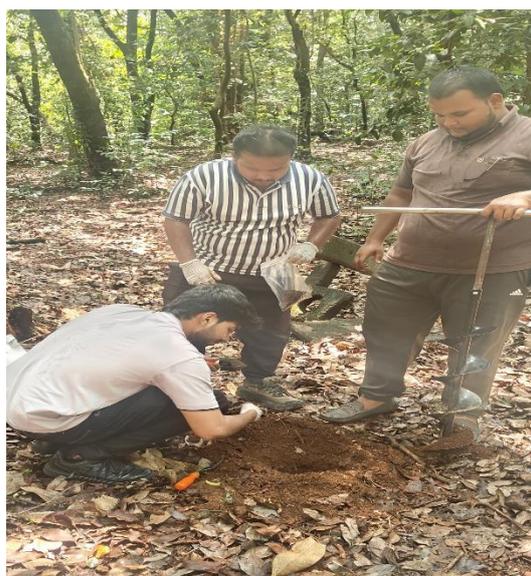
Soil Sampling Using Hand Driven Auger



Collection of Soil Samples After Auguring



Soil Samples from Forest Area



Soil Sampling in Progress

Overview of the findings

(Integrated Interpretation of Phases I, II & III)

4.1 Integrated Environmental Condition of Matheran

The three-phase monitoring unequivocally demonstrates that the environmental impacts associated with equine activity in Matheran are **systemic, cumulative, and persistent**, rather than isolated or seasonal anomalies. While monsoon rainfall temporarily redistributes pollutants, it does not eliminate them; instead, it **transfers contaminants across environmental compartments**, reinforcing long-term degradation pathways.

The study confirms that **horse dung and urine act as a continuous non-point pollution source**, interacting with topography, rainfall, tourist pressure, and trail conditions to influence air, water, and soil quality simultaneously.

4.2 Conclusions on Ambient Air Quality

Across Phase-I and Phase-III, **PM₁₀ and PM_{2.5} concentrations repeatedly exceeded eco-sensitive zone limits**, with Phase-II showing only partial dilution due to rainfall. This confirms that air pollution in Matheran is **structurally linked to surface conditions and activity patterns**, not meteorology alone.

Key mechanisms identified include:

- Drying and fragmentation of horse dung on trails,
- Hoof-induced resuspension of fine soil and organic particles,
- Concentrated equine movement during daylight tourist hours,
- Limited dispersion due to valley topography and forest canopy.

Although SO₂ and NO₂ levels remain within statutory limits, their **co-presence with fine particulates, bio-aerosols, ammonia vapours, and microbial**

fragments significantly elevates respiratory risk in a confined hill environment.

Conclusion:

Air quality degradation in Matheran is **chronic, activity-driven, and incompatible with ESZ objectives** unless equine pressure and waste handling practices are fundamentally restructured.

4.3 Conclusions on Water Quality

Phase-II (Monsoon) monitoring clearly established that **surface runoff is the dominant pollutant transport mechanism** in Matheran. Water samples consistently showed:

- Elevated turbidity due to soil erosion and dung wash-off,
- Increased nitrates and phosphates indicating nutrient enrichment,
- Recurrent detection of E. coli confirming faecal contamination. (which may be inclusive of human faecal contamination).

Phase-III results demonstrated that **post-monsoon recovery is incomplete**, with residual contamination persisting in sediments, shallow soils, and near-shore zones. **Monsoon dilution does not help to reduce pollution**, and that contaminated soils function as secondary pollutant sources.

Conclusion:

Charlotte Lake and Simpsons Lake are getting affected in Matheran. Water bodies in Matheran are **ecologically stressed and seasonally vulnerable**, posing risks to public health, aquatic ecosystems, and downstream users. Matheran is in catchment area of Morbe Lake supplying water to NMMC and also the Deharang Lake which supplies water to Panvel MC.

4.4 Conclusions on Soil Quality

Soils along horse trails, stables, and congregation points show:

- Persistent enrichment of organic carbon, nitrogen, phosphorus, & potassium,
- Altered pH and electrical conductivity,

- Detectable accumulation of trace metals such as zinc and copper.

Repeated trampling has caused **soil compaction**, reduced infiltration and increasing runoff velocity. This creates a **self-reinforcing degradation cycle**, where compacted soils accelerate erosion, runoff transports pollutants, and downstream environments receive cumulative loading.

Conclusion:

Affected soils have transitioned from natural buffers to **active pollutant reservoirs**, sustaining long-term environmental risk.

4.5 Cumulative and Carrying Capacity Conclusions

The integrated assessment confirms that:

- Air, water, and soil impacts are **interlinked**, not independent,
- Seasonal variation alters pollutant pathways, not pollutant loads,
- Existing equine number **exceed ecological carrying capacity** of Matheran.

Overall Conclusion:

The current equine-based transport and waste management regime is **environmentally unsustainable and ecologically incompatible** with ESZ mandates.

4.6 Immediate Source-Control Measures (Highest Priority)

- **Compulsory Equine Waste Management Protocol**
 - Daily removal of dung and urine-soaked bedding.
 - Absolute prohibition of dumping on trails, slopes, forest margins, and drainage lines. Animals shall be provided with horse diapers, or excrement collectors to collect the dung without dropping on to ground. Horse attendant shall deliver such bags at dung deposit points established along route of horse movement.
 - Covered, lined interim storage at designated collection points.

- **Scientifically Determined Carrying Capacity**

- Fix a maximum permissible number of horses per day.
- Enforce seasonal reduction during monsoon months.
- Link permits strictly to waste handling capacity.

4.7 Engineered Treatment and Infrastructure Controls

- **Centralized Manure Treatment Facility**

- Impermeable flooring with leachate collection.
- Composting, bio methanation, or biochar production only.
- Prohibit untreated disposal within ESZ limits.
- It may be attempted to promote the making of dried pellets or cakes made from horse dung and compulsorily used for boilers or chulhas in hotels

- **Runoff and Erosion Control**

- Contour drains, sediment traps, and check dams along slopes.
- Vegetative buffer strips near trails and water bodies.
- Constructed wetlands for urine-rich runoff treatment.

4.8 Air Quality Protection Measures

- **Trail Surface Stabilization**

- Dust-binding yet permeable materials for movement trails & routes
- Controlled wetting during dry periods.
- Mud clay compacted Paver blocks

- **Dung Exposure Minimization**

- Immediate removal from open surfaces.
- No drying or stockpiling in exposed areas.

4.9 Institutional, Legal and Monitoring Measures

- **Strengthened Environmental Monitoring**

- Quarterly monitoring of air, water, and soil.
- Public disclosure of results.

- **Defined Accountability and Enforcement**

- Clear responsibility allocation among authorities.
- Penalties under the Polluter Pays Principle for non-compliance.

4.10 Transition and Long-Term Sustainability Measures

- **Phased Transition to Low-Impact Transport**

- Regulated introduction of electric carts for goods & visitors.
- Livelihood transition support for equine operators.

- **Capacity Building and Awareness**

- Mandatory training on waste management and animal welfare.
- Tourist sensitization on ESZ responsibilities.

Final Statement

The findings of this assessment conclusively demonstrate that incremental adjustments will not suffice. Number of horses & ponies shall be restricted. If the basis of Particulate Matter (PM) Concentration in Ambient air (Pre Monsoon) PM10 (24 hrs. avg) as $150 \mu\text{g}/\text{m}^3$ is associated to presence of 1000 horses, the number required to keep PM10 (24 hrs. avg) as $100 \mu\text{g}/\text{m}^3$ or less can be estimated to be 660, meaning around 35 % reduction in present number of horses. To begin with number may be reduced by 50 % and parametric studies (as in present report) shall be continued to monitor the pollution levels whether getting within limits.

A Systemic transformation, integrating scientific controls, regulatory enforcement, and socio-economic transition, is essential to preserve Matheran's ecological integrity. Immediate implementation of these recommendations is critical to ensure environmental protection, public health safety, and compliance with ESZ and NGT mandates.

Sustainable Management of Horse Dung in Matheran

5.0 Introduction

Matheran is a notified **Eco-Sensitive Zone (ESZ)** and India's only officially designated **pedestrian hill station**, located within the ecologically fragile Western Ghats. Judicial scrutiny by the Hon'ble Supreme Court and the National Green Tribunal (NGT) has repeatedly emphasized that **continuous, non-industrial anthropogenic pressures**, even if individually small, can cumulatively cause **severe ecological degradation** in hill ecosystems.

Equine-based tourism constitutes the **dominant non-point pollution source** in Matheran. NGT-linked committee records, affidavits, and media-verified reporting consistently indicate the operation of approximately **460 horses and 200 ponies (~660 equines)** on a daily basis, collectively generating **more than 3 tonnes of dung per day**. Unlike municipal solid waste, horse dung is:

- continuously generated,
- spatially dispersed across trails, slopes, and stable areas, and
- directly exposed to wind and rainfall,

making it particularly harmful in a steep, high-rainfall ESZ setting.

Multi-Media Environmental Impact Pathways

Unmanaged horse dung contributes simultaneously to **air, water, and soil degradation**, creating a cumulative pollution burden:

- **Air pollution:** Drying and fragmentation of dung, combined with hoof-induced disturbance of unpaved trails, leads to resuspension of **PM₁₀ and PM_{2.5}**, with observed exceedances of **National Ambient Air Quality Standards (NAAQS)** during peak tourist seasons.
- **Water pollution:** Rainfall-induced runoff transports suspended solids, nutrients, and pathogens (*E. coli*) into **Charlotte Lake and feeder**

streams, violating **IS 10500 drinking-water criteria**, which require complete absence of *E. coli*.

- **Soil degradation:** Repeated dung deposition and trampling cause **organic overload, compaction, reduced infiltration, localized acidity/salinity changes, and accelerated erosion**, particularly on mud roads and slopes-effects explicitly noted by NEERI and acknowledged in Supreme Court proceedings.

In response, NGT proceedings have stressed the need for **horse-number regulation (order of hundreds per day)** and **structured dung management systems**, including composting and biogas-based treatment, implemented under the **precautionary principle and carrying-capacity doctrine**. This chapter evaluates feasible technologies, institutional mechanisms, and judicial precedents relevant to sustainable horse-dung management in Matheran.

5.2 Technology Options (Comparison Matrix with Elaboration)

Horse-dung management technologies must be evaluated against Matheran's **ESZ constraints**, limited land availability, topography, and regulatory expectations. Importantly, each technology addresses **different segments of the pollution pathway**, and therefore a **hybrid approach** is required.

Table 5.1 Comparison of Horse-Dung Processing Technologies (Indicative Design Values)

Technology	Design Capacity	Capital Cost	O&M Cost	Emission Control	By-products	Spatial Footprint	Matheran Applicability
Composting (Aerobic)	~1–5 t/day (windrow/vermi compost)	Low–moderate	Low–moderate	Moderate (reduced CH ₄ vs dumping; odour controlled by cover & C: N balance)	Compost (organic manure)	Medium–high	Very feasible – low-tech, ESZ-compatible; strongly recommended
Anaerobic Digestion (Biogas)	2–6 t/day	Moderate–high	Moderate	High (sealed system, methane capture)	Biogas + digestate	Moderate	Technically proven ; scalable with trained O&M
Biochar (Pyrolysis)	0.5–1 t/day	Moderate	Moderate	Requires strict emission control	Biochar	Small–moderate	Supplementary option ; suitable with compost blending
Constructed Wetlands	Runoff/leachate only	Moderate	Low–moderate	High nutrient/pathogen attenuation	Improved effluent	High	Supportive role for water-body protection

Technology	Design Capacity	Capital Cost	O&M Cost	Emission Control	By-products	Spatial Footprint	Matheran Applicability
Pellets/Briquettes	Variable	Moderate	Moderate	Requires regulated combustion	Fuel pellets	Moderate	Caution advised; Kufri experience shows cost sensitivity

Note-Operational Problem were reported due to high fiber in the existing plant located in Matheran during biogas generation in anaerobic digester

Interpretation of Table 5.1

The table demonstrates that **a single technology cannot address the entire dung burden**. Composting and biogas systems are the **primary treatment options**, while constructed wetlands act as **secondary interception systems** for runoff. Biochar serves as a **value-addition pathway**, improving compost quality and carbon sequestration, while pelletization remains a niche option requiring careful economic assessment.

5.3 Action Plan and Institutional Roles

Effective dung management in an ESZ requires **institutional coordination**, as emphasized in NGT-directed Joint Committee frameworks. Fragmented implementation leads to enforcement gaps and underperforming systems.

Stakeholder Roles and Responsibilities. The roles of key stakeholders in horse-dung management are mentioned in Table 5.2

Table 5.2 Roles of Key Stakeholders in Horse-Dung Management

Stakeholder	Role & Responsibility
Maharashtra Pollution Control Board (MPCB)	Nodal agency; environmental monitoring; approval of technologies; compliance reporting
MoEF&CC / NGT/ Matheran Monitoring Committee	ESZ oversight; review of Action Taken Reports (ATRs)
Matheran Municipal Council (NP Matheran)	On-ground implementation: collection, transport, processing facilities, awareness

Stakeholder	Role & Responsibility
Forest Department (Maharashtra)	ESZ compliance; trail regulation; buffer enforcement; ecological restoration
Tourism Department	Integration with eco-tourism; promotion of low-emission alternatives
Technical Institutions: DBATU	Design validation, pilot studies, monitoring protocols, training
Horse Owners' Associations	Compliance with caps/rotation; support collection and segregation

5.2.1 Phased Implementation (Elaborated)

Short-Term (0–6 months)

- Immediate segregation and collection of dung at hotspots and trails.
- Pilot composting pits and/or biogas demonstration units.
- Enforcement of interim horse caps and route zoning.
- Installation of vegetated buffers near streams.
- Continuation of monitoring under **NAAQS and IS 10500**.

Objective: Arrest further environmental deterioration.

Medium-Term (6–18 months)

- Commission full-scale composting/biogas facilities.
- Establish runoff interception systems (wetlands, grassed drains).
- Publish SOPs for dung handling and enforcement.
- Strengthen seasonal licensing and quotas.

Objective: Achieve stabilization and visible improvement.

Long-Term (18–36 months)

- Integrate dung management into ESZ by-laws and tourism policy.
- Demonstrate sustained reduction in PM exceedances & water contamination.
- Gradual transition to low-emission transport.

Objective: Permanent pollution prevention.

5.3 Reference Case Study – Kufri (Himachal Pradesh)

The Kufri–Mahasu trail case provides a **direct judicial and administrative precedent** relevant to Matheran. Table 5.3 elaborates Kufri case outcomes

Table 5.3 Kufri Case Outcomes and Relevance to Matheran

Kufri Experience	Matheran Relevance
NGT-reported cap: ~293 horses/day	Supports feasibility of order-of-hundreds/day cap
Mandatory dung management plan	Reinforces need for structured logistics
Bio-methanation recommended	Validates biogas as scalable option
Cost-benefit scrutiny by NGT	Ensures economic realism in technology choice

The Kufri case confirms that **horse regulation and dung processing are judicially enforceable** and not to be considered discretionary.

5.4 Eco-Tourism and Public-Health Considerations (Expanded)

Unmanaged dung undermines Matheran’s **eco-tourism value** through visual pollution, odour, and dust. Sustainable dung management improves visitor experience and preserves the town’s eco-branding.

From a **public-health perspective**:

- PM-laden dust increases respiratory morbidity.
- Microbial runoff elevates waterborne disease risk.
- Composting and biogas treatment significantly reduce pathogen survival and fly breeding.
- Sealed digestion reduces methane emissions, contributing to climate mitigation.

5.5 Expert Synthesis

Sustainable horse-dung management in Matheran is a **core environmental protection strategy**, not merely a waste-handling exercise. Judicial findings have established that **unregulated equine activity causes cumulative degradation of air, water, and soil**. A **phased, hybrid, and institutionally coordinated system**—combining horse-number control, structured collection, composting/biogas treatment, and runoff interception—offers the most **scientifically sound and legally defensible pathway** for long-term environmental protection under ESZ governance.

Measures for pollution control through regulation and reduction of horse numbers

6.0 Context and Pollution Causation Framework

Matheran, a notified **Eco-Sensitive Zone (ESZ)** and India's only designated pedestrian hill station, is not affected by industrial or stack-based emissions. The dominant pollution load is **non-point, bio-organic, and activity-driven**, arising primarily from **intensive equine operations** within the ESZ core.

As recorded in statutory proceedings, approximately **460 horses and 200 ponies (~660 equines)** operate daily in Matheran, generating **more than 3 tonnes of dung per day**. These figures are referred to in this report on the basis of information in *Order dated 25.10.2024: Original Application No. 210/2024 (WZ) passed by National Green Tribunal (2024)*. This information needs to be confirmed because the excretion rate of a healthy horse is likely to be 15 to 20 kg per day per horse. The number of horses+ponies at present are around 1000. This number need to be confirmed by inclusion of private stables in Matheran area. The revised number of horses and excretion rate will lead to horse dung generation of 15 ton per day. This is dispersed along trails, near stables, market areas, and water-catchment zones. This creates a continuous and cumulative pollution pathway:

Equine Numbers & Intensity of Use → Dung/Urine Deposition → Drying, Fragmentation & Trampling + Runoff Transport → Air, Water & Soil Degradation → Human and Ecological Exposure

Accordingly, **regulation and phased reduction of equine numbers, intensity, and spatial footprint** is the **only intervention** that simultaneously reduces:

- **Air pollution:** PM₁₀ and PM_{2.5} from dried dung particulates and trail dust resuspension due to trampling.

- **Water pollution:** nutrient enrichment (NO_3^- , PO_4^{3-}), microbial contamination (*E. coli*), suspended solids, and associated metals entering streams and lakes via runoff.
- **Soil degradation:** organic overload, localized acidity and salinity, compaction, erosion, and loss of soil aggregate stability.

Within ESZ governance, this approach reflects the **precautionary principle**, mandating **pollution prevention at source**, rather than post-damage remediation.

6.1 Short-Term / Immediate Measures (0–6 Months)

Objective

To achieve **immediate and measurable reduction in pollutant loading**, arrest further irreversible ecological damage, and establish **enforceable institutional controls** pending finalization of scientifically derived carrying capacity.

6.1.1 Immediate Interim Cap on Operating Horses (Daily Permit System) Measure

1. Impose an **interim daily cap of 300 equines/day** (horses and ponies combined) as a precautionary risk-control measure until carrying capacity is finalized using Phase I–III environmental data.
2. Introduce a **daily operating permit system** (QR-based or uniquely numbered tags).
3. **Freeze new registrations** immediately; permit only verified, registered animals.
4. Enforce the rule “**No permit = No operation**” without exception.

Implementation Protocol

- **Permit issuance point:** Dasturi Naka / designated entry control.
- **Eligibility:** veterinary health certification, unique animal ID, registered owner/handler.
- **Transparency:** daily permit list displayed publicly.

Pollution Reduction Logic:

As per record, **≈660 equines generate >3 tonnes dung/day**.

Capping operations at **300 equines/day** reduces active animals by **≈360/day (≈55%)**, resulting in:

- **Minimum dung load avoided:**
 $3 \text{ t/day} \times (360/660) \approx \mathbf{1.6-1.8 \text{ tonnes/day}}$
- **Urine load avoided:**
 $\approx \mathbf{2,500-3,500 \text{ litres/day}}$ (based on standard excretion ranges)

This reduction is **immediate, quantifiable, and verifiable**, directly lowering trail dung accumulation, runoff contamination risk, and particulate resuspension.

6.1.2 Route Zoning and Eco-Sensitive Buffers around Water Bodies Measure

Prepare and notify a **horse-movement zoning plan**:

(a) Red Zones – No Horse Entry

- Lake peripheries (Charlotte Lake), streams, springs, water intake points.
- Riparian corridors, steep slopes, erosion-prone forest patches.
- **Buffer:** minimum **50–100 m**, expandable based on slope/runoff risk.

(b) Amber Zones – Restricted Use

- Mixed pedestrian–horse trails with moderate gradients.
- Limited trips under supervision.

(c) Green Zones – Designated Corridors

- Pre-identified routes with manageable slopes, engineered drainage, and dung-collection feasibility.

Pollution Reduction Logic

Prevents direct fecal contamination of water bodies, reduces nutrient and pathogen transport into catchments, and minimizes erosion-driven turbidity spikes.

6.1.3 Trip Limitation and Horse Rotation System

- Maximum **2 trips/day/equine** (or **1 trip/day** during peak dry/dust hrs).

- Group-based rotation schedules and **mandatory rest days**.

This regulates **activity intensity**, controlling dung deposition frequency, hoof-induced dust resuspension, and soil compaction even after numerical caps.

6.1.4 Rapid Dung Hotspot Removal (“24-Hour Clean Trail Protocol”)

Daily mechanized/manual cleaning of:

- Parking and entry areas,
- Market and railway station zones,
- Stable surroundings,
- Major trail junctions.

With covered bins every **200–300 m**, leak-proof temporary storage, and strict prohibition of dumping/burning.

6.1.5 Immediate Enforcement Framework

Three-tier compliance:

1. **Administrative:** permit issuance and daily equine count.
2. **Route enforcement:** zoning compliance.
3. **Pollution enforcement:** penalties for dumping and non-collection

Without enforcement, regulatory measures remain ineffective.

6.1.6 Horse Corridor along the Matheran Railway Alignment Measure

Develop a **separate, designated horse movement corridor parallel to the Matheran hill railway track**, subject to safety and technical clearance, to serve as the **exclusive equine movement route** between Dasturi Naka and approved riding zones.

Rationale

The railway alignment represents an **already disturbed linear corridor**.

Routing horses along this corridor:

- concentrates impact into a single controllable footprint,
- prevents dispersion into forest soil and water-catchment areas,
- simplifies monitoring and dung collection.

Pollution Reduction Logic

- **Air:** reduced dust resuspension due to stabilized surface.
- **Water:** prevents dung runoff into streams and lakes.
- **Soil:** confines compaction and erosion to engineered zones.

6.2 Medium-Term Measures (6–18 Months)

6.2.1 Carrying Capacity–Linked Licensing

Shift from a fixed cap to **environmental indicator-linked licensing**, reviewed seasonally using:

- PM₁₀/PM_{2.5} trends,
- *E. coli*, turbidity, nutrients in water bodies,
- Soil EC and organic carbon near trails and stables.

Deterioration triggers **mandatory permit reduction**.

6.2.2 Stepwise Permanent Reduction Schedule

Indicative framework (conditional on monitoring):

- 0–6 months: **300/day**
- 6–12 months: **250/day**
- 12–18 months: **200/day**

6.2.3 Trail Engineering and Dust Mitigation

- Stabilization of designated corridors using permeable surfaces.
- Vegetative dust buffers (native species).
- Designated dung drop points.

6.3 Long-Term Measures (18–36 Months and Beyond)

6.3.1 Transition to Low-Emission Alternative Transport

Phased introduction of e-carts/e-rickshaws on approved routes, with priority employment for existing horse owners and handlers.

6.3.2 Permanent No-Horse Zones and Ecological Restoration

Restoration of degraded trails, soil de-compaction, vegetation recovery, and stream protection works after reduction of equine pressure.

6.3.3 Institutionalization in ESZ Governance

Embed horse caps, zoning, and monitoring into municipal by-laws, ESZ Management Plan, and tourism policy, with annual Action Taken Reports.

6.3.4 Relocation of Horse Stables Outside Matheran ESZ Core (Dasturi Naka Model)

Measure

All horse stables presently located **within Matheran municipal/ESZ core** shall be **shifted to centralized stable complexes near Dasturi Naka**, outside the main entry gate.

Only a **limited, pre-approved number of horses** shall enter Matheran **daily on a pass/token basis**, and **all horses shall exit Matheran after stipulated duty hours**, with **no overnight retention** inside the ESZ core.

Quantitative Pollution Reduction (Night-Time Load Elimination)

- Recorded dung generation: **>3 tonnes/day**
- Minimum average rate: **>125 kg/hour**
- Typical night confinement: **10–12 hours**

Night-time dung currently deposited inside Matheran:

- **≥1.25–1.50 tonnes per night**

Relocation of stables outside Matheran therefore **eliminates at least 1.25–1.5 tonnes of overnight dung accumulation**, along with **~1,900–3,300 litres of urine per night**, drastically reducing:

- morning PM resuspension,
- first-flush runoff contamination,
- chronic soil organic overload at stable sites.

6.4 Monitoring and Verification

Key Performance Indicators

1. Daily equine count at entry points.
2. Dung collected (kg/day).
3. PM₁₀ and PM_{2.5} trends.
4. *E. coli* and turbidity trends.
5. Soil EC and organic carbon near trails/stables.

Night-time dung inventory inside Matheran (target: near-zero).

Data submitted during Proposed monitoring after taking measures shall be monitored by MPCB and monitoring committee and ATR to be submitted to Hon. NGT.

Period – 3 to 6 years

6.5 Expert Statement

Regulation, spatial segregation, and phased reduction of equine numbers—combined with **relocation of stabling outside the ESZ core** and **dedicated movement corridors**—constitute the **primary pollution-prevention-at-source strategy** for Matheran. These measures directly reduce dung and urine loading, limit particulate resuspension, and minimize nutrient and pathogen runoff, fully aligning with the **precautionary principle, carrying capacity doctrine**, and ESZ protection objectives.

Chapter 7 Conclusion and Way Forward

7.1 Integrated Summary of Findings Across All Chapters

This study has comprehensively assessed the environmental impacts associated with equine-based tourism activities in **Matheran Eco-Sensitive Zone (ESZ)**, through phased air, water and soil monitoring, institutional review, legal analysis and technology evaluation. The findings across Chapters 1 to 6 establish that **horse-related activities constitute the dominant, continuous and cumulative source of environmental stress in Matheran**, unlike conventional industrial or vehicular pollution.

The core conclusions emerging from the integrated assessment are summarised below:

(a) Air Environment

Ambient air quality monitoring during pre-monsoon, monsoon and post-monsoon phases consistently indicates **elevated PM₁₀ and PM_{2.5} concentrations**, with frequent exceedances of **National Ambient Air Quality Standards (NAAQS)**. The pollution is non-combustion in nature and is strongly linked to:

- drying and pulverisation of horse dung on trails,
- resuspension of loose lateritic soil due to hoof action,
- repeated traffic on unpaved and degraded pathways.

These findings confirm that **dust-based particulate pollution in Matheran is activity-driven**, not infrastructure-driven, and therefore **cannot be mitigated by end-of-pipe controls**.

(b) Water Environment

Water quality analysis of **Charlotte Lake, feeder streams, runoff channels and downstream locations** demonstrates:

- seasonal spikes in turbidity during monsoon,
- presence of faecal contamination indicators (E. coli),
- elevated nutrients (nitrates/phosphates) at runoff-influenced locations.

These conditions are **inconsistent with IS 10500 drinking water standards** and establish a clear **faecal contamination pathway from trails and stables to surface water bodies**, particularly during rainfall events.

(c) Soil Environment

Soil investigations reveal:

- excessive organic carbon accumulation near stables & high-traffic trails,
- localised acidity and salinity shifts,
- Physical degradation including compaction & loss of infiltration capacity.

These changes reduce soil resilience, increase erosion susceptibility, and intensify sediment transport into water bodies.

(d) Cumulative and Non-Point Pollution Character

A critical cross-chapter finding is that **horse numbers act as a pollution multiplier**. The relationship is linear and cumulative:

Horse numbers → **dung/urine load** → **dust formation + runoff transport** → **air, water and soil degradation** → **public and ecological exposure**

This establishes that **population control and spatial management of horses are the single most effective pollution-prevention tools** available in Matheran ESZ.

7.2 Regulatory and Judicial Context

The conclusions of this study are strongly supported by existing judicial and statutory frameworks:

- **NGT Pune Bench (OA No. 210/2024)** has formally recognised that approximately **460 horses and 200 ponies generate over 3 tonnes of dung per day**, causing air, water and land pollution, and has constituted a Joint Committee with **MPCB as nodal agency** to assess damage and recommend mitigation.
- Supreme Court orders under the **T.N. Godavarman Thirumulpad** line of cases and the **Matheran ESZ Notification (2003)** mandate strict application of the **precautionary principle, carrying capacity doctrine**, and **pollution prevention at source**.

- Comparable NGT interventions at **Kufri (Himachal Pradesh)** demonstrate that **horse caps in the order of hundreds per day are legally sustainable and environmentally necessary**.

Thus, the recommendations made in this report are not novel restrictions but **judicially consistent corrective measures**.

7.3 Evaluation of Mitigation Measures and Strategic Direction

The technology and management options evaluated in Chapter 5 confirm that:

- Composting, biogas generation and biochar production are **supportive mitigation measures** that reduce secondary impacts,
- However, **no waste-processing technology can compensate for unchecked horse numbers** in a confined ESZ.

Accordingly, Chapter 6 correctly positions **regulation and phased reduction of horse numbers** as the **primary pollution-control strategy**, supported by:

- route zoning and buffer protection,
- relocation of stables outside the municipal ESZ boundary,
- controlled entry through daily permits/tokens,
- gradual transition to low-emission alternative transport.

A particularly important conclusion is that **shifting horse stables outside Matheran (e.g., near Dasturi Naka)** will:

- eliminate night-time dung accumulation within the town,
- significantly reduce baseline organic load even before daily operations begin,
- improve sanitation, odour conditions and vector control.

This measure alone provides **disproportionately high environmental benefit** relative to cost.

7.4 Monitoring, Verification and Adaptive Management (3–5 Year Framework)

For regulatory defensibility and long-term ESZ protection, this study concludes that **pollution control measures must be accompanied by sustained monitoring for a minimum of 3–5 years after implementation**.

7.4.1 Purpose of Extended Monitoring

- To verify actual environmental improvement following horse-number reduction.
- To enable **adaptive licensing** linked to environmental performance.
- To provide legally robust **Action Taken Reports (ATRs)** to NGT and MoEF & CC annual reports to MPCB and Monitoring Committee.

7.4.2 Recommended Monitoring Parameters and Frequency

Environmental Component	Key Parameters	Frequency	Responsible Agency
Ambient Air	PM ₁₀ , PM _{2.5}	Seasonal (Pre, Monsoon, Post)	MPCB, Technical Institute
Surface Water	pH, turbidity, E. coli, nutrients	Seasonal	MPCB/ Municipal Council
Soil	Organic carbon, EC, pH	Annual	MPCB/ Technical Institute
Activity Load	Daily horse count, dung removed (kg/day)	Continuous	Municipal Council
Compliance	Route violations, permit breaches	Continuous	Forest Dept / Local Authority

7.4.3 Monitoring Philosophy

Monitoring should not be treated as a passive reporting exercise. Instead:

- **If indicators improve** → maintain or cautiously relax caps.
- **If indicators stagnate or worsen** → further reduce horse numbers and/or trips.
- Decisions must be **data-triggered**, not politically negotiated.

7.5 Socio-Economic and Ethical Considerations

The study recognises that horse-based livelihoods are real and longstanding. However, the evidence demonstrates that **unregulated continuation imposes unacceptable environmental and public-health costs.**

The recommended approach therefore aligns with **just transition principles:**

- gradual reduction rather than abrupt bans,

- priority alternative employment in e-transport, waste management, trail maintenance,
- institutional support rather than displacement.

Environmental protection and livelihood protection are **not mutually exclusive**, but only if regulation is **planned, phased and enforced**.

7.6 Final Expert Conclusion

Based on comprehensive field data, regulatory standards, judicial precedent and environmental science, this report concludes that:

Equine activity in its present scale and spatial form is environmentally unsustainable in Matheran Eco-Sensitive Zone.

Effective protection of Matheran's air quality, drinking-water sources, soil health and ecological integrity **cannot be achieved through downstream cleaning alone**. It requires **source-level intervention**, namely:

- strict regulation and phased reduction of horse numbers,
- relocation of stables outside ESZ limits,
- zoning of routes and protection of water catchments,
- Continuous monitoring over 3–5 years to validate outcomes.

If implemented as recommended, Matheran can evolve into a **national model for scientifically managed, pedestrian-only eco-tourism**, fully consistent with the **precautionary principle, carrying capacity doctrine and ESZ governance framework**.

Failure to act, on the other hand, will result in **progressive, and potentially irreversible, degradation**, undermining both environmental integrity and the very tourism economy that depends on it.

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1. DBATU, Lonere Team

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Annexure -I

Methodology for Selection of Monitoring Stations for Air, Water & Soil Quality Assessment

1. Introduction and Conceptual Framework

The selection of monitoring stations is the **foundation of any credible Environmental Impact Assessment**, particularly in **Eco-Sensitive Zones (ESZs)** where even small anthropogenic pressures can trigger irreversible ecological damage. In the present study, the monitoring network for air, water, and soil quality assessment in Matheran was designed to **scientifically isolate, quantify, and attribute environmental impacts arising from horse-based transport and associated dung and urine deposition**.

Given the **non-motorised nature of Matheran**, conventional urban pollution paradigms are not applicable. Instead, the dominant pollution sources are **bio-organic in origin**, spatially dispersed, non-point in nature, and strongly influenced by **topography, rainfall, animal movement patterns, and human exposure pathways**. Therefore, station selection was approached not as a routine sampling exercise but as a **systems-based environmental diagnosis**.

The methodology integrates:

- Environmental engineering principles
- EIA best practices
- CPCB/MPCB monitoring protocols
- National Green Tribunal (NGT) jurisprudence on precaution and cumulative impact

2. Overarching Principles Governing Station Selection

The station selection strategy was governed by the following **five interlinked principles**, applied uniformly across air, water, and soil components.

2.1 Source–Pathway–Receptor (SPR) Approach

Each monitoring station was selected by explicitly identifying:

- **Source:** Horse dung, urine, hoof action, stabling activity
- **Pathway:** Airborne dispersion, runoff, leaching, soil accumulation

- **Receptor:** Humans (tourists, workers), water bodies, forest soils, biota

This approach ensures that monitoring data directly supports **cause–effect relationships**, which is critical for regulatory decision-making and enforcement.

2.2 Impact-Focused (Risk-Based) Sampling Philosophy

Rather than uniform random sampling, the study adopted **impact-oriented sampling**, which is internationally recognised for EIA studies in sensitive regions. Stations were intentionally biased toward:

- High-risk zones
- Pollution accumulation points
- Areas with repeated and chronic exposure

This ensures that the monitoring network captures **worst-case and realistic exposure scenarios**, a requirement repeatedly emphasized in NGT orders related to ESZs.

2.3 Inclusion of Control and Background Stations

For every environmental component, **control sites** were selected that:

- Are geographically comparable
- Have similar natural characteristics
- Experience negligible or no horse activity

These stations establish **baseline environmental quality**, allowing differentiation between:

- Natural background conditions
- Anthropogenic impacts attributable to equine activity

2.4 Seasonal and Temporal Representativeness

Identical or comparable stations were monitored during:

- **Pre-Monsoon** (dry accumulation phase)
- **Monsoon** (runoff, leaching and transport phase)
- **Post-Monsoon** (residual and cumulative impact phase)

This ensures that the station selection captures **dynamic environmental behaviour**, rather than static snapshots.

2.5 Regulatory and Legal Defensibility

All station locations were selected to ensure:

- Compliance with CPCB and BIS monitoring guidance
- Relevance to MESZ Notification provisions
- Evidentiary value before MPCB and NGT

The selection methodology is **transparent, reproducible, and auditable**, meeting the evidentiary standards expected in statutory proceedings.

3. Selection of Air Quality Monitoring Stations

3.1 Environmental Rationale

In Matheran, air pollution is not dominated by combustion sources but by **mechanical and biological processes**, including:

- Hoof-induced resuspension of fine soil and dung particles
- Drying and fragmentation of dung into respirable fractions
- Ammonia volatilization from urine-rich soils
- Secondary particulate formation under humid conditions

Thus, air monitoring stations were selected to represent **maximum human exposure and dust generation potential**, rather than vehicular emission corridors.

3.2 Technical Criteria for Air Station Selection

Air quality monitoring locations were selected based on:

1. **Intensity and frequency of horse movement**
2. **Surface characteristics** (unpaved, semi-paved, compacted soil)
3. **Micro-meteorology** (poor dispersion, enclosed valleys)
4. **Human presence duration** (tourist waiting zones, markets)
5. **Proximity to dung accumulation zones**

Stations were installed at **1.5–2.0 m above ground level**, representing the **human breathing zone**, in strict accordance with CPCB norms.

3.3 Spatial Classification of Air Monitoring Stations

Air stations were categorised into:

A. High-Impact Zones

- Horse parking and congregation areas

- Market and railway station zones
- Administrative and service areas with daily exposure

These locations reflect **peak PM₁₀ and PM_{2.5} generation conditions**.

B. Moderate-Impact Zones

- Trekking routes with intermittent horse movement
- Mixed pedestrian–equine corridors

C. Background / Control Zones

- Areas away from horse routes
- Vegetation-dominated locations with minimal disturbance

This stratification allows **gradient analysis of air quality deterioration**.

4. Selection of Water Sampling Locations

4.1 Environmental Rationale

Water bodies in Matheran are particularly vulnerable due to:

- Steep slopes accelerating runoff velocity
- Shallow soils with limited attenuation capacity
- Direct hydrological connectivity between trails and lakes

Horse dung and urine act as **mobile pollution sources**, especially during monsoon rainfall, leading to:

- Nutrient enrichment
- Microbial contamination
- Elevated turbidity and organic load

4.2 Hydrological Logic of Site Selection

Water sampling stations were selected by mapping:

- Drainage patterns
- Slope directions
- Runoff convergence points
- Upstream–downstream relationships

This ensured that stations capture **pollution transport mechanisms**, not merely water quality at isolated points.

4.3 Categories of Water Sampling Stations

Water stations were selected to represent:

1. **Source-proximal sites**

- Near horse routes
- Near stables and parking zones

2. **Receiving water bodies**

- Lakes and tanks used for drinking or recreation

3. **Upstream control sites**

- Hydrologically isolated from horse activity

4. **Runoff-impacted locations**

- Especially during monsoon season

This design enables **pollution fingerprinting** and impact attribution.

5. **Selection of Soil Sampling Locations**

5.1 **Environmental Rationale**

Soil serves as the **primary long-term sink** for pollutants arising from:

- Repeated dung deposition
- Chronic urine infiltration
- Trampling-induced compaction

Unlike air and water, soil reflects **cumulative and historical impacts**, making site selection critical.

5.2 **Criteria for Soil Station Selection**

Soil sampling locations were selected based on:

- Visible and repeated dung accumulation
- Horse resting and halting behaviour
- Proximity to stables and veterinary facilities
- Low-lying zones receiving runoff
- Undisturbed forest soils for background comparison

5.3 **Sampling Depth and Spatial Logic**

- Sampling depth: **0–30–60 cm**, representing biologically active topsoil
- Composite sampling where appropriate to reduce micro-scale variability
- Control soils selected from ecologically similar but undisturbed locations

This ensures assessment of:

- Nutrient overload
- Organic carbon enrichment
- Microbial persistence
- Trace metal accumulation

6. Integration Across Environmental Media

A key strength of the station selection methodology is **cross-media integration**:

- Air stations overlap with soil dust generation zones
- Soil stations coincide with runoff source areas
- Water stations lie downstream of both air and soil impact zones

This enables **holistic environmental interpretation**, rather than compartmentalized analysis.

7. Relevance to EIA Objectives and NGT Compliance

The adopted station selection methodology ensures that:

- All significant impact pathways are captured
- Seasonal variability is scientifically documented
- Results support enforceable mitigation measures
- Carrying capacity assessments are evidence-based

The monitoring network has been designed to capture **maximum plausible environmental stress conditions** in accordance with the precautionary principle applicable to Eco-Sensitive Zones, thereby ensuring that environmental risks are neither underestimated nor masked by spatial averaging.

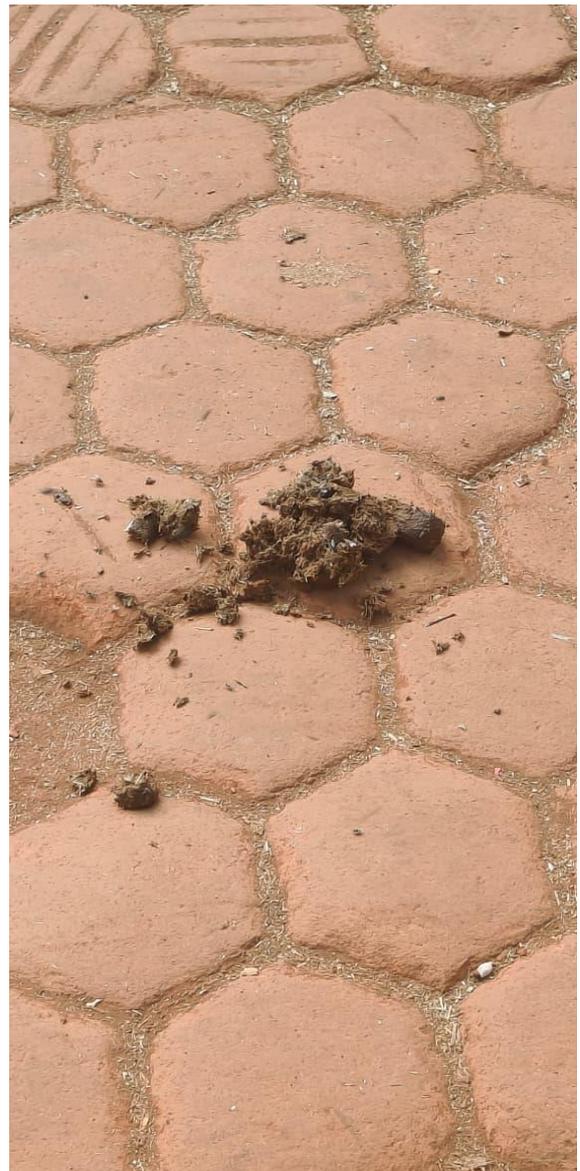
Annexure II: Photographs during Visit



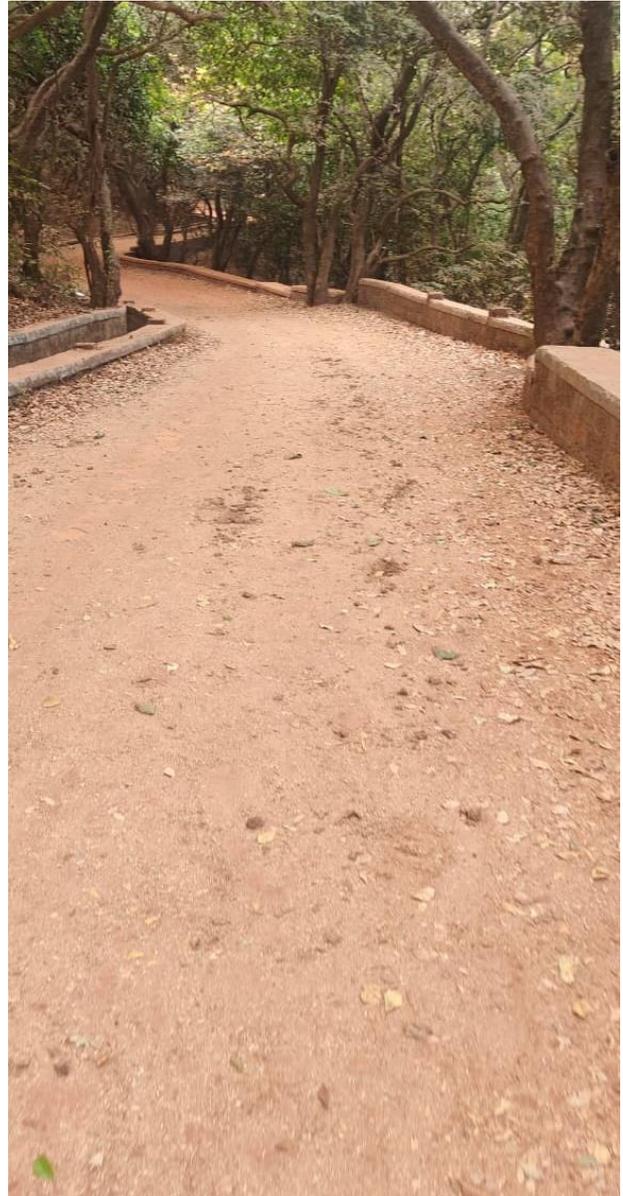
Photo 1: Horse dung waste/s accumulated on streets of Matheran during monsoon.



Photos 2 to 3: Horse dung waste/s accumulated on unpaved streets of Matheran



Photos 4 to 6: Horse dung waste/s accumulated on streets of Matheran



Photos 7 to 9: Horse dung waste/s accumulated on streets of Matheran



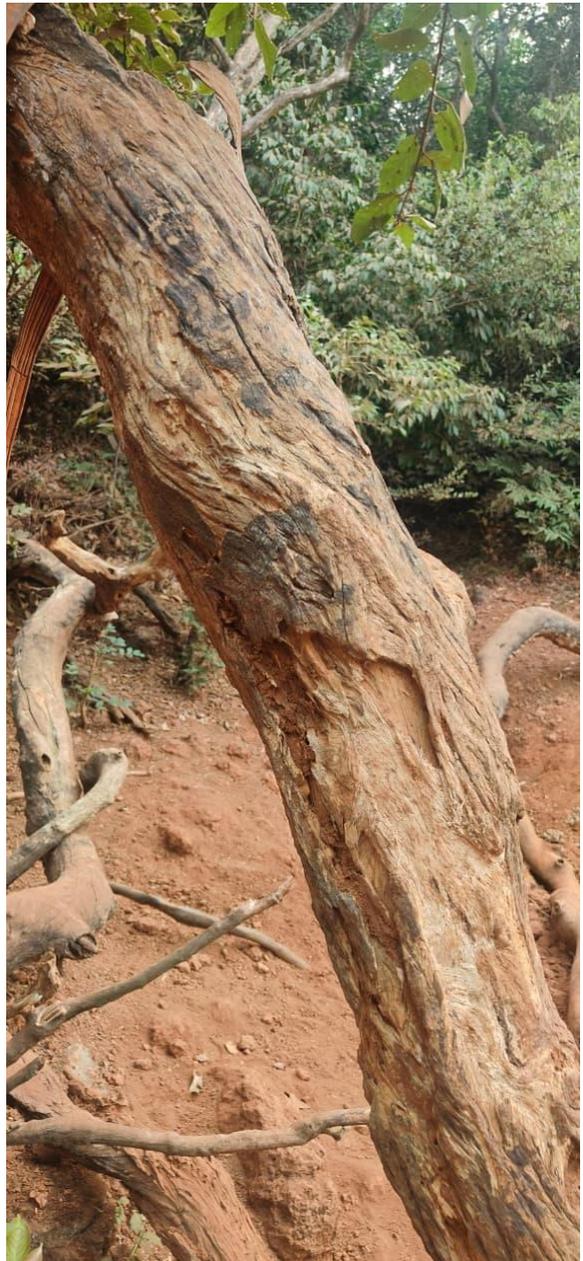
Photos 10 to 12: Open burning of accumulated Horse dung waste/s and collection of soil samples near to Horse stable area



Photos 13 to 15: Herd of horses tied with ropes along the roadside near their stable.



Photos 16 to 18: Collection of horse dung wastes deposited on the streets by manual way.



Photos 19 to 21: Damage caused by horses to trees along streets / near to stable areas



Photos 22 to 24: Herd of horses carrying gas cylinders and other materials on the streets of Mathern



Photos 25 to 26: Herd of horses tied with ropes along the roadside.



Photos 27 to 28: Herd of horses tied with ropes along the roadside. Horse dung waste/s accumulated on streets is clearly visible.



Photo 29: Field Air monitoring stations installed near to council office for air samplings.



Photos 30 to 31: Collection of soil samples by auger for testing.



Photo 32 to 33: Collection of soil samples.



Photo 34 to 35: Collection of water samples coming from the streets of Mathern to Sharllote lake near to stone arch bridge.



Photo 36 & 37: Collection of stagnant & storm water samples



Photo 38 & 39: Collection water samples from local water body & sharllote lake area



Photo 40 & 41: Photos site visit during sampling with officials of MPCB & MHMC



Photo 42 & 43: Photos site visit during sampling with officials of MPCB & MHMC to existing biogas plant in the Matheran area.



Photo 44 & 45: Photos site visit during sampling with officials of MPCB & MHMC to Organic composting machine "GOLDUST" installed in the Matheran area.