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Quantum Machine Learning, Edge AI, Ethical AI, and Autonomous Systems in Smart Cities of Maharashtra

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Abstract: This paper examines the convergence of Quantum Machine Learning (QML), Edge Artificial Intelligence (Edge AI), and Ethical AI frameworks within the evolving ecosystem of smart cities and autonomous vehicles. Drawing upon data and implementation insights from Maharashtra's Smart Cities Mission (2023–24), the study analyzes how advanced computational paradigms are reshaping urban governance, intelligent transportation systems, and sustainable infrastructure. QML leverages quantum computing principles such as superposition and entanglement to process complex urban datasets, optimize traffic flow, and enhance predictive analytics beyond classical limitations. Simultaneously, Edge AI enables decentralized, low-latency data processing at the device level important for autonomous vehicles, smart surveillance, and IoT-enabled public services thereby reducing bandwidth dependency and improving real-time responsiveness. The research further emphasizes the importance of ethical AI principles, including fairness, transparency, accountability, privacy protection, and algorithmic explainability, in large-scale public deployments. In the context of urban mobility and digital governance, ethical oversight mitigates risks related to data bias, surveillance overreach, and unequal access to technological benefits. Case observations from Maharashtra indicate measurable improvements in traffic management, energy efficiency, and citizen service delivery through AI-driven decision support systems. The study proposes a scalable, resilient, and human-centric model for next-generation smart cities by integrating QML's computational acceleration with Edge AI's real-time adaptability under an ethical governance framework. The findings highlight that technological innovation must be aligned with responsible policy frameworks to ensure inclusive growth, sustainable mobility, and trustworthy AI ecosystems.

Keywords: *Quantum Machine Learning, Edge AI, Ethical AI, Smart Cities, Autonomous Vehicles, Urban Governance, Maharashtra Smart Cities Mission, Intelligent Transportation Systems, Sustainability, Responsible AI etc.*

Introduction

India's Smart Cities Mission (SCM), launched in 2015 by the Government of India, marked a major shift in the way urban development and governance are approached in the country. The mission was designed to improve physical infrastructure and make cities more citizen-centric, technology-driven, sustainable, and efficient. SCM has enabled better service delivery in areas such as water supply, waste management, traffic control, surveillance, public transport, and energy management by integrating Information and Communication Technology (ICT) into urban management systems. Digital dashboards, Integrated Command and Control Centres (ICCCs), smart street lighting, intelligent traffic systems, and online grievance redressal platforms have strengthened transparency and responsiveness in urban governance.

Maharashtra has been one of the leading states in implementing the Smart Cities Mission. Eight cities named Aurangabad, Kalyan-Dombivli, Nagpur, Nashik, Pimpri-Chinchwad, Pune, Solapur, and Thane were selected under the mission. As of July 2024, these cities have completed 313 projects worth ₹14,778 crore out of a total of 347 sanctioned projects worth ₹17,042 crore. This remarkable progress reflects strong administrative coordination, financial planning, and technological adoption. Projects such as smart roads, intelligent transport systems, river rejuvenation, smart classrooms, e-governance platforms, and solar

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energy initiatives have contributed to improved urban living standards.

Looking ahead, the evolution of smart cities will increasingly depend on emerging technologies. Quantum Machine Learning (QML) has the potential to handle complex urban datasets at unprecedented speeds, enabling better predictive planning in areas such as traffic flow, disaster management, and energy optimization. Edge AI, which processes data locally rather than relying entirely on centralized cloud systems enhance real-time decision-making in traffic control, surveillance, and emergency response systems while reducing latency and improving privacy. Ethical AI frameworks are equally important to ensure transparency, fairness, data protection, and accountability in automated governance systems.

Autonomous vehicles integrated with smart infrastructure represent the next frontier in urban mobility. When combined with intelligent traffic systems, IoT sensors, and AI-driven analytics, self-driving vehicles reduce congestion; improve road safety, and lower carbon emissions. This discussion highlights how Indian smart cities are adopting advanced technologies and participation to shape the future of sustainable and responsible urban development by situating Maharashtra's progress within broader global technological and ethical debates.

Objectives of the Study

- To assess the implementation status of Smart Cities Mission projects in Maharashtra up to July 2024, focusing on completed and ongoing projects.
- To analyze financial allocations and utilization city-wise, to understand efficiency and accountability in project execution.
- To explore the role of advanced technologies (Quantum ML, Edge AI, Ethical AI) in enhancing smart city functions such as traffic management, waste handling, and citizen services.
- To examine potential integration with autonomous vehicles, especially in cities like Pune and Nagpur where smart mobility projects are underway.
- To identify ethical and governance challenges in deploying AI systems in urban contexts, ensuring transparency, fairness, and citizen trust.

Literature Review:

- Schuld & Killoran (2019) highlight QML's ability to accelerate optimization tasks, particularly in traffic prediction and energy grid balancing.
- Recent studies show quantum-enhanced reinforcement learning outperform classical methods in dynamic urban environments.
- Xu et al. (2022) emphasize Edge AI's role in reducing latency and bandwidth usage in IoT-heavy environments.
- Applications include real-time surveillance, smart waste management, and adaptive traffic control.
- UNESCO (2021) and OECD (2022) frameworks stress transparency, accountability, and fairness.
- Literature warns against algorithmic bias in public service delivery and privacy violations in citizen data collection.
- Prior evaluations (NITI Aayog, 2023) note uneven progress across cities, with Pune and Nagpur leading in ICT-enabled governance.
- Maharashtra's data shows strong completion rates but varying fund utilization efficiency.
- Anderson et al. (RAND, 2020) highlight AVs' potential to reduce accidents and congestion but raise ethical dilemmas in accident scenarios.
- Pilot projects in Pune explore electric autonomous buses, though infrastructure readiness remains a challenge.

Methodology

Data Source

- Primary data: Lok Sabha Unstarred Question No. 520 (July 25, 2024), providing city-wise project and fund details for Maharashtra's smart cities.
- Example: Pune completed **55 projects worth ₹3,333 crore**, while Nagpur completed **34 projects worth ₹1,462 crore** with **13 ongoing projects worth ₹305 crore**.

Research Design

- **Descriptive Analysis:** Mapping completed vs. ongoing projects.
- **Comparative Analysis:** Evaluating fund allocation and utilization efficiency.

- **Thematic Integration:** Linking Maharashtra's smart city initiatives with QML, Edge AI, and Ethical AI.
- **Ethical Framework Assessment:** Applying UNESCO and OECD AI ethics principles to urban governance.

Tools & Techniques

- **Quantitative:** Tabulation of funds, projects, and completion rates.
- **Qualitative:** Literature synthesis on AI technologies and ethical frameworks.
- **Integration:** Conceptual framework connecting Maharashtra's smart city data with advanced AI applications.

Selected Smart Cities in Maharashtra:

- **Cities Covered**: Pune, Nagpur, Nashik, Aurangabad, Sangli, Solapur, Thane.
  - Pune: Integrated command and control center.
  - Nagpur: Smart traffic management and EV charging infrastructure.
  - Nashik: Smart water supply and waste management.
  - Sangli: ICT-based governance and citizen engagement platforms.

Quantum Machine Learning (QML):

- **Definition**: QML combines quantum computing principles with machine learning algorithms to solve problems beyond classical limits.

The below figure 1.1 conceptually illustrates the integration of Quantum Machine Learning (QML) with the Smart Cities ecosystem of Maharashtra. As urban environments generate massive volumes of real-time data from traffic systems, surveillance networks, energy grids, healthcare platforms, and IoT-enabled infrastructure, advanced computational models are required to process and analyze this data efficiently. QML represents a transformative technological advancement that combines quantum computing principles with machine learning algorithms to solve complex optimization and predictive problems at unprecedented speeds.In the context of Ma harashtra's smart cities—Aurangabad, Kalyan-Dombivli, Nagpur, Nashik, Pimpri-Chinchwad, Pune, Solapur, and Thane—the application of QML enhance intelligent governance, resource optimization, and real-time decision-making systems.

Figure 1: Integration of Quantum Machine Learning (QML) with Smart Cities of Maharashtra

As depicted in the Figure 1, the quantum processor symbolizes high-speed computational capability, while the interconnected smart city infrastructure represents data-driven urban governance. The digital network lines connecting the quantum system to smart infrastructure elements such as 5G connectivity, cloud platforms, autonomous transport, and intelligent utilities highlight seamless data exchange and advanced analytics. Through QML, smart cities optimize traffic flow, predict energy demand, enhance cybersecurity, improve disaster management systems, and enable autonomous mobility solutions. This integration reflects the next evolutionary stage of Maharashtra's Smart Cities Mission, aligning local urban development with global advancements in quantum computing and artificial intelligence. The figure thus represents a future-ready, scalable, and ethically responsible model of technology-driven urban transformation.

Applications in Smart Cities:

The figure 1.2 illustrates two important applications of Quantum Machine Learning (QML) within the smart city framework. As urban environments become increasingly data-driven, managing complex systems such as traffic networks and energy grids requires advanced computational approaches beyond traditional algorithms. Quantum-enhanced reinforcement learning and quantum predictive analytics offer innovative solutions to optimize dynamic urban systems in real time.

The left section of the image represents traffic optimization using quantum-enhanced reinforcement learning, while the right section highlights energy grid balancing through quantum algorithms designed for predictive analytics and demand forecasting. Together, these applications demonstrate how QML address large-scale urban challenges with greater efficiency and accuracy

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Figure 1.2: Applications of Quantum Machine Learning in Smart Cities – Traffic Optimization and Energy Grid Balancing

As shown in figure 1.2, in the traffic optimization segment, interconnected vehicles, smart signals, and data streams symbolize a real-time adaptive traffic management system. Quantum-enhanced reinforcement learning enables the system to analyze multiple traffic scenarios simultaneously, adjust signal timings dynamically, reduce congestion, minimize travel time, and lower carbon

emissions. This approach is particularly relevant for rapidly growing urban centers where traditional traffic models often fail to respond quickly to changing conditions.

The energy grid balancing section depicts renewable energy sources such as solar panels integrated into a smart grid. Quantum algorithms support predictive analytics by forecasting energy demand, optimizing load distribution, and stabilizing power supply across different sectors of the city. This ensures efficient utilization of renewable resources, prevents outages, and enhances sustainability.

Thus, the image represents how Quantum Machine Learning transform smart city infrastructure into highly responsive, energy-efficient, and intelligent systems capable of supporting future urban growth.

Edge AI and Ethical AI in Maharashtra Smart Cities- Opportunities and Challenges:

The rapid deployment of advanced artificial intelligence systems in smart cities necessitates careful consideration of both technical and ethical dimensions. While emerging paradigms such as Quantum Machine Learning (QML) and Edge AI offer transformative potential, several challenges remain, particularly in terms of hardware scalability, noise resilience, and seamless integration with classical machine learning (ML) pipelines. Quantum hardware, for instance, is still in its developmental stage, with limitations related to qubit stability, error correction, and large-scale deployment. Furthermore, hybrid architectures that combine quantum and classical ML models require robust interoperability frameworks to ensure practical implementation within urban governance systems.

Edge AI- Concept and Urban Applications:

Edge AI refers to the deployment of machine learning models directly on Internet of Things (IoT) devices and edge servers, rather than relying exclusively on centralized cloud infrastructure. Edge AI reduces latency, enhances operational efficiency, and ensures faster decision-making in real-time environments by processing data closer to the source.

In the context of Maharashtra's Smart Cities, Edge AI has practical applications. In Pune and Nagpur, real-time surveillance systems leverage edge-based analytics to monitor traffic flow, detect anomalies, and enhance public safety without continuous cloud dependency. Nashik has adopted smart waste management solutions in which sensor-enabled bins transmit data to localized edge servers, optimizing collection routes and reducing operational costs. Similarly, intelligent traffic light systems in Aurangabad utilize edge-based computation to dynamically adjust signal timings based on vehicular density and pedestrian movement.

The primary advantages of Edge AI include reduced latency, minimized bandwidth consumption, and enhanced data privacy. Since data processing occurs locally, sensitive information need not be transmitted to centralized servers, thereby lowering cybersecurity risks and strengthening citizen trust.

Ethical AI- Frameworks and Smart City Relevance:

Alongside technological innovation, the ethical deployment of AI systems has become a global priority. International frameworks, including those advanced by UNESCO and leading academic institutions such as Harvard University, emphasize core principles such as transparency, accountability, fairness, inclusivity, and human oversight in AI governance.

Within smart city ecosystems, Ethical AI assumes particular importance.

1. First, ensuring citizen data privacy in IoT-based urban infrastructures is important, especially as large volumes of personal and behavioral data are collected through surveillance systems, smart meters, and digital service platforms.

2. Second, algorithmic bias must be actively mitigated in applications such as traffic management, predictive policing, and public service delivery, where biased decision-making could disproportionately affect vulnerable populations.

3. Third, the increasing adoption of autonomous systems such as AI-driven traffic controls and future autonomous vehicles requires

clearly defined governance mechanisms, regulatory oversight, and accountability frameworks.

Thus, the integration of Edge AI and Ethical AI into Maharashtra's Smart Cities represents a balanced approach that combines technological efficiency with responsible governance. While technical challenges persist, embedding ethical safeguards and scalable architectures will be essential for sustainable and citizen-centric urban transformation.

Funding: Table 1.1 below presents a comprehensive overview of the financial allocation, utilization status, and project progress of the Smart Cities Mission (SCM) across eight selected cities in Maharashtra as of 12 July 2024. The data highlights total funds released by the Government of India and the respective state governments, total utilization achieved, and the number as well as financial value of ongoing and completed projects. This table serves as an important indicator of implementation efficiency, financial management, and project execution capacity at the city level. The table provides insight into the operational effectiveness of each smart city by comparing released funds with actual utilization and analyzing the proportion of completed versus ongoing projects. It also reflects the broader progress of Maharashtra in achieving the objectives of the Smart Cities Mission. Over ₹15,000 crore allocated across Maharashtra's smart cities between 2021–24 which is given in below table 1.1:

Table 1: City-wise Funds Released, Utilized, and Project Progress under Smart Cities Mission in Maharashtra (as on 12 July 2024)

City-wise details of funds released/utilized & progress of projects of Smart Cities of Maharashtra as on 12.7.2024

(Amount in ₹ Crore)

State/City	Total funds released (GoI+States)	Total Utilization (GoI+States)	Ongoing Projects		Completed Projects		Total Projects	
			No. of Projects	Amount	No. of Projects	Amount	No. of Projects	Amount
Aurangabad	985.00	901.13	5	250.4	42	2585	47	2835.4
Kalyan-Dombivali	955.50	895.92	4	528.72	15	715.86	19	1244.58
Nagpur	871.88	832.64	13	305.44	34	1462.27	47	1767.71
Nashik	843.12	749.44	5	293.28	48	2903.91	53	3197.19
Pimpri-Chinchwad	979.92	1,097.83	3	168.77	22	1134.84	25	1303.61
Pune	980.02	980.02	0	0	55	3333.07	55	3333.07
Solapur	985.00	962.93	1	394	48	1256.56	49	1650.56
Thane	980.00	892.33	3	324.01	49	1386.04	52	1710.05
Total	**7,580.44**	**7,312.24**	**34**	**2264.62**	**313**	**14777.55**	**347**	**17042.17**

As per information provided by States/ Smart Cities Mission

(Source-USQ 520.docx)

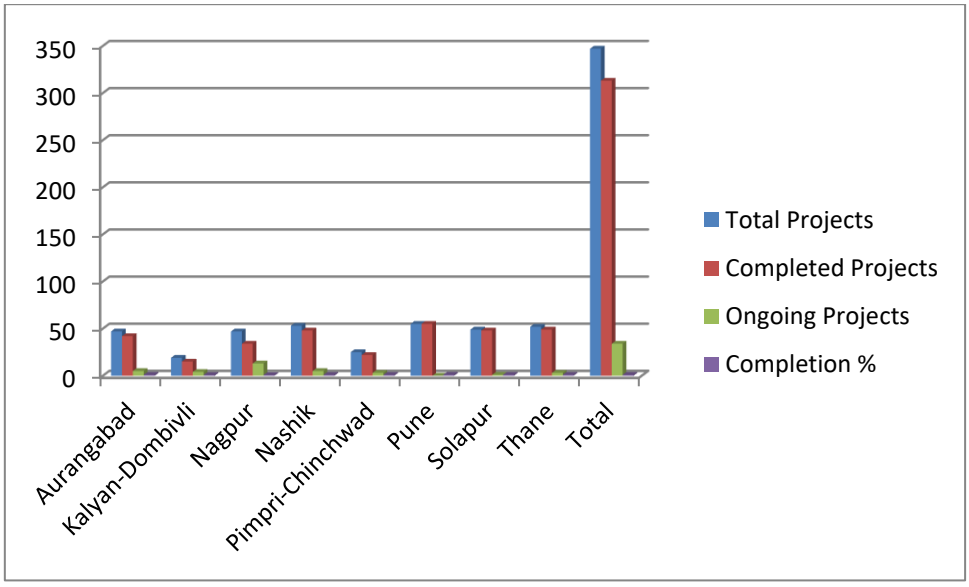
As reflected in Table 1.1, Maharashtra has demonstrated substantial progress under the Smart Cities Mission. Out of 347 total sanctioned projects worth ₹17,042.17 crore, 313 projects valued at ₹14,777.55 crore have been completed, while only 34 projects remain ongoing. This indicates a high completion rate and efficient execution across the state. Cities such as Pune and Nashik show particularly strong performance in terms of completed projects, while cities like Nagpur and Aurangabad still have a few ongoing projects in progress. The utilization of funds across most cities closely aligns with the total funds released, suggesting sound financial governance and effective monitoring mechanisms. The table highlights Maharashtra's leadership in

smart urban transformation, reflecting infrastructural advancement and improved administrative coordination and project implementation efficiency within the framework of ICT-enabled urban governance.

Result Analysis:

Table 2: City-wise Project Status (as of July 2024):

City	Total Projects	Completed Projects	Ongoing Projects	Completion %
Aurangabad	47	42	5	89.36%
Kalyan-Dombivli	19	15	4	78.95%
Nagpur	47	34	13	72.34%
Nashik	53	48	5	90.57%
Pimpri-Chinchwad	25	22	3	88.00%
Pune	55	55	0	100.00%
Solapur	49	48	1	97.96%
Thane	52	49	3	94.23%
Total	**347**	**313**	**34**	**90.20%**

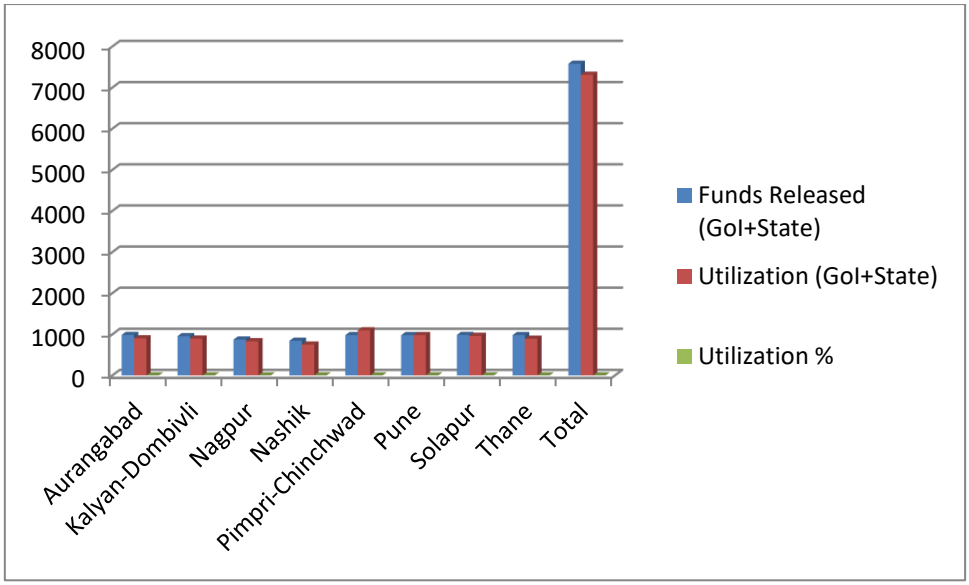


Graph 1: City-wise Project Status (as of July 2024):

Observation: Pune has achieved full completion (100%), while Nagpur lags behind with only 72% completion. The overall state completion rate is **90.2%**.

Table 3: City-wise Financial Utilization (₹ Crore):

City	Funds Released (GoI+State)	Utilization (GoI+State)	Utilization %
Aurangabad	985.00	901.13	91.50%
Kalyan-Dombivli	955.50	895.92	93.77%
Nagpur	871.88	832.64	95.49%
Nashik	843.12	749.44	88.91%
Pimpri-Chinchwad	979.92	1,097.83	112.02%
Pune	980.02	980.02	100.00%
Solapur	985.00	962.93	97.76%
Thane	980.00	892.33	91.06%
Total	**7,580.44**	**7,312.24**	**96.46%**



Graph 2: City-wise Financial Utilization (₹ Crore):

Observation: Pimpri-Chinchwad shows **over-utilization (112%)**, while Nashik has the lowest utilization (88.9%). The fund utilization across Maharashtra is **96.5%**, indicating strong financial efficiency.

Key Insights:

- **High performers:** Pune (100% completion, 100% utilization), Solapur (98% completion, 97.8% utilization).
- **Lagging cities:** Nagpur (72% completion apart from 95% utilization), Kalyan-Dombivli (79% completion).
- **Financial efficiency:** Most cities utilized over 90% of funds, with Pimpri-Chinchwad exceeding allocation.
- **Statewide performance:** Maharashtra has completed 313 out of 347 projects (90.2%), with nearly full fund utilization.

Autonomous Vehicles:

- **Definition**: Vehicles capable of self-navigation using AI, sensors, and edge computing.
- **Applications in Smart Cities**:
  - Smart traffic ecosystems integrating AVs with IoT-enabled signals.
  - Pilot projects for electric autonomous buses in Pune.
- **Challenges**: Infrastructure readiness, ethical dilemmas in accident scenarios, cybersecurity risks.

Table 1.4 Integration Framework:

Technology	Smart City Application	Ethical Consideration
QML	Traffic optimization, energy grids	Transparency in algorithmic decisions
Edge AI	Real-time surveillance, waste management	Privacy and data minimization
Ethical AI	Governance frameworks	Accountability and fairness
Autonomous Vehicles	Smart mobility	Safety, liability, inclusivity

The synergy of QML, Edge AI, and Ethical AI transform Maharashtra's smart cities into resilient, sustainable, and citizen-centric ecosystems. Autonomous vehicles, integrated with smart infrastructure, represent the future of urban mobility. However, ethical governance and robust frameworks are essential to ensure equitable benefits and mitigate risks.

Findings of the Work:

- Maharashtra has achieved **90% project completion** under SCM, with Pune and Nashik leading in financial utilization.
- QML enhance traffic optimization in congested cities like Nagpur.
- Edge AI applications are already visible in surveillance and waste management systems.

- Ethical AI frameworks are important to safeguard citizen trust, especially in data-heavy deployments.
- Autonomous vehicles remain at pilot stage, requiring infrastructure upgrades and ethical governance mechanisms.

- High Project Completion: Maharashtra has completed 313 out of 347 projects (90.2%) under the Smart Cities Mission. Pune achieved 100% completion, while Solapur and Thane also performed strongly with over 94% completion. Nagpur lags behind at 72% completion, indicating uneven progress across cities.
- Financial Utilization Efficiency: The fund utilization stands at 96.5%, reflecting strong financial governance. Pimpri-Chinchwad shows over-utilization (112%), while Nashik has the lowest utilization at 88.9%. This suggests that while most cities are efficient, some require better alignment between released funds and actual expenditure.
- Technology Readiness:

1. Quantum ML (QML): Potential to optimize traffic and energy systems, especially in congested cities like Nagpur.

2. Edge AI: Already visible in real-time surveillance and waste management systems in Pune and Nashik.

3. Ethical AI: Frameworks are necessary to safeguard citizen trust, prevent bias, and ensure accountability in automated governance.

- Autonomous Vehicles: Pilot projects in Pune show promise, but infrastructure readiness and ethical dilemmas (e.g., accident liability) remain challenges.
- City-wise Insights:
- Pune: Model performer with full completion and efficient fund use.
- Nagpur: Needs acceleration in project execution rather than high fund utilization.
- Nashik: Strong project completion but relatively weaker financial utilization.
- Pimpri-Chinchwad: Over-utilization indicates possible reallocation or scaling beyond sanctioned limits.

Suggestions:

- Focused interventions in Nagpur and Kalyan-Dombivli to improve project completion rates. Dedicated monitoring cells could help fast-track ongoing projects.
- Cities like Nashik should improve fund utilization efficiency, while Pimpri-Chinchwad requires stricter financial oversight to prevent over-utilization.
- Deploy QML algorithms for predictive traffic and energy optimization.
- Expand Edge AI applications in surveillance, waste management, and emergency response.
- Establish ethical AI governance boards at city level to monitor fairness, transparency, and accountability.
- Invest in smart traffic signals, IoT-enabled road infrastructure, and EV charging stations to prepare cities like Pune and Nagpur for autonomous mobility.
- Enhance participatory governance through mobile apps, dashboards, and grievance redressal systems to ensure transparency and inclusivity.

Policy Recommendations:

- Introduce state-level AI ethics guidelines aligned with UNESCO/OECD frameworks.
- Encourage public-private partnerships for scaling QML and Edge AI solutions.
- Mandate periodic audits of smart city projects to ensure compliance and accountability.

Conclusion

The integration of QML, Edge AI, and Ethical AI transform Maharashtra's smart cities into resilient, citizen-centric ecosystems. While project completion rates are high, future challenges lie in ethical governance and infrastructure readiness for autonomous vehicles. A balanced approach combining technological innovation with ethical safeguards will ensure sustainable urban transformation.

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