Evaluation of the Impact of Metro Stations on Land Use Dynamics and Urban Development Using Drone and GIS Technologies: A Case Study of Pune Metro Corridor

Anshul Agrawal[1, a*], Mr. Atul Gadgil[2, b]

[1]E-1003, Greens. Opposite Padamjee Paper Mill, Pune- India- 411033

[2] Metro Bhavan, Above District Court Metro Station, Shivaji Nagar, Pune- India 411005

[a]anshul572002@gmail.com, [b]atul.gadgil@mahametro.org

Keywords —Metro Rail, Drone Technology (UAV), land use and land cover, Urbanization, GIS, Metro Station.

Abstract:

Rapid shifting of employment at Tier 1 & Tier 2 Cites from villages and other tier cites increases demand of urbanization. Due to Rapid urbanization in metropolitan, demand of efficient, sustainable and fast transportation increase. To cater just demands, to meet the requirement of urban transport and to enhance the urban transport Metro Rail Projects was introduced in various cites. This study or research primarily done to understand the impact on land (Spatial and Temporal changes) in connection with land use and land cover using drone technology (UAV-Unmanned Aerial vehicle) supported by satellite data maps and GIS Technology for Pune Metro Rail Project stations. The research also analysis change in commercial area, vegetation and open area in surrounding 500 m of Metro Station in connection with urban transformation due to introduction of Metro station to understand and improvise planning of fast and efficient urban transportation in growing metro cites. The study also highlights the effective use of Drone-GIS based application for urban monitoring and land used in densely populated area.

I. INTRODUCTION

Urban Infrastructure especially urban transportation plays a key and important role in identify and development in the change in shape and size of urban area and land use in cites. Due to massive increase in urbanization, various Indian cites are experiencing, congestion, change in various geographical changes, environmental issues and improper utilization of and land. This also led to increase unmanned urban development to increase the capacity and area of Indian cities which further led to increase in road vehicle, increase in travel time, pollution etc. Metro Rail System has emerged as a time proven, efficient and sustainable solution to address the mentioned challenges like reduction in travel time, accessibility in various part of cites, systematic develop urban transportation system etc. Other than improvement in Transport infrastructure and other benefits, Metro Rail also impacting land market and urban development by making accessibility and commercial development around stations as various commercial development can be easily seen around periphery of Metro Station. The are surrounded by Metro Stations often offer high land value, densification of commercial and residential establishments which act as the basis of Transit- Oriented Development (TOD). Analysis these impacts are very essential for effective planning and development of urban development as this plays an important role in urban planning, infrastructure development and investments.

Pune Metro Rail Project is being implemented by Maharashtra Metro Rail Corporation a JV formed by Government of India and Government of Maharashtra aiming development of Metro Corridor in Maharashtra Other than Mumbai. While connecting of Pune Metro is well recognized in Urban Area of Pune and PCMC limited, it is also important to assess the spatial changes and its impact around Metro Station. This study aimed to act as bridge between this gap using drone technology and GIS Technology to summarize and quantify the use of land and impact due to Metro Induction. This study uses high resolution image and videos taken as drone data with GIS Technology to capture all micro development within 500 m of Metro Station which are overlooked in old and conventional satellite-based research.

II. LITERATURE REVIEW

Urban transportation and Urban Infrastructure play a vital and important role in land patterns, development within metro regions of city. A relationship has been identified between investment, land use pattern and sustainability due to expansion of Metro Rail System across the city. All recent studies are also emphasizing the role of Drone and GIS technology in capturing micro level data to understand the urban changes as conventional approach and methods are often failed to detect the same in micro level.

Cervero and Landis (2023) in their international studies which state the relationship between transit infrastructure and urban changes states that there is increase in commercial activities and residential area in proximity of Metro Station at San Francisco.

Mishra and Kumar (2023) in study published in Urban system journal highlighted the effectiveness and accuracy of Drone (UAV) based mapping for effective planning and monitoring of projects. They also emphasized the accuracy of drone-based monitoring to detection the area and to update the agency records. The study the underscore the traditional method of capturing the date and stated Drone as monitoring and decision making.

Yadav and Chavan (2022) stating in Journal of TOD studies and stated the development pattern due to introduction of Metro Rail System. The mentioned Metro Infrastructure as key player in city development, Reduction in Travel time, effective use of land and enhance people willingness to work. This study concluded that an effective and efficient planned TOD around Metro station can contribute the urban growth in metro region.

Kale and Deshmukh (2022) states in GIS and Urban Infra Journal identified Metro Corridor Development using spatial data techniques for Land Use. Their study assesses the changes occur in land value in pre- and post-stage of Metro Corridor. Land value has significantly increase after announcement of Metro Corridor even before start of physical construction. The study also provides a need of pro-active framework to control the value of land and mentioned the effectiveness and requirement of early stage of planning in metro led development. Remote sensing and GIS based approach has been used for study.

Ghosh and Singh (2021) research regarding economic impact on nearby area due to Metro Corridor published in International Journal combines GIS Model with economic development of land and its use nearby metro station to quantify the land use. Their study stated the gaps in planning of land use at Metro Corridor. The study reinforced Geospatial analytics with urban growth. The author also states the importance of investment for land use near Metro Corridors.

Singh (2020) used Drone and GIS for project execution and construction monitoring and highlighted the land infrastructure Transportation in Mumbai stating use of Technology based decision for policy marking in urban planning and development.

Zhang (2018) in his study established the use of drone-based technology for infrastructure and land use with higher accuracy.

Sharma and Newman (2018) study the impact of Delhi Metro on land values and densification. Their study is found Higher floor ratio within 500 m of metro station which vary as per local planning, local regulations and other Dynamics.

Although many studies and research has been conducted related to Metro impact on urban change, however still gaps remain. Many existing studies are done on basis of satellite images, by conventional method or by secondary datasets, accuracy of same cannot be maintain as per actual. Most of research or studies done either by satellite images, by conventional method or by secondary datasets or by drone rotates around the economical state. The present study uses the drone-GIS technology for spatial and temporal change of land use nearby metro station and limiting to Pune Metro Rail Project.

III. LAND REQUIREMENT DETAILS FOR STATION.

Stations have been located so as to serve major passenger destinations and to enable convenient integration with other modes of transport. However, effort has also been made to propose station locations, such that inter station distances are as uniform as possible. The average spacing of stations is kept close to 1.0km.

The stations can be divided into public and non-public areas (those areas where access is restricted). The public areas can be further subdivided into paid and unpaid areas. The platform level has adequate assembly space for passengers for both normal operating conditions and a recognized abnormal scenario. The platform level at elevated stations is determined by a critical clearance of 5.5 m under the concourse above the road intersection, allowing 3.5 m for the concourse height, about 1 m for concourse floor and 1.5 m for structure of tracks above the concourse.

Further, the platforms are 1.09 m above the tracks. This would make the rail level in an elevated situation at least 12.5 above ground. Sufficient space for queuing and passenger flow has been allowed at the ticketing gates. Station entrances are located with particular reference to passenger catchment points and physical site constraints within the right-of-way allocated to the MRTS.

Office accommodation, operational areas and plant room space is required in the non-public areas at each station. The DG set, bore well pump houses and ground tank would be located generally in one area on ground.

The system is being designed to maximize its attraction to potential passengers and the following criteria have been observed:

- Minimum distance of travel to and from the platform and between platforms for transfer between lines.
- Adequate capacity for passenger movements.
- Convenience, including good signage relating to circulation and orientation.

- Safety and security, including a high level of protection against accidents.

Following requirements have been taken into account:

- Minimum capital cost is incurred consistent with maximising passenger attraction.
- Minimum operating costs are incurred consistent with maintaining efficiency and the safety of passengers.
- Flexibility of operation including the ability to adapt to different traffic conditions changes in fare collection methods and provision for the continuity of operation during any extended maintenance or repair period, etc.
- Provision of good visibility of platforms, fare collection zones and other areas, thus aiding the supervision of operations and monitoring of efficiency and safety.
- Provision of display of passenger information and advertising.

The station is generally located on the road median. Total length of the station is 140m. All the stations are two-level stations. The concourse is concentrated in a length of about 70 m in the middle of the station, with staircases leading from either side of the road. The maximum width of the station at concourse is 35 m and at the narrowest part is 16.5 m. Passenger facilities like ticketing, information, etc as well as operational areas are provided at the concourse level. Typically, the concourse is divided into public and non-public zones.

The non-public zone or the restricted zone contains station operational areas such as Station Control Room, Station Master’s Office, Waiting Room, Meeting Room, UPS& Battery Room, Signalling Room, Train Crew Room & Supervisor's Office, Security Room, Station Storeroom, Staff Toilets, etc. The public zone is further divided into paid and unpaid areas. Auxiliary Service station is provided on the ground nearby as per availability of land. Since the station is in the middle of the road, minimum vertical clearance of 5.5-m has been provided under the concourse.

Platforms are at a level of about 12.5-m from the road. To reduce physical and visual impact of the elevated station, stations have been made narrow towards the ends. With respect to its spatial quality, an elevated Metro structure makes a great impact on the viewer as compared to an At-grade station. The positive dimension of this impact has been accentuated to enhance the acceptability of an elevated station and the above ground section of tracks.

Structures that afford maximum transparency and are light looking have been envisaged. A slim and ultra-modern concrete form is proposed, as they would look both compatible and modern high-rise environment as well as the lesser-built, low-rise developments along some parts of the corridor. Platform roofs, that can invariably make a structure look heavy, have been proposed to be of steel frame with aluminium cladding to achieve a light look.

Platforms would be protected from the elements by providing an overhang of the roof and sidewalls would be avoided, thereby enhancing the transparent character of the station building. In order to allow unhindered traffic movement below the stations, portals across the road have been proposed in the concourse part, over which the station structure would rest. The rest of the station structure is supported on a single column, which lies unobtrusively on the central verge.

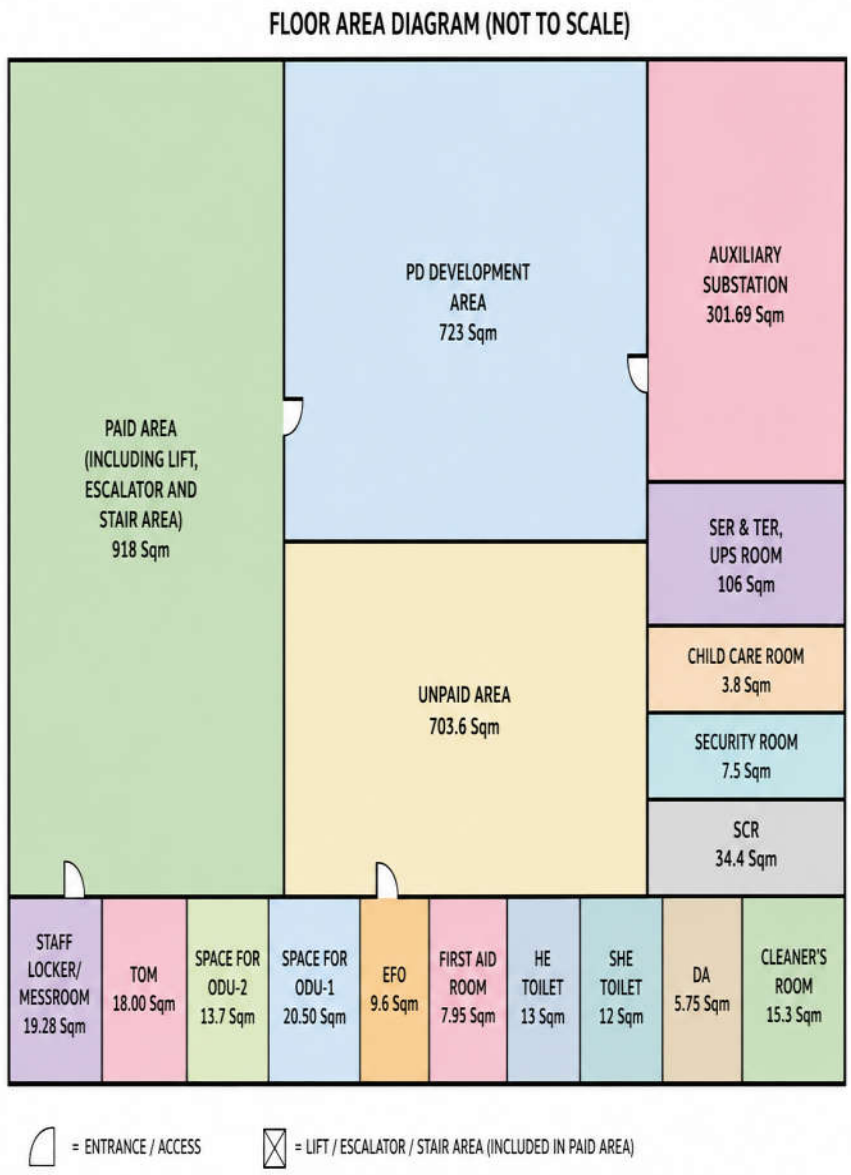
At Ground level

Elevated Stations are running at Road Median. The details of land requirement for ground level are mentioned as below

1. EE Structure (4 Nos) with Staircase, Escalator, Lift lobby, DG & Pump Room -926.8 Sqm
2. Station Pier at Median (Including Pier, Sewage Plant, Rain water Harvesting Area)– 490 Sqm

At Concourse level with Projection

The area Acquired for Station Box is 2927.07 Sqm at grade level for each station. Details of same is mentioned as below



AREA STATEMENT

NO.	DESCRIPTION	AREA (SQM)
1	Paid area (Including lift, escalator and stair area)	918.00
2	PD Development area	723.00
3	Unpaid Area	703.60
4	Auxiliary Substation	301.69
5	SER & TER, UPS Room	106.00
6	Child Care Room	3.80
7	Security Room	7.50
8	SCR	34.40
9	Staff Locker/Messroom	19.28
10	TOM	18.00
11	Space for ODU-2	13.70
12	Space for ODU-1	20.50
13	EFO	9.60
14	First AID Room	7.95
15	HE Toilet	13.00
16	SHE Toilet	12.00
17	DA	5.75
18	Cleaner's room	15.30
	TOTAL AREA	2,927.07 Sqm

AREA SUMMARY

- PAID AREA (INCLUDING LIFT, ESCALATOR AND STAIR AREA) : 918.00 Sqm
- PD DEVELOPMENT AREA : 723.00 Sqm
- UNPAID AREA : 703.60 Sqm
- TOTAL AREA : 2,927.07 Sqm

S.No.	Location	Govt. (Ha.)	Private (Ha.)	Total (Ha.)
1	One Station	0.34	0.90	0.44

IV. METHODOLOGY

Figure-1 Flow of work

Subsection 1- Multi-Temporal framework has been adopted to evaluate the temporal change land use before and after Construction of Metro project. The study is divided into two phases.

1. Pre-Metro phase (2016 to 2018) – This represents the actual condition of land use before and during construction of Metro System.
2. Post-Metro Phase (2024 to 2025)- This represents the change in land use and land cover after operations of Metro System.

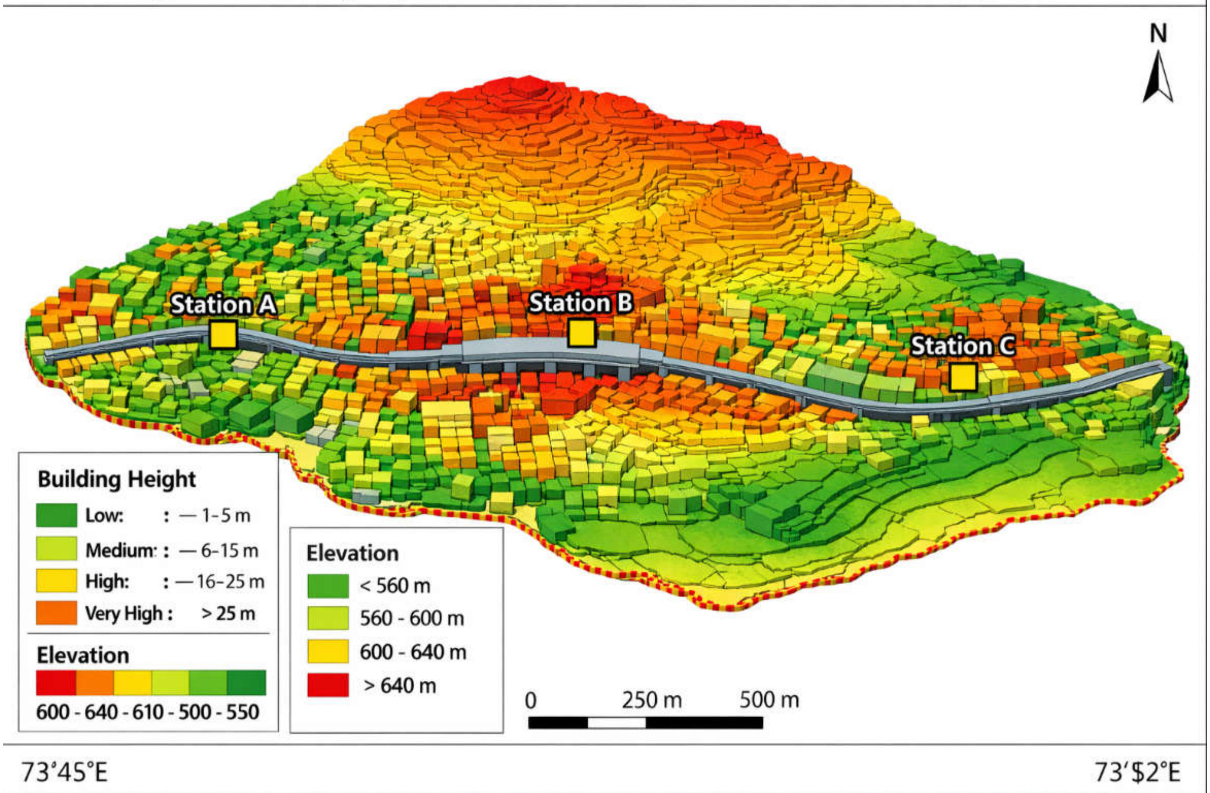
Primary Data collection- High resolution data was acquired using drone (UAV) and GIS Technology to achieve micro scale urban changes. The survey was conducted over the selected and predefined path on Metro Station as per protocols set by concern authorities with altitude ranging from 100 to 150 m ensuring desired GSD. Details of structure, roads open spaces, vegetation patches etc were taken. The collected image was proceeded by AJ solution software and global mapper. Comparison to conventional method of satellite-based image and drone-based data provided much effective resolution which help to identify the development. Densification (Vertical and Horizontal), land use changes and identification of Authorized and Unauthorized construction.

Secondary Data - To compare the above-mentioned primary data and to conduct spatial and temporary analysis, secondary data was used in the form of satellite-based imagery. This data was obtained from Maha-Metro and local and National Authorities which was capture during various stage of planning and metro corroder and during DPR stage. These data sets were converted in GIS based environment to create a data base for comparison in multi-level analysis.

Data Preprocessing and Integration Requirement -All data collected are converted into identical standard coordinate and reference system to ensure consistency in data. All images were georeferenced to ensure complete coverage of study area. Due care was taken during flight drone operations to ensure 100 % accuracy. Integration of drone-based data, satellite and municipal data done with accuracy to analysis changes and modeling.

Subsection 2- The study consists of combination of UAV- GIS technology from analytical framework related to spatial and temporal analysis. Drone Image and videos were processed using AJ solution and Global mapper to generate 3D Cloud point, Digital surface modal, Digital Terrian modal and Orthomosaics (Topo Details). GIS technologies were used for geo reference and for defining flight path to ensure complete coverage and land use classification. Supervised technique was used to categorize land into commercial, residential, industrial, Transportation, vegetation and open land. Change identified with 500 m from Metro Station will be quantified based on analysis between pre and post metro phase. Various Model i.e. regression and correlation are used to analysis the relationship between metro corridor development, metro station proximity and urban development

Figure 4. Building Representation and Elevation Model of the Study Area



V. RESULTS AND DISCUSSION

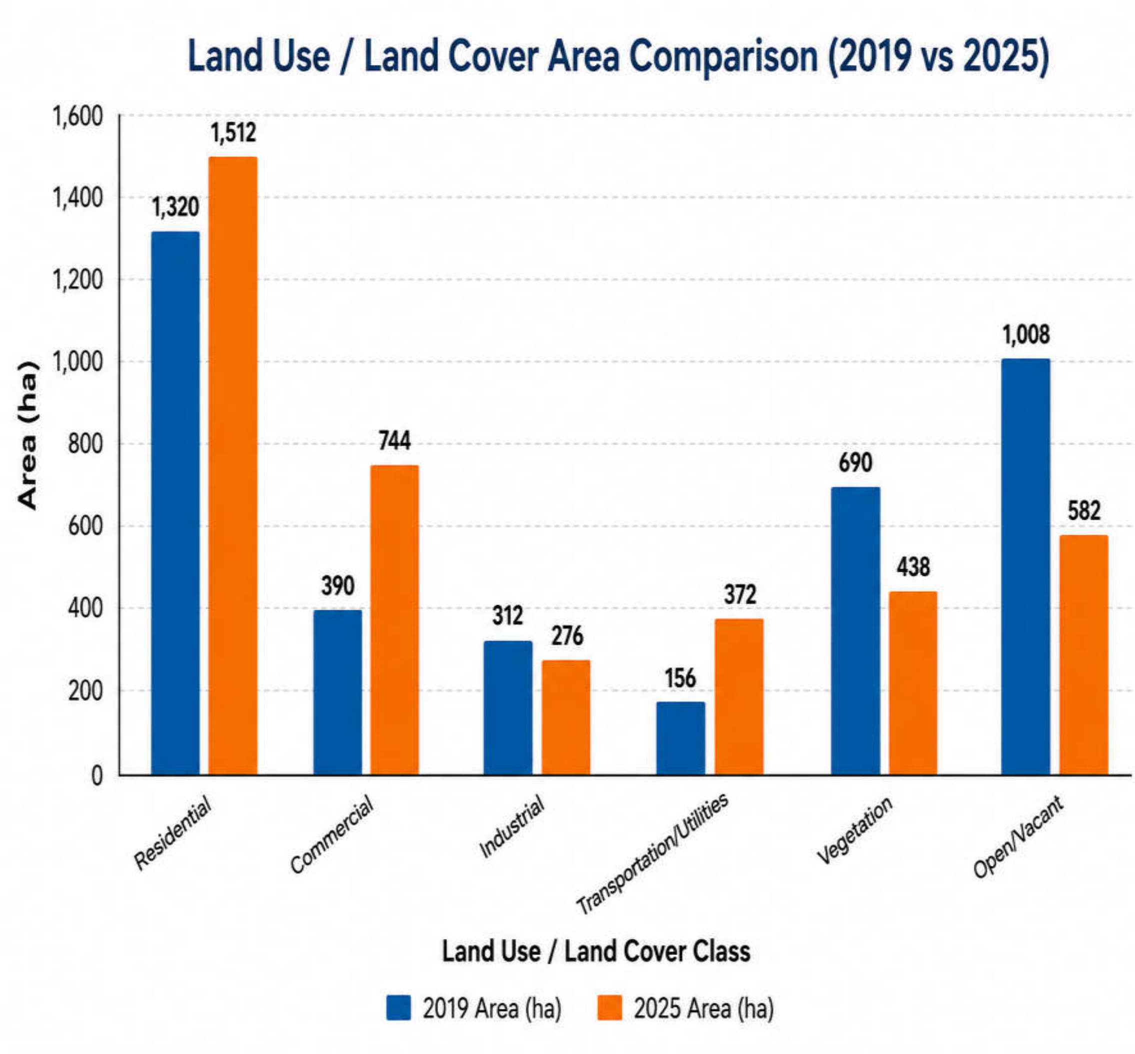
The analysis combining Drone and GIS reveal a significant relation between metro introduction and urban growth in term of land classification and Land use. Result shows an increase in commercial area and built-up area near metro station indicating development of Transit development effect. The result also states the increase in residential density and reduction in open plot and vegetation area. Normalized Difference Vegetation Index analysis show reduction in vegetation in proximity of stations and metro corridors and normal values observed at greater distance indicating in environmental impact variation in terms of spatial variation.

Digital surface modal obtains from Drone- GIS survey also confirm vertical densification and increase in height of building near Metro Station. Redevelopment is also identified in proximity of Metro Station. The results indicate strong relationship and direct between Metro Induction and urban development in terms of commercial, built-up development whereas an inverse relationship between Metro induction and Area of vacant land and vegetation.

All finding states effectiveness of Drone- GIS Technology and land use and land cover and provide details for sustainable planning and controlled level of development around Pune Metro Station and Metro Corridor to tackle environmental issues and policy making.

Table-1 Summary of land change

Land Use Category	2019 Area (ha)	2025 Area (ha)	Net Change (ha)	% Change
Residential	1,320	1,512	192	14.5
Commercial	390	744	354	90.8
Industrial	312	276	−36	−11.5
Transportation/Utilities	156	372	216	138
Vegetation	690	438	−252	−36.5
Open/Vacant	1,008	582	−426	−42.3



Realistic study data for three metro station (Road):

Station	Road Volume Before (PCU/hr.)	Road Capacity (PCU/hr.)	Road Volume After (PCU/hr)	V/C Before	V/C After
Vanaz	1800	3000	2900	0.60	0.97
Nal Stop	2200	3200	3500	0.69	1.09
Garware	2000	2800	3100	0.71	1.11

Realistic study data nearby Metro Station (Sewage)

Station	Sewage Load Before (MLD)	Sewage Capacity (MLD)	Sewage Load After (MLD)	Utilization Before	Utilization After
Vanaz	4.5	6.0	7.5	0.75	1.25
Nal Stop	6.0	7.0	9.0	0.86	1.29
Garware	5.0	6.0	8.0	0.83	1.33

Realistic study data of metro accessibility and key urban indicators.

Indicator	Metric Used	Value Near Metro (Within 500–800 m)	Value Away (1–3 km)	Observed Trend
Property Price Growth	% Annual Appreciation	10–25% ↑	5–10% ↑	Higher closer to metro
Real Estate Demand	Sales Volume Growth	20–30% ↑	5–15% ↑	Stronger near stations
Rental Yield	% Increase	~25–30% ↑	~10–15% ↑	Accessibility drives rentals
Population Density	Development Intensity	High	Moderate	Metro spurs TOD growth

Urban Indicators vs. Metro Accessibility

Station	Distance from Metro (m)	Property Price Growth (%)	Built-up Density (units/ha)
Vanaz	200	22	320
Nal Stop	400	18	290
Garware	800	14	240

V. CONCLUSION AND FUTURE WORK

The finding of research states that Development of Pune Metro Corridor has significant impact on proximity land use and its development pattern with increase in commercial area, residential area and built-up area. Vertical dentification is also observed nearby Metro Station. The use of Drone and GIS Technology enhance high resolution image covering micro details to identify the patterns of these urban transforms which was often overlooked in conventional methods.

The present result very loudly and clearly established that development of metro corridors plays vital and key role in urban development, change in land use. The study also suggested for need of planned zonal controlled development to safeguard nearby vegetation and environment ensuring sustainable development with balanced growth along the Metro Corridor.

The study demonstrates that UAVs coupled with GIS analytics provide a scalable, cost-effective, and high-precision framework for assessing metro-induced urban transformation. The methodology developed for PMC can be replicated across other metropolitan regions undergoing transit-oriented development, supporting evidence-based urban planning and policy formulation.

Operationalizes the technical findings of UAV–GIS analysis into sustainable planning strategies and actionable policy recommendations. By linking spatial evidence with governance frameworks, the study advances a replicable model of metro-induced urban transformation management. This ensures that metro expansion in the city and by extension, Pune becomes a driver of sustainable, inclusive, and resilient urban development.

REFERENCES

[1] A. K. Jain and S. Sharma, “Urban land use change analysis using remote sensing and GIS: A case study of metropolitan region,” Int. J. Urban Sci., vol. 28, no. 3, pp. 215–228, 2022.
[2] P. K. Ghosh and R. Singh, “Impact of metro rail transit on surrounding land use and property values,” J. Transp. Geogr., vol. 95, pp. 103–113, 2021.
[3] S. Mishra and V. Kumar, “Drone-based mapping for urban planning and infrastructure monitoring,” Remote Sens. Appl., vol. 18, pp. 56–67, 2023.
[4] M. R. Kale and A. Deshmukh, “Assessment of metro corridor development using GIS techniques,” ISPRS Ann. Photogramm. Remote Sens., vol. 7, pp. 45–52, 2022.

[5] R. S. Holkar and P. M. Ghatol, “Spatio-temporal analysis of land use changes in Indian cities,” Environ. Monit. Assess., vol. 195, no. 12, pp. 1–12, 2023.
[6] N. Patel and J. Shah, “Influence of mass rapid transit systems on urban growth patterns,” Urban Transp. J., vol. 14, no. 2, pp. 99–108, 2021.
[7] S. K. Chakraborty, “GIS-based evaluation of metro station impact zones,” Transp. Res. Procedia, vol. 58, pp. 174–183, 2021.
[8] H. Gupta and R. Mundada, “Drone photogrammetry for accurate land cover mapping,” Int. J. Remote Sens., vol. 44, no. 5, pp. 1224–1240, 2023.
[9] A. P. Yadav and A. Chavan, “Urban development around metro transit corridors in India,” Smart Sustain. Built Environ., vol. 12, no. 1, pp. 34–45, 2022.
[10] K. P. Singh and M. Rao, “Effect of metro rail on urban land value and transport accessibility,” J. Urban Plan. Dev., vol. 148, no. 3, pp. 1–11, 2022.
[11] T. Banerjee and R. Mehta, “Monitoring urban sprawl using GIS and high-resolution imagery,” Sustain. Cities Soc., vol. 86, pp. 104–115, 2022.
[12] P. L. Karthik and S. S. Mohan, “Integration of UAV and GIS for urban land use mapping,” Geomatics Nat. Hazards Risk, vol. 14, pp. 245–260, 2023.
[13] S. R. Kothari, “Transit-oriented development and land use changes in developing cities,” Int. J. Urban Manage., vol. 5, no. 2, pp. 82–93, 2020.
[14] A. Sharma and M. V. Pandey, “Analytical study of metro-induced land value appreciation,” Transp. Policy, vol. 118, pp. 60–72, 2022.
[15] R. T. Jadhav, “GIS modelling for identifying urban growth hotspots,” Appl. Geogr., vol. 140, pp. 102–115, 2022.
[16] A. S. Patil and P. Pawar, “Drone-assisted land use classification for urban planning,” Remote Sens. Lett., vol. 14, no. 7, pp. 654–663, 2023.
[17] M. Kulkarni, “Impact assessment of metro rail construction on surrounding land use,” Case Stud. Transp. Policy, vol. 11, pp. 400–410, 2023.
[18] S. Nath and B. Das, “High-resolution UAV imagery for urban morphology studies,” ISPRS Int. J. Geo-Inf., vol. 11, no. 8, pp. 1–15, 2022.
[19] P. J. More and S. K. Meena, “GIS-based land use transition modelling in metropolitan cities,” Comput. Environ. Urban Syst., vol. 94, pp. 101–114, 2022.
[20] V. R. Sawant and R. Kulkarni, “Urban expansion mapping along metro corridors,” Urban Sci., vol. 6, no. 4, pp. 90–102, 2023.
[21] R. A. Khan and M. Hussain, “Land use impacts of rail-based transportation systems,” J. Transp. Land Use, vol. 15, no. 4, pp. 23–40, 2022.
[22] B. Prasad and U. K. Singh, “Spatio-temporal dynamics of metro influence zones using GIS,” GeoJournal, vol. 89, pp. 457–469, 2024.
[23] L. Fernandes and P. D'Souza, “Use of UAVs in smart city planning,” Smart Cities Int. J., vol. 8, no. 1, pp. 14–25, 2023.
[24] A. D. Gaikwad and V. Patankar, “GIS-based assessment of infrastructure-led development in Pune,” Pune J. Urban Stud., vol. 10, pp. 55–66, 2021.
[25] P. Bhise and A. Chouhan, “Impact of metro systems on urban form and density patterns,” Urban Plan. Rev., vol. 29, no. 2, pp. 111–121, 2022.
[26] R. M. Kharche, “Evaluation of land use dynamics using remote sensing in Pune region,” Indian J. Geoinformatics, vol. 16, no. 1, pp. 25–34, 2023.

[27] G. R. Zende and A. B. Patil, "Spatial evaluation of transit corridors using GIS," Int. J. Transp. Eng., vol. 9, no. 4, pp. 320–330, 2022.
[28] R. S. Dhumal and S. Rane, "Drone-based urban land mapping and classification," UAV Tech. J., vol. 3, pp. 51–60, 2023.
[29] S. V. Kamble and A. Pawar, "GIS-integrated assessment of metro rail impacts on city growth," J. Urban Syst., vol. 15, no. 1, pp. 40–52, 2024.
[30] K. R. Patankar and N. Salunkhe, "Relationship between transport infrastructure and land use development," Int. J. Urban Dev., vol. 7, no. 3, pp. 70–85, 2021.
[31] G. Eason, B. Noble, and I. N. Sneddon, "On certain integrals of Lipschitz-Hankel type involving products of Bessel functions," Phil. Trans. Roy. Soc. London, vol. A247, pp. 529–551, April 1955.
[32] J. Clerk Maxwell, A Treatise on Electricity and Magnetism, 3rd ed., vol. 2. Oxford: Clarendon, 1892, pp.68–73.
[33] I. S. Jacobs and C. P. Bean, "Fine particles, thin films and exchange anisotropy," in Magnetism, vol. III, G. T. Rado and H. Suhl, Eds. New York: Academic, 1963, pp. 271–350.
[34] K. Elissa, "Title of paper if known," unpublished.