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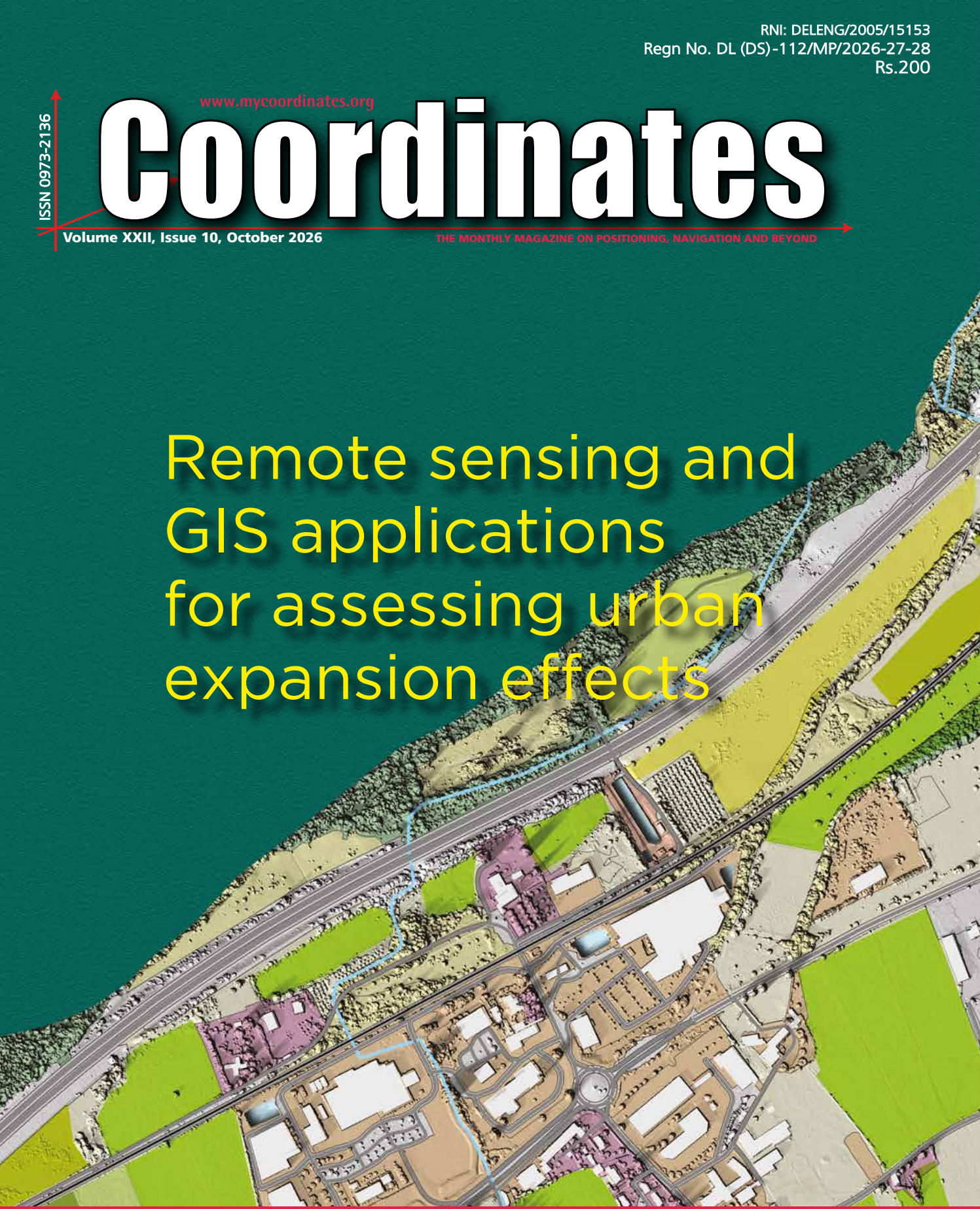
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Volume XXII, Issue 10, October 2026

THE MONTHLY MAGAZINE ON POSITIONING, NAVIGATION AND BEYOND

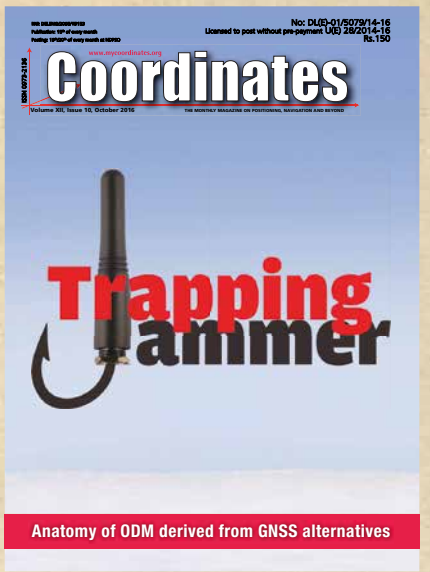
Remote sensing and GIS applications for assessing urban expansion effects



Mainstreaming and safeguarding fragile informal settlements in Delhi

In Coordinates

10 years before...



Anatomy of ODM derived from GNSS alternatives

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Anatomy of Origin- Destination Matrix derived from GNSS alternatives

Renato Filjar, Scientific Advisor, Institute of Telecommunications, Ericsson Nikola Tesla, Zagreb, Croatia, Associate Professor of Electronics Engineering, University of Rijeka, Croatia

Mia Filic, An independent deep networks, positioning methods, SDR signal processing and satellite navigation specialist, Sesvete, Zagreb, Croatia

Andrea Lucic, An independent embedded system, SDR signal processing and satellite navigation specialist, Rijeka, Croatia

Kresimir Vidovic, A railways and ITS specialist, Ericsson Nikola Tesla, Zagreb, Croatia

Dinko Saric, Department manager, Intelligent Transport System segment, Ericsson Nikola Tesla, Zagreb, Croatia

Origin-Destination Matrix (ODM) has been considered a traditional tool for transport development, being established on interviews and traffic counting. Here we present a novel approach in the ODM estimation using data related to telecommunication activity, as well as the advanced methods for the ODM visual presentation and interpretation. Our approach does not only aim at assisting transport developments, but also at supporting the larger- scale urban strategic development in relation to identified socio-economic activity.

Point cloud acquisition and wall surface extraction using indoor MMS

Masafumi NAKAGAWA, Shibaura Institute of Technology, Toyosu, Koto-ku, Tokyo, Japan
Tatsuya YAMAMOTO, Shibaura Institute of Technology, Toyosu, Koto-ku, Tokyo, Japan
Shido TANAKA, Shibaura Institute of Technology, Toyosu, Koto-ku, Tokyo, Japan
Makoto SHIOZAKI, Nikon Trimble Co. Ltd., Minami-kamata, Ohta- ku, Tokyo, Japan
Tetsuya OHHASHI, Nikon Trimble Co. Ltd., Minami-kamata, Ohta- ku, Tokyo, Japan

We have proposed a method for panoramic rendering-based polygon extraction from indoor mobile LiDAR data. Our aim was to improve region-based point cloud cluster modeling after point-cloud registration.

Shoreline protection according to Swedish environmental legislation

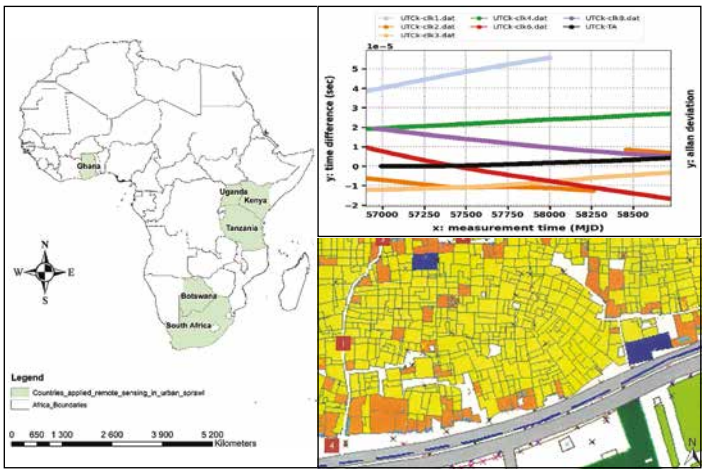
Marija Juric and Karl Hafström Magnérus
The Swedish mapping, cadastral and land registration authority, Stockholm, Sweden

The Swedish shoreline protecting has a strong position and a long history in Sweden. This has led to the possibility for all Swedes, as well as visitors to the country, to easily access open water and the area surrounding it.

Trapping the jammer: the Slovenian experiment

Gianmarco Baldini, European Commission, Joint Research Centre (JRC), Directorate for Space, Security and Migration, Italy
Daniele Borio, European Commission, Joint Research Centre (JRC), Directorate for Space, Security and Migration, Italy
Ciro Gioia, European Commission, Joint Research Centre (JRC), Directorate for Space, Security and Migration, Italy
Matej Bažec, University of Ljubljana, Faculty of Maritime Studies and Transport, Portoroz, Slovenia
Franc Dimc, University of Ljubljana, Faculty of Maritime Studies and Transport, Ljubljana, Slovenia
Andrej Stern, University of Ljubljana, Faculty of Electrical Engineering, Portoroz, Slovenia
Ales Blatnik, Agency for Communication and Services of Republic of Slovenia (AKOS), Slovenia
Niko Gaberc, Agency for Communication and Services of Republic of Slovenia (AKOS), Slovenia

This paper provides a comprehensive account of the activities jointly conducted by the European Commission Joint Research Centre, the University of Ljubljana and Agency for Communication and Services of Republic of Slovenia to characterize and ultimately mitigate the jamming threat.



In this issue

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Ashok Kumar Jain, Benett Siyabonga Madonsela, Mosa Koloko, Narayan Dhital, Thabang Maphanga and Xolisiwe Sinalo Grangxabe; Riegl, SBG System, and many others.

Mailing Address
A 002, Mansara Apartments
C 9, Vasundhara Enclave
Delhi 110 096, India.
Phones +91 11 42153861, 98102 33422, 98107 24567

Email
[information] talktous@mycoordinates.org
[editorial] bal@mycoordinates.org
[advertising] sam@mycoordinates.org
[subscriptions] iwant@mycoordinates.org
Web www.mycoordinates.org

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Editor Bal Krishna
Owner Coordinates Media Pvt Ltd (CMPL)

This issue of Coordinates is of 36 pages, including cover.



Smart cities, basic failures

For years, we have talked about smart cities in India.

Sensors, command centres, intelligent traffic systems and digital platforms promise better urban living.

Yet, our cities continue to struggle with the basics.

Unsafe roads and footpaths, Open manholes and electrical wires, Overflowing drainage, Building fires and collapses.

Inadequate housing, sanitation and waste management.

Polluted air and water.

The list is long.

And the human cost is real.

Have we confused the tools of urban planning with its purpose?

A city needs more than digital intelligence.

It needs sound planning, reliable infrastructure, effective governance,

And accountability.

Bal Krishna, Editor
bal@mycoordinates.org

ADVISORS Naser El-Sheimy PEng, CRC Professor, Department of Geomatics Engineering, The University of Calgary Canada, George Cho Professor in GIS and the Law, University of Canberra, Australia, Professor Abbas Rajabifard Director, Centre for SDI and Land Administration, University of Melbourne, Australia, Luiz Paulo Souto Fortes PhD Associate Professor, University of State of Rio Janeiro (UERJ), Brazil, John Hannah Professor, School of Surveying, University of Otago, New Zealand

Remote sensing and GIS applications for assessing urban expansion effects on protected areas in Sub-Saharan Africa

During this review was that most of research that involved the application of GIS and RS in urban sprawl monitoring seemed to be concentrated within a few countries

Mosa Koloko
Institute for Water Studies, Deparment of Earth Sciences, Faculty of Natral Sciences, University of the Western Cape, Private Bag X17, Bellville 7535, South Africa

Thabang Maphanga
Institute for Water Studies, Deparment of Earth Sciences, Faculty of Natral Sciences, University of the Western Cape, Private Bag X17, Bellville 7535, South Africa

Benett Siyabonga Madonsela
Department of Environmental and Occupational Studies, Cape Peninsula University of Technology, Faculty of Applied Sciences, Corner of Hanover and Tennant Street, Zonnebloem, Cape Town, South Africa

Xolisiwe Sinalo Grangxabe
Department of Environmental and Occupational Studies, Cape Peninsula University of Technology, Faculty of Applied Sciences, Corner of Hanover and Tennant Street, Zonnebloem, Cape Town, South Africa

Abstract

Urban Sprawl in Sub-Saharan Africa presents growing risks to biodiversity and protected areas. Over recent years, there has been a notable increase in population within urban areas across the Sub-Saharan Africa (SSA). This demographic shift has precipitated urban sprawl, thereby escalating the demand for land. Urban sprawl facilitates the emergence of informal settlements, which are characterized by development that does not comply with urban planning policies, zoning regulations, and other pertinent legal frameworks. Urban sprawl poses a threat to the integrity of protected areas by altering ecosystems through disturbances caused by human presence and activities. It presents significant challenges for conservation efforts, notably through habitat and biodiversity loss, pollution, and the presence of weak regulatory frameworks. In addition, its ecological impacts on nature reserves are often unrecognized by the public due to a lack of awareness. It is important to study and map urban sprawl patterns over time using remote sensing (RS) and Geographic Information Systems (GIS) technologies to support evidence-based solutions for addressing urban sprawl in SSA while promoting a balance between urban development and environmental conservation. Despite the demonstrated utility of RS/GIS technologies, their application remains an even across the region. This systematic review synthesizes empirical research applying RS/GIS to evaluate the impact of an expansion on biodiversity within SSA's protected landscapes. The findings revealed consistent reliance on medium resolution satellite imagery and supervised classification techniques to detect patterns of encroachment, green space reduction and habitat degradation. The review furthermore underscores the importance of implementing environmental education programs targeted at urban and periurban communities to encourage participatory approaches that involve community members in the management of nature reserves, including local stewardship programs, co-management initiatives, and educational outreach programs, as the management of nature reserves encompasses not only spatial planning issues but also broader policy challenges.

1 Introduction

Urban Sprawl is widely recognized as a complex concern that poses significant threat to biodiversity and ecological integrity, particularly in rapidly urbanizing regions such as Sub-Saharan Africa (SSA). The definition of urban sprawl is often debated by urban planners and environmentalists, however the generally accepted definition is "the uncontrolled

growth of urban areas into surrounding natural and agricultural lands" [21]. In developing regions, it's characterized by low-density buildings, increased dependance on automobiles, land use conversion and environmental degradation [3]. It's caused by factors such as economic growth, population growth and regional disparities in development [51, 54]. With the rapid increase in human population, many regions within Sub-Saharan Africa have had their natural ecosystems threatened [30]. Between the years 1990 and 2014, urban sprawl increased by 95% at a global scale [31].

Urban Sprawl has been widely studied due to its environmental and socio-economic consequences globally. In their study, Sen [45] concluded that urban expansion leads to habitat degradation, loss of biodiversity and land-use conflicts. Despite the implementation of mitigation strategies such as urban edging, the challenge persists in the region [30]. While the physical manifestation of urban sprawl is the most visible aspect, it is important to view it as a multidimensional phenomenon because its consequences extend beyond simple landcover change Zhang, L & Shu [61]. The socioeconomic impacts of urban sprawl in the SSA are evident through the facilitation of informal settlements development that lack basic services and development space. These are areas developed without adherence to urban planning policies, zoning regulations and other legal frameworks applicable such as securing appropriate permits for developments [28]. As a result, the environmental aspect suffers through factors such as the introduction of environmental pollution [27]. Pollution from the informal settlements results mostly from improper waste management contributing to water contamination and soil degradation [24]. Furthermore, services such as pollination, water movement and infiltration and carbon sequestration are further impacted by the sprawl [24, 27]. Effective monitoring systems for quantifying impacts and informing evidence-based management are needed to prevent nature reserves losing their ecological integrity.

GIS and remote sensing technologies can provide effective monitoring functions/capabilities that will allow for a balance in growth of development and conservation in developing regions [35]. According to Parra [41], the integration of remote sensing (RS) and Geographic Information Systems (GIS) in environmental monitoring represents a critical advancement in addressing complex challenges that are posed by rapid urbanization. Urban expansion is a major global driver of land-use change, with significant implications for biodiversity and ecosystem functions (Seto et al. 2012; Angel et al. 2021). Cities in Sub-Saharan Africa (SSA) are expanding at an unprecedented rate, often outpacing global averages, and this growth is taking place in environments with limited planning capabilities, expanding informal settlements, and lax enforcement around protected areas (Li et al., 2022); [50]. Nature reserves and conservation corridors are becoming more vulnerable to habitat loss, fragmentation, and edge effects, which jeopardize their long-term ecological health [49, 53]. Satellite observations and geospatial information systems have become very important tools for tracking these impacts due to their accurate, multi-decade views of the earth that allow us to monitor land cover changes, impermeable areas, and vegetation state changes [29, 57]. Using satellite data for free, particularly Landsat and Sentinel-2, along with sophisticated analytical methods, such as machine learning, object-based analysis, and time-series change detection, has improved the evaluation of urban encroachment on protected areas in Southern Africa [18, 23, 43].

In the developing SSA countries where urbanization is happening at unprecedented rates, these technologies provide essential capabilities for quantifying, tracking and analyzing the impacts of urban sprawl in protected natural landscapes [32, 34]. Through satellite imagery, spatial analysis and detection of change over time, we can now efficiently monitor how the landscape has transformed over time.

Despite advancements, the application of remote sensing technologies to examine urban-nature interactions in Africa remains largely unexplored from a holistic perspective. Existing reviews often highlight global patterns or focus on urban areas in the Global North, offering only a limited synthesis of evidence pertinent to the unique ecological, socio-economic, and governance contexts of SSA [59], (Darko et al. 2023). This gap is significant because urban expansion in SSA is typically characterized by the rise of informal settlements, uncontrolled peri-urban development, and the encroachment of agricultural land, which differs from the scenarios in wealthier regions, necessitating context-specific analytical approaches. While remote sensing and GIS have been used to monitor urban sprawl and land cover change in the SSA, there is still a gap in reviews that specifically focus on their application in assessing the impacts of nature reserve in this region. This review will highlight how remote sensing and GIS have been applied to monitor and assess the impacts of urban sprawl on biodiversity within nature reserves in Sub-Saharan Africa (SSA) using existing studies, and identify the key methodological trends, gaps and future research priorities. It will contribute to existing literature by synthesizing recent applications RS and GIS in assessing the ecological implications of urban sprawl on protected areas in SSA. The region remains underrepresented in global spatial research and most reviews focus on urban expansion or technical methods alone. This review aims to fill this gap by putting an emphasis on biodiversity and habitat implications of urban sprawl. In addition to clarifying the situation, the review will facilitate evidence-based management of protected areas vulnerable to rapid urbanization.

2 Methodology

2.1 Literature search method

A comprehensive systematic literature review was conducted in accordance with the PRISMA 2020 statement

to synthesize existing research. This methodological approach ensures a transparent, reproducible, and extensive synthesis of the literature, distinguishing itself from traditional narrative reviews by employing explicit, predefined procedures to mitigate bias and provide an authoritative overview of the subject matter. The designated protocol aimed to address the primary research question: "To what extent have remote sensing and Geographic Information Systems been utilized to investigate and evaluate the consequences of urban sprawl on biodiversity within nature reserves in Sub-Saharan Africa?" This study employed a systematic approach to gather and review literature on the use of remote sensing and Geographic Information Systems (GIS) in monitoring the impacts of urban sprawl on biodiversity within nature reserves.

Academic databases such as Science Direct, Google Scholar and Scopus accessed through Cape Peninsula University of Technology's library were used to search for research papers, reports and published thesis. The search strategy used a combination of keywords that focused on three concepts. For urban Sprawl, the terms included ("urban sprawl" OR "urban expansion" OR "urbanization"). For technology, the terms used were ("remote sensing" OR GIS OR "geographic information system*" OR "satellite imagery"). Lastly, for the subject & location, ("nature reserve" OR "protected area" OR "national park*" OR biodiversity) AND ("Sub-Saharan Africa" OR SSA were used.

2.2 Eligibility and exclusion criteria

Study selection was based on the following predefined criteria: Population/ Subject: Nature reserves, protected areas, or wetlands of ecological significance within Sub-Saharan Africa. Intervention/ Technology: For spatial analysis, studies must make explicit use of remote sensing technologies (e.g., Landsat, Sentinel, SPOT) and Geographic Information Systems (GIS). Results: Studies should evaluate changes in Land Use/Land Cover (LULC) and correlate these changes with impacts on biodiversity, habitat quality, or ecosystem integrity. Study Type: Empirical, peer-reviewed journal articles, conference proceedings, and doctoral theses. To ensure a contemporary review covering 15 years at the time of writing, studies published prior to 2008 were excluded. Studies that were not written in English were also excluded. Additionally, review articles, editorials, and opinion pieces were not considered, although their reference lists were examined for potential sources. Studies employing RS/ GIS that did not explicitly link urban sprawl to biodiversity impacts within or adjacent to a protected area were also excluded. An article with the full text that is not available through the institution's access or the author's request for access.

2.3 Selection of studies and data extraction

Out of the 87 papers that were initially identified, 54 papers were eventually excluded. Despite having the key words of interest in their titles, they lacked data of interest therefore only 4 were considered to be relevant in the context of Sub-Saharan Africa and were used to inform this review (Fig. 1). The study selection process followed the PRISMA 2020 flow diagram. Figure 1 below is a PRISMA Flow Diagram, documenting all stages from identification to final inclusion. A total of 4 studies met all inclusion criteria and were included in the final synthesis. During the selection of literature and extraction of data, priority was given to papers that specifically analyzed and examined the application of remote sensing and GIS technologies in assessing urban sprawl and its effects on biodiversity or habitats. Emphasis was also placed on research that has been conducted in Sub-Saharan Africa. From the included studies, the data that was extracted was organized and analyzed to identify common patterns and trends. Moreover, building on the reviewed literature, this study further emphasizes the paucity of research undertaken in Sub-Saharan African (SSA) countries and examines the existing research structure and emerging trends in the application of remote sensing and GIS to monitor the effects of urban sprawl on nature reserves. A systematic search in the Web of Science database,

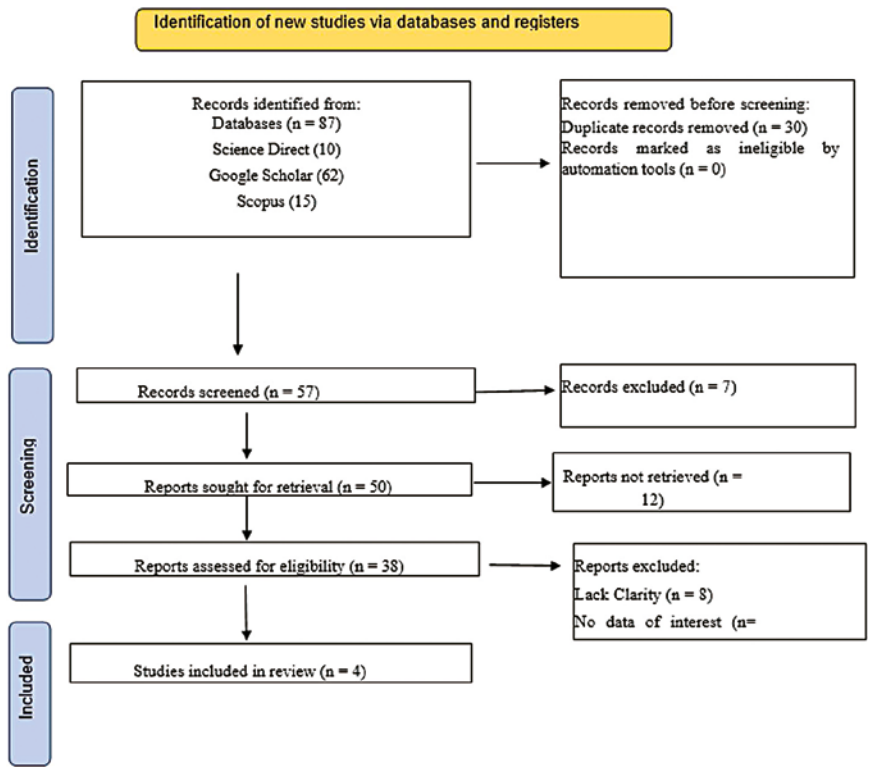


Fig. 1 PRISMA flow diagram on how they systematic selection of literature was done

Table 1 Distribution of publications by country on urban sprawl, remote sensing, and GIS applied to nature reserves

Countries	Documents
PEOPLES R CHINA	36
CHINA	24
INDIA	20
SOUTH AFRICA	3
GHANA	1

using the key terms "urban sprawl," "remote sensing," "geographic information system," and "Sub-Saharan Africa," yielded numerous publications globally.

Using the Web of Science database, an initial bibliometric analysis was conducted to gain a deeper understanding of global research on urban sprawl and the application of remote sensing (RS) and Geographic Information Systems (GIS). Sub-Saharan Africa-specific inclusion criteria were then applied. Table 1 illustrates the distribution of publications by country from this initial global search based on a predefined search syntax combining urban sprawl, RS/GIS technologies, and protected or conserved areas. Researchers in Sub-Saharan Africa do not contribute much, with only a few publications coming from South Africa and Ghana. The findings indicate that research output is heavily concentrated in a few countries, primarily China and India. China's dominant position in the dataset is due to differences in how database country affiliations are indexed, emphasizing the global imbalance in research focus.

Nonetheless, this table emphasizes the importance of regional studies rather than simply shifting the geographical focus of the review to Sub-Saharan Africa, which is underrepresented in global literature.

2.4 Data synthesis and critical analysis method

The data collected were integrated using a mixed-methods approach to provide both quantitative and qualitative insights. A quantitative analysis was conducted through systematic extraction and calculation of descriptive frequencies to identify trends, including the annual distribution of publications, the spatial distribution of case studies, the frequency of use of specific satellite sensors as well as the prevalence of certain classification and change detection methods. Furthermore, a thematic qualitative synthesis using the Babel thematic analysis method was employed to identify, analyze and present themes within data derived from the findings and discussion sections of studies. The primary themes identified were: Methodological Complexity, which encompasses the techniques and tools used for analysis; Ecological Connections, which refers to how research has transformed LULC maps into significant insights into biodiversity (e.g., through fragmentation analysis, habitat connectivity models, or associations with species data); and Policy and Management Significance, which examines the extent to which the research provides findings relevant for conservation planning and governance.

3 Results

3.1 Monitoring urban sprawl using remote sensing techniques

Remote sensing is the art where information about an object, phenomenon or area is obtained without being in direct contact with it [47]. This technology has evolved substantially over the past two decades and has become essential in detecting, monitoring and quantifying the growing environmental challenges, especially in developing countries. Several studies have applied remote sensing technologies to monitor urban sprawl in SSA. A summary of these studies is presented in Table 2.

Recent applications, particularly using Landsat imagery have been effective in mapping and quantifying land use/land cover changes of urban sprawl in the rapidly growing African cities. Figure 2 shows urban sprawl is studied using remote sensing and GIS in Sub-Saharan Africa mainly in West Africa (Ghana), East Africa (Kenya, Uganda, Tanzania), and Southern Africa (South Africa, Botswana), with a strong focus on capturing rural livelihood impacts through integrated methods, change detection techniques, and environmental impacts. The rapid urbanization of these countries makes them ideal research areas for understanding sprawl patterns, particularly in their major cities. Krishnaveni and Anilkumar, [34] highlighted that using high resolution satellite imagery and aerial photography, remote sensing enables precise mapping and classification of land cover over a period of time. Take for instance how Muchelo et al., [37] were able to monitor the associated land use/land cover (LULC) changes in Kampala and Mbarara, Uganda. From the study, the authors revealed a significant change in the land-use evidenced by the transition of agricultural land to built-up areas due to the encroachment of urban cities through the use of multi-temporal Landsat imagery. Their study demonstrates that using remote sensing allows for a visualization of the spatial and temporal changes in urban areas is essential in assisting urban planners and conservationists to track the expansion patterns, detect land conversion and assess the impacts of urbanization on natural environments. This allowed for effective and targeted environmental impact management, ensuring challenges like pollution, migration and reduction of protected natural green spaces are being effectively addressed.

The studies in Table 2 showed consistent use of medium resolution Landsat imagery (30 m) in their analysis. Magidi and Muchelo applied supervised maximum likelihood classification (MLC) to classify the imagery. MLC is a commonly used classification method when classifying Landsat imagery into their relevant land cover classes or uses. Using supervised MLC was advantageous in these studies as high accuracy in classification were reported, especially since training data was available [37]. The usage of this imagery and classification technique was cost effective. The combination of satellite imagery and socio-environmental data provided valuable

Table 2 Summary of studies that have applied remote sensing in urban sprawl analysis in the SSA

Study (Citation)	Country	Data / Sensor	Temporal coverage	Analysis approach	Key findings	Relevance to protected areas
Magidi & Ahmed [36]	South Africa	Landsat TM/ETM + /OLI	1984–2015	LULC classification landscape metrics	Rapid urban expansion with increasing fragmentation	Demonstrates how long-term urban growth increases landscape fragmentation near conservation zones
Aduko et al. [2]	Ghana	Landsat	1986–2018	Change detection, GIS overlay	Urban growth led to loss of natural vegetation	Highlights indirect pressure of urban sprawl on ecological systems
Muchelo et al. [37]	Uganda	Landsat	1989–2016	LULC change analysis	Significant agricultural land loss due to urban expansion	Illustrates expansion-driven land transformation relevant to buffer zones around protected areas



Fig. 2 Spatial distribution of Sub-Saharan African countries included in the review that have applied remote sensing techniques in urban sprawl studies. Highlighted countries include Ghana, Kenya, Uganda, Tanzania, Botswana, and South Africa

insights into habitat and biodiversity fragmentation within the study area.

Across the reviewed studies in Table 2, there is a pattern of accelerating urban growth within the cities over the study periods. The common leading driver of the growth was found to be natural and rural to urban migration across the locations. This growth occurs at the expense of natural landscapes that have been either encroached or converted into urban areas. Consequently, the conversion of these natural landscapes has led to biodiversity loss due to the fragmentation of natural habitats. At the time of study, the pattern of acceleration urban growth within the cities indicated that loss of biodiversity was likely to continue well into the future. Moreover, the accelerating growth theme has shown signs of shifting the local economies across the cities, where it was observed that most of the cities are transitioning from agriculture-based economies to service-based economies. This shift further exacerbates urban sprawl due to an increase in economic opportunities that have led to population level increases. All of the authors used freely accessible satellite Landsat data. This usage allowed for repeated systematic monitoring of urban changes during the study periods. Due to the usage of RS and GIS technologies, the authors were able to assess the extent to which urban expansion is occurring, determine the key drivers for it and provide spatial information needed to inform conservation and decision making.

While the studies have yielded significant benefits in assessing urban sprawl patterns and the usage of remote sensing technologies does face some challenges. Remote sensing usually depends on cloud free atmospheric conditions which may limit data availability [35]. In addition, high resolution spatial imagery is preferred but it is costly. Many of these studies rely on medium resolution imagery which may pose a challenge when identifying and classifying mixed land uses. When conducting such studies, it is important that the results are as accurate as possible as they may be used to inform decision

Table 3 Urbanization trends in Sub-Saharan Africa

Year	Urban Population %	Urban Growth Rate %	Largest Urban Areas
1950	11.1	4.3	Ibadan, Addis Ababa, Lagos, Kinshasa
1970	19.5	4.9	Lagos, Kinshasa, Johannesburg, Luanda
1990	27.9	4.5	Lagos, Kinshasa, Nairobi, Johannesburg
2010	36.3	3.7	Lagos, Kinshasa, Nairobi, Dar es Salaam, Luanda
2030	47.1 (projected)	3.5 (projected)	Lagos, Kinshasa, Dar es Salaam, Luanda
2050	58.1 (projected)	3.0 (projected)	Dar es Salaam, Lagos, Kinshasa, Luanda

Table 4 Urbanization trends within the largest urban areas in Sub-Saharan Africa as of recent

Country and City	Urban Population (in Millions)	Annual Urban Growth Rate	References
Nigeria, Lagos	17.2	3.75	[9], [58], [40], [56]
Democratic republic of Congo, Kinshasa	17.8	4.38	[56], [58], [26, 55]
Angola, Luanda	10	3.9	[56], [55]
Tanzania, Dar es Salaam	8.6	4.9	[56], [22]
South Africa, Johannesburg	6.4	1.9	[1], [56], [52]
Ethiopia, Addis Ababa	6	4.44	[55], [56]
Kenya, Nairobi	5.8	4.1	[56], [26, 55]

making. This common usage of medium resolution imagery may pose a challenge in accuracy as they usually are not detailed enough for small complex features. The complexities of urban landscapes must be considered when using satellite imagery to track changes overtime. Failure in doing so could lead to uncertainties or overlaps data where there's mixed pixels between the urban and non-urban surfaces [41]. Furthermore, using medium resolution usually leads to shadows from the buildings and trees further complicate the interpretation of these images. This means the results of such studies must be interpreted within some limitations, which may reduce the accuracy of the classification. It is therefore important to invest in ongoing research and technological improvements to address these challenges.

However, these limitations do not dismiss the benefits that are offered by remote sensing when monitoring biodiversity as can be seen in the accurate presentation of urban sprawl patterns within the study regions in Table 2. The consistency of the usage of medium resolution Landsat imagery over a long period of time enabled the quantification of urban expansion and landscape metric changes within the complex urban settings.

3.2 Urbanization trends in Sub-Saharan Africa

Urbanization in the SSA is driven by a combination of natural population growth, rural-to-urban migration and reclassifying rural areas as urban [11]. Urban areas attract migrants due to job opportunities, better living and housing conditions, education and health opportunities. Many of the settlements within these countries that were historically classified as rural are now being redefined and reclassified due to the partial growth, infrastructural development and the increased population densities [26]. Unlike developed regions where urban rates have stabilized, countries in the SSA must contend with the ongoing development pressure as they are rapidly transitioning into the "urban age". According to [26]. The spatial expansion of urban land in Africa is expected to increase by nearly 600% between the years 2000 and 2030. While the SSA region is a developing region and the drivers for urbanization are similar, the pace of urban growth and expansion varies from country to country and over different years [44]. When focusing on these trends, it is essential to consider the role factors like the different socioeconomic statuses and governance of the countries play in urban expansion. An overview of urbanization trends and projections across SSA's countries is summarized in Table 3, highlighting the recorded largest urban areas and their current and projected urban growth and population. These metropolitan cities were consistently identified in this review as the focal points for urbanization in the SSA. The higher the urban growth, the higher the expansion of urban areas within the countries over the years.

Table 4 provides a more detailed insight into the largest urban areas in the Sub-Saharan countries as of 2025. Cities like Kinshasa and Dar es Salam experience the highest urban growth rates indicating that the countries have two of fastest urban expansion in Africa. The high population and growth rates contribute to the challenges faced by these cities such as inadequate housing, increased transportation reliance and pressure on the ecosystem.

4 Discussions

Nature reserves play a crucial role in preserving biodiversity by providing and protecting habitats for a wide range of species [24, 38]. However, urban sprawl threatens the integrity of these areas by altering ecosystems through disturbances from human presence and activities [24]. As the human population grows, there is an increase in the demand for development space. This subsequently leads to the establishment and expansion of both formal and informal settlements resulting in the encroachment of the human population in undisturbed natural landscapes [15, 33]. Urban sprawling leads to the depletion of critical green spaces and natural habitats, which play a pivotal role in maintaining biodiversity and ecosystem services. Despite Africa being known as a continent that has a rich biodiversity, over recent years it has experienced a decline due to the growth of human population [7].

Africa currently ranks as the fifth highest in terms of urban population, with approximately 13 countries exhibiting potential for significant urbanization over

the next three decades [13, 48]. This trend is anticipated to result in a substantial decline in protected biodiversity hotspots. The ongoing reduction of urban green spaces is underscored by the study conducted by Appiah-Opoku et al. [5], which examined the effects of urban sprawl on nature reserves and protected biodiversity hotspots in Sub-Saharan Africa, with a particular focus on Dares Salaam, Tanzania. The rapid urbanization in Dares Salaam has precipitated a marked decrease in green spaces and environmentally sensitive areas, declining from 86% in 2000 to 40% in 2021. This reduction is attributed to the significant expansion of informal settlements and built-up areas encroaching upon these spaces.

The researchers also included Luanda, Angola and Accra in their study which also seemed to follow a similar pattern of having a decline in the green spaces while there's an expansion of development [5, 17]. This loss of green space coverage has significantly reduced habitat availability within these cities and has exacerbated urban environmental problems such as heat islands and pollution which have further stressed the ecosystem [33, 60]. This vulnerability of ecosystems within the nature reserves leads to a degradation of habitats forcing many species to adapt or migrate in search of refuge as they experience reduced food availability and shelter issues [38]. In addition to the study by Appiah-Opoku et al., a similar study was conducted in the Ugandan cities Kampala and Mbarara which show similar results where there was a substantial urban expansion within the city. The study was conducted by Muchelo et al., [37] and they found that a significant proportion of urban growth in both cities encroached onto the green nature reserved spaces over the years which correspondingly led to a decrease in green spaces from 48 to 16% in Kampala and from 40 to 32% in Mbarara over the years. Both these studies highlighted that the rapid urban expansion has led to a decline in the integrity of natural ecosystems. The ecological integrity of the nature reserves is also threatened by the introduction of invasive species (pets) by humans and the increased human activities that result in the illegal exploitation of land. The resulting edge effects weaken even the most well managed nature reserves [37].

Sen, [45] highlighted that urban sprawl in protected areas/nature reserves has not only led to biodiversity loss through habitat destruction, but through the introduction of multiple forms of pollution. In their study, the researchers found that the expansion of urban development's degrade ecosystems through land pollution resulting from the increased generation of waste and poor waste management. Air pollution from industrial and vehicular emissions harm sensitive plants and alter their growth. Water pollution is also experienced [31], [24, 45]. Polluted surface runs off from the established urban areas and from formal industrial activities introduces contaminants into the surface and underground waterbodies as it flows over land and infiltrates the ground, contributing significantly to the degradation of water quality within these environments [19, 20, 39]. The water containing contaminants such as pesticides, fertilizers or excessive nutrients affect the species that depend on this water for survival, rendering the water ultimately harmful [25]. Noise pollution as well as the increased artificial lighting also disturbs the species, especially the small animals as they are a nuisance. This type of pollution is often neglected, not realizing that it promotes emigration of these animals from the nature reserve [31], [13].

In light of the review's content, there we highlight challenges posed by urban development in and around conservation areas in Sub-Saharan Africa and an introduction of a novel model illustrating a vicious cycle of degradation (Fig. 3). This cycle is initiated by primary factors such as rapid population growth, economic expansion, and inadequate land-use planning. These elements contribute to urban sprawl and the subsequent fragmentation of ecologically significant land. Urban expansion presents two concurrent threats to adjacent nature reserves [19]. The first threat is direct ecological harm resulting from edge effects, pollution, and invasive species. The second threat is the intensification of human-wildlife conflict, manifested through increased road mortality, heightened poaching, and more frequent crop raiding [16, 20]. The convergence of these conditions leads

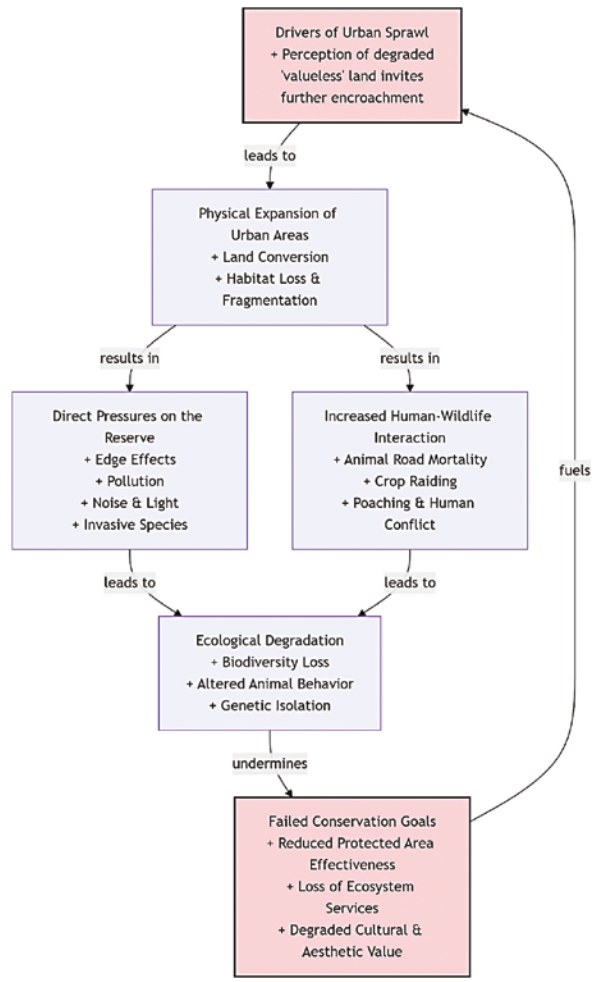


Fig. 3 Shows the fundamental socioeconomic factors such as rapid population growth, economic development that demands more space, and poorly enforced land-use policies start the process

to severe ecological damage, causing a significant decline in biodiversity, along with notable alterations in animal behavior and genetic isolation. Crucially, this model reveals a detrimental feedback loop: the failure to achieve conservation objectives diminishes the ecological, economic, and cultural significance of the reserve, thereby undermining the political and social commitment to its protection. As a result, this perception encourages further encroachment and weakens governance, contributing to sprawl. It is imperative to break this self-perpetuating cycle before conservation areas are irreversibly exhausted, which highlights the systemic nature of the threat and the necessity for integrated planning and proactive policy interventions to break it.

4.1 Challenges and opportunities for conservation efforts

In their study, Appiah-Opoku et al., [5], showed that a key challenge to conservation lies within the weak institutional and regulatory frameworks that govern urban planning in many of the SSA countries. Upon further investigation, the authors found that most of the existing urban planning regulations are outdated and fail to address urban growth pressures experienced or to protect green spaces effectively. In addition, the challenges in the legislative and policy enforcement capacity and the existence of corruption make it difficult to implement sustainable land use practices [44]. Furthermore, the socio-economic factors complicate the efforts to manage urban expansion through increasing the demand for housing spaces and establishment of informal settlements [59].

Lack of funding and resources serve as a major challenge to conservation, especially in the SSA. The protected area management in most SSA countries are underfunded with budgets being below the minimum needed for conservation efforts with a few exceptions in countries such as South Africa, Kenya and Rwanda [8].

The papers reviewed showed that despite the existence of challenges, the opportunities offered far outweigh the difficulties. Remote sensing and GIS technologies provide several opportunities for conservation efforts such as providing and enabling the identification and mapping of critical habitats under threat from urban sprawl (Nizamani et al. 2024). These tools facilitated spatial and temporal monitoring for land cover changes allowing conservation managers and urban planners to detect patterns of habitat loss in near real time [34]. This enhanced technological capability allows for adaptive management by informing where conservation is needed and by tracking the effectiveness of the employed measures over time [4, 8].

Moreover, the integration of remote sensing data with local ecological and socio-economic information helps in the designing of context specific strategies that balance urban development with biodiversity conservation [4]. For instance, satellite imagery can detect deforestation patterns while the ground level data on land use practices can reveal the underlying drivers for the deforestation such as agricultural purposes, resource extraction and/or the establishment of settlements among many. By overlaying these data sets in GIS platforms such as QGIS and ArcGIS, it becomes easy to visualize areas where deforestation had high occurrence rates. This allows informed intervention that addresses forest areas protection. For instance, a study that was conducted in Kuantan district in Malaysia where Landsat and Sentinel imagery were used to classify the LULC over time. The results from the study showed the capability of RS and GIS technologies to track deforestation and encroachment onto forested areas [62]. From the results, recommendations to practice sustainable landscape and town planning management were made in order to reduce the rate at which deforestation is occurring and reduce pressure on the ecologically sensitive areas [62].

Figure 4 illustrates the relationship between population growth, infrastructure expansion and economic development and how they contribute to urban sprawl. The result is urban expansion, which is characterized by an increase in built-up areas and the encroachment of buffer zones, straining surrounding ecosystems. The transmission of these effects exerts a direct and adverse impact on biodiversity, manifesting in the destruction of essential vegetation types, land fragmentation, and systemic ecosystem stress. To interrupt this causal chain, the proposed framework introduces a synergistic counter strategy. This strategy leverages the diagnostic capabilities of change detection indices and remote sensing for monitoring purposes, the prognostic capabilities of spatial simulation models for planning, and emphasizes the necessity of policy interventions to initiate concrete and sustainable urban development measures.

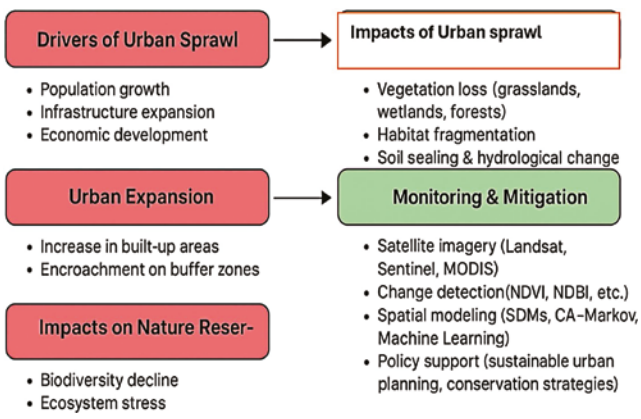


Fig. 4 The figure emphasizes the interplay between urban development pressures, ecological consequences, and the role of technology and governance in sustainable urban development

4.2 Harmonizing development with environmental protection

Balancing urban development with biodiversity conservation imperatives has become a critical policy within the SSA but remains a challenge. It requires the integration of ecological stewardship with inclusive growth strategies. Multiple approaches have emerged in order to

Urban sprawling leads to the depletion of critical green spaces and natural habitats, which play a pivotal role in maintaining biodiversity and ecosystem services. Despite Africa being known as a continent that has a rich biodiversity, over recent years it has experienced a decline due to the growth of human population

address this balance, with integrated land use planning being a fundamental strategy. This strategy places emphasis on having green buffers and wildlife corridors that maintain ecosystem connectivity while accommodating controlled urban development [8]. These green buffers act as a vital transitional zone that reduces the edge effects of urbanization on natural habitats, providing safe passages and the continuity of habitats for biodiversity. The integration of wildlife corridors is crucial as they are essential in preventing and reducing habitat degradation [8]. They do this by linking isolated patches of natural habitats, facilitating gene flow, reducing species migration and resilience against challenges faced by the environment.

In addition to the physical planning measures, many countries have adopted nature-based solutions within the urban environments. The integration of green spaces such as parks, community gardens and vertical gardens, is heavily promoted as they serve crucial ecological functions. The ecological benefits include support for pollinators, improve air and water quality, reduce urban heat island effects and provide microhabitats for biodiversity found within the developed areas. With green spaces integration it is easy to even get the community involved in environmental protection as they also enhance aesthetic and recreational appeal and opportunities [12].

According to Cassano (2020), cross sector collaboration is vital in balancing the complex interplay between increased urban development and biodiversity conservation. This means governments, urban developers, conservation organizations, academia and the public must work together to align this economic development with ecological preservations. Involving these diverse stakeholders ensures that environmental conservation efforts are socially inclusive and in other cases, culturally appropriate [12]. Aligning the national development agendas with global frameworks such as the United Nations Sustainable Development goals and the African Union's agenda 2063 should be promoted as they can guide the countries toward a more balanced development [26]. Ultimately, seeking and working towards a development that is both socially and environmentally equitable is important if we want to secure the long-term viability of the environment and for preservation of biodiversity.

4.3 Policy implications and recommendations for managing urban sprawl in nature reserves

4.3.1 Integration of nature reserves into urban planning frameworks

A major policy implication is the need to harmonize urban planning with biodiversity conservation. In many cases, nature reserves or natural green spaces are not sufficiently considered during the spatial planning process resulting in a degradation of natural land-scapes and weak buffer zones [14]. The relevant and competent authority must ensure that nature reserves are legally designated within urban development plans at both local and national levels through ensuring that the spatial development frameworks (SDF's) and Integrated Development Plans (IDPs) clearly outline ecological boundaries and provide legal protection for these nature reserves [6].The Integration of comprehensive land use regulations is a very crucial aspect as well, policies such as zoning restrictions, urban growth boundaries and conservation easements serve to protect these sensitive natural areas [10].

4.3.2 Strengthening institutional mandates and capacity

Most nature reserves have institutions that are empowered through legislative frame-works. The institutions have enforcement authority that enables them to make decisions on any unauthorized developments that may take place on the reserve. They are also responsible for managing and monitoring them [5]. Studies highlight that these institutions are usually underfunded and sometimes lack technical capacity to enforce the existing land use and conservation regulations. This poses challenges on monitoring urban encroachment within these natural landscapes. To address such an issue, the governments should prioritize the allocation of resources and support to conservation agencies. This includes but is not limited to the investments in GIS land-based monitoring tools, legal expertise and human resources that will be essential in enforcing compliance with conservation priorities [10].

According to Appiah-Opuku et al. 2023, the impacts on the environment due to urban sprawl call for a re-evaluation of the existing development policies. What this means is there needs to be a strengthening in the regulatory frameworks that govern land expansion and conversion of land especially in areas that border nature reserves/protected areas such as strengthening zoning laws, enforcement mechanisms and mandates so that the conservation priorities for nature reserves are not neglected due to short term developmental interests.

4.3.3 Public awareness and community participation

Granxabe et al., [8] showed that awareness

among local populations about the ecological value of nature reserves is important. Residents, particularly those who are living in informal settlements may unknowingly be encroaching into these protected areas in search of land. This study continues to show that residents living near nature reserves have mixed attitudes towards them, mostly due to their socio-economic statuses with some recognizing their ecological importance and value, and some not [24]. While some of the residents' value nature reserves as important sanctuaries for protecting biological diversity and maintaining ecosystem services like clean water among many, factors such as unemployment and poverty lead other residents to view the conservation efforts as challenging to their livelihood especially when they restrict their access to the protected area [24, 42]. In some cases, however, the importance of nature reserves is not recognized due to residents being unaware of their ecological importance, their protected status and their conservation objectives [46]. This is mostly due to inadequate outreach efforts by authorities and a significant lack and challenges in information accessibility.

5 Conclusion

While the physical manifestation of urban sprawl is the most visible aspect, it is critical to view it as a multidimensional phenomenon. Its causes and consequences go well beyond simple land cover change. The socio-economic dimension is evident in SSA, where sprawl is inextricably linked to urban poverty and inequality, manifesting as unplanned informal settlements lacking basic services and secure land tenure [28]. This, in turn, exacerbates the environmental dimension, as these areas frequently suffer from insufficient waste management, resulting in soil and water pollution [24], and are frequently located in ecologically sensitive areas, posing direct threats to biodiversity.

Furthermore, these dynamics are supported by a governance and infrastructural dimension that includes weak regulatory frameworks, ineffective planning policies, and the enormous financial burden of providing services to dispersed, low-density communities. The interplay of these dimensions physical, socioeconomic, environmental, and governance defines the unique challenge of urban sprawl in SSA and necessitates the use of sophisticated monitoring tools.

Within the SSA, there are emerging studies on urban sprawl demonstrating rapid urbanization within the countries. Compared to other global regions that are more developed such as China and Europe, research within the SSA is comparatively limited. Application of RS and GIS in urban sprawl monitoring has been essential in providing opportunities for conservation of natural spaces due to their ability to assess changes in LULC patterns and environmental impacts. Majority of urban sprawl studies identified during this review depended on using Landsat imagery with medium resolution for landcover detection. Landsat imagery remains invaluable due to its cost effectiveness and availability. Most importantly the usage of Landsat imagery allows for a long-term change detection due to its long-term historical archive [41]. The combination of satellite imagery and socio-environmental data provides valuable insight into habitat and biodiversity fragmentation. Using these technologies also encourages scenario building that is essential in future prediction of urban sprawl impacts on natural ecosystems. This capability allows for interventions and mitigation of impacts before they occur. These processes result in urban expansion, characterized by an increase in built-up areas and the encroachment of buffer zones, thereby exerting significant pressure on adjacent natural ecosystems. Consequently, there are direct impacts on natural reserves and biodiversity, including vegetation loss (such as grasslands, wetlands, and forests), habitat fragmentation, soil sailing, hydrological alterations, biodiversity decline, and ecosystem stress. To address these challenges, the framework underscores the importance of monitoring and mitigation measures. Remote sensing technologies (e.g., Landsat, Sentinel, MODIS) and change detection indices (e.g., NDVI, NDBI) provide essential tools for tracking land-use change. Furthermore, spatial modeling techniques, such as Species Distribution Models (SDMs), Cellular Automata-Markov models, and machine learning approaches, can aid in projecting future scenarios and guiding planning. Finally, policy support through sustainable urban planning and conservation strategies constitutes a critical component in mitigating the adverse ecological impacts of urban sprawl.

A common theme noticed during this review was that most of research that involved the application of GIS and RS in urban sprawl monitoring seemed to be concentrated within a few countries in the SSA that have the largest urban areas such as South Africa, Kenya, Ghana and Nigeria. There is still a lack of research in most of the small central African countries that needs to be investigated and addressed to close data gaps and challenges.

Author contributions

Mosa Koloko: Conceptualization; methodology; systematic literature search; data extraction; formal analysis; original draft preparation. Thabang Maphanga: Methodology refinement; validation; data interpretation; writing – review and editing; supervision. Bennett Siyabonga Madonsela: Data interpretation; writing – review and editing; visualization; critical revisions. Xolisiwe Sinalo Grangxabe: Writing – review and editing; policy and management synthesis; critical revisions. All authors reviewed and approved the final version of the manuscript and agree to be accountable for all aspects of the work.

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Data availability

No datasets were generated or analysed during the current study.

Declarations

Ethics approval and consent to participate

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Consent for publication
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Benett Siyabonga Madonsela declares they are an Editorial Board Member of Discover Environment and confirms that they were not involved in the handling or decision-making of their own submission

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GNSS Constellation Specific Monthly Analysis Summary: September 2026

The analysis performed in this report is solely his work and own opinion.



Narayan Dhital
Actively involved to support international collaboration in GNSS-related activities. He has regularly supported and contributed to different workshops of the International Committee on GNSS (ICG), and the United Nations Office for Outer Space Affairs (UNOOSA). As a professional employee, the author is working as GNSS expert at the Galileo Control Center, DLR GfR mbH, Germany.

Introduction

This article continues the monthly performance analysis of the GNSS/SBAS constellation. Readers are encouraged to refer to previous issues for foundational discussions and earlier results. The focus for this month's issue is the atomic time generation based on filtering and prediction. A sample data from BIPM learning platform is used to demonstrate how clock ensemble produces atomic time that can be the national laboratory time or the GNSS system time. It is solely for educational purposes.

1. Atomic Timescale Generation: Prediction Based Algorithm

In our previous analysis, we explored how a localized atomic timescale (Temps Atomique - TA) or UTC(k) is realized via a classic weighted average of an ensemble of atomic clocks. While weighted averaging can optimize the performance balance between high-short-term-stability Hydrogen Masers and robust-long-term-stability Cesium standards, it is acutely vulnerable to phase steps, clock drift, and data dropouts. If a clock suffers a sudden discontinuity, the unmitigated step maps directly into the averaged timescale, corrupting real-time synchronization networks.

To mitigate these instabilities, modern timing laboratories and GNSS control segments employ prediction-based timescale algorithms. By shifting from instantaneous averaging to forward-predictive models, the ensemble establishes an anomaly-resistant reference. This article details the structural working principles of the prediction algorithm provided by the BIPM E-Learning platform (Timescale Algorithms and their Applications), explains the critical selection criteria for predictive estimation spans, and interprets the performance results derived from the simulation script.

2. Working Principle

Phase 1: Pre-calculation of Inter-Clock Differences. Rather than analyzing clocks in isolation, the concept calculates the differential phase offsets between a designated reference clock (clk_0, where flg == 1) and all other clocks in the ensemble: $\Delta x_i(t) = x_0(t) - x_i(t)$. This eliminates common-mode laboratory noise and establishes a baseline matrix of inter-clock drift.

Phase 2: Frequency Rate Estimation and Forward Prediction. For every designated Modified Julian Date (MJD), it predicts the tomorrow-phase (x_hat) of each clock using historical memory. The frequency rate (slope) is estimated by tracking the clock's behavior over a predefined historical window, termed the rate estimation span (T_span):
Slope = [x(t_-1) - x(t_-(T_span+1))] / [t_-1 - t_-(T_span+1)].
The forward-predicted phase for the next epoch is then calculated linearly:
x_hat(t) = x(t_-1) + Slope * (t - t_-1).

Phase 3: Robust Error Gating and Weighted Realization. Before executing the ensemble average, it performs an outlier rejection check. It evaluates the deviation between a clock's actual measured phase (df_x) and its forward-predicted phase (x_hat) against a strict threshold limit (x_limit): |x_hat(t) - df_x(t)| < x_limit.
• If the clock passes, its preset weight is included in the scale normalization.
• If a clock undergoes a phase jump or data missing anomaly, the algorithm automatically sets its effective weight to 0.0 for that day, isolating the fault.
• The clean, weighted differences are then aggregated to yield the final continuous UTCk-TA scale.

3. Selecting the Rate (Frequency) Estimation

The choice of the rate estimation span (T_span) directly governs the operational focus and noise-filtering capability of the prediction algorithm. Two primary spans are evaluated depending on the metrological or synchronization intent:

• **The 10-Day Prediction Span (T_span = 10):** A short history focus is optimized for systems dominated by high-quality Hydrogen Masers. Masers provide superlative short-term stability but exhibit long-term frequency drift. A tight 10-day estimation window allows the algorithm to rapidly adapt to changing drift profiles, keeping the forward prediction accurate over short horizons. However, this short span is more susceptible to high-frequency measurement noise.

• **The 90-Day Prediction Span (T_span = 90):** A long history focus is designed to capture the structural aging parameters of Cesium frequency standards. Cesium clocks are noisier day-to-day but highly stable over months. Extending the rate span to 90 days effectively smooths out random white phase noise, isolating the true linear deterministic drift of the ensemble. This long horizon acts as a stabilizing flywheel, though it takes longer to recover if baseline clock parameters shift permanently.

4. Results and Interpretation

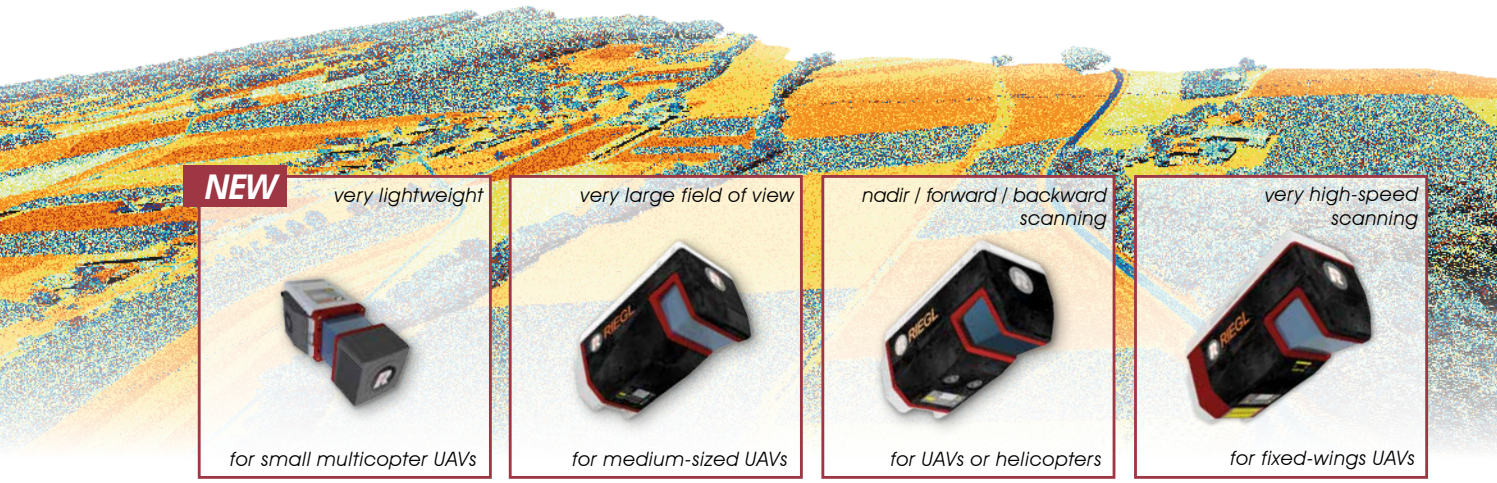
The output of the prediction script is visualized through the time-difference phase evolution plot (left) and the corresponding overlapping Allan Deviation (ADEV) stability profile (right).

Phase Evolution Analysis (Left Plot): The left plot illustrates the phase progression of the individual clocks alongside the generated composite timescale, UTCk-TA (plotted as the thick black line).

• Drift Compensation: Clocks such as clk1 (blue trace running high) and clk6 (red trace diving down) exhibit strong, uncompensated linear frequency

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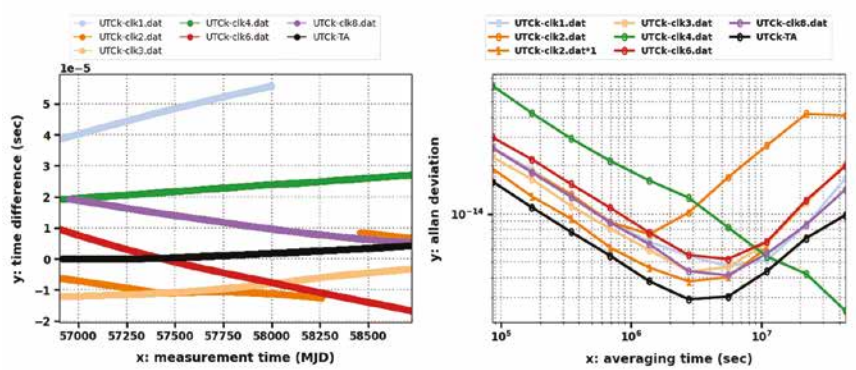


Figure 1: The TA generation based on the time span of 10 days in the prediction.

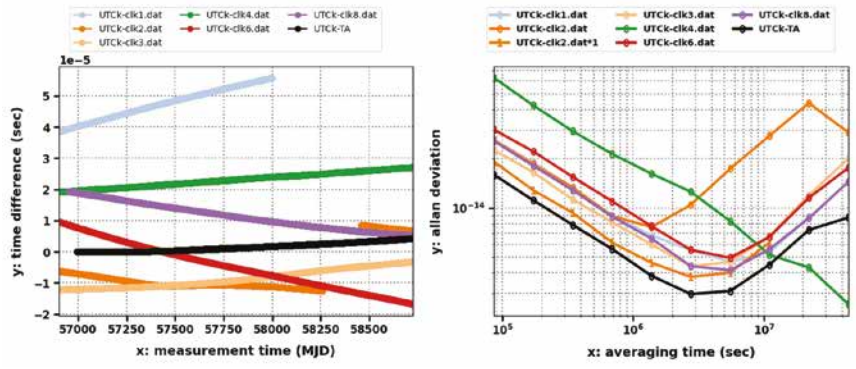


Figure 2: The TA generation based on the time span of 90 days in the prediction.

offsets. Despite these heavy trajectories, the UTCk-TA scale remains robustly bounded near zero, demonstrating that the algorithm successfully forecasts and subtracts these systemic drifts.

• Anomaly Isolation (clk2): A severe discontinuity is visible on the orange trace of clk2 around MJD 58400, followed by a data gap and a subsequent segment labeled UTCk-clk2.dat*1. In a standard averaging scale, this sharp phase drop would drag the entire ensemble down. Because the prediction algorithm recognized that the measured phase breached the x_limit relative to its 10-day history, clk2 was dynamically de-weighted. As a result, the black UTCk-TA line continues smoothly without any visible phase step or jump.

Stability Analysis via Allan Deviation (Right Plot): The right plot characterizes the fractional frequency stability across various averaging times (τ).

• Maser vs. Cesium Structural Signatures: The active clocks exhibit distinct noise slopes. Clocks like clk3 show excellent short-term stability that degrades at longer integration times (τ > 10^6 seconds) due to unsteered drift. Conversely, the classic Cesium-type signatures (clk4) display a continuous downward slope, demonstrating superior long-term performance at large averaging times.
• Ensemble Optimization: The core success of the script is proven by the UTCk-TA stability trace (black line with circles). At short averaging times (τ = 10^5 s), it traces the low-noise floor of the best masers. As integration time increases toward τ = 10^6 s, it drops significantly below the individual Allan deviation curves of the constituent clocks. The predictive steering ensures the timescale inherits the optimal white frequency noise reduction of the combined ensemble while filtering out individual hardware artifacts.

5. Conlcusion

The transition from a pure instantaneous weighted average to a prediction-based timescale algorithm represents a fundamental paradigm shift in high-precision timekeeping and metrology. By coupling historical frequency rate estimation windows—such as 10-day or 100-day observation horizons—with strict statistical error gating, the ensemble framework successfully insulates the generated timescale from real-world hardware vulnerabilities. Rather than permitting a sudden phase step or clock dropout (such as the discontinuity witnessed in `clk2`) to contaminate the reference, the algorithm dynamically de-weights failing components based on deviation boundaries relative to forward predictions. This structural resilience achieves a highly stable composite baseline (`UTCk-TA`) that inherits the optimal short-term performance of Hydrogen Masers and the robust long-term drift profile of Cesium standards.

Crucially, this mathematical «paper clock» does not merely exist as digital database coordinates. In operational timing laboratories and GNSS control stations, the calculated numerical corrections are pushed in real time to a physical hardware control loop. By utilizing an online State-Space Kalman Filter to isolate multi-component noise, a digital controller translates the paper clock's trajectory into precise tuning parameters. These parameters drive hardware microsteppers that continuously adjust the phase of a physical Master Clock, bridging the gap between abstract algorithmic modeling and the generation of a continuous, highly synchronized 1 PPS physical signal. For modern satellite networks, this continuous, steered synchronization underpins global positioning systems, ensuring that local clock replacements or orbital anomalies remain completely invisible to the end-user.

Data sources and Tools:

https://webtai.bipm.org/database/can-vas_gnss.html

Allantools, Python

elearning, BIPM, Timescale Algorithms and their Applications

Software: https://github.com/TheBIPM/Time_scale_course_material

Mainstreaming and Safeguarding Fragile Informal Settlements in Delhi

The recent collapse of buildings in Said-ul- Ajaib village and fires in Hauz Rani, Tughlakabad Extension, Palam and Vivek Vihar raise the question on the safety of buildings in the Capital's urban villages and unauthorised colonies. There is an urgent need for safeguarding and mainstreaming them in to planned development.



Ashok Kumar Jain
Worked as Commissioner (Planning), Delhi Development Authority, and UN Habitat. The author was invited at the World Urban Forum, Baku, Azerbaijan (May 17th to 22nd, 2026) for his work on In-Situ Slum Redevelopment in Delhi, selected for its global inspiration and advancing housing solutions.
ak. jain6@gmail. com

The Master Plan for Delhi 2047 promotes the redevelopment/ regeneration and densification of existing urban areas. The Plan promotes in-situ rehabilitation of slums and JJ clusters, in line with the principle of "Jahan Jhuggi, Wahan Makan", providing safe, dignified and affordable housing along with supporting social and physical infrastructure while enabling residents to remain within their communities. It also provides a comprehensive framework for the planned improvement, regularisation and redevelopment of unauthorised colonies through infrastructure augmentation, enhanced connectivity, improved public amenities and appropriate development norms, thereby integrating these areas into the formal urban fabric and improving the quality of life of their residents.

Master Plan for Delhi -2047

Slums in Delhi are an inseparable part of the national Capital with residents living there decades. An immediate halt to demolition drives in the Capital's slum clusters an unavoidable all future removals will be accompanied by advance rehabilitation.

Delhi Chief Minister, Rekha Gupta (1st August 2025)

Delhi Slum and Rehabilitation Policy (2026) has extended the cutoff date for slum dwellers eligible for rehabilitation by 10 years (January1, 2025).

The Indian Express, June 18th 2026.

Ours is a welfare state and accordingly the right to adequate shelter, if denied to citizens, amount to violation of fundamental rights enshrined in part III of the Constitution of India. It is, therefore, the bounden duty of the government and its agencies to ensure that people who are homeless and seeking medical care are provided shelter.

Delhi High Court Order
Dated 14th January 2026

A fire in Lucknow building left 15 people dead on 22th June 2026. The usual suspects-building code violations and civic neglect are evident. Another factor turning burning building into death trap is the electronic door lock.

Times of India, 24th June 2026

Delhi, the National Capital with a population of 23.078 million (2026), is a symbol of coexistence of planned development and informal growth. About half of its population is living in the slums and informal settlements. Delhi's 5.50 million households live in 2025 planned residential schemes (as

per MCD Property Tax Guide), Old City, 57 pre-Independence Residential Areas, 36 Rehabilitation Colonies, 126 plotted Cooperative Societies and about 900 cooperative Group Housing Societies, 60 odd Site and Services/ Resettlement Schemes, and public/ Government Housing. Another half of its population is living in 675 slums and Jhuggi-jhompri clusters (covering 968 Ha), 367 villages and 1797 unauthorised colonies. These unplanned areas are called informal settlements.

The process of metropolisation of Delhi has been linked to the phenomena of sub-urbanization with an increased differentiation and segmentation of the metropolitan area (Dupont, 1995). The urban limits have advanced upon the fringe of the city, by which some of the villages have been embraced, and few of them obliterated. The 'peri-urban' invasions are the unauthorised extension of village settlements, occurring through land grab or purchase of rural land through the nexus of property agents, local politicians and officials. The level of security of illegal construction corresponds to the strength of the patrons and their proximity to the power structure.

The unauthorised developments are broadly categorized as follows:

- Buildings which violate the building bye laws, such as fire safety, structural safety, height, floor area and ground coverage;
- Land Use and development in contravention of the Development Controls and Sub-division Regulations of the Master Plan, Zonal Plan and layout plan.
- Illegal transfer of agricultural land for urban use;
- Illegal sub-division and disposal of lands.
- Encroachment and appropriation of public, commercial lands, such as roads, railways, parks, public facilities and utilities.
- Violation of other Acts, such as Delhi Land Reforms Act, Stamp DutyAct, Property Registration Acts, etc.

Most of the informal settlements in Delhi have grown on agricultural land, lack municipal services, building plan approval, registration and secure tenure. Infrastructure is often fragile and deficient. Recent surveys indicate a growing trend of 'neo-colonisation' by the 'neo-rich' urban class. The general impression is that punitive action and demolition are faced by the common man, while rich and powerful manage to escape the law. The residents often face congestion, overcrowding, narrow streets fragile structures and deficient infrastructure. Due to lack of formal property rights, they are vulnerable to exclusion and threats of buying out. Institutional barriers stem from weak governance, corruption, lack of enforcement of building byelaws, fire safety regulations and absence of participatory planning framework. Municipal authorities often lack the capacity or political will to engage communities meaningfully, while lack of transparency undermines trust between the residents and state institutions.

Justice Nanavati Commission of Inquiry (JNCI) Report

The Justice Nanavati Commission of Inquiry, constituted by the Central Government on 30 August 2000, submitted its report on 3 September 2005, recommending the regularisation of existing unauthorised colonies and constructions, subject to planning and building regulations, with appropriate relaxations. It proposed excluding areas involving reserved forests, protected monuments or impediments to infrastructure, and commercial plots beyond petty shops of up to 50 sqm. Regularisation charges and penalties should be sufficiently high to discourage unauthorised development. The Commission also emphasised minimising displacement, resettling affected residents within or near their colonies, and using acquired vacant plots for rehabilitation and civic amenities. To ease pressure on Delhi's housing, it further recommended developing satellite towns and relocating government offices and industries not essential to the capital.

CAG Report on Unauthorized Colonies (2013)

The CAG report (2013) points out that Delhi Government had distributed provisional regularization certificates to 895 unauthorised colonies in 2008. However, in only about 70 colonies development work had been carried out. About 580 of these colonies had come up on government land and another 300 came up on private land but have some plots on government land. The report says that the UD department released Rs 3,666.81 crore between 2007 and 2013, of which Rs 3,029.21 crore were spent on regularization, but there was no monitoring of the physical and financial targets. Basic work on roads and drains remains incomplete in 416 colonies out of 895. The report finds that in 91 colonies inspected, DJB failed to supply water in 33. In almost all the colonies RWAs have not submitted ownership documents and the colonies were regularized without scrutiny of records submitted by the RWAs.

Regularisation of Unauthorised Colonies

The Master Plan for Delhi 2047 provides the policy framework for improving and regularising unauthorised colonies. It supports in-situ rehabilitation of slums and JJ clusters, affordable housing and essential services, and the planned redevelopment of unauthorised colonies through better infrastructure, connectivity and public amenities.

With the expansion of Delhi, most urban villages and unauthorised colonies have become an integral part of the urban fabric. Owing to increasing population, changing livelihoods and rising land values, these areas have undergone rapid densification and vertical redevelopment without corresponding augmentation of infrastructure and public spaces. Many urban villages and informal settlements also contain heritage buildings, historic water bodies, temples, mosques, havelis, orchards and other cultural assets that require conservation through area-based regeneration. Their regeneration shall be undertaken

through Area Improvement Plans and Road Network Plan (RNP) with all roads to a minimum ROW of 7.5m.

The Master Plan of Delhi (MPD 2047) allows the amalgamation of fragmented plots to a combined area of 2000 sqm on a minimum street width of 7.5 m. Additional floor area ratio (FAR) may incentivise the owners of fragmented plots to form a cooperative for a composite redevelopment of illegal/unauthorised colonies into group housing, with proper roads, parks, parking spaces and safer structures. MPD 2047 provides an FAR of 500 with 50% of FAR for market sale to make redevelopment of slums self-financing and viable for private sector participation.

According to the Gazette Notification dated 29th October 2019, 1,797 unauthorised colonies were listed for regularisation and for grant of ownership rights. Subsequently, vide Gazette notification dated 6th April 2026, *"The National Territory of Delhi (Recognition of Property Rights of Residents of Unauthorised Colonies) Regulations, 2026, the work of the regularisation of*

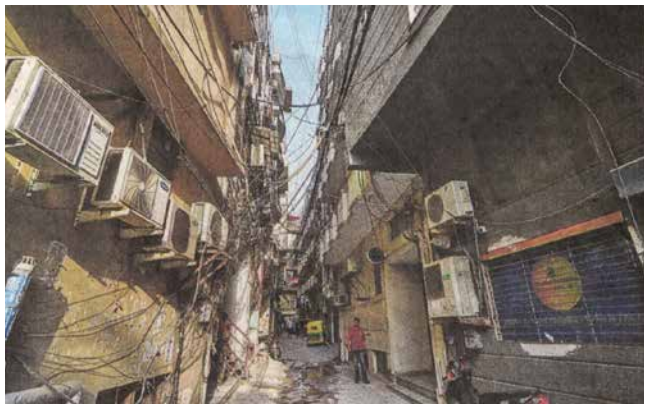


Fig. 1: Densely built-up, narrow lanes and hanging overhead cables in urban village Hauz Rani
Source: Hindustan Times, 16th June 2026

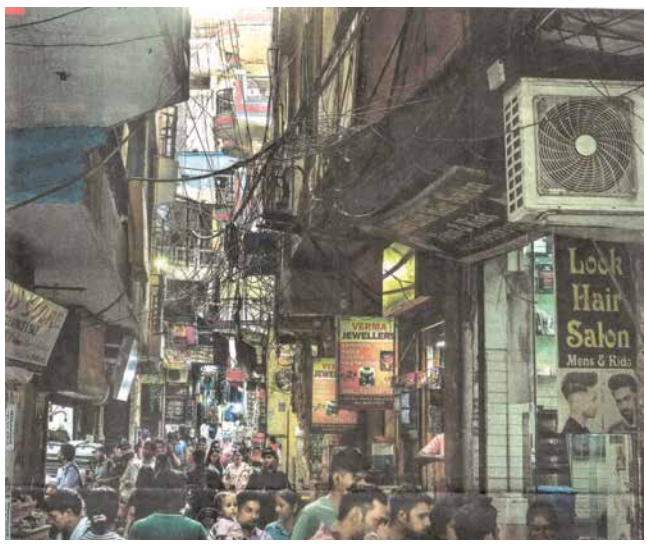


Fig. 2: Katwaria Sarai Urban Village
Source: HT, 15th June 2026

UN-Habitat's Slum Indicators

The UN-HABITAT has defined a slum household which lacks any one of the following five elements:

Access to improved water: access to sufficient amount of water for family use, at an affordable price, available to household members without being subject to extreme effort;

Access to improved sanitation: access to an excreta disposal system, either in the form of a private toilet or a public toilet shared with a reasonable number of people;

Security of tenure: evidence of documentation to prove secure tenure status or defacto or perceived protection from evictions;

Durability of housing: permanent and safe structure in non-hazardous location; and

Sufficient living area: not more than two people sharing the same room.

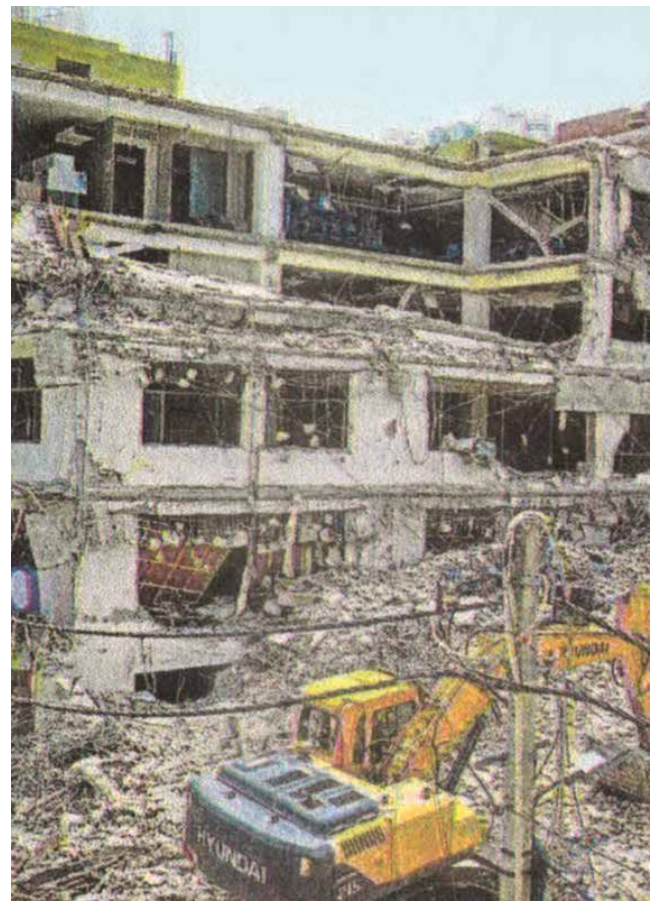


Fig. 3: Illegal construction in Said-ul-Ajaib urban village
Source: Hindustan Times, 9th June 2026

property rights in unauthorised colonies is transferred from DDA to the Government of National Capital Territory of Delhi. Every unauthorised colony specified in the notification issued under sub-regulation (1) shall be regularised on as is where is basis and the absence of an approved or notified layout plan of such unauthorised colony, or any part , or cluster thereof, shall not be a bar to consider them for regularisation."

Under the NCT of Delhi (Recognition of Property Rights of Residents in Unauthorised Colonies) Amendment Regulations, 2026, 1,511 unauthorised colonies are being given legal sanctity on 'as- is where is' basis, and the residents are not required to submit layout plan of the area to get their property registered. This may run counter to mainstream the informal settlements into planning framework of Master Plan for Delhi- 2047, Building Byelaws, Delhi Fire Service Act, besides DD Act, National Disaster Management Act 2005 and DMC Act, 1957.

Building Safety in Informal Settlements

Earlier in 1963, the village abadi (Lal Dora) was exempted from building permission, except the factories, warehouses, slaughter- houses, etc. This was later made applicable to the extended Lal Dora areas. This has led to massive, unplanned development. The peripheral areas of the villages have rapidly been built upon with illegal multi-storied buildings mainly for speculative gains. Although, after Delhi High Court Order (2003), the exemption of villages from Building Byelaws was withdrawn, in practice construction continues with blatant violation of land use and Building Byelaws.

The studies indicate that the villages cum unauthorised colonies like Zamrudpur, Mohammadpur, Shahpur Jat, Kotla Mubarakpur, Hauz Rani, Hauz Khas, Jia Sarai, Kalu Sarai, Katwaria Sarai, Yusaf Sarai, Lado Sarai, Said-ul -Ajaib, Khirki, Ashok Nagar, etc. during last 30 years have grown from 300-600 buildings to 10,000 to 15,000 buildings having up to seven floors. These have overstressed services and civic amenities to a breaking point (Fig. 1 to 6). The illegal constructions have posed danger to the lives of the inhabitants with frequent incidences of fire and structural failures, since as Delhi falls in Seismic Zone IV, where earthquakes may be severe.

According to Delhi Government there were 543 deaths due to fire incidents between 2019 and 2026 with 66 deaths in 2026 alone.

Ensuring safety is a fundamental imperative and the safety of the people is a basic human right. The city should not have any unsafe building irrespective of type of development, land ownership or land use. Every building without a structural and fire safety certificate should be sealed and a warning board should be put that building can not be occupied for use. The Master Plan for Delhi-2021 (MPD 2021) and Delhi High Court already stipulate that all buildings, especially in unauthorized colonies, villages and traditional areas should be structurally and fire safe. For access in emergency, building collapse or fire, sufficient road width should be available, clear of parking and encroachments to ensure access of emergency vehicles.

According to the MCD order dated 9th December 2011, the building plans in unauthorised colonies and village abadi shall be submitted with an affidavit by the owner/applicant along with required undertakings for compliance of building byelaws. For ensuring safety of structures, there is a need of regular monitoring, to check, retrofit and rebuild the non-engineered buildings.

As Delhi falls in Seismic Zone IV, it may be catastrophic overlooking building safety codes. In its action taken report before the Delhi High Court (September 2026) MCD said that it has identified 4762 high-risk structures. Notices were issued to 4571 of them, but structural audit reports were received in only 1155 cases. Demolition were carried out in 56 cases and retrofitting in 47.

It is also necessary to rescind impugned 1963 Notification of Delhi Administration exempting residential construction within Laldora of villages from Building Byelaws. Another Act that needs to be repealed is the NCTD Laws (Special Provisions) Second Amendment Act, 2023 which provides legal shield for protection of unauthorised buildings built up to June 2014. Initially it was meant for one year, it has been extended for over 20 years since 2006. This has created a legal loophole, since it is difficult to ascertain the age of the structure.

It is time to ponder upon whether the regulatory function of buildings can be independent of the political apparatus and is demunicipalised. It is necessary to devise a method of taking suo-motto cognisance of the massive illegal/ risky constructions taking place without submission and approval of building plans. Can it be possible to constitute an interdisciplinary and interdepartmental Delhi Building Regulatory Authority with members from the judiciary and experts in planning, digital/ GIS, urban design, architecture, engineering/structures and disaster management (fire and other risks). It should deploy new technologies, such as artificial intelligence, drone surveillance, Geospatial AI, high resolution satellite imagery digital twins, data-driven Real-Time Morphological Tracking and LiDAR, which. can remotely monitor and detect unauthorised constructions with least human interface, thus reducing corruption and pressures.

Delhi Disaster Management Plan

Under Section 31 of the Disaster Management Act, 2005, the GNCTD has formulated the District Disaster Management Plan (DDDMP), focusing on mitigation, preparedness, response and recovery. Its priorities include integrating disaster mitigation with development plans, strengthening communication and institutional mechanisms, using modern information technology, promoting insurance and public awareness, and involving the private sector. However, implementation is hindered by the

A Chronology of Planning, Housing and Informal Settlement in Delhi

1947	Independent India, five lakh refugees came to Delhi
1948-51	East Punjab Consolidation and Prevention of Fragmentation Act extended to Delhi
1951-57	36 Rehabilitation Colonies developed for refugees by the Ministry of Rehabilitation, besides other private colonies
1954	Delhi Land Reforms Act
1955	Delhi Improvement Trust superseded by Delhi Development (Provisional) Authority
1956	Slum Areas (Improvement and Clearance) Act
1957	Delhi Municipal Corporation formed under DMC Act, and Delhi Development Authority under DD Act
1957	Report of DIT Enquiry (Birla) Committee
1961	Large Scale Land Acquisition, Development and Disposal Policy
	Delhi Master Plan (1962-81)
1963	Delhi Administration Notification exempting residential construction within Lal Dora of Villages from BBL
1967-68	DDA assigned role of housing development
1973	DUAC Act
1975	Emergency, massive slum clearance relocation, and Resettlement
1978	Public Accounts Committee / Expert Committee on DDA, Baveja Committee
1985	NCR Planning Board Act
1986	Environment Protection Act
	73rd and 74th Constitutional Amendment Acts
2003	Ajit Patnaik (FM DDA) Committee on Rationalisation of Housing Cost
2004	MOUD, (Madhukar Gupta) Committee on Making Delhi Slum Free
2005	Justice Nanavati Commission of Enquiry on unauthorised Colonies/Construction in Delhi
2005-06	High Court/Supreme Court orders for Unauthorised Colonies/Villages
	Tejinder Khanna Committee on Unauthorised Construction and Misuse
	P.P. Shrivastava Committee on Delhi's Villages
	K.K. Mathur Committee on Unauthorised Colonies and Farmhouses
	Jannak Juneja Committee on Sainik Farm (GNCTD)
2007	MPD-2021 notified, Land Pooling Policy Initiated\]
2007	Delhi Fire Service Act (2007) and Delhi Fire Service Rules (2010)
2007	Administrative Staff College, Hyderabad-Restructuring & Reorganisation of DDA
2010	Areas of Reform in DDA, Centre for Good Governance, Hyderabad
	Delhi Geo-Spatial Data Infrastructure Act, 2011
2011	Building Regulations for Special Area, Unauthorised Colonies and Village
2013	Right to Fair Compensation and Transparency in Land Acquisition, Rehabilitation & Resettlement Act
2014	Street Vendors Act
2015	Madhukar Gupta Committee on DD Act constituted by the MOUD
2015	Pradhan Mantri Awas Yojana launched
2015	NCAER- Study on Affordable Housing, Safer India
	Unified Building Byelaws
2016	Real Estate (Regulation and Development) Act
2017	Delhi Village Development Board (DVDB) formed under GNCTD. 174 Village notified as urban under section 507A of DMC Act, 1957
2018	Land Pooling Policy and Regulations Notified
2018	NCTD (Recognition of Property Rights in Unauthorised Colonies) Regulation
2020	NCAER Land Records and Services Report
2023	Draft Master Plan for Delhi 2041
2023	Delhi Online Registration of Information System (DORIS) for Digitised Land and Property Records
2023	National Capital Territory of Delhi Laws (Special Provisions) Second Amendment Act 2023 (for protection of unauthorised Buildings till December 2026)
2026	DDA Gazette Notification (6th April) -NCTD Recognising Property Rights of Residents of Unauthorised Colonies (Amendment) Regulations, 2026
2026 (June)	Delhi Slums and JJ clusters R & R Policy

Source: Author

lack of updated geospatial building data and disorganised, inaccessible records maintained by Urban Local Bodies (ULBs). These records need to be systematically organised using new technologies to assess earthquake, fire, structural and other risks. Since loss of life and property often results not from natural hazards themselves but from unsafe buildings and construction, integrating spatial and non-spatial data to prepare a comprehensive District Hazard Risk Map is essential for effective disaster planning (Table 1 and Fig. 3).

GIS Based Digital Twins

Recognising the immense capabilities of digital twins, the Government of India is investing in digital infrastructure by combining the prowess of 5G, IoT, AI, AR/VR, 6G, Digital Twins and next-gen computational technologies. GIS based digital twins incorporating temporal dimensions, enables users to track changes over time, facilitating better decision making and planning by integrating real-time data, predictive analytics and comprehensive understanding of dynamic environment and disaster risks.

Table 1: New Technologies for Earthquake/Disaster Risk Reduction

Phase	Activities	Example Technology
Mitigation	Geospatial data of built environment and GIS based digital twins Baseline information of natural ecosystem Land use planning and risk management Community engagement	• Remote sensing for documentation of all the buildings, location, age, plans, category and land use • Computer modelling of risks and vulnerability • Drone supported surveys • Satellite and GIS to map natural ecosystems • Model and land use changes • Real Time warning systems using mobile phone • Mobile apps for local communication • Information campaign via digital media
Preparedness	Meteorological observation Spatial Mapping Early warning Systems Stockpiling Identifying vulnerable buildings and infrastructure	• IoT connected and AI enabled monitoring • Satellite based technologies to gather geospatial and meteorological data • Digital mapping, GIS, Open Street Maps, hazard maps • Real Time monitoring of risks • AI enabled cross checking of data • Mobile based warning apps • Digital communication systems to inform people • AI enabled forecasting, digital accounting, and monitoring tools • Digital inventory of stockpiles • Geospatial surveys using software such as Open Data Kits
Response	Emergency services such as search and rescue evacuation Provision of shelters and basic needs Surveillance Communication	• Drones for aerial surveillance • Social media monitoring • Geospatial maps • Apps to inform people about shelter facilities • Communication infrastructure • GIS mapping and aerial surveillance • Broadcasting emergency messages on mobile phones • Social media platforms
Recovery	Livelihood support Establishment and rehabilitation of basic services Reconstruction Planning	• Cash transfers via electronic/digital tools • Real-time updates on the restoration of services • Digital tools to coordinate processes, construction and operations. • Digital surveys, mapping and monitoring using drones

Source: Author

Data registries enable the planners to have access to common sets of data as a shared resource to improve collaboration and decision making. The strength of the micro-service-based stack approach is that each new program creates reusable services, increasing the speed of delivery.

The Bureau of Indian Standards (BIS), IIT (Kanpur), CBRI, BMPTC, NDMA, NIDM, etc. have evolved useful guidelines to safeguard the buildings from disasters, damages and earthquakes. The seismic damage in buildings has been categorised as given in Table 2 with empirical measures for each of them.

Integrated Command and Control Centre (ICCC)

An Integrated Command and Control Centre (ICCC) has been established in Delhi (August 2026). It coordinates multiple municipal functions such as water supply, solid waste management, property tax, environment and security, monitoring services, transportation, weather, crimes and disasters. The focus of ICCC is not the safety of individual building, but of the people and neighbourhoods. On September 21, 2026 during dark hours a 17-year-old woman was raped inside 142-acre Ashtha Kunj Park. This is not only isolated incident, but women everyday travel precariously often on foot or by bus and after dark commonly described as trip chaining. Their safety and security needs more than gender safety audits for parks, transit corridors, neighbourhoods or housing areas. This requires provision of CCTV, last mile connectivity, public toilets and inclusive spaces. It is not about policing. Unsafe infrastructure cannot be made safer by more patrolling but by better lighting, vibrant and safer spaces, and a result oriented ICCC.

ABCDE of Safe Construction

The basic principle of safe construction can be summed up as ABCDE -
A – Anchorage
B – Bracing
C – Connections
D – Detailing
E – External Environment

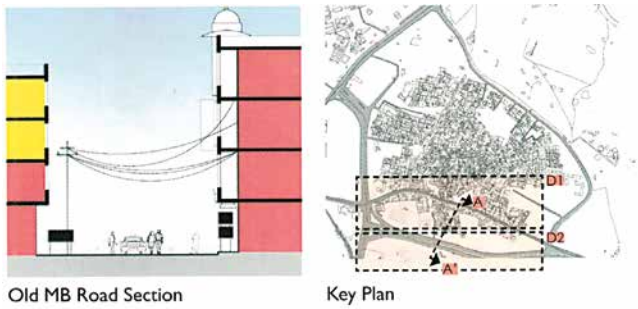


Fig. 4: Urban Village (Lado Sarai) is heavily built-up with 4 to 6 storied buildings unmindful of the street width, fire and structural safety
Source: DUAC/M.N. Ashish Ganju (2015), Lado Sarai, New Delhi

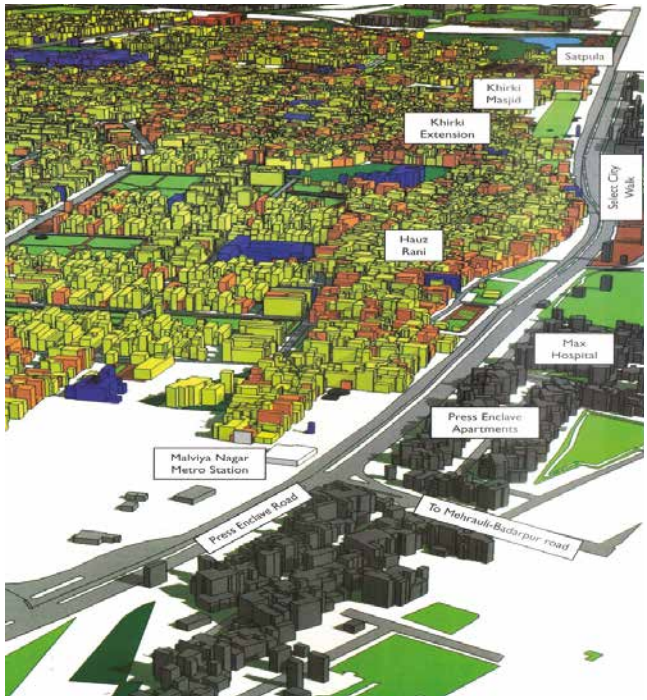


Fig.5: Malviya Nagar, Hauz Rani and Khirki Extension, New Delhi
Source : DUAC/Ashok B. Lal (2015)



Fig. 6: Hauz Rani Urban morphology
Source : DUAC/Ashok B. Lal (2015)

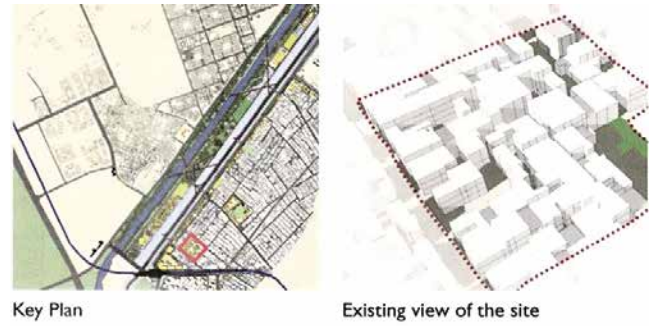




Fig.7: Proposed housing development, New Ashok Nagar unauthorised colony
Source DUAC/Divya Kush (2014) New Ashok Nagar, New Delhi



Fig.8: Proposed main road with space for street vendors, hawkers and pedestrians
Source DUAC/Divya Kush (2014) New Ashok Nagar, New Delhi

Usually, in old buildings due to dampness, the steel may get corroded, and concrete may lose strength because of ageing, fires, structural failure, overloading, vibrations and earthquakes. As such, it is necessary that structural audit is undertaken for the structures older than 50 years. For repair of concrete pillars, beams, slabs, balconies, chajjas, staircases, etc., whenever necessary, reinforcement steel may be replaced,

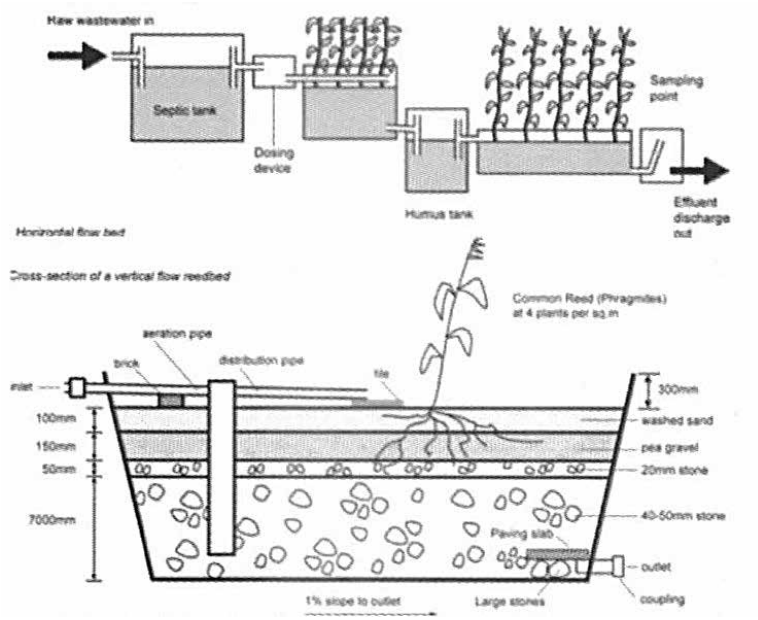


Fig. 9: Reed Beds along Barapulla Nalah, Chirag Delhi
Source: Centre for Alternative Technology Publications, www.cat.org.uk

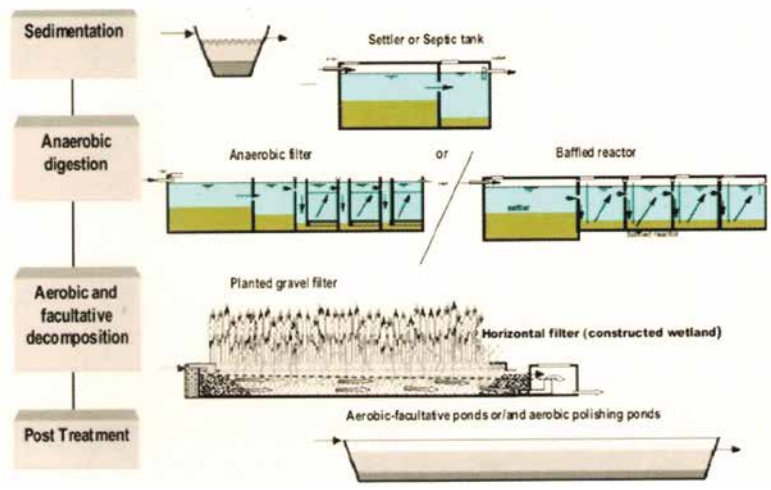


Fig. 10: DEWAT (decentralised wastewater treatment system for Unauthorised Colonies
Source DUAC/Divya Kush (2014) New Ashok Nagar, New Delhi

along with strengthening of the joints, supports, walls, pillars, etc. To protect buildings from earthquake effects, Base Isolation Devices and Seismic Dampers can be adopted to detach (isolate) the building from the ground. These act as the shock absorbers and prevent building damage from an earthquake.

Informal Settlements as a Resource

The informal settlements require a conceptual foundation that bridges incrementalism, inclusivity, participation, design and vernacular resilience. The informal growth needs to be seen not as a deficit, but as a resource. John Turner (1976) argued that multilateral and inclusive housing should be understood as a process, rather than a product, with residents shaping their environments. N Hamdi (2004) highlighted the effectiveness of small scale, community-based interventions in a fragile context, while N.J Habraken (1972) proposed structural and design supports that allow residents to adapt changes over time. Arnstein's (1969) Ladder of Participation emphasises the importance of genuine power sharing in planning process as demonstrated in his Orangi Pilot Project.

The World Urban Forum (WUF) at Baku, Azerbaijan (May 2026)

The WUF under the theme 'Housing the World: Safe and Resilient Cities and Communities, underscored that residents of informal settlements are not passive beneficiaries but active producers of housing, investing labour, resources and social organisations. Reiterating John F.C. Turner, the forum stressed that people are often the best judges of their own housing needs and they can produce housing solutions better suited to their circumstances than standardised, top-down provision. This needs a shift from criminalising people-led housing process towards creating enabling policies that provide secure tenure, basic services, infrastructure, technical support, and access to land and finances. The WUF underlined that that housing shapes not only where people live but also how they access opportunities, experience safety, maintain health and build families and communities. The commodification of housing production has deepened the housing crisis. About 80% of housing is self-produced, yet it is treated as illegal, marginalised and informal. As a result, the social function of housing seems largely broken, considering the millions living in insecure, undignified and inadequate conditions.

It underlines that housing is not simply an outcome of urban development, but as a foundational pillar of inclusive, resilient and just cities. The five basic principles of housing justice are availability, accessibility, affordability, acceptability and adaptability. The WUF reminded that inadequate housing is not about delivery, but about support, processes, power and justice. The supports-based model comprises several options, such as In-situ Upgrading, Supports-Infill, Incremental Reconstruction, Relocation, Land Sharing and Reblocking. This necessitates the changing the perceptions of urban planning and unplanned growth. This may need starting from the bottom with more participatory and enabling approaches, together with alternative, net zero buildings and services, viz. power supply, transport, water supply, disposal of wastes.

The DUAC has demonstrated alternative approach in its proposals for Malviya Nagar/ Hauz Rani, Lado Sarai, Chirag Delhi, Mohammadpur, Aya Nagar and New Ashok Nagar (2014-15). These encompass a more comprehensive design approach, considering urban mobility and decentralised services, integrating environmental sustainability and provision of health, security and community facilities (Fig. 7 to10).

Ownership/Tenure Rights

A central issue is the ownership rights in slums and illegal colonies. Conventional top-down strategies often reproduce the barriers they aim to resolve. Instead, there is a need to adopt a bottom-up human cantered approach and participatory solutions. The first step in this endeavour is the establishment of secure tenure. Clear ownership of property is essential for safer construction and approval of building plan, safeguarding residents' rights as mandated vide NCT of Delhi (Recognition of Property Rights of Residents in Unauthorised Colonies) Regulations, 2026.

Secure land tenure is the foundation of development of slums and unauthorised colonies. The communities can negotiate their own tenure arrangements through strategies such as cooperative land purchase, long-term lease contracts, land-swapping or user rights. The emphasis is on obtaining collective, rather than individual land tenure. As such, the government should encourage formation of cooperative housing societies, especially of about 20-30 persons rather than insisting on 60 or more members. Government should devise a mechanism whereby up-to-date records of land and houses in the NCTD are maintained.

Once ownership has been regularised, the Area Improvement Plans and Road Network Plans are developed for provision of essential facilities and infrastructure networks, such as water, electricity, sanitation and transportation. This enables the inhabitants to build in accordance with planning and building regulations, making a transition from informality to structured, state -supported development. The provision of greens and public spaces enhances the urban environment, reduces excessive density, improves ventilation and promotes social diversity.

Aligning Informal Settlements with Viksit Bharat

According to the Niti Aayog, in view of India's fast-growing economy/GDP, per capita residential space in India should increase from the present 5.9 m2 to 35 sqm in 2047. This means a quantum leap in housing standards and its quality. The housing needs to be more inclusive enhancing the relationship between the city and women, children, homeless, destitute and the poor. These needs mandatory reservations for social, rental housing, public facilities and services. It should be carefully considered that whether increasing the Floor Area Ratio (FAR) and density could be counter-productive by making multi-storied apartments as a commodity. Whether such housing would be accessible to the poor and meet the aim of poverty reduction, gender equity and security? Another pertinent factor to be considered in housing is making it net zero with sustainable building materials and self-sufficient in water and energy.

Incremental and participatory reconstruction is cost-effective, adaptable and rapid. It preserves social cohesion and cultural identity, builds trust between citizens and institutions, and aligns with inclusivity and sustainability. It is not only about housing, but building dignity, memory and identity within the urban fabric. Mainstreaming and safeguarding the informal settlements in Delhi can be crucial resources in providing affordable housing for all..

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How do forests recover after logging?

U.S. Department of Energy grant supports UMaine study of forest recovery after timber harvesting led by Daniel Hayes, professor of geospatial analysis and remote sensing. University of Maine researchers will study what happens after a timber harvest — and how the forest grows back.

The findings could help forest managers better understand how harvesting affects the trees left behind and the next generation of growth. The research focuses on partial harvesting, a common practice in northern U.S. commercial forests that removes some trees while leaving others standing.

Led by Daniel Hayes, UMaine professor of geospatial analysis and remote sensing, the team will study a section of Howland Research Forest in central Maine that was harvested in August 2025. Researchers will compare it with a nearby area that was not harvested to see how logging changes the forest's growth and recovery. *umaine.edu*

Mapbox announces location infrastructure for AI

Mapbox has introduced a new set of services and capabilities designed to give AI applications, agents and developer tools a more accurate understanding of the physical world. The location infrastructure enables AI applications and agents to understand locations, proximity, routes, and changing real-world conditions so they can provide more relevant answers and take more useful actions. *www.mapbox.com*

GAO report on precision navigation systems

The following is the Oct. 7, 2026, Government Accountability Office report, Precision Navigation Systems: Challenges Remain with Fielding New Capabilities.The US Department of Defense (DoD) relies on GPS for military operations. But it's vulnerable to interference and jamming. DoD's decades-long efforts to strengthen GPS are behind schedule and over budget. DoD has explored ways to get navigation data to the battlefield if GPS service is disrupted. For example, it's developing navigation receivers that use non-GPS satellites, as well as automated observations of the sun, moon, and stars. But these efforts vary in scale and are currently fragmented across the military services. Better coordination could help DOD's efforts stay on track and within budget.

Our recommendations address this.

DoD's efforts to modernize GPS continue to face delays. In response, it is developing new complementary sources of positioning, navigation, and timing (PNT) data to mitigate GPS threats. In 2026, after years of delays, DOD canceled the Next Generation Operational Control System ground control system and began modernizing the existing GPS Operational Control Segment. Among other effects, this creates risks for the launch, checkout, and operation of new GPS satellites. Given ongoing threats to GPS, DOD is operating and continuing development of (1) satellite-based PNT systems, (2) non-satellite-based PNT systems, and (3) backup timing solutions.

The Air Force continues to make progress developing modernized GPS military code (M-code) receiver cards, but challenges remain with fielding and integration. For example, the M-code aviation receiver programs continue to encounter development and integration challenges. In response, the Navy is developing an interim solution for its aircraft to use M-code. On the other hand, the Army and Navy are fielding M-code capable and multi-PNT receivers in ground vehicles, ships, and Army aircraft. All the military services are also pursuing integration of complementary PNT data into multi-PNT receivers.

Challenges with aligning multiple, fragmented PNT efforts across the military services impact DOD's ability to ensure that M-code and PNT efforts are completed promptly. Congress mandated a PNT Oversight Council to oversee the portfolio. While the council can make budget-related recommendations to the services, the services are responsible for their own budgets. The PNT enterprise could benefit from consolidating and aligning efforts among the services. DOD has taken some steps to consolidate multiple PNT efforts, such as combining aircraft PNT receivers and M-code receiver card efforts into a single Air Force managed joint program office. Benefits of consolidation could include synchronization of schedules and better strategic alignment of funding.

The U.S. military and civilians depend daily on accurate PNT data provided by GPS operated by the Space Force on behalf of DOD. DOD has worked for decades to modernize its GPS, including the use of a new signal—called M-code—and other features to counter evolving threats. Challenges have delayed these efforts. The military services have also started developing and fielding complementary PNT systems to ensure the availability of this foundational military capability.

Congress included a provision in law for GAO to report on DOD's GPS modernization efforts and development and fielding of complementary PNT efforts. This report (1) addresses the progress DOD has made in modernizing GPS and providing complementary PNT data to the warfighter; (2) discusses the status of DOD efforts to develop and field modernized PNT receivers; and (3) assesses the extent to which DOD has taken steps to oversee the PNT portfolio, and what challenges it is facing. To conduct this work, GAO reviewed documentation from GPS modernization and complementary PNT programs and efforts and interviewed relevant officials from DOD and the military departments.

GAO is making three recommendations for DOD to ensure that each of the three military departments assesses where consolidation of its GPS modernization and complementary PNT efforts would ensure better strategic alignment between DOD and the military departments and develop plans to consolidate efforts. DOD concurred with GAO's recommendations. *news.usni.org*

ML uses residuals to improve GNSS ambiguity resolution

Researchers from the School of Geodesy and Geomatics at Wuhan University, the Chinese Antarctic Center of Surveying and Mapping, the University of Electronic Science and Technology of China and Baidu Online Network Technology published a study on 30 September 2026 in Satellite Navigation. The paper presents a residual-based machine learning (ML) validator for GNSS ambiguity resolution in challenging environments. It combines residual-based features with a compact Multilayer Perceptron to decide whether a fixed integer ambiguity solution should be accepted.

The validator extracts three key residual-based features: Ambiguity Difference Root Mean Square (ADR), Phase Residuals Root Mean Square (PRR), and Phase Consistency Root Mean Square (PCR). PRR measures post-fit carrier-phase residuals, while PCR checks consistency between frequencies after ambiguities are fixed. In feature-importance tests, PRR and PCR were the most influential, with stronger correlations to wrong/correct labels than conventional indicators. The classifier is a single-hidden-layer MLP with only 16 hidden neurons, a model size of about 2.8 KiB, and an inference time of 28 ms for more than 350,000 samples. On a 260-hour UGV dataset from Suzhou and a 240-km car dataset from Wuhan, it achieved accuracy and precision above 90%. In UGV tests, the average correct fixing rate reached 85.21%, versus 77.26% for FFRT, while the wrong fixing rate fell to 1.42% from 16.37%. In the CAR-S5 urban scenario, the correct fixing rate was 85.15%, an improvement of 10.55% over FFRT, with a wrong fixing rate of 0.92%. In addition, the proposed method requires an average of only 1.244 ms per epoch for ambiguity resolution, compared with more than 5 ms for the other methods. On the public SmartPNT-POS dataset, it reached a 72.40% correct fixing rate and a 4.50% wrong fixing rate, outperforming POSM and FlexRTK.

The authors said the key advance is not simply adding ML, but giving it residual-based evidence that remains informative when conventional statistical assumptions break down. They said the most influential features were PRR and PCR, which directly test whether the fixed ambiguities are consistent with the carrier-phase observations. They said the compact MLP was chosen deliberately, because real-time GNSS users need low latency and small memory footprints. They added that the method reduces both missed and wrong fixes, although performance may still degrade under extremely weak observation models or severely biased float solutions. *www.eurekalert.org*

Joining Forces for the Future of Geodesy

Ukrainian and Polish specialists in geodesy, cadastre, photogrammetry and land management are turning years of professional contacts into systematic cooperation, with joint research, academic visits, an international webinar, publications and student exchange among the planned activities. Against this backdrop, on 9 October 2026, the first joint online meeting was held between the Department of Geodesy and Cartography at NUBiP of Ukraine and the Department of Agricultural Geodesy, Cadastre and Photogrammetry at the University of Agriculture in Krakow (URK). The meeting marked an important step from long-standing professional contacts towards a structured, long-term partnership between the two departments. *nubip.edu.ua*

Iran expands GPS network

Iran's National Cartographic Center (NCC) is strengthening its cooperation with the Iranian Space Agency (ISA) to improve the country's spatial data infrastructure. Under a joint MoU, cartography and remote-sensing specialists are processing imagery from the Khayyam satellite, aligning it with existing spatial coordinates and adjusting image resolution to meet national standards. The cooperation aims to combine satellite imagery with spatial information obtained from gravimetry. Khayyam provides nationwide coverage and its imagery is processed at different scales, including 1:25,000 and 1:2,000.

Regarding natural hazards such as land subsidence, satellite imagery must be supplemented by specialized processing and real-time measurements from GPS and gravimetry networks to provide accurate assessments. Hundreds of GPS stations currently monitor ground movements across Iran, transmitting real-time data to the NCC's central system. The data are analyzed to track crustal movements and produce comprehensive land-subsidence atlases for cities and metropolitan areas.

To strengthen this monitoring network, the center procured 24 additional GPS devices over the past month. The equipment is expected to support the establishment of 24 new monitoring stations in the near future. The Khayyam remote-sensing satellite was launched on August 9, 2022. It was designed to provide high-resolution imagery for updating spatial data, supporting land-use planning and monitoring environmental and territorial changes across Iran. *ana.ir*

M100 Avionics Hardware by Skyband Systems

Skyband Systems Inc. has announced that the M100, the world's first avionics unit to combine Iridium positioning, navigation, and timing (PNT) with inertial sensing, has entered production. The M100 alerts flight crews in real time to GPS spoofing and jamming and provides position and timing using Iridium's low-Earth orbit (LEO) satellite network. *skybandsystems.com*

NorthStandard partners with PntGuard

NorthStandard has entered into a partnership with SGM Technology to offer its Members the innovative PntGuard™ platform for authenticating ship position signals in real time on preferential terms, to help them overcome incidents of GNSS jamming and spoofing. *http://north-standard.com*

New drone technology locates Aboriginal heritage

Researchers from the Vere Gordon Childe Centre at the University of Sydney and the Australian Museum have identified three previously unregistered Aboriginal rock shelters in the Blue Mountains using drone-based LiDAR technology. Working alongside the Dharug Custodian Aboriginal Corporation (DCAC), researchers used drones to scan the Blue Mountains from the air, identifying potential rock shelters that would have been difficult and time-consuming to find on foot.

LiDAR uses laser pulses to create detailed 3D maps of the landscape, helping researchers detect features hidden beneath dense bushland and tree cover. The newly recorded shelters contain visually striking rock art, including red hand stencils, as well as stone artefacts.The team says the approach could help Aboriginal communities, archaeologists and heritage managers locate and protect cultural sites more efficiently across Australia. The research is published in the journal Remote Sensing. *www.sydney.edu.au*

Researchers map aquifer from the surface

Groundwater in many areas of the U.S. and across the globe is being depleted as pumping for drinking water and agriculture outpace nature's ability to refill aquifers. In a recent study published in Geophysical Research Letters, researchers at The University of Texas at Austin used remote sensing data and statistical methods to map a municipal aquifer in Nevada. Their goal was to create a cost-effective method of mapping an aquifer by using surface measurements to determine its permeability, or how easily water flows through rock.

When water is pumped out of an aquifer it changes the pressure underground, which can cause the ground overlaying an aquifer to sink subtly, a few millimeters to a few centimeters over months. The study's lead author Amal Alghamdi, said that this sinking reflects information about the subsurface geology of the aquifer.

Ground subsidence, or sinking, can be measured in different ways. In the study, the researchers used publicly available InSAR satellite data and a statistical method based on a Bayesian inference algorithm developed by co-author Professor Omar Ghattas' research group at the Oden Institute. They used the information to create a 3D model of how water is likely to flow and spread laterally in the aquifer. By using freely available satellite observations, they mapped a range of possible permeability fields.

The Jackson School research builds on a study conducted by a different research group that calculated the overall hydraulic conductivity of the same Nevada aquifer using subsidence data from GPS monitors. While that research offered a single overall reading of the aquifer's hydraulic conductivity, a measure that's related to permeability, the spatial variations in the Jackson School's maps provide a more detailed view of how permeability changes in different places across the aquifer. *www.jsg.utexas.edu*

South Korea launches Nuri rocket

South Korea just launched its first orbital mission of the year.

The milestone came on Oct. 6, when the homegrown Nuri rocket lifted off from the nation's Naro Space Center, carrying 15 satellites skyward.

Liftoff occurred at 11:25 p.m. EDT (0325 GMT and 12:25 p.m. local time on Oct. 7). Almost everything went well: All but one of the payloads was successfully delivered to low Earth orbit as planned, according to the state-run Korea Aerospace Research Institute (KARI).

Five of those payloads are microsatellites for South Korea's nascent New-space Earth Observation Satellite Constellation for National Safety (NEONSAT) network. *www.space.com*

Ground Control has launched RockBLOCK APNT

Ground Control has launched RockBLOCK APNT, a compact positioning and timing board that gives UAV, USV and autonomous-system manufacturers an independent source of position and precise timing from Iridium PNT. When GNSS is jammed or spoofed, a vehicle relying on it alone has no independent way to tell that its position is wrong, and no second source to fall back on.

RockBLOCK APNT gives developers and OEMs direct access to Iridium PNT, providing a source of position and precise UTC-referenced timing that can be used alongside GNSS and other navigation inputs. *www.groundcontrol.com*

RIT receives NASA support for RS experiments

NASA has awarded Rochester Institute of Technology's Digital Imaging and Remote Sensing Laboratory (DIRS) a three-year grant to lead a remote sensing field campaign and share the resulting data with researchers, educators, and the public.

The award, which comes from NASA's Commercial Satellite Data Acquisition (CSDA) Program, follows the success of ROCX 2025, a community-driven field campaign that drew 75 participants from 24 organizations across six countries to RIT's Tait Preserve. During the event, researchers collected data for 19 ground experiments using 14 ground instruments, eight UAV platforms, two aircraft, and seven satellite platforms.

As remote sensing technologies continue to evolve, the need for high-quality, well ground-truthed datasets remain critical. These data collections support sensor calibration and validation, algorithm development, and the advancement of future Earth observation capabilities. *www.rit.edu*

Vexcel Imaging Launches UltraCam Condor 5.0

UltraCam Condor 5.0 by Vexcel Imaging is a new aerial mapping system designed for wide-area and nationwide geospatial data collection. With up to 83,000 pixels across the flight strip, the it captures more ground in a single pass than any aerial mapping system to date. Combined with a new reconstruction approach in UltraMap designed for challenging image geometries, it delivers reliable photogrammetric-grade DSM, DTM, and orthophoto products across the largest aerial footprint ever deployed for mapping.

The UltraCam Condor 5.0 will be available in multiple models with cross-track image widths ranging from 57,800 to 83,000 pixels. Built around advanced Sony IMX811 Bayer-pattern CMOS sensor technology, the Condor 5.0 collects four spectral channels (RGB Bayer pattern and NIR), combining a true-nadir core with precisely aligned center cones and slightly tilted outer cones to maximize coverage while maintaining geometric consistency across its ultra-wide footprint. *vexcel-imaging.com*

PlanetiQ launches GNOMES-10

PlanetiQ's GNOMES-10 satellite was successfully launched on October 1. It's partner ground stations quickly established first contact with GNOMES-10, and spacecraft commissioning began immediately.

GNOMES-10 carries PlanetiQ's fourth-generation Pyxis GNSS-RO receiver, which was built and tested at its facility in Golden, Colorado. Pyxis is engineered to capture exceptionally high-quality GNSS signals for radio occultation measurements. Its combination of high signal-to-noise ratio (SNR), high-rate signal sampling, precise timing, and advanced antenna design enables PlanetiQ to retrieve highly detailed atmospheric profiles from each radio occultation event. *planetiq.com*

Trimble's VRS Now service is now available in Austria

Trimble is launching its Trimble® VRS Now service in Austria to provide 100% accurate and precise nationwide coverage and 24/7/365 network operations monitoring to ensure high availability and reliability. Trimble VRS Now is an instant, real-time network RTK correction service delivered via cellular connection. Powered by a fixed, highly redundant network of Continuously Operating Reference Stations (CORS), it gives operators sub-centimeter to centimeter-level accuracy (typically 2 cm horizontal and 3 cm vertical RMS) without needing a single physical base station on-site. By tracking full GNSS constellations, it ensures rapid convergence times and robust, dependable connectivity anywhere in the country. *https://positioningservices.trimble.com*

ideaForge secures orders from Survey of India

ideaForge Technology Limited has received an order from the Survey of India (SOI) for its Q6 V2 UAVs. The UAVs will support SOI's surveying and mapping requirements, enabling the collection of high-quality aerial and geospatial data across diverse terrains and project environments. The growing use of UAVs is transforming how geospatial data is collected, processed, and used for planning and decision-making. *www.ideaforgetech.com*

Net Insight launches Zyntai timenode access

Net Insight has announced Zyntai TimeNode Access, a compact, access-optimized PTP Grandmaster designed to bring resilient timing to distributed edge sites over existing packet infrastructure. Built for 5G, media, power and other mission-critical networks, it combines local GNSS with secure, network-delivered timing without requiring the underlying access network to be PTP-aware. *netinsight.net*

Oscilloquartz and Iridium collaboration

Oscilloquartz has announced the next phase of its collaboration with Iridium Communications Inc., expanding the range of Iridium PNT capabilities available across its synchronization portfolio. The latest integration brings resilient positioning and navigation alongside trusted timing to a broader range of applications. Building on the companies' existing collaboration, it strengthens end-to-end, multi-layered assured PNT architectures for critical infrastructure, defense and other GNSS-dependent applications. *www.oscilloquartz.com*

Mass-market-ready C-band GNSS antenna

TrustPoint has announced that Calian has successfully demonstrated the industry's first commercially manufacturable C-band GNSS antenna against TrustPoint's live orbital signal. Through multiple live-signal tests, the antenna reliably acquired and maintained reception of TrustPoint's C-band broadcast from orbit, marking a significant milestone in the development of the ecosystem for resilient, GPS-independent Positioning, Navigation and Timing (PNT). *www.trustpointgps.com*

BAE Systems to deliver M-Code GPS for U.S. Navy

BAE Systems has been awarded a $16 million contract from Collins Aerospace to design and develop the M-Code GPS solution for the U.S. Navy's Joint Precision Approach and Landing System (JPALS). It will provide its Digital GPS Anti-Jam Receiver (DIGAR™-500M) to upgrade JPALS to M-Code, strengthening resilience during precision landings in all environments.

JPALS is the Navy's next-generation GPS navigation system that guides aircraft to safe, accurate landings on aircraft carriers in all conditions, reducing pilot workload and enhancing operational capability. M-Code is the U.S.

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2026 K-Geo Festa
4 - 6 November
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Trimble Dimensions User Conference
9 - 11, November 2026
Las Vegas, USA
www.trimble.com

United Nations World Geospatial Information Congress (3rd UNWGIC)
16 - 19 November
Jeddah, Saudi Arabia
https://ggim.un.org/3UNWGIC

Geoworld
23 - 26 November
Dubai, UAE
https://www.geoworldevent.com

Pacific Islands GIS & Remote Sensing User Conference
30 November - 4 December 2026
Suva, Fiji
https://pgrsc.org

December 2026

IEEE India Geoscience & Remote Sensing Symposium
01 - 04 December 2026, Hyderabad, India
https://ingarss2026.co.in

ICESSG 2026
24 - 25, December
Barcelona, Spain
https://waset.org

February 2027

Geo Week 2027
23 - 25 February
Salt Lake City, UT, USA
www.geo-week.com

DGI 2027
23–25 February
London, UK
https://dgi.wbresearch.com

March 2027

Munich Space Summit 2027
15 - 19 March
Munich, Germany
www.munich-space-summit.org

Geo Connect Asia
17 - 18 March 2027
Singapore
www.geoconnectasia.com

April 2027

GISTAM 2027
20-22 April
Rome, Italy
https://gistam.scitevents.org

military's encrypted GPS signal that improves anti-jamming performance and security. *www.baesystems.com*

Sokkia Solutions adds new survey products

Sokkia has introduced additions to its portfolio of surveying, positioning and reality capture technologies, including new GNSS receivers and handheld scanning systems. The new GNSS receivers support positioning applications ranging from topographic surveys to corridor and infrastructure projects. The receivers are available in configurations designed to meet varying project requirements and budgets. *sokkia.com*

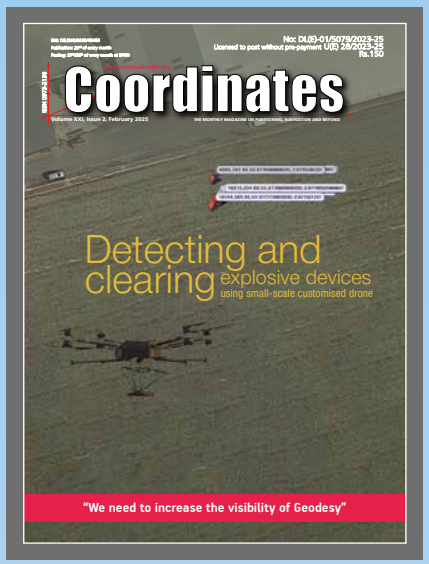
Septentrio expands mosaic-G5 GNSS ecosystem for drone

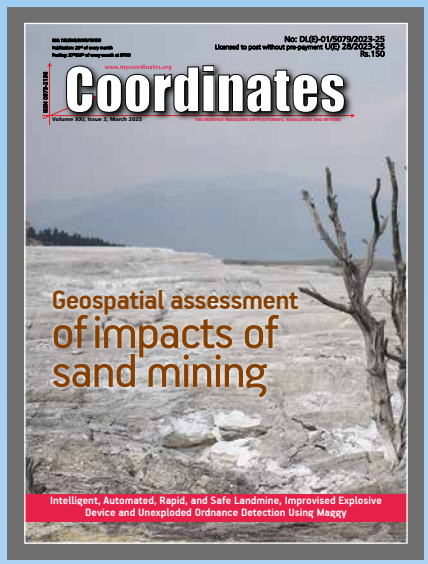
Septentrio is expanding its product line of ultra-compact mosaic-G5 receiver modules. The growing ecosystem includes mosaic-G5-based boards from Sparkfun, ArduSimple, GNSS Store, ARK electronics, ANavS, Holybro, MikroElektronika, Systork, Gateworks, and 3DR among others offering developers different form factors and integration paths. Hoverfly and CUAV are joining as new partners, further expanding the environments and platforms where mosaic-G5 technology can be deployed. *www.septentrio.com*

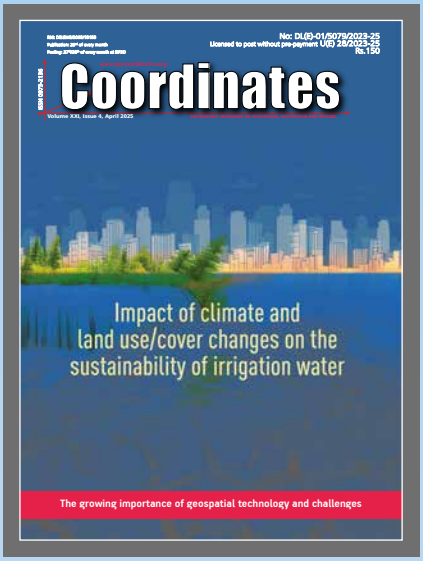
Elsight launches precise positioning solution

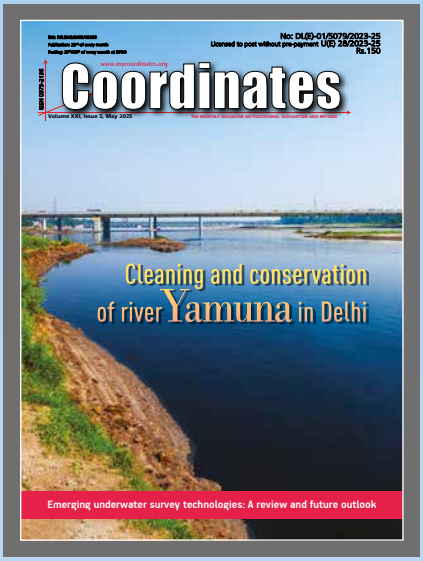
Elsight has announced its new Positioning capability, delivering accurate geolocation for autonomous platforms across air, land and maritime domains in GPS-denied, GPS-jammed, and GPS-spoofed environments. The launch comes amid ongoing global GPS jamming and spoofing, as growing usage of uncrewed systems push electronic warfare to the center of tactical planning. Jamming and spoofing tools once limited to specialist units are now fielded broadly by regular forces. *elsight.com*





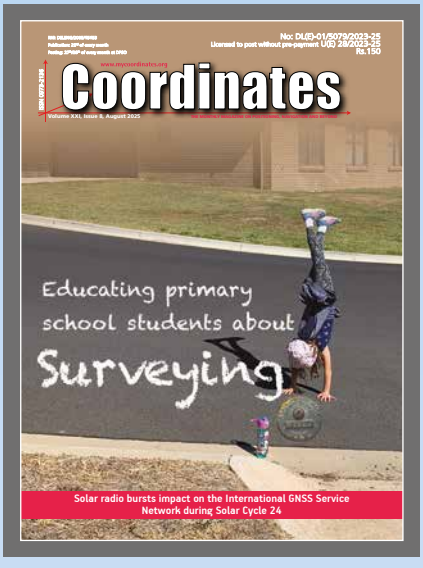


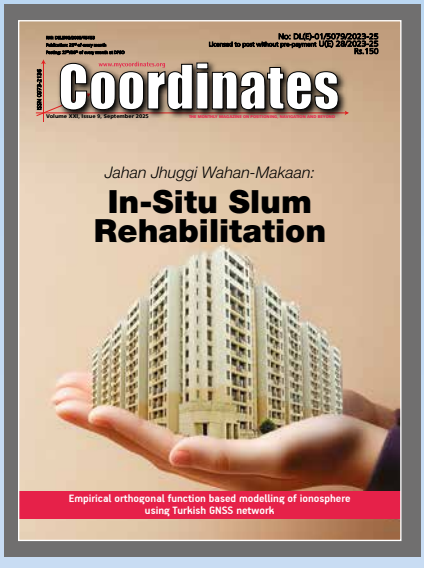












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