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THE MONTHLY MAGAZINE ON POSITIONING, NAVIGATION AND BEYOND

Experts Speak:

"Geospatial analytics is becoming more intelligent and powerful"

"GIS users can expect faster, more accurate results and improved field productivity"

Analysis of the cooling effects of urban green spaces in mitigating micro-climate change using geospatial techniques

In Coordinates

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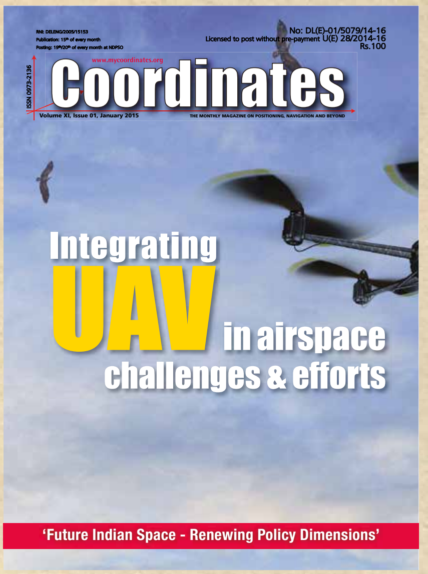

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The new application of GEONET for multi-GNSS observation and height determination

Basara MIYAHARA
Director, Physical Geodesy Division, Geospatial Information Authority of Japan, Ministry of Land, Infrastructure, Transport and Tourism, Tsukuba City, Ibaraki Pref, Japan

Tomoaki FURUYA
Geospatial Information Authority of Japan, Ministry of Land, Infrastructure, Transport and Tourism, Tsukuba City, Ibaraki Pref, Japan

Tokuro KODAMA
Geospatial Information Authority of Japan, Ministry of Land, Infrastructure, Transport and Tourism, Tsukuba City, Ibaraki Pref, Japan

Kensuke KOKADO
Geospatial Information Authority of Japan, Ministry of Land, Infrastructure, Transport and Tourism, Tsukuba City, Ibaraki Pref, Japan

Toshihiro YAHAGI
Geospatial Information Authority of Japan, Ministry of Land, Infrastructure, Transport and Tourism, Tsukuba City, Ibaraki Pref, Japan

Masaki MURAKAMI
Geospatial Information Authority of Japan, Ministry of Land, Infrastructure, Transport and Tourism, Tsukuba City, Ibaraki Pref, Japan

Tetsuro IMAKIIRE
Geospatial Information Authority of Japan, Ministry of Land, Infrastructure, Transport and Tourism, Tsukuba City, Ibaraki Pref, Japan

Geospatial Information Authority of Japan (GSI) has developed and operated nationwide GNSS continuous observation network, GEONET, since 1996. The GSI has gradually updated system of GEONET and the upgrade has enabled GEONET to receive more and more signals. GNSS observation data of GEONET, including GPS, QZSS and GLONASS, has been publicly opened to users since July 2012. The immensely-high performance in defining, maintaining and providing geodetic reference frame and position information has made GEONET an essential infrastructure not only for land surveys, but also for geospatial information management and crustal deformation monitoring in Japan.

Future Indian Space - Renewing Policy Dimensions

Dr Mukund Kadursrinivas Rao National Institute of Advanced Studies (NIAS), India
Prof Sridhara Murthi K. R. National Institute of Advanced Studies (NIAS), India
Dr V S Ramamurthy National Institute of Advanced Studies (NIAS), India

India must expand its role into the next stage of exploratory regime of space to scale new heights and become a significant contributor to meeting national needs, explore beyond and understanding of cosmos in modern terms and become a major partner of the Global Exploration Efforts of Space in the 21st Century – for which a National Space Policy is critical.

UAV system with terrestrial geo-referencing for small area mapping

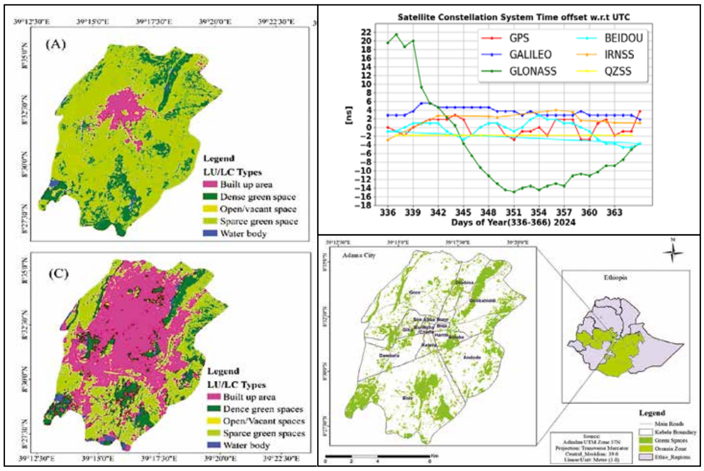
Hendriatiningsih SADIKIN
Associate Professor, Institute of Technology of Bandung and Head of Surveying and Cadastre Research Division, Faculty of Earth Sciences and Technology, Institute of Technology of Bandung, Indonesia

Asep Yusup SAPTARI
Academic Assistant, Surveying and Cadastre Research Division, Faculty of Earth Sciences and Technology, Institute Technology of Bandung, Indonesia

Rizki ABDULHARIS
Ph.D candidate on Spatial Planning in Developing Countries at Technische Universität Dortmund

Andri HERNANDI
Academic Assistant, Surveying and Cadastre Research Division, Faculty of Earth Sciences and Technology, Institute of Technology of Bandung, Indonesia

The UAV technology can be used to map a small area economically, but the quality of the resulting map is always constrained by the geometric accuracy problems as a result of the instability of the vehicle while taking the photos, so aerial photography mapping method using the usual UAV cannot be used to create an accurate map. To overcome these problems, we try to modify mapping methodology, which in this research, is done by integrating vehicle UAV systems photogrammetry with terrestrial systems.



In this issue

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Columns

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Biratu Bobo Merga, Girma Alemu Melka, Jean-Yves Lauture, Kenate Worku Tabor, and Narayan Dhital; 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
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Editor Bal Krishna
Owner Coordinates Media Pvt Ltd (CMPL)

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

Meta's Mega bet!

Meta's recent decision,

To end its independent fact-checking program,

And introduce community-generated "notes"

Reflects a growing tension,

Between free speech and content moderation on digital platforms.

This approach mirrors the model adopted by Twitter (now X).

As misinformation has become a significant challenge in the digital age,

Fact-checking initiatives were created to counter this issue,

But these have been criticized for perceived bias.

In determining what constitutes misinformation.

While community notes could foster diverse viewpoints,

It may reinforce false narratives rather than correcting them.

Meta's hands-off approach,

Raises fundamental questions about the role of tech companies,

In shaping online dialogue and curbing misinformation.

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

Exciting predictions for GIS users using GNSS technology in 2025

The ongoing year holds significant advancements for GIS professionals leveraging Global Navigation Satellite System (GNSS) technology.

Jean-Yves Lauture
CTO, Eos Positioning Systems

From enhanced accuracy to improved productivity, here are three key predictions for 2025 that could transform how GIS users collect and manage spatial data in the field.

1. Galileo High Accuracy Service (HAS) Phase 2: Precision in Minutes

In 2025, the European Union Agency for the Space Programme (EUSPA) is expected to roll out Phase 2 of the Galileo High Accuracy Service (HAS), bringing a significant enhancement to mobile GIS users worldwide. This phase promises a convergence time of just five minutes globally and under two minutes within the European Union. The precision offered—accurate to within 10-20 centimeters—will be a game changer, making high-accuracy GNSS positioning more accessible than ever before. This service is set to revolutionize mobile mapping applications, accelerating workflows for professionals across various industries. Already in 2024 we've seen Galileo HAS transform what's possible in the Galápagos Archipelago and in Senegal, Africa — a continent where we expect this corrections source to be a true equalizer. For more details on what to expect in Phase 2, refer to the EUSPA website for Galileo HAS here.

2. Tilt Compensation Becomes Standard for GIS Applications

The introduction of tilt compensation in GNSS receivers designed for GIS users, specifically with the release of the new Skadi Tilt Compensation™ from Eos Positioning Systems, marks another crucial development for 2025. Designed specifically for GIS users, this feature ensures that even when survey poles are not perfectly level, the GNSS data collected maintains centimeter-level accuracy. This innovation drastically reduces errors and increases efficiency by eliminating the need for manual pole leveling, making it a valuable tool for field crews who require precise and reliable results without added complexity. Skadi Tilt Compensation is not only accurate to within 0.3 mm per degree of tilt, but it's also offering this powerful solution at an extremely competitive price point, intended to make it accessible to the GIS masses. Skadi Tilt Compensation is available as an optional upgrade for the Skadi 200™, Skadi 300™, and Skadi Gold™.

3. Four-Constellation, All-Frequency Rover and Base Stations: A Productivity Booster

By 2025, the proliferation of four-constellation, all-frequency GNSS base stations will further optimize field productivity. Supporting all major GNSS constellations—GPS, GLONASS, BeiDou, and Galileo—these receivers will improve performance, particularly in challenging environments like dense forests or urban canyons. Field tests conducted by our partners have shown a 50% increase in productivity when using a rover/base combination wherein both the base station and rover support all four constellations, compared to older two-constellation systems. This leap in efficiency will enable users to complete more work in less time, revolutionizing GNSS-based fieldwork across various sectors. While four-constellation systems had been harder to come by in past years, more recently we are seeing an acknowledgement of the need to upgrade and benefit of doing so.

Conclusion

In 2025, GIS users can expect faster, more accurate results and improved field productivity, thanks to the advances in GNSS technology designed specifically for them. With Galileo HAS Phase 2, tilt compensation, and four-constellation base/rovers, the future of mobile mapping looks more efficient and precise than ever before.

"With the dawn of deep tech, geospatial analytics is becoming more intelligent and powerful"

Says Prof. Muralikrishna V. Iyyanki in an interview with Coordinates magazine, where he shares his insights on various topics, including the current status, emerging trends, and future prospects of geospatial technologies.

Prof. Dr. Muralikrishna V Iyyanki
PhD (Indian Institute of Science-Bangalore) FIE FIS FAPAS FISG FIGU
Former Dr RAJA RAMANNA DISTINGUISHED FELLOW, DRDO
Professor and Founder Head of the Centre for Spatial Information Technology (CSIT) at Jawaharlal Nehru Technological (JNT) University

What is your opinion about the present status of geospatial technology and education in India?

The present status of Geospatial technology is that it has evolved as a powerful gizmo for tackling concerns interconnected to the earth, environment and people. Geospatial technology is adding upfront the outcomes or spin-off boons of advances under "Deep Tech missions". Geospatial technology is in a stimulating and transformative stage. Let us understand that Deep tech is a global and all-purpose term for a basket of technologies of AI, robotics, blockchain, biotech, and quantum computing with a prescribed protocol. Consider AI, which is the prime constituent of Deep tech with applications in several areas, including healthcare, agriculture, etc. Space Technology has made significant strides with advancements primarily in the areas of remote sensing spatial resolution, spectral coverage and navigation facilities through GPS, etc., providing complex and large volumes of datasets. Conventional geospatial analytics have their boundaries when handling datasets. However, with the dawn of deep tech, geospatial analytics is becoming more intelligent and powerful. As an immediate example, it can be understood that Geo AI algorithms leading to "Geospatial Generative AI" have immense implications across many tasks, for example, Climate change adaptation, disaster risk reduction, urban infrastructure management etc., Considering the status of geospatial technology in India, it is critical to investigate the status and the essentials of geospatial technology education in India. Here are some key aspects that present the status and possible food for thought for a purpose-driven way forward

Geospatial technology and its education can be viewed through three mutually exclusive and significant domains or even towers. The first domain or tower is related to the hardware-oriented engineering discipline which is factually and directly not part of the geospatial education. The second domain or tower is related to software which is also exclusively not a part of the Geospatial education. The status of education in India in these two domains Viz., -Space technology-related Hardware and Software is unique and of the highest international quality and stands second to none at the global level. Every Indian is proud of ISRO's several advancements in satellite technology. To quote a few that are relevant here, it is ISRO's Cartosat and Resourcesat series, providing high-quality geospatial data. These are adequately supported by DST through NSDI and relevant Geospatial education missions which enhanced the value of remote sensing, data and its utilization. The superior education infrastructure related to these two domains viz Hardware and software, has facilitated amazing advancements in the aerospace sectors both in Government and Private. These two domains are the very strong potential candidates with the highest scope for facilitating the country under the Aatmanirbhar Bharat (self-reliant India) campaign.

The Third domain or tower is the Science and Technology of Geospatial Technology Applications. At the international level in many countries, all the three domains or towers mentioned here are part of their Mainstream graduate /postgraduate education and are progressing very well with state-of-the-art infrastructure and appropriate human resources for education and training. But in India the third domain or tower is yet to become part of the mainstream of formal Geospatial education unlike the first and second domains mentioned earlier. There are, of course, dedicated efforts being made by DST and DOS as well as UGC and AICTE. The National Geospatial Policy 2022 is aimed at democratizing geospatial data and fostering innovation.

In India the cream of students opts for engineering education with focus on IT and electronics due to the guaranteed campus placements and further employments. The experts belonging to the third domain provide the essential and fruitful link between satellite data providers [Domain 1 and 2] and users of the benefits of the technology i.e. Government and people. There is an unnoticed and very unsmiling cavity in terms of the volume of the students related to the third domain. The cavity is in terms of the relevance of course curriculum and employment opportunities.

In this context, there is a need for designing the curriculum with a strong focus on geospatial technology as part of the deep tech mission and demonstrate career opportunities in specific disciplines related to the third domain. The specific geospatial tools and techniques that are related to the third domain broadly should become part of the course work for students belonging to streams of Agriculture, Forestry, Architecture and Town planning, Geology and other earth sciences, Civil engineering, Management etc. The subjects like geospatial tools and techniques as well as data analytics i.e., AI tools and techniques. Inclusion of specially designed Electives which cover advanced topics like Cloud computing, Python, Generative AI, Geospatial AI, 3D printing, AR/VR, Cyber/information security, cyber-physical systems, Cyber laws, Geodesy, Remote sensing data policy, National Geospatial Policy, NSDI, GSDI etc. will help in enhancing and upbringing the status of the geospatial education with reference to the third domain.

Mini projects integrating the data analytics tools and open GIS software and knowledge of the student's specialization, say for example - Water Resources or Climate change adaptation or disaster risk reduction should be part of the Geospatial technology graduate/postgraduate degree programs. Here, the inclusion of principles of Geospatial thinking, design thinking as well as Open Innovation and Business Model Canvas on the lines of Berkeley Hass [University of California] would lead to a new brand of GEOSPATIAL TECHNOLOGY specialists who is a core discipline knowledge-empowered well qualified Geospatial technology application specialist.

Geospatial education primarily should focus on providing human resources belonging to the third domain, as explained above. This specialist will be the candidate with a passion for research and or entrepreneurship ie Geospatial Entrepreneur – Geopreneur. They become leaders to contribute to the Aatmanirbhar Bharat (self-reliant India) campaign.

Next despite ISRO's developments, there are significant gaps in the availability of remote sensing data in general and up-to-date high-resolution data in particular to meet the needs of academic institutions to provide adequate number of trained professionals. This results in shortage of trained professionals in geospatial technology, thus, limits the full utilization of National spatial data infrastructure potential.

Geospatial technology is increasingly being integrated into critical areas and projects major and minor should be part of the curriculum – To cite a few Smart cities -planning and infrastructure management , Precision farming, crop monitoring, Utilization of technologies like drones, Remote sensing data real-time mapping are used for disaster preparedness, infrastructure projects like highways, railways, Mapping deforestation, monitoring biodiversity, and studying climate change impact. Increasing adoption of drones for mapping, surveying, and monitoring, particularly in agriculture, mining etc.,

Government initiatives like the Digital India program and collaborations accelerate the geospatial sector's growth. Here development of geospatial platforms is one important activity specially for educational institutions for reducing dependency on external platforms like Google Maps etc. to facilitate India to become a global hub for geospatial innovation.

How has the growing prominence of UAV/ UAS/ Drones-based mapping impacted Remote Sensing? Please elaborate on some points where both overlap each other and where they have distinct advantages.

UAV/ UAS/ Drones are significantly contributing to remote sensing of natural resource management. Agriculture, floods and other disaster response and recovery, civil engineering construction and urban infrastructure planning and management, forest management etc. are some of the areas for which Drones have transformed significantly the field of remote sensing application. Drones with panchromatic, multispectral or hyperspectral sensors by design flying at low altitudes provide very high-resolution imagery. These imageries complement traditional satellite imagery which may belong to low resolution category. The fact is that the remote sensing imagery from both platforms becomes prime data for processing, analyzing, and visualizing geospatial data.

The ideal approach for large or medium-scale surveys is the adoption of a hybrid approach which is seemingly being identified as the best option. That means drone-satellite integration would be an operational model for a comprehensive understanding of the terrain as well as preparation for real-time applications like disaster management.

Drones can provide ultra-high-resolution imagery (up to a few cm per pixel) and can capture data on-demand, unlike satellites, which may be constrained by orbital paths or revisit times. For small to medium-sized projects, Drone mapping is more affordable. For large-area mapping, drones are not suitable or appropriate as satellites surpass in area coverage, making them suitable for regional, national, and global-scale analysis. Satellites provide a long archive of imagery (e.g., IRS LISS data since 1988] enabling temporal change detection and trend analysis.

The main concern for drone data collection is the lack of consistency in data collection over time, making them not dependable for longitudinal studies. Also, the satellite systems e.g.: RISAT or MODIS, etc., provide data from a wide range of optical and microwave passive and active sensors and bands that Drones may not yet support due to payload or other technical and viability constrictions.

There is very significant benefit of drones beyond the well talked real-time monitoring applications. It is in operations involved in combining high-resolution drone data and satellite-based low or medium-resolution data for validation, calibration and mapping with improved accuracy. Also, Drone-collected data can serve as ground truth for calibrating and validating satellite remote sensing models. A collective methodology consents researchers to analyze occurrences across distinctive spatial scales, from global tendencies to site-specific features. In a nutshell, remote sensing using Drones is ideal and needed for real-time operations and also for substantiating conventional satellite-based operations, which indeed has no substitute either from a technology point or viability point. Also, if we deliberate concerning the remote sensing undertakings in terms of the discovery of the overlap between drones and satellite platforms, it can be concluded that both have overlapping capabilities. The complementary capability that can be leveraged is based on the differences in spatial resolution (example 10 cm from Drones and 100 cm from satellites), Swath width (example 500 meters from drones and 100 or 1000 km from satellites).

The ideal approach for large or medium-scale surveys is the adoption of a hybrid approach which is seemingly being identified as the best option. That means drone-satellite integration would be an operational model for a comprehensive understanding of the terrain as well as preparation for real-time applications like disaster management. The hybrid approach gives scope for Data fusion, which can enhance the accuracy and understanding of the spectral characters of the different terrain features. This approach can also define the path for a hierarchical monitoring system. Thus, drones and satellites overlap in remote sensing but they also have complementary capabilities that can be leveraged to construct a state-of-the-art operational and equipped remote sensing system.

With Generative AI gaining prominence, could you please highlight few benefits and challenges that it may pose to the end user of remote sensing technology?

Generative AI is rapidly transforming various domains, including remote sensing technology. There are many case studies stating how Generative models can simulate different climatic / environmental situations for planning and risk assessment purposes, assisting in predictive and prescriptive analytics. It has scope for extracting features from remote sensing data. Change detection is being reported as one of the very important derived products from Gen AI to apply to disaster management. Gen AI can synthesize high-quality imagery from incomplete or noisy remote sensing data, improving accuracy in interpretation and providing a window for automated feature extraction. The Gen AI's unique capabilities of prediction and prescription help in the simulation of remote sensing imagery for specific regions or conditions. This may moderate the need for frequent data acquisition. Of course, this needs a planned validation effort.

Also, the case studies available in the literature brings out that techniques like super-resolution models are of great help to enhance the quality of low-resolution satellite images, allowing for better classification. Of course, there are many challenges as on date due to the deficiency in complete understanding in integrating particularly the features /domain knowledge of geology and geomorphology in the treatment of the terrain imagery in terms of predictive analytics and or prescriptive analytics. Accuracy, ethical concerns in data simulation and the vast computational and resource demands are identified challenges during my Geo-Spatial Gen AI application studies related to PM 2.5 and acute respiratory infection modelling, disaster risk reduction, climate change adaptation etc.,

Let us appreciate the fact that Gen AI is said to offer unique potential in remote sensing to provide desirable, feasible and viable Image data with predictive capabilities.

However, the current state of the art of the technology suggests, that the remote sensing professionals should not over-rely on Gen AI turnouts, demoting the demand for traditional domain proficiency and ground validation, which is fundamental in remote sensing. Robust validation mechanisms are indispensable.

How do you see the adoption of blockchain technology worldwide in general and in India in particular? Do you think we as a country are equipped enough to adopt this advanced technology? Are there areas of integration of blockchain technology with the geospatial domain?

The implementation of blockchain technology is growing globally, though at erratic proportions and frequencies primarily based on the technological infrastructure and regulatory aspects of governance. Globally, Blockchain is being functional within a few sectors like finance, health, supply chain management etc. Cryptocurrencies, smart contracts, and secure patient data are a few examples of the many areas of application at the global level. The current understanding of blockchain technology leads to comment that scalability and interoperability remain technical challenges. Also, the regulatory and legal frameworks are still growing in many countries, creating ambiguity.

The Indian government is working on blockchain technology for land record management, e-governance, and supply chain transparency. States like Telangana and Andhra Pradesh are using blockchain for securing land records, while Maharashtra is exploring it for fraud detection in the public distribution system. Indian startups need to be encouraged to build solutions in selected areas, including healthcare, land records management etc. The main challenge is the requirement for a strong digital infrastructure and a skilled workforce. Small and medium enterprises (SMEs) form the crucial 'middle of the pyramid' in the geospatial ecosystem. They are vital and critical to the development and deployment of cutting-edge technologies. Many sectors, including SMEs, are not fully aware of the potential of blockchain. Blockchain can transform the geospatial domain by enhancing data integrity, transparency, and security. Blockchain can ensure tamper-proof storeroom and transparent transactions for land ownership records, reducing disputes and fraud.

Disaster management, environmental monitoring, and smart cities are few examples wherein Blockchain combined with Geospatial technology can add value to traditional geospatial models. Is India ready is one question. Certainly, there is scope and need to work on blockchains combined with geospatial technology to build sandboxes. Also upskilling of geospatial professionals and education stream for blockchain-specific applications. This is one area with huge potential for Entrepreneurship, particularly in land records management in this vast country. The upskilling mission needs to include the triple helix system between government, academia, and industry, exceptionally in sectors like land records management, urban planning and disaster response.

What is the concept of exposome? What is its relevance/significance in the geospatial domain?

The exposome is a theory that expresses the totality of environmental exposures from the day of birth, along with the associated biological response. It is referred to as the exposome, a theory that has become increasingly important for discovering environmental causes of disease. WHO named air pollution as the biggest environmental risk to health in 2019. According to WHO, nine in 10 people regularly breathe air that contains microscopic pollutants that can damage their lungs, heart, and brain. The exposome theory was inducted within epidemiology. The term "exposome" was coined by Dr Christopher Wild in 2005 to encompass "the totality of human environmental exposures from conception onwards, complementing the genome"

The geospatial significance gets accredited by integrating with exposome science which indeed provides the large amount of data for modelling interfaces between environment, space, and health, ultimately driving evidence-based interventions to improve population health. The geospatial data (e.g., satellite imagery, air and water quality sensors), pollutants like PM2.5, water contamination in specific regions, and geographic disparities in exposure to environmental hazards could be quantified. This can be integrated with the availability of green spaces, walkability, noise pollution, and urban heat islands the exposome concept in the form of a geospatial exposome index like the air quality index may be demarcated.

Would you agree that there may be fewer experts in fields like Geodesy in India?

Geodesy is a well-known discipline that is central to mapping, navigation, and monitoring. Since the Earth is in constant motion, an accurate reference point is essential for determining dimensions. Geodesy measures the Earth's shape, rotation, and gravitational field. Some routine applications of general significance include floodplain mapping, which relies on precise terrain elevations, and engineering and construction activities, which depend on accurate positioning. Thus, geodesy is a critical discipline in many fields, including navigation and engineering, and is particularly important also for space exploration. In my experience, Geodesy has the scope to support and drive innovation in geospatial technology. In this Deeptech age, maximum surveying and mapping devices are gathering and generating data in digital format. For example, consider an activity of digital twin product development or enlargement. Any such activity certainly requires a standard built on codes of geodesy and surveying, which are indeed the foundation for planning, design and

> It is not an exaggeration or amplification to say that the "absolute national economy integration to the popular geospatial framework in several ways is reinforced by geodesy".

positioning. However, the issue here is related to the crisis in terms of the lack of availability of trained geodetic manpower. This archetype demands an appropriate revision of how surveyors and geodesists provide their products and services..

Let me quote here about the white paper cum report dated 1 January 2022 titled "The Geodesy Crisis" by Mike Bevis and the team available at https://www.fgdc.gov/ngac/meetings/september-2022/geodesy-presentation-ngac-sep-2022.pdf.

The white paper cum report specifies a ground reality regarding the lack of human resources and the need for funding research in geodesy, both in basic and applied aspects.

There are relatively fewer experts in specialized fields like geodesy in India compared to other units of geospatial technology per se. Let us at this stage, comprehend that remote sensing and navigation satellite amenities are crucial for various actions related to natural resources and environmental management, infrastructure development and strategic planning. The main apprehension here is related to the prevailing research gap in India and the lack of awareness of the perils associated with it. This highlights the immediate need for trained geodesy professionals. Why are there no programs that include Geodesy as a prime learning or research subject in the ongoing geospatial technology programs in different IITs and universities in the country? This cannot be overlooked by the government or academia. It is not an exaggeration or amplification to say that the "absolute national economy integration to the popular geospatial framework in several ways is reinforced by geodesy".

How do you see climate change as a challenge to the growth of human kind? Are there some actionable and acceptable solution available to combat this challenge?

Climate change is one of the realities and challenges to the growth and sustainability of humankind, impacting virtually every aspect of life, from the environment and economy to health and social stability. The challenges to be addressed due to climate change are well understood and documented through scientific and social media of all forms and of course, demand higher concentration and dedication to provide actionable solutions. What is needed is to ponder how technology, either Deeptech or traditional technologies or their appropriate combination, can provide solutions to adaptation and mitigation. Now, several approaches are being suggested for some of the fields, say, like agriculture, infrastructure, energy, water management etc. For example, the development of drought resistant crops and sustainable cultivation practices are being suggested for agriculture to adaption. Water recycling, desalination, and rainwater conservation etc. are being suggested for water management to adaptation. Some of the Actionable and Acceptable Solutions include carbon pricing, energy efficiency, renewable energy, etc. In fact, more than any of these technological considerations more important is behavioural change through the reduction of waste and the adoption of a circular economy

What are your views on the quality and level of geospatial education in India?

The quality and level of geospatial education in India have shown notable progress over the years, but some areas need further development. Some of the requirements are addressed in terms of advanced research in data processing, geospatial and generative AI, and geodesy applications. Government initiatives like the National Geospatial Policy 2021 are suitable to foster a conducive environment for geospatial education and research. What is needed is the policy implementation in a faithful manner. One important factor is the Shortage of Skilled Faculty with deep expertise in geospatial technologies and their interdisciplinary applications. Industry-academia collaboration for geospatial research and internships remains limited compared to global standards. A lot can be stated here and what is needed is policy support and investment.

How conducive is the prevailing policy scenario for the growth of geospatial technology?

The conduciveness of the prevailing policy scenario for the growth of geospatial technology varies across regions, but there are several general trends in terms of data accessibility and uneven growth. The global policy scenario is progressively becoming more conducive to the growth of geospatial technology, driven by increasing recognition of its applications in governance, business, and sustainability

What is the significance or scope of Geospatial Technology in the implementation or implantation of the Industry 4.0 plan as well as schema?

Geospatial technology provides location-based data as an added advantage. It has a decisive task in Industry 4.0, augmenting working proficiency due to this advantage. There are a good number of cases in which Geospatial technology has played a key role in industry layout optimisation and supply chain logistics improvement. The integration of geospatial technology into Industry 4.0

systems shall enrich the outcome of any product or process development plan. It is an ongoing process with limited cases of direct utilization of the geospatial technology. By leveraging location intelligence, industries are continuously working to optimize operations.

Let me convey here that the Industry 4.0 implementation schema inadvertently has a built-in technology-based ingredient, which needs a copious attachment to geospatial intelligence and geospatial technology. In simple words, this technology-based ingredient is the Geospatial technology. A prerequisite here for an outstanding industry 4.0 implementation outcome is the continuous operation of enhanced industry-academia dialogue to support the addition of numerous valid geospatial and non-spatial attributes.

The inherent and indefinite potential of geospatial data provides additional support to implement Industry 4.0 protocols in terms of manufacturing, waste management and environmental management, and beyond, making it a dynamic constituent of the Industry 4.0 ecosystem. The potential of geospatial data composes an outstanding platform for descriptive analytics, diagnostic analytics, predictive analytics and prescriptive analytics.

It may not be out of context to realize and mention here that the established processes of Artificial Intelligence (AI) technologies are a keystone of Industry 4.0. Essentially, automation and optimisation are the branded outcomes of Industry 4.0 that make AI pertinent to Industry 4.0. Thus, Geospatial AI (GeoAI) which is the integration of AI with Geospatial technology, has further enhanced scope in both the implementation and implantation of Industry 4.0. For example, view a case of the creation of a digital twin of factories along with a simulation of the possible mutual impact of surroundings and industrial areas. Such a development helps in visualising geospatial data in 3D environments for better decision-making.

NASA's SPHEREx Mission to Map the Sky in 3D Set for February 2025 Launch

An advanced NASA mission to create a three-dimensional map of the sky is set for launch in February 2025. The satellite, named Spectro-Photometer for the History of the Universe, Epoch of Reionization, and Ices Explorer (SPHEREx), will be carried aboard a SpaceX Falcon 9 rocket from Vandenberg Space Force Base in California, according to NASA reports. SPHEREx, roughly the size of a compact car, is designed to map millions of stars and galaxies visible from Earth in all directions. Scientists aim to gather unprecedented insights into cosmic events, including the universe's inflation phase following the Big Bang.

The satellite will measure the distribution of hundreds of millions of galaxies to examine the inflation process, believed to have occurred fractions of a second after the Big Bang. By analysing these patterns, researchers hope to uncover new details about the physics governing the universe's early expansion.

Another key aspect of the mission involves studying the "collective glow" of distant galaxies, enabling researchers to detect light from previously unobserved galaxies. According to NASA, this data will offer a broader understanding of the universe's structure and energy distribution.

As per reports, SPHEREx will investigate our galaxy, the Milky Way, searching for life-essential molecules such as carbon dioxide and water. Scientists anticipate that findings from this mission could provide clues about how such elements influence the formation of new planets.

The SPHEREx spacecraft weighs 329 pounds and is expected to operate for two years, generating detailed sky maps twice annually. Reports indicate that SpaceX secured the launch contract in 2021. With oversight from NASA's Launch Services Programme and management by JPL, the mission seeks to deliver transformative insights into the cosmos while advancing the understanding of life's potential building blocks.

SpaDeX Mission: Revolutionising Space Exploration

In a historic achievement of Indian Space Research Organisation (ISRO), the Space Docking Experiment (SpaDeX) mission's docking operation was successfully completed on 16th January, 2025 marking India's entry into the elite group of nations capable of executing space docking operations. With this success, India becomes the fourth country in the world to achieve this technological feat. ISRO started the mission on 30th December 2024, with the successful launch of the SpaDeX spacecrfts using Polar Satellite Launch Vehicle (PSLV)-C60, from the Satish Dhawan Space Centre, Sriharikota. This groundbreaking mission aims to showcase India's technological prowess in spacecraft rendezvous, docking, and undocking — a critical capability for future advancements such as satellite servicing, space station operations, and interplanetary exploration.

The docking process was executed with exceptional precision. The spacecraft manoeuvred seamlessly from the 15-metre to 3-meter hold point, initiating docking with accuracy leading to successful spacecraft capture. After this, retraction was completed smoothly, followed by rigidisation for stability. Post-docking, the integrated control of the two satellites as a single object has been successfully achieved, showcasing India's technological expertise. In the coming days, undocking operations and power transfer checks are scheduled to further validate the system's performance.

SpaDeX is a cost-effective technology demonstrator mission designed to showcase in-space docking using two small spacecrafts launched by 62nd PSLV flight. This mission is pivotal for India's future space ambitions, including lunar missions, sample returns, and the development of the Bharatiya Antariksh Station (BAS). *pib.gov.in*

GNSS Constellation Specific Monthly Analysis Summary: December 2024

The analysis performed in this report is solely his work and own opinion. State Program: U.S.A (G); EU (E); China (C) "Only MEO- SECM satellites"; Russia (R); Japan (J); India (I)

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

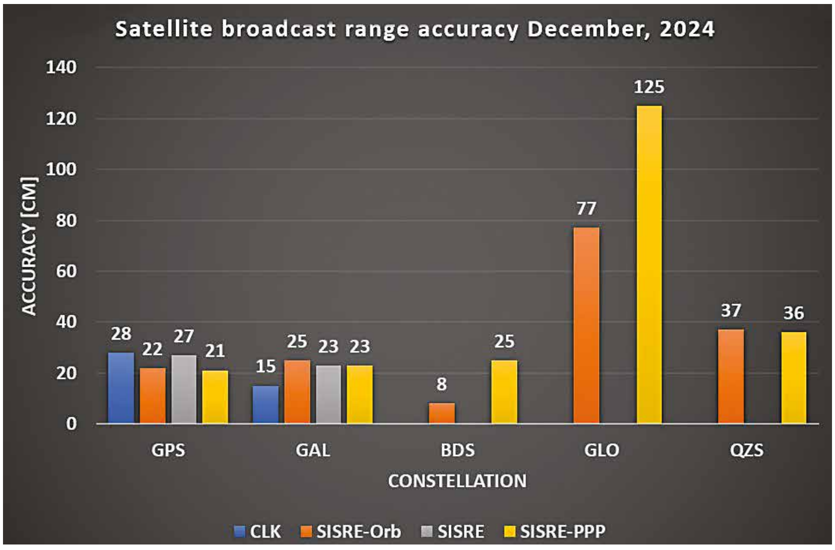
The article is a continuation of monthly performance analysis of the GNSS constellation. Please refer to previous issues for past analysis. From the application side, the new topic that is addressed is the usages of GNSS PVT solutions for the Terminal Area Energy Management of spaceplanes, re-usable space vehicles and unmanned air vehicles.

Analyzed Parameters for December, 2024

(Dhital et. al, 2024) provides a brief overview of the necessity and applicability of monitoring the satellite clock and orbit parameters

a. Satellite Broadcast Accuracy, measured in terms of Signal-In-Space Range Error (SISRE) **(Montenbruck et. al, 2010)**.
b. **SISRE-Orbit** (only orbit impact on the range error), SISRE (both orbit and clock impact), and **SISRE-PPP** (as seen by the users of carrier phase signals, where the ambiguities absorb the unmodelled biases related to satellite clock and orbit estimations. Satellite specific clock bias is removed) **(Hauschlid et.al, 2020)**
c. **Clock Discontinuity:** The jump in the satellite clock offset between two consecutive batches of data uploads from the ground mission segment. It is indicative of the quality of the satellite atomic clock and associated clock model.
d. **URA:** User Range Accuracy as an indicator of the confidence on the accuracy of satellite ephemeris. It is mostly used in the integrity computation of RAIM.
e. **GNSS-UTC offset:** It shows stability of the timekeeping of each constellation w.r.t the UTC
f. **Terminal Area Energy Management:** TAEM is a critical phase in the flight of re-entry vehicles, where precise navigation and control are essential to ensure a safe and controlled descent. Defining TAEM based on GPS involves leveraging the high-precision positioning data provided by the GPS to manage the vehicle's energy and trajectory as it transitions from hypersonic to subsonic speeds

(a), (b) Satellite Clock and Orbit Accuracy (monthly RMS values)



Note:- for India's IRNSS there are no precise satellite clocks and orbits as they broadcast only 1 frequency which does not allow the dual frequency combination required in precise clock and orbit estimation; as such, only URA and Clock Discontinuity is analyzed..

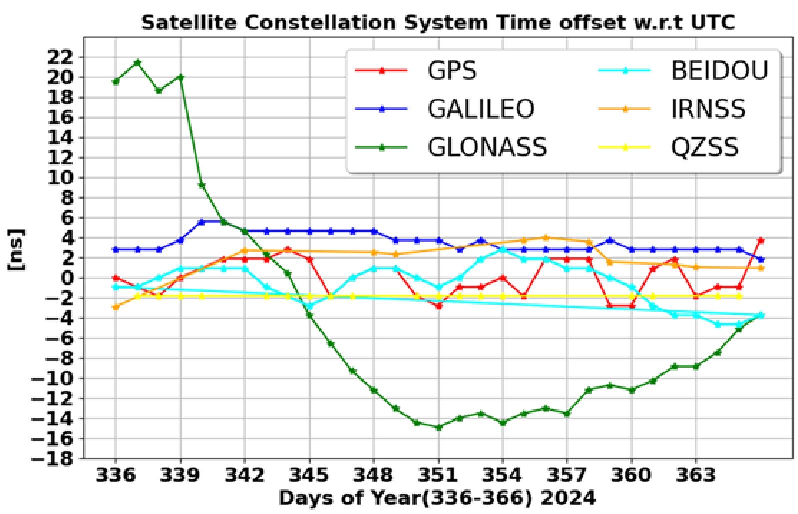
(c)-1 Satellite Clock Jump per Mission Segment Upload

Const	Mean [ns]	Max [ns]	95_Percentile [ns]	99_Percentile [ns]	Remark (Best and Worst 95 %)
IRNSS	3.52	658.68	5.69	23.24	Best I02 (4.48 ns) Worst I06 (16.77 ns) Big jumps for each satellite in multiple days
GPS	0.56	1335.52	0.94	2.29	Best G04 (0.50 ns) Worst G03 (2.65 ns) Very large jumps for G19 and G21.
GAL	0.09	6.73	0.17	0.38	Best E07 (0.15 ns) Worst E19 (0.35 ns). E16 and E23 had a few large jumps but they are newly launched satellites and are in experimental phase.

(d) User Range Accuracy (Number of Occurrences in Broadcast Data 01-31 December)

IRNSS-SAT	2 [m]	2.8 [m]	4.0 [m]	5.7 [m]	8 [m]	8192 [m]	9999.9	Remark Other URA values (frequency)
I02	3000	10	-	-	1	-	-	-
I03	-	-	-	-	-	-	-	-
I06	1223	55	2	-	2	-	-	32 m (1)
I09	511	4	1	-	3	-	-	-
I10	445	1	-	-	1	-	-	-

(e) GNSS-UTC Offset



(f) Space Re-entry Vehicles: Terminal Area Energy Management

Note: The author is an experienced air navigation engineer with flight deck experience in assessing the navigation performance of the aircraft. The flight deck pictures provided below are taken from public sources and not directly from author's work due to ethic and contractual reasons.

In the previous issues, the application of GNSS in time synchronization and orbit estimation for LEO satellite missions was explored. It is fascinating that the GNSS has played a crucial role also in the space re-entry vehicles during their missions, including the last few space shuttle missions. GNSS PVT solutions are integral to the navigation and control of re-entry vehicles, launch and lift-off vehicles, unmanned aerial vehicles (UAVs), and overall terminal area energy management (TAEM) as shown in Figure F1 and Figure 2. These systems leverage the integration of GNSS with Inertial Measurement Units (IMUs), Air Data Systems, Distance Measuring Equipment (DME), and VHF Omnidirectional Range (VOR) within the Flight Management System (FMS) as shown in Figure F2 to provide a comprehensive and accurate navigation solution. The flight computer or the FMS utilizes data from these sensors to continuously update the vehicle's position, velocity, and attitude, ensuring precise navigation and control throughout the mission. GNSS provides high-precision positioning, which is crucial for the accurate execution of flight paths and maneuvers. However, in the event of a GNSS outage or failure, the accuracy of the navigation is degraded, and it may not always meet the required performance standards, such as Required Navigation Performance (RNP), based on the combination of IMUs, DMEs and VORs. Figure F3 shows the variation in achieved accuracy as shown by the flight computer for different sensors. The Schuler tuning is applied in the IMU/IRS of aircraft to correct for the Earth's curvature and reduce drift but the sensor vibration, temperature effect and initialization errors still accumulates the drift over time to degrade the positioning. This degradation in the absence of GNSS poses a significant challenge for the envisaged integration of space traffic and air traffic management, considering the frequent launch, lift-off and re-entry of space vehicles envisaged in the coming decades. As shown in Figure F3, the accuracy of the IMU (also of DME, VOR to a larger extent) degrades significantly requiring larger separation minima in the airspace. Still, the integration of IMU, Air Data, DME, and VOR ensures redundancy and maintains navigation integrity, allowing the FMS to continue providing reliable navigation solutions. In nominal situation, the usage of the GPS (Figure F3 and F4) allows higher accuracy enabling efficient airspace management and precision operations for terminal approach and final landing. [1] provides a detail analysis on the use of GPS for the re-entry approach and landing of Dream Chaser Orbital Vehicle (like the Space Shuttle).

Re-entry vehicle dynamics are typically described by a set of nonlinear differential equations (as shown in the equations below) that account for the vehicle's motion in three dimensions over a rotating Earth. These equations include:

Equations of Motion: These describe the translational and rotational dynamics of the vehicle. The translational motion is governed by Newton's second law, considering gravitational, aerodynamic, and thrust forces. The rotational motion is described by Euler's equations, accounting for the vehicle's moments of inertia and external torques.

Energy Management: The TAEM phase involves managing the vehicle's energy to ensure a safe and controlled descent. This includes optimizing the trajectory to minimize dynamic pressure and thermal loads. The control inputs, such as angle of attack and bank angle, are adjusted to manage the vehicle's total energy and ensure it follows the desired flight path.

Path Constraints: The trajectory planning must satisfy various constraints, such as maximum dynamic pressure, thermal limits, and structural integrity. These constraints are incorporated into the trajectory optimization algorithms to ensure the vehicle remains within safe operational limits.

The **bank angle** and **angle of attack** play crucial roles in the TAEM phase. The bank angle is used to control the lateral trajectory and manage the vehicle's cross-range capability. By adjusting the bank angle, the vehicle can perform controlled turns, which helps in aligning with the desired landing corridor. The angle of attack, on the other hand, is used to control the lift and drag forces acting on the vehicle. By varying the angle of attack, the vehicle can manage its descent rate and maintain the desired flight path. These control inputs are essential for ensuring a smooth transition from hypersonic to subsonic speeds, maintaining control and stability throughout the descent.

The two important concepts in the TAEM are:

Heading Alignment Cone (HAC): As the vehicle approaches the landing site, it uses the heading alignment cone, a virtual truncated cone, to align with the runway centerline. The vehicle maneuvers into the HAC to ensure it is properly oriented for the final approach & landing.

S-Maneuver: The S-maneuver is used to dissipate excess energy and adjust the vehicle's trajectory. By performing a series of S-shaped turns, the vehicle can manage its speed and alignment, ensuring it follows the optimal path to the landing site.

$$\begin{cases} \dot{V} = \dfrac{-D}{m} - g\sin\gamma \\ \dot{\gamma} = \dfrac{L\cos\mu}{mV} + \left(\dfrac{V}{r} - \dfrac{g}{V}\right)\cos\gamma \\ \dot{\chi} = \dfrac{V\cos\gamma\sin\chi\tan\theta}{r} + \dfrac{L\sin\mu}{mV\cos\gamma} \\ \dot{H} = V\sin\gamma \\ \dot{P}_N = V\cos\gamma\cos\chi \\ \dot{P}_E = V\cos\gamma\sin\chi \end{cases}$$

$$\begin{cases} L = -F_x\sin\alpha + F_z\cos\alpha \\ D = F_x\cos\alpha + F_z\sin\alpha \end{cases}$$

$$\begin{cases} F_x = \dfrac{1}{2}\rho V^2 S C_x \\ F_z = \dfrac{1}{2}\rho V^2 S C_z \end{cases}$$

Equations: Kinematic model for the re-entry vehicles [2].

Figure F1 shows the different phases of re-entry, approach and landing of space vehicle. Based on the Space Shuttle missions, it also gives representative use of GPS and other sensors at different altitude and speed.

[4] and [5] provide an overview on the use of GPS along with other sensors that enabled the Space Shuttle re-entry, approach, and landing. It is also highlighted how the GPS augmented system can even enable precision approach and auto landing capability. Regarding the terminal approach, instead of TACAN used in earlier Shuttle missions, DME-DME or stand-alone GPS LNAV/VNAV Area Navigation up to 0.1 RNP (the accuracy can be met as shown in Figure F3 and F4) are more beneficial for contemporary missions. Further, GNSS derived ADSB provides continuous surveillance information in addition to the primary surveillance radar. GPS for Space Shuttle was used with stand-alone mode. However, with current state-of-the-art technology, augmented GPS (i.e. SBAS) provides better accuracy and most importantly higher confidence in the solution. Once the vehicle is brought down to the TAEM exit point, the final approach and landing procedures can be supported with combinations of SBAS (Approach Procedure with Vertical Guidance (APV I/APV II)), GBAS, ILS, DME-DME and Vision-Based Landing System. Overall, GNSS plays a crucial role.

In summary**,** the operation of re-entry procedures begins from the de-orbit burn and as such, the most important requirement is to identify a suitable de-orbit burn zone, during either orbit ascending or descending. One of the main design parameters driving the de-orbit burn is the cross-rang capability.

After the de-orbit burn, the high energy (high kinetic and potential energies) of the re-entry vehicle needs to be properly balanced before preparing the final approach and landing. In Figure F1 above, the experience from the Space Shuttle mission is used to distinguish different phases of the re-entry, TAEM, Heading Alignment, energy dissipation S-maneuvers, and final approach & landing. The analogy to these phases (from TAEM entry point onwards) in the routine aircraft operation is the stabilized approach of the aircraft from the en-route phase through the Initial Fix (IF) and Intermediate Approach Fix (IAF) to the Final Approach Fix

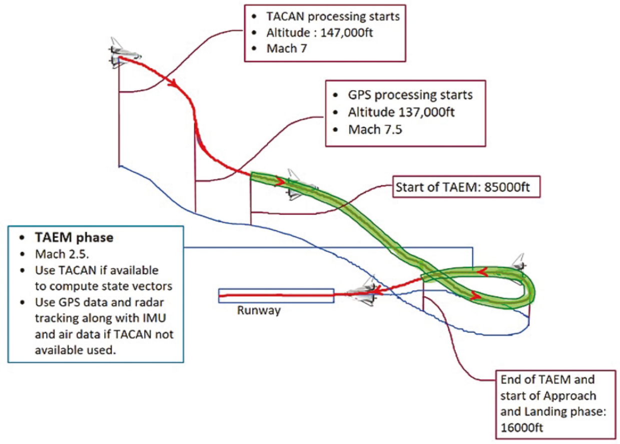


Figure F1: The atmospheric re-entry, approach, and landing phases of a typical re-entry vehicle based on Shuttle operation procedures.

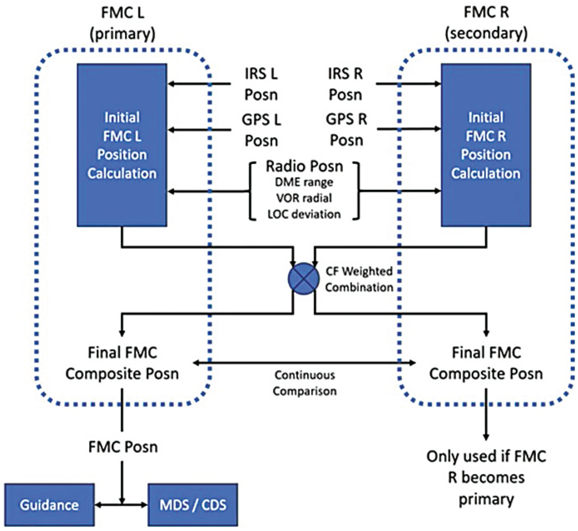


Figure F2: The architecture of the flight computer used in most of the commercial aircraft. For space vehicles and unmanned vehicles, the architecture might differ mostly incorporating vision-based navigation [3].

Figure F3: The navigation system in the representative FMS. Based on the available navigation aids and the required performances, different combinations of sensors can be used. It is visible that the flight computer is taking only the GPS position due to its high accuracy (0.05 with unit in NM), for the navigation and guidance. The accuracy is indicated by the ACTUAL value. The logics in the FMS and the pilot choices overwrite the selection and combination of sensors.

Figure F4: The flight computer that computes the real-time PVT of the space vehicles/aircraft based on GPS satellites. The figure of merit shows confidence of 21 meters accuracy, and the used number of satellites is 10. When the figure of merit value is inflated to compute the protection level, 0.1 NM is easily attainable. The approach procedure of LNAV/VNAV (see Figure F5) with 0.3 NM can be flown only based on GPS positioning.

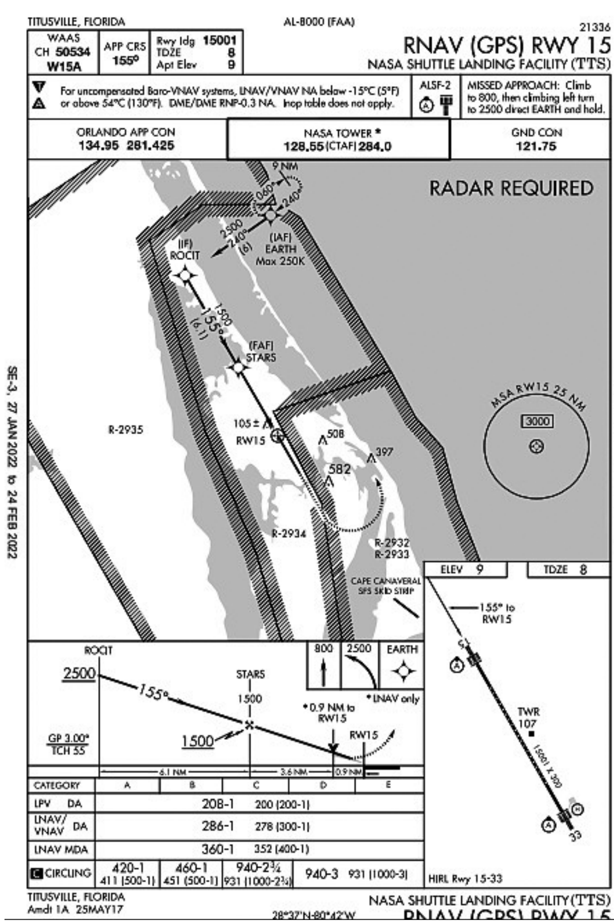


Figure F5: GPS/GNSS -based LPV procedure and GNSS-based LNAV/VNAV procedure for final approach and landing at the Shuttle landing facility.

(FAF). GNSS based approaches and landing like LPV that translate the above concept can be used as shown in Figure F5. It is the certified and published flight procedures for space shuttle approach and landing. The GPS standalone positioning is capable to support the LNAV/VNAV approach while SBAS, the augmented GPS positioning, is required to support the LPV approach.

Monthly Performance Remarks:

1. Satellite Clock and Orbit Accuracy:
   - The performance of all constellations looks similar to the last month. There is a slight improvement in Beidou 3 orbit quality.
   - For GPS, as usual there are couple of unusable satellites due to maneuver. For Galileo, E16 and E23 are not considered as there are still in test phase.
   - For IRNSS, URA value distribution for all satellites shows low spread than in previous months.
2. UTC Prediction (GNSS-UTC):
   - All constellations show stable UTC prediction with minor variations. GLONASS showed a strong deviation.

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Note: References in this list might also include references provided to previous issues.

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https://cddis.nasa.gov (Daily BRDC); http://ftp.aiub.unibe.ch/CODE_MGEX/CODE/ (Precise Products); BKG “SSRC00BKG” stream; IERS C04 ERP files

(The monitoring is based on following signals- GPS: LNAV, GAL: FNAV, BDS: CNAV-1, QZSS:LNAV IRNSS:LNAV GLO:LNAV (FDMA))

Time Transfer Through GNSS Pseudorange Measurements: https://e-learning.bipm.org/login/index.php

Allan Tools, https://pypi.org/project/AllanTools/

gLAB GNSS, https://gage.upc.edu/en/learning-materials/software-tools/glab-tool-suite

Analysis of the cooling effects of urban green spaces in mitigating micro-climate change using geospatial techniques in Adama city, Ethiopia

The study revealed that the radical changes in land use/land cover dynamics. The study compared surface temperature with green and non-green areas to ana-lyze the effects of green spaces on temperature and consequently UHI, and has analyzed the cooling effects of urban green spaces

Biratu Bobo Merga
Department of Geographic Information Science, Institute of Land Administration, Oda Bultum University, Chiro, Ethiopia

Kenate Worku Tabor
Department of Geography and Environmental Studies, College of Social Science and Humanities, Jimma University, Jimma, Ethiopia

Girma Alemu Melka
Department of Geography and Environmental Studies, College of Social Science and Humanities, Jimma University, Jimma, Ethiopia

Abstract

Greening the urban environment serves as an effective strategy to counteract the impacts of localized climate variations, such as temperature fluctuations and altered precipitation patterns. The main objective of this study is to examine how urban green spaces (UGS) in Adama City contribute to cooling the surrounding areas by using geospatial methods through considering land surface temperature and vegetation cover, thereby addressing micro-climate changes. Three different remotely sensed data of Landsat7 enhanced thematic mapper plus (ETM+) of the year 2000 and 2013 as well as Landsat8 operational land imagery/thermal infrared sensor (OLI/TIRS) (2023) were used in the study. The consistent land surface temperature data were retrieved from Landsat7 ETM+ and Landsat8 OLI/TIRS using mono window and split window algorithms, respectively. Results showed that the proportion of urban green spaces to other land use/land cover was reduced from 29.3 km2 (21.20%) in 2000 to 18.17 km2 (13.15%) in 2023. Due to the increment of built-up areas and reduction of vegetation cover, the land surface temperature of the city is increasing. The analysis determined that an optimal green space area of 5.5 ± 0.5 hectares in Adama City can effectively reduce surface temperatures by approximately 2.85 degrees Celsius. This study will contribute to understanding the role of vegetation cover in reducing urban heat effect, and also assist policymakers in regard to urban land use planning.

1. Introduction

Earth's surface temperature is a product of the balance between incoming solar energy and outgoing radiation energy (Roza et al., 2017). The warmer the earth gets, the more the energy it radiates out. Earth is being experiencing a warmer atmosphere since the pre-industrial era and contributed to a significant increase in the global mean temperature (IPCC, 2014). Urban heat island (UHI) is a result of rapid urbanization which is described as urban areas with significantly warmer temperature than its nearby rural areas (Kong et al., 2016). There are a number of contributing factors which play significant role in the formation of UHI; for instance, low albedo materials, air pollutant, wind blocking, clearance of trees and increased use of air conditioner (Nuruzzaman, 2015).

Fast urbanization leads to reduction of vegetation areas; and increases land surface temperature and consequently changes urban micro-climate (Nor, 2013). Increased replacement of natural green areas to urbanized areas, diminishing of agricultural lands, expansion of impervious surfaces, extensions of barren land because of the built-up areas have led to significant changes in the local climate conditions. Due to all these factors temperature distribution in urban areas is expressively warmer than its surrounding sub-urban areas (Effat et al., 2014; Senanayake et al., 2013).

As one of the basic elements of the urban environment, urban green space is the only type of land use with natural or semi-natural conditions inside a city; and plays a significant role in protection of the ecological environment of cities (Ngom et al., 2016; Zhong et al., 2011). Vegetation is a vital element of global environment. It modifies the ecosystem through water preservation, terrestrial soil constancy and atmospheric circulation. It also helps to sustain a balance of ecosystem prominently. Urban greenery also acts as a natural agent against air pollution in the urban environment (Buyadi et al., 2015).

Urban green infrastructure offers numerous advantages beyond just decreasing land surface temperature. Urban green infrastructure plays a crucial role in climate change adaptation by mitigating the urban heat island effect, reducing energy consumption for cooling, and providing shade and cooling effects in built-up areas (Ngom et al., 2016). These adaptations help cities become more resilient to extreme heat events associated with climate change. Green infrastructures also help to filter pollutants from the air, resulting in improved air quality. Trees absorb carbon dioxide and other harmful gases while releasing oxygen, contributing to a healthier urban environment (Teferi & Abraha, 2017).

Trees and green spaces contribute considerably to the improvement of the urban climate and to UHI mitigation. Decrease of the temperature is achieved through trees that provide solar protection, affect air movements and heat exchange, absorb solar radiation and cool the air through evapotranspiration processes. It should be noted that urban parks may extend their cooling potential and decrease ambient temperatures in adjacent urban zones depending on the thermal balance of the overall area under study. Urban parks provide thermal comfort and a high mitigation potential (Cohen et al., 2013). Because of transpiration, greenery plays a significant role in alleviating UHIs by dropping temperature and increasing humidity. Their cooling effects are especially important; and they have been regarded as natural resources for city planning (Sandra et al., 2011).

Geospatial techniques offer a comprehensive and efficient means of assessing the cooling effects of green spaces by providing precise spatial data on land surface temperature and vegetation cover. By integrating remote sensing and geographic information system (GIS) technologies, these methods enable large-scale analysis, temporal monitoring, and visualization of the impact of green spaces on urban micro-climates, facilitating evidence-based decision-making for sustainable urban planning and climate resilience strategies (Feyisa et al., 2014; Merga et al., 2022).

Previous studies on the role of green spaces in mitigating urban heat islands have been limited by inadequate methodologies, making it challenging to accurately assess the specific contributions of individual green space patches. While some research has highlighted the significant cooling effects of urban parks, there is difficulty in generalizing findings due to varying methodologies and limited consideration of other types of green spaces, such as roadside vegetation and greenery around non-religious institutions. For example, studies by Feyisa et al. (2014), Teferi and Abraha (2017), and Samson et al. (2018) utilized quadrant division methods focusing primarily on selected parks, neglecting the broader spectrum of green spaces and their respective impacts.

Little is known about the quantitative role of green spaces is in mitigating micro-climate change in the study area which needs detail investigation to make specific recommendations for urban land

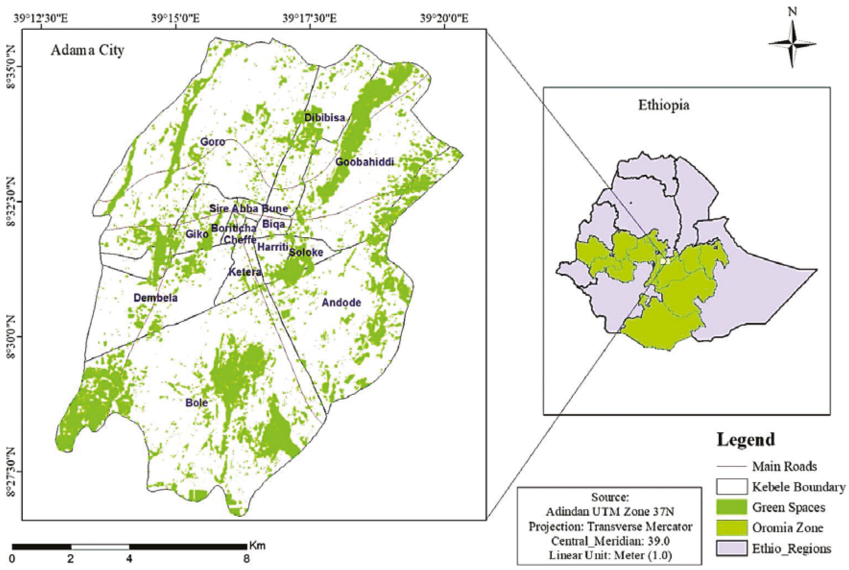

Figure 1. Location map of Adama City.

Table 1. Data types and sources

No.	Data category	Source	Purpose
1	Landsat images	USGS	For LU/LCC, LST, NDVI and, NDBI analysis
2	Temperature data	National meteorological agency (NMA), Ethiopia	To validate the value of temperature retrieved from satellite image
3	Adama city shape file	Adama city municipality	For preparation of result map

Table 2. Remote sensing images

Image	Path	Raw	Pixel size	Acquisition date	Sources
Landsat ETM+ of 2000	167	54	30 × 30	11, Feb, 2000	U.S. Geological Survey
Landsat OLI/TIRS of 2013 & 2023	167	54	30 × 30	05, Jan, 2023	U.S. Geological Survey

use optimization, landscape planning and design to mitigate the heating effects. This matter necessitates assessing the cooling effect of green space on land surface temperature (LST) using geospatial techniques. Findings from the study will provide an understanding of the LST, urban heat island (UHI) and LU/LC status of the area as an input for planning and decision-making.

2. Materials and methods

2.1. The study area

This study was conducted in Adama City, which is located in the Great Ethiopian Rift Valley; and found at about 100 Km Southeast of Addis Ababa, Ethiopia. Its absolute location stretches between 8° 27′00″to 8°36′00″North latitude and 39° 12′30″ to 39° 20′ 30″ East longitude and covering a total area of 138.2 Km2 (Figure 1).

Adama city has hot and dry weather for the greater part of winter and warm and sunny in summer. It lies in Great Rift Valley of East Africa; and the altitude of the central part of the city constitutes the lowest area.

The climate of Adama City comes under a sub-tropical agro-climatic zone. The city has hot and dry weather for the greater part of winter and warm and sunny in summer. There are four climatic seasons; Kremt (rainy period) Bega (dry period) Belg (small rains) and Meher (a spell between the long and small rain periods). The city experiences the hottest and coldest temperature during May and December respectively. On the average, rainy season is June, July, August and September; whereas, the dry month is in January, October, November and December. Among all months, the driest month is December. Adama City experiences the hottest and coldest temperature during May and December respectively (Central Statistical Authority CSA Adama Branch, 2009).

2.2. Data types and sources

Data for the study was collected from both primary and secondary sources (Table 1). The primary data source includes observations and fieldwork. The observation was made to collect ground truth points for validation of LU/LC types as well and different photographs were taken for further identification of each land use/land cover of the study area. These were carried out in order to identify the land use land cover types such as built-up, open spaces, water bodies, and the spatial distribution of green spaces. Secondary data sources include reviewing different relevant literature of the specific study area and related studies.

Two sets of remotely sensed data such as Landsat7 ETM+ of the year 2000 and 2013 and Landsat8 OLI/ TIRS of the year 2023 were used for this study (Table 2).

2.3. Data processing and analysis methods

2.3.1. Land use/land cover classification

Image pre-processing which encompasses layer stacking; image resampling and false color combination was employed using ERDAS IMAGINE V15 software. A supervised classification approach was applied to classify the years 2000, 2013, and 2023 images with a maximum likelihood classifier algorithm (MLC). MLC is one of the eminent parametric classifiers used for supervised image classification (Foody et al., 1992).

Post-classification smoothing has also been done on the land use/land cover (LU/LC) to remove noisy pixels. Sample data from the field using hand-held global positioning system (GPS) and visual interpretation of the selected land use/land cover type were prepared, and then land cover polygons were made using ArcGIS 10.8 to extract and reclassify the urban green spaces. Finally, urban green land cover classes were identified and mapped for further analysis.

Finally, an accuracy assessment was performed to evaluate the quality of classification output. Error matrix based on assessment of the overall accuracy; producer's accuracy, user's accuracy, and kappa coefficient were utilized to evaluate the pixel-based classification output for LU/LC classification. The purpose of accuracy assessment is to quantitatively assess how efficiently the pixels were tested into the correct land cover classes (Bhatta, 2008).

2.3.2. Retrieval of Land Surface Temperature (LST)

Near-surface air temperature is a consequence of the complex effects of the turbulent heat transports produced by nearby heated surfaces (Avdan & Jovanovska, 2016). The Mono window algorithm for Landsat 7 and the split window algorithm for Landsat 8 were employed.

Mono window algorithm is an algorithm that possesses the benefits of easy determination of parameters, extensive applications (Yu et al., 2014), and high precision reversal which could accurately reflect regional land surface heat distribution. The specific formulae are:

$$Ts = \ a6\ 1 - C6 - D6\ + \ b6\ 1 - C6 - D6) + C6 + D6)T6 - D6Ta\}/C6 \quad (1)$$

$$C6 = 6\tau6$$

$$D6 = \ 1 - \varepsilon6\ \ 1 + \ 1 - \varepsilon6\ \tau6$$

Where; T6 is brightness temperature, ε6 is land surface emissivity, τ is atmospheric tanemissivity in thermal infrared and Ta is an average atmospheric temperature which can be calculated by the parameter estimation method of the mono-window algorithm. Also, A6 = −67.355351, b6 = 0.458606, C6 and D6 are intermediate variables and Ts is the Land Surface Temperature (LST) to be calculated.

Split-window algorithm is used to retrieve land surface temperature from Landsat 8 data that has two bands (Band 10: 10.6–11.2 µm, Band 11: 11.5– 12.5 µm). Split-window algorithm uses the brightness temperature of the two bands of Thermal Infrared (TIR), mean, and difference in land surface emissivity for estimating LST. The process of acquiring LST values follows the conversion of thermal infrared Digital Numbers (DNs) (Bands 10 and 11) to radiance Top of Atmosphere (TOA) and at-satellite brightness temperature. The effective at-sensor Brightness Temperature (BT) is also known as black body temperature which was obtained from the spectral radiance using Plank's inverse function. Spectral radiance values for bands 10 and 11 were converted to radiant surface temperature under an assumption of uniform emissivity using pre-launch calibration constants for the Landsat 8 OLI sensor. After spectral radiance is converted to radiance, the raw digital numbers of the thermal bands are converted to Top of Atmosphere (TOA) brightness temperatures, which are the effective temperature viewed by the satellite under an assumption of emissivity using Planck's equation (Sobrino et al., 2012).

$$\begin{aligned} LST = {} & TB10 + C1(TB10 - TB11) \\ & + C2(TB10 - TB11) + Co \\ & + \ C3 + C4W \ \ 1 - \Delta\varepsilon \ + \ C5 + C6W \ \Delta\varepsilon \end{aligned} \quad (2)$$

Where; C0, C1, C2, C3, C4, C5 and C6 is the split-window coefficients; TB10 = brightness temperature of band 10 (Kelvin K); TB11 = brightness temperature of band 11 (Kelvin K); ε is mean value of land surface emissivity (LSE) of TIR bands; W content of water vapors in the atmosphere; Δε = difference between LSE of bands 10 and 11 emissivity, difference of land surface emissivity, and then to estimate LST;

$$BT = \frac{K2}{ln \ \frac{K1}{} + 1} \quad (3)$$

Where; BT is effective at-sensor brightness temperature (K); K2 is calibration constant 2 (K); K1 is calibration constant 1 (W/(m^2 *sr * μm)); Lλ is spectral radiance at sensors aperture (W/(m2 * sr * μm)); and Ln is a natural logarithm.

To compute Land Surface Emissivity (LSE), it is essential to know the characteristics of the earth's surface and change the thermal radiance energy during calculation of LST (Sobrino et al., 2012). The emissivity is calculated using;

$$\varepsilon = 0.004^{*}PV + 0.986 \quad (4)$$

Where; PV is Vegetation Proportion which is obtained using the following formula;

$$PV = \left[\frac{NDVI - NDVImin}{NDVImax - NDVImin}\right] \quad (5)$$

Where; NDVI is normalized difference vegetation index; NDVImin is a minimum value of normalized difference vegetation index and NDVImax is a maximum value of normalized difference vegetation index.

The calculated radiant surface temperature is then corrected for emissivity using the the following equation;

$$LST = \frac{TB}{1(\lambda \ TB/P)In\varepsilon} \quad (6)$$

Where; LST is Land Surface Temperature, TB is radiant surface temperature in (K), λ is the wave-length of emitted radiance (11.5 μm), ρ is Planck's constant (6.26 × 10−34 J s); and ε is land surface emissivity.

2.3.3. Extraction of built-up index

The normalized difference built-up index (NDBI) is often mixed with plant noise, and its values range from −1 to 1. The greater the NDBI is, the higher the proportion of built-up land is (Varshney, 2013). NDBI is derived from Landsat ETM and Landsat 8, from reflectance measurements in the red and mid-infrared (MIR) portion of the spectrum. The NDBI value is obtained using the following equation and applied to identify urban built area. Extraction NDBI is calculated using the following equation.

$$NDBI = \frac{MIR - NIR}{MIR + NIR} \quad (7)$$

Where; MIR is Md Infrared (Band 6 for Landsat 8) and NIR is Near Infrared (Band 5 for Landsat 8) (Zhou et al., 2014).

2.3.4. Extraction of normalized difference vegetation index (NDVI)

The spatial distribution of urban green spaces in Adama city was extracted and analyzed on the basis of the value of NDVI. The values of NDVI generally range between -1 to + 1. The −1 value depicts the absence of vegetation and + 1 value shows the presence and density of vegetation. Moreover, NDVI values are suitable for the calculation of change detection analysis. Very low value of NDVI (0.1 and below) correspond to barren areas of rock, sand, or snow (Pervaiz et al., 2018).

The values of NDVI can further categorized as non- vegetated for the value < 0, unhealthy vegetation for the value between 0.02–0.03 and moderate values represent bush and grasses (0.2 to 0.3), whereas, high NDVI value correspond to dense vegetation (0.6 to 0.8) (Gandhi et al., 2015). These activities was computed and analyzed in ArcGIS Software environment using the following formula.

$$NDVI = \frac{NIR - R}{NIR + R} \quad (8)$$

Where; NIR is a Near Infrared (the pixel Digital Number (DN) of TM Band 4 and Band 5 for Landsat 7 and 8, respectively); and R is Red Band (Band 3 and Band 4 for Landsat7 and 8, respectively) (Gandhi et al., 2015).

2.3.5. Determination of green spaces' cooling effect

To determine the contribution of green spaces in relation to other LULC types in mitigating UHI, each green space patches was extracted with corresponding LST values for the identified years. In consideration of the possible varying temperature conditions during LST acquisition, the temperature means of green spaces in relation to the entire landscape for the identified years was computed separately. With the mean temperature within the study area as baseline, the thermal influence of each of the green space patches to the entire urban landscape was computed by the contribution index (CI) (X. L. Chen et al., 2006) using function:

$$CI = D^{*}St \quad (9)$$

Where: CI is Contribution Index i.e. the influence of each green space patch to the entire landscape, D is the difference in mean temperature between the green space patches and the entire urban landscape; and St is the proportion of the area to the entire landscape.

The Green Index (GI) percentage of green space patches was calculated based on binary classification (green and non-green classes) of NDVI measurements. The negative values of NDVI measurement is classified as built up area and positive values are classified as green class (Kshama, 2012).

Green space cooling effect is determined as the difference in temperature between inside the green space and the average land surface temperature of the entire landscape (Choi et al., 2012). To determine the cooling effects of green spaces, surface temperature of green spaces and the entire land scape should be computed using the following equation.

$$\Delta T = (T_u - T_p) \tag{10}$$

Where; ΔT is Change in Land Surface Temperature, Tp is the average LST of green space; and Tu is the average LST of the entire landscape.

2.3.6. Software used for the study

For the achievement of the study's purpose, different software required is stated as table below (Table 3). General workflow for this study is presented in Figure 2.

3. Results and discussion

3.1. Accuracy assessment

Accuracy assessment was done from land use land cover types of 2000, 2013 and 2023 for the analysis of cooling effects of green spaces in mitigating micro-climate change in Adama City (Table 4).

3.2. Land use/land cover (LU/LC) map of the period 2000 to 2023

The LU/LC of the year 2000 shows that the city had a built-up area with a total area of 31.75 Km2 (22.97%)

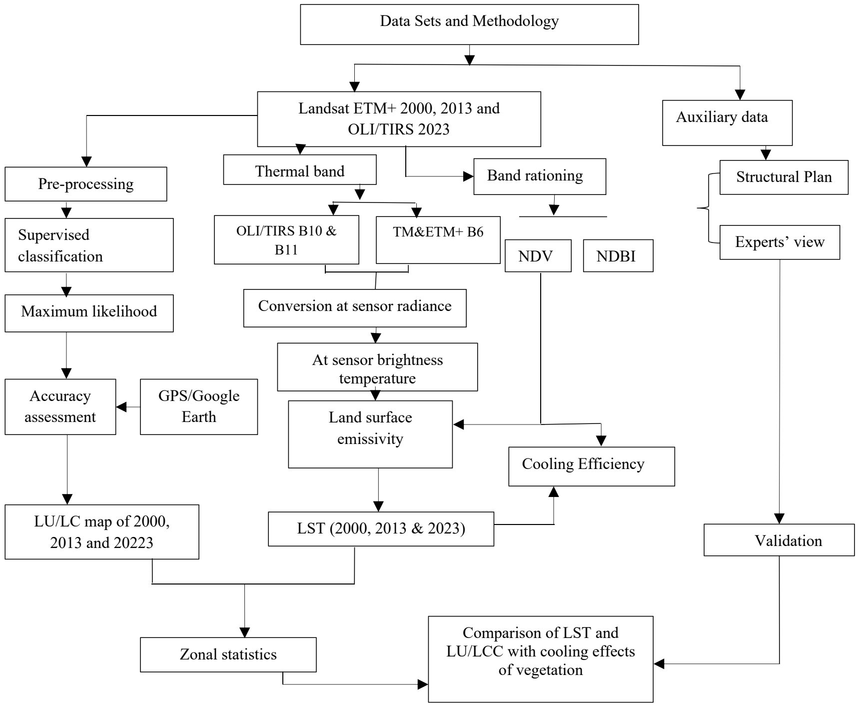

Figure 2. Methodological flow chart.

Table 3. Software used for the study

No	Software	Purpose
1	ArcGIS 10.3	Analyzing and visualization of spatial data
2	ERDAS 2015	For Image classification and accuracy assessment
3	Google Earth Pro & GPS	For LULC accuracy assessment

Table 4. Accuracy assessment of land use and land cover for 2000, 2013 and 2023

	2000		2013		2023	
	Producers accuracy (%)	Users accuracy (%)	Producers accuracy (%)	Users accuracy (%)	Producers accuracy (%)	Users accuracy (%)
Dense veg.	94.5	98.3	99.3	99.8	98.6	99.8
Built-up	98.8	95.9	98.9	97.4	97.3	98.22
Open space	100	99.4	100	99.4	100	98.4
Sparse veg.	99.5	99.5	43.2	97.2	92.6	98
Water bodies	98.6	99.8	99.3	98.3	94.5	99.8
Overall accuracy	98.4%		97.6%		98.7%	
Kappa coefficient	0.96		0.97		0.97	

Table 5. Land Use/land cover (LU/LC) of the Year 2000, 2013 and 2023

	2000		2013		2023	
Class name	Area (lkm²)	(%)	Area (km²)	(%)	Area (km²)	(%)
Denseveg.	29.38	21.26	24.14	17.47	18.17	13.15
Built-up	31.75	22.97	67.13	48.57	86.0	62.24
OpenSpace	2.26	1.64	3.17	2.29	0.36	0.26
Sparseveg.	72.88	52.74	41.34	29.92	32.27	23.35
Waterbody	1.93	1.40	2.42	1.74	1.38	1.00
Total	138.2	100.00	138.2	100.00	138.2	100.00

and dense and sparse vegetation cover with a total area of 102.26 Km^2 (74%) respectively. However, these green spaces were rapidly eradicated and replaced by built-up areas. It is rapidly increasing which corresponds to the context of rapid urbanization in Adama City.

As part of developing countries' cities, Adama City is also facing a high rate of land use/land cover change due to urban development activities. Due to the increase in population, industrialization and other natural and human activities, land use/land cover of the city is changing. The transformation of agricultural lands into urban areas has greatly affected the land components and the environment. Consequently, the natural vegetation in and around the city is also converted into impervious surfaces. Expansion led by government and private sectors mainly mass housing programs like condominiums, single residential and real state constructions, and other developmental activities such as the construction of roads and factories are visible evidence for the eradication of green spaces and rise in land surface temperature in the city. The proportion of urban green spaces (UGS) particularly, dense vegetation which includes indigenous forest and thicket were reduced from 29.3 Km^2(21.20%) in 2000 to 18.17 Km^2 (13.15%) in 2023, whereas built-up area increased from 31.75 Km^2(22.97%) to 86.0 Km^2 (62.24%); whereas, built-up areas occupy the dominant LU/LC classes which is the most significant change in land cover type proportion (Table 5 and Figure 3).

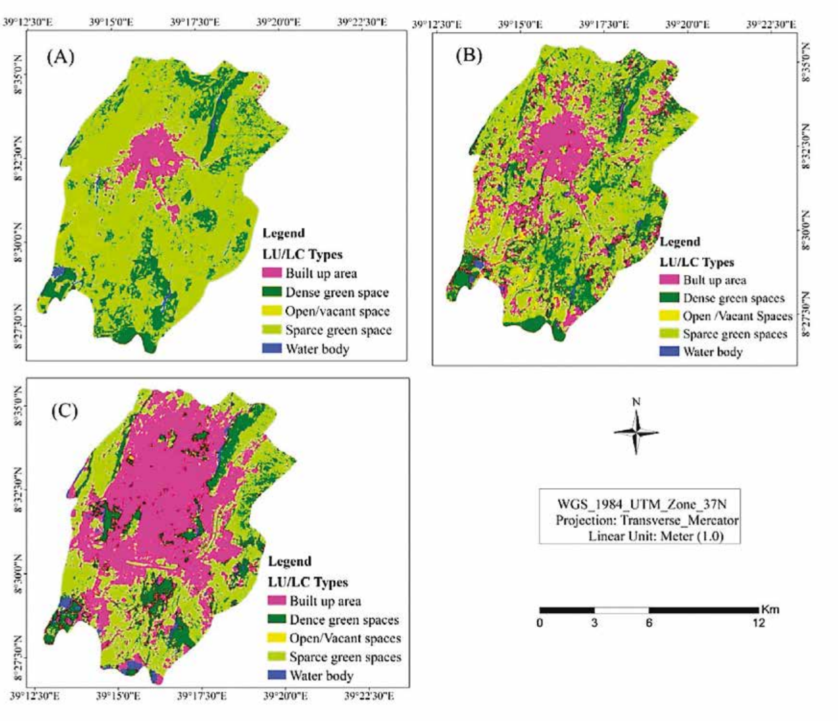

Figure 3. LU/LC maps of the year 2000 (A), 2013 (B) and 2023(C).

Table 6. Summary of LST values of the year 2000, 2013 and 2023

LST Values (°C)	Landsat ETM+ (2000)	Landsat ETM+ (2013)	Landsat OLI (2023)
Minimum	19	17.8	18.8
Maximum	36.4	38.2	39.7
Mean	27.08	28.25	31.78

Table 7. Variations of LST values from the year 2000 to 2023

2000			2013		Difference (%)	
LST (°C)	Area (km^2)	Area (%)	Area (km^2)	Area (%)	Difference (km^2)	2000–2023
<22	24.57	17.78	36.72	26.57	12.15	+10.42
22–26	64.51	46.69	32.84	23.76	–31.67	– 22.93
26–30	29.33	21.22	14.04	10.16	–15.29	– 11.06
30–34	8.23	5.95	38.97	28.2	30.74	+20.62
>34	11.54	8.35	15.63	11.31	4.09	+2.96

Studies conducted by; Teferi and Abraha (2017) and Dagnachew (2018) also indicate that built-up areas consume a considerable amount of land from vegetation cover during urban development. These reveal that rapid population growth and expanding built-up areas in cities reduce the cooling effects of vegetation cover. Of all land use land cover types, bare land (rocky areas) and built-up areas are the most land cover types that experience high land surface temperature. Green spaces such as parks, trees along streets, and gardens absorb solar radiation, provide shade, and release moisture through transpiration, effectively cooling the surrounding air. This helps alleviate the urban heat island effect, where cities experience higher temperatures compared to rural areas due to human activities and built-up infrastructure. Overall, the presence of green spaces in urban areas plays a crucial role in creating more comfortable and sustainable living environments by reducing heat stress and enhancing the overall well-being (Merga et al., 2022; Moisa & Gemeda, 2021; Moisa et al., 2022).

3.2.1. Land surface temperature analysis

Land surface temperature (LST) distribution was classified into appropriate ranges and color-coded to generate a thermal pattern distribution map of the study area. The result of this study shows that different LU/LC classes have different LST values. The average surface temperature of Adama City has increased from 28.25°C in 2013 to 31.78°C in 2023 with differences of 3.53°C (Table 6). High LST values were found in bare lands (vacant spaces, uncovered areas) and built-up areas. This finding clearly shows that both bare land and built- up areas are the two major possible causes for the rise of surface temperature in the study area. LST value ranges from 30–34°C in 2000 was grew from 8.23 km2 to 38.97 Km2 in 2023. The high rate of activities in the manufacturing and transport sector along with power generation accelerates the mean LST.

The result is in agreement with (Avdan & Jovanovska, 2016; Feyisa et al., 2014; Merga et al., 2023 Samson et al., 2018) that the major factors for the increase of LST both in rural and urban areas are land use/land cover changes and unplanned use of land resources (Table 7 and Figure 4).

Results from Figure 4(a–c) showed that the mean land surface temperature of the study area has increased from 27.08°C in 2000, 28.25°C in 2013, and to 31.78°C in 2023. A great variation in surface temperature was observed in areas having dense vegetation, impervious surfaces, uncovered soil, and lowest altitude. A Northeastern part of the City, particularly, Goba Hiddi Kebele, experiences higher surface temperature with a mean LST value of 34.26 °C due to its lower altitude and bare surface. However central parts of the study area showed a decrease in land surface temperature. These variations in LST could have resulted from the existence of dense vegetation cover and its topographic setup (higher altitude).

Other studies have also shown similar results. For instance, (Melkamu & Meseret, 2019; Samson et al., 2018) pointed out that the lowest mean LST was recorded by water body and green vegetation classes. This means that areas with lower vegetation cover are experiencing higher land surface temperatures and vice versa. From this, it is clear that vegetation has a cooling and regulating effect on the surface temperature of an area. Studies showed that vegetated surfaces

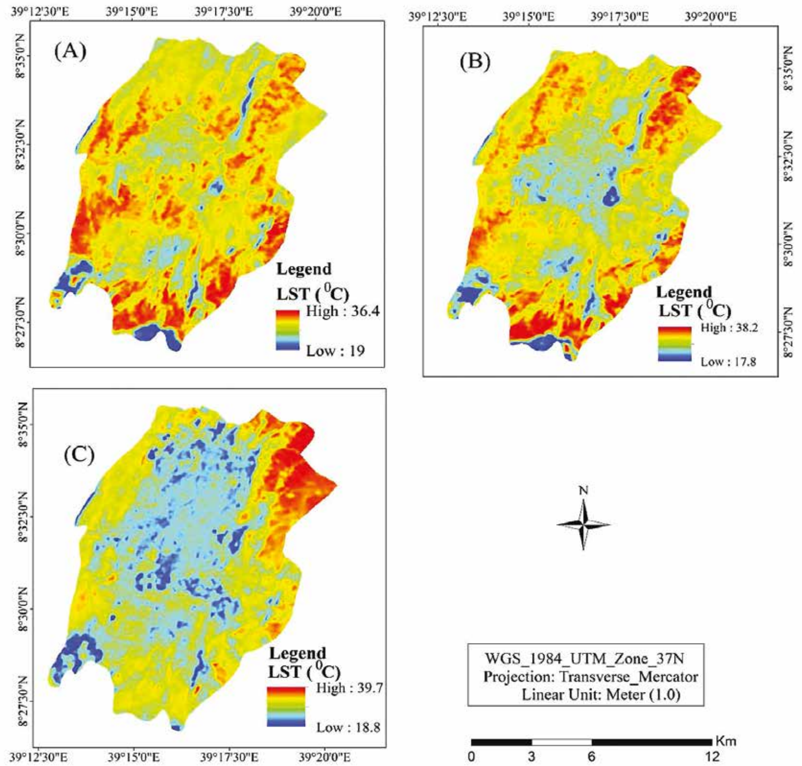

Figure 4. LST map of the year 2000(A) and 2013(B) and 2023(C).

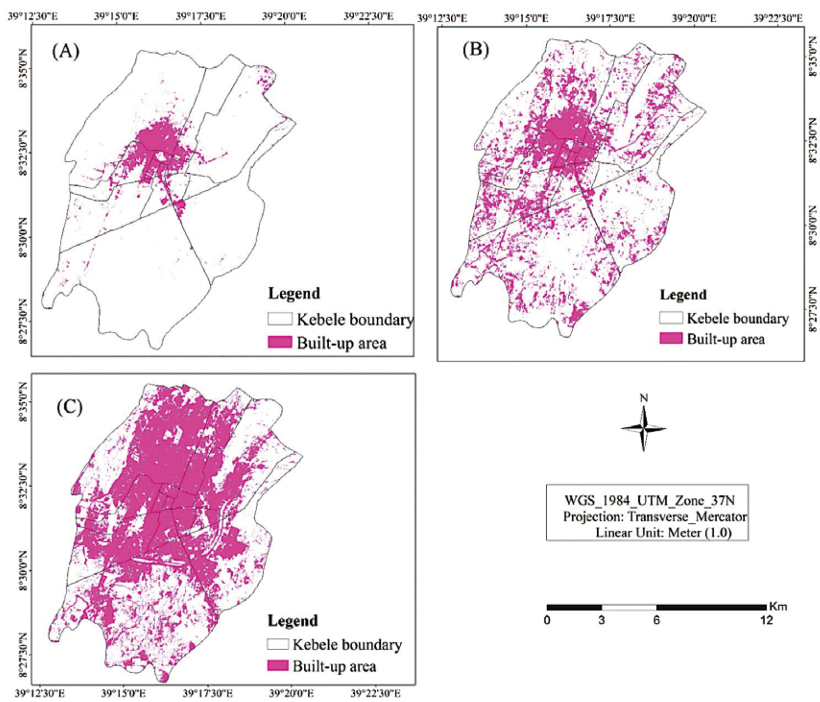

Figure 5. Built-up areas of Adama City in 2000 (A), 2013 (B) and 2023 (C).

can contribute significantly to human comfort and better health conditions by decreasing the land surface temperature (Gémes et al., 2016; Melkamu & Meseret, 2019; Merga et al., 2024).

3.2.2. Normalized difference built-up index (NDBI)

This study clearly shows that the vegetation cover of the study area where decreased due to rapid expansion of different buildings. Therefore, built-up areas are an inducing many surface temperature variations (Figure 5). Of the total area, built-up area alone accounted for about 18.87 Km^2 (13.67%) in 2000; and 76.4 Km^2 (55.29%). Currently, the built- up area occupies the largest portion of the city. The central and Northern parts of the city are packed with man-made features which made the temperature to be higher than the surrounding regions.

Some other studies also reveal that the sharp decrease in green spaces and rapid increase of built-up areas decline the cooling effect of green spaces (Žuvela-Aloise et al., 2016). High-temperature irregularities are comprehensively related to built-up land, densely populated areas, and greatly industrialized zones (Moisa et al., 2023; Samson et al., 2018).

3.3. Correlation of land surface temperature with built-up and green areas

These two indices were used to examine temperature variations and also determine their relationship with LST. Strong correlations between LST and both urban parameters were found in the study area. A positive correlation was identified between LST and built-up areas with R2 = 0.9276. This shows that the higher the built-up areas, the higher the LST values. The positive correlation found between the Normalized Difference Built-up Index (NDBI) and LST indicates that the built-up area is producing many LST variations and is the main contributor to urban heat islands (Figure 6). This finding is in agreement with Moisa et al. (2022) that the effect of the increment of the built-up area will result in severe effects of urban heating.

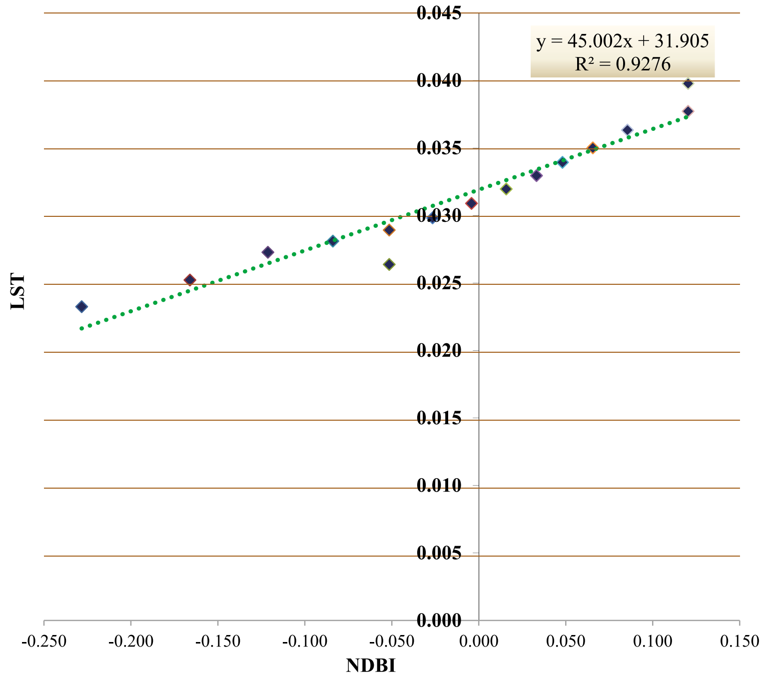

Figure 6. Relationship between LST and NDBI.

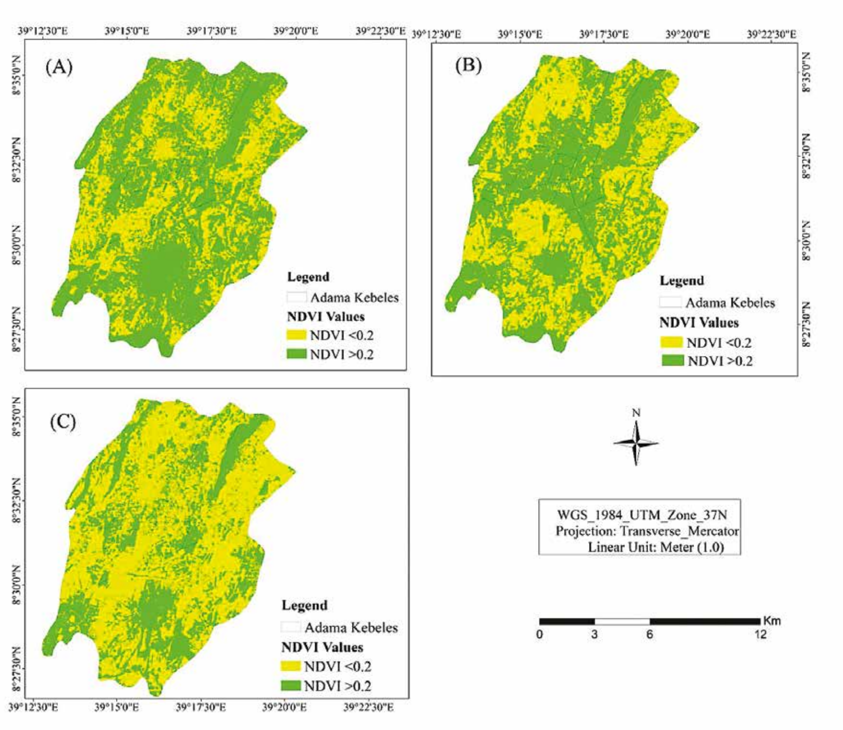

Figure 7. Normalized difference vegetation index for the year 2000(A), 2013(B) and 2023(C).

Table 8. Comparisons of the NDVI values in the year 2000 and 2023

2023

NDVI values	Landsat ETM+ (2000)	Landsat ETM+ (2013)	Landsat OLI (2023)
Min.	–0.31	–0.265	–0.128
Max.	0.62	0.516	0.456
Mean	0.35	0.28	0.124

3.2.3. Normalized difference vegetation index (NDVI)

The results of NDVI of both 2000 and 2023 showed that the northeast and southwest parts of the study area have higher NDVI values. The low values of NDVI were also observed in dense residential areas with less vegetation coverage. Vegetation cover has decreased and non-vegetated area has been increasing gradually over the study period (Figure 7). The average value of NDVI of the year 2000 was reduced by half percent by the year 2023. Relatively, a high value of NDVI in 2023 is observed in the south and southwestern parts particularly in Bole Kebele whereas the northeast part i.e. and the rest parts of the study areas have low values of NDVI. By comparing the NDVI of the two different periods (2000 and 2023), it is observed that maximum NDVI values were decreased over the study period.

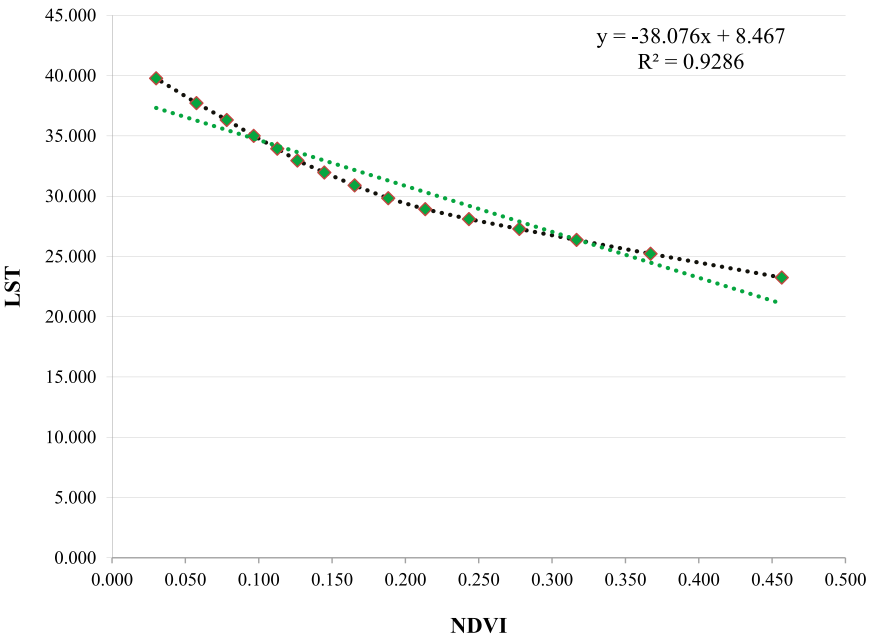

Figure 8. Relationship between LST and NDVI.

Table 9. Estimated LST value of selected test spot (Gooba Hiddii Kebele)

Increase of built-up area by	Estimated mean LST in (°C)	Increase green area by	Estimated mean LST (°C)
25%	35.02	25%	32.98
50%	35.78	50%	31.76
75%	36.54	75%	30.46
100%	37.31	100%	29.16

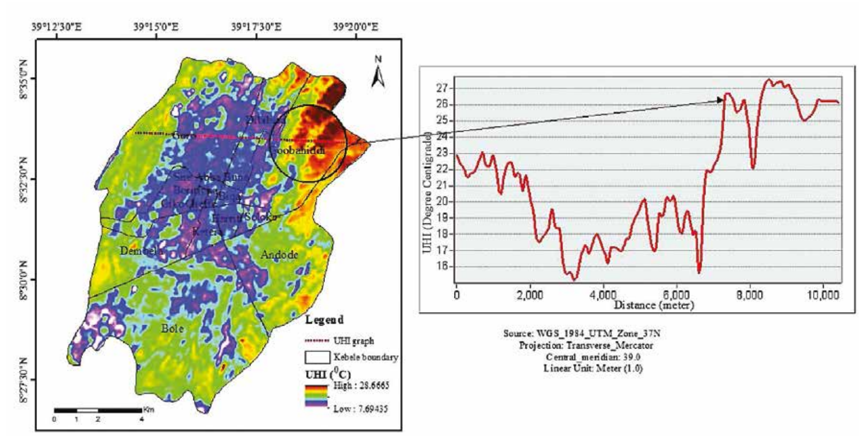

Figure 9. Estimation of LST in the selected test spot in Adama City.

The study shows that 64.54 Km2 (46.71%) of the study area in 2000 was covered by NDVI values greater than 0.2. But in the year 2023, only 47.84 Km2 (34.62%) of the study area was covered by the same NDVI class. These confirmed that there has been a dynamic vegetation cover change from one class to the other in the study area. NDVI values between 0.06 and 0.4 represent agricultural fields in the surrounding periphery. Patches of dense vegetation cover in the southern parts of the City show relatively high NDVI values. A number of studies have also shown that NDVI values of river banks and around water bodies experience higher NDVI values than other classes, owing to the presence of agricultural land (Feyisa et al., 2014; Samson et al., 2018). The NDVI values of the different years showing that there has been marked vegetation cover change during the study period (Table 8).

The results indicated that the high value of NDVI was distributed in the outskirts and in southwestern parts of the city. For green areas, a negative correlation was identified with the LST of the study area, that is, R2 = −0.9286. It can be concluded that, if the area is densely vegetated, the LST is found to be lower. Healthy vegetative cover plays a key role in lowering of the surface temperature. The high value of LST was detected in built-up areas and bare faces; whereas low surface temperature was found in areas covered with vegetation. The decrease in mean patch size may increase LST because a larger, continuous green space produces stronger cool island effects than that of several small pieces of green spaces.

The analyzed Landsat images of 2000 and 2023 indicated that NDVI and LST have indirect relationships. A Low NDVI value has high LST and high NDVI values have low LST. The results of this study showed that NDVI was correlated with LST with statistical significance. This finding is consistent with studies conducted by X. L. Chen et al. (2006); and Buyadi et al. (2015) which confirmed that there is a negative correlation between LST and the richness of green spaces measured by NDVI (Figure 8).

Trees and other plants help cool the environment, making green space a simple and effective way to mitigate urban heat island effects. Therefore, the effects of the increase in patch density on LST can be explained by a decrease in the mean patch size of green spaces. Generally, a negative correlation was found between NDVI values with LST. This finding is in agreement with Zhou et al. (2014); and Feyisa et al. (2014) and Melkamu and Meseret (2019) that green spaces can lower surface and air temperatures by providing shade that prevents land surfaces from direct heating from sunlight.

3.3. Estimation of LST in the selected test spots of Adama city

From the total of fourteen (14) kebeles in Adama City, Gooba Hiddi kebele experiences extreme LST values. The mean LST of the kebele was found to be higher than other kebeles with a mean LST value of 34.26°C. The area is covered by man-made features (built-up area) and found at the lowest altitude with a large portion of bare lands. The increment of built-up area in the selected site will result in a severe effect of urban heating whereas the increment of green areas within the selected site is seen to be the most suitable measure to reduce the LST value by about 5.1°C. Estimating the land surface temperature (LST) values when both the built-up area and green spaces in the selected test spot are increased by different percentages (25%, 50%, 75%, and 100%) compared to their current levels (Table 9). Essentially, it's exploring how changes in the extent of built-up areas and green spaces affect the temperature of the land surface in a particular test area, depicted in Figure 9.

3.4. Cooling effects of urban green space

Variations in land surface temperature and cooling efficiency of green spaces in Adama City have been evaluated. Areas of green space patches are in a logarithmic relationship with the maximum temperature difference with the coefficient correlation of (R2 = 0.6922). This demonstrates that the areas of green spaces are highly associated with the cooling range and maximum surface temperature difference. Based on the statistics of the cooling range appropriate to the areas of the green spaces, a regression analysis of the area with the cooling extent and maximum surface temperature difference respectively was made. The range of 5.5 ± 0.5 ha can bring a change in surface temperature by about 2.85°C. This indicates that the bigger the size of green space, the higher the cooling efficiency of green space patches. The inclination of the model curve is very steep on the left-hand side which means that the cooling efficiency of green space increases with the size of green spaces. On the right-hand side, the gradient is low and the cooling efficiency is reduced and stable. A threshold value of the cooling Efficiency of green space is then calculated as (TVoE = 5.50 ha) (Figure 10).

The formula of the cooling efficiency curve of green space is y = 0.6641ln(x) + 1.5997 (R2 = 0.692). This turning point is the maximum ΔLST and is defined as the cooling intensity of urban green spaces. The cooling efficiency is expressed as a logarithmic curve between the area of each UGS and its maximum ΔLST.

In this study, to further validate the results, the size of green space patches was divided into three segments (<1 ha, 1–4 ha, 2–4 ha, and greater than 5 ha. The results indicate that in the 0–5 ha segments, correlations between ΔLST and the size of green space show a positive relationship, which changes to a negative relationship in the 5 ha segment. This study validates that the calculated threshold value of efficiency (TVoE) in this study is consistent (Figure 11).

The TVoE of the study clearly shows that smaller green spaces have a positive relation with change in LST, but green spaces with an area greater than 5.5 ± 0.50 ha have a negative relation with LST change. Some studies also revealed that the cooling effect of green spaces has a size-based threshold value. For instance, X. Chen et al. (2012) pointed out that 5 ha of green space area is a vital

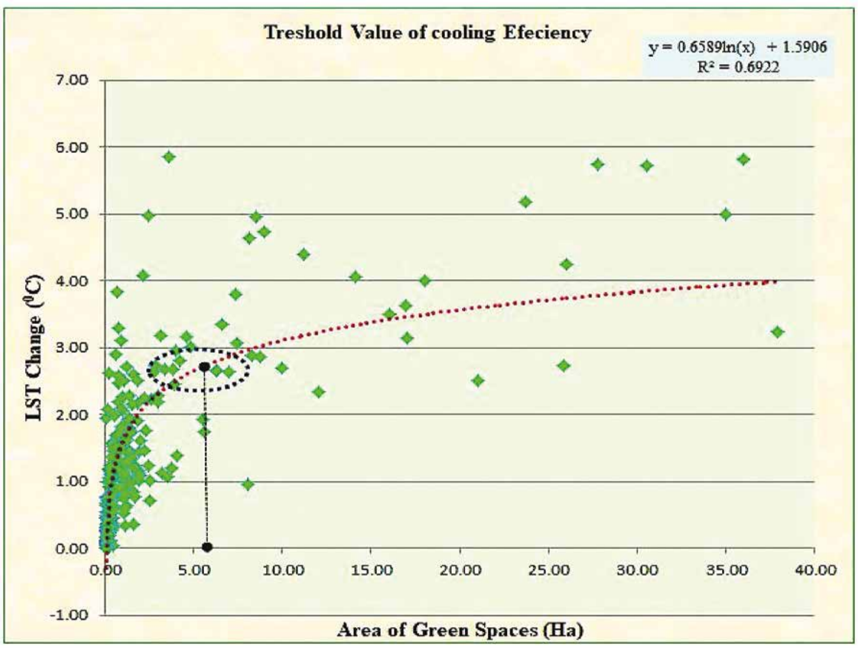

Figure 10. Relationship between change in LST (°C) and green space area (ha).

onset value for cooling. Study conducted by Zhaowu et al. (2018) also indicated that 4.55 ha of green space area is an important threshold value for cooling; and agreed that the maximum cooling extent of Urban Green Spaces (UGS) is stated as the distance between the edge of the vegetation cover and the first turning point of temperature drop compared with the urban green space temperature.

3.5. LU/LC and its contributions to urban surface heating

Among the five land use and land cover (LU/LC) classes examined, only built-up areas and vacant spaces (bare land) showed positive contribution indices in 2023, with values of + 1.75 and + 0.25, respectively. Built-up areas accounted for 12.6% of the landscape, while vacant spaces represented 8.7% (Figure 12). Notably, built-up and dense green space classes consistently exhibited significantly positive and negative deviations, respectively, compared to the overall landscape composition. Areas classified as built-up, such as urbanized zones, consistently contribute to local temperature increases. This suggests that urbanization is a significant factor in raising temperatures locally and may also have implications for global warming. On the other hand, areas categorized as green spaces, such as parks and vegetation-covered areas, show minimal contribution to heat buildup. The negative contribution index observed in vegetation-covered areas indicates that these spaces act as effective heat sinks, helping to mitigate the urban heat island effect. Overall, this underscores the importance of incorporating green spaces into urban environments to counteract rising temperatures associated with urbanization.

This finding follows the built-up heat source and vegetation heat sink that characterize most urban landscapes. In this regard, as suggested by a number of authors (X. L. Chen et al., 2006; Choi et al., 2012; Tong et al., 2005), consideration of urban heat sinks is critical in designing sustainable urban plans. Such initiatives could offset the local high urban temperature and mitigate global warming.

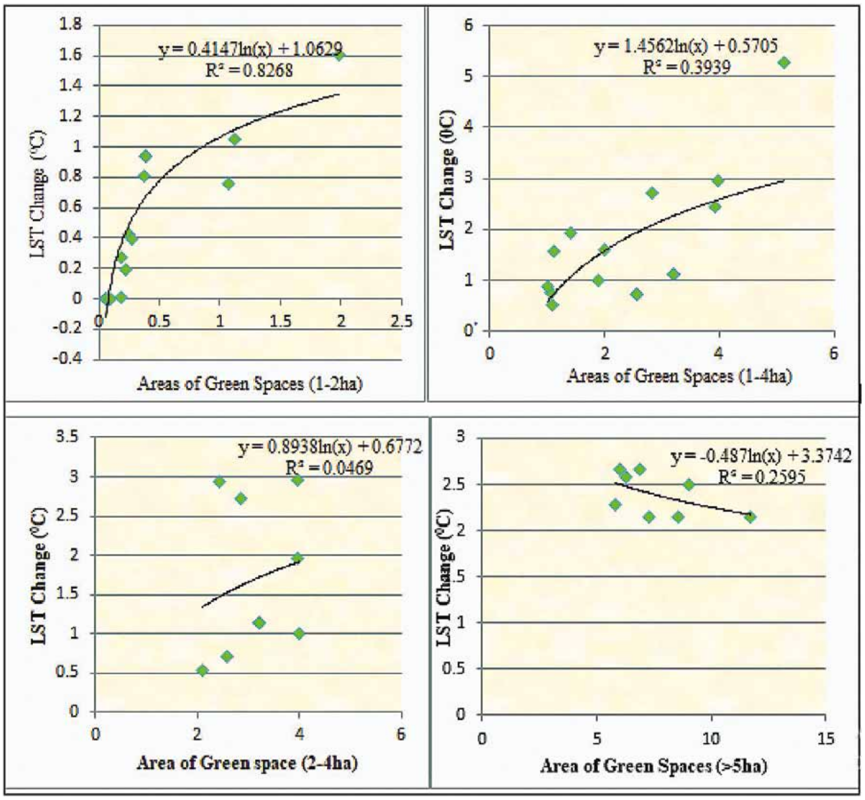

Figure 11. LST change with respect to areas of green spaces.

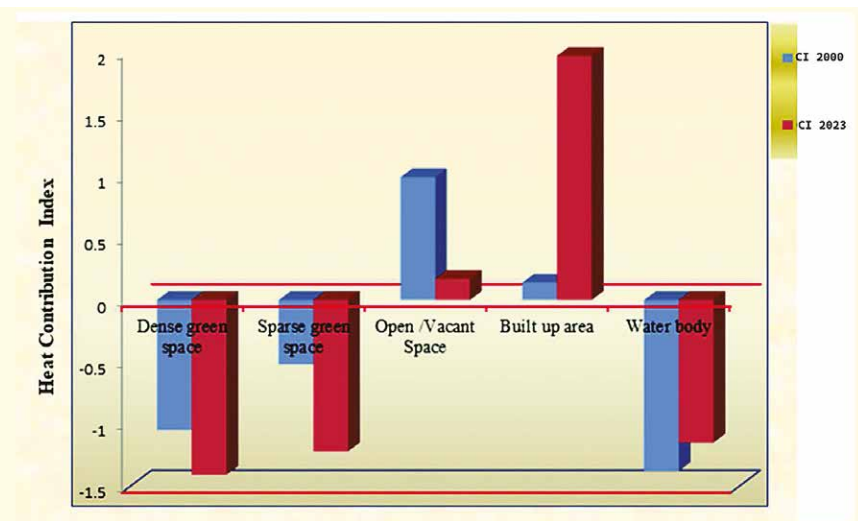

Figure 12. Heat contribution index of LU/LC of the years 2000 and 2023.

Conclusion

This study analyzed the cooling effects of urban vegetation cover in mitigating micro-climate change using geospatial techniques in Adama City central Ethiopia. The study revealed that the radical changes in land use/ land cover dynamics. The study compared surface temperature with green and non-green areas to analyze the effects of green spaces on temperature and consequently UHI, and has analyzed the cooling effects of urban green spaces from the year 2000 to 2023. The rapid expansion of built-up areas and reduction of green spaces in the city are the major possible causes for the rise of land surface temperature. The study revealed that radical changes in land use/ land cover (LU/LC) dynamics. NDVI of the year 2000 having a value > 0.2 was reduced from 64.54 Km^2 (46.71%) to 47.84 Km^2 (34.62%) in the year 2023. It clearly shows that the expansion of built-up land has caused significant land cover change (LCC) as well as changes in the LST. It is a very interesting fact that LST distribution in Adama City is very closely related to the distribution of vegetation cover (NDVI) and built-up areas (NDBI) with values of $R^2 = 928$; and $R^2 = 927$, respectively. Differences in temperature between the areas covered and uncovered with vegetation clearly reveal that vegetation can minimize surface temperature and can significantly mitigate UHI effects. The derivation of cooling efficiency that is significant for urban planning and decision makers was calculated as 5.5 ± 0.50 ha which means that when the Adama City municipality implements landscape planning, a green space size of 5.5 ± 0.50 ha is the most efficient to cool the heat effect. This study did not analyze the individual contributions of different types, species, shapes, and forms of green spaces to mitigating micro-climate changes separately. Therefore, further research is necessary to explore these factors in depth and gain a more comprehensive understanding of how various aspects of green spaces affect their cooling efficiency in urban areas. The study suggests strengthening the development of urban green spaces as an important strategy to mitigate the effects of micro-climate change.

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ORCID

Biratu Bobo Merga http://orcid.org/0000-0002-7249-7576

Authors' contributions

BBM is involved in data collection, literature work, data analysis, and manuscript writing. KWT and GA were also engaged in providing critical comments and approving the final manuscript.

Consent for publication

The authors agreed to publish in journal of urban ecosystem.

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Ultra-high-speed remote sensing image laser transmission test

A commercial Chinese satellite company has conducted an ultra-high-speed, high-resolution satellite-ground remote sensing image laser transmission test using an independently developed, vehicle-mounted laser communication ground station and the laser terminal aboard one of its Jilin-1 satellites. The 100-Gbps (gigabits per second) image transmission test was a success, said Chang Guang Satellite Technology Co., Ltd. To complete the test, a research team from the company comprehensively updated the vehicle-mounted ground station and overcame a series of technical difficulties. They also established a coherent, ultra-long distance, high sensitivity laser communication link between Earth and space.

Ultra-high-resolution remote sensing satellites can generate data volumes several times greater than other remote sensing satellites, with image data generation rates reaching tens of gigabits per second, according to the company. https://english. *www.gov.cn*

China launches Earth observation satellite for Pakistan

China recentl launched the first satellite of a remote sensing constellation for Pakistan. The China Aerospace Science and Technology Corporation (CASC) confirmed launch success, announcing the previously undisclosed payloads as being for Pakistan and Chinese commercial companies. The China Great Wall Industry Corporation (CGWIC), under CASC, arranged the combination of the international and domestic payloads. CGWIC signed a multi-launch service contract with Pakistan's Space and Upper Atmosphere Research Commission (SUPARCO) for launch of a remote sensing satellite constellation in 2022. PRSC-EO1 is the first of a series of three optical remote sensing satellites for Pakistan, which will join the country's existing remote sensing satellites, PRSS-1 and PakTES-1A, in orbit. *https://spacenews.com*

LiDAR put in use to map Asia's largest slum redevelopment project

In a first for any slum rehabilitation project in India, the Dharavi Redevelopment Project (DRP) has embraced cutting-edge technologies to survey and document Asia's largest slum in Mumbai, India. Drones and remote sensing technology Light Detection and Ranging (LiDAR) are being used to map the 620 acres densely populated Dharavi slums. This is to ensure accuracy, transparency, and efficiency in a redevelopment project of this scale and complexity. Traditionally, surveys for Slum Rehabilitation Authority (SRA) projects relied on conventional methods such as total station surveys and manual collection of physical documents. However, the DRP has implemented modern tools such as drones, LiDAR technology, and mobile applications to collect and evaluate data digitally.

These tools are being used to create a 'digital twin' of Dharavi – a virtual replica that facilitates better data analysis and decision-making, a Dharavi Redevelopment Project-Slum Rehabilitation Authority (DRP-SRA) official said. LiDAR is an active remote sensing technology which plays a pivotal role in this project. Known for its ability to rapidly capture geospatial data, LiDAR uses laser light to measure distances and create highly accurate 3D representations of terrain, buildings, and objects. A portable LiDAR system, such as a backpack-mounted scanner, is being used to navigate the narrow and congested lanes of Dharavi. Drone technology supplements this by capturing aerial images of the area, providing an overhead perspective that aids in mapping and planning. On the ground, survey teams use mobile applications for door-to-door data collection.

These apps ensure that information is gathered at the actual location of each slum dweller, with all data stored and evaluated digitally. This not only improves accuracy but also reduces the scope for errors or data loss. The digital model will allow authorities to evaluate data more effectively, especially when determining the eligibility of residents for rehabilitation at the end of the survey.

Overture Maps Foundation releases transportation dataset

The Overture Maps Foundation announced recently, the General Availability (GA) of its global Transportation dataset. This open map dataset supports new and expanded use cases across a broad swath of industries. The Transportation dataset includes 86 million kilometers of roads worldwide and is already in use by early adopters like Microsoft, Meta, and TomTom in mapping applications. The GA release means the data and underlying schema is now stable and that developers can start using the data in applications. *overturemaps.org*

PCMC launches GIS-based road asset management system

The Pimpri Chinchwad Municipal Corporation (PCMC) has launched the GIS-based road asset management system (RAMS) to overhaul road maintenance and management in the city.

One of the major issues identified by the PCMC is the lack of a unified database for road assets, leading to fragmented information and inefficient planning. Additionally, the absence of a unique road identification system has made tracking and managing infrastructure challenging. The RAMS project introduces a technology-driven solution to these problems by creating a centralised GIS platform that provides detailed and real-time data on roads and related infrastructure. This includes road conditions, maintenance history, and asset details such as utility poles, streetlights, and signage. The system leverages advanced tools like GPS-enabled vehicles equipped with high-resolution cameras to collect data and assess road conditions.

GIS-based asset mapping and consumer indexing project in Jharkhand

Jharkhand Bijli Vitran Nigam Limited has appointed Rudrabhishek Enterprises Limited to execute a wide-range of GIS project. It involves consumer indexing, GIS-based asset mapping, creation/upgradation of GIS databases and applications. Spanning over over five years, it will have two years of implementation and three years of facility management services. The initiative is a part of the Revamped Distribution Sector Scheme (RDSS), launched by the Ministry of Power, Government of India, with a vision to enhance the quality, reliability and affordability of power supply to consumers.

Operation Dronagiri launched along with GDI

Secretary, Department of Science and Technology, Professor Abhay Karandikar launched the Operation Dronagiri, a pilot project under National Geospatial Policy 2022 in New Delhi on 13 November, 2024.

"In the first phase, Operation Dronagiri will be implemented in the states of Uttar Pradesh, Haryana, Assam, Andhra Pradesh & Maharashtra, where pilot projects will be run and use cases will be demonstrated to showcase the potential applications of integration of geospatial data and technology in 3 sectors --Agriculture, Livelihoods, Logistics and Transport."

Professor Karandikar emphasised that Operation Dronagiri gains a powerful backbone with support from Integrated Geospatial Data Sharing Interface (GDI), that will make spatial data accessible, bringing transformation similar to the process in which UPI has brought about financial inclusion.

The Integrated Geospatial Data Sharing Interface (GDI) enables seamless data sharing, access, and analysis for urban planning, environmental monitoring, disaster management, and more. Built with advanced data exchange protocols and privacy-preserving features, it empowers organisations to make data-driven decisions for the public good, fostering innovation and responsible use of geospatial data. GDI offers tools to unlock actionable insights and drive collaboration. It enables efficient data processing, analysis, and sharing among stakeholders. This collaboration ensures faster, more coordinated responses in areas like infrastructure monitoring, disaster relief, and environmental protection. A Grand Challenge was also announced in which startups will be selected and supported in developing Proofs of Concept (POCs) that address specific problems within the designated sectors. The initiative executed through geospatial innovation accelerators will provide a platform for both early-stage and growth-stage startups, offering them mentorship, resources, and access to geospatial datasets, fostering their potential to contribute meaningfully to India's thriving geospatial ecosystem.

The activities under Operation Dranagiri will be overseen by IIT Tirupati Navavishkar I-Hub Foundation (IITTNiF). The Geospatial Innovation Accelerators (GIAs) at IIT Kanpur, IIT Bombay, IIM Calcutta and IIT Ropar will act as the operational arms of Operation Dronagiri. The entire implementation process will be driven by Geospatial Innovation Cell, Department of Science and Technology, Govt of India. *https://pib.gov.in*

Indian Institute of Soybean Research identifies potential soybean cultivation region with GIS mapping

To enhance the production of soyabean at the national level and incorporate new potential areas under the crop, the Indian Institute of Soybean Research, Indore has utilised GIS mapping system to chart potential regions in the country which are optimally suitable for soyabean cropping. The institute has collaborated with the ICAR-National Bureau of Soil Survey and Land Use Planning, Nagpur and Solidaridad Network, an international civil society organisation working to support producers and establish supply chains in agricultural products, for GIS mapping of the soyabean producing regions in India.

The GIS mapping has identified regions in Madhya Pradesh, Gujarat, Maharashtra, Karnataka, Telangana, Uttar Pradesh, Punjab, Haryana and Rajasthan where soil and climatic conditions are conducive for soyabean cultivation.

UP Aerospace launches suborbital flight to test GNSS payloads

Colorado-based UP Aerospace launched its 21st suborbital space flight from the world's first purpose-built commercial spaceport occurred at 7:09 a.m. local time Tuesday (Oct. 1, 2024).

UP Aerospace partnered with NASA's Flight Opportunities program on its latest flight, SL-15, which featured its SpaceLoft rocket shuttling a variety of payloads to sub-orbital heights.

One payload was a suite of multi-GNSS receivers from NASA's Space Communications and Navigation (SCaN) program, the European Space Agency, the Italian Space Agency, and their contractors Fraunhofer and Qascom. Determining the scope of interoperability was of paramount importance to the flight test, the results of which will be presented to the International Committee on GNSS (ICG) as part of the United Nations Committee for the Peaceful Uses of Outer Space (COPUOS).

NASA's Flight Opportunities program demonstrates technologies developed by industry, academia, and NASA and other government scientists through testing with a variety of commercial flight providers. *spaceportamerica.com*

ESA FutureNAV Industry Day 2025

The first FutureNAV Industry Day, on 18 February 2025, will bring together European stakeholders in satellite navigation to explore the future of positioning, navigation and timing technologies. This gathering will spotlight emerging opportunities and foster a network of European companies in the PNT and GNSS sector.

In 2022, the new programme FutureNAV was launched to consolidate these efforts. Under this initiative, two first missions were approved by the ESA Council at Ministerial Level: LEO-PNT, which aims to demonstrate the potential of navigation satellites in low Earth orbit; and Genesis, a mission that will combine four geodetic techniques in one satellite to contribute to a highly improved reference frame of Earth. *www.esa.int*

USSF field commands successfully launch GPS III

U.S. Space Force's Space Systems Command and Space Operations Command executed an accelerated timeline to meet a specific warfighter need through a Rapid Response Trailblazer launch. SpaceX's Falcon 9 rocket launched this National Security Space Launch mission with a GPS III Space Vehicle aboard, named SV-07, Dec. 16, from Space Launch Complex 40, Cape Canaveral Space Force Station, Florida.

The mission successfully achieved a complex effort across multiple Space Force organizations to pull an existing GPS III satellite from storage, accelerate integration and launch vehicle readiness, and rapidly process for launch.

The success of the launch proved a two-fold concept of operations. For SSC, Assured Access to Space successfully demonstrated and highlighted its agility in partnership with industry to respond to changing national needs by executing an NSS-class launch in less than five months.

For SpOC, the event not only marked a first for Mission Delta 31 as the SV lead but also demonstrated flexibility and responsiveness by reducing the typical six-month SV pre-launch processing timeline to approximately three months. Similar to the flexibility with launch partners for AATS, this also included coordination with MD 31 and Lockheed Martin in Colorado to process SV-07 out of storage within the reduced timescale.

This launch was the first exercise of trailblazer capabilities for the GPS constellation. *www.ssc.spaceforce.mil*

A2Z Drone Delivery launches BVLOS drone dock network

A2Z Drone Delivery has launched multi-use drone dock network operating beyond-visual-line-of-sight (BVLOS) with a single operator managing a fleet of four drones simultaneously. Conducting both autonomous patrol of protected urban waterways, supporting water rescue, and expediting regional retail delivery, the deployment marks the company's first as a drone service provider. In this first phase of the network rollout, A2Z Drone Delivery is partnering with the Anji Bureau of Water Resources to conduct autonomous aerial patrol of the Bureau's protected waterways and reservoirs that weave through the urban setting of Anji City, China. *www.a2zdronedelivery.com*

BAE Systems' Phasa 35 drone completes stratospheric test flights

BAE Systems has completed a round of flight tests with its Phasa 35 stratospheric drone, crucially demonstrating its ability to be launched, flown, landed and relaunched again quickly. Designed to operate as a high-altitude, long-endurance surveillance and reconnaissance platform the aircraft – defined as a High Altitude Pseudo Satellite (HAPS) Uncrewed Aerial System (UAS) – has been designed by BAE Systems subsidiary Prismatic, a division of the company's FalconWorks R&D arm. Alongside reconnaissance, the aircraft has the potential to be used to deliver communications networks for a range of applications, such as disaster relief etc. *www.baesystems.com*

Arcsky launches the X55 V2

The X55 V2 drone now incorporates dual Here 4 GPS modules for improved accuracy and redundancy. It also offers an optional moving baseline RTK feature, powered by the professional-grade u-blox F9P dual-band RTK GNSS module. This feature is particularly beneficial for areas with magnetic field anomalies as well as during high-voltage power line inspections, and allows the GPS system to be used for yaw estimation, rather than relying on compasses. The drone platform's main body, which is still precision-machined from a single aluminum block, has been redesigned to significantly enhance stiffness and reduce vibration. *www.arcskytech.com*

Testing drone-based transport of research blood in Japan

ITOCHU Corporation, Japan, have tested the transport of research blood using Wingcopter's delivery drone in a research project. Together with ANA Holdings and the local blood center of the Japanese Red Cross, research blood was flown between the cities of Urasoe and Nago in Okinawa Prefecture. *wingcopter.com*

CHCNAV introduces the X500 Multirotor Drone

CHC Navigation (CHCNAV) has launched the X500 Multirotor Drone, a professional drone designed for precision aerial operations. It is equipped with dual GNSS, triple IMU redundancy, and millimeter-wave radar for precise obstacle detection. Its video transmission system delivers stable HD video feeds over a range of up to 20 km, while V-SLAM visual positioning ensures accuracy for tasks such as landing on moving platforms. *www.chcnav.com*

Nationwide UTM Network to be Implemented in Norway

Thales has partnered with Avinor to implement Norway's next-generation nationwide Unmanned Traffic Management (UTM) system, which will enhance airspace management for both unmanned and manned aircraft while ensuring full compliance with European regulatory standards.

This strategic partnership with Avinor, the Norwegian air navigation service provider and airport operator, will enable the deployment of Norway's next-generation nationwide Unmanned Traffic Management system. It also signifies a key milestone for Thales in the integration of AstraUTM, a recently acquired leader in cutting-edge UTM software development. *www.thalesgroup.com*

Hexagon to acquire Septentrio

Hexagon has announced an agreement to acquire Septentrio NV, an OEM provider of GNSS technologies, to drive innovation and expand the market reach of Resilient Assured Positioning solutions.

Combining Septentrio's pioneering GNSS platform with Hexagon's extensive positioning portfolio, including sensor fusion, anti-jamming, correction services and perception technologies, will enable cutting-edge solutions for diverse markets and applications. *hexagon.com*

L3Harris to design resilient GPS satellite concepts

L3Harris Technologies has received a contract from the U.S. Space Force's Space Systems Command to design concepts for Phase 0 of the Resilient Global Positioning System (R-GPS) program.

The R-GPS program is a procurement of cost-effective small satellites that will augment the existing 31-satellite GPS constellation providing resilience to military and civil GPS users. Space Force plans to produce and launch up to eight satellites to address jamming, spoofing and more permanent disruptions. *www.l3harris.com*

Honeywell and NXP expand partnership

Honeywell and NXP Semiconductors have expanded their partnership to advance aviation technology and autonomous flight capabilities. This collaboration merges Honeywell's aerospace expertise and Anthem avionics system with NXP's high-performance computing architecture to develop AI-driven aerospace technologies. *www.honeywell.com*

u-blox launches new GNSS chip for wearable applications

u-blox has launched the UBX-M10150-CC, a GNSS chip designed for wearable devices. It offers advancements in size, power efficiency and performance for battery-powered devices. It utilizes low energy accurate positioning technology, which achieves power consumption as low as 10mW. This technology, combined with smart adaptation to signal conditions, allows for a 50% reduction in power consumption compared to previous M10 chips, according to u-blox. *www.u-blox.com*

ANELLO Photonics Launches Maritime INS

ANELLO Photonics has launched the ANELLO Maritime Inertial Navigation System (INS). It integrates the company's groundbreaking SiPhOG™ technology with its advanced sensor fusion engine to deliver unparalleled precision and reliability for autonomous surface vessels (ASVs) and autonomous underwater vessels (AUVs). *www.anellophotonics.com*

Burro and GEODNET partnership

Burro and GEODNET have announced a strategic partnership to integrate GEODNET's cutting-edge RTK (Real-Time Kinematic) GPS technology into Burro's autonomous robots.

Through this agreement, GEODNET will provide RTK corrections and base stations to Burro, enabling their robots to operate efficiently in regions lacking current GPS coverage. *www.burro.ai*

SIIS Signs MOU with Pixxel

SIIS Co., Ltd. Korea has signed a memorandum of understanding (MOU) on November 19th with Pixxel, India. The signing ceremony, held during the Satellite Utilization Conference, marks a significant step towards providing hyperspectral data to relevant institutions and companies in the country. *www.si-imaging.com*

Swift Navigation and Quectel partnership

Swift Navigation and Quectel Wireless Solutions have joined forces to enable centimeter accurate positioning across

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London, UK
https://dgi.wbresearch.com

Geo Week 2025
10 - 12 February
Denver, USA
www.geo-week.com

MENA Geospatial Forum
24 - 25 February 2025
Dubai, UAE
https://menageospatialforum.com

March 2025

Munich Satellite Navigation Summit
26 - 28 March 2025
Munich, Germany
www.munich-satellite-navigation-summit.org

April 2025

GISTAM 2025
1-3 April
Porto, Portugal
https://gistam.scitevents.org

Geo Connect Asia
09 - 10 April 2025
Singapore
www.geoconnectasia.com

Assured PNT Summit
23-24 April 2025
Washington DC, USA
https://pnt.dsigroup.org

May 2025

17th Baška GNSS Conference
11-15 May 2025
Baška, Croatia
https://rin.org.uk

GeoIgnite
12-14 May2025
Ottawa, Canada
https://geoignite.ca

June 2025

GEO Business 2025
04-05 June
London, UK
www.geobusinessshow.com

July 2025

Esri User Conference
14-18 July 2025
San Diego, USA
www.esri.com

September 2025

Commercial UAV Expo 2025
2-4, September
Las Vegas
www.expouav.com

ION GNSS+
08-12 September 2025
Baltimore, USA
www.ion.org

diverse industries. The collaboration integrates Swift's Skylark® Precise Positioning Service with Quectel's suite of high-precision GNSS modules to enable accurate, reliable precision across a remarkably broad range of use cases. *www.swiftnav.com*

ComNav's AG501 Pro Autosteer

ComNav Technology Ltd. has launched AG501 Pro autosteer system to the world. It seamlessly integrates state-of-the-art technology to offer a robust and adaptable solution tailored for agriculture, ensuring ultimate precision and efficiency in versatile agricultural activities. It encapsulates the GNSS antenna, GNSS module, gyroscope, as well as datalink functionalities within one unit, hence bringing farmers the benefits of advanced automation without complex installations and calibrations. *comnavtech.com*

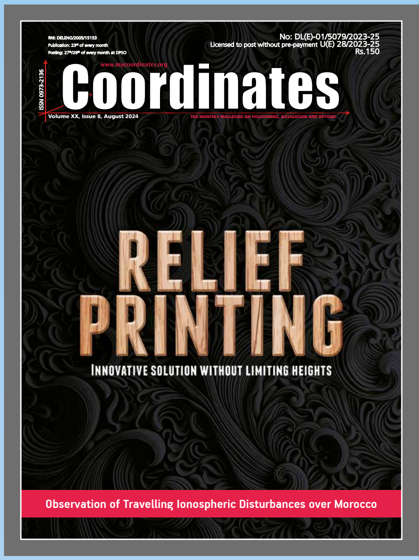
Voyant Photonics unveils Carbon Lidar sensor

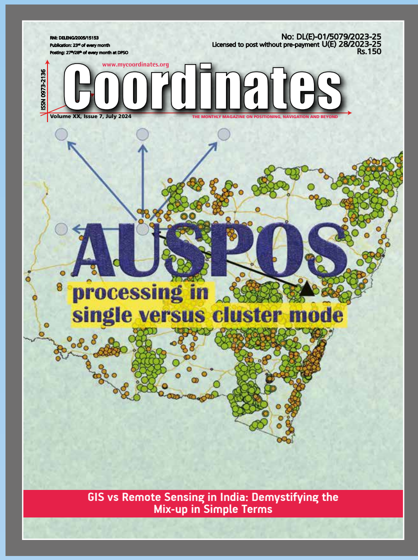
Voyant Photonics has introduced the Carbon frequency modulated continuous wave (FMCW) lidar sensor. It features lidar on a chip with solid-state beam steering integrated into a fingernail-sized silicon photonic chip. The Carbon sensor offers high-resolution imaging with millimeter precision and object detection capabilities up to 200 m. *voyantphotonics.com*

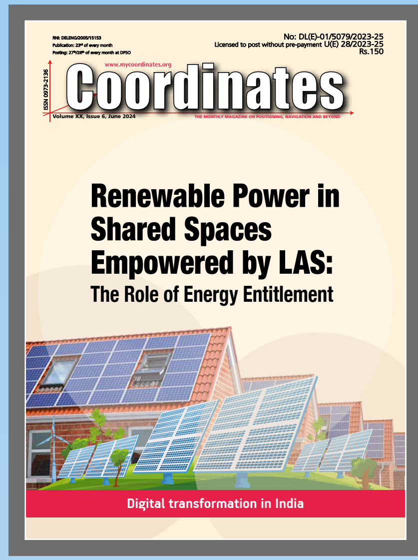
Lockheed Martin advances uncrewed capability for combat-proven HIMARS

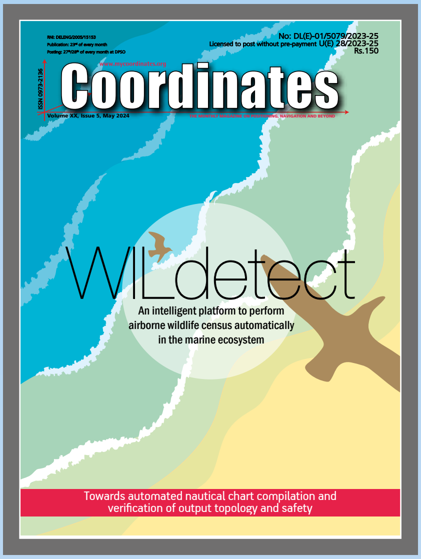
Lockheed Martin has successfully demonstrated an uncrewed capability with a surrogate HIMARS® launcher, a significant milestone in the development of autonomous systems that can operate collaboratively with manned vehicles.

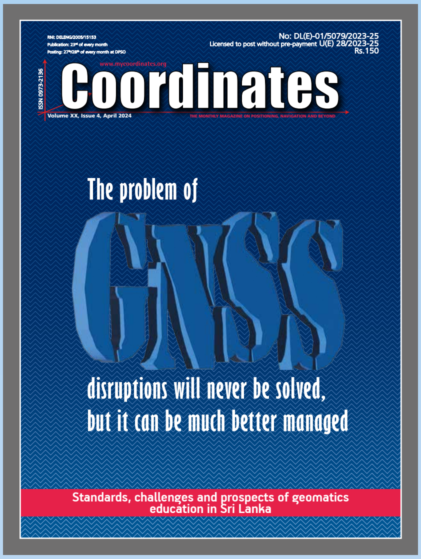
On Dec. 4, the surrogate launcher showcased its ability to navigate without a driver using non-emitting perception sensors, enabling seamless day and night operations without a crew. *www.lockheedmartin.com*

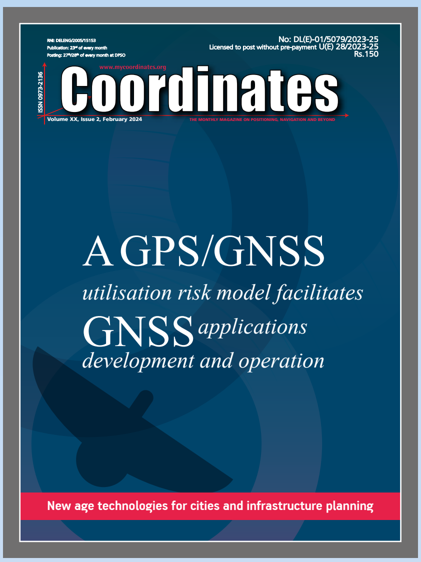


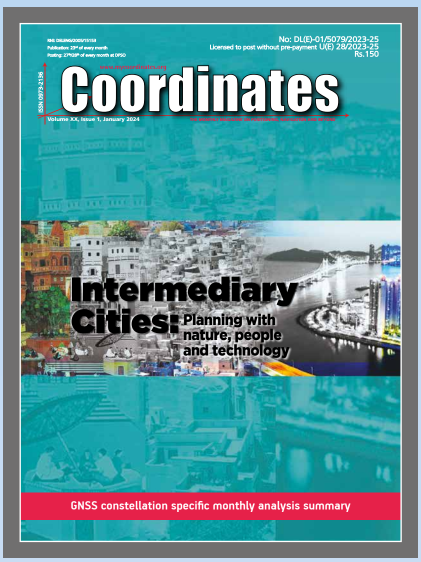


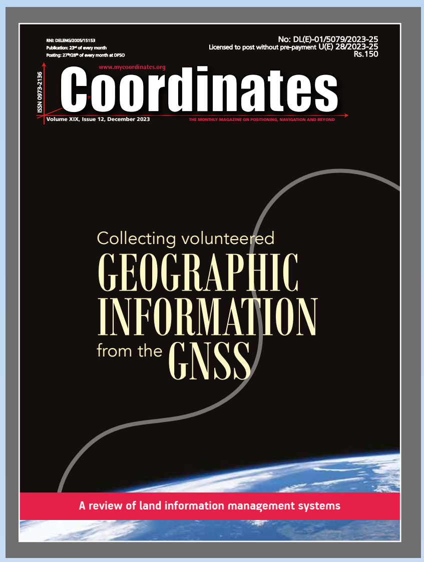












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